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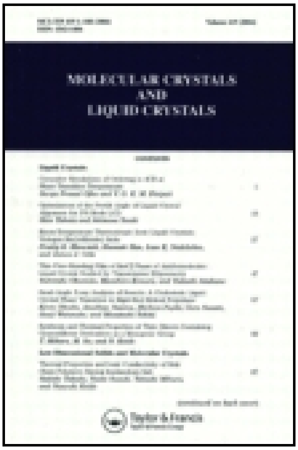

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The Effect of Dopants on the Twist Elastic Constant and the Rotational Viscosity Coefficient for Nematics

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The twist elastic constant, K_2, and the rotational viscosity coefficient, γ_1, are of importance when the response time for the in-plane switching mode is studied. Since adding dopants is one technique to improve the response characteristics, the effect of dopants on these physical properties is significant. The effect on K_2 and γ_1 of adding alkyl(alkoxy) phenylcyclopentenones and alkyl(alkoxy) cyanobiphenyls to the base mixture ZLI-4792 together with their temperature dependence have been investigated using different temperature scales. The reduced temperature scale showed the effect of these dopants on K_2 is small. On the other hand, the temperature dependence of γ_1 depends on both the absolute temperature scale and the reduced temperature scale. Therefore, it is clear that the choice of temperature scale with which to compare γ_1 for different systems raises fundamental questions which way not have a unique answer.

Keywords: rotational viscosity coefficient; twist elastic constant; in-plane switching mode; liquid crystal displays; dynamic light scattering

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INTRODUCTION

The physical properties of liquid crystals need to be investigated and understood in order to improve the characteristics of liquid crystal displays (LCD). Among the many physical properties, the elastic constants and the rotational viscosity coefficient are of special importance since they determine the response times. In particular, for the in-plane switching (IPS) mode, the twist elastic constant is the predominant elastic constant since the switch-on response time τ_{ON} and the switch-off response time τ_{OFF} are given by[1]

$$\tau_{ON} = \frac{\gamma_1 d^2}{\varepsilon_0 \Delta\tilde{\varepsilon} V^2 - \pi^2 K_2} \quad , \qquad (1)$$

$$\tau_{OFF} = \frac{\gamma_1 d^2}{\pi^2 K_2} \quad , \qquad (2)$$

where γ_1 is the rotational viscosity, $\Delta\tilde{\varepsilon}$ is the dielectric anisotropy, K_2 is the twist elastic constant and d is the thickness of the LCD cell. In order to improve the response times, a smaller γ_1 and a larger $\Delta\tilde{\varepsilon}$ are needed. For K_2, a compromise would be required because this property affects the two response times in different ways. The first step for the development of liquid crystal materials with the desired physical properties could be to design or discover the dopants needed to be added to existing liquid crystals. When we examine the effect of these dopants on physical properties, the temperature dependence of the physical

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properties should be studied because in many cases they change the nematic-isotropic transition temperature of the host liquid crystal. However, the appropriate temperature scale to be used when comparing the results can be different depending on the physical properties. Therefore, it is quite important to choose the temperature scale carefully. In this paper, we examine the temperature dependence of γ_1 and K_2 using different temperature scales to investigate the effect of the dopants.

EXPERIMENTAL

Materials and Samples

The dopants used were 4-pentyl (and pentyloxy) phenylcyclopentenone (5(O)PCP)[2] and 4-pentyl (and pentyloxy) 4'-cyanobiphenyl (5(O)CB) which are shown in FIGURE 1. As the host liquid crystal, ZLI-4792 (MERCK) was chosen. Approximately 13mol% of the dopants were added to ZLI-4792. 5(O)PCP were synthesized and the other materials were purchased.

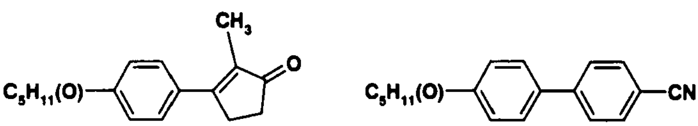

FIGURE 1 The molecular structures of the dopants used. The left hand side is 4-pentyl (and pentyloxy) phenylcyclopentenone (5(O)PCP) and the right hand side is 4-pentyl (and pentyloxy) 4'-cyanobiphenyl (5(O)CB).

Dynamic Light Scattering Measurement

The theory of the dynamic light scattering method for determining properties of liquid crystals is given in the literature[3,4]. The Lorenzian linewidth of the scattered light is determined by a combination of elastic constants, viscosity coefficients and the scattering vectors. If the conditions of the experimental system are constructed from (1) homeotropically aligned cell, (2) vertical polarised incident light, (3) horizontally polarised collection and (4) at scattering angle less than 15° , the linewidth, Γ, is given by[5]

$$\Gamma = \frac{K_2 q_\perp^2}{\gamma_1} + \frac{\varepsilon_0 \Delta\tilde{\varepsilon}}{\gamma_1} E^2 \quad . \tag{3}$$

In the first term of this equation, $q_\perp$ is the scattering vector perpendicular to the nematic director which is constant for a fixed scattering angle. The second term of the equation appears in the presence of an applied electric field, E. Therefore, by plotting Γ as a function of E^2, K_2 and γ_1 will be obtained separately provided $\Delta\tilde{\varepsilon}$ is known.

