The role of long-range forces in Porin channel conduction

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The porin OmpF is a wide ion channel found in the outer membrane of *Escherichia coli*. It is a trimer with each subunit consisting of 16 β-strands folded into a barrel structure. The barrel is constricted in the middle of the pore by a long polypeptide loop (L3). Charged residues surrounding the narrow constriction region generate a strong transverse electric field that plays a central role in ionic transport through the channel [1]. The cross-section of the OmpF monomer at the constriction is shown in Fig. 1, where the L3 loop and the charged residues giving rise to the field are explicitly shown.

Brownian dynamics (BD) [2], [3] methods are attractive for modeling transport in porin because they represent an excellent compromise between computational accuracy and efficiency. Within the BD formalism, the channel is generally treated as a rigid structure and the water is treated implicitly, reducing the computational effort to ion trajectory tracking. Several BD simulations have been performed to investigate porin channels by modeling the macroscopic properties of ion conduction [4], [5], [6]. However, the approaches used to model the electrostatic interactions in OmpF systems may be oversimplified. In particular, the use of periodic boundary conditions may not be adequate to realistically include effects due to the long-range forces within the system.

In this work, a P^3M force field scheme [7] is self-consistently coupled with a BD kernel to study the role of the long-range electrostatic forces in OmpF conduction. The P^3M method is well suited for investigating electrostatic effects in these systems because it can accurately account for the inhomogeneous, nonequilibrium behavior of the charge distribution. Within the computational domain, the atomic coordinates of the OmpF trimer are embedded in a uniform dielectric membrane, while the fixed charge distribution is obtained with the Gromacs simulation package [8]. A slice of the initial potential energy profile obtained by placing an ion throughout the domain of the trimer is shown in Fig. 2 for the constriction region. Superimposed is the corresponding OmpF structure constriction. The left plot shows the contribution due to the short-range interaction (including the van der Waals interaction), while the right one shows the total potential energy computed with the P^3M. As can be seen, the inclusion of the long-range force results in a lower potential as felt by the cation along the permeation pathway. The calculation has not been corrected for the particle self-energy [9], but its inclusion will not influence the relative potential energy differences of the two plots. The impact of the P^3M electrostatic description on ionic conduction through OmpF will be discussed, both in terms of selectivity and permeation.

It should be noted that since the channel is generally treated as a rigid structure within BD simulations, the effects related to channel flexibility cannot be resolved, although they could play a critical role in the channel selectivity [10]. Methods to include channel motion within the BD formalism will be discussed.

A full journal publication of this work will be published in the Journal of Computational Electronics.

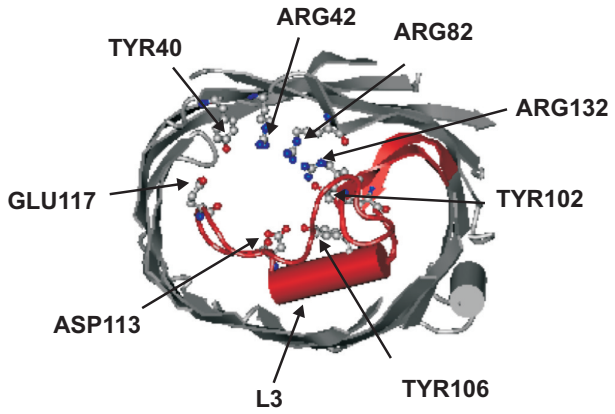

Fig. 1. The constriction zone of one monomer of the OmpF porin. The L3 loop and the charged residues giving rise to the transverse electric field are explicitly shown.

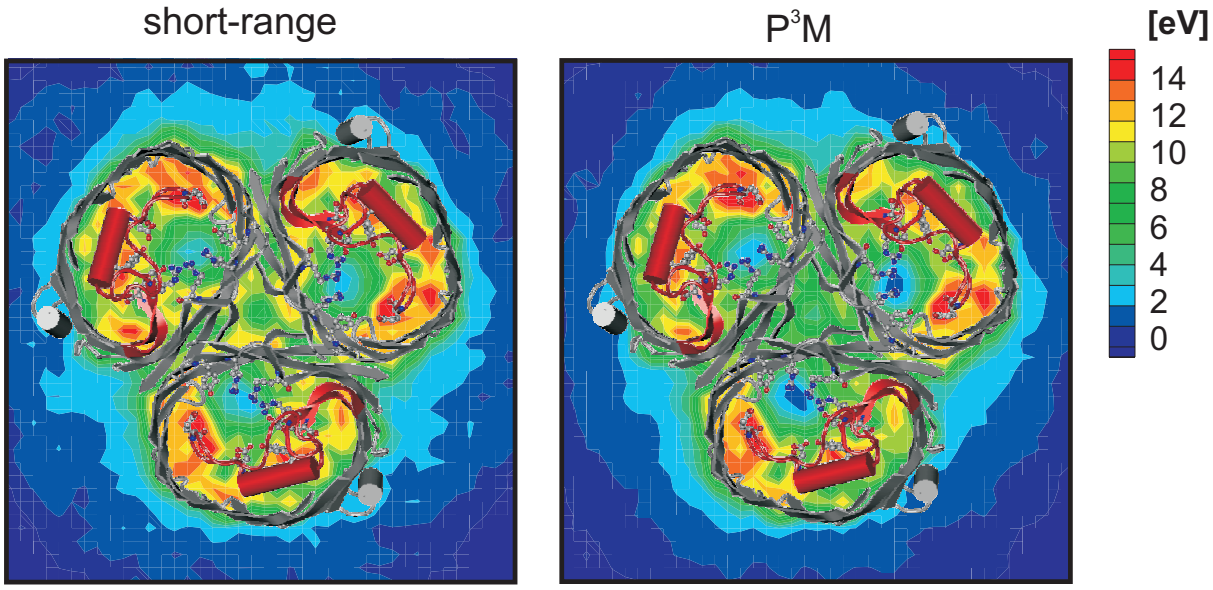

Fig. 2. Potential energy profile for a cation in OmpF. The left figure shows the contribution from the short-range interaction and the right figure shows the total energy computed with the P^3M. The structure of the OmpF in the constriction region of the pore is superimposed over the potential energy plots.

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