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Communication

MECHANISMS OF THE MEMBRANE POTENTIAL CHANGES UNDER THE INFLUENCE OF EXTERNAL ELECTROSTATIC FIELD

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Abstract

Present-day theoretical developments, which describe processes in biological membranes, are based upon studies of these processes in the absence of external fields superimposition. Within processes relevant to functioning of different biological systems, particularly of biological membranes, certain electrostatic interactions, which generate electrostatic fields rather strong at times, are of crucial importance. The influence of external electric fields can modify processes based on the electrostatic interactions within the membrane. Extensive literature data on the influence of external high strength electrostatic fields, on the functional and structural state of natural and artificial membranes is available.

The purpose of the given work is a basic research on physicochemical processes occurring in biological membrane under the influence of external electrostatic fields. General equations describe membrane potential referring to those without the external electric field influence. We have considered changes of Nernst - Plank equation of the membrane potential under the influence of external electrostatic fields.

When the external electric field is applied, the ion concentration is changing, which leads to creation of a new additional internal field. If the external field is contradirectional to electric field, which initially existed in a membrane due to initial ionic concentrations gradient, then the field induced by redistribution of ions, reduces the internal field. If the external field is having the same direction as the electric field, which initially existed due to the initial ionic concentrations gradient, then the field induced by redistribution ions, intensifies the internal field.

We have determined the value of dipole moment of the molecule, which will allow defining the orientation of polarization. In our research, a dependence between the ion concentration and the dielectric permittivity was found. This dependence enables us to calculate the change of concentrations and, hence, the additional contribution to the internal electric field strength.

Based on the above-mentioned, it is possible to conclude: at the external field of approximately $10^2 \div 10^4$ V/m the change of membrane potential values will vary in the range from 0.07 to 10.7 mV, and there occurs the main contribution to changes of the membrane potential at the external field influence, because of ions redistribution between the internal and external phases of the membrane. The membrane potential would decrease, if the external field is directed from internal phase into the external phase, and membrane potential would increase, if the external field is directed from external phase into the internal one

Keywords: influence, external electrostatic field, concentration changes, biological membranes

INTRODUCTION

Current theoretical developments, which describe processes in biological membranes, are based upon studies of these processes in the absence of superimposition of external fields. Within processes relevant to functioning of different biological systems, particularly of biological membranes, certain electrostatic interactions, which generate electrostatic fields rather strong at times, are of crucial importance. The influence of external electric fields can modify pro-

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cesses based on the electrostatic interactions within the membrane. Extensive literature data on the influence of external high strength electrostatic fields, on the functional and structural state of natural and artificial membranes is available [*Cange S., 1993; Chalyi A., Samko S., 2002; Sens P., Isambert H., 2002; Staike-Peterkovic T. et al., 2005; Vasilkoski Z., 2006*].

The purpose of the given work is basic research on physicochemical processes occurring in biological membranes under the influence of external electrostatic fields.

General equations describe membrane potential referring to those without the external electric field influence. We are to consider processes appearing in membrane under the influence of external electrostatic fields.

According to the Nernst – Plank equation, the membrane potential is defined by the unequal distribution of ions inside and outside of a cell; there is a potential difference on the membrane due to the concentration gradient [*Rubin A., 1987*]:

Under the influence of external electromagnetic field, the electrochemical potential shall have the

$$\varphi_m = \varphi_e - \varphi_i = \frac{RT}{Fz}\ln\frac{c_i}{c_e} \qquad (1)$$

following form (2) [*Landau L., Lifshitz E., 1982; Samko S., Chalyi A., 2003*]:

$$\mu = \mu_0^* - \frac{\varepsilon_0}{2}\frac{\partial\varepsilon}{\partial c}E^2 - \frac{\overline{\mu_0}}{2}\frac{\partial\overline{\mu}}{\partial c}H^2 \qquad (2)$$

