Ministry of Health of Ukraine
Ukrainian Medical Stomatological Academy

It is approved
on meeting of department of
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Methodical instructions
for students' self-preparation work at preparation for a practical lesson
at home and at the classroom

Subject matter	**Medical and biological physics**
The unit	1. Fundamentals of higher mathematics and biological physics
Theme of lecture:	**Membrane potentials of rest and activity.**
Year	1
Faculty	Medical
Speciality	Medicine

Poltava - 2020

The topic significance.

Generation and spreading of electrical potentials is most important physical phenomenon in live cells and tissues. It lies in base of cell excitation, intracellular processes regulation, nervous system work (conducting of nervous impulses), muscles contraction, i.e. coordinated action of whole organism.

Cell biopotentials origination study bases on use of cell electrophysiology methods, which includes microelectrode technique, amplification of biopotentials, happy choice of researched object, for example, giant axon of squid.

In unexcited cell always there is potential difference between inner and outer sides of cell membrane – between cytoplasm and environment. It is rest potential. It appears as result of ionic concentration difference in a cell and out the cell, and different permeability of a membrane to different ions. Ions distribution and its mechanisms are different for different types of cells.

Specific targets:

- To master ideas about ions that participates in biopotentials origination .
- To learn mechanism of equilibrium biopotentials generation .
- To learn mechanism of diffusion potential generation .
- To learn the mechanism of originating of rest potentials and action potential, and also a spreading process of action potential in myelinated and unmyelinated nerve fibers .
- To characterize typical concentrations of main ions determinative cell charge and potentials. .
- To learn mechanism of Donnan potential generation .
- To learn mechanism of Nernst potential generation .
- To learn mechanism of Goldman-Hodgkin potential generation .

- To write down: the equation for definition of equilibrium potentials (Nernst; Donnan; diffuse; stationary); ***Goldman-Hodgkin-Katz*** phenomenological equations. .
- To familiarize with principles and methods of biopotentials measurement .
- To familiarize with methods of electrophysiological examinations of membrane potentials and application of their results in medicine .
- To learn method of concentration potential origination studying.
- To be able to carry out laboratory work.
- To seize technique of the solution of typical problems;
- To get skills of a problem solving on a finding of rest potentials;
- To be able to apply the received knowledge in nonstandard situations.

Basic knowledge, experience, skills necessary for studying the topic in connection with other subjects:

Disciplines	**Obtainable skills**
Previous (providing disciplines): physics, mathematics, chemistry, biology	To know concepts: electric field, potential, potential difference, gradient. Ohm’s law, electrolytic dissociation, diffusion potential (electrochemical potential) To describe them. To describe electrokinetic appearances, membrane’s pumps work, membrane’s permeability
The subsequent disciplines: Normal physiology	To know role of electric processes in cell, tissues and whole organism functioning. To define such concepts: transmembrane potential; rest potential; equilibrium potential; Nernst potential; diffuse potential; Donnan potential; stationary potential; action potential or spike; depolarization; repolarization; hyperpolarization; reversion; portal currents.

Materials for the before-class self-preparation work:

List of main term, parameters, characteristics, which student have to learn at preparation to class:

Term	Definition
Membranous potential	The membranous potential is a particular case of the diffusion potential incipient on a boundary of two fluid mediums as a result of various ionic mobilities.
Rest potential	Rest potential it the potential difference (potential drop, electric potential) existing between the outside and intrinsic sides of a membrane of a cell, taking place in a state of physiological rest
Action potential	Action potential is a process of change of a transmembrane potential difference down to change of its sign, proceeding on the rules determined for the given tissue even after the terminal of irritator action
Sodium-potassium pump	Na^+-K^+-ATPase is membrane structure realized active transport for one cycle of work (splitting one ATP molecule) brings in a cell two ions K^+ and deduces outside three ions Na^+.
Schwann cells	Cells wraping up axon some times and form myelin cover with high electric resistance.
Saltatory propagation	The action potential wave does not propagate over the entire surface of the myelinated nervous fiber, but it jumps from one node to the other one to increase the velocity of transmission of nerve impulses.

