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The Effect of Sample Geometry on the Anisotropy of Turbidity and Elastic Constants of Nematic Liquid Crystals

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The experimentally modified Raleigh light scattering technique was utilized to determine the anisotropy of turbidity and, simoultaneously, the three elastic constants of "splay" (K_1), "twist" (K_2) and "bend" (K_3) in the *n*-alkly-cyanobiphenyl (*n*CB) nematic systems. We found that the anisotropy of turbidity, and hence the elastic constants, are influenced by the sample geometry, i.e. from the surface and bulk effects. We studied the turbidities of uniaxial nematic systems at various sample thicknesses, where by a correct choice of the sample geometry and elimination of the undesired surface and bulk contributions, we then evaluated the corresponding K_1, K_2 and K_3 values. The results are in quantitative agreement with those reported in the literature obtained by the conventional field-induced techniques.

INTRODUCTION

The elastic properties in mesophases can provide valuable insights on the structure-property relations of the condensed matter states. In liquid crystalline media, particularly in nematic phase, the short-range molecular interactions, transmitted to the bulk by a long-range orientational fluctuations, result into many measurable anisotropic physical properties. These insights are particularly useful in liquid crystal display technology, as well as in polymer characterization.

The continuum nematic moduli of elasticities, i.e., the three elastic constants of "splay" (K_1), "twist" (K_2) and "bend" (K_3), are direct bulk manifestations of the anisotropy of molecular interactions, and are known to be sensitive to the physico-chemical environment of the system. Apart from the well developed field-induced methods, the light scattering (anisotropy of turbidity) techniques have a number of advantages. These include the experimental simplicity, avoiding the surface treatment, simultaneous evaluation of all three elastic moduli, and, last but not least, their potential utilization in measurement of the elastic moduli in both thermotropic and lyotropic polymer systems.

With light scattering approach, the measurements of total scattering intensities at three selected geometries of a uniaxial nematic phase provide the values of the anisotropy of turbidity, from which all three elastic constants can be simultaneously

evaluated.[1,2] In the previous works, we have reported the three elastic constants in a number of thermotropic[3-6] and lyotropic[5,7] nematic systems. In all those studies, we have noticed that the evaluated elastic moduli, particularly K_1 and K_3, had given a systematically larger values (as much as one order of magnitude) than those reported by field-induced techniques. Although in the later studies[5,7] the origin of these discrepancies had been noticed, yet it has not been possible to make a quantitative improvement of the technique. Consequently, until now, the light scattering from turbidity anisotropy has not been considered as a reliable quantitative method for measurements of the elastic constants in nematic systems.

In the present work, we modified the light scattering experimental set-up and by improvements in turbidity measurements method, evaluated the correct elastic moduli values of the nematic systems. Precise turbidity measurements were carried out by systematic elimination of the sources of experimental errors arising from the nematic director orientation and the cell geometry due to undesired surface and bulk contributions. The magnetic field intensity and cell geometry determine the degree of order and anisotropy of turbidity of the nematic phase. These effects are manifested by a competition between the surface-induced orientation and bulk-induced disorientation (thermal fluctuations) of the nematic director. Within the limit of the utilized magnetic field intensity and cell geometries, here we found that the surface ordering effect to be dominant in thinner nematic cells, whereas the thermal disordering effect to be dominant in thicker nematic cells.

Although the procedure for the elastic constants evaluation was the same computer fitting routine used in the previous studies,[1-3,7] the major improvements of the present study were based on the experimental and analytical precision in measurements of the anisotropy of turbidity in uniaxial nematic phases.

EXPERIMENTAL

The nematic materials utilized in this study were the nematogenic *n*CB series, such as the single components 5CB and 6CB, the binary mixture 5CB/7CB (1:1), as well as the eutectic E7 mixture. The materials were obtained from Merck UK Ltd. with purities of 99.9% and were used without further purification. The transition temperatures of the nematogens were determined with a Zeiss Universal polarizing microscope equipped with a Linkam THM600 hot-stage and a TMS90 Automatic Temperature Programmer. The nematic materials were placed in Wilmad or Helma precision optical cells with "square" cross-sections having the inside thicknesses (optical path) of $l = 0.3$, 0.4, 0.5 and 1.0 cm. The cells at smaller thicknesses were consisted of optical glass plates having rectangular gravings with 0.1 and 0.2 cm thick spacings, which provided samples with "rectangular" cross-sections.

The nematic materials were put in the optical cell and the cell was placed in a home-built temperature control unit designed to fit between adjustable poles of an Oxford Instrument N38 electromagnet. The magnetic field intensity of up to $\mathscr{B} = 0.6$ tesla was used to induce a uniaxial orientation of the nematic director. Figure (1) presents the layout of the modified instrumental set-up and measurement technique of this work.

