Stimuli-Responsive Cubosomes Formed from Blue Phase Liquid Crystals

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Liquid crystals (LCs) confined within micrometer-scale domains have been explored as the basis of a wide range of field- and stimuli-responsive materials for use in technologies spanning from biological sensors to electro-optical devices.[1] In this context, past studies of micrometer-sized droplets of nematic LCs have, in particular, provided fundamental insight into the competing effects of surface interactions (so-called anchoring), elastic strain and topological defects on the ordering of LCs confined within spherical microdomains (dispersed in polymeric matrices or aqueous solutions).[1b, 2] Because the structure (symmetry), elastic properties and surface interactions of other LC phases are substantially different from those of nematics, an opportunity exists to explore and tune the properties and responsiveness of a much broader range of LC phases via confinement in microdroplets.[3] To this end, in this paper, we report the formation of aqueous dispersions of droplets of blue phase (BP) liquid crystals (comprised of single domains of BPs) and reveal the effects of confinement on their structure and optical properties. We find that BPs are a particularly interesting class of LCs to confine within microdroplets because the periodic internal organization, which gives rise to Bragg diffraction of visible light, is influenced by confinement within the microdroplets, thus providing a means to tune their optical properties. We also report that confinement influences the responsiveness of BP droplets to biological adsorbates, and demonstrate that adsorbates can trigger changes in Bragg diffraction of visible light from BP droplets.

Particles or droplets formed from lyotropic liquid crystalline cubic phases (so-called cubosomes) have been widely explored for their ability to host and release (e.g., for drug delivery) molecular and macromolecular solutes including proteins.[4] The internal periodicity of lyotropic cubosomes is typically 5-10 nm and thus changes in the internal organization of these cubosomes (such as a change in lattice spacing) do not generally lead to significant changes in optical appearance.[4a] The micrometer-sized droplets of thermotropic BPs reported in this paper, which possess cubic symmetry, can also be viewed as cubosomes ("thermotropic" cubosomes) but they are distinguished from the previously reported lyotropic cubosomes by lattice spacings of 200 – 300 nm that give rise to diffraction of visible wavelengths of light. BPs form upon addition of high concentrations of chiral dopants to thermotropic

nematic phases, which induces a double-twist strain into the LCs.[5] To minimize the elastic energy associated with the strain, these materials form a network of double-twist cylinders of finite diameter separated by line defects (disclinations) that, for BPI and BPII (see below), organize into lattices with cubic symmetry (see Figure 2a below and associated discussion for additional details).[5-6] BPI and BPII possess body centered cubic (BCC) and simple cubic (SC) crystal lattices, respectively.[5-6] The experiments described in this paper were designed to address several key questions. (i) How does the phase behavior change when a BP is contacted with water? (ii) What is the influence of confinement within a spherical cavity on the domain morphology and lattice periodicity of BPs? (iii) How does droplet size affect BP phase stability? and (iv) Can interactions with adsorbates change the internal ordering and thus optical response of the BP droplets?

First, we sought to determine if BP droplets could be formed in aqueous dispersions. To this end, we measured the phase behavior of aqueous dispersions of droplets of the mesogen MLC 2142 mixed with 37.5 wt% of the chiral dopant 4-(1-methylheptyloxycarbonyl)phenyl-4-hexyloxybenzoate (S-811; Figure 1a). LC-in-water emulsions of these mixtures were formed by using a homogenizer (see Methods for details) at 50 °C (at this temperature, the mixture forms an isotropic phase). For these initial measurements, we used large LC droplets (diameters of 10-20 μm) to minimize any effects of confinement on phase behavior (see below). Inspection of Figure 1b reveals the temperature-dependent phases observed after incubation of the droplets against an aqueous solution for 1 hour (Iso-BPII-BPI-Chol) to be similar to that of 20 μm-thick films of the same material sandwiched between glass slides (the phase transition temperatures of the droplets reported in Figure 1b did not change with further incubation against water for 3 days; Table S1). We note, however, that the absolute values of the transition temperatures were lowered by 0.9 °C in the droplets as compared to the BP films. We established that the lowering of the phase transition temperatures of the droplets was caused by the reversible uptake of water into the blue phases (see SI) and not dissolution of components of the BP mixture into the aqueous phase (or hydrolysis of components). In this context, we note that we measured MLC 2142 to partition to a greater extent than S-811 into the aqueous phase (detailed in SI). However, the experiments reported here were performed within a few hours of preparation of the samples and, under these conditions, the partitioning of MLC 2142 into the aqueous phase did not change the phase behavior. Overall, the key initial result reported here is that stable BP droplets can be formed in aqueous phases and the sequence of phases observed as a function of temperature is similar to bulk BP samples.