Theoretical questions to class:

1. What is termed as electric field?

2. What is electric field intensity [electromotive intensity, electric field strength, electrostatic stress]?
3. What is electric field potential?
4. What is membrane rest potential?
5. Specify, what are interrelations between permeabilities of living cells membranes for ions?
6. What is electrolytic dissociation potential?
7. What ions create potential difference in the cells?
8. What is diffusion potential?
9. What requirements are taken into account at definition of membranous equilibrium Nernst potential?
10. Specify quantities of equilibrium Nernst potentials for ions Na^+, K^+ and Cl^- in norm.
11. What is Donnan potential?
12. What requirements are taken into account at definition of equilibrium Donnan potential?
13. Specify, for what cases Donnan potential is the closest to potential of a cell?
14. What requirements are taken into account at definition of diffuse membrane potential?
15. What requirements are taken into account at definition of stationary membrane potential?
16. What is Goldman-Hodgkin potential?
17. Methods of biopotential measurement (including squid axon).
18. What is the action potential?
19. Specify the causes of formation of action potential.
20. What are the determinative factors of the shape of an initial phase of a membrane depolarization at formation of action potential?
21. What are the determinative factors of the phase of membrane repolarization at formation of action potential?
22. Specify duration of action potential in norm for a squid axon.
23. Whether there will be an action potential if to remove completely ions of sodium from a surrounding medium of a cell?

Practice work executed at class:

Algorithm of a problem solving.

Task 1. J.Bernshtejn has assumed that the membrane potential originates owing to a nonuniform distribution of potassium ions. Considering that the membrane is permeable only for ions of potassium and impermeable for others, to estimate the rest potential of a squid axon membrane, if: $[K^+]_i$*=392 mmol/l,* $[K^+]_e$*=22.4 mmol/l, T=293K*.

The solution.

According to a statement of a task the rest potential to be determined by equilibrium potassium potential and can be designed with the help *of a Nertnst equation*:

$$\Delta\varphi_n = \frac{RT}{F}\ln\frac{[K^+]_e}{[K^+]_i}.$$

Evaluation: $\Delta\ _N = \frac{8.31\cdot 293}{96484}\ln\frac{22.4}{392} \approx -72[mV]$.

The answer: –72 mV. At physiological values $[K^+]_e$ and $[K^+]_i$, quantity $\Delta\varphi < 0$.

4.3. Educational problems, III level tests.

Test problems

1. If endocellular concentration of K+ in 50 times exceeds extracellular, then the rest potential at temperature 27°C is approximately equated …

a) –116 mV. b) +101 mV. c) –101 mV.

d) +116 mV. e) –0,101 V.

2. If to consider, that cytoplasmic membrane of nerve fiber is permeable only for sodium ions at temperature t=37°C (interior and extracellular concentrations of sodium are equal accordingly C_i=23 mmol/l, C_e=150 mmol/l), then theoretical value of a maximum of action potential is approximately equated …

a) –50 mV. b) +50 mV. c) +0,5 V.
d) –0,05 V. e) +0,05 V.

3. At temperature 300K amplitude of action potential is (if concentration of potassium and sodium inside a cell of an excited tissue accordingly: 125 mmol/l, 1,5 mmol/l, and from the outside 2,5 mmol/l and 125 mmol/l) approximately equal to...

a) –107mV. b) +0,107 V. c) –0,107 V.
d) +107 mV. e) +0,0107 V.

Tasks

Task 1. Nervous excitation is spread along an axon in one side from a zone, in which it was appeared. Why?

Task 3. Calculate membrane potential of a squid axon at temperature 25ºC. At calculations to use such ion concentrations in axoplasm: $[K^+]_i$=340 mmol/l; $[Na^+]_i$=49 mmol/l and $[Cl^-]_i$=114 mmol/l, in a surrounding medium: $[K^+]_e$=10,4 mmol/l; $[Na^+]_e$=463 mmol/l and $[Cl^-]_e$=592 mmol/l. To accept permeability coefficients of ions through a membrane $P_{K+} : P_{Na+} : P_{Cl-}$ =1 : 0,04 : 0,45, that is the reference for potential of rest. To accept permeability coefficients of ions through a membrane $P_{K+} : P_{Na+} : P_{Cl-}$ =1:20:0,45, that is the reference for action potential.