The turbidities of oriented nematic phase were determined by accurate measurements of the "total scattering cross section" σ_j $(j = 1,2,3)$ in the following three selected geometries:[1-3,7]

$$G1: k \| v_0 \quad G2: k \perp v_0, i \perp v_0 \quad G3: k \perp v_0, i \| v_0,$$

where k is the wave number of the incident light, v_0 is the direction of the nematic director and i is the unit vector representing the polarization direction of the incident light. The light intensity in the three above geometries were measured by sending the beam of a 7 mW polarized He-Ne laser in two orthogonal direction through the cell (see Fig. 1) and by measuring with photodiode at the corresponding polarization modes with a Stanford Research Systems SR510 lock-in amplifier. A SR540 chopper controller was utilized to reduce the laser beam's intensity fluctuations through a reference beam. The light intensities at the above three geometries were measured as a function of the angle of detection and the values at the plateau level were chosen to measure the corresponding turbidities σ_1, σ_2 and σ_3 in the three geometries according to the following relation:

$$\sigma_j = (\ln I_j^0 - \ln I_j)/l \tag{1}$$

where I_j^0 is the incident laser intensity in the isotropic phase at the related geometries $j = 1, 2$ & 3; I_j is the measured intensity of laser in the oriented nematic phase and l is the optical path length (sample thickness).

In comparison to the original works,[3-7] the experimental improvements of the present work consist of the following modifications (see Fig. 1); a) the use of lock-in amplifier and chopper to reduce the laser intensity fluctuations; b) the use of on-line reference beam for precise measurements of turbidities; c) the application of variable magnetic field in order to study the orientation of the nematic phase; d) the use of perforated electro-magnet in order not to disturb or rotate the sample during measurements.

Evaluation of the elastic constants requires not only the precise values of the turbidities, but also those of the refractive indices n_0 and n_e, as well as the temperature of nematic phase. The values of n_0 and n_e at room temperature were directly measured with an Abbe refractometer, using the same on-line beam, whereas those at other temperatures were extracted from the available literature data[8] by making the necessary corrections for the transition temperature and wavelength differences (see ref. 3). The temperature of the sample during the study was controlled by circulating water around the cell and was measured by a thermocouple with an accuracy of $\pm 0.5\,^{\circ}C$. Most nematic materials were studied at room temperature, whereas the temperature-dependence of turbidities and elastic moduli were carried out only for the nematic 5CB.

The final evaluation procedure of the elastic constants were carried out by a comparison between the experimental and theoretical values of turbidities, refractive indices and temperature of the uniaxial nematic phase with a computer search routine which uses the necessary iterations to converge and to find the best elastic constants with a tolerance of less than 0.1%. The theoretical and experimental

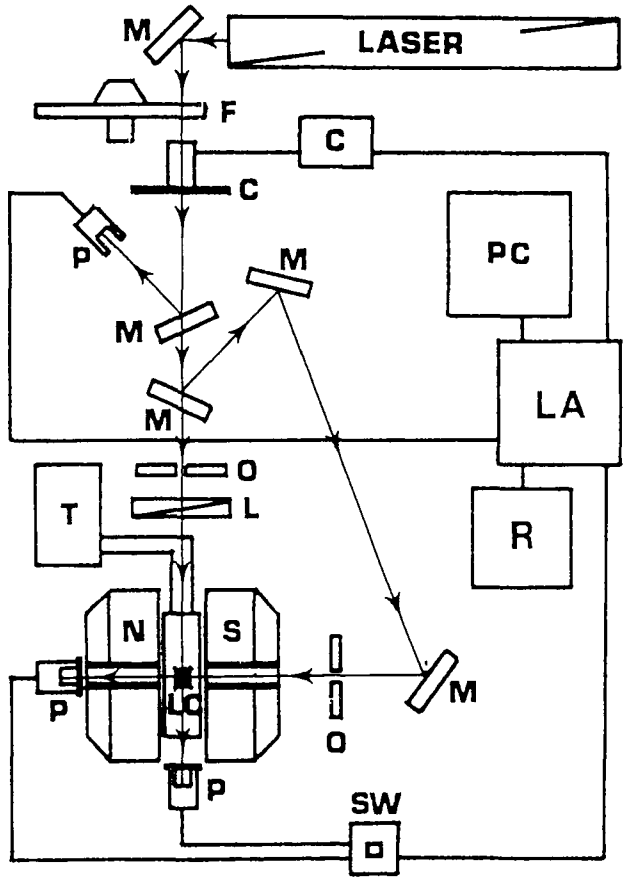

FIGURE 1 The instrumental layout of the experimental set-up of light scattering technique showing: the He-Ne laser source; the interference mirrors (M),; the filters (F); the chopper (C); the lock-in amplifier (LA); the pin-holes (O); $1/2\lambda$ rotators of polarization (L); the thermostat (T); the liquid crystal cell and temperature control holder (LC); the electro-magnet (NS); the photo-diod cells (P); the geometry converting switch (SW); the recorder (R); and the personal computer (PC). See the experimental set-up in reference 3 for further comparison.

