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Introduction

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One contribution of 14 to a Theo Murphy Meeting Issue 'New frontiers in anisotropic fluid–particle composites'.

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New frontiers in anisotropic fluid–particle composites

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1. Introduction

Liquid crystal displays have a myriad of applications, from simple thermometers to mobile phones, computer and TV screens. They have impacted our lives, invading our houses, transportation and workplaces. With the present online culture and increasing demands for energy efficiency has come the need for displays that can be read in all kinds of lighting conditions and limit the drain from the batteries of portable devices. In the search for new technologies, researchers are increasingly turning to composite materials. Our aim for this meeting was to bring together world leaders plus young researchers in two key areas: isotropic particles in anisotropic liquid crystals, and colloidal liquid crystals (clay platelets or carbon nanotubes in isotropic fluids, for example). These two areas of modern materials research are rich in complex science and have substantial applications potential, ranging from electrophoretic inks through to biofluidics.

Before we give a brief summary of each paper to portray the flavour and scope of the meeting, we would like to thank a number of those who made the meeting possible.

The meeting would not have happened without the generous support of the Royal Society, which hosted the Theo Murphy Meeting on *New frontiers in anisotropic fluid–particle composites* at the Kavli Royal Society International Centre. The local organization was excellent, and we would like to thank all the Royal Society personnel who took on the load of the organization and many of the interactions with the speakers, particularly Tracey Wheeler. The marvellous setting at Chichley Hall was appreciated by all

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Figure 1. Participants of the Theo Murphy meeting: New frontiers in anisotropic fluid-particle composites, 28–29 June 2012. (Online version in colour.)

participants (figure 1) and the relaxed atmosphere fostered by Professor Sir Peter Knight, Principal of the Kavli Royal Society International Centre, was influential in promoting scientific dialogue.

Second, we would like to thank all those who contributed to the scientific content of the meeting. The speakers all accepted our invitations with enthusiasm, and prepared informative, stimulating and often entertaining talks; they have all made our editorial task easier by the timely provision of their manuscripts. The attendees not only were responsible for the lively discussions both during and after talks, but also provided some half dozen excellent posters and made the question-and-answer session a resounding success at the end of the meeting.

The meeting itself, and the papers in this Theo Murphy Meeting Issue, show that, even though liquid crystals have been explored for many years, and have an enormous impact on our lives, there is still much more to discover about them.

2. Non-organic particles in liquid crystals

The opening session, on non-organic particles in liquid crystals, was opened by Oleg Lavrentovich [1]. Oleg first described the unusual properties encountered when colloids are suspended in liquid crystal phases, particularly the levitation induced by the energy balance between the surface anchoring and elasticity of the liquid crystal. When a field is applied across very dilute suspensions, interesting electrophoretic effects occur (figure 2), which cannot be observed in isotropic solvents: particles can be driven by an AC field and zero-charge particles can move. Electrically induced backflow generates bidirectional motion, and allows controlled anisotropic aggregation.

