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Observation of the annihilation process of wedge disclinations in P-4-BCMU liquid crystals

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The first experimental observation of the annihilation process of wedge disclinations through a certain special configuration between a pair of wedge disclinations with $s = \pm\frac{1}{2}$ in the nematic P-4-BCMU lyotropic liquid crystal phase is reported in this communication. Our results indicate that besides the transitional motion, a rotation of disclinations with $s = \pm\frac{1}{2}$ occurs in the liquid crystal phase, leading to the formation of a certain special configuration shortly before annihilation. The rotation of disclinations is explained qualitatively by the elastic anisotropy of the liquid crystals.

1. Introduction

It is well known that disclinations with opposite sign attract each other and then annihilate in a nematic sample, leading to a decrease in the number of disclinations and coarsening of textures. The annihilation process of wedge disclinations with opposite sign has been experimentally observed in low molecular mass liquid crystals [1, 2] as well as recently in polymer liquid crystals [3–6]. The interaction of a pair of wedge disclinations with opposite sign has been studied in theory [7–10]. Recently, much more emphasis in theoretical [11, 12] and experimental [3, 5, 13] investigations of the interaction of a pair of wedge disclinations has been placed on the kinetics or dynamics of the annihilation process. Even so, the details of the annihilation process of two wedge disclinations with opposite sign are far from being understood.

Our previous investigations have shown that solutions of P-4-BCMU, a soluble polydiacetylene, in chloroform can form a stable lyotropic liquid crystal phase at room temperature when the concentration of the solutions is beyond a critical concentration [6, 14]. A film of the lyotropic solution with a free surface shows a typical schlieren texture frequently observed for low molecular mass nematic liquid crystals when viewed between crossed polarizers in the light microscope. Wedge disclinations with strength $s = \pm\frac{1}{2}$ were most frequently observed in the liquid crystal phase. The relation between the texture and the density of the disclinations was determined. We found that beyond a critical density, a striated texture could appear in the solid film prepared by solidifying the lyotropic sample [6, 14]. The striation trajectory can easily help to distinguish the strength and the orientation of disclinations [6, 14, 15]. Very recently, the elastic anisotropy of the lyotropic liquid crystal phase was studied and it was found that the Frank elastic constant anisotropy is approximately 0·5, indicating that splay is an unfavourable deformation [15]. In these cases it is possible for us to explore further the details of the annihilation process of two disclinations with opposite sign in this lyotropic liquid crystal and to understand in more detail the influence of the elastic anisotropy on the annihilation process.

In this communication we will present an experimental result observed by optical microscopy concerning the annihilation process of wedge disclinations with $s = \pm\frac{1}{2}$ in the P-4-BCMU lyotropic liquid crystal phase and discuss the results obtained in terms of the elastic anisotropy of the P-4-BCMU liquid crystal. We observe that a pair of wedge disclinations with $s = \pm\frac{1}{2}$ annihilates through a certain special configuration between them. To our best knowledge, this is the first experimental observation showing details of the annihilation process of wedge disclinations with $s = \pm\frac{1}{2}$. We believe that this result can provide further insights into the annihilation process of wedge disclinations with opposite sign and also promote its theoretical study.

2. Experimental

The sample of P-4-BCMU used was the same as the one studied previously [6, 14, 15]. The material is a soluble polydiacetylene which can form a nematic liquid

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crystal phase in chloroform solution. The weight and number average molecular weights of the sample are $\bar{M}_w = 5{\cdot}15 \times 10^5$ and $\bar{M}_n = 2{\cdot}16 \times 10^5$, with a polydispersity index $\bar{M}_w/\bar{M}_n = 2{\cdot}4$ [16, 17]. These data were determined by gel permeation chromatography in tetrahydrofuran (THF) solution after calibration by light scattering [17]. Yellow solutions of P-4-BCMU in chloroform were prepared by allowing the polymer to dissolve at room temperature for at least one day. For the investigation of optical textures, liquid crystalline films with a thickness of about 10 μm were prepared by increasing the concentration of the solutions from an initial value of $5\,\mathrm{g\,l^{-1}}$ on the glass slide. Before the films were studied, they were annealed in the lyotropic liquid crystalline state at room temperature until a recognizable schlieren texture could be observed. During isothermal annealing, disclinations with opposite sign annihilate and the distance between two neighbouring disclinations increases, leading to a coarsening of the textures [6, 14].