The answer: –52 mV; 45mV.

Contens of the topic.

The potential difference (potential drop, electric potential) existing between the outside and intrinsic sides of a membrane of a cell, taking place in a state of physiological rest, refers to as a **rest potential**.

Living cells and tissues are capable on influence of various factors (irritators) to react change of any parameters (transmembrane potential difference, biochemical structure, rate and character of chemical changes). This ability refers to as irritability.

Process of generating refers to ***exaltation***. **Action potential** is a process of change of a transmembrane potential difference down to change of its sign, proceeding on the rules determined for the given tissue even after the terminal of irritator action. To excitable tissues carry all kinds of a muscular, nervous and glandular tissue. For excitable tissues specific reactions during exaltation are characteristic also. For a muscular tissue it is a contraction, for glandular – secretion of secret, for nervous – carrying out of exaltation.

Rest potential

Resting Membrane Potential – positivity outside and more negativity inside the cell.

The ionic imbalance is produced mainly by two transport mechanisms in the cell membrane:

1. Sodium-potassium pump and
2. Selective permeability of cell membrane.

Between endocellular medium and external environment there is a difference of ions concentrations. So, K^+ concentration in a cell at 20–40 times more, than in extracellular medium; Na^+ concentration is lower at 10–20 times, than in extracellular medium. Ions of Cl^- the same as Na^+, mainly are in extracellular medium. Such non-uniform allocation of ions is provided by "ionic pumps" – the integrated membranous proteins-transmitting agents exercising active transport of ions.

1. *Sodium-potassium Pump.*

So-called Na^+-K^+-pump (Na^+-K^+-ATPase) by conjugate active transport for one cycle of work (splitting one ATP molecule) brings in a cell two ions K^+ and deduces outside three ions Na^+. Thus: **three sodium ions** move out of the cell and **two potassium ions** move inside the cell by using energy from ATP. This leads to negativity inside and positivity outside the cell.

Such interrelation is fair for a membrane of a giant axon of a squid. In other cells these sizes can be smaller (1 K^+ ion : 2 Na^+ ions; 1 K^+ ion : 1 Na^+ ion, but in any case Na^+ ions is deduced not less, than introduced ions K^+. As negative charges inside a cell are connected mainly with organic anions, including high-molecular proteins which cannot freely diffuse through a membrane, owing to work of Na^+-K^+-ATPase in a cell there is an excess of negative charges in comparison with environment.

2. ***Selective Permeability of Cell Membrane.***

The sodium (Na^+) and chloride (Cl^-) ions are more outside and potassium (K^+) ions are more inside.

Inorganic ions (such as Na^+ and K^+) are able to penetrate through pores within integral proteins that span the thickness of the double phospholipid layers.

Besides the cell membrane has a selective permeability for ions. The ion channels available in a membrane, can be open or closed, that depends on transmembrane potential and a membrane state. So, in a cell which is taking place in rest, sodium channels are closed, potassium channels – are open. Therefore the membrane permeability for different ions is various. An interrelation of permeabilities for ions K^+, Na^+ and Cl^- in rest (we accept a permeability for K^+ for 1): $K^+ : Na^+ : Cl^- = 1 : 0{,}04 : 0{,}45$ (data of Hodgkin and Katz for giant axon of squid). Cell membrane is about twenty times more permeable to potassium (K^+) than to sodium (Na^+); consequently, K^+ diffuses much more rapidly than Na^+.

It results to that K^+ ions diffuse from a cell in extracellular space on a concentrations gradient. The counter current of Na^+ ions is very small (in 25 times below) and it is compensated by work of Na^+- K^+-pump. In result between an internal cell environment where there is an anion excess, and the outside medium where cation excess collects, potential difference is created which for different cells is peer from –60 mV to –100 mV and results in the stoppage of the further K^+ ions diffusion. This transmembrane potential difference also refers to as a rest potential.