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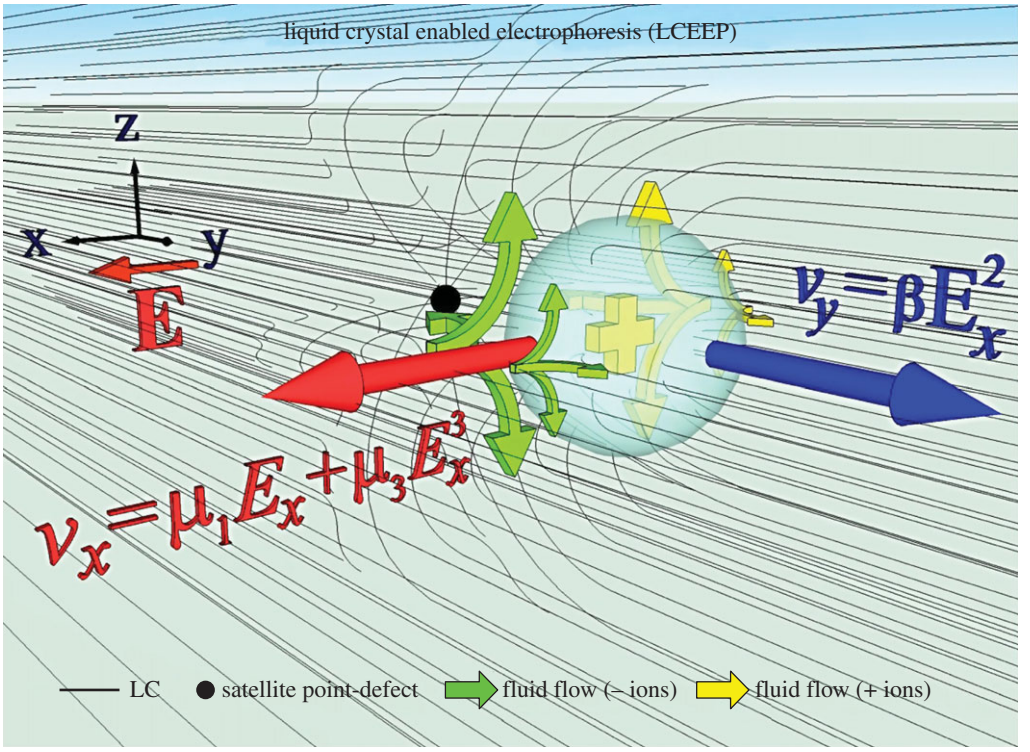

Figure 2. Oleg Lavrentovich's cartoon summary of electrophoresis in a liquid crystal. (Online version in colour.)

Torsten Hegmann [2] described the use of gold nanoparticles as additives for liquid crystals. He discussed the importance of the synthesis method for gold nanoparticles and how the capping with alkyl thiols helps to stabilize the dispersion of the nanoparticles in the liquid crystal. He mentioned in particular the use of conjugated thiol–silane compounds to produce extremely stable gold nanoparticles in liquid crystals (figure 3). Torsten concluded with some results illustrating the application of gold nanoparticles in liquid crystals to control thermally the alignment and electro-optic switching effects.

In the final paper of the session, Yuriy Reznikov [3] discussed the strong coupling between ferromagnetic particles and rod-like particles in aqueous suspensions. Yuriy showed how the Onsager model for two-component dispersions in an external field predicts strong order coupling between the components. A mixture of magnetic and non-magnetic rods with the magnetic component close to the isotropic–nematic transition concentration, but the total concentration below the nematic concentration, behaved like a single-component suspension, with all components following the behaviour of the magnetic component.

Another interesting research topic is the influence of nanoparticles on ferroelectric, magnetic and dielectric properties of liquid crystalline suspensions, not discussed during the meeting but touched upon in the paper on the influence of suspended nanoparticles on the Freedericksz threshold of the nematic host [4].

3. Structural studies and modelling

The first afternoon session was devoted to structural studies and modelling, and was opened by Rob Richardson [5], who presented a paper on colloidal nematic liquid crystals made from pigment nanoparticles. The underlying principles being used are that anisotropic nanosized pigment particles can form liquid crystalline phases in isotropic solvents and can be aligned by

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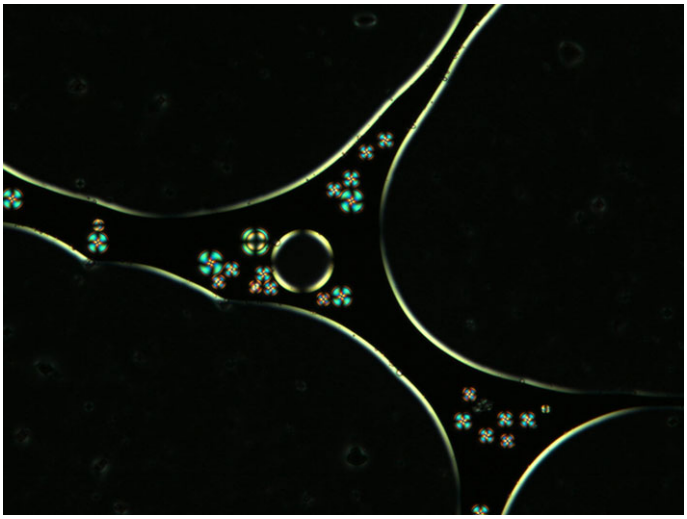

Figure 3. The beauty of Torsten Hegmann's suspended gold rods viewed with a polarization microscope. (Online version in colour.)

