Magnetically-Induced Ordering of Dispersions of Non-Magnetic Hard Rods Doped With Spherical Superparamagnetic Nanoparticles

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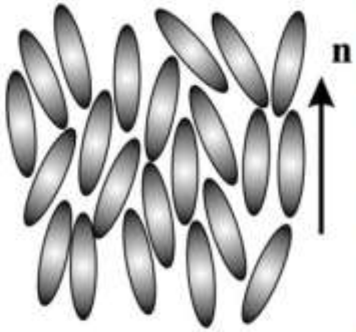
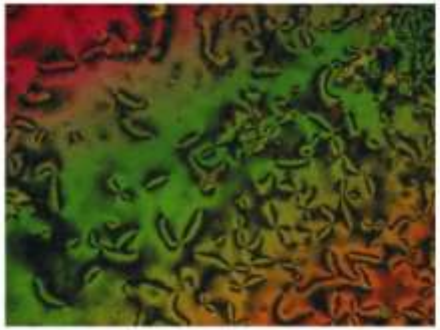
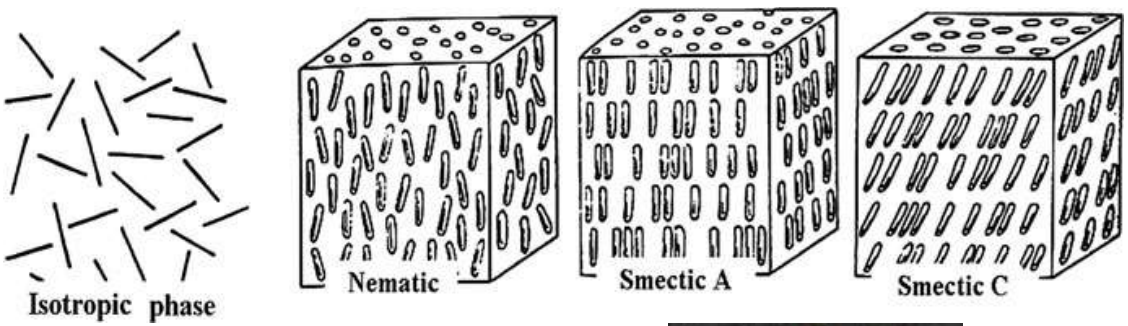
Liquid crystals phase

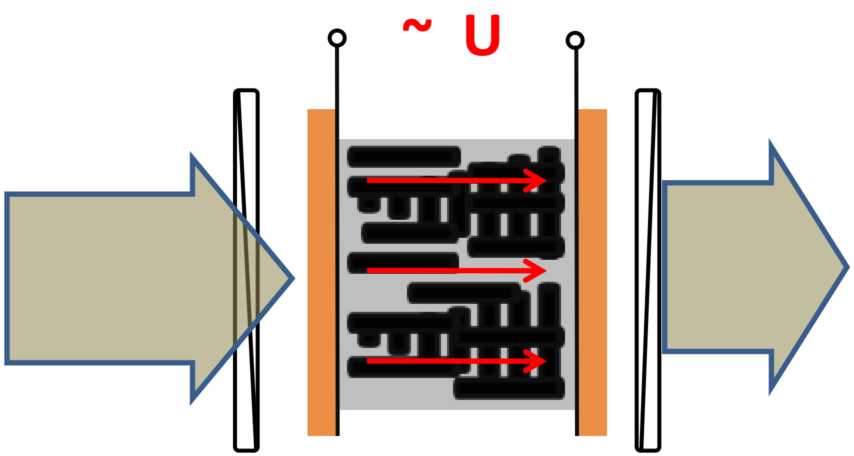
F.Reinitzer
1857-1927

O.Lehmann
1855-1922









Rigid Rod-like Particles. Onsager Model

L. Onsager:

Ann. N. Y. Acad. Sci. 1949

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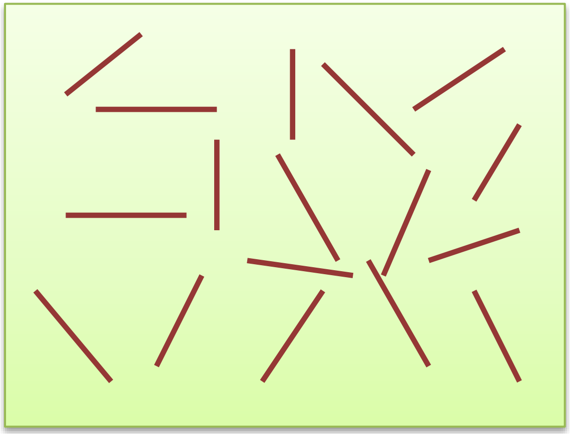


Low density: isotropic phase

Competition between a rise of translation entropy

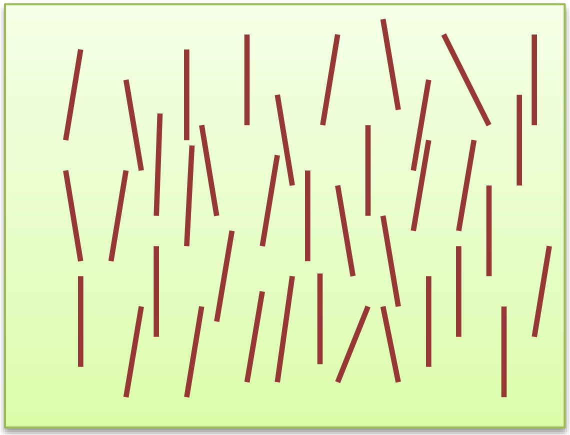
$$\Delta S_{tr} = -k_B \ln\left(1 - V_{excl}/V\right) \sim k_B \rho L^2 D \quad \rho = N/V$$

and decrease of orientation al entropy

$$\Delta S_{or} \sim k_B \, ln\left(\Omega_N / \Omega_i\right)$$

results in the transition to nematic phase with increase of the volume fraction of rods

