Ferrofluids

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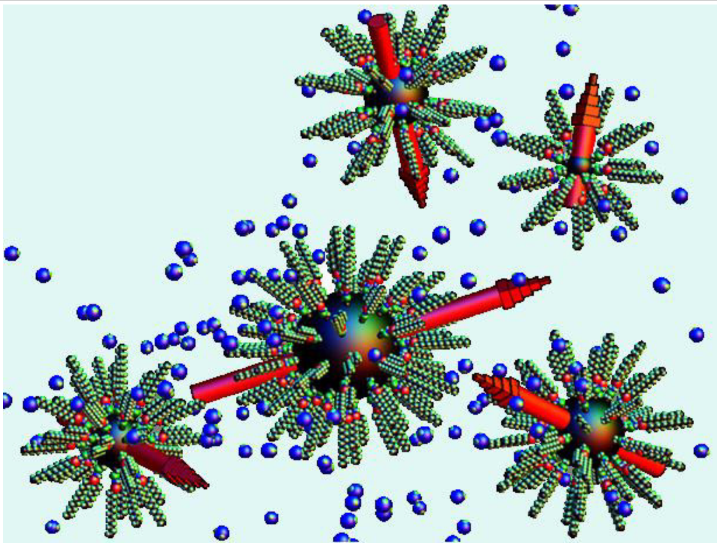
- Rectification of thermal motion
- Meniscus around a current-carrying wire

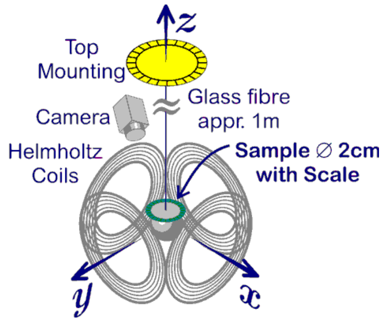
image by: Opoterser

Rectification of thermal motion

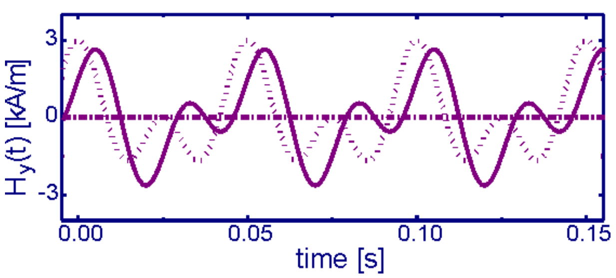
Ferrofluids are superparamagnetic liquids that contain a suspension of ferromagnetic particles. They find a broad application in technology and medicine. But they also represent interesting systems for fundamental research. In the ferrofluid ratchet experiment, we rectify random Brownian motion of the ferroparticles. The idea of the experiment was proposed by Engel et al. (*Phys. Rev. Lett.* **91**, 060602 [2003]).



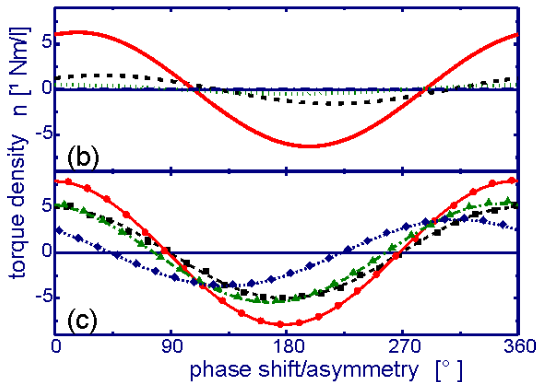
Schematic drawing of ferrofluid particles coated by surfactants in water. Each ferromagnetic particle carries a spontaneous magnetization. The surface treatment with surfactants suppresses agglomeration of the individual particles



Experimental setup for the ferrofluid ratchet [John2009]. Two orthogonal magnetic fields are produced by Helmholtz coil pairs. In the simplest case, one coil pair produces a static field, the second coil generates field that is modulated with the superposition of two harmonic waves. The Brownian motion of the magnetic particles is rectified and mechanical torque acts on them. This torque is transferred to the fluid and the container. We measure the torque from the distortion of a glass suspension fiber.



Superposition of two sine waves with frequency ratio 1:2 and phase shifts 0 (solid) and 90 deg (dashed) [John2009].