where $\mu_0^* = \mu_0 + RT\ln c + zF\varphi$ is the electrochemical potential without electromagnetic field influence; $\frac{\varepsilon_0}{2}\frac{\partial\varepsilon}{\partial c}E^2$ describes the electric field influence on phase with the dielectric permittivity *ε*, (*E* is the strength of the external electrostatic field, ε_0 is the electrostatic constant), and $\varepsilon' = \frac{\partial\varepsilon}{\partial c}$; $\frac{\overline{\mu_0}}{2}\frac{\partial\overline{\mu}}{\partial c}H^2$ describes the magnetic field influence on phase with magnetic permittivity $\overline{\mu}$, *H* is the strength of the external magnetic field, $\overline{\mu_0}$ is the magnetic constant, and $\overline{\mu}' = \frac{\partial\overline{\mu}}{\partial c}$; $\overline{\mu_0}$ is the chemical potential of the pure solvent (we assumed that μ_0 value is identical on both sides of the membrane).

According to (2), we can present the generalized formula for the electrochemical potential in the electromagnetic field:

$$\mu^{E,H} = \mu_0 + RT\ln c + zF\phi - \frac{\varepsilon_0}{2}\frac{\partial\varepsilon}{\partial c}E^2 - \frac{\overline{\mu_0}}{2}\frac{\partial\overline{\mu}}{\partial c}H^2 =$$
$$= \mu_0 + RT\ln c + zF\phi - \frac{1}{2}\left(\varepsilon_0\varepsilon' E^2 + \overline{\mu_0}\,\overline{\mu}'H^2\right) \qquad (3)$$

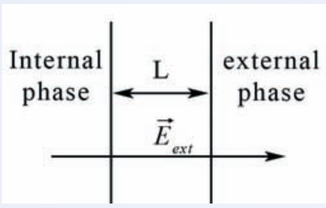
We consider a condition for the ionic balance in the presence of external electrostatic field (i.e. equality of electrochemical potentials μ_e^E outside and inside μ_i^E the cell) $\mu_e^E = \mu_i^E$.

Under the influence of external electrostatic field the Nernst equation will be as follows:

$$\varphi_m^E = \frac{RT}{Fz}\ln\frac{c_i}{c_e} + \frac{\varepsilon_0}{2}\frac{E^2}{Fz}\left(\varepsilon_e' - \varepsilon_i'\right) \qquad (4)$$

From the equation (4) it it is obvious that under the influence of external electrostatic field, the membrane potential is defined not only by the concentration gradient on both sides of membrane, but by the difference of derivatives of the dielectric permittivity with respect to concentration as well $\left(\frac{\partial\varepsilon_e}{\partial c} - \frac{\partial\varepsilon_i}{\partial c} = \varepsilon_e' - \varepsilon_i'\right)$.Let us consider some section of the membrane that has geometry of a plane-parallel layer with the thickness *L*.

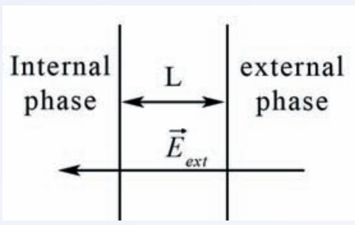
1. Supposing, the $\vec{E}_{ext}$ is the strength vector of the external electrostatic field, and the field is directed from internal phase to the external one, and the change of concentrations on both sides of the membrane remains constant Δ*c* (it is assumed that positive ions move from internal phase to the external one ⇒Δ*c*>0).



Then $c_{int}^E = c_{int}^0 - \Delta c$

$c_{ext}^E = c_{ext}^0 + \Delta c$

2. If $\vec{E}_{ext}$, the strength vector of the external electrostatic field, is directed from external phase to the internal phase, the change of concentrations on both sides of the membrane remains constant Δ*c*.



Then $c_{int}^E = c_{int}^0 + \Delta c$

$c_{ext}^E = c_{ext}^0 - \Delta c$

It is known that the membrane potential is identified as the difference of potentials between internal (the cytoplasmic) and the external phase membrane without an influence of the external field $\Delta\varphi_m^0 = \varphi_{in}^0 - \varphi_{ext}^0$.

