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Theoretical Model for Calculation Electrophysical Properties of Erythrocytes and Its Application in Biomechanics

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Abstract- **The theoretical model is proposed for calculating the electrophysical properties of erythrocytes and its application in biomechanics. The research is based on the fact that existing theoretical models of electrophoresis of blood elements do not reflect often the real properties of cells in pathological conditions. Of the numerous biophysical and biomechanical studies of blood cells, it follows that in the course of aging, the permeability of the cell membrane changes and the differentiation of cell structures is disturbed. Analogous arguments arise when studying the evolution of ion-exchange properties of blood cells in the pathology of the organism. Hence it follows the usefulness of the electrophoretic technique for studying cells under these conditions and the value of the proposed model for the interpretation of these experiments.**

Keywords- electrophoretic mobility; erythrocyte electrokinetic potential; dielectric permeability.

I. Introduction

Electrophoresis as a biophysical and biomechanical method for determination the value of the surface charge of cells has become widespread in medicine as a relatively simple experimental method for studying the most important properties of blood cells [1]. Taking into account the value of the cell charge proves essential in determining the thrombore resistance of newly synthesized materials, which are supposed to be used in bioengineering devices, hemosorption and ultrafiltration of blood. Although the used devices that can have various modifications, the electrophoretic measurement technique has not principally changed since its first development. As for the theoretical interpretations of the data of such experiments, they are ambiguous and depend on the choice of one or another model of the electrophoretic behavior of the particles under study.

Most researchers start from the assumptions and formulations of the problem, similar to the one considered firstly by M. Smolukhovsky for the derivation of electrophoretic mobility and non-conducting colloidal particles of suspensions or emulsions, according to which $U = \frac{\varepsilon\varsigma}{4\pi\eta}$, where ε is the permittivity of the dispersion medium, η is its viscosity, ς is the electrokinetic potential. According to the theory developed by M. Smoluchowski, the particle was considered to be a dielectric, and the double layer was assumed to be flat. The latter made it difficult to interpret experiments for particles with real thicknesses of the double layer, the finite size of the self-particle. The results were subsequently generalized to the case of particles of spherical shape and used to experimentally study the properties of blood cells, in particular erythrocytes [3]. However, as demonstrated by our analysis, the determination of the electro-surface properties of erythrocytes by electrophoresis cannot be considered developed and completed even for the blood of healthy donors, since different formulas for calculating the electrokinetic potential of erythrocytes give different values.

The role of electrical charge of cells in maintaining the blood structure and functioning of the microcirculation system is widely discussed in literature [1-7]. The theory of the stability of such processes in the overwhelming majority of papers is based on the work of Deryagin-Landau-Verwey-Overbeck (DLLO theory). Nevertheless, within the framework of such an analysis, the discrepancy with the results of experimental studies of aggregation of blood cells reaches large discrepancies, which may be due to incorrect interpretation of the results of electrophoretic measurements. In accordance with the electrophoresis technique, the EFT is directly determined, and the recalculation for any surface electrophysical characteristic of the particle is carried out with the help of some form provided by theoretical models. Consequently, the problem arises of justifying the assumptions adopted in the classical and frequently used theory of electrophoresis M. Smolukhovsky in terms of its applicability to erythrocytes.

II. Results and Discussions

It is known that Henry's formula is used for quantitative interpretation of measurements during electrophoresis of conducting colloidal particles, from which the formula of M. Smolukhovsky follows as a particular case in limiting conditions. However, it does not take into account the polarization of the double layer and corresponds only to those experimental conditions for which the surface conductivity of the double layer is sufficiently small and the potential distribution is determined by the ratio of the volume conductivities of the particle and the medium. Henry's formula is not suitable for describing the EFT of particles that have an exchange of predominantly one ion of ions with a dispersive medium, which are erythrocytes.

The study of ion-exchange properties of erythrocytes has shown that they contain anions to which the cell membrane is impenetrable. Therefore, to preserve the water-osmotic balance in the blood plasma, non-permeable cations should be present, which is provided by the active cation transport system, for example, potassium-sodium pump [4, 5]. The cell exchange pumps sodium and potassium against the gradients of their electrochemical potentials, sodium to the outside, potassium to the inside of the cell, which is equivalent to the membrane impermeability to the outer cation. As for the penetrating ions, they are distributed according to the Donnan equilibrium [6]. Consequently, the erythrocyte model can be considered as an ion-exchange model, but as a suspension of erythrocytes as a model of a dispersed fraction of ion-exchange particles.

We will assume that the difference in the co-activity coefficients of the solvent ions in the volume of the particle and the electrolyte is small. Then the equilibrium double layer of particles is formed due to differences in the properties of the volume of particles and electrolyte, mainly due to unequal ion concentrations. In this case, the diffusion fluxes of ions arise, which in the steady state lead to the formation of a double layer around each particle. The effect of the membrane on the formation of a double layer will affect the diffusion processes and the values of the potential of the surface of the particle, which can differ greatly from Donnan's in the case of a sufficiently large membrane thickness. Accounting for the latter can be very important when considering nonstationary processes, i.e. when the diffusion time of ions through the membrane are large. Under steady-state conditions, the effect of membrane thickness determines a greater voltage drop across the membrane, which corresponds to a decrease in the Don-Nan potential. In the case where the thickness of the membrane has the size of the microunits, the particle potential completely coincides with the value of the Donnan potential [7]. The above condition restricts the applicability of the obtained formulas to biological cells with a sufficiently small membrane thickness, which is the case for erythrocytes, and corresponds to the erythrocyte model if it is regarded as a liquid drop.

Let the ions Cl- be penetrating for erythrocyte membranes. The values of the Donnan potential of particles for the concentrations known from the literature within (~ 70-80 mmol / L) and outside (~ 100-110 mmol / L) of erythrocytes is (~ 10 mV). Provided that the effective thickness of the erythrocyte membrane depends on the diffusion coefficient and the concentration of ions inside the cell, for erythrocyte the ratio for electrophoretic mobility can be written in the form $U_{er} = \frac{\varepsilon\varsigma^{eff}}{4\pi\eta}\cdot(1+d^{eff})^{-1}$, where ς^{eff} is the effective electrokinetic potential of the cell.

The latter formula determines the dependence of electrophoretic mobility not only on the changing surface properties of the erythrocyte, but also on the ratio of ion mobilities (diffusion coefficients) inside and outside for each cell. The practical study shows systematically higher values of the zeta potential at any values of the ratios of the mobilities of ions inside and outside the cell in the ionitic model of the erythrocyte, in comparison with the calculations proposed in M. Smolukhovsky's theory.

III. Conclusions

Existing theoretical models of electrophoresis of blood elements often do not reflect the real properties of cells in pathological conditions. Of the numerous biophysical and biomechanical studies of blood cells, it follows that in the course of aging, the permeability of the cell membrane changes and the differentiation of cell structures is disturbed. Analogous arguments arise when studying the evolution of ion-exchange properties of blood cells in the pathology of the organism. Hence follows the usefulness of the electrophoretic technique for studying cells under these conditions and the value of the proposed model for the interpretation of these experiments.

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