

Visualization and description of the macroscopic biaxiality of nematic liquid crystals: the first steps

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Abstract

How one can see that a nematic is indeed biaxial ? I consider some macroscopic effects in the basic biaxial cells and present results of the recent observation of the macroscopic biaxiality in the bent-core mesogens "C7" and "C12" [1,2].

1. Introduction

Generically, a nematic liquid crystal (N) can have three mutually orthogonal directors and should be biaxial (BN). For a long time, however, the Nature has been showing us only uniaxial Ns (UNs) with a single director. At last recently, there has been a tentative consensus [3] in that the desired balance was achieved in a number of compounds with boomerang-shaped molecules ODBP-Ph-C₇ (C7) and ODBP-Ph-C₁₂ (C12) [4,5]. The degree of biaxiality was studied by NMR spectroscopy, dynamic light scattering, infrared spectroscopy. These complicated techniques allowed one to detect and estimate manifestation of the biaxial order in these materials on the microscopic level. But Ns are most distinguished by their macroscopic elastic, dielectric, and optical properties. The authors of Ref. [1] designed an experiment that could prove macroscopic biaxiality, analyzed macroscopic properties of C7, and demonstrated the effects that can be attributed only to the existence of three directors. The main idea was that in place of a single planar alignment of a UN, a BN has three different principal alignments that, in appearance, look like planar but actually have different homeotropic directors, different pair of the planar directors, as well as

different dielectric, elastic, and optic properties. This difference is an unambiguous sign of biaxiality as in a UN all planar cells are the same. To make a biaxial cell BC1, in which one of the director, say \mathbf{n}_1 , is homeotropic, and a cell BC2, in which the same director is planar, glass substrates with two different orienting layers were used: the first one of polyamide PI AL60702 used for homeotropic alignment of a UN (H-polyamide), and the second one of polyamide PI AL 22620 used for planar alignment of a UN (P-polyamide). The dielectric and optic properties of these two apparently planar cells were found to be different which indicated a macroscopic biaxiality of C7. However, to exclude a possible effect of specific surface treatment (i.e., the effect of particular polyamides PI AL60702 and PI AL 22620) and to see how general is the observed biaxial effects, one has to use a larger number of different polyamides. Here I report results [2] of such a study both for C7 and C12. The results provide a further support to the macroscopic biaxiality of C7 and, in a similar manner, suggest macroscopic biaxiality of C12. All the polyamides used for the homeotropic alignment of UNs result in similar cells of the type BC1, whereas all the polyamides used for the planar alignment of UNs result in similar cells of the type BC2, the two types being substantially different in their elastic and optic properties. This difference requires three directors and is impossible in a uniaxial nematic phase.

2. Three basic biaxial cells

Both for studying the macroscopic properties and for

applications, a NLC is taken in the form of a thin layer sandwiched between two solid substrates. In the simplest and most frequently used cases the single director of a UN is aligned along the layer normal or along its surface, Fig. 1a, b. These alignments are called, respectively, homeotropic and planar. The macroscopic images of a uniaxial homeotropic cell (UHC) and uniaxial planar cell (UPC) are very different.

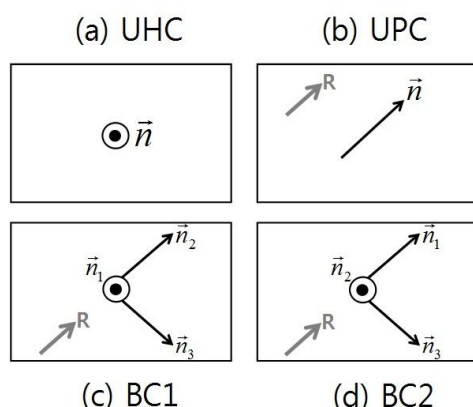


Fig. 1. Schematic top view of the director alignment in different uniaxial and biaxial cells: a) uniaxial homeotropic cell (UHC) with the director \mathbf{n} normal to the cell surface; b) uniaxial planar cell (UPC) with the director \mathbf{n} lying in the surface plane along a rubbing direction \mathbf{R} ; c) biaxial cell BC1 in which director \mathbf{n}_1 is normal to the surface whereas \mathbf{n}_2 and \mathbf{n}_3 are planar; d) biaxial cell BC2 in which director \mathbf{n}_2 is normal to the surface, whereas \mathbf{n}_1 and \mathbf{n}_3 are planar.

