Ionic Coulomb blockade as a fractional Wien effect

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Ionic transport is key to numerous processes from neurotransmission to ultrafiltration. The recent advances in nanofluidics have allowed tremendous progress in the exploration of ionic and fluid transport at the ultimate scales. However, artificial porins are still far from reaching the considerable richness and subtlety of the biological ionic machinery, which exhibits advanced functionalities such as high selectivity, ionic pumping, and electrical and mechanical gating. A key step towards such functionalities is achieving active control of ionic transport. In particular, the realisation of single ion transport that is tuneable by an external gate – the ionic analogue of the famous electronic Coulomb blockade (CB) – would open considerable new avenues in this pursuit. Despite several claims of ionic CB signatures in experiments and simulations, the understanding of this effect has never gone beyond the electronic analogy, ignoring the particularities of electrolyte systems at room temperature.

We explored theoretically the many-body dynamics of ions confined in a charged nanochannel. By exactly solving a 1D Coulomb gas type model, we obtained analytical predictions demonstrating that ionic conduction is allowed only at discrete values of a gating charge. This result is analogous to the electronic CB, and it is in full agreement with numerical simulations. Surprisingly, this classical quantisation of ionic transport takes its root in the dissociation of 'Bjerrum pairs', through a mechanism reminiscent of Onsager's Wien effect. Our findings open the way to novel nanofluidic functionalities at the single-ion level. As a proof-of-concept, we demonstrate an ionic-CB-based ion pump inspired by its electronic counterpart.

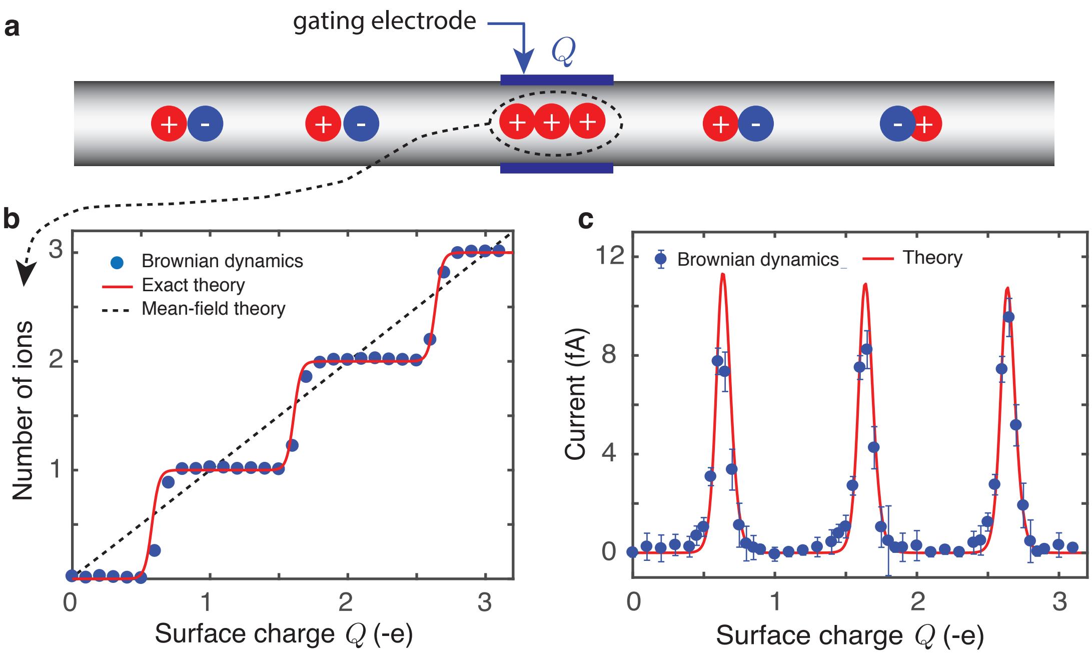

Figure 1. **a.** Schematic of the model under consideration: ions confined in one dimension interact with a variable surface charge Q. **b.** The average number of positive ions that screen the negative surface charge is "quantised"; the result from our analytical theory agrees with brownian dynamics simulations. **c.** The ionic current peaks at discrete values of the surface charge; the theoretical prediction agrees with brownian dynamics simulations.

Reference

N. Kavokine, S. Marbach, A. Siria and L. Bocquet, "Ionic Coulomb blockade as a fractional Wien effect", *Nature Nanotechnology* (2019).