Experimental report

13/02/2019

Proposal: 9-11-1883 **Council:** 4/2018

Title: SANS study of magnetic nanoparticles ordering in liquid crystal host

Research area: Soft condensed matter

This proposal is a new proposal

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Samples: liquid crystal
cobalt ferrite nanoparticles

Instrument	Requested days	Allocated days	From	To
D33	4	2	24/09/2018	26/09/2018

Abstract:

Liquid crystals (LCs) belong to a class of soft condensed matter- characterized by the combination of fluidity of ordinary liquids with the direction dependent electric and optical properties of crystalline solids. The majority of LCs are formed by rod-like organic molecules, where their ordering is a function of temperature. In the nematic phase the molecules have no positional order, but they tend to point in the same direction (along the director n). Due to the anisotropy of the dielectric permittivity and of the diamagnetic susceptibility it is possible to control the orientational order of LCs. A promising method how to modify the properties of LCs is to doped them with magnetic nanoparticles (MNs) in low volume concentrations. Stable colloidal suspensions of fine MNs in nematic LCs called ferronematics (FNs) can be easily aligned by a magnetic field and these therefore act as nanomagnets. The most essential feature of FNs is a coupling between the MNs (their magnetic moment m) and the LC matrix (the director n). mentioned existing coupling ensures that the effect of the magnetic field will be transferred into the nematic host.

SANS study of magnetic nanoparticles ordering in liquid crystal host

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Liquid crystals (LCs) belong to a class of soft condensed matter that are characterized by the combination of fluidity of ordinary liquids with the direction dependent electric and optical properties of crystalline solids. The majority of LCs are formed by rod-like organic molecules with a length of approximately 2.5 nm, where their ordering is a function of temperature. In the nematic phase the molecules have no positional order, but they tend to point in the same direction (along the director ***n***). Due to the anisotropy of the dielectric permittivity and of the diamagnetic susceptibility it is possible to control the orientational order of liquid crystals. A promising method how to modify the properties of liquid crystals (LCs) consists in doping them with magnetic nanoparticles (MNs) in low volume concentrations. This concept was theoretically introduced by Brochard and de Gennes [1]. Stable colloidal suspensions of fine MNs in nematic LCs called ferronematics (FNs) can be easily aligned by a magnetic field and these therefore act as nanomagnets. The most essential feature of FNs is a coupling between the MNs (their magnetic moment ***m***) and the LC matrix (the director ***n***). The mentioned existing coupling ensures that the effect of the magnetic field will be transferred into the nematic host.

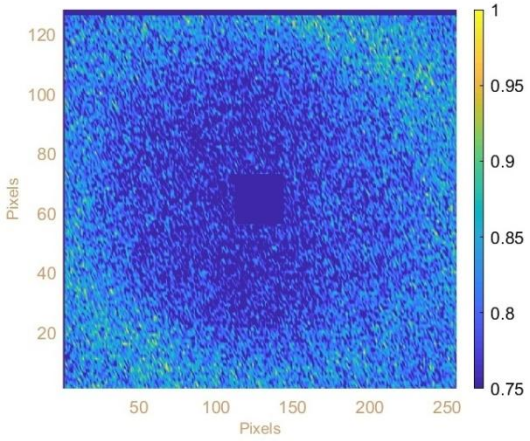
In our previous work we have studied the changes in the LC structure of a simple nematic mesogen caused by doping with cobalt ferrite nanoparticles as well as the influence of phase transition on the colloidal stability, especially on the alignment of MNs in different phases. The experimental SAXS results showed that the aggregates formed by MNs were formed at the beginning and they were oriented in the nematic phase under ambient conditions. Upon heating, the LC has a transition for the nematic into the isotropic phase in which the 5CB molecules lose the orientational order and the aggregates follow them. Upon cooling, the nematic order is restored but the aggregates do not fully reach the degree of alignment as before, must likely because of partial phase separation. Moreover, the FN sample showed unexpected behaviour, where a sudden change in magnetization at 7000 Oe was observed (the weight concentration of MNs was 0.085 wt%). Surprisingly, the magnetic properties of the second FN sample (the weight concentration of MNs was 0.062 wt%) were very similar to the magnetic properties of the pure LC [2]. The observed different behaviour of two FN samples based on the same LC and doped with the same kinds of magnetic particles suggest that it is possible to change the magnetic properties of such a composite system, very dramatically by changing the weight concentration of magnetic particles. Therefore, we intent to study different weight concentrations of the same cobalt ferrite MNPs in liquid crystal 5CB to better understand the process of reorientation of MNs. As the LC molecules are ordered in the nematic phase one can suppose that due to the coupling between the MNs and the LC matrix the MNs (elongated aggregates) will be oriented in the nematic phase as well. This magnetic ordering of MNs will be similar to ferromagnetic order, which occurs not due to the magnetic interaction among the magnetic moments of MNs but due to the elastic properties of the LC matrix [3]. This is a unique method to prepare ferromagnetic ordering in the liquid state.