Part of the K^+ ions which have left a cell and Na^+ ions as result of electrostatic interaction with endocellular negative charges collect near to cellular membrane. In a result the cell behaves in a choronomic electrical field as a particle carrying negative charge, but it appears smaller, than a charge of internal cell environment as positive ions in perimembranous space in part compensate it.

Diffusion includes all transport phenomena occurring within thermodynamic systems under the influence of thermal fluctuations (i.e. under the influence of disorder; this excludes transport through a hydrodynamic flow, which is a macroscopic, ordered phenomenon).

Fick's first law (Fick's equation) is used in steady-state diffusion, i.e., when the concentration within the diffusion volume does not change with respect to time ($J_{in} = J_{out}$).

Diffusion flux (rate of diffusion) is $\boldsymbol{J = \frac{dm}{dt}}$.

$$J = -D\frac{dC}{dx}S, \quad \text{where}$$

J is the diffusion flux in dimensions of (mol m^{-2} s^{-1});

D is the diffusion coefficient or diffusivity, (m^2 s^{-1});

C is the concentration (mol m^{-3});

S – is surface area, through which diffusion happens;

x is the coordinate (m).

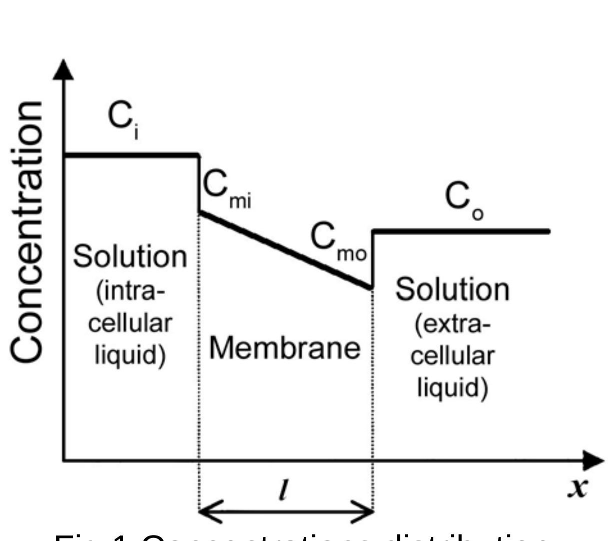

Fig.1.Concentrations distribution.

D is proportional to the velocity of the diffusing particles, which depends on the temperature, viscosity of the fluid and the size of the particles. For the biological molecules the diffusion coefficient normally ranges from 10^{-11} to 10^{-10} m^2 s^{-1}.

In case of diffusion through biomembrane particles concentrations at both sides of membrane are equal to C_i and C_o. In the membrane concentration change from C_{mi} to C_{mo} correspondingly. Let assign, that these concentrations are constant, and in the membrane concentration changes linearly: $\frac{dC}{dx} = \frac{C_{mo} - C_{mi}}{l}$,

where l – thickness of membrane.

As there is relation $C_{mi}/C_{mo} = C_i/C_o$, $C_{mi}/C_i = k$, $C_{mo}/C_o = k$, where k is coefficient of substance distribution between membrane and outer medium. Substitution into Fick's equation gives:

$$J = -D\frac{dC}{dx} = -\frac{Dk(C_o - C_i)}{l} = \frac{Dk(C_i - Co)}{l}.$$

Let coefficient of permeability ***P=Dk/l***, then substance flow through biologic membrane: $J = P(C_i - C_o)$.

The membranous potential is a particular case of the diffusion potential incipient on a boundary of two fluid mediums as a result of various ionic mobilities. It arises, if in a vessel there is the semipermeable membrane transmitting only cations. Such membrane can be a membrane with major concentration of the fixed negative charges.

If in one half of such vessel there is a solution of dissociating substance, for example, hydrochloric acid, and in another – only a solvent only cations (hydrions) diffuse through a membrane into right part of a vessel. The diffusion of hydrions will not be the infinite process as they undergo attraction ions of chlorine to resting on other part of a membrane.

