MINISTRY OF HEALTH OF UKRAINE
ZAPORIZHZHYA STATE MEDICAL UNIVERSITY
Department of Medical Physics, Biophysics and Advanced Mathematics

MEDICAL PHYSICS AND BIOPHYSICS

TEXTBOOK
for the first-year foreign English-speaking students of the second international faculty of specialty «General medicine» 7.12010001. ***Module 2***

НАВЧАЛЬНИЙ ПОСІБНИК З МЕДИЧНОЇ ТА БІОЛОГІЧНОЇ ФІЗИКИ *для англомовних студентів першого курсу другого міжнародного факультету спеціальності Лікувальна справа» 7.12010001.* ***Модуль 2***

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Навчальний посібник з медичної та біологічної фізики для англомовних студентів першого курсу другого міжнародного факультету спеціальності «Лікувальна справа» 7.12010001. Модуль 2.- Запоріжжя, ЗДМУ, 2016.
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INTRODUCTION

This textbook includes theoretical material of second module revised and adapted for the first-year international students according to curriculum.

Biophysics is that branch of knowledge that applies the principles of physics and chemistry and the methods of mathematical analysis and computer modeling to biological systems, with the ultimate goal of understanding at a fundamental level the structure, dynamics, interactions, and ultimately the function of biological systems. Biophysics is an interdisciplinary science. It spans all levels of biological organization, from the molecular scale to whole organisms and ecosystems. Biophysical research shares significant overlap with biochemistry, nanotechnology, bioengineering, agrophysics and systems biology.

ВСТУП

Посібник містить оновлений теоретичний матеріал з медичної та біологічної фізики, призначений для англомовних студентів першого курсу другого міжнародного факультету спеціальності «лікувальна справа». Теми, розглянуті у даному посібнику, відповідають навчальному плану практичних занять та програмі з відповідної дисципліни за обсягом та вмістом. Кожна тема містить розгорнуте пояснення біофізичних явищ та їх практичне застосування у медицині, що сприяє підвищенню мотивованого та свідомого сприйняття інформації студентами. Матеріал має на меті спростити та підвищити ефективність підготовки студентів до практичних занять з дисципліни. Інформація викладена у логічній послідовності, доповнена ілюстративним матеріалом та описом актуальних методів практичного застосування фізичних феноменів.

CONTENTS

DIRECT AND ALTERNATING ELECTRIC CURRENT. PHYSICAL BASIS OF RHEOGRAPHY

The electric current in a conductor, i.e. a wire, is the rate at which electric charge moves in it. If a net charge Δq crosses the cross-sectional area of conductor in a time Δt, the average current is

$$I = \frac{\Delta q}{\Delta t} \qquad (1)$$

The instantaneous current is

$$I = \frac{dq}{dt} \qquad (2)$$

The current unit is the ampere (A). From the definition (1) it follows that an ampere is a coulomb per second. Often it is convenient to use milliampere (mA). 1 mA = 0,001 A. Conventionally, the current in a conductor is assumed to be in the direction of motion of positive charges.

Another quantity related to the flow of electric charges is current density, the flow of current per square unit. It is measured in amperes per square metre:

$$J = \frac{I}{S} \qquad (3)$$

Direct current is such a current that does not change during a time. Generators that maintain the constant potential difference at the ends of conductor produce it. If the current varies in time, it is called the alternating current.

The Ohm law

Accordingly to the Ohm's law the current in conductors is usually proportional to the potential difference between their ends, or electric tension (*U*):

$$I = \frac{U}{R} \tag{4}$$

The quantity *R* is named the electric resistance. The resistance is the property of conductors to oppose electric current and to transform electric energy into heat energy. The resistance arises from collision of the charged particles (current carriers) with the internal structures of conductor - its atoms and molecules. The unit of resistance is ohm. The quantity reciprocal of resistance is named electric conductance (*D*).

For many materials the resistance is a constant independent of the current. The resistance of conductor is the function of its size, shape, composition and temperature. The value of resistance of a wire is:

$$R = \rho \frac{l}{S} \tag{5}$$

where l - length, S - cross-section area. The proportionality constant ρ is called resistivity. It depends only on the properties of the material and the temperature. The quantity reciprocal to resistivity is named conductivity (γ). Conductivity characterises materials on the basis of how well electric current flows in them. Good electrical conductors have high conductivity. Good insulators, or dielectrics, have low conductivity. Semiconductors have intermediate conductivity. Using conductivity as the characteristic of material it is possible to introduce the Ohm's law in another form:

$$J = \gamma E \tag{6}$$

It means that the current density is directly proportional to the intensity of electric field and the conductivity of material.

There are two kinds of conductors. First of them are metals. In a metal many of electrons are free to move under the influence of electric field. The second kind of conductors is the electrolyte solutions. The electric current is carried in them by the positive and negative ions, which move in the opposite directions. The biological tissues belong to the second type of conductors.

The conductivity of electrolytes and biological tissues

The electric charge of positive and negative ions, their concentrations and the velocity of their movement in electric field define the electric current density of electrolyte solution:

$$J = q_+ n_+ v_+ + q_- n_- v_- \qquad (7)$$

Let us assume that the charge and concentration of positive and negative ions are equal. Then

$$J = qn(v_+ + v_-) \qquad (8)$$

The velocity of ions v is proportional to electric field intensity E and depends on the ion mobility u which is the function of their size, hydration, viscosity of solvent:

$$v = uE \qquad (9)$$

Substitution (9) to (8) yields:

$$J = qn(u_+ + u_-)E \qquad (10)$$

It is the definition of Ohm's law for electrolyte solution. The electric charge, concentration and mobility of positive and negative ions define the conductivity:

$$\gamma = qn(u_+ + u_-) \qquad (11)$$

The biological tissues do not differ significantly by their ionic composition. They differ greatly by the conditions of ion movement. The tissues are heterogeneous from the point of their electrical properties. Cell membranes are a great obstacle to the ion movement. Their electric resistance is much more then that of intracellular spaces and biological liquids. That is why blood, lymph, cerebrospinal fluid are characterised by low resistance. The interior organs containing a great deal of water (muscles, liver, kidneys, spleen etc.) also have comparatively low resistance. But the resistance of such tissues as skin and bones is very high. The direct electric current penetrates badly through dry skin. It spreads in a human body mainly along the blood and lymphatic vessels and muscles. The direct current is used in medical practice. There are two methods of treatment that use it: galvanisation and medicine electrophoresis.

Galvanisation and medicine electrophoresis

Galvanisation is the method of medical treatment based on the application of direct current. The method is named in honour of Italian physician and scientist Luigi Galvani. He was the first who studied electric currents, which are generated by biological tissues.

The method of galvanisation consists in passing the direct current through the definite parts of human body. The voltage magnitude must be not more than 30 volts. The wide metal electrodes are used with the moistened flannel interleaf. The current value ranges from several milliamperes to 50 milliamperes. But the current density must not exceed 0,1 milliampere per square centimetre. The current must not disturb a patient.

The current density in various tissues depends on the voltage value and the electric resistance in a zone of current action. The most resistance is inherent to skin, bones, lipid tissue, and connective tissue. The tissues with minimal resistance are blood, lymph and other fluids in organism.

The inorganic ions and water ions move under the action of electric field. The mobility of organic ions is considerably less than that of inorganic. The most changes in galvanisation take place at the cell membranes. These changes consist of electrochemical processes, which change the membrane polarisation and influence the membrane permeability and transmembrane potentials. These processes stimulate receptors, give rise to various physiological reactions and changes of metabolism. Galvanisation is used mostly to treat the nervous system diseases.

Galvanisation is usually combined with the medicine electrophoresis. It is the kind of treatment which use the direct electric current to introduce drugs into body tissues for therapeutic purposes. The great variety of drugs can dissociate in water solution to the positive and negative ions. Salts, antibiotics, local anaesthetics, alkaloids and many others are among them. Electric field forces them to move: the positive ions towards the negative electrode and vice versa. Under the influence of electric field these drugs can penetrate undamaged skin barrier. The main paths of ions penetrating a skin are the ducts of sweat glands. The most part of ions penetrates through intracellular spaces, less - through cells. The drugs concentrate mainly in skin and hypodermic tissue and form a kind of depot. The local concentration of drugs in such a depot may be comparatively high. The drugs are slowly absorbed into the blood that results in prolongation of medicinal effect.

Fig.1. Medical electrophoresis

Alternating current. Impedance.

Alternating current varies in time. Electric current transmitted from generating plants to users involves sinusoidal oscillations at the frequency of 50 Hz:

$$I = I_{max}(\omega t + \varphi_0) \qquad (12)$$

Electrical circuits include such basic electrical components as resistors, capacitors and inductors. Their specific qualities are resistance, capacitance and inductance.

Capacitance

Suppose that two conductors (plates) are separated by an insulating medium. They can take some amount of electric charge. The ratio of the amount of charge transferred to the potential difference resulting is called capacitance, which is measured in farad (F):

$$C = \frac{q}{U} \qquad (13)$$

Inductance

Inductance L is associated with the magnetic field that surrounds a wire or a coil carrying a current. Alternating magnetic field generates self-induced electromotive force that opposes the change in current:

$$\mathrm{E} = -L\frac{dI}{dt} \qquad (14)$$

Here E - electromotive force, $\frac{dI}{dt}$ - instantaneous velocity of current change, L - inductance that depends on the geometry of circuit and on the magnetic materials present in vicinity. The inductance is measured in henry (H).

Reactance

It was mentioned earlier that resistance is the property of electric circuit to oppose a current and to transform electric energy into heat energy. Reactance is the measure of the opposition that a circuit presents to electric current if it is alternating. Reactance is associated with the capacitance and inductance of some parts of a circuit. It does not transform electric energy into heat energy. Reactance is present in addition to resistance when conductors carry alternating current. Steady electric current undergoes only resistance but not reactance. Reactance is of two types: inductive and capacitive.

The capacitive reactance X_C equals the reciprocal of the product of angular frequency ω of the current and the capacitance of that part of the circuit:

$$X_C = \frac{1}{\omega C} \qquad (15)$$

The inductive reactance X_L equals the product of the angular frequency of the alternating current and the inductance of the conductor:

$$X_L = \omega L \qquad (16)$$

It may be proved that inductive reactance X_L causes the voltage to lead the current by quarter-cycle ($\pi/2$). In other wards, the voltage across a pure inductance is a quarter-cycle out of phase with the current. It may be explained by considering that back electromotive force opposes the current in inductors.

On the contrary, capacitive reactance X_C causes the voltage to lag behind the current by a quarter-cycle ($\pi/2$). It may be said also that the current is a quarter-cycle out of phase with the voltage. Fig.1 illustrates this law.

That is why total reactance X is the difference of the inductive and capacitive reactances:

$$X = X_L - X_C \qquad (17)$$

Total sum of the resistance and reactance that may oppose the alternating current in electrical circuit is named impedance Z. It is defined by the equation:

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \quad (18)$$

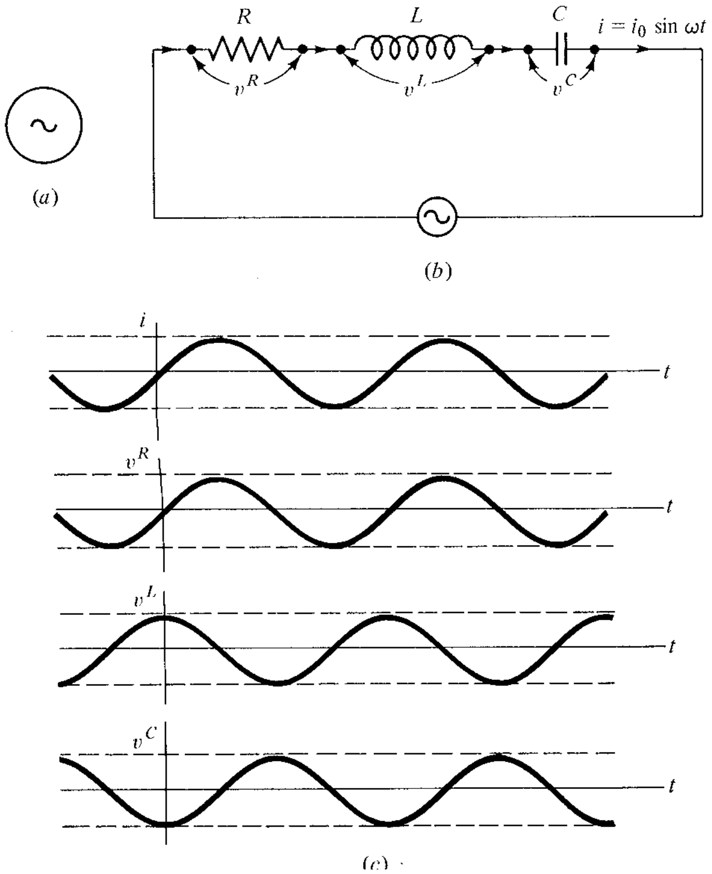


Fig.2. (a) Symbol for AC generator. (b) An *RLC* series circuit. (c) The potential drops across each of the elements and the current versus time.

The physical basis of rheography

The blood-repletion of various organs and tissues depends not only on the power and frequency of heart contractions but also on the state of blood vessels. The arteries of some organ may get narrow as a result of illness. In such a case the bulk of blood that flows into the organ is decreased. Rheography is the method that gives the possibility to measure the blood-repletion of extremities, brain, heart and many other organs.

When some bulk of blood flows into the vessels of any organ during systole, the volume of this organ rises corresponding. These changes of volume were studied in the past by the so-called pletysmography. It was based on the mechanical measurement of the volume changes. But the possibilities of this method were limited. It can be applied only for measuring the blood-repletion of upper extremity. Later it was found that when more blood flows into the vessels of the organs their electric resistance changes. This change is generally defined by Kedrov formula:

$$\frac{\Delta V}{V} = -k\frac{\Delta R}{R} \qquad (19)$$

Here V is a volume of organ and ΔV - its change during systole, R - resistance and ΔR - its change. k is the proportionality coefficient. ΔR is negative because the electric resistance of blood is less than that of muscles, connective tissue, skin etc. That is why the resistance of organs decreases during systole and rises during diastole. The change in electric resistance gives rise to the impedance change. For the technical reasons the measurement of latter is more convenient than that of the resistance to direct current. Rheography (rheopletismography, impedance pletismography) is based on the measuring of the impedance kinetics in human body depending on the pulse and local blood supply.

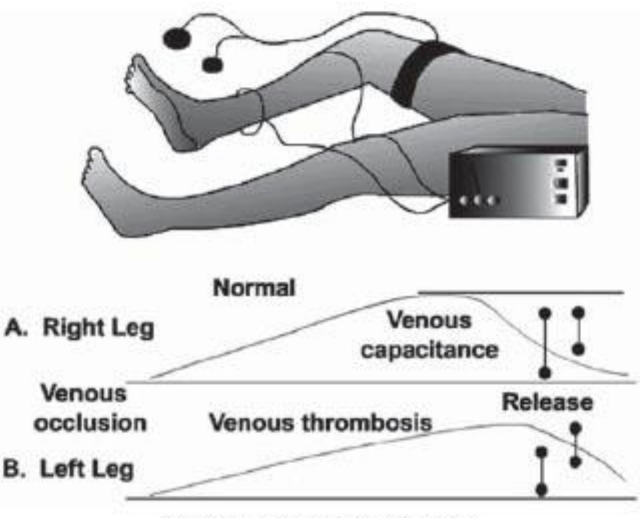


Fig. 5 : Impedance plethysmography.

Fig.3. Impedance plethysmography

In order to measure impedance changes of biological object high frequency alternating current is passed through it. The optimal frequency used in reographs is 100 - 500 kHz since beyond the 500 kHz limit distinctions in conductivity between blood and surrounding tissues smooth out. The changes of impedance that depends on the arterial pulse are very small. For example they are 0,08 ohm for shank and forearm, 0,1 ohm for hand and foot.

The basic rheogram describing the bulk pulse oscillations within the examined organ is depicted on the fig.1. Its ascending part arises in consequence of systole and descending part in consequence of diastole. The differential rheogram is always recorded simultaneously. It is the first-order time derivative of the bulk rheogram. The differential rheogram describes the rate of change in blood-repletion of the examined organ.

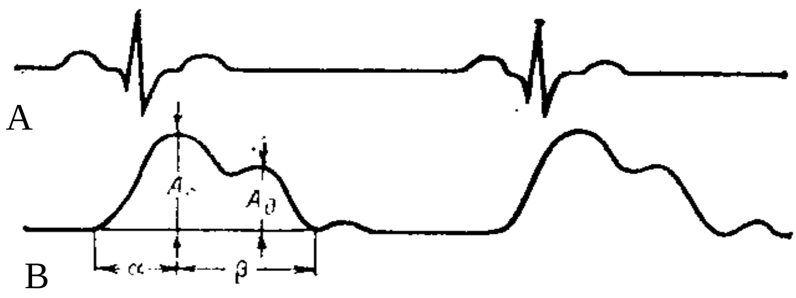


Fig.4. A - electrocardiogram; B - basic rheogram.

The rheography studies the electric impedance kinetics in various organs: in heart (rheocardiography), brain (rheoencephalography), lungs (rheopulmono-graphy), liver (rheohepatography), eyes (rheoophtalmography) etc.

TESTS FOR KNOWLEDGE CONTROL

1. Electric current cannot be produced in such kind of materials as:

A. Conductors of 1 type;

B. Conductors of 2 type;

C. Semiconductors;

D. Insulators

E. semi insulator

2. The average current is:

A. $I = U \cdot R$;

B. $J = \frac{\Delta I}{S}$;

C. $I = \frac{dq}{dt}$;

D. $I = \frac{\Delta q}{\Delta t}$

E. $I = \frac{\Delta T}{\Delta q}$.

3. The instantaneous current is;

A. $I = \frac{dq}{dt}$;

B. $I = \frac{\Delta q}{\Delta t}$;

C. $I = U \cdot R$;

D. $J = \frac{\Delta I}{S}$.

E. $I = \frac{\Delta T}{\Delta q}$

4. If Δq=100Cl, Δt=200ms, what is the value of I?

A. 0,5A

B. 5A;

C. 50A;

D. 500A;

E. 5000A

5. Ampere (A) is the unit of:

A. Current;

B. Resistance;

C. Voltage

D. Conductance

E. Intensity

6. Ohm is the unit of:

A. Current;

B. Resistance;

C. Voltage;

D. Conductance

E. Intensity

7. The value of electric current per square meter is called:

A. Electric conductivity;

B. Electric inductance;

C. Current density;

D. Current capacitance

E. Current intensity

8. Ampere per square meter is the unit of:

A. Current density;

B. Current capacitance;

C. Electric conductivity;

D. Electric inductance

E. Current intensity

9. Generators that maintain the constant potential difference at the ends of conductor produce:

A. Constant current;

B. Stable current

C. Direct current

D. Alternating current

E. Modulated current

10. Some charges are relatively free to move producing electric current in:

A. Insulators and conductors;
B. Semiinsulators and semiconductors;
C. Insulators and semiconductors;
D. Conductors and semiconductors
E. 2 type conductors and insulators

11. If the electric current varies in time it is called:

A. The alternating current;
B. The varying current;
C. The eddy current;
D. The circulatory current
E. Modulated current

12. Sea water in accordance with its electric properties is:

A. Insulator;
B. Semiinsulator;
C. Conductor;
D. Semiconductor
E. 1 type conductor

13. Iron accordingly to its electric properties is:

A. Insulator;
B. Conductor of 1 type;
C. Conductor of 2 type;
D. Semiconductor
E. electrolyte

14. Blood has the properties of:

A. Insulator;

B. Conductor of 1 type;

C. Conductor of 2 type;

D. Semiconductor

E. electrolyte

15. The property of conductors to oppose electric current and to transform electric energy into heat energy is called:

A. Capacitance;

B. Inductance;

C. Reactance;

D. Resistance

E. intensity

16. Formula of the Ohm is:

A. $U = \frac{I}{R}$, where I - electric current, U-voltage; R- electric resistance;

B. $I = U \cdot R,$ where I - electric current, U-voltage; R- electric resistance;

C. $I = \frac{U}{R}$, where I - electric current, U-voltage; R- electric conductance;

D. $I = \frac{U}{R}$, where I - electric current, U-voltage; R- electric resistance.

E. $I = U \cdot R,$ where I - electric current density, U-intensity; R- electric resistance;

17. To calculate the value of resistance in a conductor such equation is used:

A. $R = \rho \cdot T;$

B. $R = \frac{l}{S;}$

C. $R = \rho \cdot \frac{1}{T};$

D. $R = \rho \cdot \frac{l}{S}$.

E. $R = \frac{J}{S}$;

18. Differential form of the Ohm law which includes such characteristic as conductivity is:

A. $J = \frac{E}{\gamma}$;

B. $I = \gamma \cdot E$;

C. $J = \gamma \cdot U$;

D. $J = \gamma \cdot E$.

E. $J = q \cdot U$;

19. The current carriers in the 1 kind of conductors are:

A. Positrons;

B. Electrons

C. Protons

D. Ions

E. Anions

20. The formula of Ohm law for electrolytic solutions is:

A. $J = q \cdot n \cdot (u_+ + u_-) \cdot E$;

B. $J = q \cdot n \cdot (\upsilon_+ + \upsilon_-) \cdot E$;

C. $J = q \cdot n \cdot (u_+ + u_-)$;

D. $I = q \cdot n \cdot (u_+ + u_-) \cdot E$

E. $J = q \cdot n \cdot (u_+ + u_-) \cdot U$

21. If *I=10mA, U=20mV*, what is the value of *R*:

A. 0,01 Ohm;

B. 0,1 Ohm

C. 0,02 Ohm;

D. 1 Ohm;

E. 2 Ohm

MAGNETIC FIELDS, THEIR INFLUENCE ON HUMAN ORGANISM AND APPLICATION IN MEDICINE

The magnetic field like the electric field is the studying object of electrodynamics, because both they are created by electric charges and are the parts of a single electromagnetic field. The magnetic field, as well as electric, reveals itself in space by its power which influences on the electric charges. However unlike the electric field, it effects only on **mobile** electric charges.

The magnetic field arises up round single **mobile** charges and round current-carrying conductors. Also the sources of the magnetic field are the magnetized objects.

The magnetic fields which do not change in time are named the static (constant) fields and those magnetic fields which change in time in accordance with a sine law – by the alternating fields.

