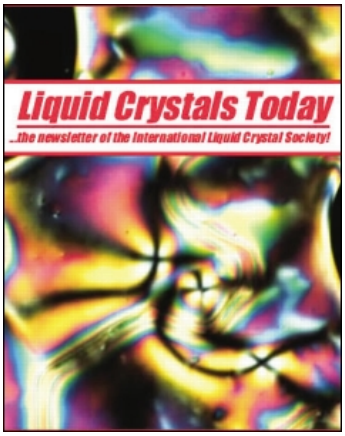

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Liquid crystal blue phases—recent advances

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Liquid crystal blue phases—recent advances

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The liquid crystalline blue phases, among the most esoteric of the mesophases, have recently hit the news with a number of significant advances. The following article summarizes the properties of the blue phases and describes the most significant advances that have been reported over the last year.

Blue phases are exhibited by highly chiral materials and occur above the cholesteric phase, commonly only existing for a few degrees before the isotropic phase. Blue phases are frustrated phases (a class of materials that also includes several smectic and reentrant nematic phases in compounds with large longitudinal permanent dipole moment and/or chirality [1]) resulting from the competition between chiral forces and packing topology. In the cubic lattice of blue phases, the basic unit is the double-twist cylinder (DTC) in which the director is parallel to the axis at the centre, and rotates spatially about any radius. Theoretical work over the past 20 years has indicated that the DTC is more stable than the single twist structure of N*. However, the DTCs cannot fill space uniformly and completely so that the directors match everywhere, consequently disclination lines, lines of singularity in the molecular arrangement, are formed. The structure of the blue phase is stabilized by its coexistence with disclination lines. The cores of disclination lines are assumed to be isotropic liquid.

Three such phases have been observed, separated by first order transitions: the colourful BPI and BPII and the misty blue BPIII. The phases appear in this order as a function of increasing temperature. Both BPI and BPII exhibit long-range orientational order, which has 3D cubic symmetry, body-centred cubic (BPI) and simple cubic (BPII). BPIII is isotropic and only present in highly chiral compounds.

At lower temperatures other frustrated phases including twisted grain boundary (TGB) phases, occurring between the smectic and the cholesteric phases, have been observed. Blocks with smectic ordering are slightly rotated with respect to one another, along a line that is parallel to the smectic layers of all the blocks (creating dislocations between layers in neighbouring blocks due to incompatibility of smectic ordering with chirality). Recently, there has also been evidence for a smectic blue phase [2], analogous to 'normal' blue phases, but with smectic-like translational symmetry of the molecular mean positions. The smectic 'sheets' are not perfect planes, but instead hypothetically rotated about an axis (as in a screw) in compounds that lack a helical phase (i.e. the smectic blue phases occur directly between the smectic and isotropic phases. According to [2], smectic blue phases are original phases given that at least one of them reveals not cubic but hexagonal symmetry and the determination of the symmetry of other smectic blue phases is in progress.

The most prominent property of blue phases is probably their striking appearance: they often come as a display of many colourful platelets (figure 1), or as in the case of BPIII a foggy bluish substance.

The blue phases BPI and BPII exhibit 3D order with periods of up to 500 nm. Because of this huge period, of the order of the wavelength of visible light, blue phases can Bragg scatter in the visible range. This causes a given colour to be seen at a given angle, which will be different for each domain. Blue phases have

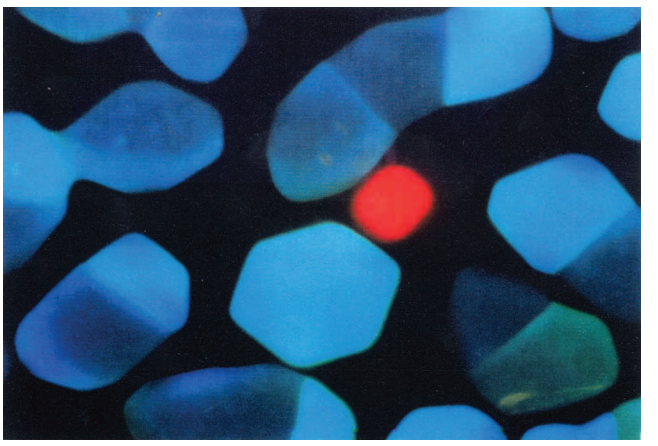

Figure 1. Blue phase BPII (platelet texture). Photo courtesy of R. Miller, PhD Thesis, 1994, University of Manchester, UK.

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been measured to display strikingly large viscosity, lending further weight to the argument for 3D extended structure in the blue phase.

From an applications perspective, although blue phases are of interest for fast light modulators or tuneable photonic crystals [3], the narrow temperature range over which they exist has always been a problem. Recently stabilization of blue phases over a temperature range of more than 60 K, including room temperature, has been reported [4], making the exploitation of their unique characteristics, such as electrically controllable Bragg diffraction of visible light and a photonic band gap possible. These highly extended blue phases were achieved through a photopolymerization process in the blue phase, creating a network structure of polymer chains, which appeared to have a dominant influence on its stabilization.

As discussed in [4], in the case of the polymer/BP composites, polymerization proceeded in a template of the cubic lattice formed in the blue phase. Because the Bragg reflection of the blue phase was maintained after polymerization, the lattice structure of the blue phase was not destroyed by the polymerization of the monomer molecules in it. It is known that the miscibility of a polymer with a liquid crystal is dependent on the degree of orientational order of the liquid crystal molecules. In general, a polymer is more miscible with an isotropic phase than a liquid crystal phase. Therefore, it is reasonable to assume that the polymer chains are selectively concentrated in the disclination core, being in an isotropic state rather than in the DTC.

According to [5], photonic band gap materials, with periodicity in one, two or three dimensions, offer the potential for control of spontaneous emission and photon localization. Although mirrorless lasing was predicted and observed in one-dimensional helical cholesteric materials and chiral ferroelectric smectic materials, it is of great interest to probe light confined in three directions [5]. Blue phases are self-assembled three-dimensional photonic-band gap structures. The first observation of lasing in 3D photonic crystals has been reported in the cholesteric BPII. Distributed feedback is realized in three dimensions, resulting in almost diffraction-limited lasing with significantly lower thresholds than in one dimension. In addition to mirrorless lasing, these self-assembled soft photonic-band gap materials may also be useful for waveguiding, switching and sensing applications.

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