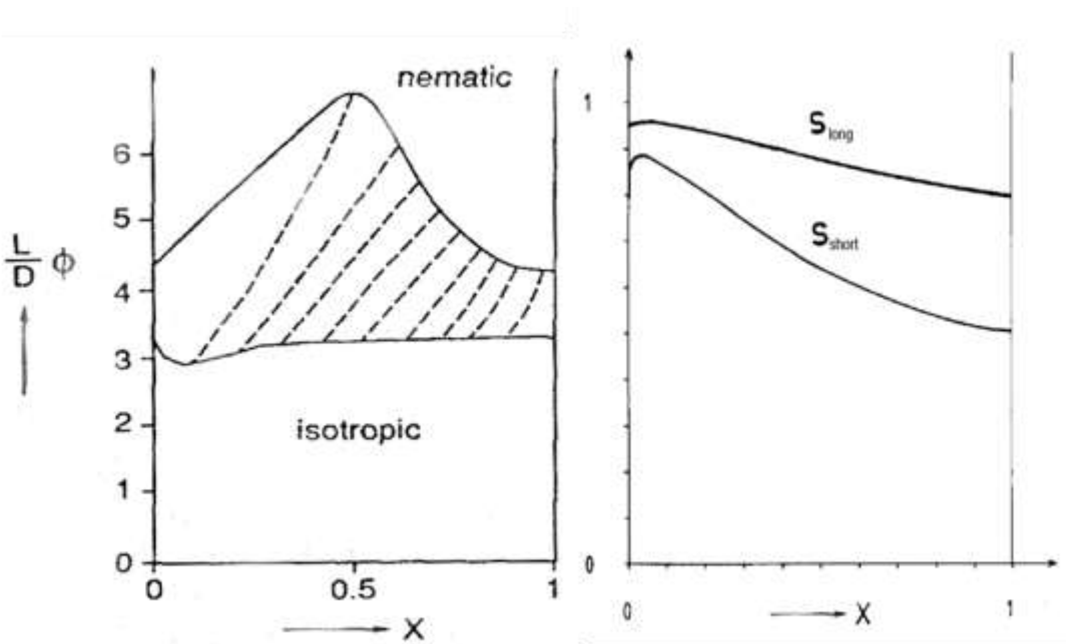
$$\Delta S_{tr} = \Delta S_{or} \qquad \rho \approx 4.5 \frac{D}{L}$$



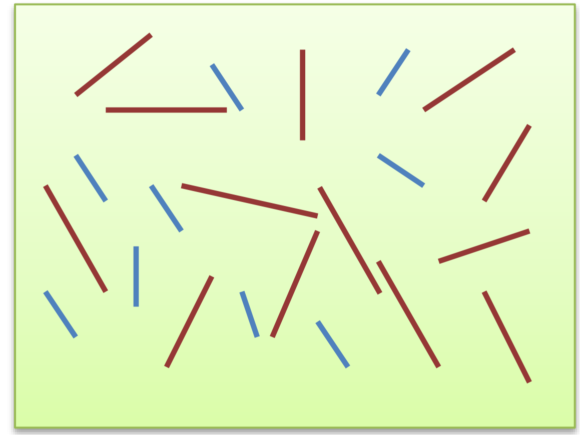
High density: nematic phase

Onsager Model for Two-component Dispersion

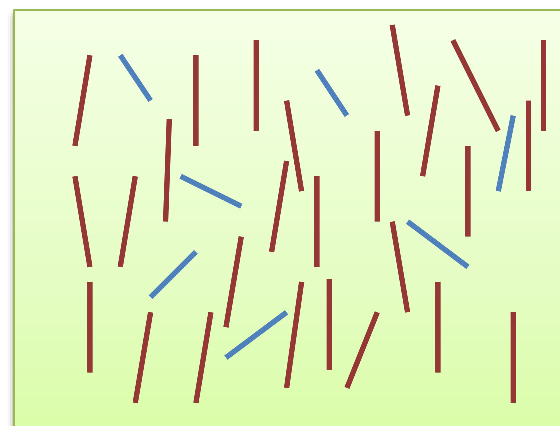
The studies of Lekkerkerker et al. showed that the order parameters of the long and short rods are different in the nematic phase; the order parameter of the longer rods, S_l, is rather high while it can be rather small for the short rods, S_s.