PHYSICAL DESCRIPTIONS OF THE MAGNETIC FIELDS

Power characteristic of the magnetic field is **magnetic induction**. For its measurement it is possible to enter in the magnetic field the trial charged body which moves there with some velocity. Magnetic induction is vector quantity. Its absolute value is equal to force, acting on the single electric charge *q*, which moves with single speed in direction, perpendicular to the direction of magnetic induction:

$$B=F/q*v$$

Unit of magnetic induction is *tesla* ***(T)*.**

Direction of magnetic induction vector can be defined by the *left hand rule*: if four extended fingers of left hand specify the direction of positive charge’s q motion, and a thumb, at 90^o to the other fingers, points in the direction of force, exerted upon this charge, then the vector of magnetic field enters a palm.

Direction of the magnetic forces' action can be represented graphically by the lines of magnetic induction. These are imaginary lines, which tangents in each of points of the field coincide with direction of magnetic induction vector in these points. The lines of magnetic induction are closed on itself. They differ by this feature from the force lines of the electrostatic field, which begin and close on the electric charges.

If a rectilinear conductor carries electric current, the lines of magnetic induction are circumferences, located in a plane, perpendicular to a conductor (fig. 1). Their direction is determined by the rule of right screw.

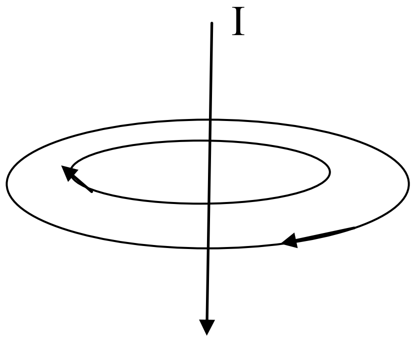


Fig. 5

The value of magnetic induction depends not only on the source of the magnetic field but also on the properties of the matters inside it. Therefore additional characteristic of magnetic field is used. It is called the *magnetic field intensity*.

It depends only on the source of the field and remains constant independent on the matter in the field. Its value is determined by equation:

$$\vec{H} = \frac{\vec{B}}{\mu_0 \mu}.$$

In this equation B is magnetic induction, μ_0 - magnetic constant, μ it is relative permeability of medium. It shows the value of the magnetic induction in definite medium by comparison with that in a vacuum.

Influence of the magnetic field on conductor with a current and on a mobile electric charge

If a current-carrying electric conductor is placed in magnetic field the field influences it with certain force. It is called **Ampere force**. Let the size of magnetic induction is B, and electric current in conductor is I. Conductor can have different length and configuration.

Therefore for determination of Ampere force it is necessary to select the small enough area of conductor dl, which can be considered rectilinear and examined as a vector, directed toward a current. *Idl* is the current element. In this case Ampere force differentially can be presented by the next equation where *k* is a proportional coefficient, and β is an angle between vectors *dl* and *B*:

$$d\vec{F} = k \cdot Id\vec{l} \cdot \vec{B} \cdot \sin\beta.$$

Force, which acts on a current-carrying conductor in the magnetic field, is the result of the field' effect on the mobile charges. Force of the magnetic field, operating on a single mobile electric charge, can be defined by transformation of Ampere equation and named **Lorentz force** F_L. It is described by the next equation, where q is a size of charge, *v* is speed of its movement, *B* is magnetic induction, *β* is an angle between vectors *v* and *B*:

$$\vec{F}_{л} = q \cdot \vec{\upsilon} \cdot \vec{B} \cdot \sin\beta.$$

Lorentz force is always perpendicular to a plane of the velocity and magnetic induction vectors. It changes direction of particle motion only, but not its velocity. Lorentz force gives a possibility to manage the streams of elementary particles, particularly electrons, by means of the magnetic fields. They help to change direction of electrons' motion and focus them (like the refraction of light ray by lenses). Devices, applied for this purpose, are named the electronic lenses. Change of the electron stream's direction through the magnetic field is used in many devices, from domestic television sets to electronic microscopes.

Magnetic field round a current-carrying conductor

There is the magnetic field around a conductor where an electric current flows on. Its induction in any point, located in the distance from the element of current is possible to find, using Biot-Savart law. It shows that magnetic induction in selected point depends on magnetic properties of the matter $\mu_0 \cdot \mu$, electric current element *Idl*, radius *r*, which is a distance between conductor and selected point of magnetic field and angle between the vector to this point of magnetic field and conductor sinα.

$$\vec{B} = \frac{\mu_0 \cdot \mu}{4\pi} \cdot \frac{I \cdot d\vec{l} \cdot \sin\alpha}{r^2}.$$

Magnetic moment. Magnetic properties of bodies.

Let us consider a current-carrying loop (fig. 2), which generates the magnetic field. This magnetic field depends current I in a loop and area S, circled a loop. Magnetic field can be characterized by a magnetic moment Pm. It is determined by equation: Pm = I S.

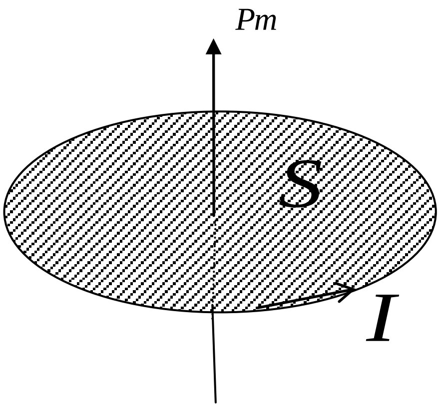


Fig. 6

Magnetic moment is a vector quantity. It is directed perpendicularly to a plane of loop and related to the direction of current by the rule of right screw. If a current-carrying loop appears in the magnetic field, it rotates under the influence of magnetic forces until a vector of the magnetic moment and a vector of the magnetic induction of the field will coincide by their direction.

The concept of the magnetic moment has important value for explanation of magnetic properties of the different matters. All the matters change their state in the magnetic field, and become the field sources. In this sense matters are named magnetics. The magnetic properties of the different matters are conditioned by the structure of their atoms and molecules.

Each electron in an atom rotates along the orbital. Motion of an electron, like an elementary negative charge, may be presented as an electric current in the closed loop. Hereupon an electron has an **orbital magnetic moment**. Its value depends on the charge of electron e, rate of movement *v* and radius of orbital r:

$$P_{m.orb} = \frac{e \cdot \upsilon \cdot r}{2} \quad .$$

Besides an orbital magnetic moment an electron has its own magnetic moment named spin Pm_s. This magnetic moment is possessed by other elementary particles, including protons and neutrons. Therefore atomic nuclei have a magnetic moment also. Quantum mechanics interprets these concepts more exactly.

The magnetic moment of an atom as whole is equal to the vector sum of the magnetic moments of the nucleus and all its electrons. By the same way the magnetic moment of a molecule is equal to the vector sum of the atomic magnetic moments in its composition.

When the matters are placed in the magnetic field, they acquire the magnetic properties (magnetize). In accordance with their magnetic properties the matters are divided into three types: diamagnetics, paramagnetics and ferromagnetics.

The most of the matters belong to **diamagnetics**, particularly many chemical elements (hydrogen, carbon, phosphorus, sulphur, gold, copper and other), and also water and overwhelming part of organic compounds. In the diamagnetics orbital, spin and nuclear magnetic moments of their atoms are compensated without the external magnetic field. Hereupon the total magnetic moments of their atoms and molecules are equal to zero. If diamagnetics are placed in the magnetic field, a magnetic moment arises in their atoms. It is directed oppositely to the external field. Therefore they weaken the external field. Relative permeability of diamagnetic is less then one. When delete of the external field the induced magnetic moments of the atoms of diamagnetic disappear, and it becomes demagnetized.

Some elements belong to the **paramagnets** (nitrogen, oxygen, aluminum and other). In the case of paramagnets orbital, spin and nuclear magnetic moments do not compensate each other, and their atoms always have a magnetic moment, different from zero. Without the external magnetic field the magnetic moments of the separate particles of paramagnet are oriented disorderly. Hereupon a matter has not magnetic properties as the whole. If a paramagnet is placed in the external magnetic field, the magnetic moments of its particles are oriented mainly in the direction of this field. The external magnetic field increases therefore. Relative permeability of paramagnets is more then one. There is also a diamagnetic effect in the particles of paramagnets, placed in the magnetic field, but it does not reveal itself against a background of paramagnetic effect.

The following metals belong to **ferromagnetics**: iron, cobalt, nickel and other. They are characterized by the ability to strengthen the external magnetic field in many times. Relative permeability of the ferromagnetics is considerably more then one. In addition, it is inconstant and depends on the intensity of the external magnetic field. The features of the ferromagnetics are explained that in them. There are the large spontaneously magnetized areas in the ferromagnetics. They are called domains. Presence of these domains can explain the ferromagnetics' features.

The biological molecules are diamagnetics in considerable majority. The examples of paramagnets in the bioobjects are free radicals which play an important biological role. Recently ferromagnetics in the living organisms were found, probably connected with the influence of magnetic field on living organisms.

INFLUENCE OF THE MAGNETIC FIELDS ON HUMAN ORGANISM

The magnetic fields in a human environment are named the exogenous (external) fields. Such fields, in the first place, are natural, presented by the geomagnetic field and its natural influences, and also artificial (technogenic), which are created as a result of the industrial human activity. The magnetic fields, applicable in medicine for the therapeutic purposes, belong to the artificial fields too.

Natural magnetic fields. Earth has its own magnetic shell – *magnetosphere*. In accordance with modern theory, its origin is connected with the electric currents in the external nucleus of Earth at the depth about 2900-5100 km. Induction of the geomagnetic field has the average value about 50 mcT. The south magnetic pole of Earth is located nearby the north borders of Canada, and the north magnetic pole – nearby the south geographical pole, on verge of Antarctic continent.

The parameters of the magnetic field of Earth (geomagnetic field) vary. The most changes of the geomagnetic field are caused by the magnetic storms which arise up during the flashes of sun activity and related to the influence of sun wind on the geomagnetic field. This wind is formed by two types of sun radiation - electromagnetic (EM) and corpuscular. EM radiation includes X-rays, ultraviolet, infra-red radiations, flow of visible light etc. The corpuscular sun radiation is formed by neutral plasma (positive ions and electrons) and sun ultra rays (by the particles of high energies which are generated during sun flashes).

The magnetosphere of Earth effectively protects the planet from sun wind, declining it to the magnetic-poles in the periods of moderate sun activity (hereupon Aurora appears). But during the flashes on the Sun a magnetosphere «compresses» (its border in some places becomes less than 6,6), that results in the appearance of the magnetic storms.

Nowadays the role of the geomagnetic field is well-proven as an ecological factor in the vital activity of the organisms. In the process of evolution biological objects adjusted to the presence of permanent variations of the geomagnetic field. It is known that these variations have an informative function for the healthy organisms – serve as «time-signals» and allow tuning the internal rhythms of organism in accordance with the rhythms of environment. It is well-proven that absence of the geomagnetic field effects on an organism (screening, for example, in airplanes, subway, submarine boats et cetera) influences on a health unfavorably.

However the most problem of the magnetic storms' influence on a human health has an important medical value. As early as 1928 A.L. Chizhevsky specified on the increase of the accidents and transport and industrial traumatism in relationship with the increase of sun activity. The scientist explained this information by the high sensitiveness of the nervous system to the action of the electromagnetic fields. Experimental information and the results of the clinical supervisions, which show that the changes of different indexes of the vital functions (for example, speeds of motive reaction, arteriotony, cardiac rhythm, biochemical processes et cetera), are presently accumulated during the magnetic storms. The consequences of such changes depend on the state of human health. However these data testify that magnetic storms cause a deterioration of human organism's state, enlarge the number of cardiac attacks, strokes, attacks of epilepsy, psychical violations et cetera.

Problem of the technogenic magnetic fields' influence on a human health has a medical value also. Such fields, mainly, are variable or impulsive. They are created by the high-voltage lines of electricity transmissions, electric transport, by industrial and domestic electrical engineering devices. The technogenic fields have much more intensity, then the geomagnetic field, and by uneven localization in space. Negative consequences of the technogenic magnetic fields' influence can be very substantial. The modern medical problems include their investigation and prevention.

Biophysical mechanisms of the magnetic fields' influence on the biological objects

When consider the influence of the most environmental factors (light, smell, sound et cetera), foremost, the scientists take into account a presence of specific receptors which are sensible to the energy of this influence. Information from them is passed to a brain, where the analysis of irritation is carried out and the return reflex reaction of organism gets organized. But specific human receptors, which are able to react on the action of the magnetic field, have not been found yet.

However it is necessary to note that the crystals of magnetite were found out in a brain and abundantly innervated sieve bone of human skull (fig.6). It is known that the external magnetic fields are able to effect on these ferromagnetic particles. But now the crystals of magnetite can not be acknowledged.

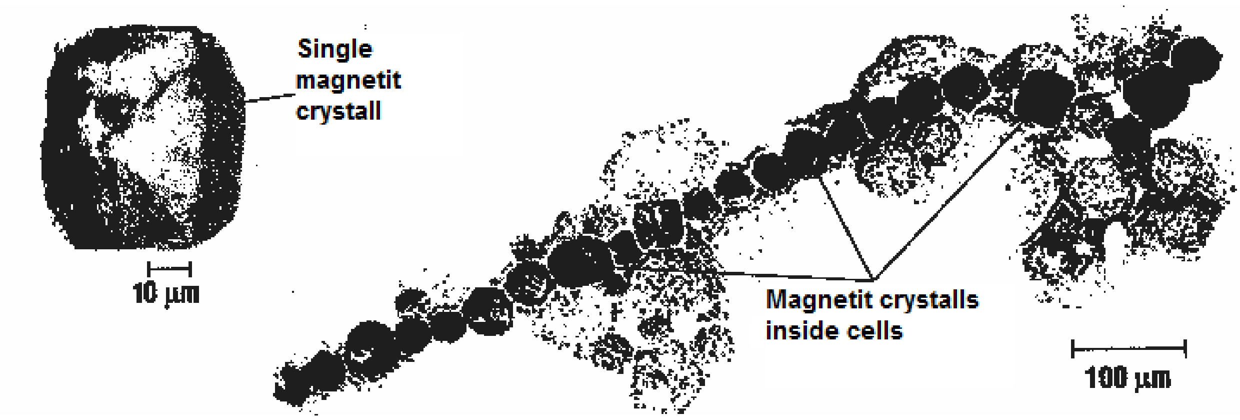


Fig. 7. Crystals of biogenic magnetite

The way of information from the magnetoreceiptors to the nerve centers and concrete reactions, which would be conditioned by activation of the magnetoreceiptors, are unknown.

It is necessary to mark also that certain progress in search of the magnetoreceiptors is attained in the experiments on the migratory animals (pigeons, trout, salmon et cetera). They orient very exactly by means of the geomagnetic field and are able to feel the smallest its changes, even about 200nT. It is known that such properties of the migrant animals relates to the completions of certain nerves and to the change of the magnetic field. However the mechanisms of such activation and following processes in the nervous system are unknown.

Nowadays for the explanation of the mechanisms of magnetic fields influence on the human organism, mainly, we take into account:

1. Magnetic properties of the substances of the tissues;

2. Presence of the mobile ions in the tissues which are sensible to the external magnetic fields.

The tissues of the human organism, mainly, are formed by diamagnetic materials (water and practically all the organic substances). However there are some paramagnetic particles (free radicals) in them. The magnetic fields change the properties of diamagnetic and paramagnetic atoms and molecules. These changes are named diamagnetic and paramagnetic effects. They are a basis of the magnetic fields' influence on the more complex structures (for example, membranes, organoids of the cells and other), and further – on the cells, tissues, organs and organism as a whole. It is established that practically all the structures and systems of organs are sensible to the action of the magnetic fields.

It is important to note, when consider the action of the magnetic fields at a molecular level, that sensitiveness of such biologically important molecules as DNA, RNA, ATP, many enzymes to them was shown. High biological efficiency of the magnetic influence can bases on this sensitiveness.

Researches of an action of the magnetic fields on water is very interesting, because its maintenance in an organism exceeds the amount of any other matters, and the properties of water change under the action of the magnetic fields enough.

Besides the diamagnetic and paramagnetic effects the magnetic fields can influence on the tissues of organism by the power effects on the mobile ions. The variable and impulsive fields cause an appearance of the inducted currents. This mechanism of the magnetic fields' influence on biological tissues is called the mechanism of the caused currents. The weak magnetic fields cause microvibrations and microcurrents of the ions in the biological tissues, changes rate of the metabolic processes, permeability of the cell membranes, speed of reagents' and informative molecules' delivery to the membrane surfaces. The intensive magnetic fields can cause the induction currents, their force exceeds threshold values for the excitation of nervous, muscle and ferrous cells of organism.

Application of the magnetic fields for medical purposes

The medical influence of the magnetic fields is used in many branches of medicine. At the fig. 8 the systems of organs with the largest relative sensitiveness to the influence of the magnetic fields are shown. It depends on electric and magnetic properties of the tissues, organs and systems. Also specific properties of microcirculation in the organs, intensity of metabolism and the state of the nervous regulation play an important role.

Magnetotherapy is one of the physiotherapeutic methods, when body of patient is affected by the constant or variable low-frequency magnetic field. Such fields influence on distance, without heating of the tissues. Permanent magnets and solenoids are applicable (inductive coils) for the magnetotherapy. Latter direct or alternating (about 50 Hertz) electric voltage, which causes appearance of the constant (to 60 mT) or variable magnetic field, is used. It is known that the effect of variable magnetic field is more expressed, than that of constant. However the effect of influence of the magnetic fields also depends on the parameters of the field, duration of its influence and individual sensitiveness.

It is discovered that a magnetotherapy, applied natively (locally), has the brightly expressed analgesic, antioedematous and regenerative action. At the system level a hypotensional, tranquilizing effects of magnetotherapy, and also action of the magnetic fields on the metabolism, functions of blood and immune processes are used more frequently. In addition, there are methods of the reflex influence and their mediated action of the magnetic fields (in bioactive areas and points of acupuncture).

Magnetostimulation is one of the modern methods of treatment and diagnostics by means of the magnetic field.

In the process of magnitostimulation the impulsive electric current of high intensity flows through a coil, situated nearby a patient' body. There the impulsive magnetic field, which induce an electric impulse in the tissues, appears. Its intensity can be sufficiently enough to cause an excitation of the nervous and muscle cells. Magnitostimulation applies for diagnostic researches of excitability of the nervous and muscle systems, and also for treatment of nervous, blood circulatory and other diseases.

MAGNETIC FIELDS OF HUMAN BODY
(endogenous magnetic fields)

The appearance of the magnetic fields in the human body is connected with the processes of excitation in the nervous and muscle cells, the definite structures and organs, and motion of the biological liquids (blood, lymph).

The vital activity of the excitable cells (muscle and nervous) follow the appearance of the electric currents, which generate the magnetic fields. They are much weaker than the magnetic field of Earth, and also the technogenic magnetic fields. However the biomagnetic fields can be recorded by the special highly sensitive sensors. Their principle of action is based on the phenomenon of superconductivity. The methods of registration of the heart's and cerebrum's magnetic fields have clinical importance.

Magnitocardiography is a method of the heart magnetic field's recording. During excitation of the heart muscle electric currents arise there, it causes the changes of the characteristics not only of the heart's electric field (it is recorded on ECG) but also its magnetic field. Thus, a magnetocardiogram (MCG) reflects the same processes in a heart, like ECG: different phases of the heart cells' excitation in the atriums and ventricles. Therefore the shape of ECG and MCG are similar (fig. 9).

Fig. 8. Electrocardiogram in the 1 lead (above) and magnetocardiogram in the same lead (down)

Magnetocardiograms are recorded many times by means of a sensor movement on the surface of thorax in the area of heart. In comparison with the other methods of heart's investigation, MCG allows to expose the local diseases of myocardium more exactly. Because of contactless registration of MCG it is possible to use this method for research of the heart activity in the process of functional test by the mobile load, and also in the tests on animals.

Magnitoentcefalografy is a registration method of the brain's magnetic field. It arises up because of the ions motion during excitation and braking of the neurons. Oscillations of the magnetic fields are very small. Therefore not only highly sensitive sensors but also special screened apartments, which weak the effects of the external magnetic fields are required for their registration.

A magnetoencephalogram looks like an electroencephalogram (fig. 10), because the similar physiological processes are reflected in them. Advantages of magnetoencephalography consist in enhanceable exactness of cerebral activity's localization, and also in possibility of contactless registration (during the motions of patient also). The last circumstance allows to use magnetoencephalography in the researches of mechanisms of the motive regulation, and also for inspection of child in the womb of mother.

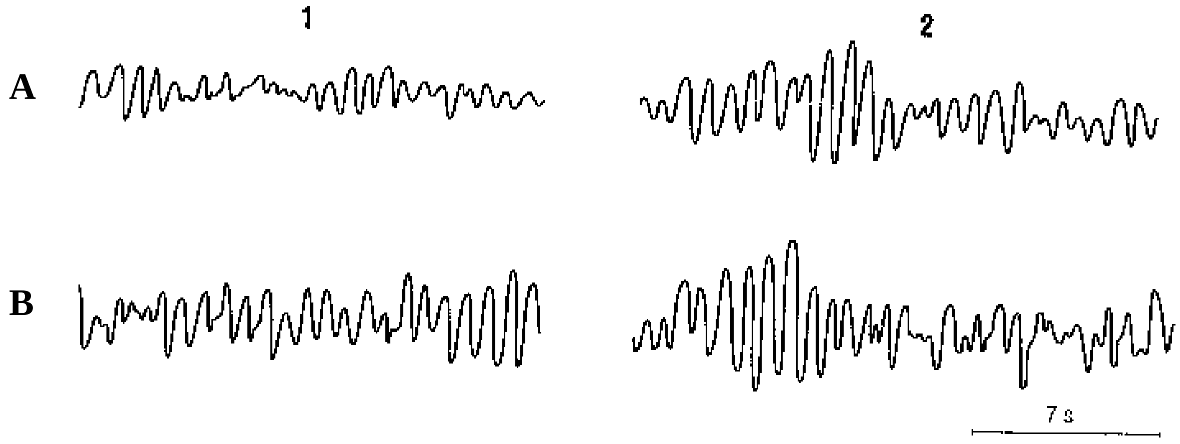


Fig. 9. Electroencephalogram (A) and magnetoencephalogram (B), recorded, when the eyes are opened (1) and closed (2).