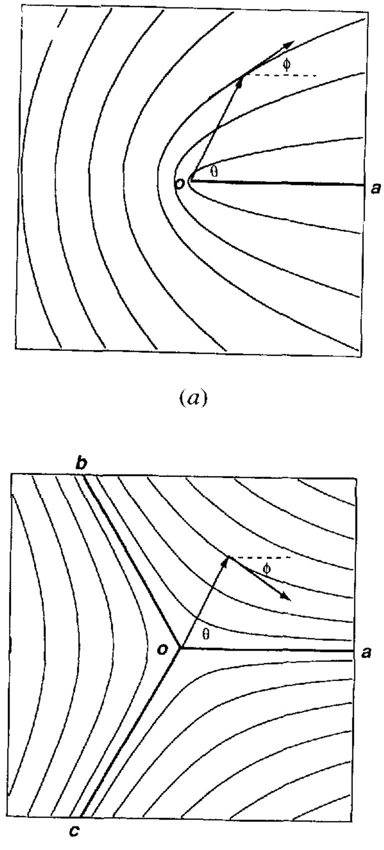
All films of the P-4-BCMU liquid crystals on the glass slide had one free surface. Their optical textures were observed *in situ* at room temperature by optical microscopy (Zeiss Photomikroskop III), with or without crossed polarizers, either for the chloroform solutions or for the solid state obtained after complete evaporation of the solvent.

3. Results and discussion

Firstly, to help understanding of the experimental results that will be presented, we define for this investigation the orientation axis or axes of wedge disclinations with strength $s = \pm\frac{1}{2}$, as shown in figure 1 in the case of $\varepsilon = 0$. Here ε is the Frank elastic constant anisotropy, defined by $\varepsilon = (k_{11} - k_{33})/(k_{11} + k_{33})$, where k_{11} is the splay Frank constant and k_{33} the bend Frank constant [18]. For the disclination with $s = +\frac{1}{2}$, the trajectory at $\theta = 0$, i.e. line *oa* in figure 1 (*a*), is the orientation axis, but for the disclination with $s = -\frac{1}{2}$, the three trajectories at $\theta = 0$, i.e. lines *oa*, *ob* and *oc* in figure 1 (*b*), are the orientation axes due to its D_{3h} symmetry [19].

As mentioned above, in the previous study we investigated the relation between the texture of lyotropic samples and annealing time [6, 14]. At a late stage in the procedure, the distance between two adjacent disclinations is large enough for studying the properties of a single disclination by optical microscopy [6, 14, 15]. In this situation, a striated texture, which can, as mentioned above, help us to distinguish the orientation axis or axes of disclinations, appears in the solid sample. In figures 2 and 3, two sets of micrographs show typical textures of a P-4-BCMU sample at this late stage. All these micrographs were taken from the same area of the same sample. The time interval for taking the two sets of micrographs was 48 h. The micrographs (*a*) in figures 2 and 3, taken using optical microscopy with crossed polarizers, show a typical schlieren texture of the P-4-BCMU sample in the lyotropic state. The orientation of the polarizer and analyser is indicated by the letters P and A in the upper right corners of the micrographs. According to our previous study, we know that the Frank elastic constant anisotropy of this sample is not equal to zero, but is approximately 0·5 [15]. In this case, angles other than 180° between two consecutive dark brushes around singularities can be seen in the micrographs as shown in figures 2 (*a*) and 3 (*a*).