details of this procedure have been mentioned elsewhere.[3-7] The largest uncertainties in the experimental values basically arise from the turbidity measurements, (within 5%), which provides an estimated error of the same order of magnitude in the extracted elastic constant values.

RESULTS AND DISCUSSIONS

1. Turbidity and Magnetic Field

The turbidity of a randomly oriented nematic phase in the absence of an external orienting field (such as magnetic, electric or surface anchoring) is expected to be

equal in all three geometrical directions and may be presented by a "zero-field average turbidity", $\langle\sigma\rangle = (\sigma_1^0 + \sigma_2^0 + \sigma_3^0)/3$, where σ_1^0, σ_2^0 and σ_3^0 are the zero-field turbidities at the corresponding geometries G1, G2 and G3, respectively. A magnetic field can orient the nematic director and, if strong enough, can even quench both microscopic and macroscopic director orientational fluctuations.[9-11] The quenching of nematic director fluctuations in a relatively strong magnetic field (i.e., > 1 tesla) had been reported to yield a significant reduction of the σ_1, σ_2, σ_3 values and larger elastic constants.[5]

The nematic director response to a magnetic field depends on factors such as the chemical nature, viscoelastic properties, temperature and thickness, which would result to spatial discrimination of $\langle\sigma\rangle$ and the unset of anisotropy. With a gradual increase of the field, the turbidity began to show such discrimination at the three geometries, where σ_1, σ_2, and σ_3 began to diverge according to $\sigma_1 < \sigma_2 < \sigma_3$ inequality trend. Among the three turbidities σ_1 (which exhibits the lowest value of the three) is the most sensitive turbidity with respect to the surface anchoring effect and sample thickness.

In Table (I), we present examples of the magnetic field dependence of the turbidities in 6CB, 5CB/7CB and E7 mixtures in a 0.3 cm thick sample. The results at this and other studied thicknesses indicate that, below a critical magnetic field intensity range of about $\mathscr{B} = 0.4$ tesla, all three σ_j values decrease nonlinearly. This is a result of bulk orientation of the nematic director with the field. Above this critical magnetic field threshold, σ_j values reach a plateau level, (i.e., a complete orientation of nematic director) and the total scattering from the anisotropy of turbidity. Variations of σ_j below the critical field was the largest for σ_1 and smallest for σ_3, because at these two geometries, the measurements are taken along and perpendicular to the nematic director orientation, respectively. This behavior was qualitatively observable at all sample thicknesses, with quantitative differences in the rate of turbidity changes, which becomes more significant for σ_1 in thinner samples due to the surface effect.

2. Turbidity and Order Parameter

The orientational order parameter in the nematic phase is conveniently measured by a number of well-developed spectroscopic and macroscopic methods. Likewise, the light scattering technique can provide a direct evaluation of the macroscopic or "director order parameter", S_d, from the experimental values of the anisotropy of turbidities (σ_1, σ_2 and σ_3). As it has been reported previously,[5] σ_1 and σ_3 represent the perpendicular and parallel components of the anisotropy of nematic director fluctuations, respectively. Consequently, the director order parameter S_d can be presented by the following straightforward relation:

$$S_d = (\sigma_3 - \sigma_1)/\langle\sigma\rangle \tag{2}$$

where $\langle\sigma\rangle$ is the experimental "zero-field average turbidity" of the unoriented nematic phase in the absence of the magnetic field ($\mathscr{B} = 0$). Note that, the denominator on the right-hand-side of equation (2) had been previously represented by the

average turbidity $(\sigma_3 + 2\sigma_1)$.[6] That definition had resulted to relatively large and inconsistent values of the order parameter due to both the quenching of turbidity in the strong magnetic field ($\beta = 1.4$ tesla), as well as the different effects of the surface-induced orientation on σ_1 and σ_3. In the present study we, instead, utilized a magnetic field of $\mathscr{B} = 0.6$ tesla, far below the quenching range, and furthermore substituted the "average-zero-field turbidity" $\langle\sigma\rangle$ for $(\sigma_3 + 2\sigma_1)$ in the right-hand-side of equation (2), which provided a more consistent and realistic presentation of the random turbidity in an unoriented nematic phase.