J. Chem. Phys. **80** (7), 1984; *Rep. Prog. Phys.* **55**, 1241-1309, 1992.

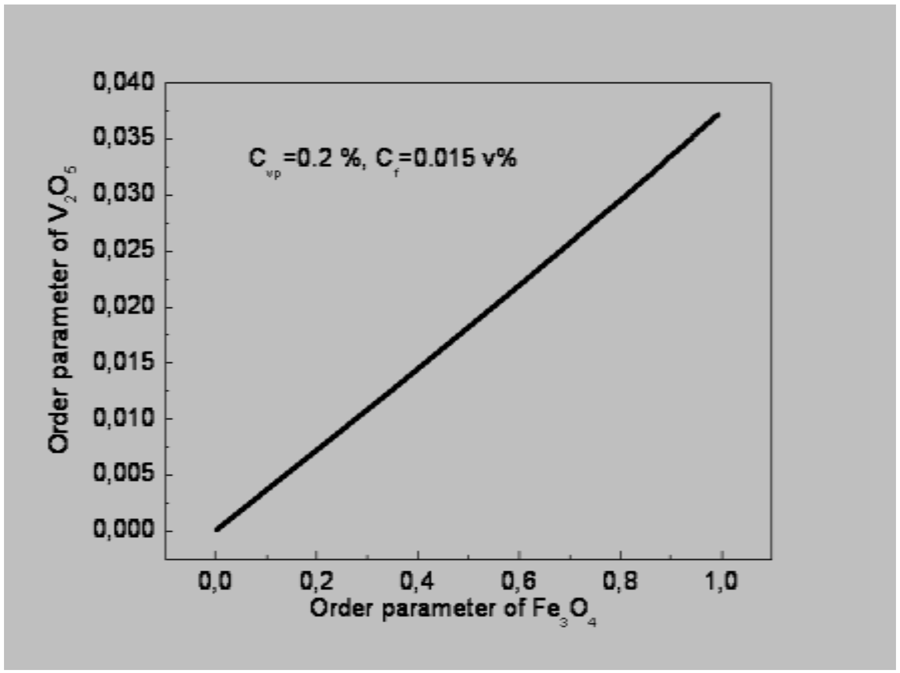


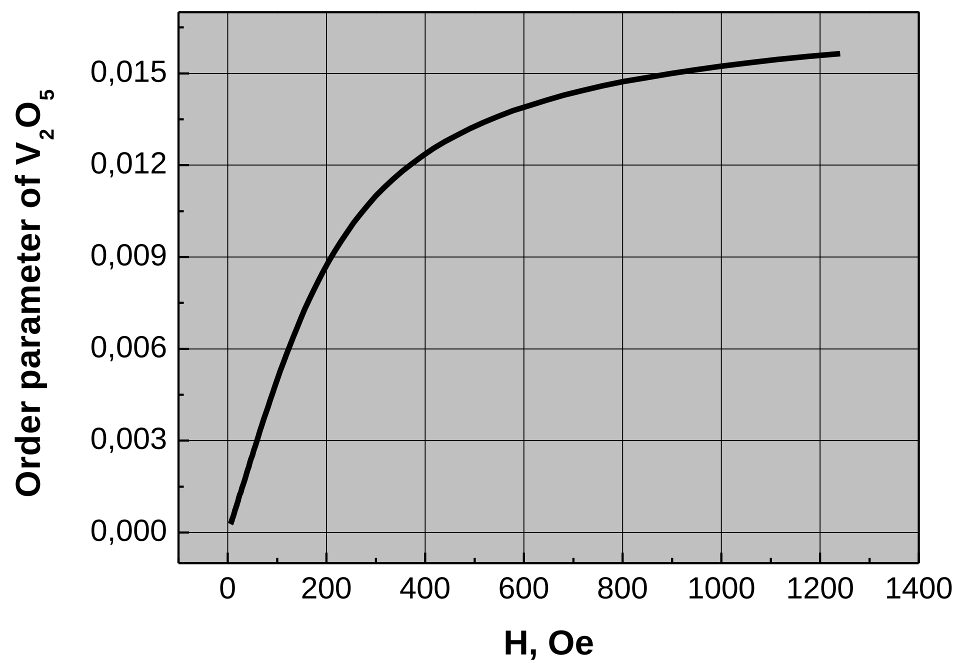
Low density: isotropic phase



High density: nematic phase

Onsager model for two-component dispersion in external field: isotropic phase

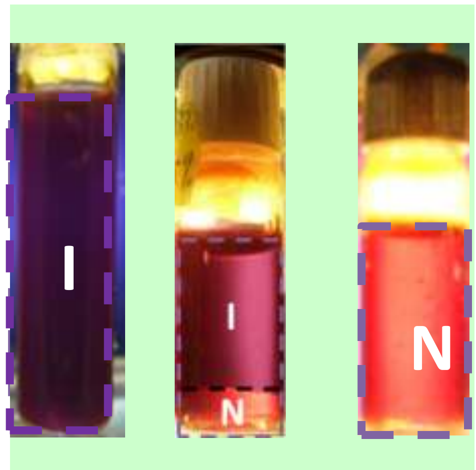




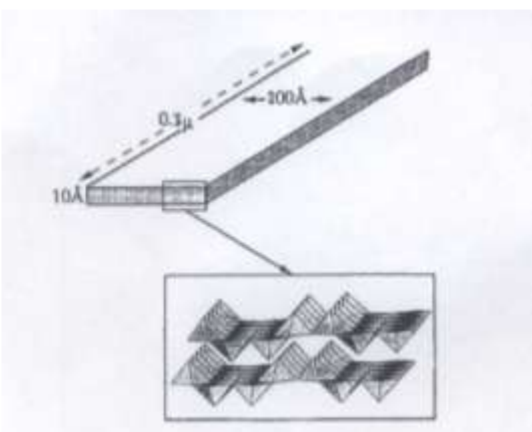
Control of the order of one of the components by external field allows effective way to ordering of the other component.

