Understanding “supernematics” created by dispersing ferroelectric nanoparticles

Theory of Ferroelectric Nanoparticles in Nematic Liquid Crystals

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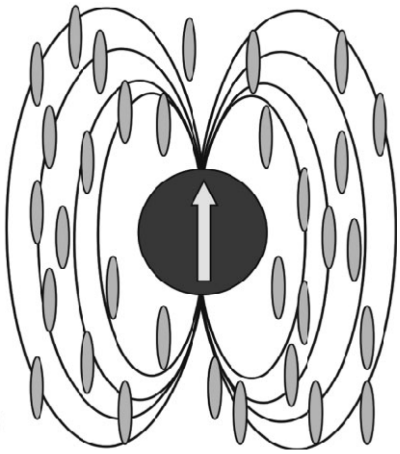
Physical Review Letters **102**, 197802 (2009)

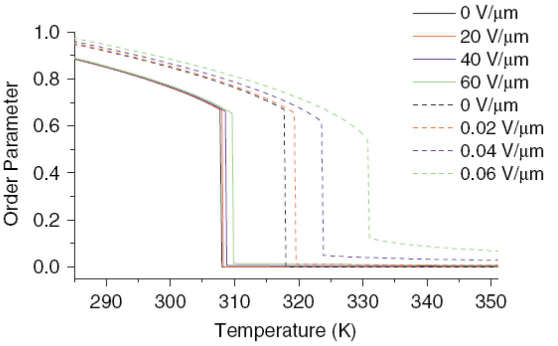
Recommended with a Commentary by Slobodan Zumer, University of Ljubljana

Colloidal dispersions of micron and supramicron size particles in liquid crystal solvents are very different from dispersions in nonmesogenic solvents. The effective long range interaction, originating from the sharing of deformed order parameter areas, allows formation of two-dimensional colloidal lattices and self-assembly of colloidal superstructures [1]. Usually the perturbation of order caused by the particles is expected to become negligible with decreasing their size to the nanometer range. Nevertheless, recent experiments on stable nematic dispersions of nanoparticles have reported that already low concentration of ferroelectric nanoparticles greatly increases their sensitivity to applied electric fields [2]. In particular, $Sn_2P_2S_6$ or $BaTiO_3$ nanoparticles at low concentration (<1%) increase the orientational order parameter of the host liquid crystal, increase the isotropic-nematic transition temperature by several degrees, and decrease the switching voltage for the Frederiks transition [3-5]. Out-of-phase fluctuations of the nematic director and electric polarization have been detected [6]. Studies also indicate large dependence on the preparation procedure [5,7].



Ferroelectric particle with electric dipole moment, which produces an electric field that interacts with orientational order of the nematic phase (Figure 1 taken from the recommended paper).

The understanding of rather diverse experimental findings stimulated theoretical investigations. Li and coworkers [7] have suggested that the nanoparticles produce large local electric fields, which polarize the nematic molecules and thus indirectly increase the intermolecular interaction. Although this approach does not take into account the orientational distribution of the nanoparticles themselves, it yields a prediction of the increase of the isotropic-nematic transition temperature T_{NI} with concentration of dispersed particles. In the discussed paper the authors propose a new approach based on a simple statistical mechanics of ferroelectric nanoparticles in nematic liquid crystals. The orientational distribution of the nanoparticle dipole moments is characterized by a tensorial orientational order parameter, analogous to the standard liquid-crystal order tensor. This order parameter interacts with the orientational order of the nematic molecules and stabilizes the nematic phase. The predicted enhancement in T_{NI} is in good agreement with experiments. Its dependence on ion screening of electrostatic interactions offers explanation of very diverse experimental results. The authors study also the coupling to the external electric field. Therefore the polar order parameter of colloidal particles is introduced as well. The authors skip the discussion on the well known linear field effect and concentrate their attention on the response of the isotropic phase to an applied electric field. This phenomenon, known as Kerr effect, is predicted to be greatly enhanced by the presence of nanoparticles.



Prediction for field-induced nematic order parameter as a function of temperature for several values of an applied electric field, with (dotted lines) and without ferroelectric (solid lines) nanoparticles (Figure 3 taken from the recommended paper).

In conclusion, the theoretical approach based on a simple statistical mechanics of ferroelectric nanoparticles in nematic liquid crystals provides a sound explanation of the majority of current experimental evidence. Although the approach is qualitative, as all other Landau-type approaches, it demonstrates how, without a chemical synthesis, the coupling of particular nanoparticles with macroscopic orientational order can provide an opportunity to create a “supernematic” medium with greatly enhanced physical properties relevant for applications.

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