Next, we investigated the morphology of the BP domain structure within the droplets. This series of experiments was motivated, in part, by the goal of forming BP monodomains within droplets in order to study the effects of confinement within a spherical domain on the periodic structure of the BP lattice (see below). To enable and justify our interpretation of the optical appearance of the BP droplets, however, we first used planar BP films to identify the colors generated by diffraction of white light from the different crystallographic planes of the BPs. Immediately following cooling of a film from 50 °C to 42.0 °C at 0.5 °C/min (Figure 2d), we established the blue appearance of the sample to be due to the reflection of light from [100] planes of BPII with a lattice spacing of 150 nm (Figure 2a and c, leading to diffraction of light with a wavelength of 450 nm). The coexisting dark domains in Figure 2d are due

either to the reflection of light at wavelengths below the visible cut-off (such as reflection from the [110] or [111] plane of BPII, which would occur at wavelengths of 320 nm or 260 nm, respectively) or BPII domains that possess orientations that do not reflect light to the camera. For BPI (Figure 2e; observations at 41.2 °C after cooling from 50 °C at 0.5 °C/min), the green domains arise from the reflection of light from [110] lattice planes with periodicity of 255 nm (Figure 2b and c, wavelength of 540 nm) whereas the darker domains are reflections from [200] planes (these domains are blue but appear dark because they are on the edge of the range of visible wavelengths). Overall, the identical colors of the multidomain films and droplets also provides evidence that optical effects associated with the curved interfaces of the droplets do not change the colors of the BP droplets. We also comment on the time-dependent coarsening of the BP domains within the polycrystalline films shown in Figure 2. Whereas the BPII films in Figure 2d (with initial domain sizes of approximately 10 µm) were observed to coarsen significantly over an hour (to a domain size of 60 µm; Fig S3a), BPI films remained polycrystalline with small domain sizes (10-40 µm; Figure S3b) even after incubation overnight (due to the high viscosity of BPI). In contrast, as detailed below, monodomains of BPII and BPI are formed readily within microdroplets.

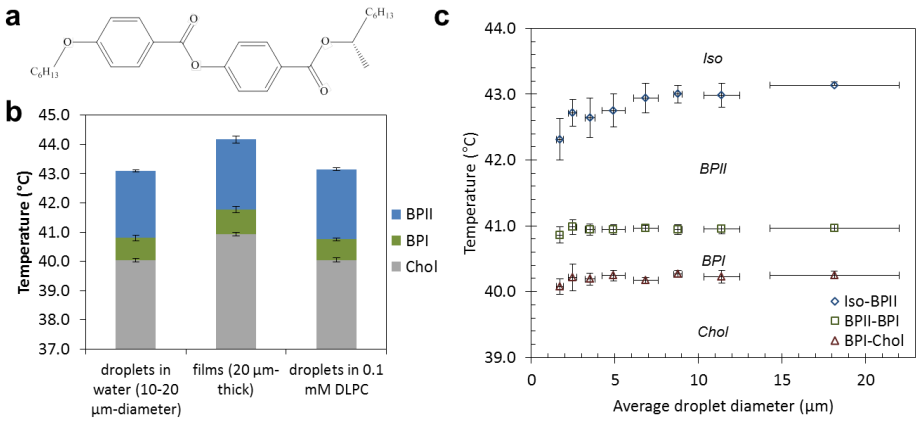

Figure 1. (a) Molecular structure of the chiral dopant, S-811, used in this study. **(b)** Phase behavior aqueous dispersions and films of MLC 2142 and 37.5 wt% S-811. **(c)** Influence of droplet size on phase transition temperatures of MLC 2142/37.5 wt% S-811 droplets (dispersed in water).