From equation (2), we then evaluated the degree of orientation of the nematic director as a function of the field intensity and sample thickness. In the last column of Table (I), we also presented the field-dependence of the order parameter S_d in the three nematic systems. As expected, S_d increases with the magnetic field intensity, reaching the corresponding threshold values of 0.58 (6CB), 0.55 (5CB/7CB) and 0.57

TABLE I

The magnetic field effect on turbidities and orintation of nematic 6CB, 5CB/7CB and E7 ($l = 0.3$ cm, $T = 296$ °K)

$\mathscr{B}$(tesla)	$\sigma_1(\text{cm}^{-1})$	$\sigma_2(\text{cm}^{-1})$	$\sigma_3(\text{cm}^{-1})$	S_d
0	9.30	10.80	11.70	0.23
0.04	6.45	10.15	11.05	0.43
0.10	4.65	9.40	10.20	0.52
0.20	4.20	9.20	10.00	0.55
0.30	4.10	9.15	10.05	0.56
0.40	3.90	9.15	10.05	0.58
0.50	3.95	9.20	10.05	0.58
0.60	3.95	9.20	10.05	0.58
		5CB/7CB (1:1)		
$\mathscr{B}$(tesla)	$\sigma_1(\text{cm}^{-1})$	$\sigma_2(\text{cm}^{-1})$	$\sigma_3(\text{cm}^{-1})$	S_d
0	8.45	8.20	10.10	0.20
0.04	4.55	8.05	9.25	0.47
0.10	3.35	7.55	8.00	0.53
0.20	3.20	7.55	8.00	0.54
0.30	3.20	7.55	7.95	0.55
0.40	3.15	7.55	7.95	0.55
0.50	3.15	7.55	7.95	0.55
0.60	3.15	7.55	7.95	0.55
		E7		
$\mathscr{B}$(tesla)	$\sigma_1(\text{cm}^{-1})$	$\sigma_2(\text{cm}^{-1})$	$\sigma_3(\text{cm}^{-1})$	S_d
0	5.60	6.70	7.70	0.31
0.04	4.20	6.70	7.45	0.49
0.10	3.80	6.65	7.25	0.52
0.20	3.65	6.55	7.20	0.53
0.30	3.50	6.50	7.15	0.54
0.40	3.50	6.50	7.15	0.55
0.50	3.50	6.55	7.20	0.56
0.60	3.50	6.50	7.25	0.57

(E7) at complete orientation of the nematic system. The field-dependence of order parameter is a direct manifestation of the nematic director alignment, which also indicates the correct quantitative presentation of S_d from the equation (2). These results are in good agreement with the literature data obtained for the conventional "optical order parameter".[10-11]

3. Turbidity and Sample Geometry

In the previous studies, it had been pointed out that, in addition to dampening of the nematic director fluctuations, another major source of the experimental error in the measurements of turbidities arises from the undesired orientation (anchoring) of the nematic director at or near the nematic-glass surfaces.[1,2,5,6] This surface-induced effect becomes dominant in thinner samples of the order of 0.1 cm and less, whereas in thick samples of larger than 0.3 cm, the bulk thermal fluctuations becomes a significant factor of disorientation.

In principle, elimination of the surface-induced anomalies could be accomplished by measurement of the anisotropy of turbidity in thick samples (of the order of 0.5 cm and more). However, at this thickness range the bulk thermal fluctuations tend to disrupt the orientational order of the uniaxial nematic director even in presence of a strong magnetic field (i.e., $\mathscr{B} > 1$ tesla). The use of a stronger field may, however, dampen the director fluctuations, resulting to quenching of the turbidities and, hence, to larger elastic constant values.[6] Evidently, in an oriented nematic phase confined to a restricted geometry, there always exists a competition between the thermal disordering and surface ordering effects. Consequently, at any given experimental condition, there must be an "optimum" geometry and surface treatment, at which the surface and bulk induced effects are modified in order to provide accurate turbidities values and reliable elastic moduli of the system.

