Transport and Concentration of Charged Molecules in a Lipid Membrane

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Abstract

Lipid membranes are essential for eukariotic cells. They enable them to compartmentalize themselves into different regions, such as the nucleus, mitochondria or the golgi apparatus. The membranes also play an essential part in material transport within the cell. Lipids are also the main components of cell walls, which host membrane proteins (Figure 1). Both are very important in cell replication and are therefore of high interest for drug development. These membranes can be understood as a planar sheet in which the lipid molecules can undergo 2D movement and diffusion, but will not leave their membranous environment. We use solid supported lipid membranes (SLMs) as a model for cell membranes and study their behavior under the application of external electric fields. Transport, concentration and separation of membrane components are vital problems for applications such as drug development and membrane protein investigation.

Lipid membranes are modeled as 2D fluid planes in COMSOL Multiphysics®. Using experimentally obtained diffusion coefficients for the lipids, this is a suitable representation of the cell membrane. The transport and concentration of charged membrane components was monitored during the application of an external electric field by solving the Nernst-Planck equation. For different applications, different geometries were investigated. Brownian ratchets are used for transport in the membrane while different trap geometries allow for a high concentration of membrane components in pre-defined regions (Figure 2). COMSOL Multiphysics® was used to determine the influence of different geometrical parameters on the efficiency of the proposed devices.

We designed Brownian ratchets for lipid membranes in which transport perpendicular to an applied electric field was achieved. It could be shown that the main influence on the efficiency of a Brownian ratchet is the ratio of ratchet height to the distance covered by a charged membrane component during one period. We were also able to predict the overall transport in a ratchet pattern and found good agreement with experimental results.

In different patterns we achieved an accurate prediction of the concentration of membrane components in a given region after the application of electric fields. With a DC approach we developed a geometry where different concentrations could be achieved in adjacent regions. These regions of interest can then be used as highly sensitive biosensor areas.

We designed and produced patterned SLMs, which can be used as a model of a cell membrane.

In these model systems we created transport perpendicular to an externally applied electric field. This can be used to build long channels of lipid membranes in which charged material can readily be pumped between two reservoirs. The influence of different parameters was investigated in both, experiment and model. A different pattern for the SLMs can be used as a concentrator for membrane components. Here different concentrations of membrane components can be achieved in adjacent regions. Such a device can be used as a biosensor for drugs targeting either the cell wall or membrane proteins.

Figures used in the abstract

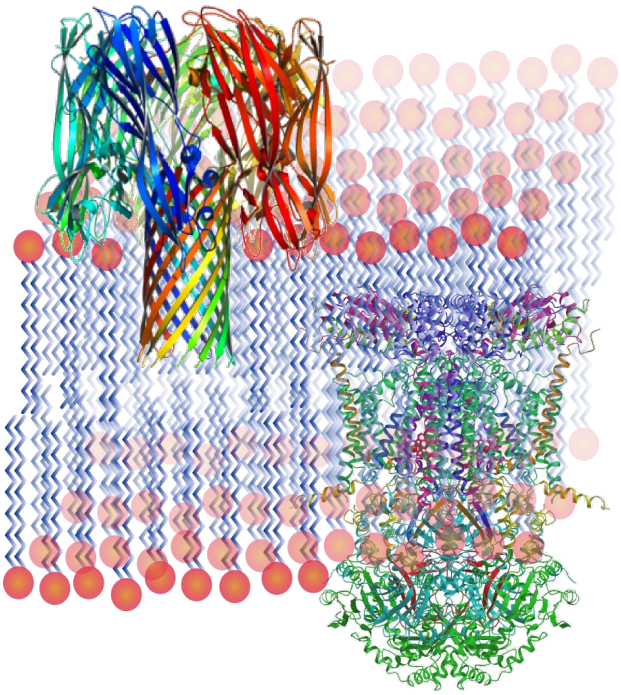

Figure 1: Schematic of a lipid bilayer and membrane proteins. The lipid bilayer is used as a model for the cell membrane.

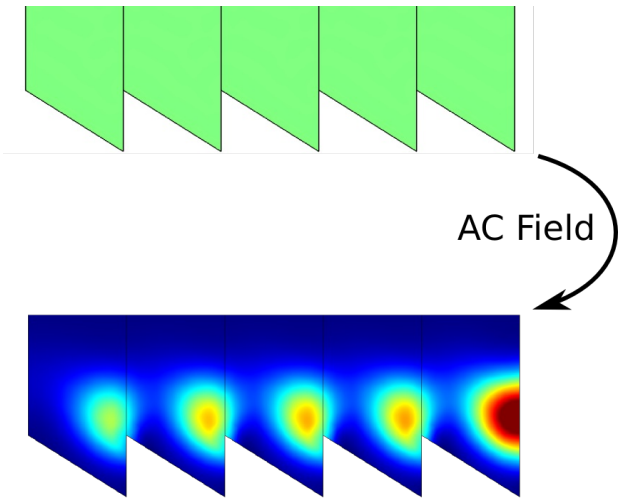

Figure 2: A Brownian ratchet showing transport of charged species in a 2D plane after the applicaton of an AC electric field. The field is applied perpendicular to the movement of the charged species.