TESTS FOR KNOWLEDGE CONTROL

1. Magnetic field arises up round

A. magnetic charges

B. static charges

C. mobile charges

D. only positive charges

E. only negative charges

2. Power characteristic of the magnetic field is

A. magnetic intensity

B. magnetic power

C. magnetic lines

D. magnetic induction

E. electromagnetic force

3. Unit of magnetic quantity B is

A. Ampere

B. Tesla

C. Coulomb

D. Volt

E. Newton

4. Lines of force of magnetic field

A. are going from one charge to another

B. begin on positive charge and close on negative

C. begin on negative charge and close on positive

D. are closed on itself

E. begin on positive charge and go to infinity

5. The lines of magnetic field

A. located in a plane perpendicular to a conductor

B. located in a plane parallel to a conductor

C. directed by the rule of left screw

D. are not circumference for conductor

E. begin and close on a rectilinear conductor

6. . Additional characteristic of the magnetic field which depends on the properties of the matter inside the magnetic field is

A. magnetic intensity

B. magnetic power

C. magnetic lines

D. magnetic induction

E. magnetic relative permeability of medium

7. If a current-carrying electric conductor is placed in magnetic field the field influences it with certain force. It is called

A. Lorentz force

B. Newton's force

C. magnetic induction

D. the current element force

E. Ampere force

8. Which force gives a possibility to manage the streams of elementary particles, particularly electrons, by means of the magnetic fields?

A. Lorentz force

B. Newton's force

C. magnetic induction

D. the current element force

E. Ampere force

9. Which direction the charge should move in magnetic field to be affected by the field with highest force?

A. parallel to the field

B. along the field

C. to some critical angle to the field

D. perpendicular to the field

E. along the force lines of the field

10. In what kind of matters magnetic moments of their atoms are compensated without the external magnetic field?

A. amagnetics

B. promagnetics

C. paramagnetics

D. diamagnetics

E. ferromagnetic

11. What kind of matters according to the magnetic properties the gold belongs to?

A. amagnetics

B. promagnetics

C. paramagnetics

D. diamagnetics

E. ferromagnetic

12. In what matters the total magnetic moments of their atoms and molecules are equal to zero?
A. amagnetics
B. promagnetics
C. paramagnetics
D. diamagnetics
E. ferromagnetic

13. What kind of matters according to the magnetic properties the oxygen belongs to?
A. demagnetics
B. promagnetics
C. paramagnetics
D. diamagnetics
E. ferromagnetic

14. In what matter the magnetic moments of its particles are oriented mainly in the direction of external magnetic field?
A. demagnetics
B. promagnetics
C. paramagnetics
D. diamagnetics
E. ferromagnetic

15. Relative magnetic permeability of what matters is considerably more than one?
A. demagnetics
B. promagnetics
C. paramagnetics
D. diamagnetics

E. ferromagnetic

16. Mobile phone magnetic field is

A. natural

B. endogenous

C. eccentric

D. industrial

E. medical

17. Method of treatment that causes muscle cells contraction?

A. magnetocardiography

B. magnetoencephalography

C. magnetostimulation

D. magnetoreception

E. magnetostriction

18. Method of the brain’s magnetic field registration

A. magnetocardiography

B. magnetoencephalography

C. magnetostimulation

D. magnetoreception

E. magnetostriction

19. Method of the heart magnetic field’s recording

A. magnetocardiography

B. magnetoencephalography

C. magnetostimulation

D. magnetoreception

E. magnetostriction

20. What is the main advantage of using methods of diagnostics and treatment based on magnetic field application?

A. no contact with body

B. magnetic field is safe

C. no radiation applied

D. no pain

E. easy to use

21. What is called the mechanism of the caused currents?

A. influence of magnetic field on proteins

B. influence of magnetic field on DNA

C. influence of magnetic field on ATP

D. influence of magnetic field on water

E. influence of magnetic field on ions

22. Magnetic field of what maximal value is used in therapeutic medicine?

A. 0,6mT

B. 6 mT

C. 16 mT

D. 60 mT

E. 6 T

ELECTRONIC MEDICAL EQUIPMENT

Electronic medical equipment is used intensively in all the branches of modern medicine. The progress in diagnostics and medical treatment depends to a considerable degree on the use of various special equipment. Medical electronics is the field of electrical technology which is engaged in working up and operation of this equipment.

All the variety of medical electronic devices may be classified in general outline into several groups:

a) diagnostic devices destined for obtaining information concerning the status of patient organism;

b) the devices destined for all kinds of medical treatment, including physiotherapeutic apparatus;

c) computers intended for processing and storing of medical information.

The basis of safety engineering

Every medical device must be safety at all the circumstances that are foreseen by safety regulations. The safety of each apparatus is guaranteed by its correct construction. There are several classes of medical devices according to the safety engineering that protects the patients and medical personal from electric trauma.

Class 0 - the safety of devices is ensured only by electric insulation. That are the devices of everyday use that are not destined for the special aims of medical treatment.

Class I - the safety is ensured not only by electric insulation but also by the grounding of apparatus. The plug of the apparatus must be supplied by the ground connection.

Class 0I - grounding is achieved by the grounded conductor that must be connected to the special terminal.

Class II - the apparatus have not only basic but also additional augmented electric insulation. The apparatus of this class have no grounding connections.

Class III - besides electric insulation, the safety from electric trauma is supplied by the autonomous low-voltage power supply (less than 24 volts).

Electrodes and transducers

Electrodes are the special conductors destined to record biopotentials of a heart, muscles, brain etc. There are electrodes of various shape and size. Electrodes used in clinic must have low electrical resistance and transmit electric signals without distortions.

Transducers are the special devices destined to transform input non-electric quantities (movement, pressure, temperature, light luminance etc.) into electric signals. Application of transducers is necessary for transmission, processing and recording of information.

There are two principal types of transducers: active and passive (parametric). Active transducers are able to generate electromotive force under the influence of non-electric energies.

For example, piezoelectric transducer, made of quartz or some other crystals, can transform mechanical pressure into electric potential difference. It can be used to record arterial pulse, blood pressure etc. Thermoelectric transducer generates electromotive force under the influence of temperature difference.

Passive transducers need the power supply (dc or ac voltage). They consist of electric circuit some parameters of which can be changed under the influence of input non-electric quantity. There are resistive, capacitive, inductive transducers.

All transducers are characterized by their sensitivity, resolution, inertness, dynamic range.

Stimulators and physiotherapeutic apparatus.

Electronic stimulators

Electronic stimulators are used in order to normalize the functions of some organs. One of them is a human heart. A healthy heart contains the so called conducting system capable to stimulate its contractions. The impulses are generated normally at the sinoatrial node in the right atrium wall. They induce the contraction of both atriums and pass to the atrioventricular node that is located in the partition between atriums and ventricles.

Then the impulses pass through the His bundle and initiate the contraction of both ventricles.

The conduction of impulses may be hampered or even interrupted at the certain types of heart disease. Then the artificial electronic heart pacemakers (stimulators) are used on purpose to normalize the rate of heartbeats. In temporary pacing, an electrode attached to the fine wire is introduced into the heart through a vein, usually in the arm. The pacing device is a generator of the square electric pulses of appropriate amplitude and duration. It remains outside the body and maintains the heartbeats.

In permanent pacing the miniature stimulator is placed surgically beneath the musculus pectoralis major. The electrode may again be passed into the heart through a vein or it may be surgically implanted on the heart's surface. The implanted stimulators use electric batteries as a power source. They require replacement at regular intervals, generally every four to five years.

The first generation of heart pacemakers were of a type called asynchronous. They generated regular electric pulses more frequently than the injured natural heart pacemaker did. Once set they could not change their rate. More recent devices are asynchronous, or demand, pacemakers. They initiate heart contractions only when the normal beat is disturbed. The pacemakers of this type begin to generate pulses when the natural heart rate falls below its normal value. They have electrode and special device which is designed to detect the atrial biopotentials and measure their rate.

There are many types of stimulators intended for treating of the nerve and muscle diseases. They are provided with external electrodes and generate rectangular or modulated sinusoid pulses.

These stimulators are used to combat various types of muscle palsy and algesic states: low-back pain, neuralgia, joint pain.

Impulse defibrillators are designed for treating ventricular fibrillation which is a very dangerous heart disorder. It is known that normal heartbeat arises when the heart muscles cells excite synchronously. Fibrillation is the result of irregular and asynchronous contraction of the individual cardiomyocytes. At the state of fibrillation a heart cannot produce systole, and the blood circulation ceases.

The current defibrillator involves a capacitor which may be charged to the high voltage. It discharges through the electrodes contacting with the patient's chest. The pulse duration is about 5-10 milliseconds, and the electric current passing the patient's body attains several amperes. Application of this method helps to restore the normal heartbeats an to save human life.

Electrical physiotherapeutic apparatus

Alternating current of diverse parameters is widely applicable in electrophysiotherapeutics. All medical apparatus utilizing this factor can be divided into the two different groups: low-frequency and high-frequency devices.

Physiotherapy is a field of medicine that studies physiological and medical effect of natural and artificial physical factors and develops methods of their application for preventive and medical purposes; a group of physical methods of treatment and their practical application.

In the early 1890s, French physiologist Arsene d'Arsonval began studying the medical application of high-frequency currents. The term diathermy was coined by German physician Carl Franz Nagelschmidt, who designed a prototype apparatus in 1906. Around 1925, United States doctor J. W. Schereschewsky began studying the physiological effects of high-frequency electrical currents on animals. It was several years, however, before the fundamentals of the therapy were understood and put into practice.

Fig. 10 . Arsene d'Arsonval

The original high-voltage transformer generating high frequency current was manufactured in 1895 by the E. Ducrett & L. Lejeune company from Paris based on Tesla's description (Tesla's lecture, Paris, 1892). It was used for therapeutical purposes by Dr. d'Arsonval, after whom the way of applying alternating current in medicine was named "darsonvalisation". In 1892 d'Arsonval demonstrated how a human being could conduct an alternating current strong enough to light an electric lamp.

Darsonval forhair:

Promotes hair growth and fights with hair loss due to activation of the blood circulation, stimulate the activity of germ cells of the hair bulb, reduce the function of sweat and sebaceous glands. Application of device Darsonval "Crown" for hair successfully combat dandruff, seborrhea and other skin diseases.

Darsonval for skin:

Helps to improve skin elasticity and prevent the development of wrinkles due to activation of the blood circulation in the skin and the appearance of centers of of micronecrosis, which is accompanied by the release of biologically active substances, mediators and inhibitors. Application of the device to the skin helps with eczema, herpes, dermatitis, psoriasis, scleroderma, keloid scars, exudative diathesis, and others.

Fig.11. Electrods for darsonvalization

Low-frequency physiotherapeutics is represented by diadynamic and amplipulse devices. Diadynamic apparatus produces modulated half-wave or full-wave rectified sinusoidal current by the frequency of 50 or 100 hertz. The electric pulses are delivered by trains during which the pulse amplitude rises and falls gradually. Amplipulse generates electric oscillations by the frequency of five kilohertz. They can be half-wave and full-wave rectified and modulated by the low frequency oscillations.

Both diadynamic and amplipulse act upon the cell membranes. They activate metabolism and have the analgesic effect. When rectified they can be used to introduce the drugs by means of electrophoresis. They are used mostly to combat neuromuscular diseases and algesic states. Both of them are able to excite nerve and muscle cells or skin nerve endings and cause pain and muscle contractions. Therefore, the current must be restricted to be only slightly perceptible by a patient.

Diadynamotherapy engages direct currents with 50 and 100 Hz semi-sinusoidal pulses for medicinal purposes. Generally, two types of diadynamic currents are used: continuous single-phase and continuous two-phase, as well as different modulations and combinations of these currents – interrupted rhythmic current, modulated by short or long periods, etc.. Being direct currents, they are exposed to strong epidermal resistance and, primarily, cause excitation of exteroreceptors, which is manifested by burning and pricking sensation under the electrodes, as well as hyperemia appearance due to enlargement of surface vessels and accelerated blood circulation. Increasing the current strength causes rhythmic excitation of nerves and muscular fibers. This leads to activation of peripheral blood circulation, increased metabolism, pain relief in the application area, which is generally used when treating diseases of peripheral nervous system and musculoskeletal system. Further increase of current strength effect tetanic contraction of muscles.

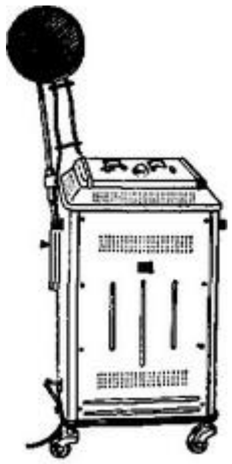
The medical application of the high-frequency apparatus is essentially different. The frequency of electric pulses generated by all of them is more than one megahertz, and the duration of a single pulse is less than one microsecond. Therefore, they are too short to trigger excitation of nerve or muscle cells. The transmission of such electric pulses through a body is neither perceptible nor troublesome to patient, and the current intensity may be sufficient enough to heat the body tissues.

The methods of high-frequency physiotherapeutics most often used in medical practice are diathermy, inductothermy, ultra high frequency-therapy and microwave-therapy.

Diathermy. Diathermy is the form of physiotherapeutics in which deep heating of tissues is accomplished by the use of high-frequency electric current (1-1,5 MHz). The current intensity may attain one ampere. Large area electrodes must be used in order to restrict current density. This method is not safe enough in view of the danger of burns and it is rarely used now.

On the contrary, the methods of electrosurgery (diathermotomy and diathermocoagulation) are widely used in medical practice. The difference between these method and diathermy lies in the form of electrodes. One of electrodes has sufficiently large area and serves as a mere current conductor. The other has the form of scalpel or loop. The current density at its surface may be large enough to cut or coagulate the tissues and stop bleeding at the same time.

Inductotermy. This method has the advantage over diathermy because it needs no contact between electrodes and human body. The electric current (10-15 MHz) is passed from the high frequency generator through the special inductor placed near some part of a body. The local heating is produced by the eddy (Foucault) current induced in the tissues by the high frequency magnetic field.



1. Fig. 12 Machine for inductothermy DQC-1

Under the influence inductothermy normalization of nervous system, stimulates the function of various organs and glands of internal secretion, increases by 1-6 degrees (or more) of local and slightly (by 0.3 to 0.9 degrees) General body temperature, metabolism, improves blood circulation, enhances the protective reactions of the organism, has been delayed reproduction of pathogenic microbes.
The inductothermy used in subacute and chronic inflammatory diseases of different organs

and systems, dystrophic and adhesive processes in them, fractures, violations of peripheral blood and in some acute diseases:pneumonia, pleurisy, nephrite, reflex anurii. Inductothermy contraindicated in malignant tumors, toxicosis, blood diseases, atherosclerosis, strokes, blood circulation disorders of the II and III degree, inclinations to different types of bleeding, sharp depletion, pregnancy.(slide 19).

The inductothermy can not be performed in the presence of metal bodies in the area of the projection of the inductor, damp plaster bandages. The simultaneous use of the same region inductothermy and galvanization is called galvanopuncture.

Ultra high frequency-therapy. This method is also contactless. The part of patient body is placed between two flat electrodes connected to the ultra high frequency generator (40,68 MHz). The special safety precautions insulate a patient from the power supply. The heating of tissues is produced mostly by the displacement current. At such a frequency the tissue dielectrics are heated more than conductors. The alternating displacement current causes alternating polarization of biological molecules. They oscillate at the ultra high frequency, and the heat energy is dissipated at the tissues.

UHF-therapy (ultrahigh-frequency therapy; synonym ultrashortwave therapy) is a method of treatment, is the impact on the body electric field of ultra-high frequency (EP UHF), often with the number of oscillations 40,68 MHz (wavelength 7,37 m), which is applied to the patient via a capacitor plates (electrodes). When exposed to pulses EP UHF (2-8 requirement)alternating with long pauses, the method is called pulse UHF - therapy. Therapeutic factor UHF-therapy is energy EP UHF absorbed by the body tissues. Therapeutic action EP UHF is determined not only by the formation in the tissues of heat, but also a number of physical and chemical processes in the tissues of the body that lies at the basis of local and systemic physiological reactions. UHF-therapy has a positive effect on the functional state of the nervous system, endocrine glands, the blood and lymph circulation, improves metabolism.

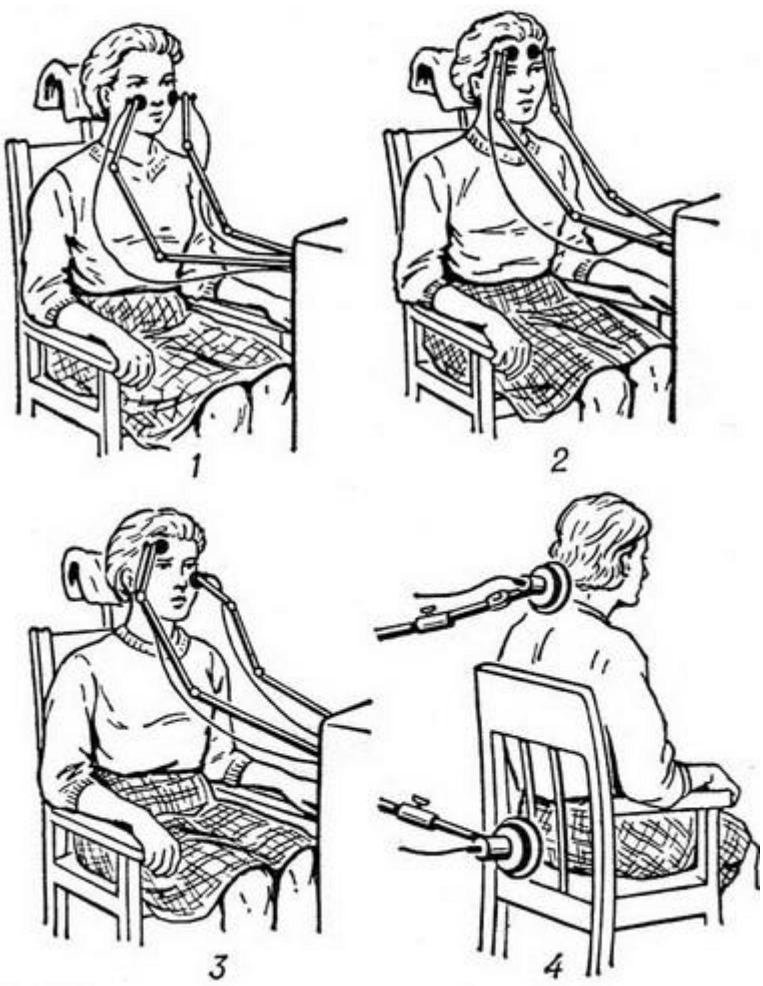


Fig.13UHF-therapy:

1-3 - sinuses (1 - jaw, 2 - frontal, 3 - maxillary, frontal and lattice); 4 - the area of the spine.

Microwave-therapy. Electromagnetic microwaves (2375 MHz) are directed by the waveguide on a patient body. They are absorbed by the tissues and cause fast reorientation of the dipole molecules. Water molecules are of major importance at this process. Therefore, the muscles and other tissues rich in water are heated more than bone or fat tissues.

TESTS FOR KNOWLEDGE CONTROL

1. These devices are used to normalize the functions of different organs with excitable tissues:

A. Amplifiers;

B. Oscillators;

C. Electrographs;

D. Transducers;

E. Stimulators

2. The impulses of human heart are generated normally at the:
A. Sinoatrial node in the right atrium wall;
B. Sinoatrial node in the left atrium wall;
C. Atrioventricular node in the right atrium wall;
D. Atrioventricular node in the left atrium wall;
E. Hiss bundle in the right atrium wall;

3. The artificial heart pacemakers substitute:
A. Conducting system of heart;
B. Contracting system of heart;
C. Exciting system of heart;
D. Right atrium of heart;
E. Right ventricle of heart

4. The pacemaker device is a generator of:
A. Square impulses;
B. Rectangular impulses;
C. Triangle impulses;
D. Sinusoidal impulses;
E. Cosinusoidal impulses

5. The electric batteries of the implanted stimulators require replacement every:
A. One or three years;
B. Four or five years;
C. Six or seven years;
D. Eight or nine years;
E. Ten or eleven years

6. These pacemakers are characterized by the constant frequency of impulses:

A. Synchronous;

B. Asynchronous;

C. Stable;

D. Unstable;

E. Irregular

7. These pacemakers begin to generate pulses only when the natural heart rate falls below its normal value:

A. Synchronous;

B. Asynchronous;

C. Stable;

D. Unstable;

E. Regular

8. Such devices are destined for treating of ventricular fibrillation:

A. Fibrillators;

B. Refibrillators;

C. Infibrillators;

D. Defibrillators;

E. Unfibrillators

9. The devices for fibrillation treating include:

A. Capacitor;

B. Inductor;

C. Oscillator;

D. Resistor;

E. Amplifier

10. The devices for fibrillation treating also include:

A. Transducers;

B. Electrodes;

C. Electrographs;

D. Resonators;

E. Inductive coils

11. The current using to stop fibrillation attains:

A. Several microamperes;

B. Several milliamperes;

C. Severel amperes;

D. Severel kiloamperes;

E. Several megaamperes

12. Low frequency physiotherapy is represented by:

A. Diathermy and inductothermy;

B. UHF-therapy and microwave therapy:

C. Diathermy and microwave therapy;

D. Diadynamic and diathermy;

E. Diadynamic and amplipulse

13. This kind of physiotherapy uses current by the frequency 50-100 Hz:

A. Diadynamic;

B. Amplipulse;

C. Diathermy;

D. Inductothermy;

E. Microwave therapy

14. Amplipulse generates electric oscillations by the frequency:

A. 5 Hz;

B. 50Hz;

C. 5 kHz;

D. 50 kHz;

E. 500 kHz

15. These methods activate metabolism and have the analgesic effect:

A. Diathermy and inductothermy;

B. UHF-therapy and microwave therapy;

C. Diathermy and microwave therapy;

D. Diadynamic and diathermy;

E. Diadynamic and amplipulse

16. This kind of treatment produces heat in the body tissues:

A. Electrostimulation;

B. Lithotripsy;

C. Defibrillation;

D. Low-frequency therapy;

E. High-frequency therapy

17. The frequency of oscillations generated by the high-frequency devices is more than:

A. One Hz;

B. One hundred Hz

C. One kHz;

D. One MHz;

E. One GHz

18. The duration of a single pulse in high-frequency physiotherapy is less than:

A. 1 minute;

B. 10 seconds;

C. 1 millisecond;

D. 1 microsecond;

E. 10 microseconds

19. In human body high frequency electric current 10-15MHz produces:
A. Excitation;
B. Analgesic effect;
C. Fibrillation
D. Electric trauma;
E. Heating

20. In diathermy such frequency of current is used:
A. 1-1,5 kHz;
B. 10-15 kHz;
C. 1-1,5 MHz;
D. 10-15 MHz;
E. 1-1,5 GHz

PHYSICAL BASIS OF OPTICAL MEDICAL INSTRUMENTS

Optics is usually devided into three parts. Two of them are called wave optics and quantum optics. This division is based on the dualistic nature of light which has the properties of both the waves and particles. The third part is named geometrical optics. It leaves out of account the nature of light and is based on the geometry of light rays. A ray of light is the direction along which the light energy trevels. The light rays are presented in diagrams by straight lines. A beam of light is a collection of rays.

