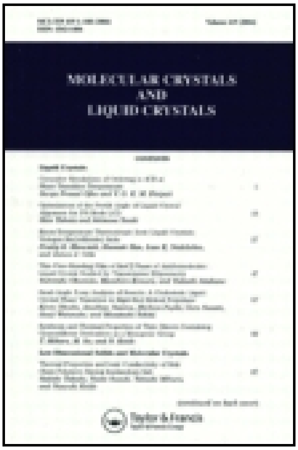

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Study of Composite System: Silica Colloidal Particles in Nematic Liquid Crystal

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STUDY OF COMPOSITE SYSTEM: SILICA COLLOIDAL PARTICLES IN NEMATIC LIQUID CRYSTAL

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We investigate a composite system formed by micrometer-sized silica spheres and a nematic liquid crystal with positive dielectric anisotropy. The surface of the spheres has been treated to obtain homeotropic alignment either by grafting molecules of n-Octadecyltrimetoxysilane or by using lecithin.

In a glass cell with planar anchoring conditions, we have experimentally observed the dipole and the Saturn-ring configurations. Due to the planar treatment of the glass substrates the particles align and can form chains. We studied the effect of an electric field applied parallel to the direction of the rubbing, in the plane of the cell.

Keywords: colloidal dispersions; nematic liquid crystals; topological defects; two-particle interaction

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INTRODUCTION

The study of suspensions of solid particles or immiscible liquid droplets in liquid has recently attracted attention due to their application in industry and for fundamental research [1–3]. Colloidal systems obtained by dispersing solid microspheres in nematic liquid crystals (LC) are of special interest [4–6]. The difference from ordinary colloids arises from the orientational ordering of the LC molecules and the resulting structure in the colloid [6–9]. Topological defects and additional long-range forces between the particles are immediate consequences of this ordering.

The nematic ordering makes it difficult to suspend small particles in a LC host. Particles often segregate into agglomerates distributed nonuniformly in the cell. When the surface of spherical particles is treated to obtain homeotropic alignment of the liquid crystal, the particles can align and form chains. Furthermore the possibility to reversibly change the positions or the orientation of colloidal particles embedded in a matrix is very promising in the field of adaptive materials.

In our experiment, micrometer sized silica spheres have been treated to obtain homeotropic alignment of the nematic liquid crystal by using lecithin or by grafting molecules of n-Octadecyltrimethoxysilane [10]. These microspheres arrange themselves in chains when the colloidal system spheres/nematic liquid crystal was filled in a glass cell with planar anchoring conditions, the chains being oriented in the direction of the rubbing.

For these solid spherical spheres, with homeotropic alignment of the LC, we have checked experimentally Stark's theoretical prediction [7] that an elastic dipole transforms into a quadrupolar configuration known as Saturn ring in the presence of an electric field applied in the plane of the cell.

EXPERIMENTAL

The system, we are interested in, consists of micrometer-sized silica spheres and a nematic liquid crystal E7 (Merck), with positive dielectric anisotropy, $\Delta\varepsilon > 0$. We used silica spheres of 1.5 μm and 40 μm diameter. The concentration of the mixtures was 2% b.w.

On the silica microspheres, homeotropic anchoring was obtained by grafting of n-Octadecyltrimethoxysilane or by using lecithin.

The colloidal system containing 40 μm silica spheres was introduced in cells made by two glass plates separated by 80 μm copper spacers, which served as electrodes. The distance between the electrodes was of 1 mm and the electric field was applied in the plane of the cell. The surface treatment of the glass plates was planar anchoring, obtained by using polymide with the direction of the rubbing perpendicular to the electrodes. The

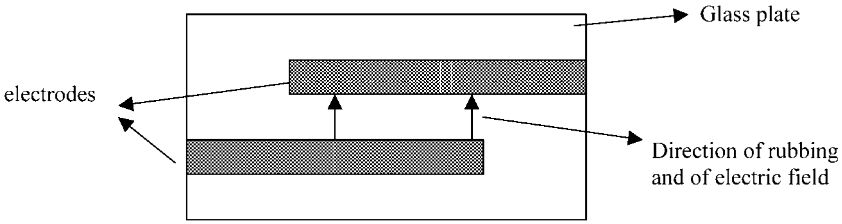

FIGURE 1 Schematic representation of the liquid crystal cell.

mixture containing 1.5 μm/LC was filled in cells of 5 μm thickness, the gold electrodes being also spacers between the two glass plates.