Guided by the results described in the above paragraph using thin films of BPs, we next interpreted the optical appearance of BP droplets. Specifically, Figure 2f shows the optical appearance of a single droplet (diameter of 20 µm) during cooling from 50 °C to 37 °C at 0.5 °C/min. Upon cooling to 43.0 °C, we observed the nucleation of BPII domains at the aqueous interface of the isotropic droplet (indicated by arrows) and the subsequent growth of the BPII domains. Ultimately, at 42.8 °C, the entire volume of the droplet was filled by multiple domains of BPII. We determined that the dark domains evident in Figure 2f at 42.8 °C are not isotropic regions but domains of BPII that do not reflect light into the camera. Specifically, as the droplets rotated during our experiments, the dark domains began reflecting

light consistent with the 150 nm lattice spacing of BPII (Figure S5). Upon further cooling of the droplet to 40.9 °C, a phase transition from BPII to BPI was signaled by the appearance of a green color consistent with diffraction of light from the 255 nm lattice spacing of BPI. In contrast to the isotropic-to-BPII phase transition, this transition occurred simultaneously throughout the volume of the LC droplet (Movie S1). We note that the colors of the BP domains observed in these polycrystalline droplets were indistinguishable from the planar films described above (Figure 2d and 2e), indicating that the BP lattice spacings in these multidomain droplets are the same as the polycrystalline films (this contrasts to the BP monodomain droplets below). We note also that further cooling led to an expansion of the BPI lattice, as evidenced by a red-shift in the color of light reflected from BPI droplets (see image at 40.0 °C).[7] Finally, upon cooling to 37.2 °C, we observed the formation of a cholesteric (Chol) phase. This latter phase transition was observed only after supercooling of BPI (note that the BPI-Chol phase boundary is at 40.0 ± 0.1 °C, see Figure 1b). We comment that cholesteric mixtures of MLC 2142 and S-811 containing up to 20 wt% of S-811 assumed a tangential orientation at aqueous interfaces. Mixtures containing concentrations of S-811 higher than 20 wt% possessed pitches that were sufficiently small that it was not possible to determine optically the surface-induced orientation of the cholesteric phase.

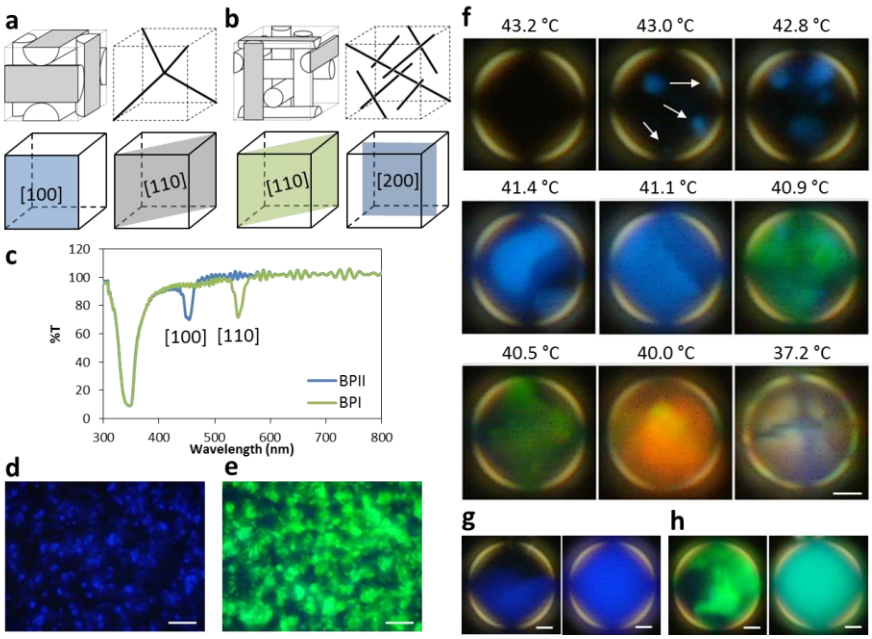

Figure 2. Optical characterization of blue phase films and droplets. Sketches of the double-twist cylinder configuration (top-left), defect structures (top-right), and the two lattice planes reflecting highest wavelength colors (bottom row) for (**a**) BPII and (**b**) BPI. (**c**) UV-vis transmission spectra of 20 µm-thick films of BPI and BPII sandwiched between two glass substrates. Optical appearances of 20 µm-thick films of (**d**) BPII (42.0 °C) and (**e**) BPI (41.2 °C) between two glass substrates. (Scale bars: 50 µm) (**f**) Sequence of micrographs showing phase transitions within BP droplets (Sample was cooled at 0.5 °C/min). Optical appearances of droplets of (**g**) BPII (41.0 °C) and (**g**) BPI (40.5 °C) incubated in water for the indicated duration. (Scale bars: 5 µm) Samples were cooled from the isotropic phase at 0.5 °C/min.

