Self phoretic colloids near interfaces

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Chemically active colloids can achieve force- and torque-free motility (“self-propulsion”) via the promotion, on their surface, of catalytic chemical reactions involving the surrounding solution. Such systems are valuable both from a theoretical perspective, serving as paradigms for nonequilibrium processes, as well as from an application viewpoint, according to which active colloids are envisioned to play the role of carriers (“engines”) in novel lab-on-a-chip devices.

The motion of such colloids is intrinsically connected with a “chemical field”, i.e., the distribution near the colloid of the number densities of the various chemical species present in the solution, and with the hydrodynamic flow of the solution around the particle. In most of the envisioned applications, and in virtually all the reported experimental studies, the active colloids operate under spatial confinement (e.g., within a microfluidic channel, a drop, a free-standing liquid film, etc.). In such cases, the chemical field and the hydrodynamic flow associated with an active colloid are influenced by any nearby confining surfaces, and these disturbances couple back to the particle. Thus, an effective interaction with the spatial confinement arises. Consequently, the particle is endowed with means to perceive and to respond to its environment.

In this contribution I present several examples of complex behaviors exhibited by active particles near interfaces (see also the review [1]) and I discuss, by employing simple models of chemical activity and self-phoretic motion [2], the basic physical principles governing the phenomenology.

For Janus spheres (half of the surface is coated with the catalyst; e.g., silica spheres decorated with Pt which promotes decomposition of hydrogen peroxide in the surrounding aqueous solutions in which the particles are suspended) assumed to be moving via a self-phoretic mechanism, it has been often observed that during their motion near walls they exhibit a stable preference for orienting their symmetry axis parallel to the wall [3]. This ”sliding” state, Fig. 1(a), can be rationalized as a stable attractor of the overdamped dynamics of a particle which moves, in the absence of external forces or torques acting on it, due to a ”phoretic slip” hydrodynamic actuation, proportional to the local tangential gradient in the chemical composition of the solution, at its surface [4]. Based on the concept of sliding states it has been possible to explain the emergence of topographically-guided motion of chemically active particles, i.e., steady-state motion along the edges of patterns imprinted on a wall [3]. Upon further accounting for the emergence of osmotic flows at the walls (due to the same inhomogeneities in the chemical composition of the solution induced by the activity of the particles), additional spatially localized steady states, such as sliding along a chemical stripe or along the edge of chemical stripes, have been predicted [5].

For a Janus particle near a wall, in addition to the sliding state discussed above a second steady state (stable attractor of the dynamics) may exists: the particle hovers at a fixed distance from the wall, while stirring the fluid, Fig. 1(b). For a Janus particle, this theoretically predicted state, which can exist even in the absence of gravity, has proved difficult to be evidenced experimentally. However, its equivalent for a heavy, uniformly active sphere near a wall turns out to provide the means for a new method of separation of similarly-sized, but surface-properties different, particles [6].

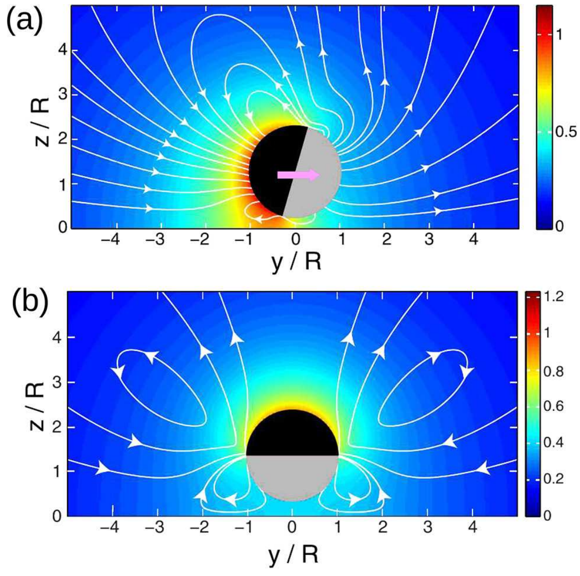

Fig. 1. A chemically active Janus particle in sliding (a) and hovering (b) states above a planar wall. The active part is indicated in black, and the magenta arrow shows the translational velocity of the particle. The white streamlines correspond to the flow field in the laboratory frame. The chemical field c(r) (in units of a characteristic density) is color coded.

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