Journal of Molecular Liquids 200 (2014) 319–322

Contents lists available at ScienceDirect

Journal of Molecular Liquids

journal homepage: www.elsevier.com/locate/molliq

Short Communication

# Conoscopic image of an induced biaxial nematic lyotropic phase

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ARTICLE INFO

*Article history:*
Received 9 September 2014
Accepted 17 October 2014
Available online 28 October 2014

*Keywords:*
Uniaxial discotic nematic
Positive biaxial nematic
Thermal gradient
Induced biaxial nematic

ABSTRACT

Recently, it has been shown by Lavrentovich and co-workers that when a uniaxial nematic thermotropic is subjected to a thermal expansion, the resulting fluid flow can create textures that produce conoscopy images similar to those used to characterize biaxial samples. This works aims to provoke a thermal expansion in a uniaxial discotic nematic lyotropic and compare the resulting conoscopic image with the one obtained in a biaxial nematic phase widely known in lyotropic materials. Our experimental results show that they are perfectly distinguishable; the thermal expansion really leads to a biaxial nematic conoscopic image, but the orientation of the optical axes is rotated by 90°.



## 1. Introduction

Lavrentovich and co-workers [1,2] have observed that a thermal expansion of a uniaxial nematic ($N$) thermotropic sample can cause a fluid flow induced reorientation of the molecules with the appearance of a secondary optical axis that, when optical conoscopic measurements are made, produce conoscopic images similar to the one of a biaxial nematic phase. The conoscopic image, apparently biaxial, returns to a uniaxial nematic configuration when the thermal gradient and material flow disappear and the nematic sample acquires the thermal equilibrium. That is, the system remains intrinsically uniaxial nematic. In addition, the phase biaxiality can be induced either by the boundary conditions of the cell material or by external fields [3–5]. In this lyotropic material, we will study the conoscopic images of a uniaxial discotic nematic lyotropic phase ($N_D$) subject to a thermal gradient while the temperature is changed with a cooling rate. The flow-induced reorientation of the micelles causes opening of conoscopic isogyres in a transient state similar to that reported for uniaxial nematic thermotropic [2,6]. The transient state will be named as an induced biaxial nematic phase ($N_B^i$). The conoscopic image and the optical signal of the $N_B^i$ phase are determined and compared with the biaxial nematic phase ($N_B$) obtained from the phase diagram reported by Yu and Saupe [7]. As we shall see, there are differences that allow a clear distinction between them. In addition, $N_D$ and $N_B^i$ nematic textures are also investigated by means of image processing [8,9]. The transient state domain, between aligned $N_D$ phases, caused by the material flow is clearly identified by this optical technique. In this context, our experimental results are presented and discussed.

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## 2. Fundamentals

The uniaxial discotic nematic ($N_D$) phase between the reentrant isotropic ($I_{RE}$) and isotropic ($I$) phases investigated here is obtained in a phase diagram line [7] of a lyotropic mixture (concentration in weight percent) of potassium laurate ($KL$ : 25.60), decanol ($DeOH$ : 6.24) and heavy water ($D_2O$ : 68.16). The $KL$ was synthetized from lauric acid via neutralization with potassium hydroxide and further purified by being recrystallized with ethanol several times in the laboratory; $DeOH$ and $D_2O$ are commercially available and were obtained from Aldrich. The phase sequence, characterized by means of optical microscopy, digital image processing and optical conoscopy techniques, is determined as following: $I_{RE} - N_D$ (12.53 °C) and $N_D - I$ (43.38 °C). The nematic sample was prepared in sealed glass cells. The 1–2 plane of the sample is defined with 1(2) axis parallel to the length (width) of the cells and 3 is the axis normal to the largest surface of the sample holder. It is important to emphasize that the $N_D$ phase presents positive optical birefringence and negative anisotropy of diamagnetic susceptibility [7,11–13]. Homeotropic alignment of the $N_D$ phase is obtained by a magnetic field ($\sim 1\ T$) parallel to the 1-axis combined with rotations of the nematic sample around the 3-axis [4,14]. The $N_D$ phase subjected to thermal gradient with a cooling rate is then studied through the optical conoscopy technique.