As mentioned above, we also investigated the coarsening of the domain morphology of the polydomain BP droplets and the impact of domain morphology on the BP lattice spacing. To this end, we annealed BPII droplets (diameter of 25 μm) at 41.0 °C (2.1 °C below the Iso-BPII transition temperature) following their cooling from 50 °C (Figure 2g). Although we initially observed the presence of multiple domains of BPII (with sizes of 10 μm, left image in Figure 2h), within 3 mins, coalescence led to the formation of a monodomain droplet (right image of Figure 2g). We also observed polydomain BPI droplets to anneal into monodomains, but in contrast to BPII, this process occurred over several hours at 40.5 °C (Figure 2h). Overall, however, and in contrast to the films described above, we found that BP droplets provided a convenient means by which to rapidly form monodomain samples. We characterized the optical appearance of the BP droplets to determine if the multidomain-to-monodomain transition was accompanied by the introduction of strain into the BP lattice. Here we focus first on BPI, and subsequently describe our observations regarding BPII. Specifically, for BPI, whereas the wavelengths of light reflected from multidomain BPI droplets were identical to those observed with thin films (see above and Figure S6), inspection of Figure 2h reveals that formation of monodomain BPI droplets was accompanied by a change in the wavelength of diffracted light. Specifically, prior to formation of the monodomain, BPI droplets appear green (left image in Figure 2h). After monodomain formation, however, light with a blue hue was reflected from the droplets, consistent with reflection of light with a shorter wavelength and thus a decrease in the lattice spacing of the BPI. Quantitatively, we measured a 30 nm shift in the wavelength of light reflected from the [110] planes, leading us to calculate that the spacing of the [110] planes of the BPI droplet change from 255 nm to 240 nm during the polydomain-to-monodomain transition. Although we did not observe a distinct change in the color of the BPII droplets during the transformation from multidomain and monodomain morphology, we note that a decrease in the BPII unit cell will, in contrast to BPI, result in a decrease in apparent intensity of the diffracted visible light (blue) because shorter wavelengths of light are not be visible to the naked eye. While we can conclude that the wavelength of diffracted light did not increase for BPII upon monodomain formation, we could not determine if the changes observed in the intensity of diffracted light resulted from changes in domain orientation (due to rotation of the droplets) or changes in the lattice spacings. Here we note that several past studies have reported that confinement of BPs between two solid surfaces leads to straining of the BP lattice when the thickness of the BP film is incommensurate with the BP lattice spacing.[8] For BP droplets ranging in size from 4 μm to 20 μm, however, we observed the lattice size of the BP to be independent of the droplet size (Figure S7). In addition, we note that the above-mentioned range of BP droplet sizes correspond to 15-100 periods of the BP lattice, and thus the 5% strain of the BP lattice in droplets, as described above, is not due to BP droplet diameters that are incommensurate with BP lattice spacings. Instead, we conclude that confinement of the BPs within the spherical cavities of the droplets leads to a straining of the BP unit cells (see below for additional support for this conclusion). Finally, we mention that the electro-optical properties of BPs dispersed in polymeric films have been described, but the morphologies of the individual BP droplets were not reported.[9]

