Bidirectional Locomotion of Magnetically Assembled Nanorod-sphere Propeller

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Field driven direct assembly of nanoscale matter and its propulsion in fluid media have the potential to revolutionize different emerging technologies, since they can be used as efficient drug-delivery vectors in microfluidic and biological networks, as non-invasive microsurgery vehicles or as chemical biodetectors. One of the challenges is to break the time-reversal symmetry at low Reynolds number to allow the motion of these systems. The use of magnetic elements is advantageous as it allows controlling directionality and speed wirelessly. Thus, the objective of the present work is the fabrication of a self-assembled nanorod-sphere propeller that can be manipulated and transported in viscous fluids via application of simple in-plane time-dependent magnetic field.

Our microwimmer is based on the magnetic interaction between a superparamagnetic particle and a ferromagnetic nanowire (Figure 1). The assembly of both microstructures near a surface breaks the time-reversal symmetry in an oscillating magnetic field as it induces a synchronized cooperative motion between the two elements that periodically attract and repel due to dipolar forces. The periodic relative displacement induces a fast rotation of the nanorod during each field cycle that is rectified into a net translation due to the proximity of a bounding plate. Varying field amplitude and frequency of the in-plane oscillating magnetic field $(H = H_0(\sin \omega t, 0, 0))$ allows changing the microswimmer motion between two different mechanisms. Numerical simulations reveal that the balance between magnetism, gravity and hydrodynamics allows explaining both mechanisms.

The hybrid propeller developed here shows exceptional functionalities that make it especially suitable for single or multicargo applications, as the microstructures are not permanently linked to each other, and they can be pulled apart at any time depending on the applied magnetic field parameters. This particularity makes this kind of swimmers very interesting.

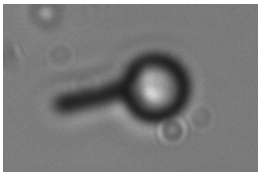

Fig 1: *Magnetically assembled superparamagnetic particle and ferromagnetic nanowire.*