To simplify the denotation let us take $\Delta\varphi_m^0 \equiv \varphi_m^0$.

Under the influence of external electrostatic field, the membrane potential will be as follows:

$$\varphi_m^E = \varphi_m^0 + \Delta\varphi_m^{conc} + \Delta\varphi_m^E \qquad (5)$$

$\varphi_m^0 = \frac{RT}{Fz}\ln\frac{c^0{}_i}{c^0{}_e}$ is the membrane potential without an action of the external field.

$$\Delta\varphi_m^{conc} = \frac{RT}{Fz}\ln\frac{1\mp\frac{\Delta c}{c_{int}^0}}{1\pm\frac{\Delta c}{c_{ext}^0}} \qquad (5.1)$$

(5.1) is the additional contribution to the membrane potential caused by distribution of ion concentrations under the influence of external electrostatic field.

$$\Delta\varphi_m^E = \frac{\varepsilon_0}{2}\frac{E^2}{Fz}\left(\varepsilon_e' - \varepsilon_i'\right) \qquad (5.2)$$

(5.2) is the membrane potential difference due to the presence of the external electrostatic field.

Finally we get the following result:

$$\Delta\varphi_m^E = \frac{RT}{Fz}\ln\frac{c^0{}_i}{c^0{}_e} + \frac{RT}{Fz}\ln\frac{1\mp\frac{\Delta c}{c_{int}^0}}{1\pm\frac{\Delta c}{c_{ext}^0}} + \frac{\varepsilon_0}{2}\frac{E^2}{Fz}\left(\varepsilon_e' - \varepsilon_i'\right) \qquad (5.3)$$

(5.3) is the total membrane potential under the influence of the external electrostatic field.

The total strength of the electrostatic field can be presented as a total vector sum of the strength of external electrostatic field $\vec{E}_{ext}$ and the strength of internal electric field $\vec{E}_{int}$.

$$\vec{E}_{sum} = \vec{E}_{int} + \vec{E}_{ext} = \vec{E}_{int}^0 + \vec{E}_{int}^{conc} + \vec{E}_{ext} \qquad (6)$$

The internal electric field can be presented as a sum of two fields:

$$\vec{E}_{int} = \vec{E}_{int}^0 + \vec{E}_{int}^{conc} \qquad (6.1)$$

where E_{int}^0 is the electric field, which was prior to the external field influence as a result of initial gradient of ion concentrations c_{int}^0 and c_{ext}^0; E_{int}^{conc} is an additional contribution into the internal electric field strength caused by change in the ionic concentrations.

When the external electric fieldis $\vec{E}_{ext}$ applied, the ion concentration is changed leading to generation of a new additional internal field E_{int}^{conc}. The prior internal electric field $\vec{E}_{int}^0$ permanently presents before the external field superimposition. The internal phase limited by the membrane is charged negatively, in relation to the surrounding environment, and hence the strength vector $\vec{E}_{int}^0$ is directed inwards. Such a situation is valid for the biological membranes, where $E_{int}^0 \sim 10^6 \div 10^7$ *V/m*.

Let us calculate magnitude of the internal electric field strength vector of $\vec{E}_{int}^0$ for calmar's giant axon. The Nernst concentration (φ_m^0) potential for K^+ at the temperature T=273K is 72.67 *mV* and for $L=10^{-8}$ *m* the internal electric field (E_{int}^0) strength is $7.3 \cdot 10^6$ *V/m* (according to (1),(7)).

Let us observe the flux of charged particles (ions).

It is known that the internal electric field strength in membrane, in the absence of the external field is equal to mean gradient of the potential [*Rubin A., 1987*]:

$$E_{int}^0 = -\frac{d\varphi_0}{dx} \approx \frac{\varphi_{in}^0 - \varphi_{ext}^0}{L} \approx \frac{\varphi_m^0}{L} \qquad (7)$$

A general equation representing the flux of ions obeys to Nernst – Plank equation for electrodiffusion (8)

$$J = -D\frac{dc}{dx} - cb\frac{d\varphi}{dx}zF \qquad (8)$$

$F = eN_A$ is Faraday constant (*F*=96500 *C/mol*), *R* is the gas constant (R=8.31 *J/mol·K*), *T* is the absolute temperature, *b* is ion mobility, *D* is diffusion coefficient. The relationship between the ion mobility b and diffusion coefficientis *D* given by Einstein formula $b = \frac{D}{RT}$; $E_{int}^0 = -\frac{d\varphi_0}{dx}$ [*Vladimirov Yu. et al., 1983*].