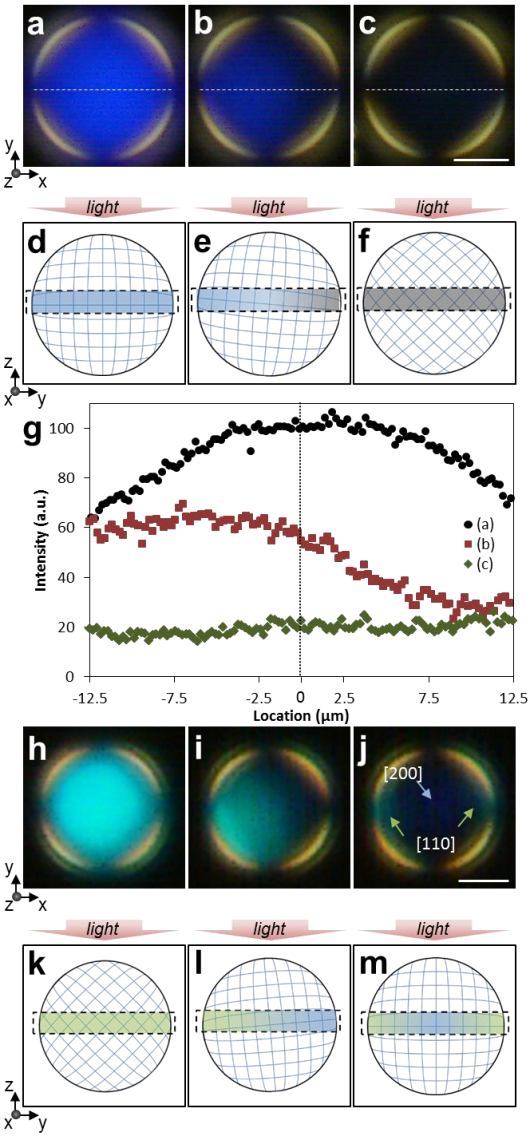

Figure 3. (a-c) Optical appearance of a rotating BPII droplet at 41.0 °C. Scale bar: 10 µm. **(d-f)** 2D sketches of the internal organization (orientation of unit cells) of BPII droplets with respect to the incident light. **(g)** Intensity profiles along the dashed lines shown in a-c. **(h-j)** Optical appearance of a rotating BPI droplet at 40.5 °C. Scale bar: 5 µm. **(k-m)** 2D sketches of the orientation of BPI unit cells with respect to the incident light. Note that blue lines in (d-f) and (k-m) indicate the orientation of [100] planes, colored rectangles indicate the focal planes and the color of the reflected light. Note that the images (a-c) and (h-j) are top views, and sketches (d-f) and (k-m) are side views.

Figure 3 shows additional images of monodomain BPII and BPI droplets that provide further insight into the effects of confinement on strain induced into the BP lattices. Figure 3a shows a monodomain BPII droplet imaged with the focal plane at the equator of the droplet. Inspection of Figure 3a reveals a blue central region that reflects light with an intensity that decreases in the radial direction (see Figure 3g for

quantification of the intensity). This variation in intensity is consistent with a BPII lattice that is strained in the manner shown in Figure 3d. Specifically, we interpret the orientation of the droplet in Figure 3a to place the [100] plane of BPII in the equatorial plane of the droplet (see schematic illustration in Figure 3d in which the blue lines indicate the orientation of the [100] planes). Support for this interpretation comes from subsequent observations of the BPII droplet after it had rotated to the orientation shown in Figure 3b. Inspection of Figure 3b shows that the left side of the droplet is brighter than the right side. This change in optical appearance arises because strain in the BPII lattice on the left side (but not right side) of the droplet is such that the [100] plane diffracts light into the objective (see Figure 3e). Further rotation of the droplet (as imaged in Figure 3c), results in orientations of the strained [100] planes such that light is not reflected to the observer (Figure 3f), and thus the BP droplet appears dark.

The interpretation presented above for BPII, which leads to the conclusion that confinement within monodomain droplets deforms the BPII lattice, is further supported by observations of BPI droplets (Figure 3h-n). In brief, Figure 3h and 3k shows a BPI droplet with [110] planes perpendicular to the incident light, and Figure 3i and 3l shows the droplet rotated such that [110] planes on the left size of the droplet reflect light to the objective but [110] planes on the right side of the droplet do not. Figure 3j and 3n show an orientation of the BPI droplet such that the [200] plane is perpendicular to the incident light at the center of the droplet. In addition, the [110] planes (diagonals of the squares) near the droplet edge are almost perpendicular to the incident light leading to the green appearance of the droplet edges (indicated by arrows in Figure 3j). Overall, the observations described above (Figure 2 and 3) suggests that there are two main effects of confinement on monodomain BPs, a change in the spacing of the cubic lattice, and a bending of the cubic lattice towards the edge of the droplets.