Laws of geometric optics

Law of reflection. Light rays are reflected from the mirrors, highly-polished metal surfaces etc. (Fig.1). The law of reflection states that the incident ray, the reflected ray, and the normal to the mirror at the point of incidence all lie in the same plane. The angle of incidence is equal to the angle of reflection.

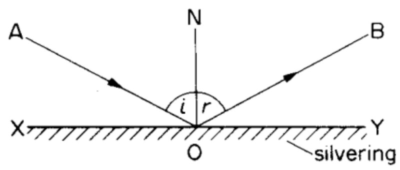


Fig.14. Plane mirror

Law of refraction. When a light rays go from one medium to another (e.g. from air to glass), some of the light is reflected from the plane that divides the media in accordance with the law of reflection. The rest of the light travels into another medium along a new direction. (Fig.2).

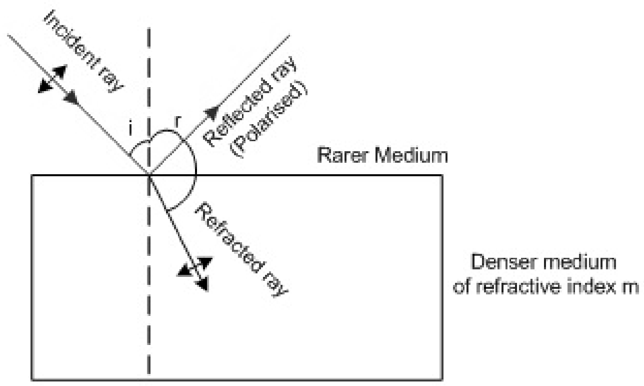


Fig.15. Refraction at plane surface

On account of the change in its direction, the light is said to be bent or refracted. The law of refraction states that the incident and refracted rays, and the normal in the point of incidence, all lie in the same plane. For two given media (1 and 2), the ratio $\sin i / \sin r$ is a constant, where i is the angle of incidence and r is the angle of refraction. This constant ratio is known as the relative refractive index for the two given media n_{21}. Light is refracted because it has different velocities in different media. The value of relative refractive index n_{21} is defined by

$$n_{21} = v_1 / v_2 ,$$

where v_1 and v_1 are the velocities of light in the media 1 and 2.

The absolute refractive index of a medium is the ratio of the light velocities in vacuum c and given medium v:

$$n = c/v$$

One of two media having greater value of refractive index is considered to be optically denser.

Total internal reflection. Critical angle.

Total internal reflection may occur only if a light travels from one medium to another which has a smaller refractive index, i.e. which is optically less dense (e.g. from glass to air).

If a ray AO is incident at a small angle α on a glass-air boundary, the part of the incident light is reflected along AE, while the remainder is refracted (Fig.3). When the angle of incidence is increased, the angle of refraction is increased at the same time. At some angle of incidence in the glass the refracted ray OL travels along the glass-air boundary, making the angle of refraction of 90°. Such angle of incidence is known as the critical angle. If the angle of incidence becomes slightly more than critical one, the reflected ray becomes bright, and no refracted ray is then observed. Since all the incident light energy is now reflected, total reflection is said to take place.

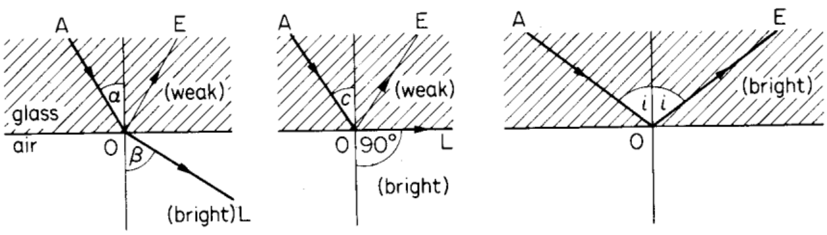


Fig.16.Total internal reflection.

Fiber optics. Endoscopy.

The phenomenon of total internal reflection is the physical basis of fiber optics. The medium of fiber optics is very thin flexible fiber that is made of plastic or glass. It is covered by the special substance which has a smaller refractive index so that total internal reflection occurs at its boundary with the glass. Light rays are beamed into the fiber and can travel along for great distances with little reduction of intensity. The bundle of such fibers forms a light guide.

Fiber optics is widely used in medical endoscopy. Various kinds of endoscopy (gastroscopy, tracheobronchoscopy, cystoscopy, laparoscopy etc.) give the possibility to observe internal organs from inside for diagnostic purposes and to take photographs. One bundle of fibers is used to illuminate the examined area with light. Another bundle serves for transmitting the image to the human eye or photographic camera.

Light guides are used also in endoscopic surgery. Nowadays many surgical operations need no broad sections. They can be performed by means of remote manipulators under the control of endoscopes. These methods are less traumatic than usual surgical technique. Ablation of gall- bladder is one of examples of the endoscopic surgery.

Lenses

A lens is an object made of glass or other transparent material, bounded by one or two spherical surfaces. There are converging and diverging lenses. The principal axis of a lens is the line joining the centers of curvature of its two surfaces.

Optical center of a thin lens is the point that lies at its middle on the principal axis. Incident light rays passing through optical centre do not refract.

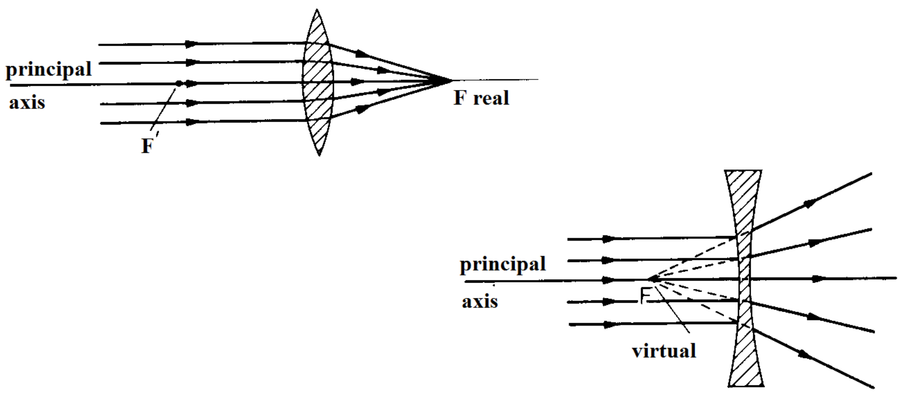


Fig.17. Focus of converging, and diverging lenses.

An incident beam of rays parallel to the principal axis is brought by a thin converging lens to a point that is called principal focus (Fig.4). There are two principal focuses on both sides of a lense. The distance between the optical centre of a lense and its principal focus is named the focal distance. The quantity inverse to the focal distance is called the lens power. Its unit is named diopter. One diopter is the power of a lens which focal distance is equal to one meter.

Image in lenses

Suppose an object OP is placed so that it is farther from the thin lens than its principal focus (Fig.5). A ray *PC* incident on its centre passes straight through the lens. A ray parallel to the principal axis is refracted so that it passes through the focus *F*. Thus the image *Q* of the point *P* is formed below the principal axis, and hence the whole image *IQ* is real and inverted. The image formed by a converging lens is always real and inverted if the object is placed at the distance more than the focal length.

If the object is placed nearer the lens than its focal length (Fig.5ii), the rays from the top point diverge after refraction through the lens. Hence the image *IQ* is virtual, erect and magnified. Therefore the converging lens can be used as "magnifying glass".

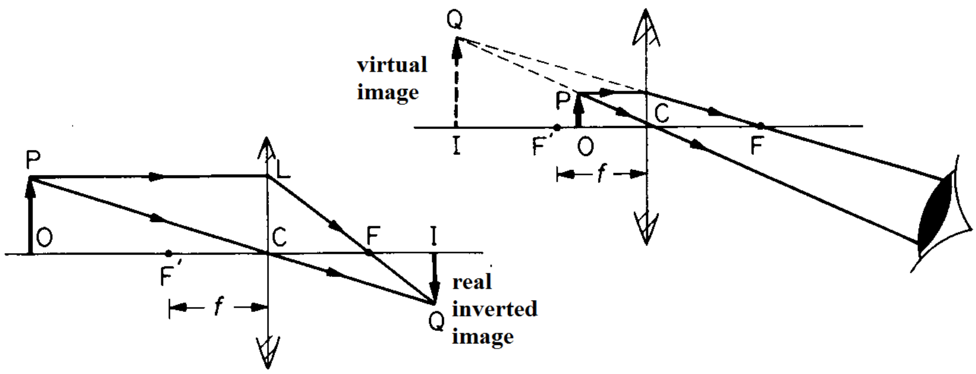


Fig.18. Images in converging lenzes

Lens aberrations

Lens aberrations are the defects which can distort an image. The image of an object formed by a real single lens can be distorted from a variety of causes.

The main defect of lenses is chromatic aberration, i.e. the colouring of image that they produce. Experiment shows that if a parallel beam of white light is incident on a converging lens, the red rays in the light are brought to a focus , and the blue rays are brought to slightly nearer the focus as the result of difference in refractive indecis. Thus a single lens produces coloured images of an object which are at slightly different positions. Chromatic aberration of a converging lens can be compensated by placing a suitable diverging lens beside it.

Experiment shows also that the central and peripheral parts of a converging lens have unequal ability to refract monochromatic light rays. It is the cause of so called spherical aberration. Incident monochromatic rays are more refracted by the peripheral parts of a lens than by its central part. Thus the image of a luminous point is not clear but vague. Spherical aberration can be can be annulled by the compensation method or by using diaphragm.

Astigmatism is mostly the result of imperfection in the lens sphericity. A lens may have different curvatures in different directions.If its surface has not a spherical but ellipsoid shape, the image may be distorted and disproportional.

Basic phenomena of wave optics

Since the works of Maxwell on electromagnetic radiation, it is known that light is the flux of electromagnetic waves. They are transverse waves with the electric and magnetic fields oscillating at right angles to the direction of motion. Electromagnetic waves travel in a vacuum with the velocity of 300000 kilometers per second. Wave theory is consistent with such basic light phenomena as interference, diffraction and polarization.

Interference of light. Interference is the result of the light wave superposition. Superposition occurs always when two or more waves are present in a medium. But interference takes place only when the light waves coming from different sources are coherent. The waves are called coherent if they have a stable phase relationship. Two natural light sources cannot be coherent because electromagnetic waves are emitted in them at random by many atoms and molecules, and the wave phases change frequently in disorder.

Coherent light rays are formed if they originate from a single source. They must be split in some way, e.g. by the prism. Light rays may become coherent also if they are reflected from both sides of a thin film. Lasers are the sources of the coherent light. If the coherent light rays fall on a screen, they form a stable combination of light maxima and minima (light and dark bands). Light maxima are formed at the places where coherent rays from both sources are in phase, minima - where they are in antiphase (opposite phase).

Diffraction of light. Diffraction of waves occurs when they pass through apertures and around obstacles. Experiment shows that the waves can round objects provided their size is sufficiently small. The smaller is the width of aperture or obstacle in relation to the wavelength, the greater is diffraction of the waves. Diffraction occurs when the light beam passes through the narrow splits. Diffraction grating consists of a large number of close parallel splits. Grating diffraction depends on the wavelength of light. Thus the grating can be used for the white light dispersion into spectrum.

Polarization of light. Light can be polarized , like any other transverse wave. When the transverse wave propagates in the medium, the disturbance can be along any line perpendicular to the direction of the wave motion. If the disturbance is always along the same line, the wave is said to be polarized along this line.

Electromagnetic waves have electric and magnetic fields oscillating at right angles to the direction of the wave motion. If the electric field vector is always along a certain direction, the wave is said to be linearly polarized along this direction. The radiation from a single atom or molecule is polarized, but since the many individual atoms and molecules act randomly, the light beam is unpolarized.

Polarized light can be produced from an unpolarized beam in several ways. The most familiar way is by absorption of light in Polaroid filters. These filters are maid of crystalline materials. They have the property of allowing light oscillations only of a particular polarization to pass through.

Polarimetry

Polarization of light is widely used in the concentration measurements of optically active substances. The devices destined for this purpose are called polarimeters. Optically active substances can rotate the plane of linearly polarized light passing through their crystals or solutions. Some of them rotate it clockwise. They are called dextrarotatory substances (d-substances). The other substances rotate the polarization plane counter clockwise (levorotatory substances, or l-substances).

Sugars and aminoacids are optically active substances. Their molecules can be in two forms that are chemically identical but differ in the spatial disposition of atoms. They may be considered as the mirror images of each other. Such forms of molecules are called stereoisomers (d-isomers and l-isomers). It may be noted that substances of biological origin are represented by only one form of stereosimers. For example, all proteins consist of l-aminoacids.

Polarimetry permits not only to distinguish d-isomers from l-isomers but also to measure their concentration. Polarimetr consists of two polaroid filters: polarizer and analyser. Polarizer transforms the beam of natural light into plane polarized light. Analyser is physically the same as polarizer. If they are oriented in parallel, analyser lets the polarized light to pass through it. If polarizer and analyser are crossed, the latter blocks the light passed by the polarizer.

In the polarimeters the solution of sugar is placed between polarizer and analyser. Sugar rotates the polarization plane at some angle that depends upon its concentration. The amount of rotation of the analyser required to restore light extinction determines the concentration of the solution.

THE BRIGHT-FIELD LIGHT MICROSCOPE

Microscope is one of the most wideluy used physical instrument in medicine. The bright-field light microscope can be found in every clinical laboratory. The lenses in the condenser focus the incident light on the object. The diaphragm regulates its intensity. Two separate lenses are used to obtain a high magnification. The lens nearer to the object is called the objective. The lensthrough which the final image is viewed is called the eyepiece, or ocular. The objective and the eyepiece are both converging, and both have the small focus length. In practice, both of these are made of several lenses, which together reduce chromatic aberration as well as spherical aberration.

When the microscope is used, the object is placed at a slightly greater distance from the objective than its focus length (Fig.6). F_1 is the focus of this lens. The objective produces a real, inverse and enlarged image of the object in the microscope tube. The image of the objective is the object for the eyepiece. The eyepiece is adjusted so that the image of the objective is nearer to the eyepiece than the focus F_2 of this lense. The eyepiece functions as a simple magnifying glass, used for viewing the image formed by the objective. It produces a virtual straight and enlarged image of the object.

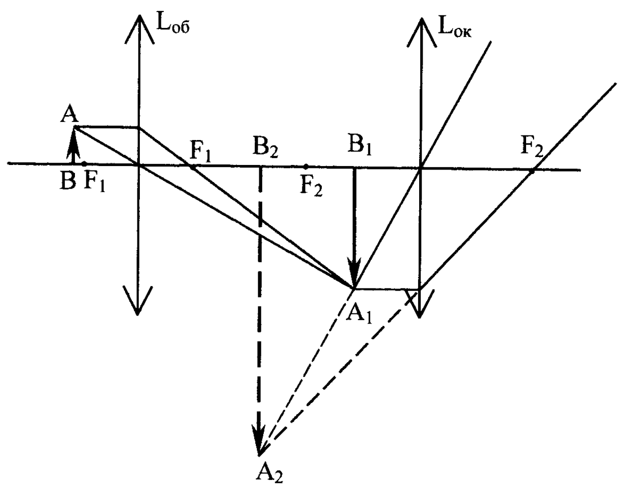


Fig.19. Light in microscope.

The total magnification of a microscope is equal to the product of objective and eyepiece magnifications. It may be shown that it has the inverse relation to the focal lengthes of objective and eyepiece.

Resolution and useful magnification in microscopes

The quality of image obtained by a microscope depends on its resolution. Resolution of a microscope is the minimal distance between two points in a specimen which are seen separately. When this distance is comparable with the wavelength of the light, the effect of light difraction becomes important, and the image becomes dim. The minimal separation *d* that can be resolved by a microscope is:

$$d = \frac{\lambda}{2n\sin\theta}$$

Here λ is the wavelength of light in air, n is the refractive index of the medium between the objective lens and the object under study, and .θ. is the so called aperture angle (Fig.7.). The product 2n sinθ is named the microscope numerical aperture and is marked on the instrument. If two points in a specimen are separated by less than d, their diffraction patterns overlap so much that their images cannot be distinguished.

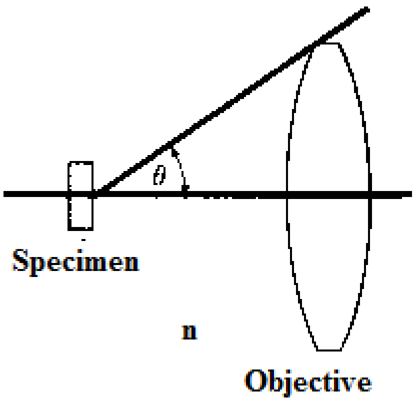


Fig.20. Aperture angle

It can be calculated that the resolution limit of every light microscope is about 250 nanometres that corresponds to the useful magnification of about 400. It is the useful magnification limit of the ordinary light microscope. Larger magnifications reveal no additional details of an object.

There are two ways to improve the resolution of a microscope: use shorter wavelength light and media with larger indices of refraction. With oil immersion objectives some improvement is obtained by immersing the object in the oil of cedar which has n = 1,4. Ultraviolet microscopes use light with wavelrngth some what shorter than visible light. In addition, ultraviolet microscopes are useful in studying biological objects because substances such as nucleic acids and proteins strongly absorb ultraviolet light. This lead to very good contrast.

Polarizing and interference microscopes. Electron microscope.

Polarizing and interference microscopes exploit the wave properties of light in improving the contrast of transparent structures.

A polarizing microscope uses polarized light to illuminate an object. When the object has a random and irregular character, the polarisation of the light passing through it is unaffected. If this light then passes through an analyser set at 90.. to the original polarization plane, no light is transmitted.

However, the object may contain some regularly oriented materials, whose refraction indices depend on the direction of the light beam and on the electric field direction. For example, such are the A-discs at the sarcomers of striated muscles. Then the polarization plane of the light is rotated and some light passes through the analyser.

In an interference microscope, the illuminating light is split into two beams. One beam passes through an object whose refractive indexvaries with the position inside it. The phases of the different rays passing the object have variations after they leave it. The second beam travels through identical optic path, except it does not go through the object. When the two beams are recombined, interference between them produces the variations in light intensity. Thus, many kinds of structures can be made visible, even though the object is completely transparent.

As it was mentioned above, the light microscope resolution is restricted by the magnitude of light wavelength. Much greater resolutions can be achieved by substituting light for electron flow in microscope. Although electrons are particles, they also have wave attributes In the electron microscopes electrons are generated by termionic emission, accelerated by electric potential difference and focused by magnetic lenses. The weavelength associated with electrons accelerated through 50 kilovolts is about 10^{-5} times that of visible light. In practice the resolution of electron microscope is about 1000 times better than can be achieved with light microscopes.

TESTS FOR KNOWLEDGE CONTROL

1. According to the law of reflection, the angle between reflected ray and perpendicular to the point of light ray incidence (normal) is

A greater than the angle between normal & incident ray

B smaller than the angle between normal & incident ray

C equal with the angle between normal & incident ray

D smaller or greater than the angle between normal & incident ray, depending of media properties

E greater than the angle between refracted ray and normal

2. According to the law of refraction, the angle between refracted ray and perpendicular to the point of light ray incidence (normal) is

A greater than the angle between normal & incident ray

B smaller than the angle between normal & incident ray

C equal with the angle between normal & incident ray

D smaller or greater than the angle between normal & incident ray, depending of media properties

E greater than the angle between reflected ray and normal

3. Refraction occurs because light

A has different density in different media

B has different pressure index in different media

C has different velocitiy in different media

D changes direction, moving round obstacles

E has different polarization in different media

4. Absolute refractive index of a medium equation is:

A $r = {}^{v}/_{c}$

B $n = {}^{c}/_{v}$

C $n = v/c$

D $c = n/v$

E $c = v/n$

5. Total internal reflection occurs when light travels from one medium (1) to another (2), where

A medium, 1 has higher density than medium 2

B medium, 2 has higher density than medium 1

C light has different velocity

D both media have equal densities

E light has different pressure

6. In which case the total internal reflection occurs? When light goes from

A air to water

B water to air

C water to glass

D plastic to water

E ice to water

7. Optical fibers in medicine are used to

A reflect the light

B to refract the light

C to conduct the light

D to increase light intensity

E to increase light velocity

8. Fiber optics endoscopy is based on effect called

A interferention

B diffraction

C refraction

D total internal reflection

E total internal refraction

9. Medical method of surgery operation during which the fiber optics is being used is called

A tracheoscopy

B branchoscopy

C gastroscopy

D laparoscopy

E cardioscopy

10. Which material optical lenses cannot be made of?

A ice

B glass

C wood

D plastic

E metals

11. Lens focus is a

A point where light rays are collected after passing through the lens

B point where light rays are dispersed after passing through the lens

C point of the lens in which the rays do not refract

D a central point of the lens

E point where only half of rays are collected after refraction through the lens

12. What is lens power?

A the density of lens material

B the distance between the optical centre of a lens & its principal focus

C value inverse to the focal length of lens

D strength of lens material

E value measured in meters

13. Focal distance of convex lens is 2 meters. What is lens optical power?

A 0,5 dioptres

B 2 dioptres

C 3 dioptres

D 4 dioptres

E 6 dioptres

14. Lens power of convex lens is 10 dioptres. What is lens focal distance?

A 1cm

B 1dm

C 1m

D 10m

E 10dm

15. In which part of lens the incident rays do not refract?

A in focus

B anywhere on principal axis

C optical centre

D edges of the lens

E light refracts in every part of the lens

16. The object is placed at the distance more than the focal length. The lens is convex. The image of the object is:

A virtual, enlarged, straight

B virtual, enlarged, inverted

C real, enlarged, inverted

D real, reduced, straight

E virtual, reduced, straight

17. The object is placed at the distance less than the focal length. The lens is convex. The image of the object is:

A virtual, enlarged, straight

B virtual, enlarged, inverted

C real, enlarged, inverted

D real, reduced, straight

E virtual, reduced, straight

18. If the image produced by the lens is colored, but the object is not, we deal with

A chromatic aberration

B astigmatism

C spherical aberrations

D chemical aberration

E solid aberration

BIOPHYSICS OF VISION

The structure of human eye

The human eye is a remarkable evolutionary achievement and a perfect optic instrument. Its threshold sensitivity is close to the theoretical limit imposed by the quantum properties of light. It has a resolution close to the limits imposed by diffraction. It has an intensity range of 10*9 and can rapidly shift its focus from very short distance to infinity.