The dielectric and optic properties of a uniaxial nematic (UN) differ for electric field along and perpendicular to the director \mathbf{n} which is the single optical axis of a UN. These properties are determined by the two different dielectric constants, ϵ_{\parallel} and ϵ_{\perp} , and, respectively, by the single birefringence $\Delta n = \sqrt{\epsilon_{\parallel}} - \sqrt{\epsilon_{\perp}}$.

There are no patterns in the plane of a UHC, Fig. 1a. A light beam incident normally on such a layer experiences no anisotropy and remains ordinary so that the cell is black under crosspolarizers regardless of their orientation. In contrast, the in-plane director orientation in a UPC offers a variety of patterns called schlieren textures. To consider a BN, we conventionally label its directors by subscripts 1, 2, and 3. In contrast to the case of UN, a cell with a BN

cannot be labeled as homeotropic or planar, Fig. 1c,d: if one of the director is homeotropic then the other two are planar. There are three different possibilities depending on which director is homeotropic. Two particular cases are shown in Fig.1 c, d. In the cell BC1, the director \mathbf{n}_1 is homeotropic whereas the other two, \mathbf{n}_2 and \mathbf{n}_3 , are planar, Fig.1c; in the cell BC2, \mathbf{n}_2 is homeotropic whereas \mathbf{n}_1 and \mathbf{n}_3 are planar, Fig. 1d. The fundamental difference between cells BC1 and BC2 and any UPC lies in their physical properties. In contrast to the single optic anisotropy $\Delta n = \sqrt{\epsilon_{\parallel}} - \sqrt{\epsilon_{\perp}}$ of a UPC, a BN has three: $n_{32} = \sqrt{\epsilon_3} - \sqrt{\epsilon_2}$, $n_{31} = \sqrt{\epsilon_3} - \sqrt{\epsilon_1}$, and $n_{21} = \sqrt{\epsilon_2} - \sqrt{\epsilon_1}$. This can manifest itself in the difference between optical transmittance of BC1 and BC2. The difference between BC1 and BC2 cells can also manifest itself in their elastic properties since the elastic anisotropy in these cells is described by different elastic constants.

3. Experiment, results and discussion

(1 line spacing)

To make experimental cells of the type BC1, in which one of the director, say \mathbf{n}_1 , is homeotropic, we used glass substrates with the following H-polyamides: PI 60702 (used in [1]), AL1H659(JSR, Japan), and OIM23(JSR, Japan). To make cells of the type BC2, in which the same director is planar, we used glass substrates with the following P-polyamides: PI AL 22620 (used in [1]), SE7492(NCK, Korea), PI 8613(II San Chemical, Korea), and ROIM23(JSR, Japan). All the cells had thickness $H=13\mu\text{m}$ and were filled with C7 and C12 in their isotropic phase. The material C7 becomes an isotropic liquid at $T_I \approx 222^\circ\text{C}$ and SmX at $T_{Sm} \approx 173^\circ\text{C}$. The C12 becomes an isotropic liquid at $T_I \approx 204^\circ\text{C}$ and SmC at $T_{Sm} \approx 193^\circ\text{C}$. In the range between T_{Sm} and T_I the phases of C7 and C12 are certainly nematics. We show here that these nematic phases are macroscopically biaxial.

