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Physics in biology: field studies

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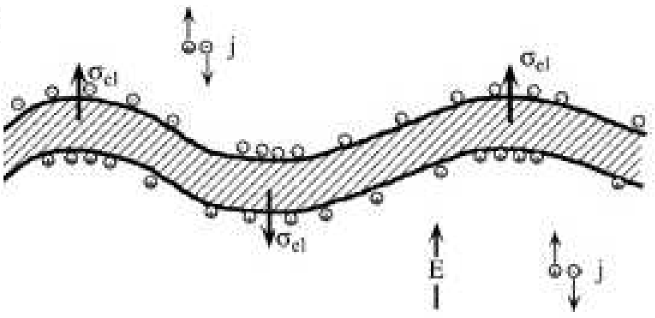
As the building blocks of cell walls, lipid membranes are commonplace in biological systems. And in the form of liposomes, they are attracting increasing medical interest as a means of containing — and delivering — therapeutic chemical agents. Because lipid membranes are poor conductors and are largely impermeable to electrolytes, their form is acutely sensitive to applied electric fields. Reporting in *Physical Review Letters*, Pierre Sens and Hervé Isambert investigate theoretically the influence of an external field on such membranes, and identify a pronounced deformation instability that might underlie some of their field-induced properties.



Accumulation of positive and negative charges on opposite sides of a curved lipid membrane under an electric field. In contrast to the case of a perfectly flat membrane, any curvature leads to non-uniform surface charge densities and hence a net electric stress s_{el}

Such stresses serve to amplify the initial fluctuations.

For a perfectly flat membrane in a conducting solution, an applied field has little effect: the symmetric and uniform build-up of charge on the two interfaces leads to zero net electric stress, and the membrane is simply compressed. But the presence of any curvature — arising from thermal fluctuations, for example — leads to non-uniform distributions of surface charge. This unbalances the stresses and enhances the small initial undulations, so increasing the membrane's area — the result is tension (see figure).

To elucidate the out-of-equilibrium properties of the deforming membrane, Sens and Isambert first turned their attention to the electric-field-response of a membrane attached to a fixed frame. This enabled them to calculate the tension in the membrane once it had equilibrated with the field, which takes the membrane about 10^{-6} seconds. Under these fixed-frame conditions, no particular membrane shape (or undulation wavelength) is favoured.

What if the membrane is freely floating? Simple: it will attempt to reduce the build-up of tension by contracting. At first sight, this situation seems to be difficult to analyse as it involves two intertwined deformation mechanisms — normal undulations and lateral contraction — combined with several sources of viscous dissipation in and around the membrane. But as Sens and Isambert point out, the theoretical situation is greatly simplified by the fact that lateral contraction typically takes place on a much slower timescale — about 10^{-3} seconds — than the normal deformation, allowing the tension to be treated as effectively constant.

Having made this approximation, Sens and Isambert find that one particular undulation wavelength, in the micrometre range, is now favoured and grows exponentially faster than the others. They attribute the existence of this preferred length scale to the crossover between membrane and solution dominated dissipation processes. The authors conclude with the intriguing possibility that predominance of this one undulating mode might explain a range of membrane phenomena, such as the relative uniformity of the vesicles produced during the field-induced formation of liposomes.

Undulation Instability of Lipid Membranes under an Electric Field

PIERRE SENS AND H. ISAMBERT

The influence of an external electric field on a poorly conductive membrane such as a lipid bilayer is studied theoretically. The unbalanced electric stress created by an ionic current across a nonperfectly flat membrane gives rise to a destabilizing surface energy enhancing undulations. The deformation of a membrane attached to a frame is derived and the electrohydrodynamic instability of a free floating membrane is studied. We find a most unstable mode of undulation, of wavelength in the µm range, connected to the crossover between membrane and solvent dominated dissipations.

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