The eye is a lens system which forms an inverted real image on a light-sensitive surface. The eyeball is approximately spherical in shape with a diameter of about 2,3 cm. Its outer covering is a nearly opaque fibrous layer called the sclera. Light enters the eye through the cornea, which covers a transparent bulge on the front surface of the eyeball. The iris is a colored ring behind the cornea. It acts like a diaphragm and aids in regulating the amount of light entering the eye through the pupil.

The lens crystalline is composed of fibrous transparent material. Its shape and therefore its focal length can change. They are controlled by the ciliary muscles inside the eyeball. The space between cornea and the lens contains a watery fluid called the aqueous humor. Behind the lens is a transparent jelly called the vitreous humor.

Inside the eyeball is a dark pigment membrane which absorbs stray light. The inner surface of the eyeball is retina which contains numerous nerve cells and light receptors: rods and cones. They respond to light by generating biopotentials. The eye is most sensitive at a small retinal depression, the yellow spot. Its central portion, the fovea centralis, contains only densely packed cones. The eye tends to rotate so that the object under examination is imaged on the fovea centralis.

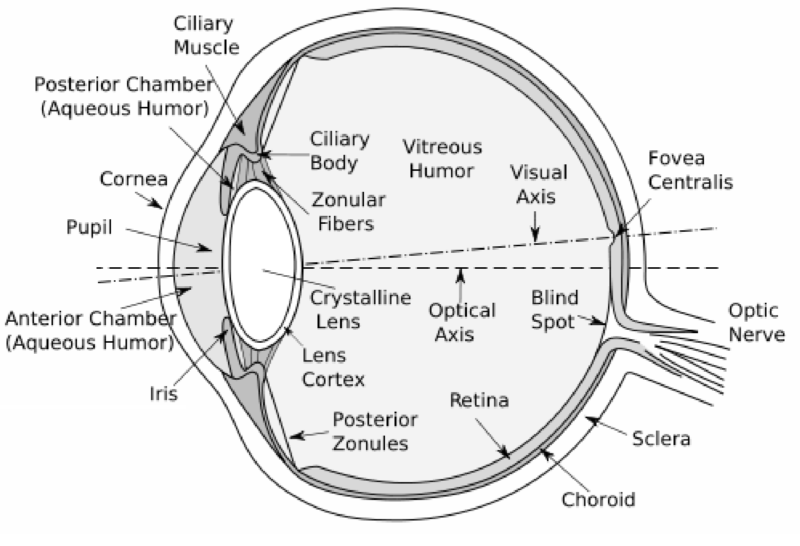


Fig. 21. The human eye

Light refraction at the eye

The lens system of the eye is composed of four refractive medias: cornea, aqueous humor, lens crystalline, vitreous humor. Their refractive indices do not differ significantly. They are 1,38 for the cornea, 1,33 for the aqueous humor, 1,40 for the lens and 1,34 for the vitreous humor.

The lens system of the eye is composed of four refractive surfaces:

1) the interface between air and the anterior surface of the cornea;
2) the interface between the posterior surface of the cornea and the aqueous humor;
3) the interface between the aqueous humor and the anterior surface of the lens crystalline of the eye;
4) the interface between the posterior surface of the lens and the vitreous humor.

Most of the refractive power of the eye is provided by the anterior surface of the cornea. This is because the cornea has a small radius of curvature and the refractive index of cornea is markedly more than that of air.

The total refractive power of crystalline lens is less than that of the cornea. It is about one-third the total refractive power of the eye's lens system. The reason for this difference is that the fluids surrounding the lens have refractive indices not greatly different from the refractive index of the lens itself. The smallness of their difference greatly decreases the amount of light refraction at the lens surfaces. If the crystalline lens would be removed from the eye and then surrounded by air, its refractive power would be about six times as great. But the function of lens is very important. Its curvature can be increased markedly to provide the fine adjustment needed to focus on objects at different distances.

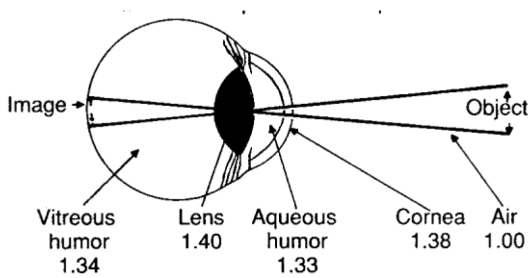


Fig.22. The eye as a camera. The numbers are the refractive indices.

Reduced eye

Reduced eye is the simplified model of the real eye. It represents schematically the optics of the normal human eye. The reduced eye is a single lens with only one refractive media. At the reduced eye all refractive surfaces of the real eye are added algebraically together to form a single refractive surface.

The reduced eye is useful in simple calculations. Its total refractive power is about 59 diopters when the lens is accomodated to the distant vision. The central point of the reduced eye lies at 17 millimeters in front of the retina. The beam from any point of object comes into the reduced eye and passes its central point without refraction. In the same manner that a glass lens can form an image on a sheet of paper, the lens system of the eye can form an image on the retina. The image is real and inverted with respect to the object. However, the mind perceives objects in the upright position despite the upside-down orientation on the retina. The brain is trained to consider an inverted image as the normal.

Accomodation

The image formed by the eye must appear on the retina in order to be clearly seen. The maximum variation of the eye refractive power for focusing on near or distant objects is called accomodation.

The most distant point the eye can focus, called the far point, is the infinity for a normal vision. In this case the parallel rays entering the eye are focused on the retina. The image distance is approximately the diameter of the eye.

The object may be seen in great detail when it is placed as near as possible to the eye while remaining in focus. The minimal distance of distinct vision is about 25 cm for a normal vision. The point at this distance is called the near point of the eye.

If the eye is focused on an object at the near point, it must adjust its focal length and increase refractive power. This process occurs due to the changes of the lens crystalline shape. When an object approaches the eye the shape of lens is changed from that of a moderately convex lens to that of a very convex lens.

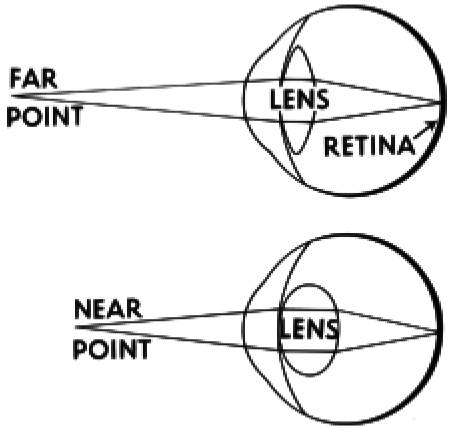


Fig 23. Accommodation of normal eye

The lens crystalline is composed of a fibrous, jellylike material. It has a strong elastic capsule. The special ligaments attache the lens edge toward the outer circle of the eyeball. These ligaments are constantly tensed. The shape of lens crystalline is controlled by the ciliary muscle. Its contraction lessens a certain amount of tension on the lens capsula and the lens become more convex. It assumes a more spherical shape because of the natural elasticity of its capsule. Therefore, when the ciliary muscle is completely relaxed, the refractive strength of the lens is as weak as it can become. On the other hand, when the ciliary muscle contracts as strongly as possible, the refractive strength of the lens becomes maximal. This process is controlled by the central nervous system.

Presbyopia

The refractive power of lens crystalline can be increased from 20 diopters to about 34 diopters in young children. This is a total accomodation of 14 diopters. As a result the total refractive power of the eye is about 59 diopters when it is accomodated for distant vision and 73 diopters at its maximal accomodation.

As a person grows older, the lens crystalline growth thicker and becomes far less elastic. Therefore, the ability of the lens to change its shape progressively decreases with age. The power of accomodation decreases from about 14 diopters in the child to less than 2 diopters by ages 45 to 50 and to about zero at age 70. Thereafter the lens is almost totally nonaccomodating. This condition is called presbyopia. The eyes remain focused permanently at an almost constant distance. They can no longer accomodate for both near and far vision. Therefore, to see clearly both in the distance and nearby, an older person must wear bifocal eye-glasses with the upper segment focused for far-seeing and the lower segment focused for near-seeing.

Errors of refraction

Emmetropia. The eye is considered to be normal (emmetropic), if parallel light rays from distant objects are focused on the retina when the ciliary muscles are completely relaxed. Emmetropic eye can see all distant objects clearly, when its ciliary muscle is relaxed i.e. without accomodation. But to focus objects in close range, the eye must contract its ciliary muscle and provide appropriate degree of accomodation.

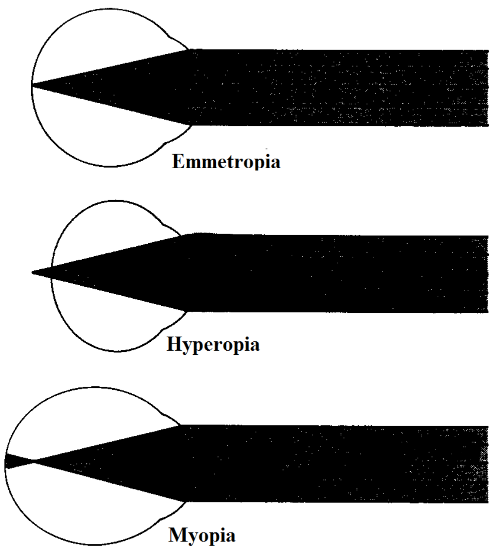


Fig.24. Parallel light rays refraction at the human eye.

Hypermetropia (hyperopia). Hypermetropia is also known as farsightedness. It is usually due either to an eyeball that is too short or to a lens system of the eye that is too weak. In this condition the parallel light rays are not refracted sufficiently by the lens system. As a result they do not come to the focus when they reach the retina. To overcome this abnormality, the ciliary muscle must contract to increase the optical strength of the eye. Therefore, the farsighted person is capable to focus the distant objects on the retina, using the mechanism of accomodation. If the person has used only a small amount of accomodation to see the distant objects, then he has much accomodative power left. He may use this power to see objects that are closer to the eye.

But when the reserve of accomodation is small, the farsighted person often is not able to accomodate his eye sufficiently to focus not only close but even distant objects. Then correction with a converging lenses is needed to increase the refractive power of eye. A suitable convex lenses are used to add refractive power to the eye optic system.

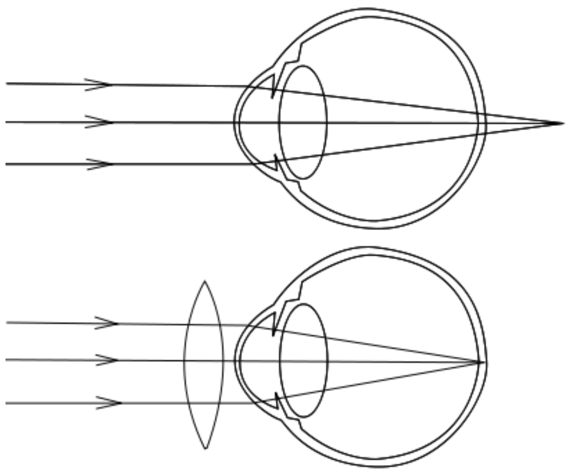


Fig.25. The correction of hypermetropia.

Myopia. In myopia, or nearsightedness the parallel light rays from distant objects are focused in front of the retina, in spite of ciliary muscle being completely relaxed. This is usually due to too long an eyeball, but it can also result from too much refractive power of the eye optic system.

There is no mechanism by which the eye can decrease the refractive strength of its lens to less that exists. The process of accomodation only makes the vision worse. Therefore, the myopic person has no mechanism by which he can focus distant objects on the retina. The image can be focused only if an object comes near enough to the eye. Therefore, a myopic person has a definite limiting far point for clear vision.

It is known that light rays passing through a concave lens diverge. If the eye refractive force is too much, as in myopia, some of this excessive refractive power can be neutralized by concave lens. Using laser technique, the operation can be done also to correct too much concavity of cornea.

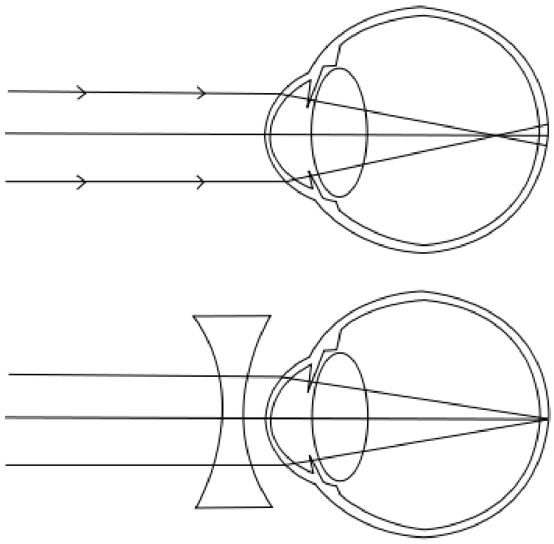


Fig.26. The correction of myopia.

Astigmatism. In anastigmatic eye the refracting surface of the cornea is not spherical but elliptical. It results from too great a curvature of the cornea in one of its planes. As a result, light rays striking cornea in one plane, are not bent so much as the rays striking it in the other plane. They do not come to a common focal point. Astigmatism cannot be compensated by the eye accomodative power. It can be corrected with the cylindrical lens only. It corrects the error in one of the planes.

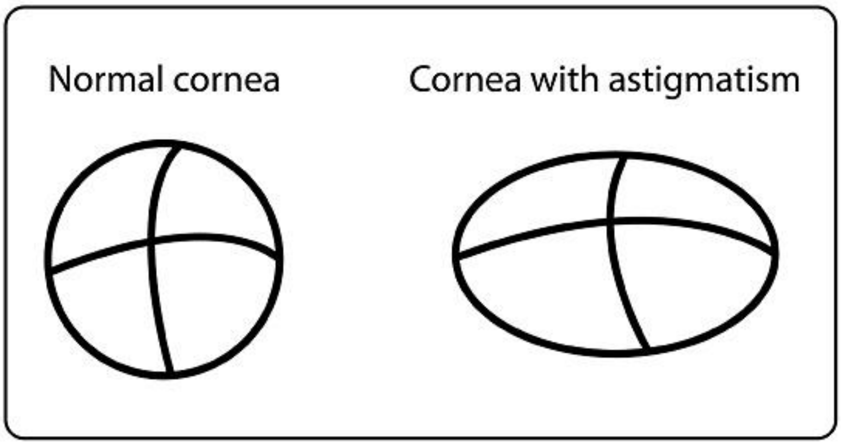


Fig.27 Cornea sgape normal and with astigmatism

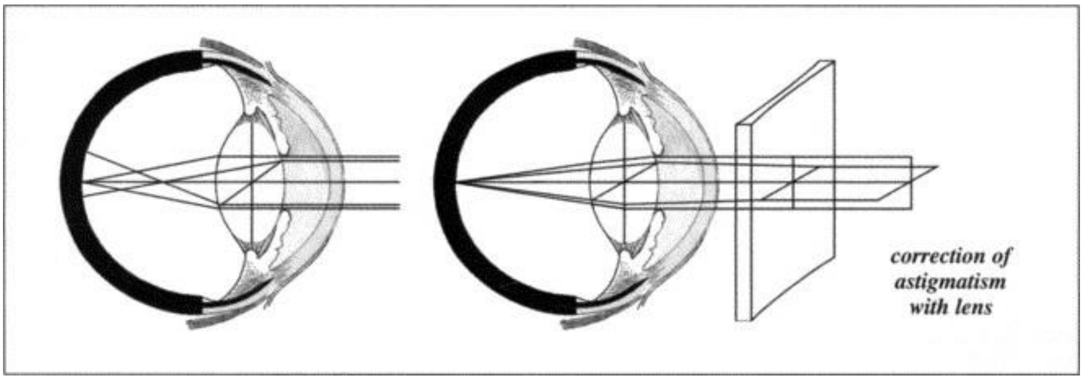


Fig. 28 Correction of optical abnormalities by contact lenses

Recently plastic contact lenses have been used to correct various abnormalities of vision. They are placed against the anterior surface of the cornea and held in place by a thin layer of tears that fills the space between the lens and cornea. Hard contact lenses are made of rigid plastic. They are about 1 mm thick and 1 cm in diameter. Soft contact lenses have been also introduced.

Contact lens replaces the cornea as the front of the eye and nullifies almost entirely the refraction that normally occurs at the anterior surface of the cornea. When using the contact lens, the anterior surface of the cornea does not play any significant role in the eye's refraction. Instead, the anterior surface of the lens now plays the major role and substitutes the cornea's usual refraction. This is especially important in persons with abnormally shaped cornea. Another advantage of the contact lenses is that they turn with the eye and give a broader field of clear vision than do usual glasses. They are also more convenient for artists, sportsmen etc.

Visual acuity

The ability of human eye to see clearly small details is limited. The normal visual acuity of the human eye for discriminating the point sources of light is about 25 seconds of arc. That is, when light rays from two separate points strike the eye with an angle at least 25 seconds between them, they are recognized as two points. The rays with the smaller angular separation cannot be distinguished. That means that a person with normal visual acuity can distinguish two points of light 10 meters away, when they are 2 millimeters apart.

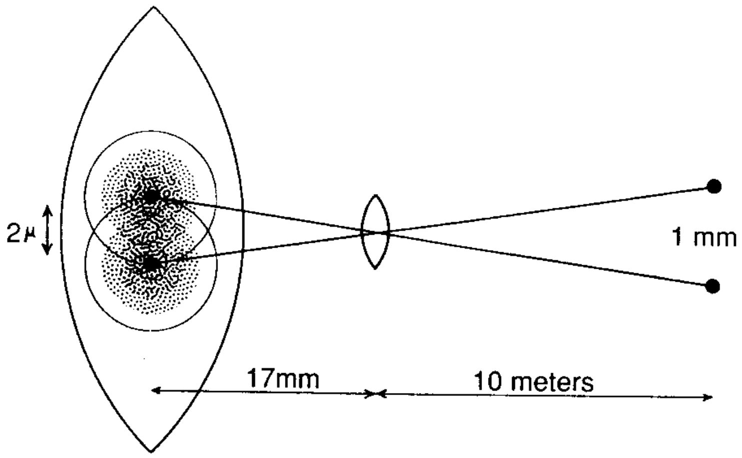


Fig.29. Maximum visual acuity for two point sources of light.

The explanation of this limit is provided by the structure of retina. The average diameter of cones in fovea centralis is about 1,5 micrometers. It is estimated that a person can normally distinguish two separate light spots on the retina if the distance between them is as much as 2 micrometers. Thus, to distinguish two small objects, they must excite two different cones. At least one unexcited cone must intervene between the excited cones.

TESTS FOR KNOWLEDGE CONTROL

1. The eye is a lens system which forms an image

A. inverted, real, enlarged

B. inverted, real, reduced

C. direct, real, reduces

D. inverted, virtual, enlarged

E. straight, real, enlarged

2. The eyeball has a diameter of:

A about 2,3 cm;

B about 3,3 cm;

C about 3,5 cm.

D about 4,3 cm.

E about 5,3 cm

3. The outer covering of eyeball is a nearly opaque fibrous layer called:

A the diaphragm;

B the iris;

C the cornea;

D the sclera.

E choroid

4. Light enters the eye through:

A the diaphragm;

B the iris;

C the cornea;

D the sclera.

E choroid

5. The iris is a colored ring behind the:

A the diaphragm;

B the pupil;

C the cornea;

D the sclera.

E choroid

6. It acts like a diaphragm and aids in regulating the amount of light entering the eye through the pupil:

A the eyeball;

B the iris;

C the cornea;

D the sclera.

E the choroid

7. Its shape and therefore its focal length can change:

A the eyeball;

B the lens crystalline;

C the cornea;

D the sclera.

E choroid

8. The inner surface of the eyeball is:

A sclera;

B retina;

C cornea;

D lens crystalline.

E choroid

9. The eye retina is most sensitive at light in:

A the yellow spot;

B the blind sport;

C any points of retina;

D the peripheral part.

E at the nerve tract

10. Mark main parts of the **human eye** on your answer paper (fig.1)

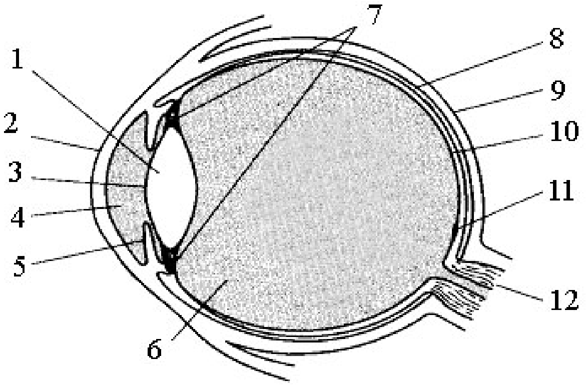


Fig. 1

11. The lens system of the eye is composed of four refractive media. Enumerate them on your answer paper.

12. The total refractive power of crystalline lens is:

A about one-fourth the total refractive power of the eye's lens system;

B about one-third the total refractive power of the eye's lens system;

C about one-second the total refractive power of the eye's lens system;

D approximately equal with total refractive power of the eye's lens system

E twice greater than total refractive power of the eye's lens system

13. If the crystalline lens would be removed from the eye and then surrounded by air.

A its refractive power doesn’t change essentially;

B its refractive power would be about six times greater;

C its refractive power would be about two times greater;

D its refractive power would be about six times smaller.

14. The curvature of crystalline lens:

A can’t be changed;

B can be increased or decreased;

C is maximal in any case;

D is minimal in any case.

E depends on temperature

15. The total refractive power of eye, when it is accommodated for distant vision is:

A about 14 diopters

B about 34 diopters

C about 59 diopters

D about 63 diopters

E about 73 diopters

16. The accommodation is:

A the decreasing of the eye refractive power for focusing on near objects;

B ability of the eye to focus its optical system only on distant objects;

C ability of the eye to focus its optical system only on near objects;

D variation of the eye refractive power for focusing on near or distant objects

E the increasing of the eye refractive power for focusing on far objects.

17. The most distant point the eye can focus on is called:

A the point of optimal vision;

B the far point of the eye;

C the point of minimal vision;

D the point of maximal vision.

E the distant point

18. The most distant point the eye can focus is:

A infinity for a normal vision;

B is situated on 25*cm* from eye;

C is situated on 1*m* from eye;

D is situated on 10*m* from eye.

E is situated 100km from eye

19. The object may be seen in great detail when it is.

A placed as near as possible to the eye (distance may be less than 1*cm*);

B placed at distance of 25 cm

C placed as far as possible to the eye while remaining in focus;

D placed as near as possible to the eye while remaining in focus

E placed straight in focus of an eye

20. The minimal distance of distinct vision is:

A infinity for a normal vision;

B about 25*cm* for a normal vision;

C less 1*cm* for a normal vision;

D is situated on 1*cm* from eye.