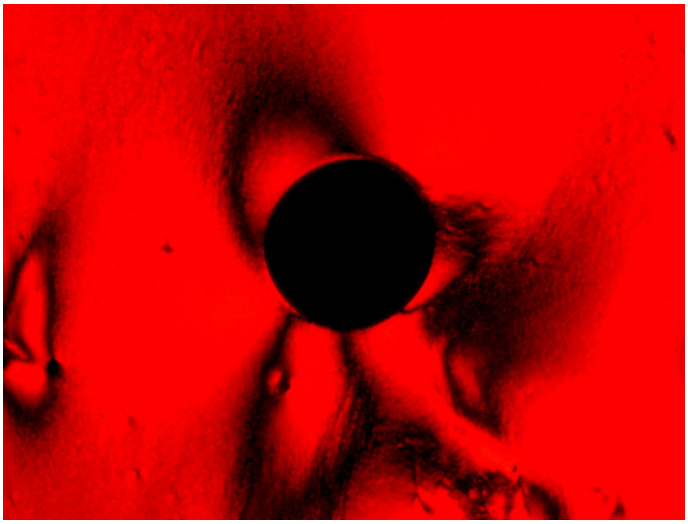

Figure 4. Schlieren structures in Rob Richardson's colloidal nematic liquid crystals. (Online version in colour.)

electric fields. In nematic liquid crystals, such particles show improved orientational ordering, although there is some aggregation (figure 4). Rob also reported that the electro-optic response could be predicted quite accurately from the order parameter for the transition dipoles measured by X-rays. The prospect of rod-shaped particles with a co-axial transition dipole promises high dichroism in devices.

Jan Lagerwall [6] explored liquid crystals in new geometries, particularly microfluidic-produced structured bubbles and shells (figure 5), and electro-spun responsive structures for wearable devices. These ingeniously produced shells are easy to study and reveal new physics and textural sequences linked to phase transitions. They have the prospect of applications, if their size can be reduced by two to three orders of magnitude. Jan concluded his presentation with a fascinating insight into the properties and potential applications of electro-spun liquid crystal fibres.

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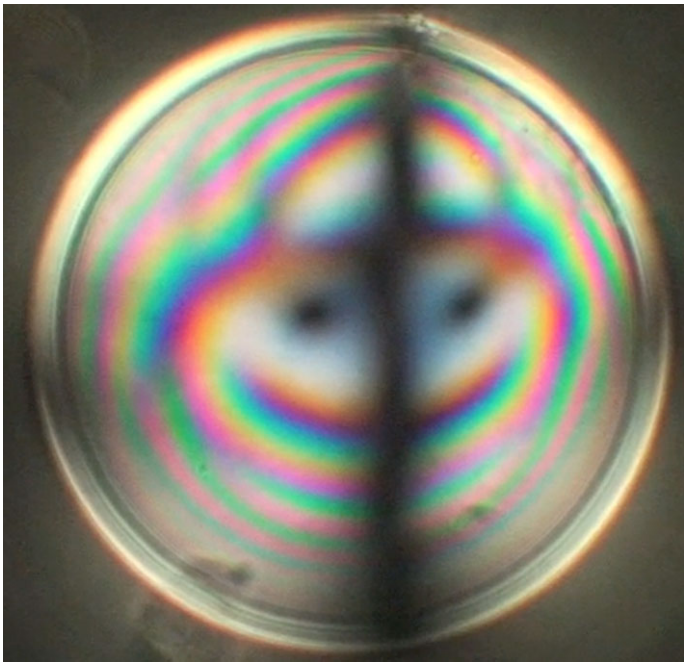

Figure 5. In Jan Lagerwall's hand, liquid crystal shells are happy. (Online version in colour.)