The micrographs (*b*) in figures 2 and 3 were taken using optical microscopy with crossed polarizers in the same area of the same sample as that in figures 2 (*a*) and 3 (*a*), but the sample had solidified from the lyotropic state. The schlieren texture observed on the micrographs is almost the same as that in the micrographs (*a*) in figures 2 and 3, indicating that the molecular orientation in the lyotropic state is preserved in the solid sample. It is important to note from the micrographs (*b*) that many striations appear in the solid film.

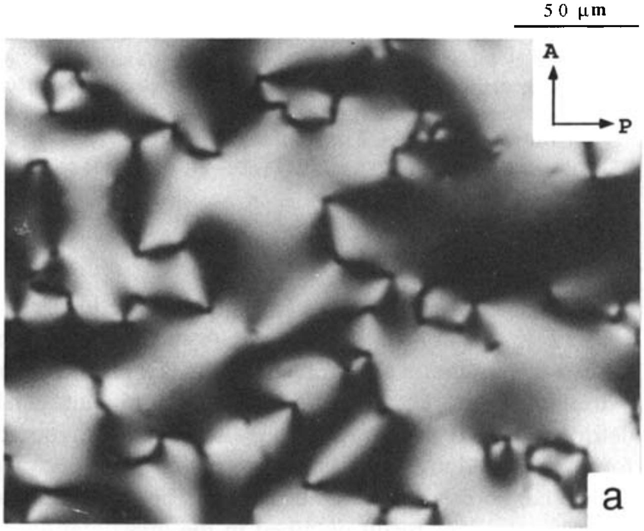


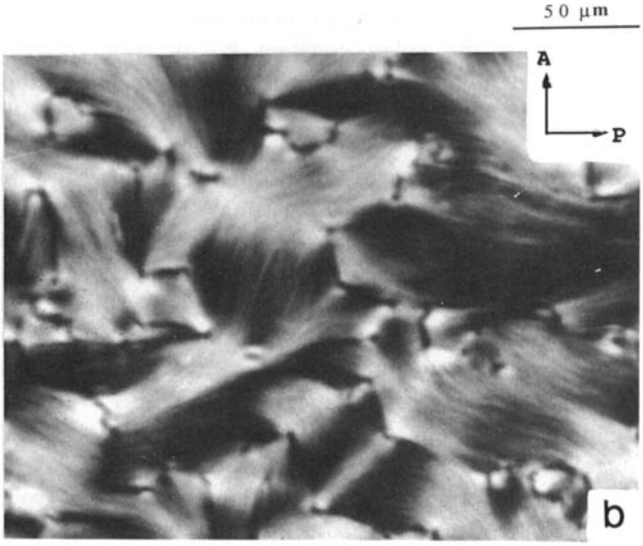
(*a*)

(*b*)

Figure 1. Configurations of disclinations with $s = \pm\frac{1}{2}$ in the case of $\varepsilon = 0$. (*a*) $s = +\frac{1}{2}$: the orientation axis is defined by the line *oa*; (*b*) $s = -\frac{1}{2}$: the orientation axes are defined by the lines *oa*, *ob* and *oc*.

The micrographs (*c*) in figures 2 and 3 were again taken using optical microscopy, but without crossed polarizers in the same area of the same sample as that in the micrographs (*a*) or (*b*) in figures 2 and 3. From the micrographs we can directly distinguish the strength, sign and orientation axis or axes of disclinations from the striation trajectory. For example, disclination A is one with $s = +\frac{1}{2}$ and its orientation axis is indicated by a white line, while disclination B is one with $s = -\frac{1}{2}$ and its three orientation axes can be defined directly and easily from the micrographs. A few pairs of disclinations with $s = \pm\frac{1}{2}$ are indicated by the pairs of arrows, some of which are indicated by letters. Comparing the micrograph in figure 3 (*c*) with that in figure 2 (*c*), we can find at least three variations after isothermally annealing for 48 h at room temperature. Firstly, some pairs of disclinations with $s = \pm\frac{1}{2}$ disappear or annihilate; for example, the pair denoted by letters E and F can be found in figure 2, but not in figure 3; secondly, the distance between a pair of disclinations with $s = \pm\frac{1}{2}$ is reduced before they annihilate each other; thirdly, the relative orientation between a pair of disclinations with $s = \pm\frac{1}{2}$ is changed. The reduction in distance, related to the transitional motion, indicates the attraction of disclinations with opposite sign which will later lead to their annihilation. From these micrographs we cannot define the relative velocity of the transitional motion of the disclinations, i.e. we do not know which kind of disclination moves fast. The change in the relative orientation between a pair of disclinations with $s = \pm\frac{1}{2}$ indicates the occurrence of a relative rotation of disclinations before they annihilate each other. Comparing the pair of disclinations denoted by letters A and B on the micrographs (*c*) in figures 2 and 3, it seems to show that the positive disclination A rotates much more than the negative one B. This rotation results in the formation of a specially relative orientation or configuration between the pair of disclinations as indicated by a few pairs of arrows on the micrograph in figure 3 (*c*).





