LETTER TO THE EDITOR

Comments on the Dipole Model and Membrane Excitation

Dear Sir:

In a recent analysis of the dipole model for negative steady-state resistance in excitable membranes, Hamel and Zimmerman (1970) employed a technique developed by Fowler (1935) to describe the configurational transitions of the polar groups, the resulting voltage changes across the polar region then being manifested in the existence of negative resistances for steady-state phenomena. As they point out, this polar group configurational transition is a function only of the membrane voltage.

We are presently doing calculations based upon the Ising (1925) model of dipoles on a lattice and the bimolecular phospholipid leaflet to explain the various thermodynamic properties of biological membranes, e.g., see Reinert and Steim (1970), as well as similar steady-state characteristics as discussed by Hamel and Zimmerman. However, also in our analysis we have taken the view that in the excitation process per se, at some critical potential, i.e. the threshold for excitation, an order-disorder transition occurs which corresponds to a configurational transition of the polar head groups, which in turn initiates a configurational transition of the hydrophobic regions. The idea here is the same as that expressed by Hamel and Zimmerman (1970) in that the electric field is analogous to temperature in relation to the order-disorder transitions.

Thus, we define an effective temperature as did Hamel and Zimmerman by

$$T_e \equiv T + \frac{pE}{k}$$

$T_e \equiv$ effective temperature

$T \equiv$ absolute temperature

$p \equiv$ electric dipole moment

$E \equiv$ electric field

$k \equiv$ Boltzmann's constant (1)

Thus, we can expect the rotational transition to occur approximately at

$$kT_e = \frac{W}{3}, \qquad (2)$$

where $W \equiv$ intrinsic energy of a single dipole in a lattice. Equation 2 corresponds to equation V 4 of Hamel and Zimmerman. Combining equations 1 and 2 yields

$$E = \frac{1}{p}\left(\frac{W}{3} - kT\right). \qquad (3)$$

Therefore, provided that reasonable values for the parameters p and W may be estimated, we can calculate the critical field E that will lead to excitation and initiate a discontinuity in the thermodynamic properties.

The magnitude of the dipole moment p is much debated with the value depending on whether one chooses to associate the dipoles with the polar ends of the phospholipids, with the constituent protein, or with various domains. Typical estimates range from 25 debyes up to 1000 debyes (Wei, 1969).

Obtaining a reasonable value for W is also difficult. However, assuming as a first approximation that W is the simple electrostatic pairwise coupling energy between the dipoles, we can proceed with an order of magnitude calculation. An obvious simplification here is that W is a constant whereas in fact it is a function of T_e, the effective temperature.

Substitution of the approximate values of $p = 100$ debyes and $W = 10^{-20}$ joules into equation 3 yields a threshold potential on the order of 120 mv. Equation 3 is of course expected to give only rough agreement with actual excitation fields considering the complexity of the system and the relative uncertainty in p and W. The primary point, however, is that equation 3 does produce a threshold potential within an order of magnitude of the experimental value and thus justified some confidence in more sophisticated and realistic treatments of transitions in membranes based on the framework of the dipole model.

Received for publication 8 December 1970.

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