Our interpretation of the above-described experimental observations is supported by the results of complementary computer simulations in which Landau-de Gennes free energies of BP droplets were minimized.[3, 10] A separate publication will detail these computer simulations, but here we briefly describe two snapshots of the structures of the BP droplets (Figure 4) and comment on aspects of the simulations that support the interpretation of our experiments. First, similar to our experiments, the computer simulations predict the BPI lattice spacing at the center of a monodomain droplet (410 nm) to be smaller than the bulk BPI lattice size (422 nm). This predicted difference in lattice spacing would generate a 36 nm blue-shift in the wavelength of the light reflected from the droplets as compared to bulk, which is in good general agreement with our experimental observation (see above and Figure 2h). Second, the simulations reveal that the BP unit cells are strained (and also smaller) close to the BP-water interface of the droplets, which again is consistent with the interpretation of our experiments in Figure 3.

We hypothesized that the strain of the cubic BP lattice induced by confinement within the monodomain droplets (as described above) may lead to a phase behavior of the LC that is dependent on the size of the droplets. To explore this possibility, we optically determined the phase transition temperatures of mixtures of MLC 2142 and S-811 within droplets with diameters of 1.3 – 25 μm after incubation for 1 hr at 55 °C. Inspection of Figure 1c reveals that $T_{Iso\text{-}BPII}$ is influenced by confinement in droplets with sizes below 4 μm. We comment that past studies have observed the nematic-to-isotropic phase transition temperatures of simple nematics to decrease by 1 °C when confined within pores with diameters of 0.2

µm (due to the effects of elastic energies).[11] Although the BP droplets in which we measure the isotropic transition temperature to decrease by 1 °C are an order of magnitude larger (2 µm), we note that the BPs possess internal structure (periodicity of the BP cubic lattice) that is absent in simple nematics.[11] Here we note also that the decrease in the phase transition temperatures due to confinement is not consistent with the effects of a Laplace pressure difference across the interface of the BP droplets, as we calculate Laplace pressure effects to cause the transition temperatures to decrease by only 0.06 °C for droplets with diameters of 2 µm (see SI). A surprising result observation, however, is that the droplet size does not influence $T_{BPII-BPI}$ and $T_{BPI-Chol}$. We note that $T_{BPII-BPI}$ was measured by cooling monodomain BPII droplets, and that $T_{BPI-Chol}$ was measured by heating monodomain Chol droplets. We tentatively interpret the droplet size-independent values of $T_{BPII-BPI}$ and $T_{BPI-Chol}$ to suggest that the frustration experienced by the various phases is comparable for a given droplet size, although this point requires further investigation.

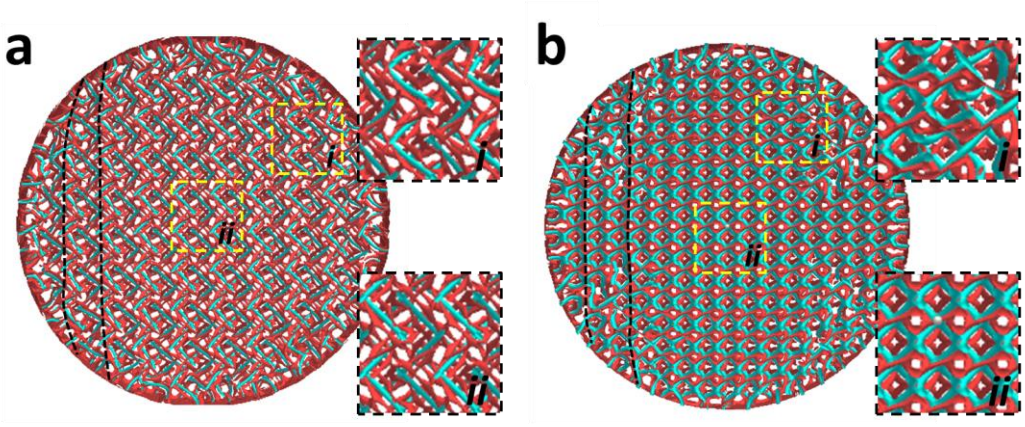

Figure 4. Snapshots of **(a)** BPI and **(b)** BPII droplets from computer simulations. Blue color indicates the LC defects, red color indicates the splay-bend parameter, S_{SB} = -0.008. Examples of deformed unit cells are indicated by *(i)*, and undeformed unit cells are indicated by *(ii)*. Black dashed lines indicate the orientation of the [100] lattice planes.