Not-magnetic component: nano-ribbons of vanadium pentoxide V_2O_5

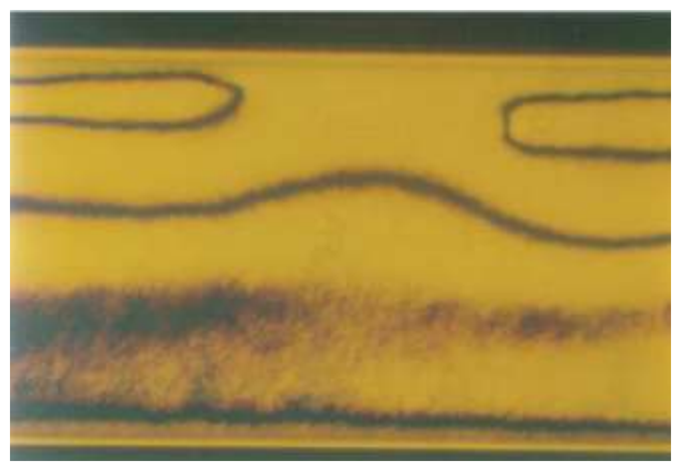
Hans Zocher



$c_{vp} < 0.4\%$ $0.4\% < c_{vp} < 0.6\%$ $c_{vp} > 0.6\%$



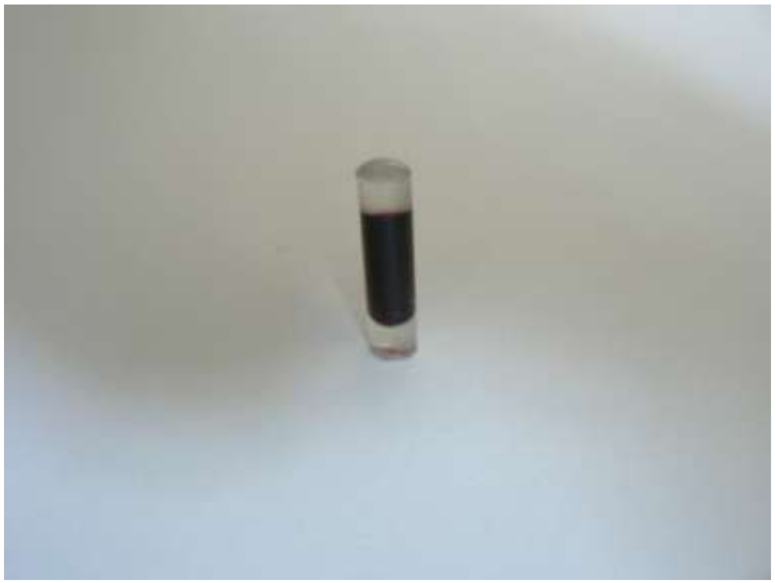
Spatial structure

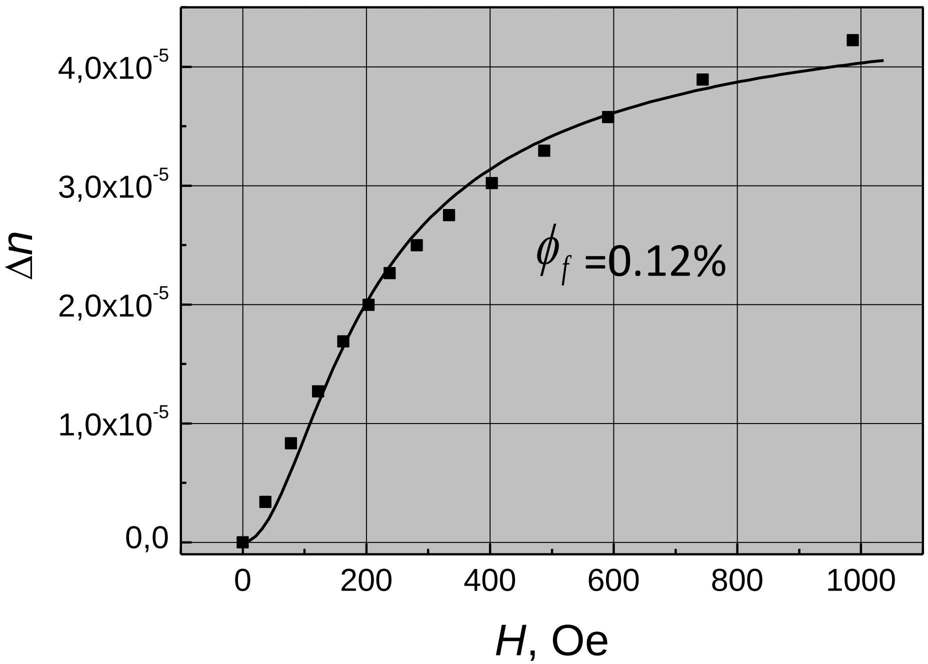


Nematic texture

Magnetic component: superparamagnetic nanoparticles of magnetite Fe_3O_4

Sample: $Fe_3O_4 + H_2O$





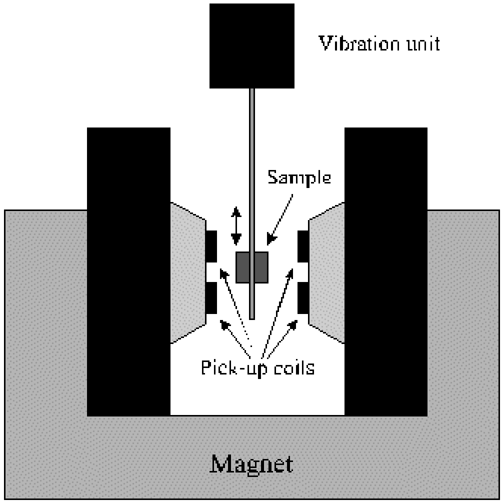
M. Xu and P. J. Ridler. J. Appl. Phys. **82**, 326 (1997)

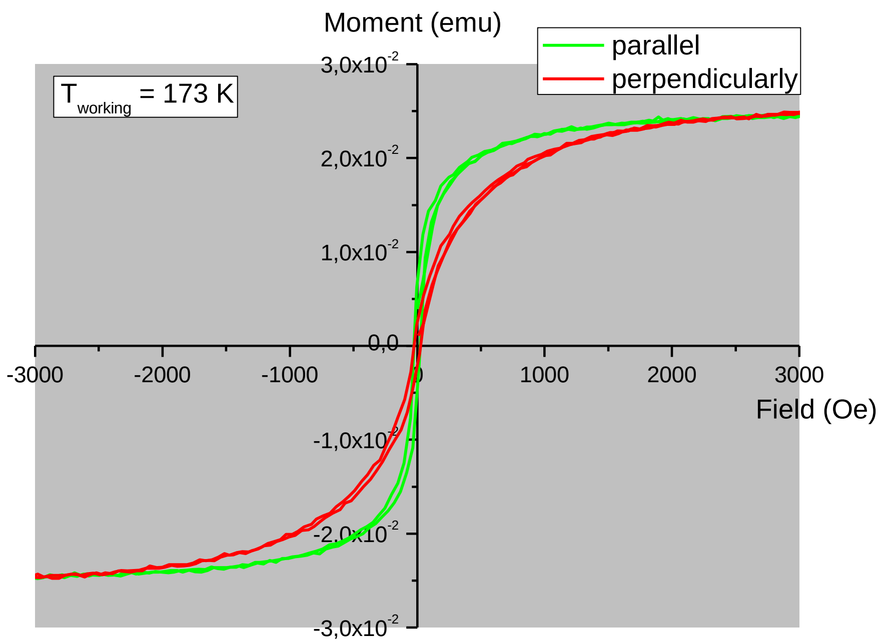
$$\Delta n = \frac{1}{2} n_{aq} C_f \gamma_{af} \left(1 - \frac{3}{aH} \coth(aH) + \frac{3}{(aH)^2} \right)$$

Applying a magnetic field induces a magnetic dipolar coupling between the particles. This results in the formation of chains that disappear after the magnetic field is turned off. The formation of chains of magnetic Fe_3O_4 particles brings about a magnetically-induced birefringence of the suspension.