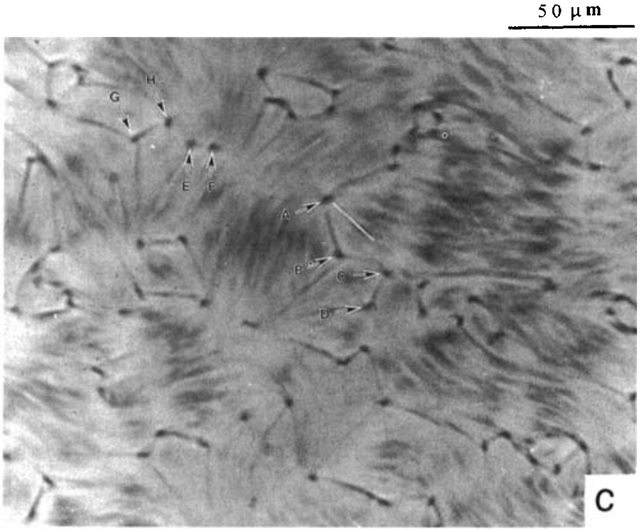
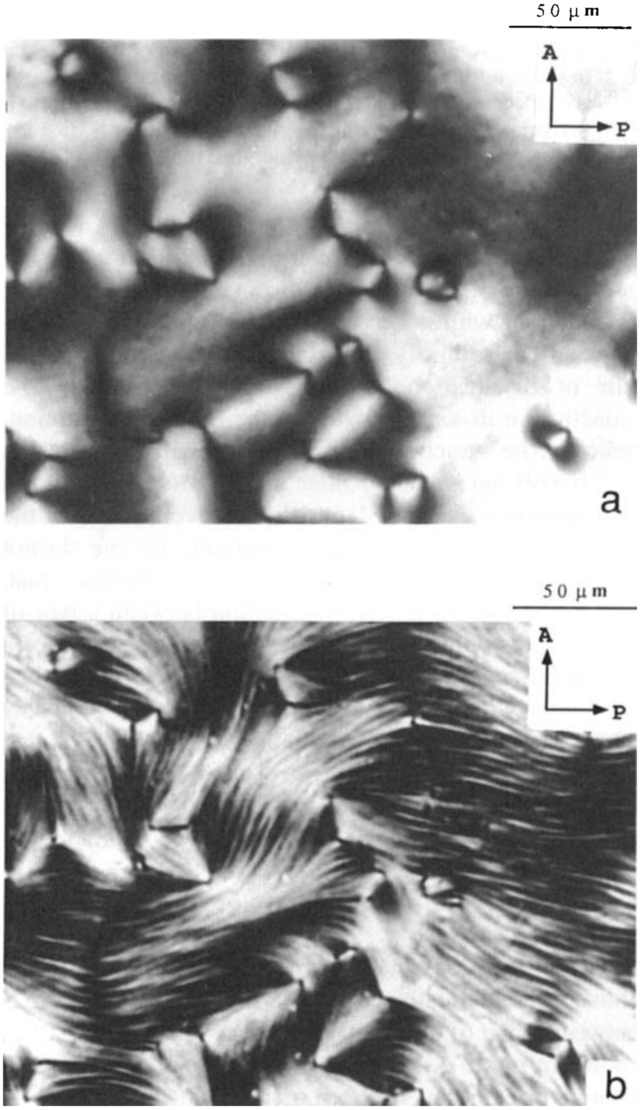


