







"Dispersion of magnetic nanoparticles in a nematic liquid crystal host: Phase behavior, Fredericks transition and deformation of droplets

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Nematic Liquid Crystals



Ferrofluids

- Magnetic fluids : colloidal suspension of magnetic nanoparticles
- Stabilization in an organic solvent by an appropriate surfactant coating :





- Core diameters : $d_0=7$ nm, $\sigma=0.4$ (could be lowered down to $\sigma=0.15$)
- Magnetization under weak champ magnetic : Superparamagnetism
- Remains mono-phasic in strong magnetic fields (and in gradients...)

Preparing and observing a "ferronematic" sample



• Surface treatment : SDBS 0,2 % in H_2O/C_2H_5OH (1:1)





Nanoparticle – 5CB – surfactant system: Microscopic Observations (1: cooling down)



Nanoparticle – 5CB – surfactant system: Microscopic Observations (2: heating up)



Nanoparticle – 5CB – surfactant system: Microscopic Observations (3: droplets)



 $T < T_{(N-I)}$

Parallel polarizers: Magnetic liquid droplets in clear (non magnetic) 5CB phase.





<u>Crossed polarizers:</u> Droplets exhibit Malta crosses (hedgehog defects) Because Nematic outer phase is oriented (homeotropic)



C. Da Cruz, O. Sandre, V. Cabuil, Journal of Physical Chemistry B (2005) <u>109</u>, 14292-14299.

Nanoparticle – 5CB – surfactant system: Thermodynamics



Analogy with water/DDAB micelles in 5CB:

T. Bellini et. al, PRL2003 G. Toquer et al. Langmuir 2007

Nanoparticle – 5CB – surfactant system: Structure of nanoparticles inside droplets



no real gap between T_c and T_{N-I} !

no magnetic N phase ↔ no "clear" (microemulsion) N phase with water/DDAB/5CB

Behavior of droplets under magnetic field



1. Chaining

2. Deformation

Magnetic dipolar energy vs. interfacial energy: Theory

• Ellipsoidal deformation of droplet (initially spherical)



• Aspect ratio $K = \frac{a}{b}$

 $\frac{H^2 R_0}{\sigma} = g(K, \alpha) \qquad \begin{cases} \sigma : \text{ interfacial tension} \\ \alpha = \frac{\mu_1}{\mu_2 - \mu_1} : \text{ magnetic "contrast"} \end{cases}$

J.-C. Bacri, D. Salin J. Phys. France Lett. 43, L-649 (1982)

Magnetic dipolar energy vs. interfacial energy: Results



• From Φ_{loc} ~18% we get α =0,438 and σ = 4,5.10⁻² dyn/cm

Fredericks Transition: Classical scheme for pure LCs

• Elastic coupling (surface alignment)



Magnetic orientation (bulk dipolar energy)

 $\vec{n} = -$

Brochard and de Gennes (1970) : H_c should decrease with magnetic grains anchored strongly to the LC matrix

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H > H_c
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Fredericks Transition: Observation in presence of a magnetic droplet



• Fact:

Threshold field increases!

Ex:

Hc=500 Oe (pure 5CB)

Ĥc=700 Oe (ferronematic)

Observation

Fredericks Transition: Tentative explanation of threshold field shift

• Result : $\widetilde{H}_c \approx 700 \ Oe$ $(H_c = 500 \ Oe \ for \ pure \ 5CB)$



Perpendicular anchoring of LC molecules on the droplets surfaces



Competes with the bulk orientation by the magnetic field

Fredericks Transition: Tentative explanation of threshold field shift

• Experiment: raising of threshold field

homeotropic anchoring on droplets

• S.V. Burylov & Yu. L. Raikher's model :

 $\widetilde{H}_{c}^{2}=H_{c}^{2}+G^{2}$ with $G^{2}=\frac{2W\phi}{\chi_{a}d}$ χ_a : magnetic anisotropyW: anchoring energy ϕ : volume fractiond: "particle" diameter $W \longleftrightarrow \sigma$ and $d \longleftrightarrow R_0 \longrightarrow G \sim 10^2 \text{ Oe}$ compares with experiment! $\left(H_c \propto \frac{1}{L} \Rightarrow \text{ increase sample thickness}\right)$

Perspectives for ferronematics

Replace organics:
BNE ↔ SDBS or LC surfactant

$5CB \leftrightarrow other LC$

• Replace inorganic nanoparticles:



FIGURE 5 Electro-optic response to the applied voltage for the pure 5CB liquid crystal cell and the cell filled with the mixture of the 5CB and 1.0 wt.% of $Sn_2P_2S_6$ ferroelectric nanoparticles and the 5CB and BaTiO₃ particles.

Molecular Crystals and Liquid Crystals, 453:227-237, 2006 Y. Reznikov et coll.

or α -FeOOH (goethite) nano-needles \rightarrow