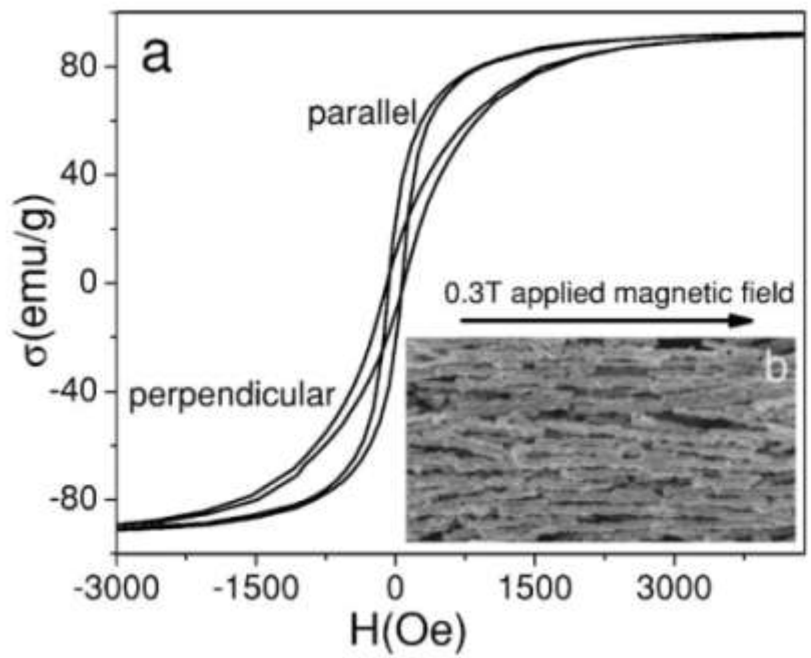
Magnetization of superparamagnetic nanoparticles of magnetite Fe_3O_4. Magnetic anisotropies of chains.

Vibration magnetometer



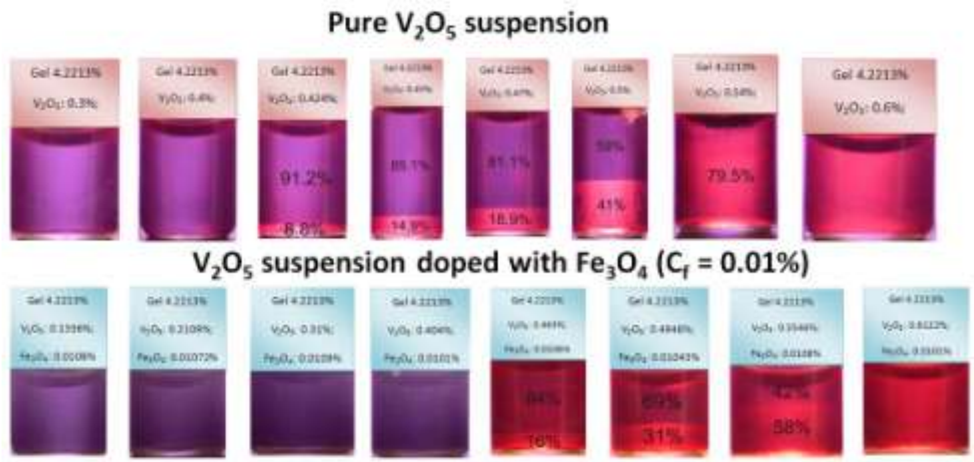


Magnetic anisotropies of chains

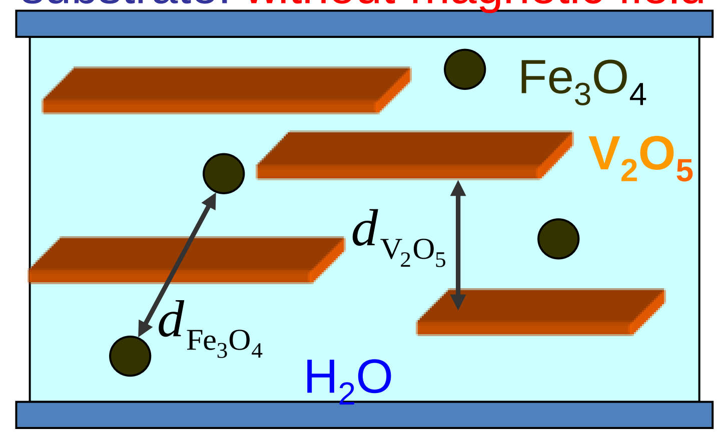


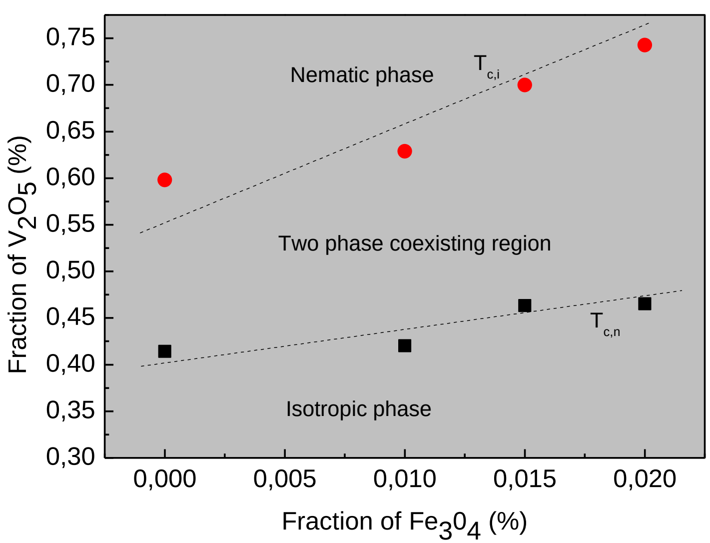
Y. Zhang, L. Sun, Y. Zhai. Appl. Phys. **101**, 09J109 (2007)

