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Insights into ion channel selectivity with ionic Coulomb Blockade

The flow of ions through a biological ion channel can be considered as transitions between energy levels in the channel and either of the connecting bulk reservoirs [2]. Discreteness of ions and an electrostatic exclusion principle ensure that the number of channel energy levels equals the number of occupying ions. Using these fundamental physical principles we have recently introduced [1] an ionic Coulomb blockade (ICB) theory developed by analogy with the similar phenomenon of electron tunnelling in quantum dots [2,3]. In this picture channel selectivity is governed by energy level changes [1].

In this paper we present details of the ICB theory for ion transitions through the channel. It incorporates physiological solutions and channel properties: physical dimension, voltage drop and fixed charge, and hence allows for comparison with physiological data. The set of kinetic equations obtained using ICB is analysed. The channel probability of occupancy as a function of transition rates (and hence fixed charge and number of ions) is obtained in the steady-state approximation. It is shown that this probability displays the staircase structure familiar from analysis of occupancy in quantum dots. It is also shown that current through the channel displays sharp peaks as a function of fixed charge, hence relating channel selectivity to the structure and position of energy levels.

The contribution of hydration energy is also discussed. We anticipate that inclusion of this energy into ICB theory will provide insights into the selectivity and conductivity of ion channels.

References:

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