FIGURE 2 shows the photon correlation light scattering apparatus with which Γ was measured. The details of this apparatus are explained in the literature[6]. The light source used was a HeNe gas laser and the sample cell was placed in a temperature-controlled unit. The scattered light was detected by a photomultiplier tube (PMT) which was mounted in the direction of the scattering angle. Then the output signal pulse from the PMT was conditioned by the amplifier discriminator and analysed using the correlator system. Using clipped correlation, an exponential correlation function results with a time constant that is the inverse of Γ. In this light scattering apparatus, the heterodyne mode was used in order to avoid static scattering from surface imperfections, for example a scratch on the glass.

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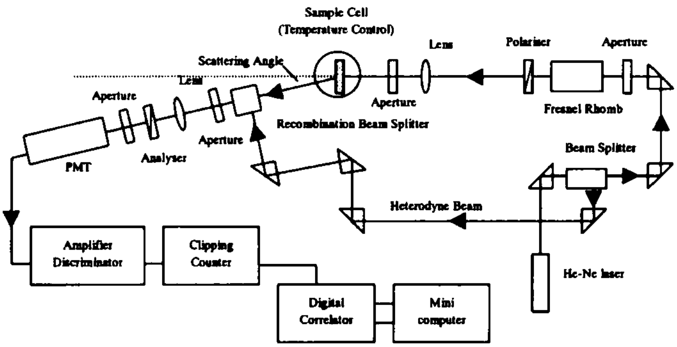

FIGURE 2 The dynamic light scattering apparatus

Table 1 shows the values of K_2 and γ_1 for 5CB at 28.4℃ which were measured to test the methodology. The scattering angle chosen was 14° and the frequency of the applied electric field was 1kHz; these conditions were used for all the measurements described here. Homeotropic alignment cells were used to measure the dynamic light scattering and the cell thickness was 60 to 70μm. As TABLE 1 shows, the values of K_2 and γ_1 in this system are in good agreement with their literature values[7,8]. The dielectric anisotropy was measured at the same temperature as the dynamic light scattering measurement using uniform planar cells[9].

TABLE 1 Test of the methodology for determining the K_2 and γ_1

	This work	Literature value
K_2 / N	3.23×10^{-12} (28.4℃)	3.1×10^{-12} (29.0℃)
γ_1 / mPa·s	58.2 (28.4℃)	60.7 (29.0℃)

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RESULTS AND DISCUSSION

The Nematic-Isotropic Transition Temperature

The nematic-isotropic transition temperature (T_{NI}) for materials prepared by adding the dopants to the base mixture ZLI-4792 were measured. FIGURE 3 shows the effect of the dopants on T_{NI} as a function of the molar concentration of the dopants. Here, because ZLI-4792 is a mixture, the average molecular weight of 345.3g[10] was used. It is obvious that 5(O)PCP decreases T_{NI} of ZLI-4792 significantly while 5(O)CB has a much smaller effect. This is because 5(O)PCP do not have liquid crystal phases while 5(O)CB are nematogens with only slightly lower T_{NI}.

In addition, the pentyloxy compounds decrease T_{NI} less than the pentyl compounds, which may show that alkoxy compounds are more likely to have a higher T_{NI} than those with alkyl chains. Actually, T_{NI} for 5OCB and 5CB are 341K and 308K, respectively. From FIGURE 3, the variation of T_{NI} with composition for 5OCB and 5CB are seen to be not quite linear. It may be because the dimerization of the cyano compounds is destroyed in ZLI-4792 which would spoil the linear dependence of T_{NI} on the mole fraction.

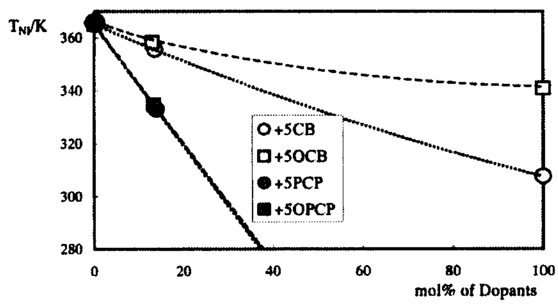

FIGURE 3 The effect of the dopants on T_{NI}

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Temperature Dependence of the Twist Elastic Constant

FIGURE 4 shows the dependence of K_2 on the absolute temperature, T, for ZLI-4792 together with 5(O)CB and 5(O)PCP dissolved in ZLI-4792. As FIGURE 4 shows, the data for 5CB and 5OCB are similar as are the data for 5PCP and 5OPCP. In addition, 5(O)PCP decrease K_2 significantly while 5(O)CB do not change it to any significant extent. For this comparison, the relationship between K_2 and the reduced temperature, T/T_{NI}, is shown in FIGURE 5. This indicates that the effect of the dopants is very small. This is related to the fact that 5(O)PCP decrease T_{NI} significantly. In addition, K_2 is essentially proportional to $\overline{P}_2^{\,2}$ ($\overline{P}_2$ is the second rank orientational order parameter) and $\overline{P}_2$ is a universal function of T/T_{NI} [11], consequently these compounds do not change K_2 at the same reduced temperature.