Vanadium Pentoxide + Fe_3O_4: ribbons and chains

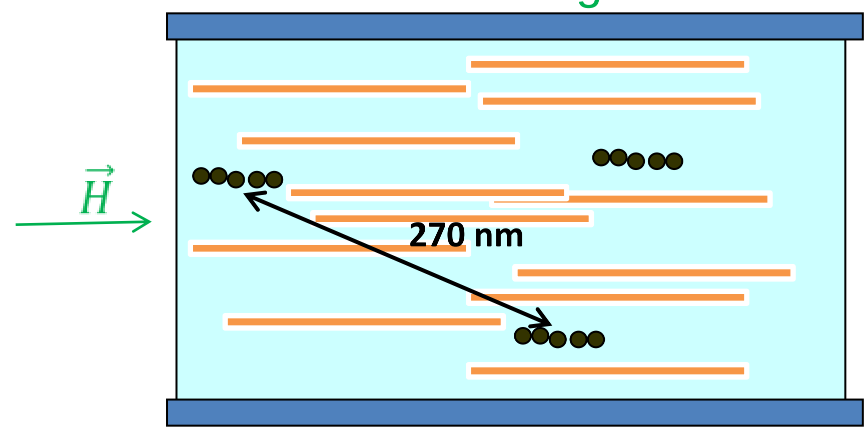


substrate: without magnetic field





substrate: with magnetic field

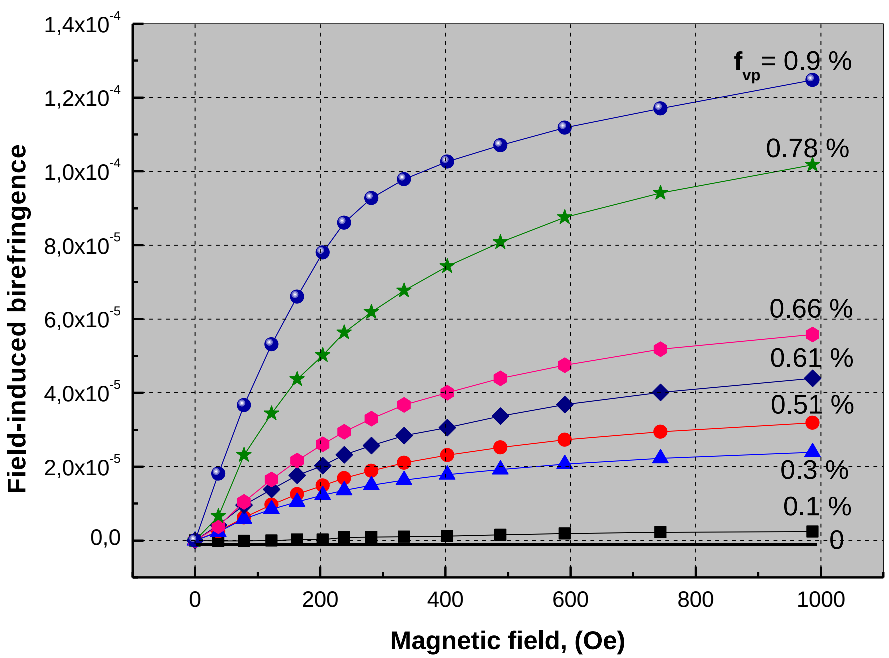


Typical composition: V_2O_5 0.02% + Fe_3O_4 0.015 v%

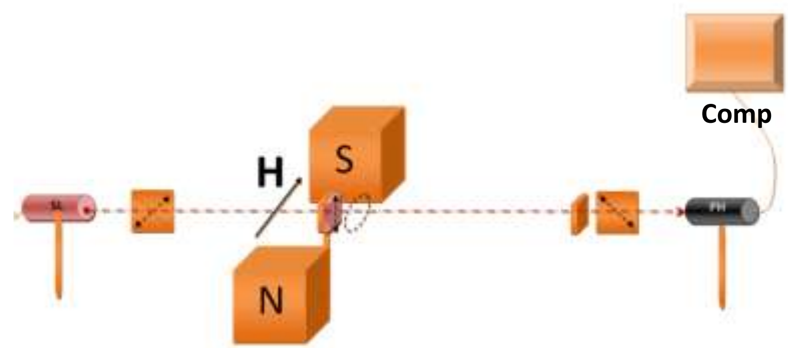
V_2O_5 **ribbons: 300 x 20 x 1 nm**

Fe_3O_4 **nanoparticle chains: 10 nm x 7 = 70 nm**

Ribbons and chains in isotropic phase: H-induced birefrigence. Cotton-Mouton Effect



Senarmont technique

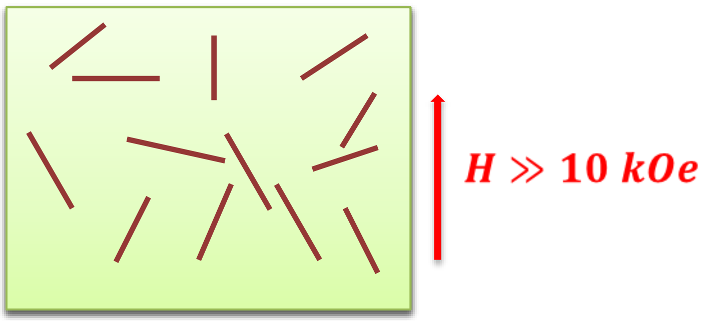


Phase retardation measurement:
absolute precision is about 0.2 nm

None of the components separately do not reveal H-induced birefringence, but together they demonstrate a strong Cotton-Mutton effect!

