Pumping a ferrofluid

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In the theory of ferrofluids one considers a suspension of spherical particles, each carrying a magnetic dipole moment. On a macroscopic length scale and a slow timescale the mean magnetization and magnetic field satisfy Maxwell's equations of magnetostatics. The magnetic force and torque density acting on the suspension cause net flow, as well as a net spin velocity. The coupled equations of motion for flow velocity and spin velocity must be considered in conjunction with the equations of magnetostatics. The equations for the flow velocity are just Stokes' equations with a source term given by the magnetic force and torque density. The subject is called "Ferrohydrodynamics". The same equations with magnetization and magnetic field replaced by electric polarization and electric field are thought to apply to a polar liquid like water. In that case one speaks of "Electrohydrodynamics".

We discuss the question whether the application of a rotating field or of a plane wave field can cause net rotational or translational motion of a ferrofluid in confined geometry. In the case of rotation we consider both cylindrical and spherical geometry. Experiments on rotation in cylindrical geometry have led to surprising results, with rotation observed both in the direction of and opposite to the rotation vector of the magnetic field. We show that the theory leads to bifurcation of solutions of the nonlinear equations at strong magnetic field, in qualitative agreement with the observations. In the case of a plane wave magnetic field running along a planar duct or a cylindrical tube a similar derivation shows that one can achieve net translational motion, in agreement with recent experiments.

A crucial role in the theory is played by the concept of spin viscosity, or equivalently, spin diffusion. The concept is controversial. Theoretical and computer simulation study of the behavior of a ferrofluid near a wall, including the effect of magnetic dipole and hydrodynamic interactions between suspended particles, are required to elucidate the issue.