Using a frequency generator (HP) and an amplifier we applied variable a.c. electric fields. The system was visualized using an Olympus polarizing microscope, with a CCD camera, at room temperature.

RESULTS AND DISCUSSIONS

In Figure 2 we present the photo of the chains formed by 1.5 μm grafted silica spheres, in nematic liquid crystal. The mixture was filled in a 5 μm thick cell, with planar alignment of the surfaces. Due to the nematic order, the spheres align in the direction of the rubbing; even in the absence of the electric field.

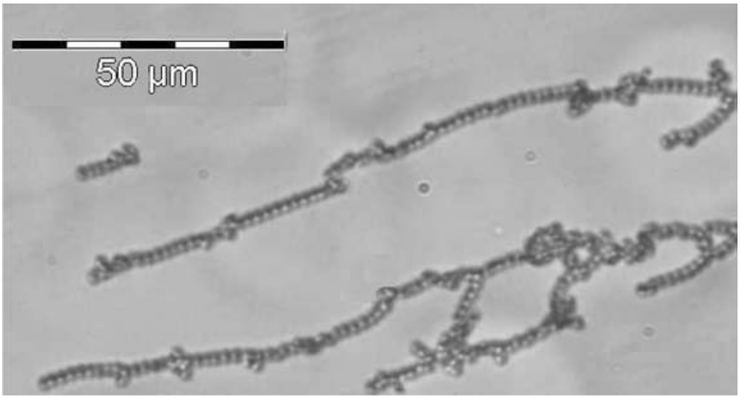

FIGURE 2 Chains of 1.5 μm grafted silica spheres, in nematic liquid crystal. The mixture was filled in a 5 μm thick cell, with planar alignment of the surfaces. The spheres align in the direction of the rubbing; even in the absence of the electric field.

For the mixture: 40 μm diameter spheres (treated with lecithin) and nematic LC, we initially obtained the dipolar configuration of the director field around the particles. In Figure 3 we present the photo showing three such spheres and their schematic presentation as elastic dipoles.

To understand the interaction between such particles, let us consider an isolated microsphere with a sufficiently strong homeotropic (perpendicular) anchoring. The orientation of the director induces a radial point (hedgehog) defect with topological charge +1. Because the director field is uniform far from the particle, the total charge of the whole system is zero, and from topological considerations it follows that an additional defect must be created in the medium to compensate the radial hedgehog [5–7]. In Figure 4 are presented two possible configurations of the director field around the particle; one can pass from the dipole configuration to the quadrupole one, by decreasing the dimensions of the particle or by applying an electric or magnetic field.

In the electrostatic analogue, the particle becomes a conducting sphere with charge Q placed in an external electric field which produces the field

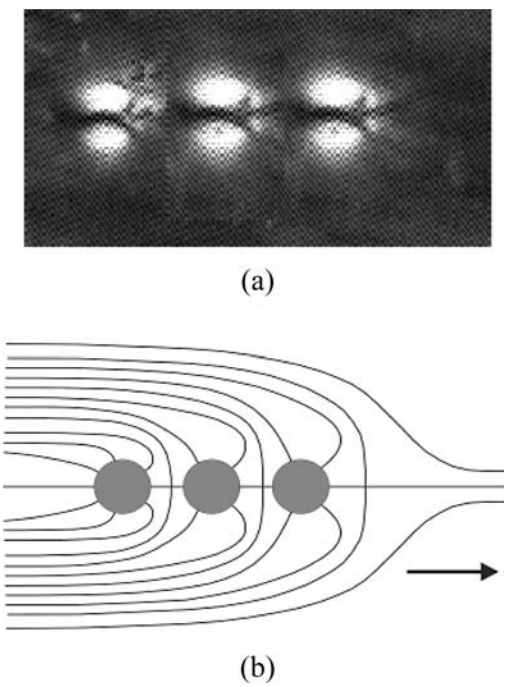

FIGURE 3 (a) Photo of three 40 μm diameter silica particles aligned without external electric field. (b) Schematic representation of three aligned dipoles.