In order to verify and modify the opposing contributions of the surface and bulk effects to the anisotropy of turbidity, we measured the turbidities of uniaxial nematic phases as a function of the cell shape and thickness. Within the limits of the studied thickness range (0.1 – 1.0 cm), we found that both surface effects (in thin cells) and bulk effects (in thick cells) contribute to anomalous values of σ_1, σ_2 and σ_3. Obviously, for a correct evaluation of the elastic constants our attempt was to eliminate these anomalies. The surface-induced orientational anomalies, which is the major source of the error in turbidity measurements, had been also reported in the literature.[10] In thin nematic samples ($l < 0.2$ cm), due to the "rectangular" geometry of the optical cell, the three turbidities could not be measured simultaneously and the cell ought to be rotated by 90 degrees during the measurements. In this circumstance, the non-uniform shape of the cell, the sample rotation and the surface-induced ordering are dominant factors, which result into discrimination in zero-field turbidities at the three geometries, where σ_1 is subjected to larger experimental errors. However, in thick nematic samples ($l > 0.3$ cm), where the thermal fluctuations of the bulk dominates the surface-induced orientation, the "zero-field average turbidity", $\langle\sigma\rangle$, provided the same value in the three geometries. Particularly, in optical cells with "square" cross-section, the turbidities exhibited equal values at all experimental directions.

In Table II, we present an example of thickness-dependence of turbidities in the nematic phase of 6CB. The results clearly indicate an almost linear decrease of σ_1 with increasing thickness within the whole range of 0.01 to 1.0 cm, whereas σ_2 and σ_3 exhibit such a trend above the thickness of 0.1 cm. The linear inverse variations of turbidities of 6CB with thickness is in agreement with those of 8CB in a previous study.[5] This is a reflection of increasing of the surface-induced orientation (i.e., smectic-like or cybotactic order) of nematic director as the sample thickness decreases. Obviously, such a surface-induced effect would result into erronous values of the measured turbidities and evaluated elastic constants. Furthermore, in Table (II) we also notice that, by increasing the sample thickness, σ_1 remains almost unaffected whereas σ_2 and σ_3 tend to converge to a common value at the thicker limit of 1.0 cm. This trend can be simply explained by the geometrical conditions of the experiment, where thermal fluctuations overcomes the orientation order of the nematic director. Consequently, we found that the measured turbidities of the studied nematogens usually provide the correct order of magnitude of σ_1, σ_2 and σ_3 values in the optical cells having square cross section and thickness range of 0.3–0.5 cm. In such experimental conditions the surface and bulk competitions tend to be optimized and, evidently, result in the correct measurements of the anisotropy of turbidity.

In addition to turbidities, in Table (II) we also tabulated the effect of sample thickness on the order parameter of 6CB, from equation (2). In this nematic system, as well as in other studied nematogens, we also found that the evaluted S_d gives more realistic values (of the order of 0.58–0.54) in optical cells with square cross-section and the thickness range of 0.3–0.5 cm.

A further systematic approach to eliminate the observed turbidity anomalies induced by sample shape and thickness was accomplished by extrapolation of the turbidities to the "infinite thickness" in a typical turbidity vs inverse thickness plot. A typical example of such a plot and measurement is presented in Figure (2), where the three σ_j values of the nematic 6CB are plotted versus the inverse of the cell thickness ($1/l$). Variations of σ_j with thickness demonstrate two different trends at the lower and upper limits of the thickness range. In the lower region of thickness (larger $1/l$), all three σ_1, σ_2 and σ_3 decrease almost linearly with thickness increase ($1/l$ decrease), a manifestation of the decreasing effect of surface-induced contribution. In the upper thickness region (lower $1/l$) where the bulk effect becomes domi-

TABLE II

The effect of cell thickness on turbidities of nematic 6CB ($B = 0.6$ tesla, $T = 296$ °K)

l(cm)	σ_1 (cm^{-1})	σ_2 (cm^{-1})	σ_3 (cm^{-1})	S_d
0.01	4.50	8.75	9.70	0.69
0.1	4.25	9.90	12.70	0.64
0.2	4.20	9.40	11.60	0.62
0.3	3.95	9.20	10.05	0.58
0.5	3.70	8.90	9.70	0.56
1.0	3.75	6.85	6.90	0.46