The final paper in this session, presented by Matthias Schmidt [7], showed that, by using a geometry-based fundamental measure density functional theory, it is possible to calculate the bulk phase diagram for colloidal mixtures of vanishingly thin hard circular platelets and hard spheres. He formulated a fundamental measure functional for mixtures of colloidal platelets and freely overlapping spheres that represent ideal polymers, and used it to calculate phase diagrams. Matthias also showed that in addition to the isotropic—nematic and nematic–nematic phase transitions, platelet–polymer mixtures display isotropic–isotropic demixing for low platelet/polymer size ratio. In contrast, isotropic–isotropic demixing does not occur in hard-core platelet–sphere mixtures for the size ratios considered.

4. Colloidal liquid crystals and carbon nanotubes

The first presentation in the session on colloidal liquid crystals and carbon nanotubes was given by Philippe Poulin [8] of the University of Bordeaux, who described the ability of nanocarbon materials such as carbon nanotubes (CNTs), graphene oxide and reduced graphene oxide to show liquid crystalline behaviour. Flakes of reduced graphene oxide, not normally soluble, could be suspended in water in the presence of bile salts, and under certain circumstances liquid crystal phases may be formed.

Giusy Scalia [9] considered the complementary issue of CNTs dispersed in liquid crystals. Polarized Raman spectroscopy was used to study the alignment behaviour of CNTs in liquid crystals. Doping the liquid crystal with small amounts of CNT does not change the dielectric behaviour of the liquid crystal, but it can have an effect on its conductivity.

Following these two talks on nanocarbon materials, the last two talks in this session considered the occurrence of liquid crystal phases in colloidal suspensions of clay particles. Jeroen van Duijneveldt [10] gave the first of these on the topic of the occurrence of liquid crystal phases in suspensions of natural clays. Rod-shaped clays, such as sepiolite, form nematic suspensions, but plate-like clays, for example montmorillonite, do not. The flexible nature of

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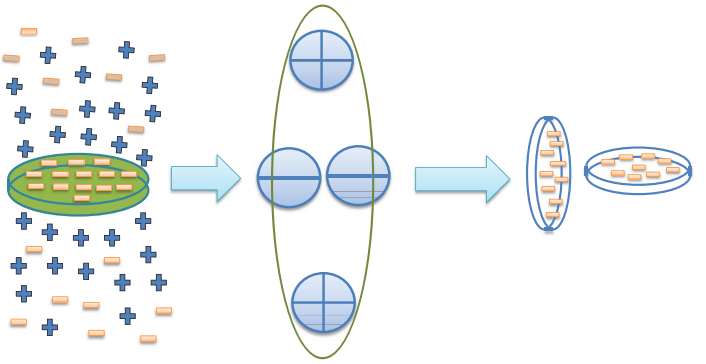

Figure 6. Jeroen van Duijneveldt's cartoon 'Modifying the structure and flow behaviour of aqueous montmorillonite suspensions with surfactant.' (Online version in colour.)

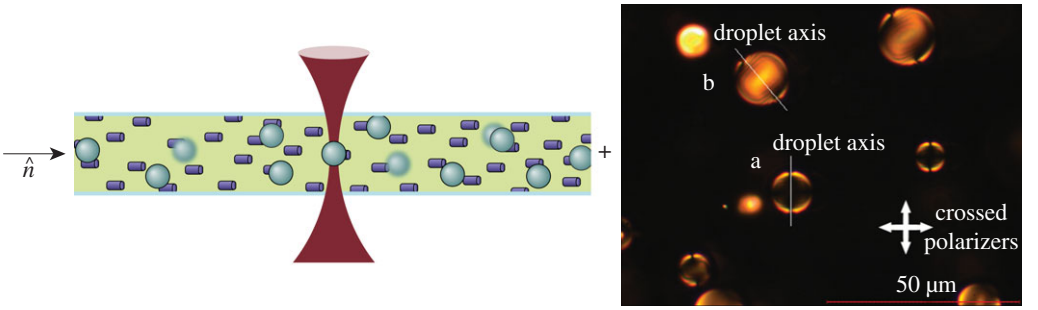

Figure 7. Squeezed by Helen Gleeson, in theory and practice. (Online version in colour.)