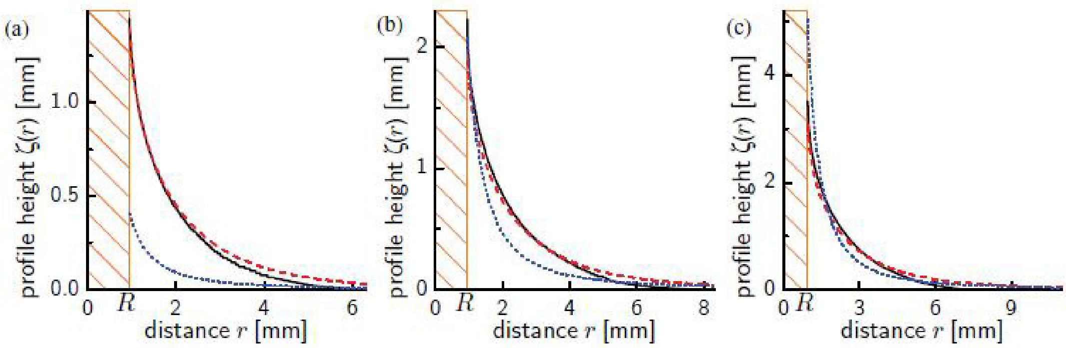
Torque density measured for a ferrofluid exposed to a stationary magnetic field and a modulated two-frequency magnetic ac field perpendicular to the static field. The abscissa gives the phase shift of the two sine waves (see image to the left). The top curves are results of the model calculations, the bottom curves are experimental results for different excitation frequencies [John2009].

Meniscus around a current-carrying wire

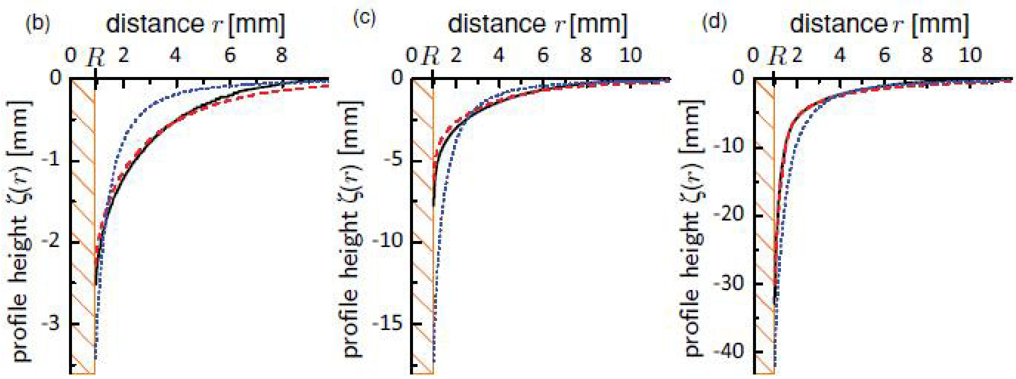
The meniscus of a ferrofluid around a metal wire changes its shape when the wire carries an electrical current. The shape of the meniscus is determined by a balance of magnetic, capillary and gravitation forces. Even though the axial symmetry of the problem is a simplifying condition and the magnetic field direction is not influenced by the ferrofluid, the calculation of the meniscus shape is a non-trivial mathematical task. All three forces can be in a comparable order of magnitude. Experiments were performed to compare the shapes of the meniscus for different currents with the calculated predictions. [John2011]

The image shows the meniscus around a wire carrying 70 A.

Meniscus of a ferrofluid around a wire carrying a current of 70 A. The ferrofluid is embedded in a liquid of higher density (glycerol/water mixture)



Meniscus profiles of the ferrofluid-air interface from experiments (solid black line), calculated with (dashed red line) and without
(dotted blue line) interface tension. The currents in the 1.9 mm diameter wire are a) 20 A, b) 45 A, and c) 70 A.



Meniscus profiles of the ferrofluid-glycerol/water interface from experiments (solid black line), calculated with (dashed red line) and without
(dotted blue line) interface tension. The currents in the 1.9 mm diameter wire are a) 20 A, b) 45 A, and c) 70 A.

Th. John and R. Stannarius. Experimental investigation of a Brownian ratchet effect in ferrofluids. *Phys. Rev. E*, **80** 050104(R), (2009).
T. John, K. May, and R. Stannarius. Meniscus of a ferrofluid around a vertical cylindrical wire carrying electric current. *Phys. Rev. E*, **83** 056308, (2011).

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last modified Feb. 28, 2013, R. Stannarius