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Field Induced Dynamic Pattern Formation in Ferromagnetic Ferrofluids

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Ferromagnetic ferrofluids are obtained as stable suspensions of magnetic nanoplatelets when the particle concentration exceeds a critical threshold [1]. Typically, barium hexaferrite nanoplatelets, possessing a permanent magnetic moment perpendicular to the platelet plane, are suspended in 1-butanol concentrations of around 10 vol. %. By exposing such a fluid to dynamic external magnetic fields, a variety of interesting dynamic phenomena can be observed.

In the simplest case of an oscillating magnetic field, polarisation microscopy reveals regular, periodic bright and dark stripes forming perpendicular to the magnetic field, which we identify as elongated magnetic domains. The formation of these domain structures is accompanied by pronounced magnetically driven flows along particle-depleted domain boundaries in alternating directions, with velocities reaching several μm/s [2].

More complex patterns are formed when the ferromagnetic fluid is exposed to rotating magnetic fields. We observe a wide variety of different dynamic patterns, including lines, dots, vortices, and static winding lines. At low frequencies, spots distributed in a hexagonal array can be seen. At higher field rotation frequencies vortices appear, rotating in the same direction as the magnetic field but at a significantly lower frequency. The vortex pattern is not static, as the structures continuously appear, move, and annihilate.

The morphology of the observed patterns depends on the sample thickness and can be tuned by adjusting the amplitude and frequency of the rotating field or by superimposing a static component onto the applied magnetic field. The observed vortices can reach sizes of several tens of microns, scaling proportionally to the cell thickness.

Moreover, adding polystyrene tracer microparticles to the suspension reveals another interesting phenomenon: depending on the rotation frequency, the direction of particle chain rotation reverses, switching from co-rotation with the external field to counter-rotation. We find that the critical frequency at which this transition occurs depends on the strength of the applied magnetic field.

References

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