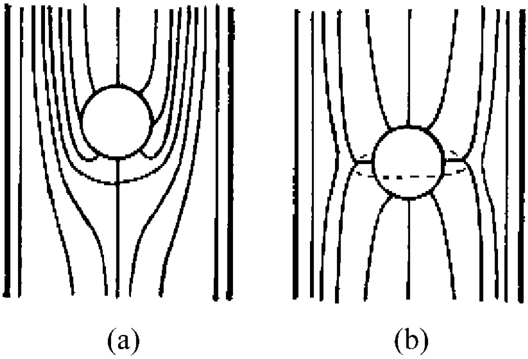

FIGURE 4 Schematic representation of the distortions around particles in nematic LC. The black lines outside the particle represent the axis of preferential orientation of the LC molecules. For relatively large particles, homeotropically treated, the alignment is normal to the surface. (a) Dipole configuration, (b) quadrupole–Saturn ring-configuration.

lines determining the orientation of the director. The configuration with hedgehog defect has dipolar symmetry and the system with disclination loop, also called Saturn ring configuration, has quadrupolar character [6,8,11,12]. When an external a.c. electric field (1 kHz) was applied parallel to the direction of rubbing, in the plane of the cell, the initial dipolar configuration of the spheres changed into Saturn ring configuration. A better alignment of the sphere was observed, and, at the increase of the electric field, the particles approach. This phenomenon was theoretically predicted by Stark [7], and observed experimentally for silicon oil droplets in nematic

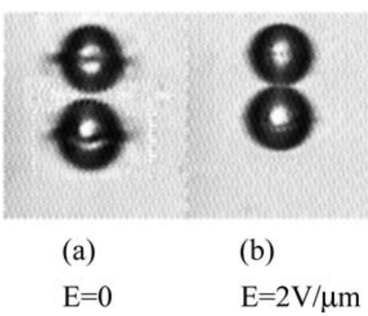

FIGURE 5 Photo of elastic quadrupoles–Saturn rings configuration; (a) $E = 0$, (b) $E = 2V/\mu m$. The particles approach when applying the electric field, the movement being reversible.

liquid crystal by [13,14]. According to our observations, the phenomenon is completely reversible, the particles regaining their initial positions when cutting of the electric field.

When observing short chains of about five spheres (40 μm diameter) under the effect of magnetic field of about 300 mT, in the plane of the cell, the dipolar configuration of the spheres also changed into quadrupolar one and the spheres approached, as in the case of electric field. When rotating the magnet, the chains slowly followed the direction of rotation of magnetic field. These rotations are due to the magnetic anisotropy of the molecules of liquid crystal which induces a torque when the magnetic field is not aligned with the director. The chains of particles just follow the orientation of the director.

CONCLUSIONS

Micrometer sized silica spheres have been treated to obtain homeotropic alignment of the nematic liquid crystal by using lecithin or by grafting molecules of n-Octadecyltrimethoxysilane. When a mixture of these sphere and the nematic liquid crystal E7 was filled into a cell with strong planar alignment obtained using polymide, due to the nematic order, the sherical particle arrange themselves in chains which are oriented in the direction of the rubbing.

For these solid spherical spheres, with homeotropic alignment of the LC, we have checked experimentally Stark's theoretical prediction that an elastic dipole transforms into a quadrupolar configuration known as Saturn ring in the presence of an electric field applied in the plane of the cell.

At the application of a.c. electric field or of magnetic field in the plane of the cell, parallel to the rubbing direction, the dipoles transform into quadrupoles and the particles approach. The phenomenon is reversible.

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