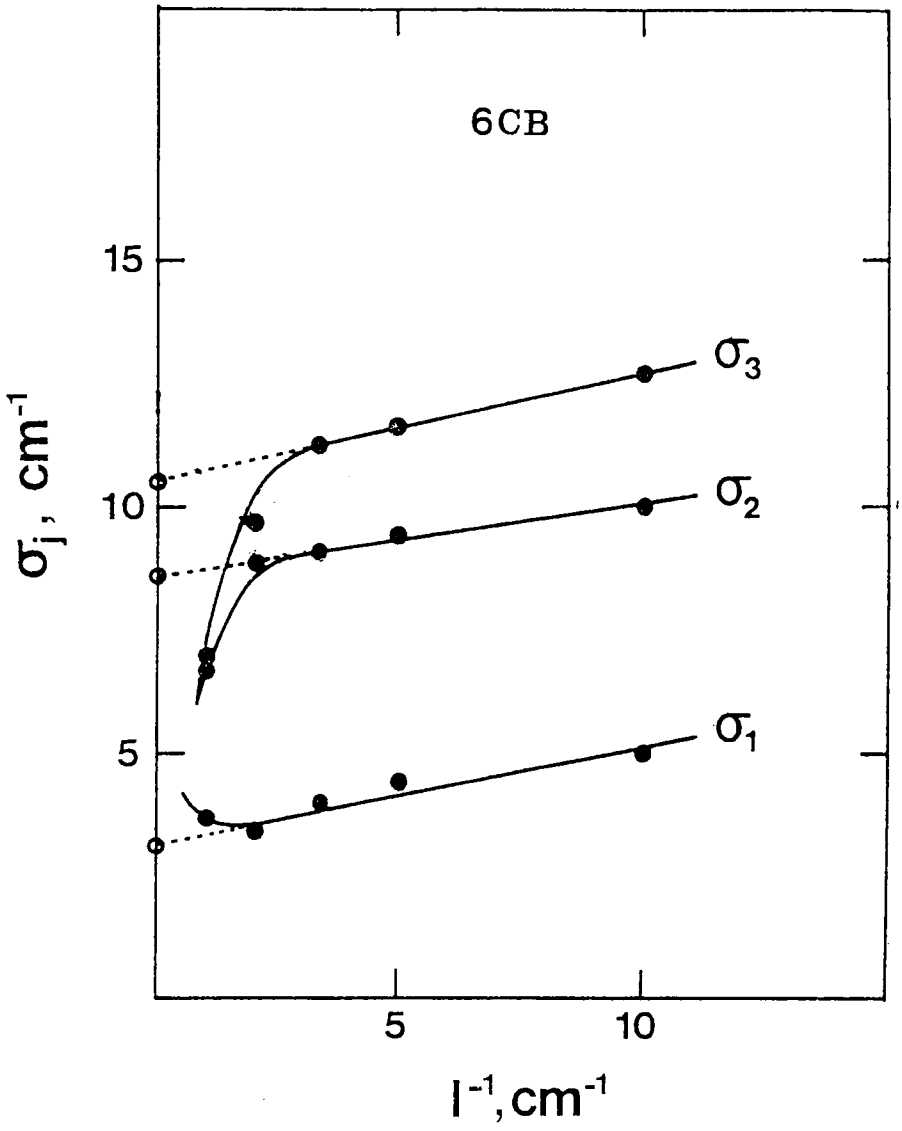

FIGURE 2 Dependence of turbidities σ_1, σ_2 and σ_3 of nematic 6CB on the inverse sample thickness ($1/l$) at 0.6 tesla and $T = 296$ K.

nant, σ_1 increases smoothly whereas both σ_2 and σ_3 decrease nonlinearly and become almost indistinguishable at $l = 1.0$ cm limit. From the trend of σ_j vs $1/l$, we could extract an "optimum" values of turbidities by an extrapolation of the linear portion (upper $1/l$, range) of the corresponding curves to infinite thickness, i.e., $1/l = 0$. We found that this empirical approach could result in a quantitatively more consistant turbidity values, from which a more reliable elastic constants may be evaluated. In another words, by an extrapolation approach, it is possible to

eliminate both the surface-induced orientation and bulk-induced disorientation effects. This is a much more accurate method for measuring of the turbidities than the approximation approach that had been utilized in the previous works.[5-7] In Table (III), we present the results of the turbidity measurements in four nematic systems obtained by extrapolation approach from a typical $\sigma_j - 1/l$, plot. These values were then utilized to evaluate the correct elastic moduli of the nematic systems.

In addition to the extrapolation procedure, a reliable measurement of turbidities can also be achieved by proper coating of the inside surfaces of optical cells with materials, such as lecithin, which provide a homeotropic (perpendicular) orientation of the nematic director. With the surface treatment it is possible to minimize the surface-induced anomalies and to measure σ_j (and K_i) values in even rectangular optical cell with thicknesses less than 0.1 cm. This type of experiment is recommended only when the experimental setup does not allow the use of square cross-section cells and the simultaneous measurements of turbidities cannot be performed without disturbing the sample. It is even expected that a combination of an appropriate surface treatment and sample geometry could provide a further improvement of the quantitative determination of the anisotropy of turbidity.

