

Swimming modes of self-assembled magnetic micropropeller

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Controlling the motion of micro and nano propellers is of great interest and the focus of intense research due to their potential applications as efficient drug-delivery vectors, non-invasive microsurgery devices, or chemical biodetectors. A variety of strategies have been devised to design microswimmers and direct their trajectories at low Reynolds numbers, where these systems operate.

Here, we propose the use of self-assembled magnetic aggregates as micropropellers and theoretically investigate the different swimming modes that can be induced by their actuation with time-dependent magnetic fields. In particular, we focus on a hybrid system composed of a ferromagnetic nanorod and a paramagnetic spherical microparticle which self-assemble due to their mutual dipolar attraction. We discuss two different actuation strategies which generate locomotion. We show that the application of in-plane linearly oscillating magnetic fields results in the rotation of the ferromagnetic rod, which governs the motion of the swimmer. We demonstrate that the direction of the rod's rotation (and, thus, of propulsion of the microswimmer) can be selected by balancing gravity, magnetic and hydrodynamic interactions [1] (see Fig. 1).

We also investigate the locomotion of the self-assembled propeller under an in-plane field of constant magnitude which oscillates about a given direction. The basic locomotion mechanism is discussed and leading-order analytical expressions are obtained for the velocity and efficiency of the propeller under small fields, which are tested against computer simulations.

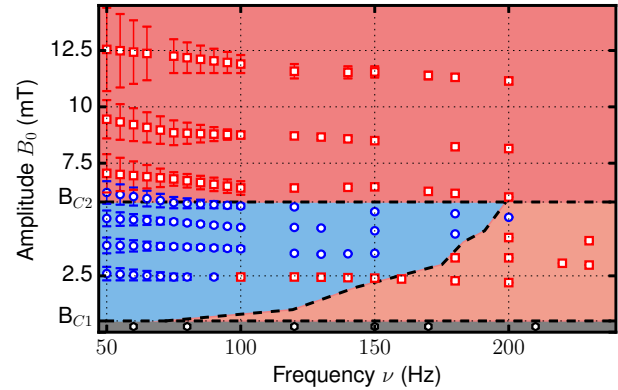


Fig. 1. Diagram of locomotion modes of self-assembled microswimmer as a function of the amplitude and frequency of the external magnetic field. The red (blue) regions indicate values in which the microswimmer is predicted to act as a puller (pusher). Red squares (Blue dots) represent experimental points where the microswimmer acts as a puller (pusher).

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- [1] J. M. Torres-García, C. Calero, F. Sagués, I. Pagonabarraga, and P. Tierno, Magnetically tunable bidirectional locomotion of a self-assembled nanorod-sphere propeller, *Nat. Commun.* **9**, 1663 (2018).