As noted in the Introduction, a number of past studies have examined cubosomes formed from lyotropic LCs. In lyotropic LCs, the cubic unit cell structure has a pronounced influence on the overall shapes of dispersed cubic particles (cubosomes) in aqueous media.[12] In contrast, our measurements of the shapes of BP droplets using an optical microscope did not reveal any significant deviation from a spherical shape. We interpret this result to be due to the high interfacial tension of BP-water interfaces (typically ~10^{-2} J/m^2) as compared to interfaces of lyotropic LC phases (typically ~10^{-6} J/m^2).[13] For the largest BP droplets observed in our study (~20 µm-in-diameter), we calculate the Laplace pressure resulting from this interfacial tension to be ~1000 Pa, which is an order of magnitude higher than prior estimates of the elastic moduli of BPs (10-100 Pa) and thus consistent with our observations of spherical

droplets.[14] We note also that past studies have examined free surfaces of BP films using atomic force microscopy (AFM) and have reported surface features with sizes comparable to the BP lattice spacing (200 nm). It is possible, therefore, that the BP droplets used in our study also possess similar surface features.[15]

Finally, we report on the responsiveness of BP microdroplets to biological adsorbates. As noted above, BP droplets are a promising class of confined LC systems because changes in periodicity of the BP lattice results in changes in the Bragg diffraction of visible wavelengths of light. To illustrate this promise, we reveal that the interactions of biological analytes, specifically phospholipids, with BP droplets trigger changes in the optical properties of aqueous dispersions of the droplets. Figure 5 shows the distinct change in appearances of BPI droplets in aqueous media with and without 0.1 mM 1, 2-dilauroyl-sn-glycero-3-phosphatidylcholine (DLPC), following a thermal quench to 40.0 °C. After the BPI phase transition, the droplets dispersed in water that was free of DLPC exhibited a green appearance, and with decreasing temperature exhibited a red-shift consistent with expansion of the BPI unit cell (Figure 5a, see discussion above). In contrast, however, in the presence of DLPC, the microdroplets appeared green throughout the entire BPI temperature range with no substantial change in the wavelength upon cooling (Figure 5b). Significantly, the key result demonstrated here is that BP droplets do, indeed, respond to the presence of phospholipids with a change in Bragg diffraction. Interestingly, the result also suggests that the presence of DLPC has stabilized the BP lattice size (Figure 5b). We note, however, that the presence of 0.1 mM DLPC had no measurable impact on the temperature range over which we observed the BP phases (Figure 1b). Although additional studies are required to establish the details of the mechanism by which the DLPC changes the BP lattice size, we note that potential mechanisms include the adsorption of the DLPC at the LC-aqueous interface or the partitioning of DLPC into the BP droplets. We comment that several past studies have shown that nanoparticles can stabilize BPs.[16] In addition, our past reports have revealed that adsorption of DLPC at LC interfaces can change the orientations of LCs.[2a, 17] Future studies will be performed to investigate the dependence of the response of the BP droplets on the structure of the phospholipids and the mechanisms by which they influence the BP lattice spacing.

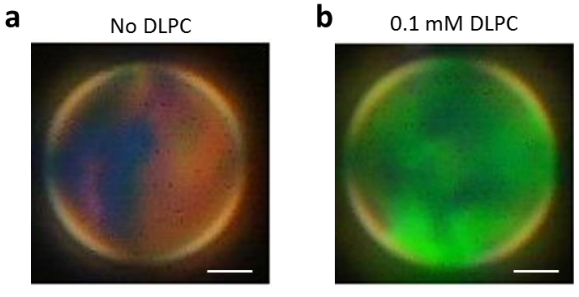

Figure 5. Optical appearance of droplets of MLC 2142 containing 37.5 wt% S-811 at a temperature corresponding to BPI (40.0 °C). Droplets were incubated in **(a)** water, and **(b)** 0.1 mM DLPC. Scale bars: 5 μm.