After an establishment of equilibrium between forces of diffusion and forces of an electric field on a membrane there is a double electrical stratum, and the diffusion of ions is stopped. If mobility of anion V=0 the ***equilibrium membranous potential difference E*** is calculated with the help of ***Nernst-Planck equation***:

$$E = \frac{RT}{nF} \cdot \ln\frac{a_1}{a_2},$$

where ***R*** – gas constant, ***T*** – Kelvin temperature, ***n*** – valence of ions, ***F*** – a Faraday constant, a_1 and a_2 – ion activity in areas, whence (a_1) and where (a_2) there is a diffusion.

After substitution of constants in this equation and transition from natural logarithms to decimal logarithms the equation gets a view:

$$E = 58 \cdot \frac{1}{n} \cdot \lg\frac{a_1}{a_2} mV$$

In most of nervous and muscles cells ***equilibrium potential (equilibrium membranous potential difference)*** for ions Na^+, K^+ and Cl^- are: E_{Na+} from +30 to +65 mV, E_{K+} from –70 to –100 mV and E_{Cl-} from –40 to –90 mV.

Electrochemical gradient for K^+ is difference between current value of membrane potential and equilibrium potential for K^+. It is a cause of K^+ passive movement through the membrane in natural conditions. Electrochemical gradients for Na^+, Cl^- and Ca^{2+} can be calculated similarly.

Membrane in rest state is permeable not only for ions of potassium, but also in a small degree for ions of sodium and chlorine. The membranous potential of cells is resultant of the electromotive forces generated by all these three types of diffusion. Penetration of sodium from an environmental fluid inside of a cell at concentration gradient gives in some diminution of membranous potential. The diffusion through a membrane of chlorine ions, which content in an intercellular fluid of the majority of tissues is higher, than in cells, causes some magnification of membranous potential. Hence, for more precise evaluation of rest potential it is necessary to take into account not only a diffusion of potassium ions, but also a diffusion of sodium and chlorine.

The best model that describes the formation of the resting potential is the model, which assumes that, in the stationary state, the sum of flows of basic-ions (K^+, Na^+, Cl^-) is equal to zero, i.e.

$$\Phi_K + \Phi_{Na} + \Phi_{Cl} = 0 .$$

The Nernst-Planck equation allows to feature membranous potential only as a first approximation; to more precise definition of potential apply the generalized ***Goldman-Hodgkin-Katz*** equation, which take into consideration permeability of the membrane for some ions:

$$E = \frac{RT}{nF} \cdot \ln\left[\frac{P_K \cdot [K]_i + P_{Na} \cdot [Na]_i + P_{Cl} \cdot [Cl]_e}{P_K \cdot [K]_e + P_{Na} \cdot [Na]_e + P_{Cl} \cdot [Cl]_i}\right],$$

where P_K, P_{Na}, P_{Cl} – membrane permeability coefficients to ions of potassium, sodium and chlorine; ***[K], [Na], [Cl]*** – their activities in (i) and out (e) of cell.

Action potential

Irritator action causes changes in cell membrane state. Because of it in a membrane ion channels open through which in a cell positively charged ions can enter which are taking place a lot of in environment. More often (in nervous cells, skeletal muscles and working myocardium cells) there is an opening of "fast" sodium channels. In atypical fibers of a myocardium and in several smooth muscles "slow" calcium channels dominate on which as well as sodium can enter. Rate of opening of calcium channels is lower, than sodium, as well as rate the inactivation following opening. At first ionic current in a cell is promoted also by transmembrane potential. Such process refers to as depolarization as results in drop of this potential difference.

If irritator is rather weak or brief, ion channels opens a little. The ionic current is insignificant. The depolarization passes slowly, changes of transmembrane potential are insignificant and quickly stop. Such changes refer to as local depolarization, after them the rest potential is restored. Changes in a state of the next fields of a membrane are not present.