Therefore, spherical $CoFe_2O_4$ MNs were used in various weight concentrations to study the effect of concentration on the structuralization effect of MNs in liquid crystal matrix under the application of magnetic field. The prior SAXS study using 5CB liquid crystal sample and its mixture

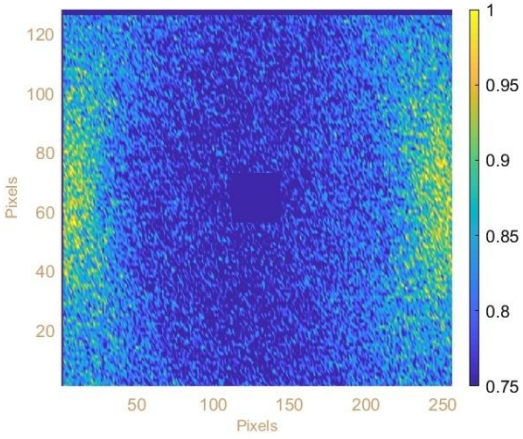
with magnetic nanoparticles were measured in zero magnetic field in different phases of liquid crystal. We have measured 6 samples in the nematic phase (T= 20°C)- one sample of undoped liquid crystal as a reference and 5 samples of ferronematic with different weight concentrations of cobalt ferrite nanoparticles. By changing the value of magnetic field (measurement at five set intensities of magnetic field at two different detector distances) for prepared samples, it was possible to study the magnetic ordering of MNs in FN suspensions.

5CB liquid crystal

0 Tesla



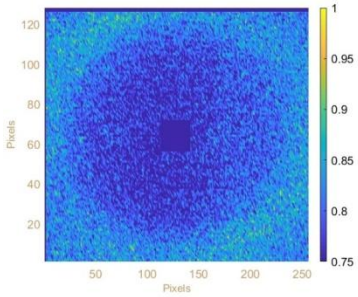
1 Tesla



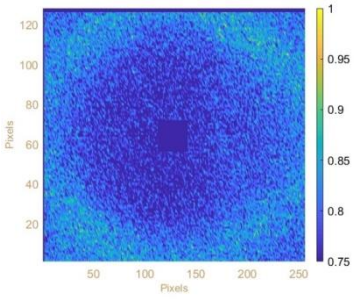
For the undoped liquid crystal 5CB, an isometric scattering pattern is observed at no field. The changes with magnetic field were observed- a transition to an elongated anisotropy (reduced intensitiy in the vertical direction) along the horizontal magnetic field direction. Here in case of undoped liquid crystal 5CB, we can see two peaks of an arc like shape appear at the q= 0.25 $Å^{-1}$. It corresponds to the distance d=25 Å between the liquid crystal molecules along the long axis.

5CB@$CoFe_2O_4$ (MH289) 0.074 wt%

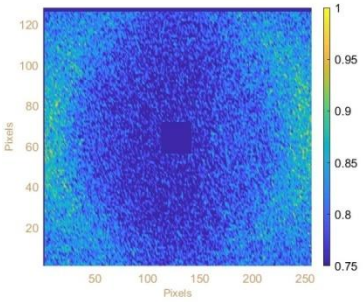
0 Tesla



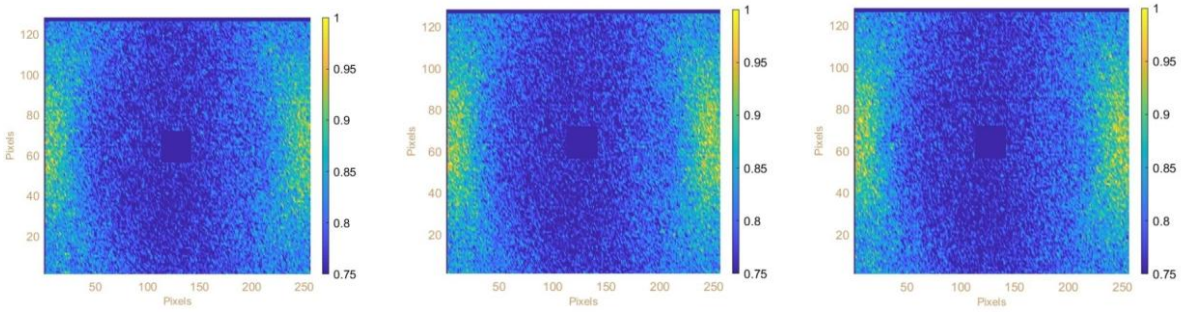
0.05 Tesla



0.1 Tesla



0.2 Tesla 0.5 Tesla 1 Tesla



For doped LC 5CB with cobalt ferrite NPs at zero field, there is an isotropic LC ensemble. For fields larger than 0.2 T the crystals start to orient with varying degree for the different samples (different weight concentration of NPs: 0.074 wt%, 0.093 wt%, 0.11 wt%, 0.129 wt%, 0.147 wt%). There is a clear difference in the field-alignment behaviour for varying degree of MNP doping (only one representative example is presented here). At 1T, it was observed an aligned structure for all samples, but the field-dependence/degree of alignment for lower field varies from sample to sample. This variation correlates with the MNP content.

With field-alignment the scattering intensity is redistributed to the horizontal direction. This means there was a reorientation of the molecules from a partially aligned initial state to a perpendicular magnetic-field aligned configuration. This is also nicely visible in the 2D scattering images.

References:

[1] F. Brochard, P. G. de Gennes, *J. Phys. (Paris) 31* (1970) 691.

[2] V. Gdovinova, M. A. Schroer, N. Tomasovicova, I. Appel, S. Behrens, J. Majorosova, J. Kovac, D. I. Svergun, and P. Kopcansky. *Soft Matter 13* (2017) 7890.

[3] A. Mertelj, D. Lisjak, M. Drofenik and M. Copic. *Nature 504* (2013) 237.