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Transport phenomena in a fluid film with curvature elasticity[1]

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— Lipid bilayers are fluid films that are elastic in bending. Cellular membranes are lipid bilayers that contain different proteins, including ion channels, receptors, and scaffolding proteins. These proteins are known to diffuse in the plane of the membrane and to influence bending of the membrane. Experiments have shown that lipid flow in the plane of the membrane is closely coupled with the diffusion of membrane proteins. Thus there is a need for a comprehensive framework that accounts for the coupling between these processes. Here, we present a theory for the coupled in-plane viscous flow of lipids, diffusion of membrane proteins, and curvature elastic deformation of lipid bilayers. The proteins in the membrane are modeled such that they influence membrane bending by inducing a spontaneous curvature. We formulate the free energy for the system as a Helfrich-like curvature elastic energy density function modified to account for the chemical potential energy of proteins. Then, we apply the principle of virtual work to minimize the free energy and derive conservation laws and equation of motions. Finally, we present results from dimensional analysis and numerical simulations and demonstrate that asymmetry in protein distribution plays an important role in driving lipid flows.

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