Generally, the flux of ions before influence of the external electrostatic field can be defined by few factors:

• An unequal distribution of ions, (i.e., gradient concentration)

$$J = -D\frac{dc}{dx} \approx -D\frac{c_{out}^m - c_{in}^m}{dx} \approx \frac{Dk}{L}\left(c_{in} - c_{out}\right) \qquad (9)$$

It is clear that the passage of ions is possible only at the presence of the internal electric field gradient potential

• External field induces change of the ion concen-

$$J = -D\frac{dc}{dx} - cbFz\frac{d\varphi}{dx} = -D\left(\frac{dc}{dx} + \frac{eczN_A}{RT}\frac{d\varphi}{dx}\right) = \cdot$$

$$= -D\left(\frac{dc}{dx} + \frac{ecz}{\kappa T}\frac{d\varphi}{dx}\right) \qquad \textbf{(10)}$$

tration compared to their initial values (the external field induces an additional contribution to the ion concentration) $\frac{dc}{dx} = \frac{dc_0^m}{dx} + \frac{dc_E}{dx}$

• The external field changes the membrane potential and causes additional contribution to the membrane potential due to the action of external electrostatic field $\frac{d\varphi}{dx} = \frac{d\varphi_0^m}{dx} + \frac{d\varphi_E}{dx}$;

The total ions flux under the influence of the external electrostatic field is

$$J_{sum} = J_0 + J_E = -D\left(\frac{dc_0^m}{dx} + \frac{ecz}{\kappa T}\frac{d\varphi_0}{dx}\right) - D\left(\frac{dc_E}{dx} + \frac{ecz}{\kappa T}\frac{d\varphi_E}{dx}\right) =$$
$$= -D\left(\frac{dc_0^m}{dx} - \frac{ecz}{\kappa T}E_{\text{int}}^0\right) - D\left(\frac{dc_E}{dx} - \frac{ecz}{\kappa T}\left(E_{\text{int}}^{conc} + E_{ext}\right)\right) \qquad \textbf{(11)}$$

$J_0 = -D\left(\frac{dc_0^m}{dx} + \frac{ecz}{\kappa T}\frac{d\varphi_0}{dx}\right)$ is flux of ions before the influence of the external electrostatic field

$J_E = -D\left(\frac{dc_E}{dx} + \frac{ecz}{\kappa T}\frac{d\varphi_E}{dx}\right)$ is flux of ions caused by influence of the external field.

In order to find the change of concentrations on both sides of membrane it is possible to use the condition of ionic balance, i.e. the total flux through membrane is zero. Before the influence of external field the system was in the ionic balance condition, and consequently $J_0=0$; and if $J_{sum}=J_0+J_\varepsilon$, so $\Rightarrow J_E=0$

The final view is:

$D\left(\frac{dc_0^m}{dx} - \frac{ecz}{\kappa T}E_{\text{int}}^0\right) = 0$ or $J_E = -D\left(\frac{dc_E}{dx} + \frac{ecz}{\kappa T}\frac{d\phi_E}{dx}\right)$

$$\Rightarrow \quad \frac{dc_E}{dx} = \frac{ecz}{\kappa T}\left(E_{\text{int}}^{conc} + E_{ext}\right)$$

$$\int_{c_{\text{int}}^0 - c_{ext}^0 - \Delta c}^{c_{\text{int}}^0 - c_{ext}^0 + \Delta c} \frac{dc_E}{c} = \frac{ez}{\kappa T}\left(E_{\text{int}}^{conc} + E_{ext}\right)\int_0^L dx \qquad \textbf{(12)}$$

$c_{\text{int}}^0 - c_{ext}^0 - \Delta c$; $c_{\text{int}}^0 - c_{ext}^0 + \Delta c$ are the limits of integration that were chosen in correspondence with the external field $\vec{E}_{ext}$ directed from internal phase to the external one.