E is 1 meter from eye

X-RAYS AND THEIR APPLICATIONS IN MEDICINE

Nature of X-rays

X-rays were discovered accidentally in 1895 by the famous German physicist Wilhelm Roentgen while he was studying cathode rays in a gas-discharge tube, which he was using with a low pressure and high voltage. Despite the tube was encased in a black box, Roentgen noticed that fluorescent screen, placed nearby by chance, emitted light whenever the tube was in operation. The tube appeared to be the source of radiation that could penetrate paper, wood, glass and even aluminum a centimeter and a half thick.

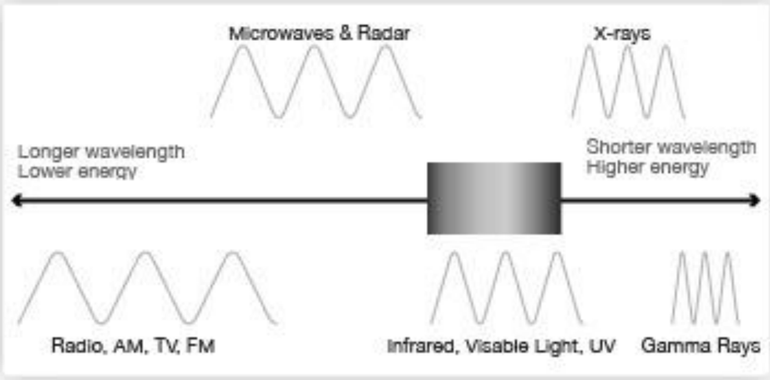


Fig. 30. Electromagnetic waves' scale

After conducting further experiments Roentgen determined that a gas-discharge tube can emit the new kind of invisible radiation of a great penetrating ability. Roentgen could not find out whether the radiation was a stream of particles or a train of waves and he decided to call it X-rays. They are called also Roentgen rays.

Now it is known that X-rays are the kind of electromagnetic radiation having the wavelength shorter than ultraviolet. The wavelength of X-rays ranges from about 70 nanometers to 10^{-5} nanometers. The shorter the wavelength of the X-rays, the greater is the energy of their photons and the more is penetrating power. The X-rays with relatively long wavelength (more than 10 nanometers) are called soft. The wavelength of 1 - 10 nanometers is inherent to the intermediate X-rays. The X-rays having short wavelength are named hard. They are characterized by the greatest penetrating ability.

X-rays production

X-rays are produced when fast electrons, or cathode rays, strike a target, such as the walls or anode of a low-pressure discharge tube. The modern X-ray tube (Roentgen tube) is the highly evacuated glass balloon with the cathode and anode situated inside . The potential difference between cathode and anode (anticathode) attains several hundreds of kilovolts. The cathode is the tungsten filament heated by electric current. It emits electrons as the result of thermoelectronic emission. They are accelerated by the electric field inside the X-ray tube. Because there is very little gas, the electrons on their way to the anode do not loose any perceptible amount of their energy. They strike anode as a target at a very great speed.

Fig. 31. X-rays tube appearance

From the A. C. mains transformers provide low voltage for heating the filament and high voltage accelerating the electrons. On the half-cycles when the target is positive, the electrons bombard it and generate X-rays. On the half-cycles when the target is negative, nothing happens at all. Thus the tube acts as its own rectifier.

Fig. 32 X-rays tube

X-rays are produced whenever high-velocity electrons are retarded by the material of anode. Much of the energy of electrons is dissipated in heat. The heat generated at the anode by the electronic bombardment is so great that anode must be cooled artificially. The anode in an X-ray tube may be tungsten, for example, which has a high melting-point.

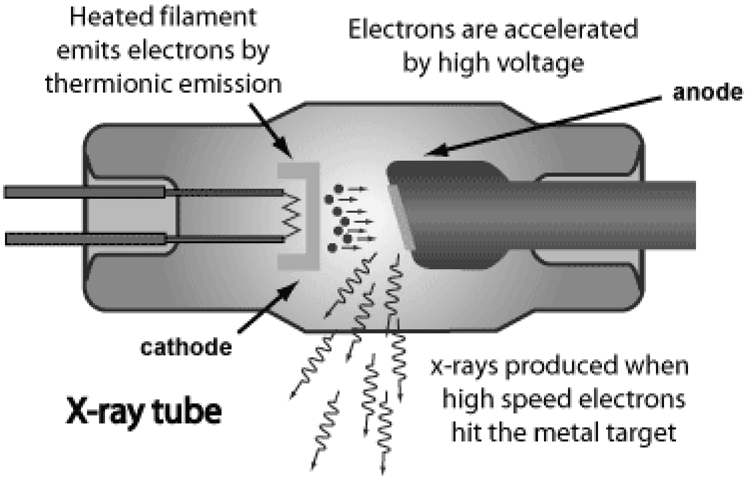


Fig.33 X-rays producing on X-rays tube

The remainder energy transforms into the energy of electromagnetic waves (X-rays). Thus, X-rays are the result of bombarding matter with electrons. There are two kinds of X-rays: braking and characteristic.

Braking X-rays
(Bremsstrahlung x-rays)

Braking X-rays are produced when the high-velocity electrons are retarded by the electric fields of the atoms of anode. It may be said that they move with the negative acceleration and become the sources of X-ray radiation. The conditions of braking of individual electrons are not the same and, as a result, various parts of their kinetic energy are transferred into the energy of X-rays.

The spectrum of braking X-ray radiation is independent of the nature of the anode material. As it is known, the energy of X-rays quanta corresponds to their frequency and wavelength. That is why the braking X-ray radiation is not monochromatic. It is characterized by the wide range of wavelength that can be represented by continuous spectrum.

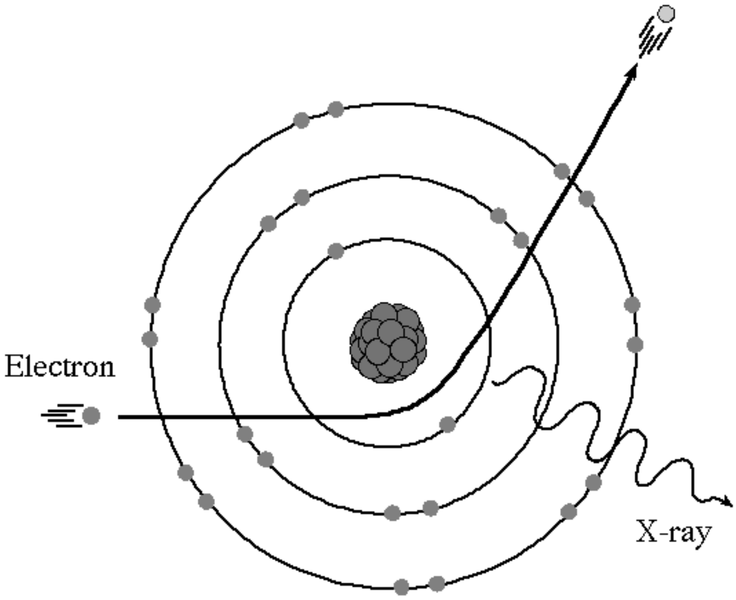


Fig.34 Breaking X-rays

X-rays emitted can have no more energy than the kinetic energy of the electrons that produce them. The sharp lower wavelength limit corresponds to the maximum energy of the bombarding electrons. The value of this limit has the inverse relation to the potential difference in the X-ray tube.

Characteristic X-rays

Characteristic X-ray radiation has not continuous but line spectrum. This kind of radiation arises when a fast-moving electron striking anode penetrates into the internal atomic orbitals and knocks out one of their electrons. As a result, a hole appears that can be filled by the other electron descending from one of the upper atomic orbitals. Such electron transition from the higher to the lower energy level gives rise to the X-ray radiation of the definite discrete wavelength. That is why the characteristic X-ray radiation has line spectrum. The frequency of its discrete spectrum lines depends completely on the structure of the electron orbitals of the anode atoms.

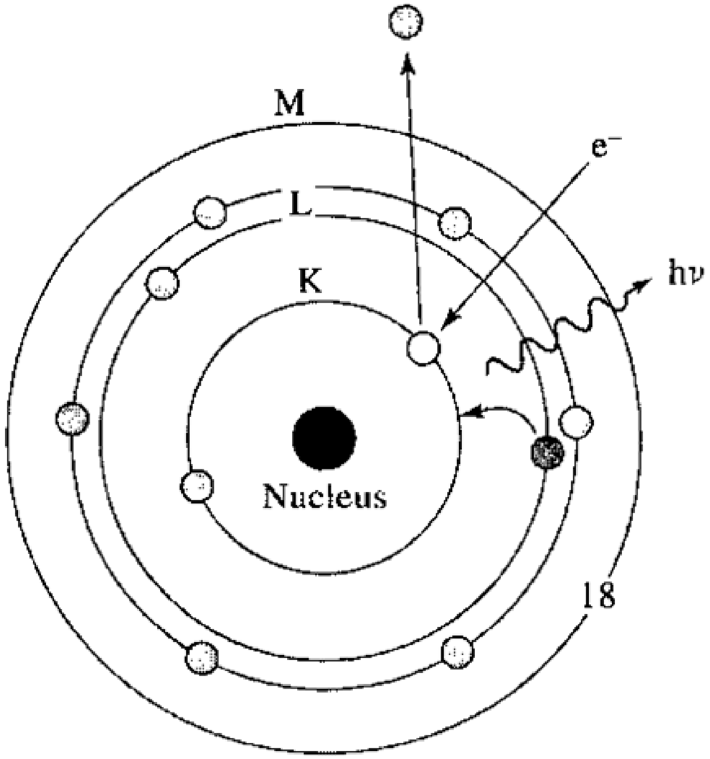


Fig.35 Characteristic X-rays

The lines of characteristic X-ray spectrums of different chemical elements have the same type because the structure of their internal electron orbitals is identical. But their wavelength and frequency is different owing to the energy difference between internal orbitals of the heavy and light atoms.

The frequency ν of the characteristic X-ray spectrum lines varies in a regular way with the atomic number of the metal. It is defined by Moseley's equation: radix of $\nu^{1/2}=A(Z-B)$, where Z is atomic number of the chemical element, A and B - the constants.

Primary physical mechanisms of the X-rays interaction with a matter

In the primary interaction between X-rays and matter, three mechanisms exist by which X-rays are absorbed or scattered. They are coherent scattering, photoelectric effect and incoherent scattering (Compton effect).

Coherent scattering. This form of scattering occurs when the X-ray photons collide with the interior atomic electrons that are characterized by strong coupling with the nuclei. In such a case the energy of photon turns out to be less than the photoelectric work function. The photon is not absorbed by the atom. The direction of its propagation changes but the wavelength remains unchanged.

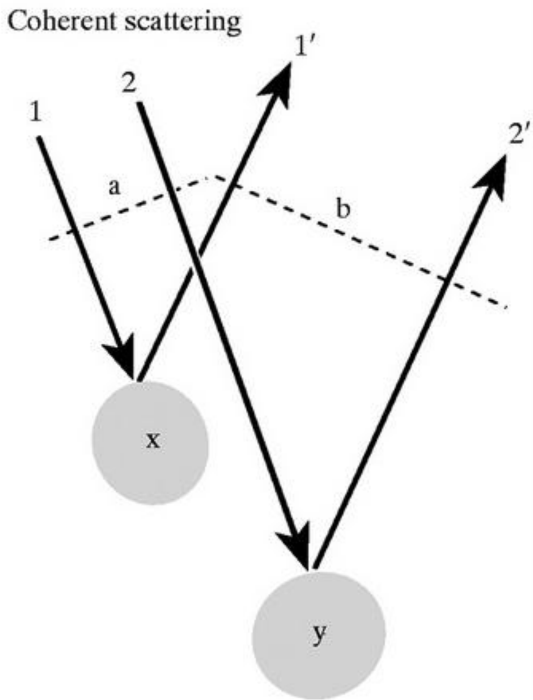


Fig.36 Coherent scattering

Photoelectric effect (photoeffect). When a photon of X-ray radiation strikes an atom, it may impinge on one of its electrons. If the energy of photon is more than the photoelectric work function, photon is absorbed and the electron ejected from the atom. If the photon carries more energy than is necessary to eject the electron, it will transfer its residual energy to the ejected electron in the form of kinetic energy. This phenomenon, called the photoelectric effect, occurs primarily when the low energy X-rays are absorbed.

The atom which loses one of its electrons becomes positive ion. The lifetime of free electrons is very short. They are absorbed by neutral atoms that turns into negative ions. The result of photoelectric effect is intensive ionization of a matter.

If the X-ray photon energy is less than photoelectric work function, atoms are excited but do not turn into ions.

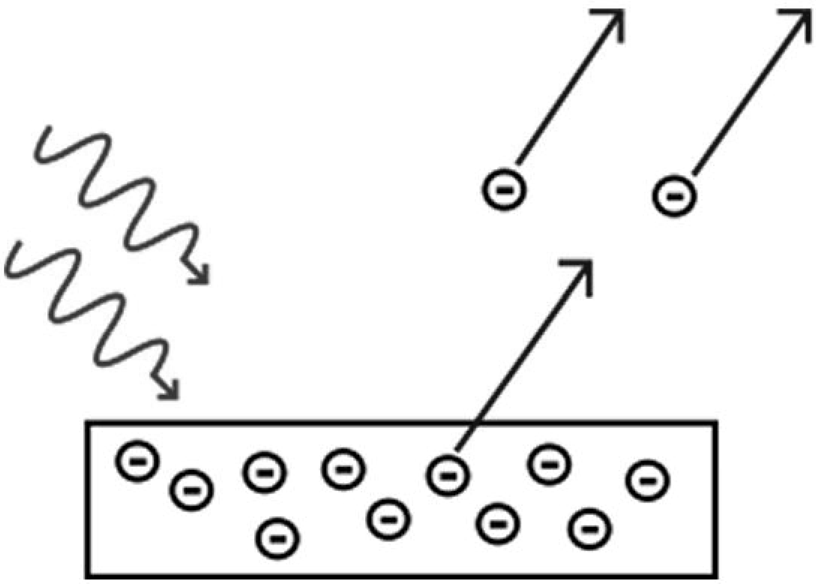


Fig.37 Photoelectric effect (photoeffect)

Incoherent scattering (Compton effect). This effect has been discovered by the American physicist Compton. It occurs when the X-rays of shorter wavelength are absorbed and the energy of X-ray photons is more than photoelectric work function. Compton effect is the result of interaction of a high-energy X-ray photon with one of external atomic electrons that have comparatively weak coupling with atomic nucleus.

A high-energy photon collides with an electron and delivers to it some part of its energy. The excited electron is ejected out of the atom. The energy excess is radiated in the form of the X-ray photon of a longer wave. It is radiated at some angle to the direction of the primary photon. The secondary photon may be able to ionize another atom. These changes of direction and wavelength of X-rays are known as Compton effect.

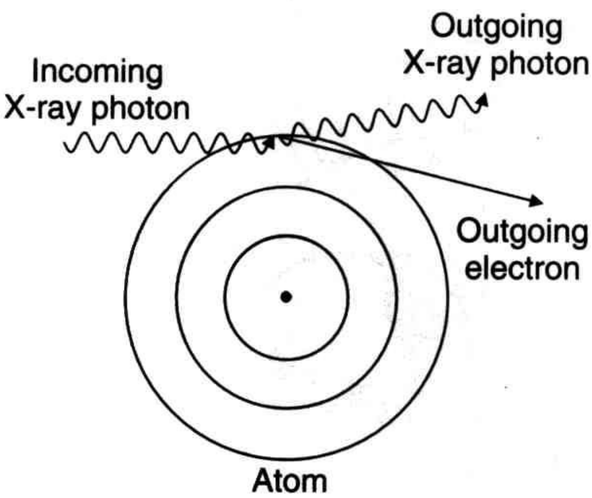


Fig.38 Incoherent scattering (Compton effect)

Some effects of X-rays interaction with a matter

As it was mentioned above, X-rays are able to excite the atoms and molecules of a matter. It may cause fluorescence in certain materials, such as zinc sulfate. The opaque objects may be observed directly if the parallel X-rays bundle passes through them and falls upon the screen coated with such material.

Fluorescent screen may be substituted by a photographic film. X-rays affect a photographic emulsion in the same way that light does. Both the methods are used in practical medicine.

Another important effect of X-rays is their ionizing power. It depends upon their wavelength and energy. This effect provides a method for measuring the energy of X-rays. When X-rays are passed through an ionization chamber, an electric current is produced that is proportional to the energy of the incident beam.

The absorption of X-rays by a matter

When X-rays pass through a matter, their energy is decreased owing to the absorption and scattering. Attenuation of the parallel X-ray beam passing through a matter is defined by the Bouguer law:

$$I=I_0\, e^{-\mu d},$$

where I_0 is the initial X-rays intensity; I - the intensity of X-rays passing through a layer of matter, the sickness of which is equal to d. μ is the linear attenuation coefficient. It is equal to the sum of two items, first of which (τ) is absorption linear coefficient and the second (σ) - scattering linear coefficient:

$$\mu = \tau + \sigma$$

It was found by experiments that absorption linear coefficient depends on the atomic number of a matter and the X-rays wavelength:

$$\tau = k \rho Z^3 \lambda^3,$$

where k is proportionality coefficient, ρ = density of matter, Z = atomic number, λ = X-ray wavelength.

The dependence of τ on Z is very important from the practical point of view. For instance, the absorption coefficient of bones, that consist of calcium phosphate, is about 150 times more than that of soft tissues (Z=20 for calcium and Z=15 for phosphorus). When X-rays pass through a human body, the shadow of bone stands out clearly upon the background of muscles, connective tissue etc.

It is known that the digestive organs have the same absorption coefficient value as the other soft tissues. But the shadow of esophagus, stomach and intestines can be clearly distinguished if a patient swallows previously the portion of so called contrast matter - barium sulfate (Z=56 for barium). Barium sulfate is highly opaque to X-rays and is often used for the X-ray examination of the gastrointestinal tract. Certain opaque compounds are administered either by mouth or by injection into the bloodstream in order to examine blood vessels, gallbladder, kidneys etc. Iodine compounds (Z=53) are widely used as the contrast matter for this purpose.

The dependence of τ on Z is used also when protection from the possible harmful action of X-rays is needed. Lead shielding is usually utilized for this purpose because its value of Z is equal to 82.

Application of X-rays in medicine

The value of X-rays in diagnostics is a consequence of their penetrating properties. At the early period after their discovery X-rays were used mostly to investigate bone fractures and to locate foreign bodies, such as bullets, within the human body. Nowadays several different methods of the X-ray diagnostics (roentgen diagnostics) are used.

Roentgenoscopy. X-ray apparatus consists of the source of X-rays (X-ray tube) and the fluorescence screen. X-rays pass through the body of a patient while physician observes its shadow image. The lead glass must be placed between the screen and physician's eyes in order to protect him from the harmful action of X-rays. This method gives the possibility to study functional state of some organs. For instance, physician can observe directly the movements of lungs, the displacement of the contrast mass along the gastrointestinal tract. The shortcomings of this method are the low image contrast and comparatively large dose of radiation during the procedure.

Fluorography. This method consists of taking photograph of the body image on the fluorescent screen. It is used mostly at the preliminary investigation of the patients.

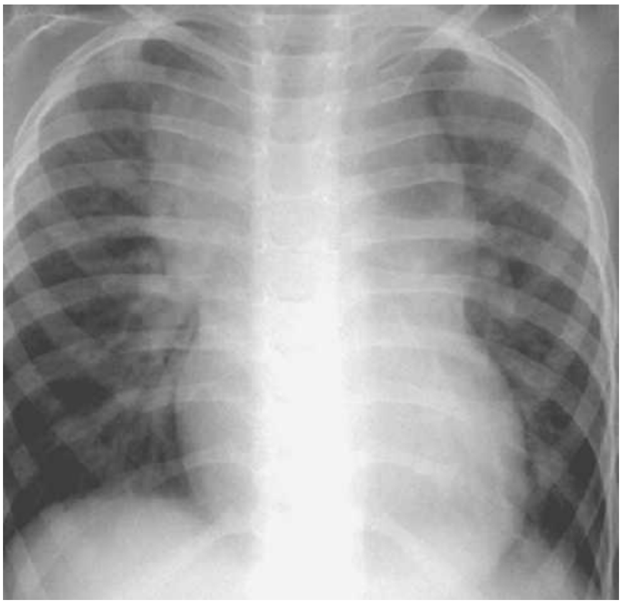


Fig.39 Roentgenography (X-ray radiography)

Roentgenography (X-ray radiography). It is the method of X-ray investigation at which the image is recorded at the photographic film. Photographs are taken usually at the two perpendicular planes. This method has some advantages. X-ray photographs contain more details than the images at the fluorescent screen and are more informative. They can be stored for the further study. The total dose of radiation is less than at the roentgenoscopy.

Fig.40 Roentgenography (X-ray radiography)

Computer roentgen tomography. Computerized axial tomography scanner (CT) is the recent X-ray device that offers clear images of any part of the human body, including soft organ tissues.

The first generation of CT consists of special X-ray tube that is fastened to the circular frame. It sends out a pencil-thin X-ray beam. Two X-ray detectors are fastened to the opposite side of the frame. A patient is placed at the center of the frame, which can be rotated 180^0 around his body.

