Electromagnetic response of living matter

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Abstract

This thesis deals with theoretical physics problems related to the interactions between living matter and electromagnetic fields. The five research papers included provide an understanding of the physical mechanisms underlying such interactions. The introductory part of the thesis is an attempt to connect as well as provide a background for the papers. Below follows a summary of the results obtained in the research papers.

In paper I we use a time-dependent quantum mechanical perturbation scheme in order to derive a self-consistent equation for the induced dipole moments in a molecular aggregate (such as a cell membrane or the photosynthetic unit), including dipole interaction between molecules. Our model is shown to be superior to standard exciton theory which has been widely used in the study of photosynthesis.

In paper II we study the process of DNA translocation, driven by a static electric field, through a nano-pore in a membrane by solving the appropriate Smoluchowski equation. In particular we investigate the flux (the number of DNA passages per unit time through the pore) as a function of applied voltage. We find a threshold-like behaviour and exponential dependence on voltage in agreement with the recent experimental findings.

In paper III we investigate the drift velocity of polarizable ellipsoidal particles, driven through a viscous fluid by an electric or electromagnetic field intensity gradient. At off-resonant frequencies the drift velocity is proportional to the squared length of the principal axis along the direction of motion. Near a resonance frequency the drift velocity is sensitive to the particle shape.

Cells are in general of non-trivial shape. Furthermore the cell membrane is typically dielectrically anisotropic. These observations led to paper IV in which we investigate Gauss equation for an ellipsoidal particle with an anisotropic coating (the coating dielectric function being different parallel and perpendicular to the coating normal). We find that the solutions to this equation can be written in terms of solutions to Heun's equation. For the case of spheroidal particles the solutions can be written using hypergeometric functions.

Finally in paper V we use the result from paper I and IV and investigate the electromagnetic response of a dipole coupled ellipsoidal cell membrane. If the constituent membrane molecules have one prominent resonance frequency then the dipole coupled membrane has two new resonance frequencies. The geometric weights for the oscillator strengths of the resonances are sensitive to the membrane shape.

Keywords: electromagnetic response, living matter, polarizability, molecular aggregates, polymers, DNA, fluid mechanics, low Reynolds number, Heun's equation, cell membranes.