To conclude, this Communication reports that it is possible to form stable dispersions of thermotropic cubosomes of BPI and BPII in water. Specifically, we found that monodomain BP droplets can be readily formed and that confinement of BPs within spherical monodomains strains the BP lattice spacings and thus changes the wavelength (color) of light diffracted from the droplets. The confinement also leads to the deformation of the cubic lattice planes near the BP-water interface, an experimental observation that is consistent with computer simulations. Finally, we have found that the addition of amphiphiles to aqueous dispersions of BP droplets influences the BP lattice size and thus also changes Bragg diffraction from these thermotropic cubosomes. Overall, these results demonstrate that BP droplets are a promising new state of responsive soft matter that may find use as the basis of low cost diagnostic devices or novel photonic technologies. In particular, because a polarized light source is not needed to transduce stimuli-induced changes in internal organization (i.e., a change in lattice spacing gives rise to a change in Bragg diffracted light), BP droplets may provide significant advantages over previously explored nematic droplets (which require polarized light for optical imaging of distinct configurations of the nematic LC). As noted above, cubosomes of lyotropic phases do not provide access to such reflections of visible light due to the small periodicity of the cubic lattice.[4a, 12] Finally, we note that the results presented in this paper suggest a number of directions for future research, including further elucidation of the mechanism of interaction of lipids with BP droplets, including the influence of lipid architecture, and characterization of the colloidal stability and coalescence behaviors of the aqueous dispersions of BP droplets.

Materials and Methods

Materials. MLC 2142 and 4-(1-methylheptyloxycarbonyl)phenyl-4-hexyloxybenzoate (S-811) were purchased from Merck (Darmstadt, Germany). Fisher Finest Premium Grade glass slides and cover slips were obtained from Fisher Scientific (Pittsburgh, PA). Toluene was obtained from Sigma Aldrich (St. Louis, MO). Purification of the water (18.2 MΩ·cm resistivity at 25 °C) was performed with a Milli-Q water system (Millipore, Bedford, MA). One-minute epoxy glue was obtained from Henkel (Germany).

Experiments. Mixtures of MLC 2142 and S-811 were prepared using a co-solvent method. Desired amounts of MLC 2142, S-811 and toluene were mixed using an ultrasonic cleaner. Toluene was then evaporated under vacuum at 60 °C overnight.

Emulsions were prepared in the isotropic phase of the mesogenic mixture (above 50 °C) by dispersing 6 µL of the mixture in 2 mL of water using a T25 digital ULTRA-TURRAX homogenizer equipped with an S25N-10G dispersing element (6500 rpm for 45 seconds).

Optical cells were prepared by spacing a glass slide and a cover slip with a 100 µm-thick spacer. The cell was glued using one-minute epoxy. Emulsions were introduced into the optical cells via capillary action in the isotropic phase of the mesogenic mixture and sealed with epoxy glue to prevent evaporation.

Microscopy observations were performed using an Olympus BX60 microscope with a 50x objective. Temperature was controlled using a Mettler Toledo FP82HT hot stage. Phase transition temperatures were determined by heating-cooling cycles at a rate 0.5 °C/min. We comment here that we used cross-polarizers in reflection mode to image BP droplets as we found this mode of imaging to enhance the appearance of the domain structure of the droplets (Figure S4).

UV-vis spectra of BP films and aqueous phases of the emulsions were carried out using a Cary 1E UV-vis spectrophotometer (Varian Instruments, Sugar Land, TX) equipped with a heated sample holder and circulating water bath. BP films were sandwiched between two glass substrates separated by 20 µm-thick spacers and an empty cell was used as reference. Aqueous samples were characterized in fused silica cuvettes and an empty cuvette was used as reference.

Simulations. Simulations were carried out with weak planar anchoring of mesogens at the droplet surfaces by minimization of Landau-de Gennes free energy. The details of the simulations are given in Supporting Information.

Supporting Information

Supporting Information is available from the Wiley Online Library or from the author.

Acknowledgements

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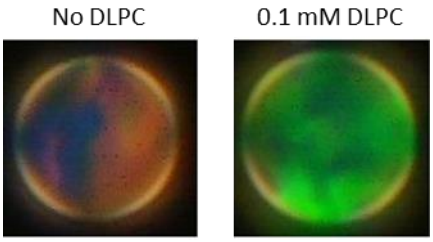
Graphical Abstract



Cubosomes formed from blue phase liquid crystals (BPs) dispersed in aqueous media exhibit optical responses to biological amphiphiles. In this study, we report formation of aqueous dispersions of BPs and characterize the effects of confinement and adsorbates on the phase behavior, optical appearance and morphology of BP droplets.