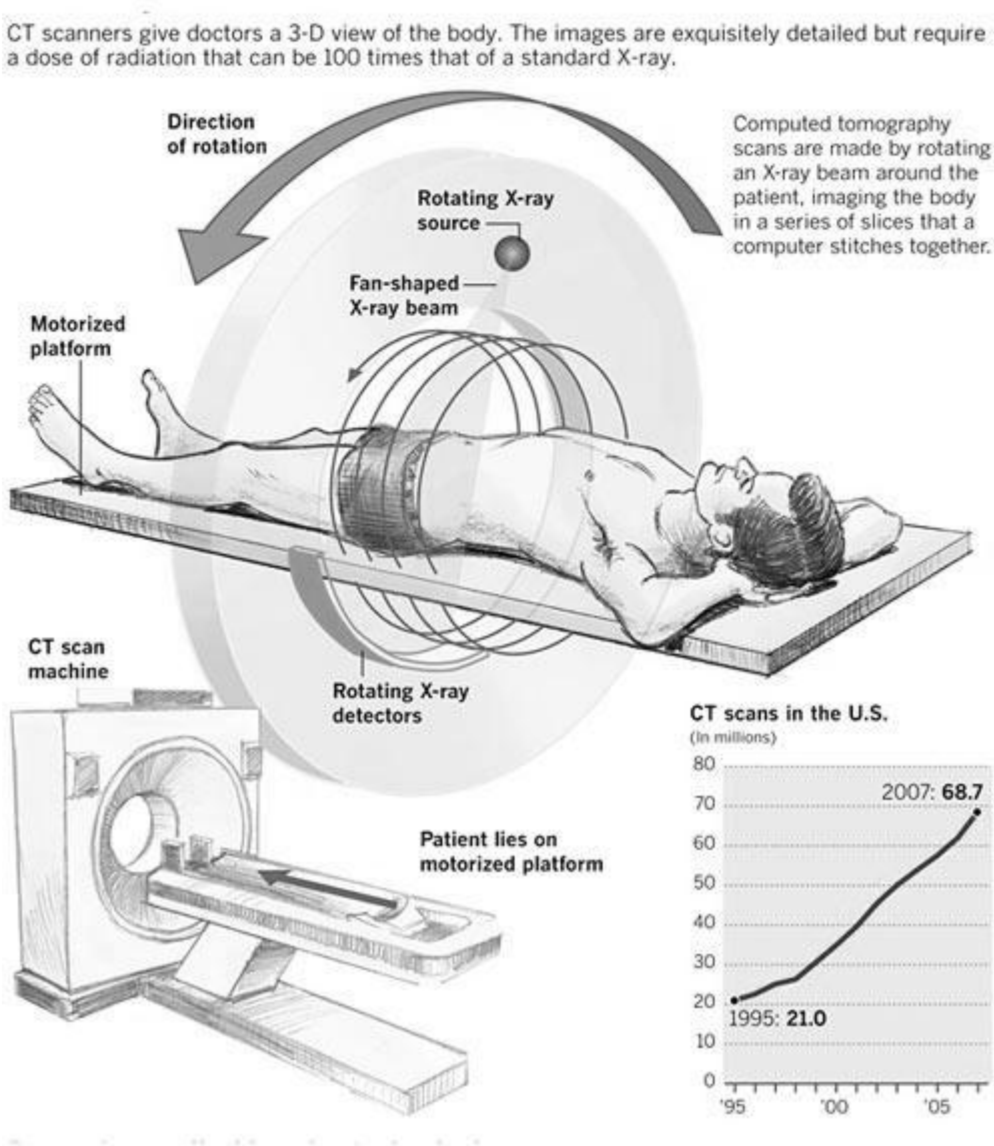


Fig.41 Computer tomography

X-ray beam passes through the motionless object. The detectors, placed on the opposite side of the frame, pick up and record the absorption rates of various tissues. The recordings are made 160 times while the X-ray tube moves linearly along the scanning plane. Then the frame is rotated by 1o and the procedure is repeated. The recordings are carried on until the frame is rotated by 180^0. Every detector records 28800 (180x160) indications during the investigation. The whole information is processed by computer and the image is obtained by means of the special computer program.

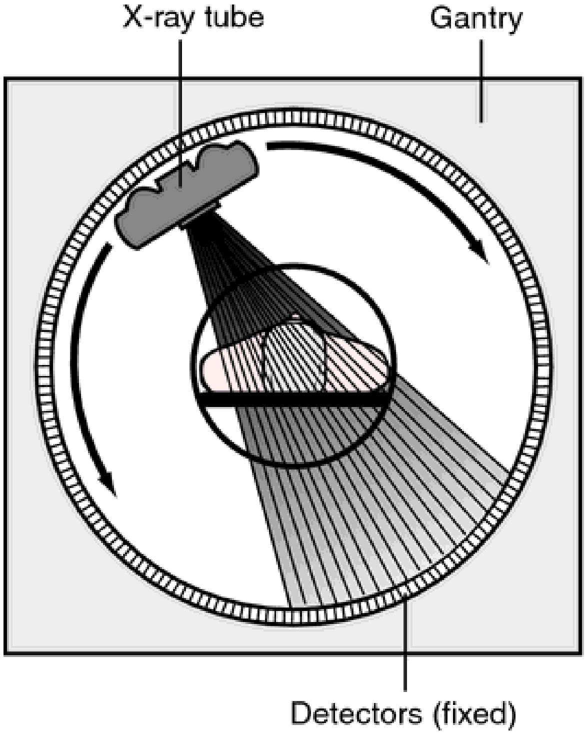


Fig. 42 Coputer tomograph

The second generation of CT use several X-ray beams and up to 30 detectors. It gives the possibility to accelerate the whole investigation process up to 18 sec. The third generation of CT use the new principle. The broad X-ray beam envelopes the whole object and is recorded by some hundreds of detectors. The time needed for investigation is shortened up to 5-6 sec.

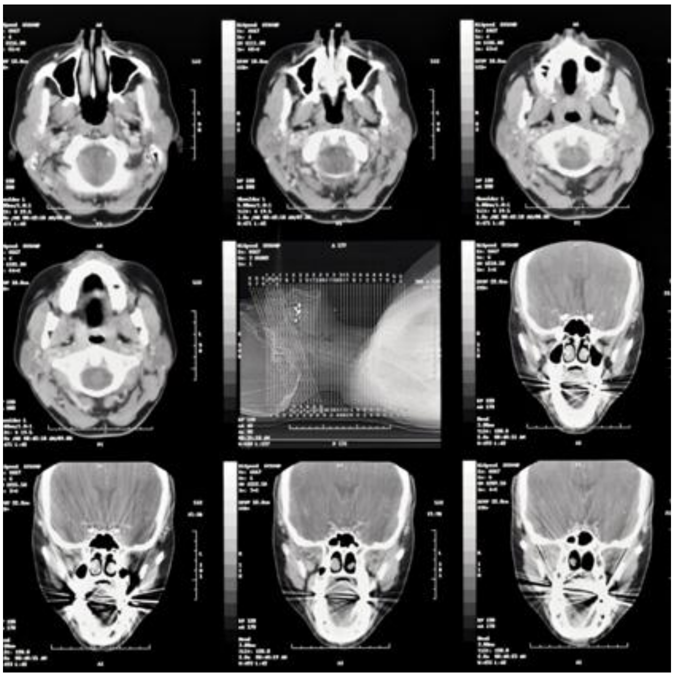


Fig.43 Tomogram

CT has a number of advantages in comparison with the earlier methods of X-ray diagnostics. It is characterized by a very high resolution, which gives the possibility to distinguish fine changes of the soft tissues. It may discover such pathological processes that can not be detected by the other methods. In addition, using of CT allows to decrease the dose of X-ray radiation received by the patients.

TESTS FOR KNOWLEDGE CONTROL

1. X-rays are the kind of:

A. Flow of electrons;
B. Flow of protons;
C. Radio waves;
D. Electromagnetic waves;
E. Mechanical waves;

2. The wavelength of X-rays ranges:

A. From about 70 nanometers to 10^{-5}nanometers;
B. From about 70 micrometers to 10^{-5}micrometers;
C. From about 70 nanometers to 10^{-5}micrometers;
D. From about 70 micrometers to 10^{-5}millimeters;
E. From about 70 millimeters to 10^{-5}millimeters

3. The X-rays with relatively long wavelength are called:

A. High;
B. Soft;
C. Hard;
D. Intermediate;
E. Penetrative

4. The wavelength of soft X-rays is:

A. More than 10 millimeters;
B. Less than 10 millimeters;

C. More than 10 micrometers;

D. More than 10 nanometers;

E. Less than 10 nanometers

5. The greatest penetrating ability is inherent to the:

A. Soft X-rays;

B. Hard X-rays;

C. Intermediate X-rays;

D. Great X-rays;

E. Killing X-rays

6. X-rays are produced when:

A. Fast electrons strike a target;

B. Fast protons strike a target;

C. Electrons are released from cathode by thermoelectric emission;

D. Electrons are released from anode by thermoelectric emission;

E. Electrons are accelerated by the electric field

7. The potential difference in modern X-ray tube attains:

A. Several kilovolts;

B. Several tens of kilovolts;

C. Several hundreds of kilovolts;

D. Several thousands of kilovolts;

E. Several megavolts

8. This part of X-ray tube emits electrons:

A. The walls;

B. Transformer;

C. Anode;

D. Cathode;

E. Anticathode

9. The anode in X-ray tube may be made of:

A. Glass;

B. Gold;

C. Iron;

D. Indium;

E. Tungsten

10. Much of the energy of electrons in X-ray tube:

A. Transforms into the energy of X-rays;

B. Transforms into kinetic energy of electrons:

C. Transforms into mechanical work;

D. Is dissipated as a heat;

E. Is dissipated as sun rays

11. When the high-velocity electrons are retarded by the electric field of anode:

A. Braking X-rays are produced;

B. Characteristic X-rays are produced;

C. Thermoelectric emission is produced;

D. Soft radiation is produced;

E. Hard radiation is produced

12. When a fast-moving electrode penetrates into the internal atomic orbitals and knocks out one of their electrons:

A. Braking X-rays are produced;

B. Characteristic X-rays are produced;

C. Thermoelectric emission is produced;

D. Soft radiation is produced;

E. Hard radiation

13. Braking X-rays have:

A. Line spectrum;

B. Continuous spectrum;

C. Discrete spectrum;

D. Zigzag spectrum;

E. Curve spectrum

14. Characteristic X-rays have such spectrum:

A. Line;

B. Zigzag;

C. Curve;

D. Discrete;

E. Continuous

15. The frequency of spectrum lines is defined by:

A. Einstein equation;

B. Einthoven triangle;

C. Roentgen equation;

D. Moseley equation;

E. Kedrov formula;

16. This kind of interaction between X-rays and matter when the X-rays photons collide with the interior atomic electrons that is characterized by strong coupling with the nuclei is called:

A. Coherent scattering;

B. Photoelectric effect;

C. Incoherent scattering;

D. Compton effect;

E. Braking effect

17. If the direction of photon propagation changes but the wavelength remains unchanged this process is called:

A. Braking effect;

B. Coherent scattering;

C. Incoherent scattering;

D. Photoeffect;

E. Compton effect;

18. If the energy of photon is more than photoelectric work function and it may impinge on one of the atomic electrons this interaction is called:

A. Coherent scattering;

B. Incoherent scattering;

C. Photoeffect;

D. Compton effect;

E. Butterfly's effect

19. This process occurs when the X-rays of shorter wavelength are absorbed and the energy of X-ray photons is more than photoelectric work function :

A. Coherent scattering;

B. Incoherent scattering;

C. Photoeffect;

D. Moseley effect;

E. Piezoelectric effect

20. Compton effect is also called:

A. Coherent scattering;

B. Incoherent scattering;

C. Photoeffect;

D. Braking effect;

E. Piezoelectric effect

RADIOACTIVITY. IONIZING RADIATION

Radioactivity

It is known that the atomic nucleus is a very small object made up of two kinds of elementary particles (nucleons): protons and neutrons. A proton has a positive electrical charge equal in magnitude of the electronic charge. Its mass is about 1840 times that of electron. A neutron is about 0,1 per cent more massive than proton. It bears no electrical charge.

Every nucleus is specified by its atomic number (charge number) Z and its mass number A. Z is the number of protons. A is the total number of nucleons in atomic nucleus. Nuclear species, or nuclides, which have the same atomic number but different mass number are called isotopes. Different isotopes of the same element are nearly identical chemically.

Three distinct types of forces act in atomic nucleus. (1) Strong interaction that is short-ranged and non-electric by its nature. It attracts nucleons and hold them together. (2) Electrical force that is smaller in magnitude but becomes more important as the number of protons in the nucleus increases. (3) Weak interaction that is much weaker than strong interaction and electromagnetic force. It is responsible for the so called beta-decay process.

Slightly over 100 naturally occurring or artificially produced elements and about 300 stable nuclides are known. But there are much more unstable nuclides that have the tendency to decay spontaneously.

Radioactivity is the spontaneous decay (disintegration) of atomic nuclei by the emission of subatomic particles and electromagnetic rays. This phenomenon was discovered in 1896 by the French physicist Becquerel. He found that uranium compounds produce invisible rays or radiation that can penetrate the opaque container and affect a photographic plate. Soon thereafter Pierre and Marie Curie found another radioactive elements: polonium and radium. Radioactivity was soon recognized as a more concentrated source of energy that had been already known.

Before long it was found that uranium radiation is composed of three components: α-, β- and γ-rays. Rutherford and Soddy showed that radioactivity is the result of the atomic nucleus decay (disintegration). In a decay process the nucleus of one chemical element changes into the nucleus of another element. There are two principal types of spontaneous nuclear decay.

α-decay.

This type of decay is usually observed in the heavier unstable nuclei. In α-decay some atomic nucleus X ("mother nucleus") emits an α-particle and turns into a new nucleus Y ("daughter nucleus"). The emitted α-particle is a helium nucleus with two protons and two neutrons.

$$_{Z}X^{A} \rightarrow {}_{Z-2}Y^{A-4} + {}_{2}\alpha^{4}$$

Thus the atomic number of daughter nucleus is diminished by two and mass number by four with respect to mother nucleus. The kinetic energy of α-particle is very large and it leaves the mother nucleus with the great speed.

Primarily the daughter nuclei are at an excited state. They occupy higher energetic levels which are unstable. At a very short time they undergo a transition to a lower energy level and the energy surplus is emitted as γ-rays. γ-rays are electromagnetic quanta or photons. They are completely equivalent to the light quanta or X-rays emitted by excited atoms, but their energies are usually much greater. The wavelength of γ-rays is shorter than the wavelength of X-rays.

β-decay

β-decay is observed in some unstable isotopes of lighter nuclei (hydrogen, sodium, nitrogen etc.). β-particle is emitted by a mother nucleus when it turns to a daughter nucleus. There are three kinds of β-decay: β^-- decay, β^+- decay and electron capture.

a) β^-*-decay*. In β^--decay, an electron e^- (β-particle) is created by a mother nucleus when it turns to a daughter nucleus. The atomic number of the latter is increased by one with respect to mother nucleus. Not only an electron but also antineutrino ν is created. It is almost massless and uncharged particle.

$$_{Z}X^{A} \rightarrow {}_{Z+1}Y^{A} + {}_{-1}\beta^{0} + \overline{\nu}$$

b) β^+- *decay*. In β^+- decay not an electron but positron e^+ is created as β-particle. Neutrino is also created. The atomic number of daughter nucleus is reduced by one.

$$_{Z}X^{A} \rightarrow {}_{Z-1}Y^{A} + {}_{+1}\beta^{0} + \nu$$

Positrons are positively charged particles with the same mass as the electrons. They are antiparticles with respect to electrons.

Today all elementary particles are believed to have antiparticles (antiprotons, antineutrons etc). The above mentioned antineutrino is the antiparticle with respect to neutrino. When some particle interacts with its antiparticle, they annihilate and γ-rays are produced.

c) *Electron capture.* One of the atomic electrons interacts with the nucleus and is captured by it.

$$_{z}X^{A} + {}_{-1}e^{0} = {}_{z-1}Y^{A} + \nu.$$

The transmutation of proton to neutron and neutron to proton is the basis of all kinds of β-decay. γ- rays are also emitted as daughter nuclei undergo the transition from higher to lower energy level.

Source activity. The law of nuclear decay.

There are two kinds of radioactivity: natural and artificial. The natural radioactivity takes place spontaneously without any external influences. It is the result of instability of some nuclides. Unstable isotopes transmutes into the isotopes of another chemical elements. Artificial radioactivity is the decay of the artificially obtained isotopes as a result of some nuclear reactions.

The source activity is the disintegration rate of a radioactive material, or the rate of decrease in the number of radioactive nuclei present. Its unit is named becquerel (Bc). One becquerel is defined as one disintegration act per second. Sometimes another unit of activity is used - curie (Ci). It corresponds to $3{,}7.10^{10}$ disintegrations per second. For instance, the source activity of 1 g of radium is $3{,}7.10^{10}$ Bc, or 1 Ci.

A nuclear decay is a random process. It is impossible to predict when a specific nucleus will decay. But the number of the nuclei remaining is invariably decreasing. The change dN in the number of nuclei present N occurring in a short time dt is proportional to N and to dt:

$$dN = - \lambda \cdot N \cdot dt.$$

The minus sign is needed because N is decreasing and dN is negative. The constant λ depends on the kind of nuclei and is called the radioactivity decay constant. The solving of this equation results in the function

$$N = N_0 \cdot e^{-\lambda t}$$

This function implies that if at time $t = 0$ there are N_0 nuclei, then at a later time t the number of nuclei remaining is N. This function is called the exponential decay formula.

It is convenient to characterize a nuclear decay by a half-life period. It is the time required for half the nuclei present to decay. The various radioactive nuclei have a half-life varying at a very wide range (e.g. from 4,5 billion years for uranium to 10^{-4} sec for one of the radium isotopes).

Ionizing radiation

The radioactive decay of nuclei produces several kinds of ionizing radiation. When this radiation passes through a matter, it ionizes atoms and molecules, i.e. turns them to electrically charged ions. The term "ionizing radiation" includes not only radioactive radiation but also X-rays.

All kinds of ionizing radiation can be divided into two species:

(1) corpuscular radiation α-particles, β-particles (electrons and positrons), protons, neutrons etc.;

(2) wave radiation - γ rays and X-rays.

The interaction of ionizing radiation with matter

α-particles. α-particles are ejected from their mother nuclei at a great speed. Most of the α particles emitted from the same substance, are ejected at very nearly the same velocity. α particles are slowed down and stopped as they pass through a matter, primarily through interaction with atomic electrons. α-particles and protons undergo frequent collisions with atomic electrons as they pass through a matter. They impart some energy to the electrons and also act on them by their electric field. As a result they excite and ionize atoms of a matter. Only a little part of α-particle energy is transferred in a single collision. So many collisions occur as the α-particle slows. It leaves the trace in a matter which may consist of some tens of thousands of ions. When its kinetic energy decreases it acquires two electrons and become a neutral helium atom.

Because an α-particle is much more massive than an electron, it is scarcely deflected in the collisions, and its path is nearly a straight line. The ranges of α-particles and protons in a matter are very short. The average range or stopping distance varies inversely with the density of the medium. The penetrating ability of α-particles is not large. They can travel only about 4 cm in air and cannot penetrate a sheet of paper or upper cell layers of the human skin.

β-particles. Electrons and positrons are ejected from their mother nuclei at much greater speeds than α particles. Unlike α particles, they are emitted at many different speeds. β particles penetrate considerably more deeply into a matter. They also collide with atomic electrons of a medium and lose energy mainly by exciting and ionizing atoms. The kinetic energy of electron is much smaller than that of α-particle. Its value is enough to ionize only some tens of atoms. Because of the small electron mass, a large deflection occurs at each collision with atomic electron. Hence the electrons do not travel in a straight line, but instead wander randomly. The range of electrons in air is some tens of centimeters. They can be stopped by a few centimeters of wood.

The range of positrons is approximately the same as that of electrons. Eventually a positron slows and comes close enough to an electron, so that they annihilate producing γ-rays.

γ rays. γ rays produce ionization by losing their energy to atomic electrons. They have a long range in matter and can even pass through a human body. γ rays, depending on their energy, require thick shielding, made of a heavy material such as lead or concrete. γ rays transfer energy to electrons by three processes.

(a) For γ rays with relatively small energies, as well as X-rays, the photoelectric effect is most important. A γ-ray photon is absorbed by an atom, and an atomic electron is ejected out of it. This process is most likely for atoms with large charge numbers.

(b) If γray energy is more, Compton effect dominates. γ-photon transfers some but not all its energy to atomic electron. Consequently it can ionize more than one atom.

(c) Electron - positron pair producing. If γ-photon energy is more considerable, it is absorbed near atomic nucleus and the pair of particles (electron and positron) are produced.

γ-ray absorption probabilities diminish as their energy rises. Consequently, as the γ-ray energy increases, the radiation becomes more penetrating or harder.

Neutrons

Neutrons are uncharged and produce ionization indirectly by interacting primarily with small atomic nuclei rather than with atomic electrons. They have a very long range in a matter. Neutrons are constituent particles of all nuclei except hydrogen. Free neutrons are produced in some nuclear reactions. They can be ejected from atomic nuclei at various speeds and energies. Neutrons are slowed down by a series of collisions with atomic nuclei of a matter at which energy transfer takes place. The excited nuclei react by by proton or γ-ray emission. Once a neutron energy diminishes, it has a high probability of being captured by atomic nucleus.

Radiation detection and measurement

There are many types of instruments that are used to detect ionizing radiation. It is detected by observing ionization it produces in matter. Gas ionization counters are most commonly used. These detectors are very sensitive to β-particles but less to the more penetrative γ-rays. A typical arrangement is a metal cylinder, the wallsides of which is used as anode. A fine wire along its axis is cathode. A cylinder is filled by the indifferent gas argon.

In the absence of ions argon cannot conduct electric current. But when ionization is produced by radiation, a brief electric current pulse results. If the applied voltage is large enough, each electron produces several secondary electrons, which in turn produce others. The resulting electric pulses can be observed and recorded by simple circuits. Such a detector is called a Geiger-Muller counter. It can be compact and suitable.

There are also other types of radiation counters, one of which is scintillating counter. Such counters have relatively high efficiencies for detecting γ rays. They are the detectors that are most widely used in biomedical applications. A scintillation counter consists of a crystal which scintillates, i.e. emits flashes of visible light as its atoms are exited by ionizing radiation.

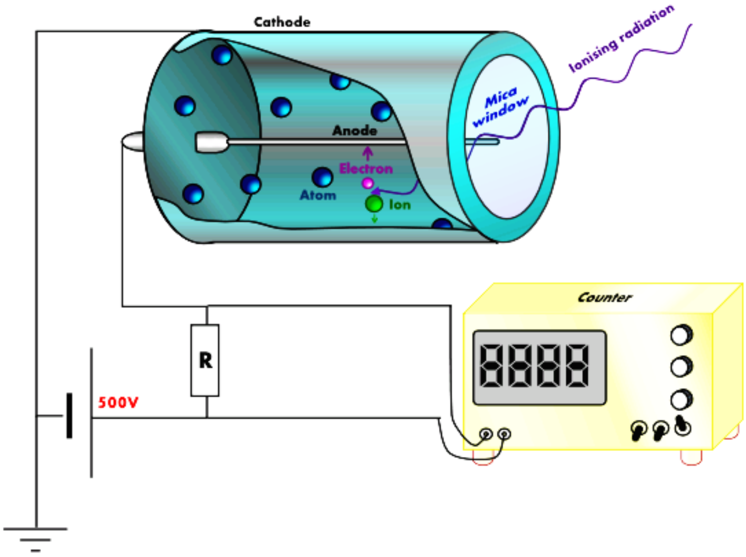


Fig.44 Geiger counter

The light flashes are counted by a high sensitive device photoelectric multiplier. The photons of visible light enter this device. It generates electric pulses that undergo very high amplification. The total charge in the current pulses is proportional to the amount of radiation. Scintillating counters can not only measure the intensity of radiation but also identify its nature.