Generally, if the external field $\vec{E}_{ext}$ have an opposite direction, that changes the limits of integration without affecting the absolute value of. Δc.

As a reesult of integration (12), we get

$$\Delta c = \left(c_{\text{int}}^0 - c_{ext}^0\right)\frac{\exp\left\{\frac{e}{\kappa T}\left(E_{\text{int}}^{conc} + E_{ext}\right)L\right\} - 1}{\exp\left\{\frac{e}{\kappa T}\left(E_{\text{int}}^{conc} + E_{ext}\right)L\right\} + 1} \qquad \textbf{(13)}$$

The given formula enables calculation of changes in concentrations Δc, if E_{ext}, the value of the external field strength and E_{int}^{conc}, the additional contribution to the internal electric field strength, are known.

For calculation of Δc we can apply the method of approximation. That means, at first the $\Delta c^{(0)}$ is to be found in zero approximation by setting E_{int}^{conc}=0 in expression (13), so E_{int}^{conc}, the additional contribution to the internal electric field strength, is absent [*Samko S., Chalyi A., 2001*].

1) $\Delta c^{(0)}$ - Δc in zero approximation, when E_{int}^{conc}=0

$$\Delta c^{(0)} = \left(c_{\text{int}}^0 - c_{ext}^0\right)\frac{\exp\left\{\frac{eE_{ext}}{\kappa T}L\right\} - 1}{\exp\left\{\frac{eE_{ext}}{\kappa T}L\right\} + 1} \qquad \textbf{(14)}$$

2) Now using the value $\Delta c^{(0)}$ and the expression (5.3) for $\Delta\phi_m^{conc}$ it is possible to calculate E_{int}^{conc}, an internal field caused by redistribution of ions, by equation of Nernst–Plank at various E_{ext} values of the applied external field;

$$E_{\text{int}}^{conc} = -\frac{d\varphi_m^{conc}}{dx} \approx \frac{\varphi_{in}^{conc} - \varphi_{ext}^{conc}}{L} \approx \frac{1}{L}\frac{RT}{F}\ln\frac{1 \mp \frac{\Delta c^{(0)}}{c_{\text{int}}^0}}{1 \pm \frac{\Delta c^{(0)}}{c_{ext}^0}}$$

When the external electric field is applied, the ion concentrations are changing, which leads to generation of a new additional internal field. Here are two possible cases:

• $\vec{E}_{\text{int}}^{conc} \uparrow\downarrow \vec{E}_{ext}$ if the external field $\vec{E}_{ext}$ is contradirectional to electric field $\vec{E}_{\text{int}}^0$, which was initially present in the membrane due to initial ionic concentrations gradient c_{int}^0 and c_{ext}^0, then the field induced by redistribution of ions, reduces the internal field (the upper sign in equations (15) and (5.3));

$$\vec{E}_{\text{int}}^{conc} \uparrow\downarrow \vec{E}_{ext} \Rightarrow \vec{E}_{\text{int}}^{conc} \uparrow\downarrow \vec{E}_{ext}\ ;\ E_{\text{int}}^{conc} < 0 \text{ i.e. } E_{\text{int}} = E_{\text{int}}^0 - E_{\text{int}}^{conc}$$

$\vec{E}_{\text{int}}^0 \uparrow\uparrow \vec{E}_{ext}$ if the external field $\vec{E}_{ext}$ is having the same direction as the electric field $\vec{E}_{\text{int}}^0$, which was initially present in a membrane due to the initial ionic concentrations gradientand c_{int}^{0} and c_{ext}^{0}, then the field induced by redistribution of ions, intensifies the internal field (the lower sign in equations (15) and (5.3)).