If irritator exceeds on force the minimal (threshold) size necessary that local changes have achieved a critical (threshold) level of transmembrane potential, then all active electroexcitable ion channels open, the depolarization is accelerated and even results in a *reversion* – to change of transmembrane potential sign which can achieve thus +40 mV.

At achievement of a maximum depolarization level the stream of positive ions inside of a cell stops, the corresponding canals are occluded. Taking place inside a cell K^+ ions surplus direct outside, resulting to regeneration of initial potential difference.

This process refers to as repolarization. In the term of repolarization activity of Na^+-K^+-pump, bringing to regeneration of initial difference of concentrations of Na^+ and K^+ ions, strengthens. In different tissues action potential has different voltage, duration and character.

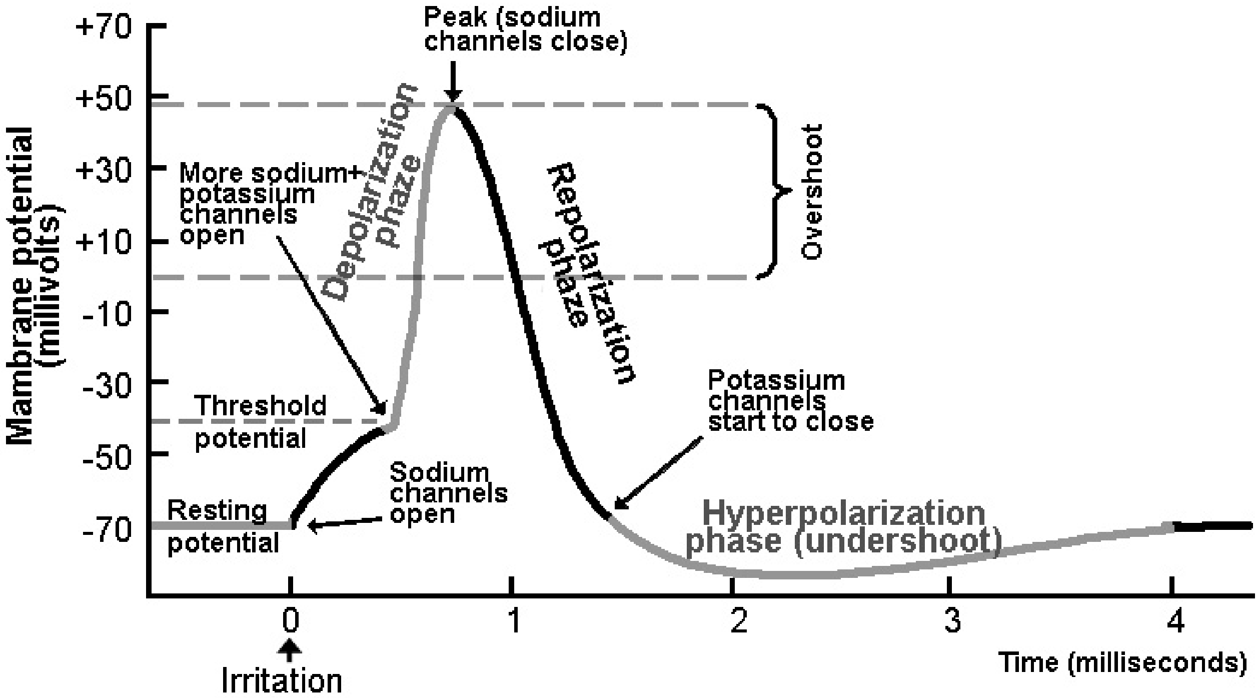

Fig.2. Activation of ionic canals during typical action potential process.

The basic functions of a nervous tissue are generating and carrying out of **action potential (AP).** Action potential, arising on a circumscribed field of a cellular membrane, results in change of an electrical field in environmental space. These changes produce opening of electroexcitable ion channels in the next fields of a membrane where action potential also develops (fig.2).

Process is spread in the sides from zone of irritation, covering more and more removed fields. Earlier excited zones are repolarized at this time. As ion channels in them remain inactivated some time, these zones are in a refractoriness state (non-excitability), action potential in the opposite direction cannot be spread. It is process of conduction of action potential (conduction of excitement).