Figure 2. A set of micrographs demonstrating the texture of a P-4-BCMU sample at a late annealing stage. Micrograph (*a*) was taken in the lyotropic nematic state between crossed polarizers; micrograph (*b*) was taken in the solid state between crossed polarizers and micrograph (*c*) was taken in the solid state without polarizers. All three micrographs are of the same area of the same sample. In micrograph (*c*) some pairs of wedge disclinations with $s = \pm\frac{1}{2}$ are denoted by pairs of arrows which are indicated by letters.

To help in discussing the experimental results obtained above, three relative orientations or configurations between a pair of disclinations with $s = \pm\frac{1}{2}$ and $\varepsilon = 0$ are shown in figure 4. Pattern (*a*) shows one of the random relative orientations between a pair of disclinations with

$s = \pm\frac{1}{2}$, but patterns (*b*) and (*c*) show two special configurations between them. In pattern (*b*) the orientation axis of the positive disclination links with one of the orientation axes of the negative disclination and in pattern (*c*) the extension line of the orientation axis of the positive disclination links with the extension line of one of the orientation axes of the negative disclination. The central region between two disclinations for the configuration of pattern (*b*) is mainly splay, but is mainly bend for the other of pattern (*c*) [9, 10]. From the micrographs (*c*) in figures 2 and 3, we can clearly see that shortly before they annihilate, the pair of wedge disclination with $s = \pm\frac{1}{2}$ chooses either one of the special configurations. The typical distance between the pairs or disclinations with $s = \pm\frac{1}{2}$ is smaller than 15 µm for the P-4-BCMU liquid crystal studied. Our previous investigation has indicated that the molecular director is perpendicular to the striation director [7], and so the pair of wedge disclinations with $s = \pm\frac{1}{2}$ in this P-4-BCMU liquid crystal chooses the special configuration shown by pattern (*c*). This indicates that this special configuration with a dominant bend deformation in the central region is energetically favoured for a pair of wedge disclinations with $s = \pm\frac{1}{2}$ approaching each other shortly before annihilating. This is consistent with our previous result obtained in the investigation of the elastic anisotropy of this P-4-BCMU lyotropic liquid crystal [15]. In the previous study [15] we found $\varepsilon \approx 0{\cdot}5$, i.e. the splay constant k_{11} is approximately three time higher than the bend constant k_{33}, further indicating that the bend deformation is energetically favoured.