$\vec{E}_{\text{int}}^{conc} \uparrow\uparrow \vec{E}_{\text{int}}^{0} \Rightarrow \vec{E}_{\text{int}}^{conc} \uparrow\downarrow \vec{E}_{ext}$; $E_{\text{int}}^{conc}>0$ i.e. $E_{\text{int}} = E_{\text{int}}^{0} + E_{\text{int}}^{conc}$

Taking E_{int}^{conc} into account, we can consider $\Delta c^{(1)}$, the change of ion concentration in the first approximation as

$$\Delta c^{(1)} = \left(c_{\text{int}}^{0} - c_{ext}^{0}\right) \frac{\exp\left\{\frac{e}{\kappa T}\left(E_{\text{int}}^{conc} + E_{ext}\right)L\right\} - 1}{\exp\left\{\frac{e}{\kappa T}\left(E_{\text{int}}^{conc} + E_{ext}\right)L\right\} + 1} \qquad \textbf{(16)}$$

where $E_{\text{int}}^{conc} = -\frac{d\varphi_m^{conc}}{dx} \approx \frac{\varphi_{in}^{conc} - \varphi_{ext}^{conc}}{L} \approx \frac{1}{L}\frac{RT}{F}\ln\frac{1 \mp \frac{\Delta c^0}{c_{\text{int}}^0}}{1 \pm \frac{\Delta c^0}{c_{ext}^0}}$

where $\Delta c^{(0)} = \left(c_{\text{int}}^{0} - c_{ext}^{0}\right) \frac{\exp\left\{\frac{eE_{ext}}{\kappa T}L\right\} - 1}{\exp\left\{\frac{eE_{ext}}{\kappa T}L\right\} + 1}$

It should be noted that in case of the upper sign in (15), $\Delta c^{(1)}$ will be negative, $\Delta c^{(1)}<0$.

This is connected to the fact that a change of concentrations Δc of on both sides of the membrane is accompanied by a decrease of the initial concentrations gradient.

In contrast to the first case, if the lower sign in (15), $\Delta c^{(1)}$ will be positive, $\Delta c^{(1)}>0$.

This is connected with the fact that a change of the concentrations Δc on both sides of the membrane is accompanied by an increase of the initial concentrations gradient.

Let us consider a component, which characterizes change of dielectric permittivity caused by the external electrostatic field. According to (5.2) and taking into account that $\varepsilon_e' = \frac{\partial \varepsilon_e}{\partial c}$ and $\varepsilon_i' = \frac{\partial \varepsilon_i}{\partial c}$ it is possible to obtain $\frac{\partial \varepsilon_e}{\partial c} - \frac{\partial \varepsilon_i}{\partial c} = \varepsilon_e' - \varepsilon_i'$ as the difference of derivatives of dielectric permittivity with respect to concentration calculated based upon the formula of Lorentz–Lorentz. [*Samko S., Chalyi A., 2003*]. The formula of Lorentz–Lorentz links the index of refraction ***n*** of substances to the electronic polarizability α_{el} of constituent particles.

In the polar dielectrics, where the orientation polarization is predominating, conditioned by rotation "on field" of constant dipole moments of the particles, the Langevin–Debye formula is used. Langevin–Debye formula links the dielectric permittivity ε of polar dielectrics with the dipole moments of $p = |q|\,l$ the particles (17).

The formula of Langevin–Debye (17) is valid for the polarization of the dielectric material or the paramagnetic susceptibility of a magnetic material, in which these quantities constitute the sum of a temperature-independent contribution. The contribution arising from the partial orientation of the permanent electric or magnetic dipole moments, which vary inversely with the temperature. It is also known as Langevin–Debye law.