We remember that optical conoscopy [15,16] has been used as a suitable tool to discriminate between uniaxial and biaxial liquid crystal materials [7,17]. The optical conoscopy is obtained inserting an Amici-Bertrand lens positioned in the optical system of the polarized light microscope. The conoscopic image produced by this optical technique in a homeotropic configuration of the $N_D$ phase is known as the Maltese cross and the arms of the cross are its isogyres. Its center is called the melatope, corresponding to the optical axis. In this way, when the $N_D$

http://dx.doi.org/10.1016/j.molliq.2014.10.019
0167-7322/

sample is rotated between crossed polarizers, the conoscopic image pattern does not change, which is an optical characteristic of this uniaxial $N_D$ phase [7,14]. On the other hand, the isogyres open when the biaxial sample in thermal equilibrium is rotated from the 0° position. This opening reaches a maximum value when the stage is rotated from the 45° position. This experimental fact has been used to identify the biaxial liquid crystal phases [7,14,17–19]. The optical sign of uniaxial and biaxial samples can be determined through this optical technique by inserting a gypsum plate into the optical path of the polarized light microscope [15,16].

The polarized light optical microscopy connected to the *CCD* camera is used to detect changes in $N_D$ and $N_B^i$ textures via image processing and only a brief summary of this texture processing technique is presented here [8–10,20,21]. So, let us consider the function $b(x, y)$, which represents the 32 bits true pixel color tone that ranges from 0 to 255 in red, green or blue colors (*RGB* image). The mean intensity of the color tones is given by, $M_0 = 1/l_x l_y \int_0^{l_x} \int_0^{l_y} b(x,y) dxdy$, where $l_x$ and $l_y$ are the rectangular dimensions of the image frame. In this way, the 2-rank statistical moments of the image frame are written by, $M_2 = 1/l_x l_y \int_0^{l_x} \int_0^{l_y} [b(x,y) - M_0]^2 dxdy$. The root square $(M_2)^{1/2}$ is known as the mean square deviation ($\sigma$). The parameter $\sigma$ is determined (Delphi program) as a function of the temperature, for each *RGB* component of the nematic textures, in the range of nematic phases. In this texture study we have chosen the red color (the most sensitive one) which best identifies the nematic textures via parameter $\sigma$ [9,18,22].

## 3. Results and discussion

Fig. 1 shows the nematic textures obtained upon cooling with a rate (~10 °C/min) from the $N_D$ phases subjected to thermal gradient (~30 °C). The homeotropic (pseudoisotropic) texture in $N_D$ phase is transformed into a yellowish texture in the transient state. This texture occurs when there is a flow-induced reorientation of the micelles caused by the fluctuation of the nematic sample's thermal expansion coefficient [1,2]. Notice that, when the thermal gradient and material flow disappear, the yellow texture is again transformed into homeotropic texture in $N_D$ phase as shown in Fig. 1(c). Fig. 2 shows the mean square deviation ($\sigma$), obtained from nematic textures during the transient state, versus time. In the range of the transient state, $\sigma$ increases and becomes maximum and then decreases toward the homeotropic configuration of the $N_D$ phase. Observe that the nematic texture in the presence of the material flow occurs between two minimum values of $\sigma$ which correspond to the homeotropic configuration of the aligned $N_D$ phase.

Fig. 3 shows the conoscopic images of the $N_D$ uniaxial phase subjected to thermal gradient obtained upon cooling cycle with the given rate mentioned above. These conoscopic images were determined when the $N_D$ sample is rotated (anticlockwise) from the 0° position to the 45° position and then fixed at 45°. The Maltese cross, characteristic of the