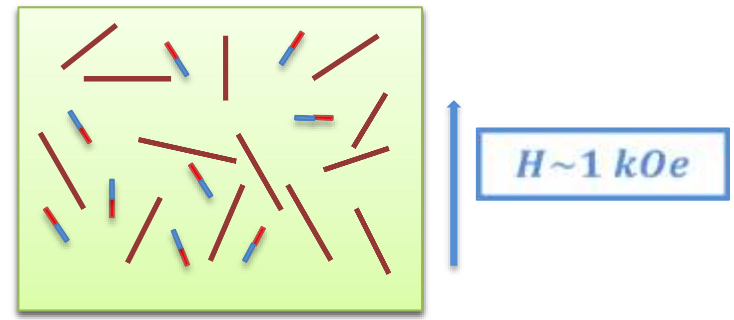
Ribbons and chains in isotropic phase: H-induced birefrigence. Cotton-Mouton Effect

Single component dispersion: $V_2O_5+H_2O$

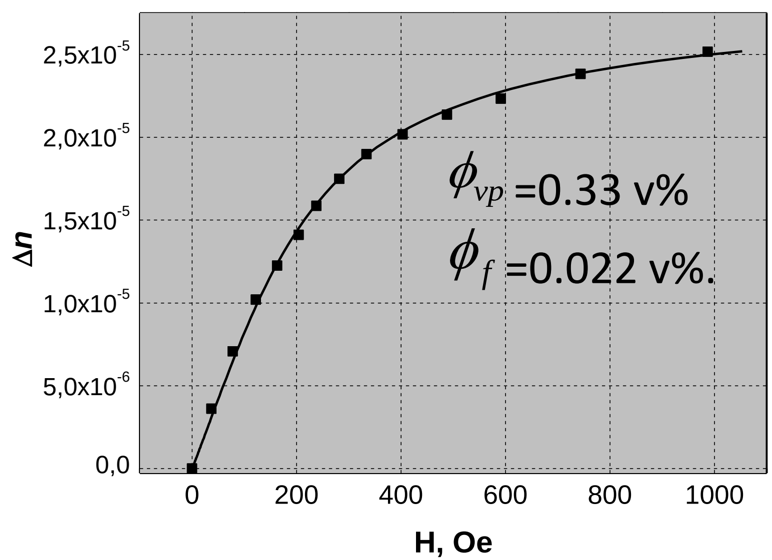


Low density: isotropic phase

Two component dispersion: $V_2O_5+Fe_3O_4+H_2O$



Low density: isotropic phase

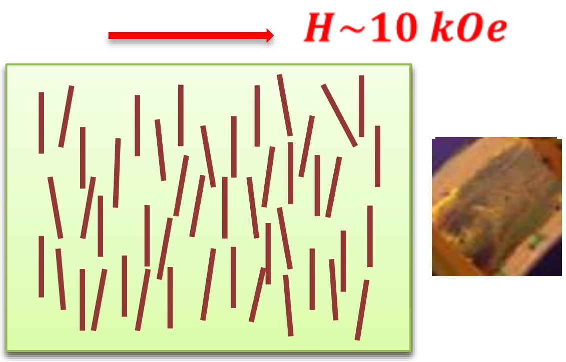


$$\Delta n_{vp} = A(\gamma_a)\phi_{vp}S_{vp}(H)$$

The experimental (square dots) and theoretical (solid line) $\Delta n_{vp}(\vec{H})$ **dependence**

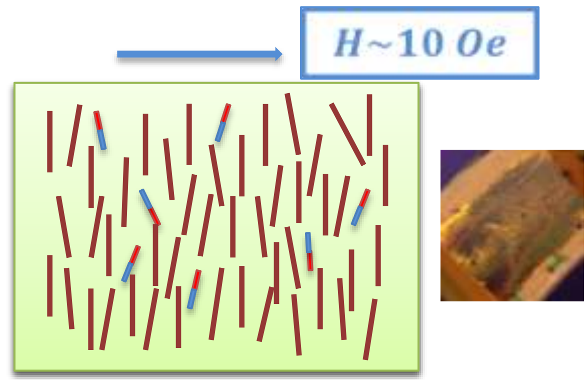
Ribbons and chains in nematic phase: H-induced director reorientation.

Single component dispersion: $V_2O_5+H_2O$

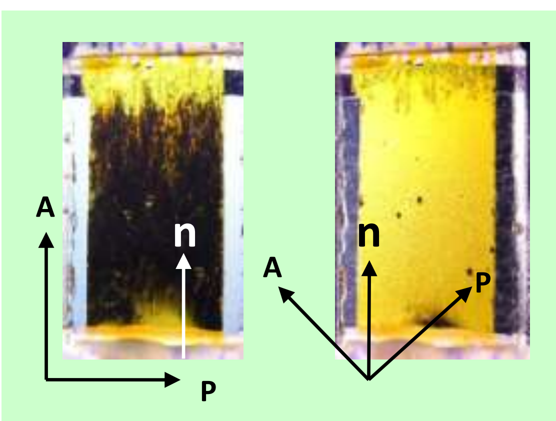


High density: nematic phase

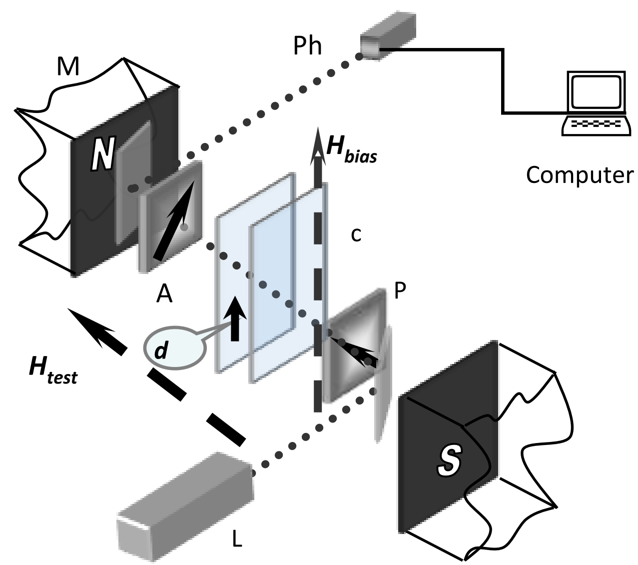
Two component dispersion: $V_2O_5+Fe_3O_4+H_2O$