4. Elastic Constants

In the previous sections we described the factors which can contribute to the experimental errors in the measurements of the anisotropy of turbidity. By elimination of the undesired surface and bulk contributions, it was possible to determine with more precision the σ_1, σ_2 and σ_3 values and to evaluate with more accuracy the three moduli of elasticities; K_1, K_2 and K_3 of the nematic systems.

Until now, due to unreliability in the turbidity measurements, light scattering methods gave consistantly larger values of the elastic constants in the published literature. The studies of the elastic constants in *n*CB nematogens with this techniques had resulted to K_1, K_2 and K_3 values of about 3 times larger than those obtained by the field-induced methods.[3-6] For example, the elastic moduli of nematic *n*CB ($n = 5.8$) have been reported to fall within: $10 \times 10^{-7} < K_1 < 30 \times 10^{-7}$, $2 \times 10^{-7} < K_2 < 6 \times 10^{-7}$ and $10 \times 10^{-7} < K_3 < 40 \times 10^{-7}$ dyne.

The results of the elastic constant data of the present work are tabulated in Table (III) and indicate that; $7 \times 10^{-7} < K_1 < 10 \times 10^{-7}$ dyne, $4 \times 10^{-7} < K_2 < 7 \times 10^{-7}$

TABLE III

The turbidities and elastic constants of nematogens ($T = 296$ °K)

	σ_j (cm^{-1})	K_i (10^{-7} dyne)
Material	$\sigma_1/\sigma_2/\sigma_3$	K_1/K_2K_3
5CB	3.00/7.85/ 9.55	7.1/4.1/ 9.2
6CB	3.30/8.90/10.70	4.9/2.6/ 8.6
5CB/7CB	2.90/7.55/ 9.15	7.4/4.4/10.8
E7	2.60/6.65/ 8.00	9.2/7.1/16.2

dyne and $8 \times 10^{-7} < K_3 < 16 \times 10^{7}$ dyne. A comparison between the current and previous results clearly demonstrate that, the elastic constants of the present study are about 3 times smaller than those obtained before. Furthermore, the order of magnitude of the elastic moduli of *n*CB nematogens presented here falls within the range of those reported in the literature by field-induced methods (for example, see reference 13 and the cited literature data).

The elastic constants of the four nematic systems of Table (III) were obtained by comparing the experimental data of turbidities, refractive indices and temperature with the theoretical model.[3-7] More specifically, a comparison between the elastic constants of 5CB and 6CB with those of a previous study[3] clearly suggests that the present results are lower by a factor of 2 in K_2 and by a factor of 3 in K_1 and K_3. All the elastic moduli of Table (III) are also in good accord with those of the literature data obtained by field induced method.[13]

In order to provide further quantitative verification of the present results, we also determined the temperature-dependence of turbidities and elastic moduli of the nematic 5CB. In Table (IV) we tabulated the temperature variations of the refractive indices, turbidities and elastic moduli in this nematic material. The refractive indices, (as mentioned in the experimental section) were extracted from the literature and corrected accordingly.[8]

In Figure (3), we show the K_1, K_2 and K_3 values of 5CB (circles and triangles) as a function of the temperature difference $(T_{NI} - T)$, where T_{NI} is the nematic-isotropic transition of 5CB. For a purpose of comparison, in this figure we also show the elastic constant data from the literature[13] (solid curves), as well as those of our previous work[3] (dashed curves). The results clearly demonstrate that within the studied temperature range, the three K_i comparing with the previously non-modified light scattering method (refrence 3) are about 3–5 times larger than those of the present modified method. Furthermore, the temperature-dependence of all three elastic

TABLE IV

Temperature dependence of the refractive indices, turbidities and elastic constants of nematic 5CB ($T_{ni} = 306.5$ °K)

		$\sigma_j(\text{cm}^{-1})$	$K_i(10^{-7}\text{dyne})$
$T(^\circ K)$	n_0/n_e	$\sigma_1/\sigma_2/\sigma_3$	$K_1/K_2/K_3$
296	1.530/1.706	3.00/ 7.85/ 9.55	7.1/4.1/9.2
298	1.531/1.702	3.05/ 8.05/ 9.80	6.6/3.9/8.7
299	1.531/1.700	3.15/ 8.30/10.10	6.4/3.6/8.2
300	1.532/1.696	3.20/ 8.50/10.35	5.9/3.4/7.6
301	1.533/1.693	3.25/ 8.70/10.60	5.5/3.2/7.1
302	1.534/1.690	3.30/ 8.95/10.95	5.0/3.1/6.5
303	1.535/1.685	3.35/ 9.20/11.20	4.7/2.9/6.0
303.5	1.536/1.682	3.45/ 9.50/11.60	4.3/2.8/5.3
304	1.537/1.680	3.50/ 9.75/11.90	4.0/2.7/5.0
304.5	1.538/1.676	3.55/10.00/12.20	3.6/2.5/4.6
305	1.540/1.672	3.65/10.30/12.60	3.4/2.2/4.2
305.5	1.542/1.668	3.70/10.55/12.90	3.1/1.9/3.6
306	1.546/1.662	3.75/10.85/13.25	2.7/1.5/3.2

