Abstract

The confinement of physical systems in small geometries is ubiquitous in nature as well as in artificial micro-devices, and can significantly modify their properties. This thesis focuses on two complex systems of topical interest in confinement which are, ferronematics and twitching bacteria. Ferronematics are suspensions of magnetic nanoparticles (MNPs) in a medium of nematic liquid crystals (NLCs). On the other hand, twitching bacteria are dynamical entities that possess a form of surface motility known as twitching motility. It is mediated by multiple extensions emerging from the cell body, known as type IV pili. We investigate the effect of confinement on the properties of these two distinct systems using various computational and analytical techniques focussing on pattern formation in ferronematics and search mechanism, transport and aggregation properties of twitching bacteria.

We study the ferronematics in confined geometries having shallow depth where the NLC and MNPs primarily lie in a plane with in-plane magnetization. We first investigate the effect of the interplay of confinement and ferronematic coupling on the pattern formation in long channels. Using variational methods, we obtain stable patterns as local or global minimizers of continuum energy in one-dimensional variational settings, using Oseen-Frank and Landau-de Gennes formalism. We obtain a set of numerical conditions on the model parameters, which allow or disallow domain formation in nematic and magnetic profiles, leading to tailored morphologies without any external fields. We then extend our formalism to the geometry of square wells and focus on the stable solution landscape of ferronematic in this geometry. We obtain exotic ferronematic morphologies in square wells with rich spatial inhomogeneities using variational techniques. Our main observation is the

stabilization of defects in both nematic and magnetic profiles which can be manipulated with the interplay of model parameters. These states are not accessible in the uncoupled system. So, the coupled MNP-NLC system offers the possibility of using them as multistable systems with singularities and stable interfaces in display devices.

The second part of the thesis deals with the study of twitching bacteria in a confined environment in which we perform extensive computer simulations using theoretical models of twitching motility. We first model the twitching motility by the coarse-grained run-and-tumble model based on the observations of the experimental trajectories of *N. gonorrhoeae*. We compute the mean first passage time $\langle t_o \rangle$ for a particle having a persistence length ℓ_p moving in a confined surface of size $\mathrm{L} \times \mathrm{L}$ with a target at the centre. For small values of ℓ_p, $\langle t_o \rangle \sim \mathrm{L}^2$ characteristic of a normal diffusion. Larger values of ℓ_p, on the other hand, introduce a crossover towards ballistic motion. A key result from our findings is that for each value of L, there exists an optimal value of the persistence length ℓ_p^* for which the mean first passage time is the least. Our simulation reveals that morphologies of bacterial aggregates have distinct fractal characteristics as a consequence of the ballistic and diffusive motion of the constituting bacteria. We also numerically investigate the twitching motility in corrugated channels. Using the stochastic tug-of-war model and run-and-tumble model, we observe that the motion is rectified in these asymmetric channels. Due to the confinement, the bacterial motility shows anomalous diffusion at different time scales. The particle current is found to be enhanced for specific values of the geometric parameters of the channels.

Finally, we conclude the thesis with a discussion on the implications, future perspectives and possible extensions of the ideas developed in the thesis.