the montmorillonite plates was described as one possible reason, charge separation could be another (figure 6).

Henk Lekkerkerker [11] brought the session to a close with a brief, but educating and entertaining, history of mineral colloidal liquid crystals. He described some of the new frontiers that are being found in mineral colloid liquid crystals, how they are ideal model systems and how they could even be used as potential candidates to demonstrate the much sought after biaxial nematic phase.

5. Optical tweezers and liquid crystals

Opening the final session of the conference, Helen Gleeson [12] showed how optical traps can be used to manipulate particles in liquid crystals to perform micro-rheology experiments to provide information about the viscosity coefficient ratios of the liquid crystal material and the trap stiffness. Laser tweezers can also be a tool to manipulate liquid crystal droplets, leading to a range of phenomena, including all-optical switches and opto-mechanical transducers (figure 7).

The final paper of the conference was given by Igor Muševič [13] on the topic of topology and nematic colloids. Igor showed how topological defects in the form of points and loops can be generated, and how these can interact with each other and, with the aid of laser tweezers, lead to links and knots in chiral nematic liquid crystal colloids, producing a very pictorial representation of known topological features (figure 8). He concluded by showing that liquid

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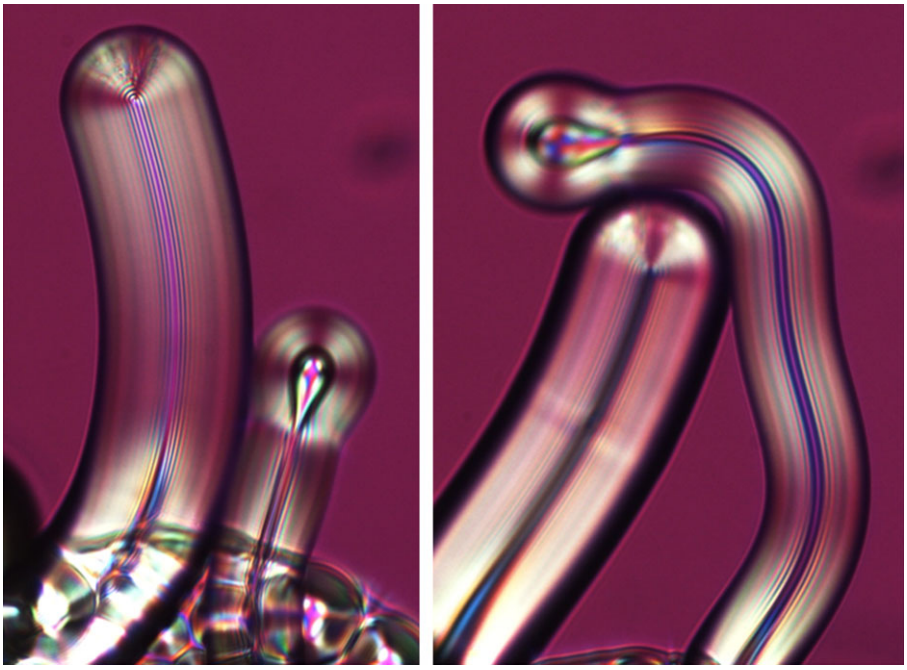

Figure 8. This is not life from Mars, but smectic A structures found by Muševič when CTAB, 8CB and water are mixed. (Online version in colour.)

crystal emulsions could even lead to optical micro-cavities and lasers that can be tuned by electric fields.

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