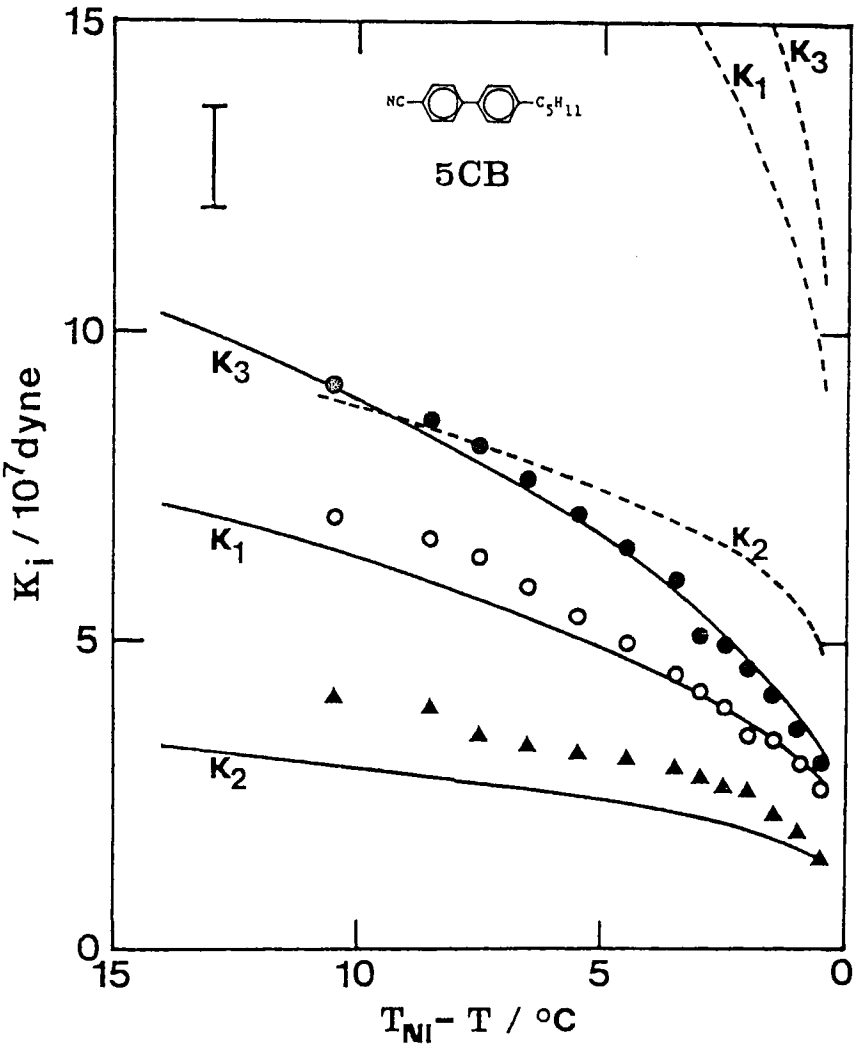

FIGURE 3 The temperature-dependence of the elastic constants of nematic 5CB at 6 tesla (circles and triangles) compared with those of our previous work of ref. 3 (dashed curves) and those with Freedericks field-induced method of reference 13 (solid curves). The curves are best fit to the corresponding data.

constants are in very good agreement with those of the literature data (solid curves). This is a further confirmation of the quantitative validity of the present experimental work.

CONCLUSION

In the present work, we determined the anisotropy of turbidity and the three Frank's elastic moduli in some cyano-biphenyl (*n*CB) nematogens by the experimentally modified light scattering technique. The experimental modifications included

improvements in the instrumental setup, the sample geometry and higher precision in turbidity measurements. These experimental improvements were then utilized to study the surface and bulk effects on the anisotropy of turbidity of these nematogens. After a systematic elimination of the sources of errors, we determined the correct values of turbidities and elastic constants in nematic systems. The agreements between the elastic moduli of this study and those in the literature confirms the validity of the results and reliability of the light scattering technique Obviously, further experimental work is needed in order to qualify this method as a routine analytical technique for the determination of elasticity in nematic systems. Currently, the present experimental modification are being utilized, to study the elastic constants of the polymer and nematic mixtures. The result of this study will be published shortly.

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