Smectic Liquid Crystals in Anisotropic Silica Gels

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Introduction

Quenched disorder in condensed matter profoundly affects dynamic and thermodynamic behavior, creating novel material properties as well as unique challenges for statistical mechanics. One successful method for introducing quenched disorder into fluids is through confinement within random porous media. For liquid crystals, the fragile nature of the mesomorphic phases and the importance of surface interactions make these materials well suited for such studies, as experiments with aerogel (highly porous, chemically bonded silica gels) have illustrated [1]. Recent research in this area has focused smectic liquid crystals confined in aerosil gels (hydrogen-bonded gels of nanometer-scale silica colloids). Aerosil gels have structures like aerogels but represent weaker disorder resulting from the partial compliance of the gel network to the liquid crystal's elastic forces. Previous x-ray studies have demonstrated quantitatively that the presence of the gel acts as a random field for smectic ordering in the liquid crystal [2]. On the basis of this idea of random confinement introducing quenched disorder, we have initiated research on liquid crystals confined in anisotropic gels at sector 8 of the APS.

An important objective of this work is to test recent theoretical predictions for new glass phases stabilized by anisotropic quenched disorder. As recent theory has emphasized, liquid crystal phases can be strongly affected by confinement in random media [3, 4]. A detailed study by Radzihovsky and Toner [4] has demonstrated the destruction of the smectic-A phase by arbitrarily weak quenched disorder and has introduced the possibility that a "smectic Bragg glass" may appear at low temperature. This topologically ordered state, distinct from the nematic by the absence of unbound dislocation loops, represents an example of the glassy phases theorized for a broad class of systems with disorder, including vortex lattices, charge density waves, and Josephson junction arrays. Building on this theory, Jacobsen et al. [5] have recently predicted that a family of Bragg glass phases should appear in smectic liquid crystals with anisotropic disorder. The parameter quantifying the anisotropy is the uniaxial strain applied to an originally isotropic confining medium, such as aerogel. Stretching the medium in one direction creates a soft axis along which the nematic director prefers to point (assuming there is parallel nematogen-surface alignment), stabilizing a low-temperature "XY Bragg glass." A compressive strain introduces a hard axis, which changes the universality of the system and leads to a novel "m = 1 Bragg glass." A distinguishing feature of these exotic phases is the smectic correlation function that exists in them; Jacobsen et al. [5] predict explicitly the x-ray scattering line shapes that the Bragg glass phases should generate.

Methods and Materials

The liquid crystal used in these studies is octylcyanobiphenyl (8CB), which, in the absence of disorder, undergoes an isotropic-to-nematic transition at 313.98K and a nematic-to-smectic-A transition at 306.97K. Highly uniform aerosil gels can be formed in 8CB following established procedures [6], and these gels can be made anisotropic through the application of external magnetic or electric fields. Specifically, because of the anisotropic elasticity of the liquid crystal's nematic phase and the compliance of aerosil gels, repeated cycling between the isotropic and nematic phases in a large magnetic field (to create a preferred nematic orientation) can reorder of the gel into an anisotropic structure. As studies in our lab have demonstrated, these anisotropic gels, in turn, stabilize macroscopic nematic alignment after the field is removed. Gels prepared in this manner thus provide a soft axis to the liquid crystal; however, their structure also includes random positional constraints that couple to smectic ordering. Small angle scattering measurements at sector 8 have characterized the structure of these gels and the smectic correlations that form in the 8CB embedded within these anisotropic random environments.

Results and Discussion

Figure 1 shows an example of x-ray measurements by using a charge-coupled device (CCD) area detector, obtained at sector 8, for the smectic ordering in 8CB within an anisotropic aerosil gel. The two lobes of intensity near 250 and 1000 on the horizontal scale correspond to smectic scattering centered at a wave vector $q = 0.2$ Å^{-1}. The full width at half maximum (FWHM) of these peaks along the azimuthal direction is less than 6°, demonstrating the high quality of nematic order induced by the gel structure. Note that the ability of the gels to stabilize such long-range nematic order is consistent with the conditions required theoretically [5] for creating Bragg glass phases.
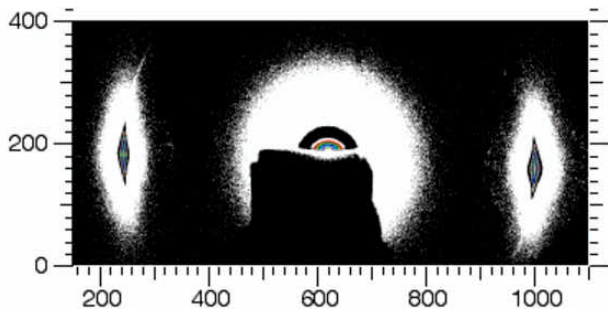
FIG. 1. CCD image of the scattering intensity from smectic 8CB confined within an anisotropic aerosil gel with a silica density 0.036 g/cm^3 at room temperature. The horizontal and vertical scales are pixel numbers. The two lobes, located near 250 and 1000 on the horizontal scale, are at q = 0.2 Å^{-1} and correspond to short range smectic correlations.

Figure 2 displays the scattering intensity I(q) measured parallel and perpendicular to the nematic director. Except for the strong enhancement near 0.2 Å^{-1} from smectic scattering, the intensity is nearly identical along the two directions. In particular, I(q) at low q, which results from the gel, is surprisingly isotropic, indicating that the reordering of the gel to stabilize nematic alignment involves only subtle changes in structure. The smectic peak is significantly broader than the resolution limit of the measurement. This broadening reflects the inability of the liquid crystal constrained by the anisotropic gel to form a well-ordered smectic phase. Analysis is in progress to characterize this line shape as a function of temperature and gel density. A particular focus of this analysis is to compare the measured smectic correlation function and those predicted both for the XY Bragg glass phase [5] and for the more conventional random field pictures [2].
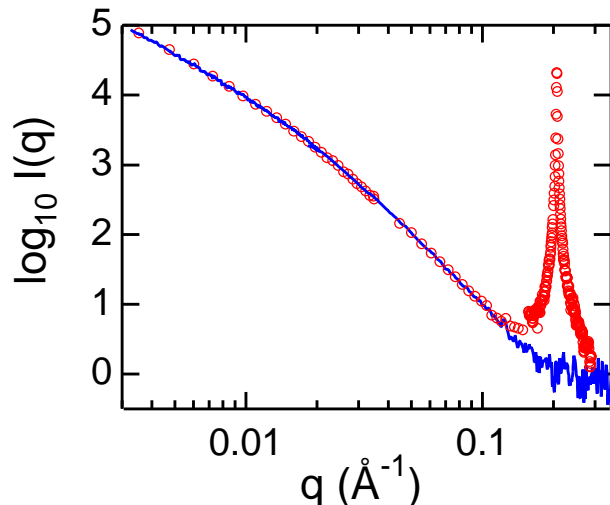
Acknowledgments

FIG. 2. Scattering intensity I(q) as a function of wave vector q extracted from the image in Fig. 1 along directions parallel to the nematic director (red circles) and perpendicular to it (blue line).

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