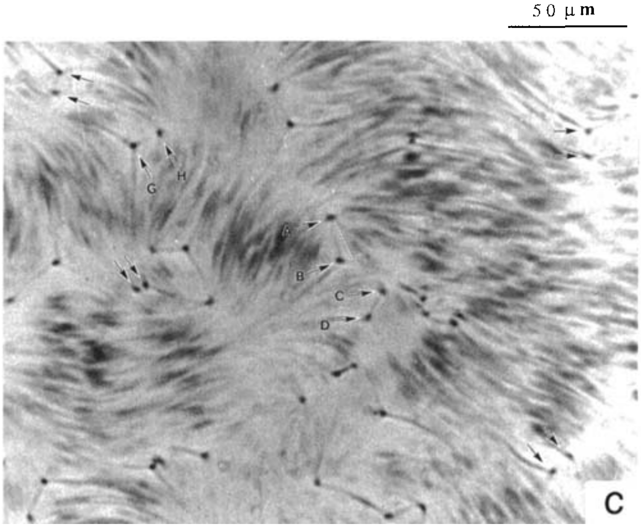
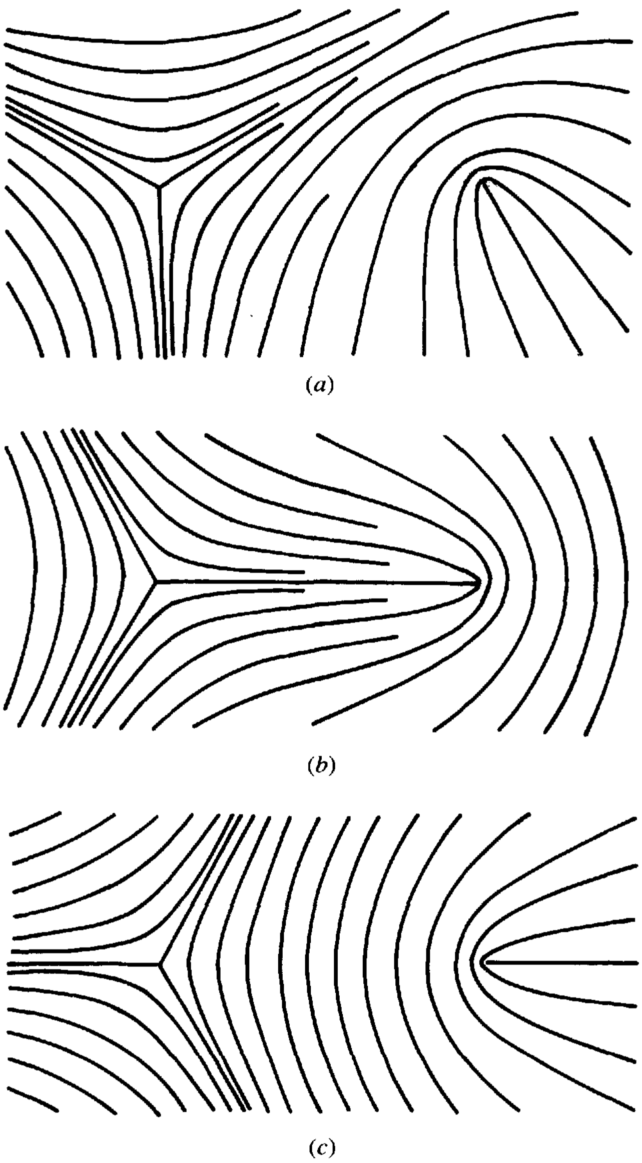


Figure 3. A set of micrographs demonstrating the texture obtained from the same area of the same sample as that in figure 2 after isothermally annealing for a further 48 h. The conditions used in taking these micrographs were the same as those in figure 2. In micrograph (*c*) some pairs of wedge disclinations with $s = \pm\frac{1}{2}$ have a specially relative orientation or configuration which is denoted by pairs of arrows, some of which are indicated by letters. These pairs of wedge disclinations with $s = \pm\frac{1}{2}$ are the same as those marked in figure 2 (*c*).

From experimental results in figures 2 and 3 and the qualitative analysis, we can infer that the special configuration can be observed only when the distance between the pair of disclinations is smaller than a critical value for the liquid crystal with $\varepsilon \neq 0$. The critical value means that at this distance, the deformation in the central region can determine the relative orientation between the pair of disclinations. The critical value for this P-4-BCMU liquid crystal is approximately 10–15 µm.

Recently, some investigations on the kinetics or dynamics of the annihilation process of disclinations were reported by considering the disclinations as point-like



(a)

(b)

(c)

Figure 4. Configurations of pairs of wedge disclinations with $s = \pm \frac{1}{2}$. (*a*) A random relative orientation of the pair of disclinations; (*b*) and (*c*) two special configurations showing that the dominant deformation in the central region is splay in (*b*) and bend in (*c*).

topological defects [11, 12]. It is clearly seen that the theoretical results can be used only in the case of $\varepsilon = 0$. When $\varepsilon \neq 0$, the disclination is not a point-like defect, as shown in this study, and a certain relatively special orientation between disclinations with opposite sign must be considered when the critical distance between them is reached.

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