Remote control of magnetocapillary microswimmers

G. Grosjean, G. Lagubeau, A. Darras, G. Lumay, M. Hubert, and N. Vandewalle

GRASP, Physics Department, University of Liège, B-4000 Liège, Belgium.

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Because they cause a deformation of the interface, floating particles interact [1]. In particular, identical particles attract each other. To counter this attraction, particles possessing a large magnetic moment $\vec{m}$ are used. When $\vec{m}$ is perpendicular to the surface, dipole-dipole interaction is repulsive. This competition of forces can lead to the spontaneous formation of organized structures [2, 3] as illustrated in figure 1. By using submillimetric steel spheres for which $\vec{m} \propto \vec{B}$, we can precisely tune the interdistances in the system.

Here, we deform these self-assemblies by adding an oscillating horizontal field $\vec{B}_x$ which induces a horizontal contribution $\vec{m}_x$ to the magnetic moment. Time reversal symmetry is broken in the system, leading to locomotion at low Reynolds number [4, 5]. Indeed, a body undergoing non-reciprocal deformations, i.e. breaking time reversal symmetry, is known to be able to swim in viscous regime [6, 7].

Moreover, swimming direction depends on the orientation of field $\vec{B}_x$, meaning that swimming trajectories can be finely controlled [8] as shown in figure 2. A simple quasistatic model allows to understand the breaking of symmetry in a three-particle system. A study of the vibration modes in a pair of particle gives further informations on the dynamics, being the basis for larger assemblies [9].

Because this magnetocapillary system spontaneously forms by self-assembly, it allows miniaturization and other possible applications such as cargo transport or solvent flows. It is highly versatile, being composed of simple passive particles and controlled by magnetic fields of the order of 1 mT.

FIG. 1. Sketch of the experiment - Floating metallic spheres of size $D = 500 \mu m$ are submitted to magnetic fields generated by a triaxis Helmholtz system. Particles self-assemble into organized structures due to a competition between dipole-dipole interaction and capillary attraction. Contact between spheres is not reversible.

FIG. 2. Trajectories of a three-sphere microswimmer - Magnetic-field-induced deformations lead to low Reynolds locomotion of the assembly. A rotation of the oscillating field leads to a change in swimming direction. Various trajectories can be obtained, such as U-turns, corners and loops. The letters ‘ULg’ are drawn to emphasize that a high degree of control is possible.