We made BC1 (with H-polyamides) and BC2 cells (with P-polyamides) with the nonrubbed and rubbed surface layers. In nonrubbed cells, the surface has no preferred direction and the directors, no matter one or two, at the surface can rotate without energy loss which favors formation of schlieren textures. In rubbed cells, the alignment is homogeneous and one of the directors' in-plane projection is expected to be along the rubbing direction. The microscope images of nonrubbed BC1 cells typical for different H-

polyamides and BC2 cells typical for different P-polyamides are shown in Figs. 2 and 3. The regular difference in the schlieren textures in Figs. 2a and 2b should be attributed to a difference in the elastic anisotropy of BC1 and BC2. This difference cannot be explained in terms of a UN, but can be understood under the assumption that both C7 and C12 have biaxial elastic properties and are of the type shown in Fig. 1c,d. This assumption will be further supported by the optic properties of BC1 and BC2 type cells.

Using crosspolarizers, we investigated the output

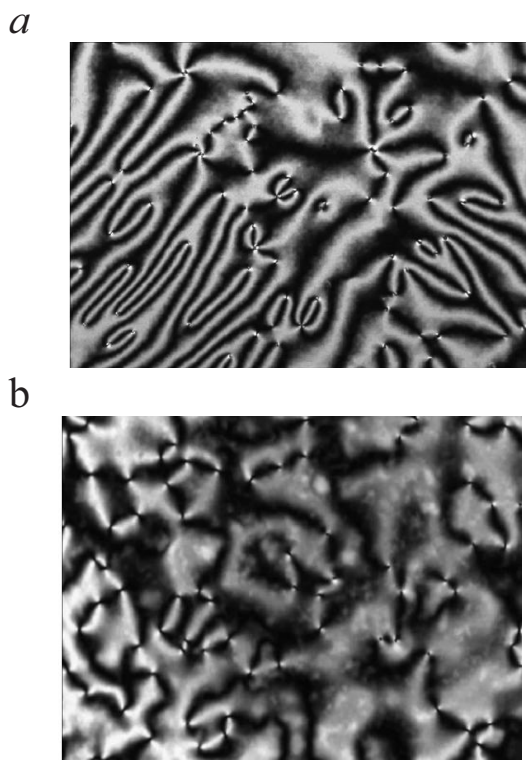


Fig. 2. a: Typical schlieren textures in nonrubbed cells of BC1 type with H-polyamides, showing both four (± 1) and two ($\pm 1/2$) brush disclination lines at all temperatures. b: Typical schlieren textures in nonrubbed cells of BC2 type with P-polyamides, showing only two ($\pm 1/2$) brush disclination lines at all temperatures. (2 line spacing)

qualitatively and quantitatively close curves. While in intensity of the red light with ($0.633 \mu\text{m}$), traversing the cell along its normal, as a function of the angle made by the polarizer axis and rubbing direction. Both in BC1 and BC2 type cells, the maximum intensity was always at the angle $\pm \pi/4$ and minimum intensity always at the angle $\pm \pi/2$ to the rubbing direction. This implies that either the single director of

a UN is parallel to the rubbing direction, Fig. 1b, or one of the two planar directors is parallel to the rubbing direction in the case of BN, Figs. 1c,d. At the same time, the maximum transmittance I_m as a function of temperature T is different in cells of BC1 and BC2 type both with C7 and C12, Fig. 3. The following property obvious from Fig. 3a,b is of crucial importance. Both in C7 and C12, the data $I_m(T)$ obtained in different BC1 cells, i.e., for all the H-polyamides, form a family $I_{m,H}(T)$ of qualitatively and

