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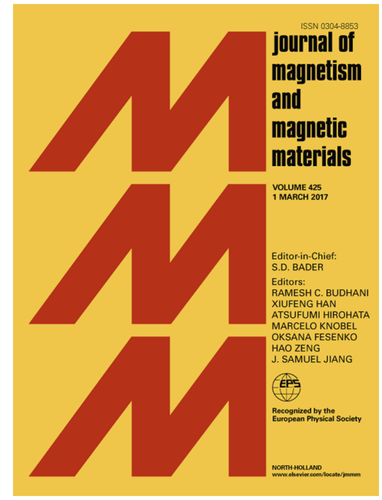


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# Magnetic particles guided by ellipsoidal AC magnetic fields in a shallow viscous fluid: controlling trajectories and chain lengths

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**Abstract**

We study the propulsion of superparamagnetic particles dispersed in a viscous fluid upon the application of an elliptically polarized rotating magnetic field. Reducing the fluid surface tension the particles sediment due to density mismatch and rotate close to the low recipient confining plate. We study the net translational motion arising from the hydrodynamic coupling with the plate and find that, above a cross over magnetic field, magnetically assembled doublets move faster than single particles. In turn, particles are driven in complex highly controlled trajectories by rotating the plane containing the magnetic field vector. The effect of the field rotation on long self assembled chains is discussed and the alternating breakup and reformation of the particle chains is described.

## 1. Introduction

Dynamical assemblies of superparamagnetic micrometric particles are attracting increasing attention. The mechanisms that govern their dynamics have been extensively examined in the past [1–10]. Particularly, time-dependent magnetic fields have been used to assemble magnetic non active material in a variety of structures [11] and to propel microscopic matter in a fluid medium in motile structures [12]. Arrays might yield highly desired additional degree of control over their properties [13] and satisfy the rising demand for the design of artificial externally controlled structures with direct applications in biomedicine [14–16], in microfluids stirring [17], and in targeted cargo delivery [10, 18, 19].

Different strategies have been followed. A noticeable example is the self-assembly of complex magnetic microstructures suspended at a water-air interface and subjected to a vertical alternating magnetic field [20, 21]. These structures denominated "snakes" arise from the coupling between surface deformations of the fluid and the collective response of particles to an external alternating magnetic field. These deformations bring particles close enough that the head-to-tail dipole-dipole attraction overcomes the repulsion caused by the external field. As a result, chains of particles are formed with resulting magnetic moments pointing along the chains. The chains produce wavelike local motion facilitating the self-assembly process and the component of the magnetic field parallel to the surface of the water further promotes the chain formation and propulsion [21].

At first sight, for particles immersed in a viscous fluid with low Reynolds number, any approach based in the application of AC drives is expected to fail to produce net propulsion because the Navier-Stokes equations become time reversible [22, 23]. However, to overcome the challenge of low Reynolds number time reversibility, the interaction between the fluid and a confining plate has been proposed to propel a rotating particle [24].

We address then an arrangement of similar particles as in Ref [21] but in a fluid where they do not float on the liquid air interface, but sediment due to reduced surface tension and density mismatch in an aqueous dispersion. The particles close to the lower planar surface of the container interact through the fluid with the wall. By applying suitable rotating magnetic fields with controlled time dependent orientation and strength, we find a way to manipulate and propel self-organized microscopic particles forming structures similar to worms assembled or disassembled at will, rotated or transported in any direction of the plane via magnetic control, per-

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