Light-mediated ion transport: speed, direction, selectivity and limitations

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Light-mediated ion transport is achieved by microbial rhodopsins that function either as light-driven ion pumps for active transport of ions against an electrochemical gradient or as light-gated ion channels, channelrhodopsins, for passive transport along a gradient. For a broader and more precise optogenetic applications of the transporters a more profound understanding of the activation and transport mechanism is urgently needed.

Although the activity of the pumps is strongly voltage dependent they always transport exactly one ion per photocycle under all conditions. The transport of only one type of ion is based on consecutive pK-changes of well-defined amino acid residues, conformational changes of the protein, and proton transfer reactions between residues and water [1]. In contrast, channelrhodopsins choose from a promiscuous array of competing cations [2] and the stoichiometry between light absorption and transported ions is highly variable. In this case, after light absorption a water filled pore is formed and the residues lining this pore and those that link the pore with the chromophore determine the kinetics of activation, open state lifetime, ion conductance and selectivity, desensitization, and voltage dependence. It is clear that proton transfer reactions and large conformational changes determine channel opening but cation conductance and selectivity depend on the size and polarity of the water pore. I will discuss these issues on the bases of the 3D-structure of the closed dark state [3], spectroscopic data, and electrical measurements on wild type and mutagenized channels.

Comparison of the evolutionary related pumps and channels reveal that the arrangement of water molecules within the protein makes most of the difference.