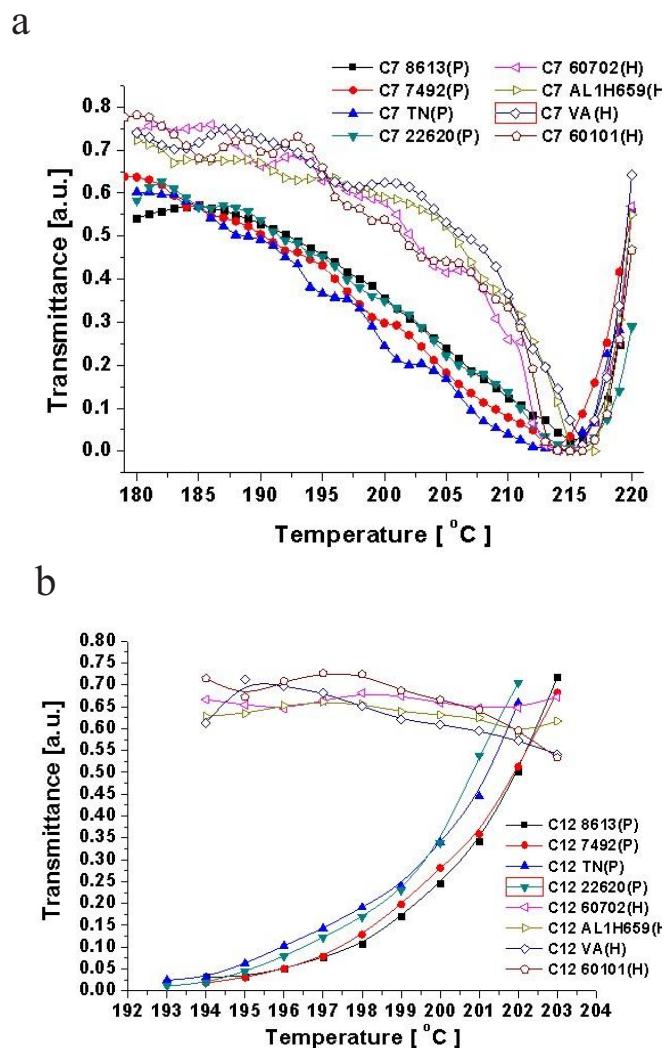


Fig. 3. Maximum transmitted intensity vs temperature for cells BC1 and BC2. a) with C7: the BC1 type cells (H-polyamides) and BC2 type cells (P-polyamides) form two distinguishably different families of curves. b) with C12: the BC1 type cells (H-polyamides) and BC2 type cells (P-polyamides) form two drastically different families of curves (unpublished results obtained by Y.-K. Kim).

quantitatively similar curves. In turn, both in C7 and C12, the data obtained in different BC2 cells, i.e., for all the P-polyamides, form another family $I_{m,P}(T)$ of the case of C7 the two families, $I_{m,H}(T)$ and $I_{m,P}(T)$, are distinguishably different, Fig.3a, in the case of C12 the difference between the two families is dramatic, Fig. 3b. This shows that the difference between cells with different surface treatment is not because of the specific chemical properties of the polyamides, but because they produce normal orientation of different directors. Thus, the similarity between all the cells of BC1 type and all the cells of the BC2 type should be attributed to the fact that all of the H-polyamides induce normal orientation of the same director \mathbf{n}_1 , whereas all the H-polyamides induce normal orientation of the same director \mathbf{n}_2 .

By the same reasoning as before, we again conclude that the difference between the dependencies $I_{max}(T)$ in BC1 and BC2 cells cannot be explained in terms of a UN: all UPCs have the same birefringence $\Delta n = \sqrt{\varepsilon_{\parallel}} - \sqrt{\varepsilon_{\perp}}$. But it can be understood under the assumption that BC1 and BC2 are biaxial. In this last case the two birefringencies are different: in the BC1 cells, $\Delta n(BC1) = \Delta n_{32}$, whereas in the BC2 cells, $\Delta n(BC2) = \Delta n_{31}$. We see that the nematic phases of C7 and C12 are macroscopically biaxial.

4. Summary

Any two planar cells with the same UN are similar, i.e., they have the same elastic, dielectric, and optic anisotropy, and thus look the same from any

point of view. We have detected that the cells of the types BC1 and BC2, which are apparently planar (as they show schlieren textures and have no pretilt), have notably different elastic and optical anisotropies both for C7 and C12 compounds. This strongly supports the idea of biaxial behavior of their nematic phases. This difference can be naturally explained if the nematic phase is biaxial and cannot be explained in terms of a UN with its single director.

Using just a single H-polyamide and single P-polyamide, it was shown in Ref. [1] that the cells BC1 and BC2 with C7 have very different dielectric properties. The dielectric study of the BC1 and BC2 type cells both with C7 and C12 is currently under way.

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5. References

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