Liquid Magnets

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Ferrofluids, consisting of magnetic nanoparticles suspended in a solvent, are in fact paramagnetic. The creation of macroscopically ferromagnetic suspensions has been a long-standing challenge. These so-called "real" ferrofluids would have spontaneous ferromagnetic order without external magnetic field. A major breakthrough was the achievement of spontaneous ferromagnetic ordering of magnetic nanoplatelets suspended in a nematic liquid crystal host [1, 2]. Later on, it has been shown that a suspension of platelet-based magnetic nanoparticles in an isotropic solvent above a certain concentration forms a ferromagnetic nematic phase [3], as well. The latter system is as interesting in the nematic phase as it is in the isotropic phase at lower concentrations.

The isotropic material is sensitive to magnetic fields as low as 10 times smaller than Earth's magnetic field, which induce nematic ordering. The change in net orientation of the material can be easily mapped under a polarizing microscope, giving us information about the environmental magnetic field. Due to the strong coupling between orientation and flow, and thus between magnetisation and flow, a range of new hydrodynamic behaviours has been observed. Here we present measurements of flow induced order and flow induced magnetisation as well as of the inverse effect, where flow is driven by an external magnetic field.

Recently we were able to synthetize a liquid magnetic material that shows a nematic phase at much lower concentrations [4]. Here we present the material's physical properties and behaviour in static and oscillating magnetic fields, studied using various methods like small angle neutron or X-ray scattering (SANS, SAXS) and polarizing optical microscopy (POM)[5]. One of the remarkable observations for this systems is the formation of closure magnetic domain structures under zero-field conditions, which are analogous to textbook examples of soft ferromagnets. Here we present their formation and evolution under small constant magnetic fields up to several μT.

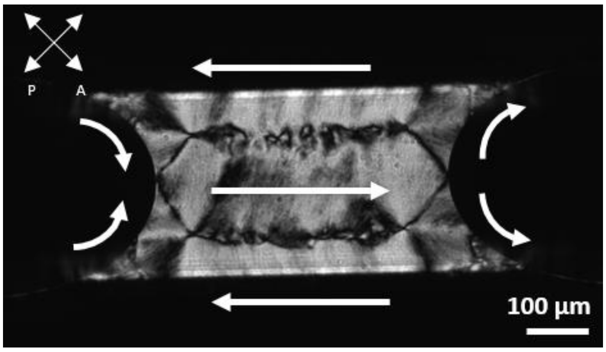

Figure 1: Domains in a platelet-based ferrofluid in a thin capillary with thickness of 30 μm and width of 300 μm annealed with the initial external magnetic field pointing to the left. The white lines represent the direction of the magnetization in the sample, observed under polarizing microscopy.

References

[1] A. Mertelj, D. Lisjak, M. Drofenik, and M. Čopič, *Nature*, vol. 504, pp. 237–241, (2013).
[2] A. Mertelj, N. Osterman, D. Lisjak, and M. Čopič, *Soft Matter*, vol. 10, pp. 9065–9072, (2014).
[3] M. Shuai *et al.*, *Nat. Commun.*, vol. 7, p. 10394, (2016).
[4] P. Hribar Boštjančič, M. Tomšič, A. Jamnik, D. Lisjak, and A. Mertelj, *J. Phys. Chem. C*, vol. 123, pp. 23272–23279, (2019).
[5] A. Mertelj, B. Lampret, D. Lisjak, J. Klepp, J. Kohlbrecher, and M. Čopič, *Soft Matter*, vol. 15, pp. 5412–5420, (2019).