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COULOMB BLOCKADE MODEL OF PERMEATION IN BIOLOGICAL ION CHANNELS

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Abstract:
Biological ion channels are protein-based natural nanotubes that can selectively conduct phys-iologically significant ions (e.g. K+, Na+, Ca2+) across cellular membranes. The selectivity of a channel is associated with the stochastic motion of ions within a short, narrow selectivity filter possessing a fixed negative charge Qf. The physical mechanisms underlying selectivity are still enigmatic.
We now demonstrate, however, that conduction and selectivity in the calcium/sodium channels can be described/explained [1] in terms of ionic Coulomb blockade (ICB) [2], an electrostatic phenomenon closely analogous to electronic Coulomb blockade in quantum dots. It is shown that ICB manifests itself strongly for divalent Ca2+ ions in a simplified, self-consistent, electrostatic, Brownian dynamics model of calcium channels. The ICB-based model of permeation predicts pronounced oscillations in the Ca2+ conductance JCa, and a Cou-lomb staircase for the occupancy PCa vs. Qf,, consistent with the multi-ion conduction bands seen in earlier Brownian dynamics simulations [3]. The ICB-based permeation model also explains numerous Ca2+/Na+ valence selectivity phenomena and their mutation-induced trans-formations seen in experiments on the calcium/sodium channels family.
We expect the ICB permeation model to be applicable to different kinds of ion channels, as well as to charged artificial nanopores (e.g. carbon nanotubes).
References
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