RADIATION DOSIMETRY. HARMFUL EFFECTS OF RADIATION. RADIATION IN MEDICINE

Radiation dosimetry

Radiation dosimetry is used for monitoring of its intensity. There are many types of radiation dosimeters. Three types of doses are used to measure the radiation intensity: absorbed dose, exposure dose and biological (equivalent) dose.

The absorbed radiation dose. The absorbed radiation dose is measured as the radiation energy absorbed in the material. It is the energy of radiation imparted by ionizing radiation to a unit mass of absorbing matter. The absorbed dose is used with all kinds of ionizing radiation. It depends on the nature of radiation and the properties of material. The absorbed dose is measured in grays (Gy). The gray is 1 joule per kilogram.

The effect of ionizing radiation depends not only on the value of its absorbed dose, but also on the period of time during which it acted upon the object. Therefore absorbed dose rate is also used to appreciate the effect of radiation. Absorbed dose rate is the ratio of absorbed dose and the period of its action.

The exposure radiation dose. The exposure dose indicates the amount of radiation reaching a material. It depends not on characteristics of a material but on characteristics of radiation alone. The exposure dose can be defined only for gamma rays and X-rays and not for other forms of radiation. It is defined as the amount of ionization produced in a unit mass of dry air at standard conditions (0^0 C, 760 mm Hg).

The unit of exposure dose is 1 coulomb per kilogram. But more convenient unit of exposure dose is roentgen (R). It is equal to $2{,}58 \cdot 10^{-4}$ coulombs per kilogram, or approximately 2 milliards pairs of ions per 1 cm^3 of air. The one roentgen exposure dose of X-rays or gamma rays produces absorbed dose of approximately 0,01 gray at the human soft tissues. Exposure dose rate is the ratio of exposure dose and the period of its action.

The biological (equivalent) dose. The previously mentioned absorbed and exposure doses refer only to a physical effect of radiation. The biological dose is used to estimate its biological effect.

The effect of radiation on biological systems depends not only on its absorbed and exposure doses. It depends strongly on the type of radiation. To characterize this dependence the relative biological effectiveness coefficient (RBE) is used. RBE of particular kind of radiation is defined by comparing its effects to those of standard kind of radiation, which is usually taken to be X-rays of some fixed energy. Their effects on the biological test-objects are compared. One of them is an animal eye, in which cataract can be caused by radiation. RBE is 1 for β-particles and γ rays, while 2-10 for neutrons, 10 for protons and 20 for α-particles.

Positive ions, which deposit more energy per unit length of their track than β or γ rays, do more biological damage than the same absorbed dose of β or γ. However, their effects are more limited to the surface tissues because they have short ranges.

The biological (equivalent) dose of radiation is its physical absorbed dose multiplied by RBY of the radiation considered. The unit of biological dose is sievert (Sv) which is equivalent to 1 gray of X-rays or gamma rays.

Harmful effects of radiation

The energy of ionization differs significantly from the other kinds of energies in its biological action. The mortal gamma rays exposure dose can raise the body temperature only for some thousandth of degree. When radiation passes through living cells, it can alter or damage the structure of important biological molecules. Protracted radiation is better tolerated because some of the damage can be repaired. The effect of radiation delivered rapidly is much greater. Large whole-body doses of ionizing radiation produce a characteristic pattern of injury. A man or animal falls ill with radiation sickness which leads to malfunctioning of organism or death.

The pathogenesis of radiation sickness is studied in details. The mainly primary effect of radiation on living cells is the ionization of water molecules which amount is much more than that of other molecules in cytoplasm. Receiving the radiation energy they lose electrons and form positive ions. Free electrons are taken up by other water molecules and negative water ions are formed.

$$H_2O \rightarrow H_2O^+ + e^-$$

$$H_2O + e^- \rightarrow H_2O^-$$

Such water ions are unstable and dissociate in a very short time forming free radicals (hydrogen and hydroxyle).

$$H_2O^- \rightarrow H\cdot + OH^-$$

$$H_2O^+ \rightarrow H^+ + OH\cdot$$

As it is known, free radicals are characterized by very great chemical activity. They come into reaction with other chemical substances forming new free radicals.

Hydrogen peroxide is also formed. This compound is known as a very strong oxydizer.

$$OH\cdot + OH\cdot \rightarrow H_2\,O_2$$

Free radicals have an effect on proteins, nucleic acids and other biological molecules. This effect may consist in distraction of protein and nucleic acid chains or making incorrect valence bonds within them. As a result, the function of this important biological molecules gets broken.

Within a living cell the nucleus is much more sensitive to ionizing radiation than protoplasm. It have been shown in experiments in which amoebae were exposed to the lethal dose of radiation. Afterwards their nuclei were extracted and replaced by the nuclei of healthy amoebae. The last, in their turn, received the nuclei from amoebae that were the objects of radiation. The first group of beings remain alive while the second group perished.

The effect of radiation is most harmful during cell-division. Usually the cells that are growing or dividing are the most radiosensitive. It concerns immature blood cells, intestine epithelium, genital cells etc. Foetuses and infants are much more readily harmed by radiation than are adults.

The knowledge of the immediate effects on human of large radiation doses comes from studies of victims of atomic bombs explosions and occasional accidents. Whole body doses under 0,25 Sv have no observable effect. As the dose increases above 1 Sv, damage to the blood-forming tissues becomes evident, and above 8 Sv severe gastrointestinal disorders occur. Death usually follows in a period of days or weeks if the dose is much more than about 5 Sv and if a patient gets no treatment.

The high sensitivity to ionizing radiation is inherent to humans and such animals as monkeys, horses, dogs etc. Rodents are less sensitive and can survive on receiving a dose of 7-8 Sv. Amphibia are able to remain alive if the radiation dose is equal to some tens of sieverts and insects - even hundreds of sieverts.

There are dangerous remote effects of radiation action. Sublethal short-term doses and doses acquired gradually over a long period may lead to a cancer after a latent period of many years. The chance of dying of cancer is doubled by a dose somewhere between 1 and 5 Sv. Over a wide range of exposures, both in animal experiments and in human data, the increase in the cancer rate is directly proportional to the total radiation dose.

Another remote consequences of radiation action are genetic effects that are represented by mutations. Most of them are harmful. It is known that mutations can be increased not only by ionizing radiation but by some chemicals etc. The mutations caused by radiation are similar to those occurring naturally. The increase in the mutation rate means more prenatal death and more children born with serious defects. It is generally believed that the rate of mutations is proportional to the radiation dose, no matter how small it is.

Chronic exposure to small radiation doses

All the humans have always been exposed to chronic low-level ionizing radiation. It arises from cosmic rays and from radionuclides naturally present in the environment. The cosmic rays include almost all kinds of ionizing radiation. It is characterized by great penetrating power. Its dose per year is comparatively little at sea level and more at the mountains.

The natural radiation background depends also on the concentration of radionuclides in soil and rocks (U, Th, Ra etc.). There are some places, particularly in Brazil, where a soil has a high thorium content. The year radiation doses at that places are some tens time more than the average norm.

A great attention is paid to radioactive gas radon, which is dissolved in the underground water. The water from some mineral springs in Italy and Austria contain up to many thousands times the usual radioactivity.

To the natural background artificially produced radiation is added. It has the amount nearly equal to the natural background radiation. The most important source of artificial radiation are the medical diagnostic X-rays.

Any radiation exposure carries with it a small but real risk. The maximum permissible dose (MPD) for radiation workers is 50 mSv per year. The average MPD for the individuals of the entire population is 1,7 mSv per year. No single radiation-producing device, such as watches, TV sets, computer displays etc, is permitted to expose the public to more than a small fraction of MPD. It is estimated also that medical exposures can be greatly reduced without any loss of the benefits of diagnostic X-rays if modern well-shielded apparatus are used.

Radiation in medicine

Medical radiology is the branch of medical science that concerns the use of radiation in the diagnostics and treatment of diseases. Despite its hazards, the use of ionizing radiation in medical research, diagnosis, and therapy is invaluable. Many different radionuclides are produced in reactors and accelerators and are available for use in medical radiology.

Radionuclides in medical research

Nowadays a great amount of various biological compounds are synthetized that contain radionuclides of hydrogen, carbon, phosphorus, sulphur etc. They may be introduced into the organism of experimental animals in order to investigate biochemical and physiological phenomema. Radioactive isotops employed in tracing the course of nonradioactive substances are called tracers. Radioactive tracers are prepared by neutron bombardment of the stable element, which capture the neutrones to form the heavier nonstable radioactive isotopes.

The radioactivity of these tracers makes it possible to folow their pathways and metabolism very accurately and conveniently. The active and passive transport of sodium and potassium, the metabolism of sugars and lipids, the protein and nucleic acid synthesis are examples of fundamental biological processes that are studied with radioactive tracers.

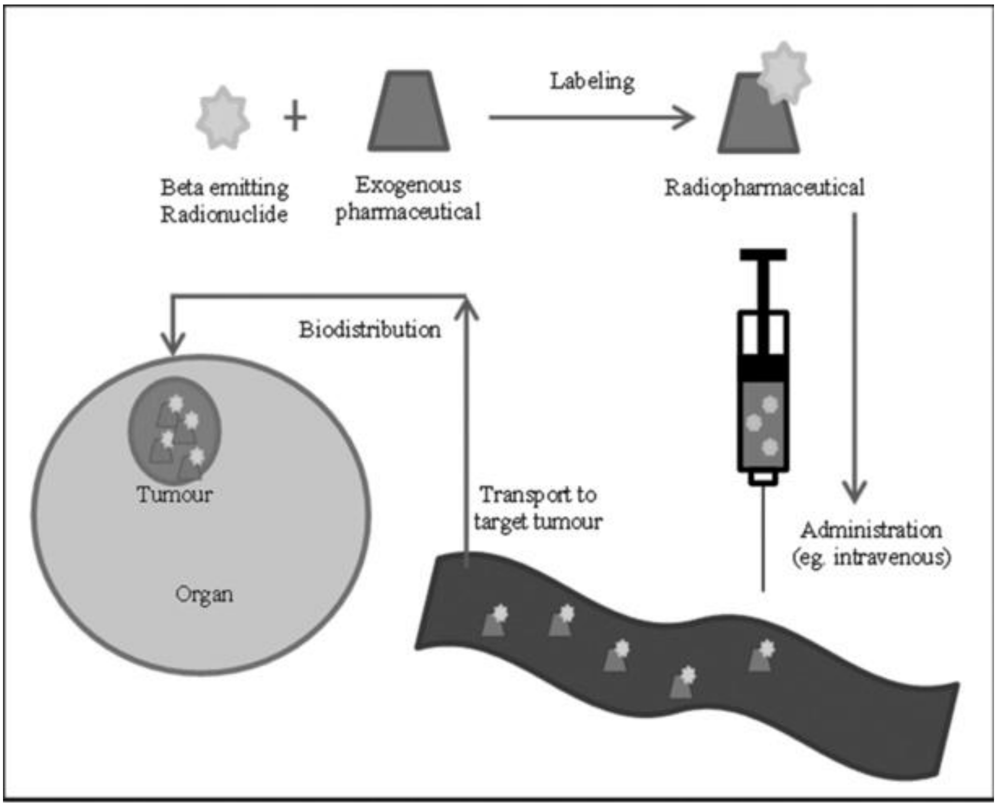


Fig.45 Radionuclides labeling

Radionuclides in diagnostics

Most diagnostic studies done with radioactive isotopes share some common features. A radioactive tracer is administered and absorbed in the organ of interest, and a detector outside the body measures radioactivity of the organ at various times or locations. To minimize the dose, short-lived radionuclides are selected. They must emit gamma rays with just enough energy to be detected. For many purposes the short-lived radioactive technetium is very suitable. This radionuclide decays to its stable state with a half-life time of six hours emitting gamma rays. In suitable chemical compounds radioactive technetium can be directed at many different organs.

Introduction of radioactive tracers permits to study the rate at which a heart, kidney, liver, brain, thyroid gland and other organs absorb and eliminate definite substances. For instance, when diuretics containing the tracer are concentrated in the kidneys, alterations from the usual patterns of uptake and excretion may signal possible abnormalities. A thyroid scan is done by administering a suitable compound containing the tracer.

Since non-functioning tissue in the thyroid does not absorb the material, it appears as a less radioactive region in the thyroid

In a gamma-ray imaging scan, a picture is produced by detecting the radiation from the absorbed tracer. The radiation from a very small regions of the organ is detected by the special counter. The counter is slowly moved or scanned over the region of interest and the pulses generated are recorded on display or sheet of paper.

Positron emission tomography is one of the most valuable methods of diagnostics that use radionuclides. This method is based on the phenomenon of annihilation which takes place when positron interacts with electron. The radionuclides with a short life-time are produced by means of cyclotron or other type of accelerators. The radioactive isotopes of oxygen, carbon or nitrogen are mostly used. All of them are capable of β^+ - decay (positron decay).

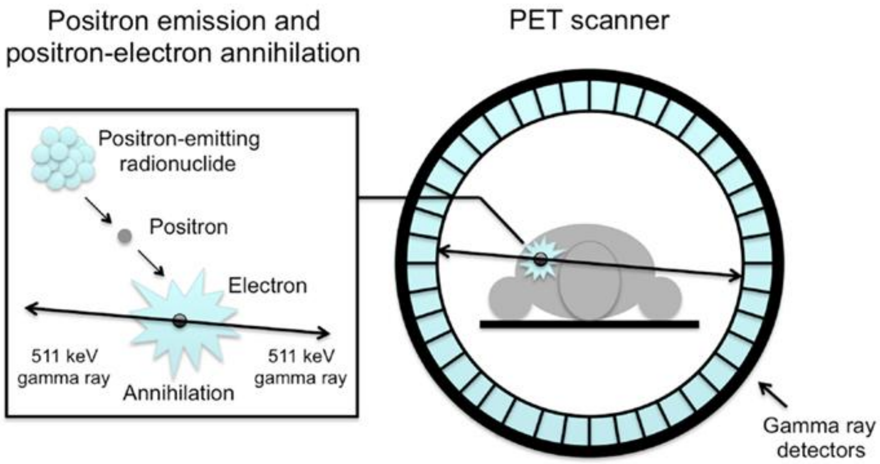


Fig.46 Scheme of positron emission tomography

The definite chemical compounds containing radionuclides are introduced into the organ of interest, for instance into the brain. Here they are utilized by metabolism and undergo β^+ - decay emitting positrons. The annihilation of positrons and atomic electrons take place and gamma-rays are radiated. This method gives the possibility to obtain a very precise information concerning the cell metabolism in the normal and pathological states.

Therapeutic radiology

It was noticed above that the cells that divide frequently are the most sensitive to the action of ionizing radiation. This fact bears a relation to malignant tumors, which cells divide much more frequently than the cells of normal tissues. Rapidly dividing cancer and sarcoma cells are highly sensitive to ionizing radiation. The normal tissues have a greater ability to recover from the effects of ionizing radiation than do malignant tumors. Thus, a radiation dose sufficient to destroy tumor cells, injure only slightly and temporarily the adjacent normal cells.

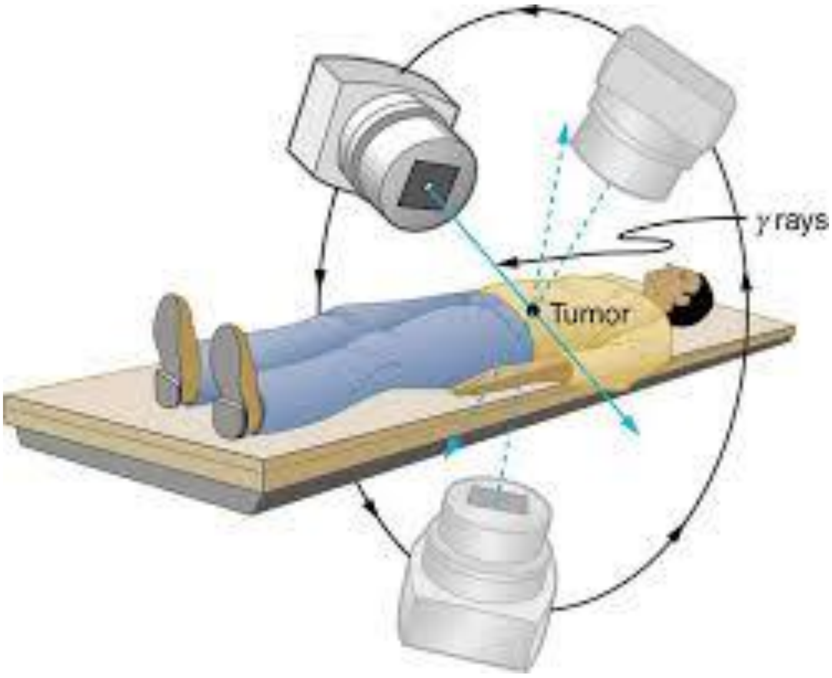


Fig.47. Scheme of radiotherapy

Most of the cancer patients receive radiation therapy, usually in conjunction with surgical treatment and cancer-treatment drugs. The radiation may be administered externally by the special X-ray machines, the devices containing radioactive cobalt, or electron accelerators. Superficial radiation therapy (mostly by means of X-rays) is used in treating malignant diseases of the skin and eyes. Gamma rays emitted by cobalt provide more effective radiation dose to tumors deep within the body. Alternatively, radium-filled needles, small seeds containing radon gas, or wires containing artificial radionuclides, may be implanted in the tumor. Accelerator-produced beams of high-energy electrons can also be used because they deposit much of their energy in a small region near the end of their range.

TESTS FOR KNOWLEDGE CONTROL

1. The unit of absorbed dose is:
A. Gray;
B. Roentgen;
C. Joule;
D. Coulomb;
E. Sievert

2. The ratio of absorbed dose and the period of its action is called:
A. Absorbed dose power;
B. Absorbed dose force;
C. Absorbed dose rate;
D. Activity of absorbed dose;
E. Efficiency of absorbed dose

3. This dose indicates the amount of radiation reaching some material:
A. Absorbed dose;
B. Exposure dose;
C. Biological dose;
D. Equivalent dose;
E. Effective dose

4. The exposure dose can be defined only for:
A. α-radiation and γ-rays;
B. β-radiation and γ-rays;
C. X-rays and α-radiation;
D. X-rays and β-radiation;

E. X-rays and γ-rays

5. The unit of exposure dose is:
A. Gray;
B. Joule per kilogram;
C. Coulomb;
D. Roentgen;
E. Sievert

6. Coulomb per kilogram is the unit of:
A. Absorbed dose;
B. Exposure dose;
C. Effective dose;
D. Biological dose;
E. Equivalent dose

7. The biological dose is called also:
A. Absorbed;
B. Effective;
C. Exposure;
D. Active;
E. Equivalent

8. Relative biological effectiveness coefficient (RBE) for β-particles and γ-rays equals:
A. 1;
B. 2;
C. 3;
D. 4;
E. 5

9. RBE for neutrons is:

A. 1-2;

B. 2-10;

C. 10-20;

D. 25-30;

E. 35-40

10. For α-particles RBE is:

A. 5;

B. 10;

C. 15;

D. 20;

E. 25

11. The unit of biological dose is:

A. Sievert;

B. Roentgen;

C. Joule;

D. Coulomb;

E. Gray

12. Free radicals are formed as result of

A. Dissociation of amino acids;

B. Dissociation of inorganic acids;

C. Ionization of water molecules;

D. Ionization of organic ions;

E. Dissolution of organic substances

13. This property is inherent to the free radicals:

A. They produce ionization of water;

B. They restore organic molecules;

C. They warm the tissues;

D. They damage biological molecules;

E. They cool the tissues

14. This part of the cell is the most sensitive to ionizing radiation:

A. Membrane;

B. Nucleus;

C. Protoplasm;

D. Reticulum;

E. Mitochondria

15. The most radiosensitive are:

A. Nerves;

B. Bones;

C. Muscles;

D. Epithelium cells;

E. Liver cells

16. This radioactive element is dissolved in underground water:

A. Uranium;

B. Radium;

C. Polonium;

D. Thorium;

E. Radon

17. The tracers are used:

A. To watch the patient;

B. To watch the doctor;

C. To treat patient;

D. To investigate radioactivity;

E. To investigate metabolism

18. A thyroid scan is done by administering a suitable compound containing the tracer:

A. Radon;

B. Radium;

C. Polonium;

D. Thorium;

E. Radioactive iodine

19. To be detected the radio nuclides must emit:

A. α-radiation;

B. β-radiation;

C. γ-radiation;

D. X-rays;

E. Neutrons

20. Positron emission tomography is one of the most useful methods of:

A. Diagnostics;

B. Treatment;

C. Surgery;

D. Chemical investigations;

E. Introduction of drugs

ANSWERS

DIRECT ELECTRIC CURRENT

1	D	15	D
2	D	16	D
3	A	17	D
4	C	18	D
5	A	19	B
6	B	20	A
7	C		
8	A		

MAGNETIC FIELD

1	C	9	D	17	C
2	D	10	D	18	B
3	B	11	D	19	A
4	D	12	D	20	A
5	A	13	C		
6	A	14	C		
7	E	15	E		
8	A	16	D		

ELECTRONIC MEDICAL EQUIPMENT FOR THERAPY

1	E	11	C
2	A	12	E
3	A	13	A
4	A	14	C
5	B	15	E
6	B	16	E
7	A	17	C
8	D	18	D
9	A	19	E
10	B	20	C

GEOMETRICAL OPTICS

1	C	10	C
2	D	11	A
3	C	12	C
4	B	13	B
5	A	14	D
6	B	15	C
7	C	16	C
8	D	17	A
9	D	18	A

OPTICS OF VISION

1	B	10		19	D
2	A	11		20	B
3	D	12	B		
4	C	13	B		
5	D	14	B		
6	B	15	C		
7	B	16	D		
8	B	17	B		

X-RAYS

1	D	9	E	17	B
2	A	10	D	18	C
3	B	11	A	19	B
4	D	12	B	20	B
5	B	13	B		
6	A	14	A		
7	C	15	D		
8	D	16	A		

RADIATION IN MEDICINE.

DOSIMETRY.

1	A	8	A	15	E
2	C	9	B	16	E
3	B	10	D	17	E
4	E	11	A	18	E
5	D	12	C	19	C
6	B	13	D	20	A
7	E	14	B		

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