In a muscle cell, this process causes its contraction; in the glandular cell, this process causes secretion (hormone, enzyme or other); in the nerve cell, action potential wave propagated along the membrane represents nerve impulse transmission.

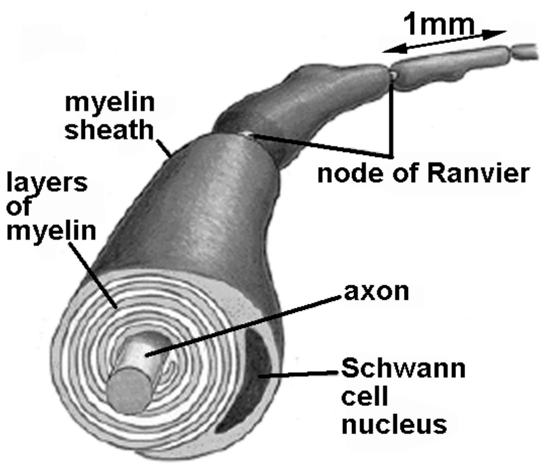

Fig. 3. Myelinated fiber.

The more velocity of nerve impulses transmission, the faster animal reaction on intra-organism changes and environmental influences. High velocity of nerve impulses transfer is evolutional factor promoted success of animal species.

The velocity of the action potential propagation along the membrane of the nerve fiber is proportional to the square root of the fiber radius. Therefore axons of many vertebrates have big radii.

Other way of acceleration (with saving of the energy need for restoration of Na^+–K^+ concentration equilibrium in the rest state) is diminution of the membrane area participated in the **AP** propagation. It is reached by covering of most part the membrane surface by the myelinic envelope. *Schwann cells* wrap up axon some times and form myelin cover.

Myelin is lipid with high electric resistance. Between *Schwann cells* there are allocated *Ranvier nodes* – short sections of axon with high concentration of Na^+-canals and, correspondingly, with high ability to support **AP** generation. They are in contact with extracellular fluid. Such *myelinated fibers* outwardly resemble thread with beads. Schwann cells and myelin isolate the nerve fiber membrane.

The action potential can be generated in the Ranvier nodes only. Membrane potential reversion in one node causes potential changes in the following one. It is realized by the means of local ionic currents flowing from one node to the next and provoking the fast local depolarization in the next node.

AP generation is result of local depolarization up to the threshold value. Hence, the action potential wave does not propagate over the entire surface of the myelinated nervous fiber, but it jumps from one node to the other one to increase the velocity of transmission of nerve impulses. Such propagation is called as *saltatory propagation*.

Besides, it is easier for the cell to ensure feeding of the thin fiber and recovering the rest potential not for the entire fiber, but for separate nodes than is the case for the nonmyelinated fiber. Therefore, myelinated fibers ensure both high velocity of nerve impulse transmission and high-energy effectiveness for vertebrates at the same time.

Self-control material:

B. Test tasks to be done:

1. In resuscitation department of clinic in patient it was determined increase of K^+ ions concentration in blood plasma. What process will be suffered in excitable tissues?
2. It proved that all live cells have various electrical charges on intrinsic and outer sides of membranes – membrane rest potential. What ion to play a head part in membrane rest potential generation?
3. In experiment in nervous cell with use of intracellular microelectrode introduction method this is registered potential difference between two sides of membrane – rest potential. What is value of rest potential?
4. In experiment isolated nervous cell was placed in solution without sodium. How it will influence on excitation development?
5. In excitable cell processes of energy production were fully blocked. What changes will be with a membrane rest potential as result of it?
6. As result of ion canals of excitable cell outer membrane activation it rest potential greatly increased. What canals were activated?
7. In time of artificial circulation for cardiac arrest in surgical practice this use solution of potassium chloride. What from listed invokes cardiac arrest?
8. As a result of inhibition sodium-potassium ATPase work of a sodium-potassium pump is blocked. How it will be reflected in size of rest potential?
9. With the help of microelectrode technical equipment it measured membrane potential of a motoneuron of a spinal cord. Thus the depolarization of a neuron after influence pharmaceutical preparation is found. To what it can be connected?
10. With the help of microelectrode technical equipment it measured membrane potential of a motoneuron of a spinal cord. Thus the hyperpolarization of a neuron after influence pharmaceutical preparation is found. To what it can be connected?
11. Isolated nervous cell was placed in Ringer solution. What ions will to play a head part in membrane rest potential generation?
12. As result of ion canals of excitable cell outer membrane activation it rest potential greatly increased. What canals were activated?

