

Catalytically Active Colloids as Particle Carriers

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The increasing interest in "lab on a chip" devices has led to a stringent need of scaling standard machinery down to micro- and nano-scales. This has raised a number of challenging issues, such as to endow small objects with the capacity to perform autonomous, directional motion within a liquid medium. This is a difficult task because at such scales viscosity and surface tension dominate over the inertia. The motion of such micro-sized objects thus occurs in the limit of low (zero) Reynolds numbers, and the classical mechanisms of propulsion based on imparting momentum to the fluid fail [1].

One approach to achieve self-propulsion at microscale consists of transforming chemical free energy into mechanical work by employing phoretic mechanisms, i.e., motion induced by interfacial interactions. The underlying idea is that an asymmetric decoration of the surface of a colloid with a catalyst, which promotes an activated reaction in the surrounding liquid medium, leads to a non-uniform distribution of product molecules around the surface of the particle [2]. If the product molecules remain dissolved in the surrounding liquid medium, concentration gradients develop along the surface of the particle, hydrodynamic flow around the particle is induced and self-phoresis becomes possible.

A potential application of such active particles is as carriers at the micro-scale. As a simple model for a carrier-cargo system we consider a catalytically active particle connected by a thin rigid rod to a catalytically inert cargo particle (Fig. 1). Adopting the standard theory of diffusio-phoresis [3] we derive the velocity of the carrier-cargo composite and show that the performance of the carrier, i.e., the resulting velocity of the composite system, strongly depends on the orientation of the link [see Figs. 1(a)-(b)] [4]. This is a paradigmatic consequence of the fact that self-phoresis involves hydrodynamics Stokes flow driven by the dynamically created and maintained solute concentrations gradients. The rather peculiar consequences of self-phoretic propulsion are further highlighted as we show that a spherical particle, which is completely covered by catalyst and thus is unable to move on its own, can act as a carrier once it is attached to a cargo [Fig. 1(c)].

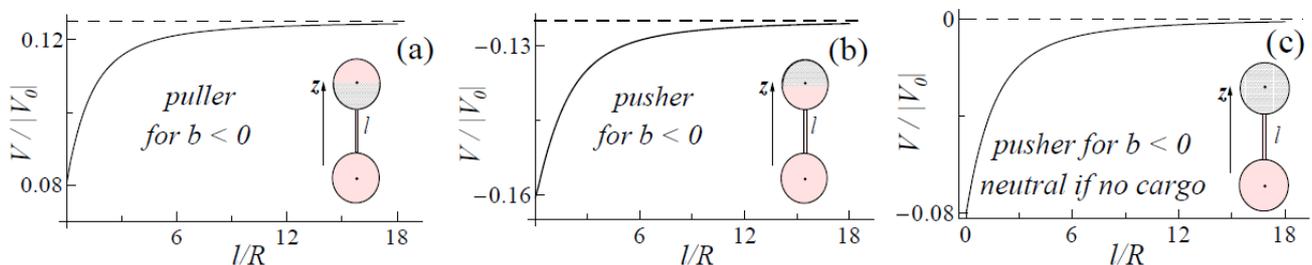


Figure 1. Dimensionless velocity V/V_0 along the z -direction as a function of the scaled length l/R of the linkage for a model active carrier-cargo system. The spherical carrier particle (light gray top circle) has its surface covered partially (a), (b) or completely (c) by a catalyst (hatched area). Results are shown for the case that the effective interaction between the product molecules and the two particles is repulsive ($b < 0$).

These effects are due to the fact that a phoretic slip is induced along the surface of the inert cargo, which then actively affects the flow produced by the carrier alone (similarly with the effective hydrodynamics of suspensions due to a particle-distribution dependent apparent slip at the wall discussed by Ref. [5]).

We anticipate a rather rich behavior to emerge as various model constraints are relaxed to allow for : (i) different effective interactions between the product molecules and the cargo and carrier material, (ii) charged active particles and charged reaction products, or (iii) convex or concave non-spherical shape of the surface of the cargo facing the carrier. One thus expects that employing catalytically active particles as carriers will allow much flexibility in the design of cargo-carrier systems for practical applications.

References

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