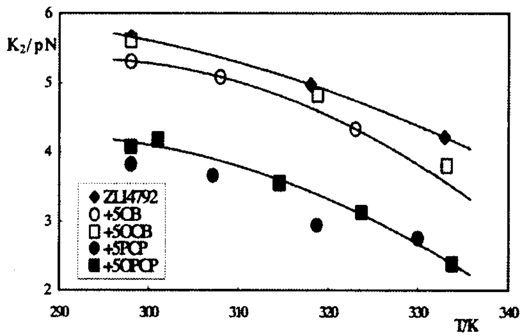

FIGURE 4 Dependence of the twist elastic constant on the absolute temperature.

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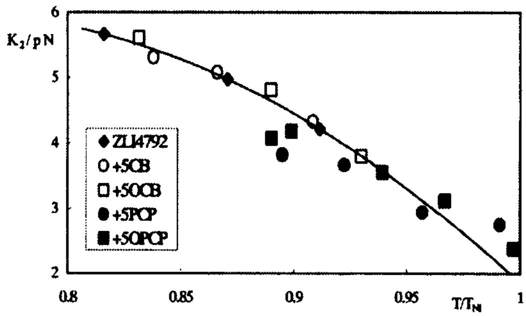

FIGURE 5 Dependence of the twist elastic constant on the reduced temperature.

The Rotational Viscosity Coefficient

Next, the effect of the dopants on the rotational viscosity coefficient, γ_1, together with its temperature dependence was measured. FIGURE 6 shows the absolute temperature dependence of γ_1; we can see that 5(O)PCP slightly reduce γ_1 while it remains unaffected by 5(O)CB. On the other hand, from the reduced temperature dependence shown in FIGURE 7, 5(O)PCP are found to increase γ_1 more significantly than 5(O)CB.

The temperature dependence of γ_1 is predicted and found to be given by[12]

$$\gamma_1 \propto \overline{P}_2 \exp(E_a / RT) \quad , \qquad (4)$$

where E_a is the activation energy and R is the gas constant. According to equation (4), γ_1 has a temperature dependence given both by Arrhenius behaviour which depends on the absolute temperature, and by the orientational order which is a function of the reduced temperature. Therefore, each of the two temperature scales can only allow for one aspect of the characteristics of the rotational viscosity coefficient and so is not sufficient to allow for the effect of the dopants which change T_{NI}.

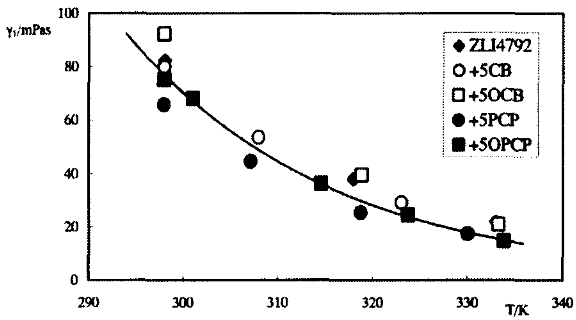

FIGURE 6 Dependence of the rotational viscosity coefficient on the absolute temperature.

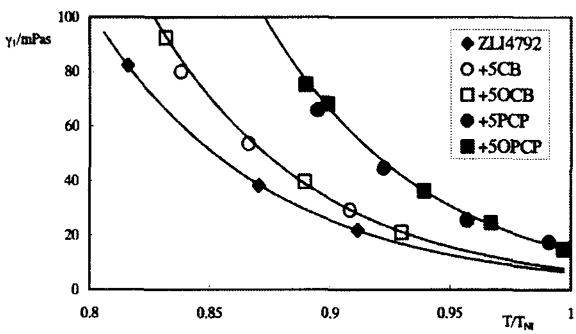

FIGURE 7 Dependence of the rotational viscosity coefficient on the reduced temperature.

CONCLUSIONS

The effect of dopants on the twist elastic constant, K_2, and the rotational viscosity coefficient, γ_1, was investigated with the following results.

1. The addition of the phenylcyclopentenones decreases T_{NI} of the base

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mixture ZLI-4792 to a greater extent than the cyanobiphenyls.

2. The effect of adding the phenylcyclopentenones and the cyanobiphenyls on K_2 is small if the orientational order is taken into account by using a reduced temperature scale.
3. The phenylcyclopentenones reduce γ_1 slightly while it remains unaffected by the cyanobiphenyls on an absolute temperature scale.
4. The reduced temperature scale reveals a large difference in the effect of the dopants on γ_1; addition of the phenylcyclopentenones increases γ_1 more than that of the cyanobiphenyls.

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