13. Gigantic axon of squid is placed in medium which similar to intracellular liquid on by composition. In time of irritation action potentials was originated in axon. Then Na^+ concentration in medium was changed up to equivalence with intra-axonal concentration and repeat irritation. What will be observed in this case?
14. In experiment in gigantic axon of squid under the action of batrahotoxin this is registered increase of Na^+ ions permeability. What will be changing of rest potential and action potential amplitude?
15. Patient long time took digitalis glycoside which blocked Na^+-K^+-pumps in cardiomyocytes. What result it has in heart muscle?

C. Test tasks

1) Membrane potential of rest …

a) $\varphi_M = \varphi_e - \varphi_i$;

b) $\varphi_M = \varphi_i - \varphi_e$;

c) $\varphi_M = \varphi_e + \varphi_i$.

2) The potential of rest is determined by...

a) Only different ion concentration on the different sides of a membrane;
b) Only a diffusion of ions through a membrane;
c) A different ion concentration on the different sides of a membrane and a diffusion of ions through a membrane;
d) A diffusion of the neutral particles through a membrane;
e) Only the active transport of ions.

3) In rest the potential of a nervous cell comes nearer to equilibrium:

a) Ca^{++} potential;
b) To the potential sodium;
c) Chloric potential;
d) Potassium potential;
e) To potential of protons.

4) The potential which originates on a membrane, which is permeable for small ions of different signs (Na^+, K^+, Cl^-, etc.) and impermeable for major charged molecules (for example, proteins, nucleic acids and other major organic ions), located inside cellular space is termed …

a) Potential of rest;
b) Diffuse potential;
c) Stationary potential;
d) Donnan potential;
e) Action potential.

5) The potential difference which originates at the cell excitation and caused for change of an ions permeability ***of a membrane is termed as...***

a) Rest potential;
b) Sodium potential;
c) Chloric potential;
d) Potassium potential;
e) Action potential.

6) During generation of action potential the potential of a nervous cell comes nearer to equilibrium:

a) of calcium potential;
b) of sodium potential;
c) of chloric potential;
d) of potassium potential;
e) to potential of protons.

7) Endocellular medium is charged in comparison with extracellular:

a) In rest – negative, on a maximum of action potential – positive;
b) In rest – positive, on a maximum of action potential – negatively;
c) Always positive;
d) Always negative.

8) A permeability of a membrane for potassium ions in rest is:

a) greatly more than permeability for sodium ions;
b) less than permeability for sodium ions;
c) approximately equal to permeability for sodium ions.

9) During generation of action potential a permeability of a membrane for potassium ions is:

a) more then permeability for sodium ions;
b) Smaller permeability for sodium ions;
c) approximately equal to permeability for sodium ions.

10) The magnification of a transmembrane potential difference is termed..., diminution –....

a) A depolarization; a hyperpolarization;
b) A hyperpolarization; a depolarization;
c) Repolarization; a depolarization;
d) A depolarization; repolarization;
e) refractory period; repolarization.

11) Velocity of spreading of nervous impulse is proportional (D - diameter of a fibril) to:

a) $\sqrt{D}$ For unmyelinated and myelinated nerve fibers;
b) D for unmyelinated and myelinated nerve fibers;
c) $\sqrt{D}$ For unmyelinated and D for myelinated nerve fibers;
d) D for unmyelinated and $\sqrt{D}$ for myelinated nerve fibers;
e) D^2 for unmyelinated and myelinated nerve fibers.

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