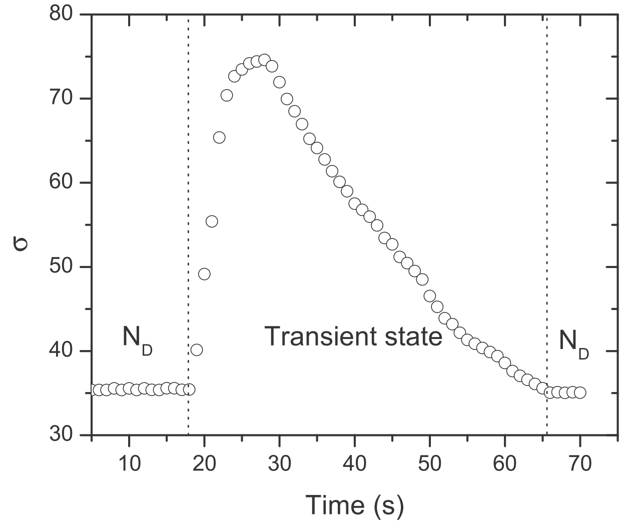


**Fig. 2.** Mean square deviation ($\sigma$) versus time.

$N_D$ phase, is shown in Fig. 3(a) and (c), as expected [7,14,18]. The isogyres open during the transient state ($N_B^i$ phase) with the melatopes positioned along the *NW* and *SE* quadrants as depicted in Fig. 3(b). Observe that the splitting of conoscopic isogyres in the transient state changes to the Maltese cross characteristic of the $N_D$ phase when the final state of thermal equilibrium (thermal gradient and material flow disappear) is reached. This is our central result and agrees with the conoscopic images obtained by Lavrentovich and co-workers [2] from a *N* thermotropic phase subjected to thermal gradient. The conoscopic image of $N_B^i$ phase is now compared to the $N_B$ phase found in Saupe diagram [7] bordered by two uniaxial nematic ($N_D$) phases, recently reported [14], as shown in Fig. 3(d), (e) and (f), respectively. These conoscopic images ($N_D$ and $N_B$ phases) are well known and were determined when the nematic sample (in thermal equilibrium) is also rotated (anticlockwise) from the 0° position to the 45° position and then fixed at 45°. Note that the melatopes ($N_B$ phase) are positioned along the *NE* and *SW* quadrants [7,14,18] as depicted in Fig. 3(e). On the other hand, a fundamental difference between the conoscopic images ($N_B^i$ and $N_B$ phases) is clearly identified when Fig. 3(b) and (e) are compared. The isogyres found in the $N_B^i$ phase are not in the expected first and third quadrants ($N_B$ phase), but rotated by 90°, in the second and fourth quadrants. This experimental result is similar to that reported for uniaxial nematic thermotropic shown in Fig. 10 of reference [2]. The optical signals of $N_B^i$ and $N_B$ phases are also determined from Fig. 3(b) and (e), respectively. In the optical configuration of the $N_B^i$ ($N_B$) phase, the optic plane (oriented *NW* (*NE*)–*SE* (*SW*)) is parallel (perpendicular) with the fast vibration direction of the gypsum plate inserted into the optical path. The observed color near the melatopes between the two isogyres turns blue (yellow) and the area inside of

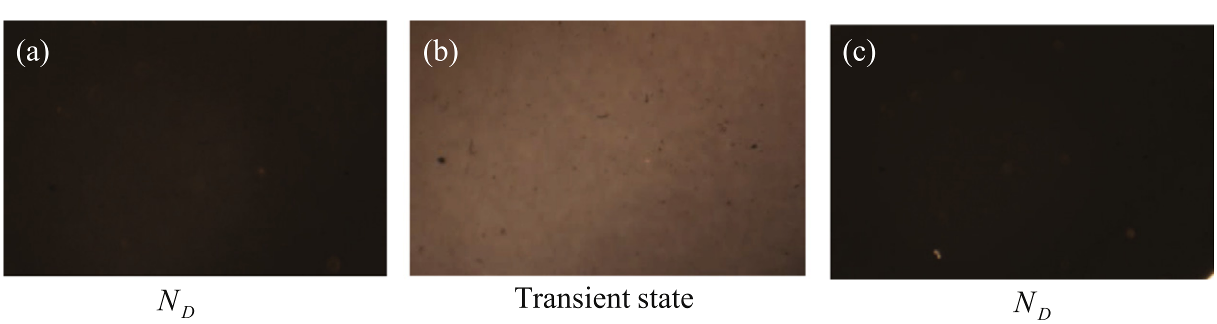


**Fig. 1.** Nematic textures: (a) Discotic nematic ($N_D$) phase, (b) transient state and (c) $N_D$ phase.