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CONDENSED MATTER & LOW TEMPERATURE PHYSICS

6 – 12 June 2021
Kharkiv, Ukraine

B. Verkin Institute for Low Temperature
Physics and Engineering of NAS of Ukraine

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Thermodynamic model to dielectric parameters of erythrocytes: effect of temperature

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Thermodynamic models play a crucial role for describe the loss of intracellular water from human erythrocytes at temperature below 5~2ºC and hydration of the erythrocyte membrane. The performed calculations which are based on the extrapolation of data obtained by UHF-dielectrometry method in the study of the dielectric properties of erythrocytes and erythrocytes membranes of healthy donors and sick patients with neurological and oncological diseases showed that temperature is an important factor controlling the interaction between the water and membrane of the cell [1,2]. The Debye's model has been generalized for a medium with a set of relaxation phenomena at different scales with different relaxation times $\left\{\tau_j\right\}_{j=1}^{N}$ in the form [3]:

$$\varepsilon^*(\omega) = \varepsilon_\infty + (\varepsilon_0 - \varepsilon_\infty)\int_0^\infty \frac{\zeta(\tau)}{1+i\omega\tau}d\tau$$

where $\zeta(t)$ is the memory function that describes the non-Markovian relaxation process. The data are analyzed together with static permittivity values. By using the single-shell model, reliable values of erythrocyte internal conductivity and permittivity have been obtained. Also, the reported values of the membrane capacitance per unit surface [4] were found to be in a good agreement with those of the solvent-free cellular membranes. Therefore, the measurement data of the ε' and ε'' values can be used for computations of the following parameters:

1) from Debye's model: the dielectric loss coefficient $\delta = a\tan(\varepsilon''/\varepsilon')$; the dielectric relaxation frequency of water $f_d = f(\varepsilon' - \varepsilon_\infty)/\varepsilon''$ in the solution/suspension, where f is the frequency of the external field; the activation energy of dipole relaxation ΔF of the water molecules in studied systems $\Delta F = RT\ln\left(\frac{RT}{hN}\tau\right)$, where τ is the time of dielectric relaxation; for different cells and tissues in healthy and impaired states. These factors include the probability of initiation of transmembrane defects at temperature below 5~2ºC, which reduce the resistance of cells to temperature effects. As the temperature decreases, the membrane conductivity becomes absorption rate-limited and, in effect, shuts off the probability of closure of defects on the membrane surface, which contributes to the decrease of cell resistance.

2) from the single-shell model: dielectric permittivity ε_m, ε_{in} of the membrane and the internal matter (cytoplasm, free and bound water) separately, provided the values σ_m, σ_{in} and the membrane thickness h are known from other measurements/experiments;

3) from the non-equilibrium thermodynamic model with single relaxation time: phenomenological and state coefficients of the model, and entropy production.

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