$$\frac{\varepsilon - 1}{\varepsilon + 2}\frac{M}{\rho} = \frac{4\pi N_A}{3}\alpha_0 + \frac{4\pi N_A}{9kT}p^2 \qquad \textbf{(17)}$$

where $\frac{4\pi N_A}{3}\alpha_0$ is the component that considers the deformative polarization, $\frac{4\pi N_A}{9kT}p^2$ is the component that considers the orientation polarization, which is caused by the external field. E_{ext} leads to the additional orientation of the dipole molecules along the field, and this process of orientation is disturbed by the heat motion of the particles (~ T^{-1}). Let us determine the value of dipole moment (***p***) of the molecule, which will allow defining the orientation polarization; here we do not consider the component, describing deformative polarization, because $\frac{4\pi N_A}{3}\alpha_0 << \frac{4\pi N_A}{9kT}p^2$, and instead of formula (17) we shall obtain

$$\frac{\varepsilon - 1}{\varepsilon + 2}\frac{M}{\rho} \approx \frac{4\pi N_A}{9kT}p^2$$

Now using the (17.1) it is possible to find the correspondence between the ion concentration ***c*** and the dielectric permittivity ***ε***, and hence to find $\varepsilon' = \frac{\partial \varepsilon}{\partial c}$.

$\frac{\varepsilon - 1}{\varepsilon + 2}\frac{1}{A} \approx \frac{4\pi}{9kT}p^2$, where $\frac{M}{\rho N_A} = \frac{1}{c}$;

$$\varepsilon_A' = \frac{\partial \varepsilon}{\partial c} = \frac{\frac{4\pi}{3kT}p^2}{\left(1 - \frac{4\pi}{9kT}p^2 A\right)^2} = \frac{4\pi p^2}{3kT\left(1 - \frac{4\pi}{9kT}p^2 A\right)^2} \qquad \textbf{(18)}$$

will be obtained.

Now we evaluate change of the membrane potential $\Delta\varphi_m^E$. The intensity of the electric field, under which the membrane breaks will be approximately $3 \cdot 10^7$ *V/m*. In accordance with this fact, we will consider the external fields approximately $E_{ext} = 1 \cdot 10^2 \div 2 \cdot 10^7$ *V/m*. If the field inside a membrane before the influence of external field will be approximately $10^6 \div 10^7$ V/m, it is possible to expect that additional contribution into the change of membrane potential $\Delta\varphi_m^E$ will have nearly the same order, as the external field. It is necessary to notice that dissolved ions react on external field much weaker, since there appears the redistribution of ion concentration that explains the great difference in values between $\Delta\varphi_m^{conc}$ and $\Delta\varphi_m^E$.

For the given interval of intensities the factor $\frac{\varepsilon_0}{2}\frac{E^2}{Fz}$ will be approximately $4.6 \cdot 10^{-16} \div 1.84 \cdot 10^{-5}$ *V mol /L* multiplied by difference of derivatives of dielectric permittivity with respect to concentrations for the giant axon of calmar $\varepsilon_e' - \varepsilon_i'$=$3 \cdot 10^2$l/mol, and hence, the change of the membrane potential $\Delta\varphi_m^E$ will be of the following values $1.4 \cdot 10^{-13} \div 5.52 \cdot 10^{-3}$ *V*; ($\Delta\varphi_m^E$ by the experimental measurements) [*Samko S., Chalyi A., 2003*].

If the external field E_{ext} is approximately $10^6 \div 10^7$ *V/m*, same values shall be obtained by calculation with the help of the formulas (5.2) and (18). On the basis of theoretical evaluation of by means of the formulas (5.2) and (19), it will be identical to that of experimental measurements [*Samko S., Chalyi A., 2003*].

For weak external fields of approximately E_{ext}=$1 \cdot 10^2 \div 1 \cdot 10^7$ *V/m* the values $\Delta\varphi_m^E$ will be 6-8 orders less than the values we get from calculation $\Delta\varphi_m^E$ (5.2).

Based on the above-mentioned, it is possible to conclude the following:

1. At the external field of approximately $10^2 \div 10^4$ V/m changes of the membrane potential values will vary in the range from 0.07 to 10.7 mV;
2. Main contribution to changes of the membrane potential at the external field influence occurs due to redistribution of ions between the internal and external phases of the membrane.
3. Membrane potential would decrease, if the external field is directed from internal phase into the external phase and membrane potential would increase, if the external field is directed from external phase into the internal.

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