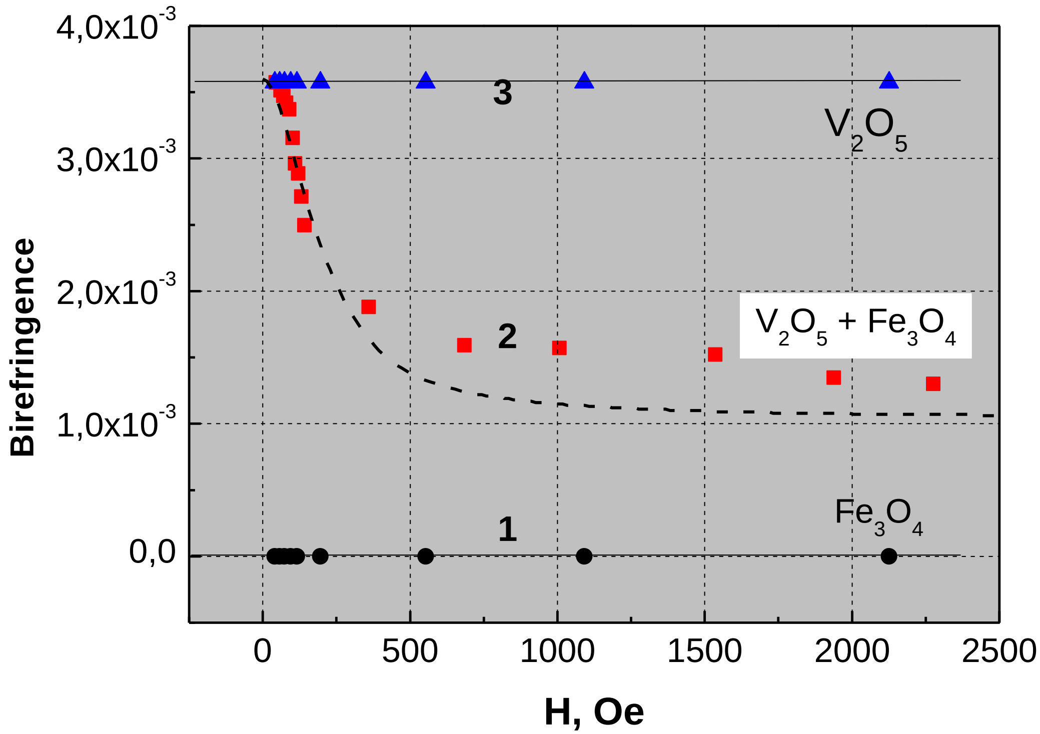
High density: nematic phase



Cell thickness - 100 μm
Liquid Crystal – $V_2O_5+Fe_3O_4+H_2O$
Planar alignment
H_{bias} = 20 Gs, H = 0-2kGs



Ribbons and chains in nematic phase: H-induced director reorientation.



H= 0

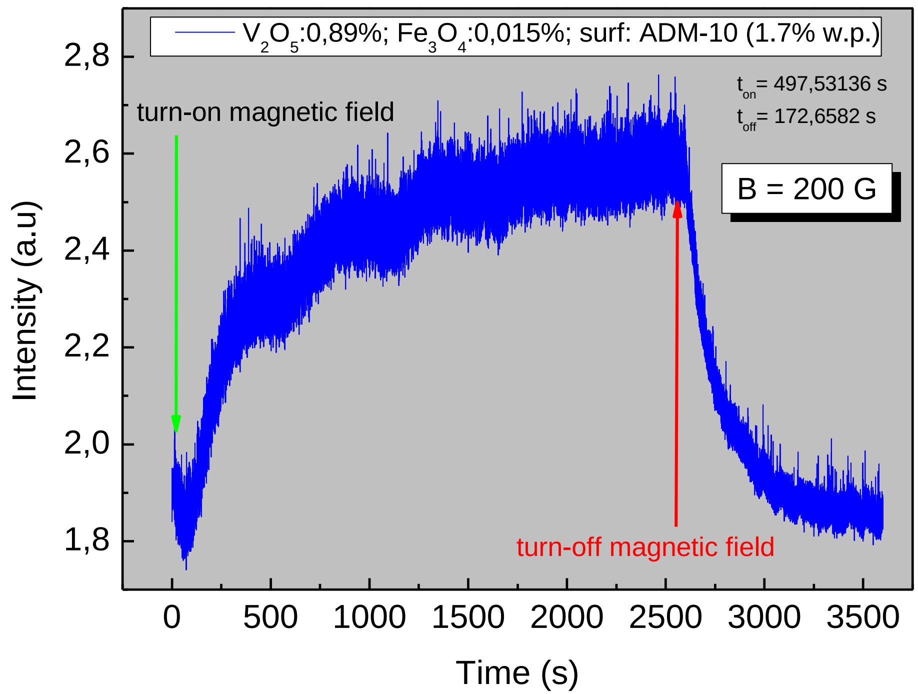
H= 10 Oe

V_2O_5: 0,707%; Fe_3O_4: 0,0111%

Cell thickness - 100 μm

V_2O_5 suspension: no response.
Fe_3O_4 suspension: no visible response.
V_2O_5 + Fe_3O_4 suspension: giant response on magnetic field!

Dynamic of magneto-optical response in nematic phase



Recovering of the initial alignment points on the producing of an easy axis. Adsorption during the cell filling.

Birefrigent amplification

H-filed induced ordering
in magnetically sensitive component
with weak anisometry

The ordering
magnetically insensitive component
with high anisometry

Strong anisotropy in the system

At H = 1 kGs Fe_3O_4 suspension gives $\Delta n \approx 4 \times 10^{-7}$

At H = 1 kGs $V_2O_5 + Fe_3O_4$ suspension gives $\Delta n \approx 5 \times 10^{-5}$

The gain coefficient is about 100

Conclusions

1. Strong order coupling between the components in two-component Onsager mixture allows effective control of the suspension anisotropy and determines unique sensitivity such mixtures to external field.

2. In isotropic phase the H-induced ordering of magnetic component of Onsager mixture results in a strong Cotton-Mouton like effect in not-magnetic Vn_2O_5 component of the mixture.

3. In nematic phase H-induced orientation of magnetic component results in reorientation of not-magnetic Vn_2O_5 component along H-field and giant sensitivity of the suspension to magnetic field.

Thanks a lot!!!