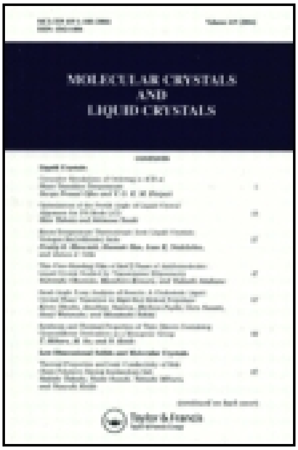

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Turbulence at the Nematic–Isotropic Transition at High Electric Fields in 7CB

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Turbulence occurring at the nematic–isotropic phase transition at high electric fields is investigated for 4-cyano-4′-*n*-heptylbiphenyl (7CB). It is found that the size of the temperature interval over which turbulence is manifested is an increasing function of field strength, and for a particular field, the size of the turbulent interval is found to be the same on cooling as on heating. The implications for locating the nematic–isotropic critical point are discussed in the context of an experiment to measure the decrease in the discontinuity of the induced birefringence.

TURBULENCE AT THE NEMATIC–ISOTROPIC TRANSITION AT HIGH ELECTRIC FIELDS IN 7CB

Pretransitional phenomena are frequently observed in mesogens with externally applied fields. In the present note, we report on a novel turbulent phenomenon associated with the nematic–isotropic (N–I) phase transition at high electric fields. It is found that for 7CB (4-cyano-4′-*n*-heptylbiphenyl) chaotic, turbulent motion of the fluid preceeds, in both directions, transitions between the nematic and isotropic phases of this material. The experiment described here examines the size of the temperature interval over which turbulence is manifested as a function of the strength of an externally applied dc electric field.

EXPERIMENTAL METHOD

7CB possesses a nematic mesophase and has a dielectric anisotropy $\epsilon_a = \epsilon_{\parallel} - \epsilon_{\perp} = 16.2 - 5.5$ at 30°C and 1592 Hz.[1] This compound was placed in a cell composed of two pieces of uncoated glass in combination with two strips of inconel metal which acted as electrodes and spacers (thickness = 0.10 cm). In this configuration the field developed is parallel to the glass substrate. The cell was placed in an aluminum clamp and positioned on the hot stage of a polarizing microscope; the material was examined between crossed polarizers. Temperatures were measured using a thermistor positioned adjacent to the cell at the location of the sample. A small amount of a thermal compound was deposited around the probe to insure good thermal contact between the cell, its clamp, and the thermistor.

With no applied field, the transition from the isotropic fluid to the nematic mesophase is demarcated by the appearance of nematic droplets. The droplets merge together when the entire sample is in the nematic phase. When an electric field is present, the nematic droplets become elongated in the direction of the field lines, and the bright nematic fluid condensing out of the isotropic melt begins to exhibit turbulent, erratic motion. This behavior is reminiscent of electrohydrodynamic instabilities characterized by rapid turbulence and intensive light scattering found in other contexts.

As can be seen in Figure 1, the length of the temperature interval over which turbulence is present is an increasing function of the applied field strength. As in the case with similar phenomena, the onset of turbulence does not occur at a well-defined point in a phase diagram but proceeds gradually to chaos. In our experiment, we began measuring the length of the turbulent interval when any portion of the sample in the microscope field (6×10^{-4} cm^2) showed any evidence of turbulence. Each point on the graph in Figure 1 represents the average value of six determinations of ΔT. The point at the highest field strength has only one determination of ΔT associated with it. A typical error bar is indicated. The data at a particular field strength were obtained by cycling through the transition a number of times. To within experimental

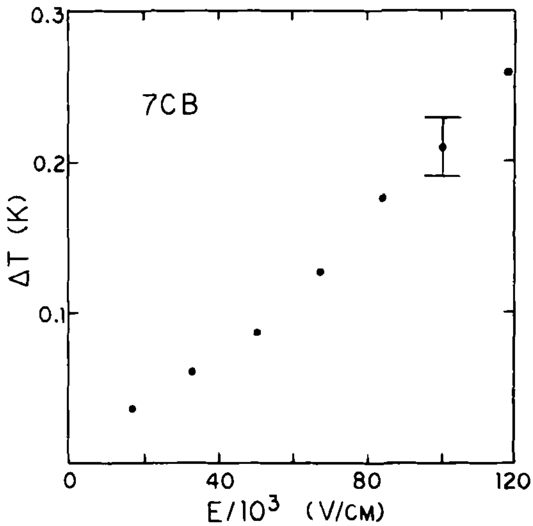

FIGURE 1 Size of turbulent interval as a function of electric field strength at the nematic-isotropic transition of 7CB.

uncertainty, the size of ΔT was found to be the same on heating as on cooling.

DISCUSSION

The presence of turbulence occurring at the nematic-isotropic transition has important implications for locating the critical point associated with this transition. If applied external fields are incorporated into a microscopic theory of the N–I phase transition, an interesting critical phenomenon can be expected. Large applied fields produce a preferential alignment of the constituent molecules on the isotropic (and nematic) side of the transition. Consequently, there should exist a critical field strength beyond which the nematic and isotropic phases should become indistinguishable; no phase transition would occur.[2] That is, there exists a critical point at a specific value of temperature and applied field strength for a substance of particular anisotropy.

Experiments have been performed to locate the N–I critical point using a magnetic field as the aligning mechanism.[3,4] Although the critical point has yet to be reached, it has been estimated that the magnetic field necessary to reach it is 100 T.[5] If the critical field were near 100 T, it is of interest to calculate approximately to what value of electric field strength this corresponds. To evaluate and compare the relative efficiencies of electric and magnetic fields as aligning mechanisms, we need to examine a specific effect that can independently be produced by the two fields. A Freedericksz transition provides such a correspondence. Experiments and calculations by Gruler and Maier[6] and de Gennes[7] show that the threshold field for a Freedericksz transition is the same in both the electric and magnetic case if

$$\frac{1}{2}\chi_a H^2 \rightarrow \frac{\epsilon_a E^2}{8\pi} \tag{1}$$

With this, roughly 0.1 V/cm is equivalent to one gauss. A critical magnetic field of 100 T would then correspond to an electric field of about 10^5 V/cm. This field strength is manageable and is below the dielectric breakdown for many liquid crystals.

One experiment that could locate the N–I critical point would be to measure the induced birefringence in a sample as a function of temperature and field strength. de Gennes[7] has shown that the induced birefringence, which is directly proportional to the order parameter, increases as

$$\Delta n \propto 1/(T - T^*)^\gamma \tag{2}$$

near the transition. T^* is the phenomenological temperature corresponding to a second order transition. γ, the susceptibility exponent, has a value of unity in both the mean-field and tricritical models. The observation in such an experiment which would indicate an approach to the N–I critical point would be a systematic decrease in the magnitude of the discontinuity in birefringence across the N–I phase change with increasing field. The size of the critical field could be extrapolated from data showing such a decrease in the magnitude of the discontinuity in the birefringence to where it would be zero. With turbulence occurring near the transition, measurements of the birefringence very near the phase change would be precluded. Consequently, an extrapolation intended to locate the critical point would be unreliable.

The initial stages of the onset of turbulence may possibly be understood in terms of electric field induced stress in dielectric fluids. The effect of an electric field on a dielectric droplet is to induce a hydrostatic pressure given by[8]

$$P_E = -\tfrac{1}{2}\epsilon_0(\epsilon - 1)^2 E_i^2(\lambda_3 - \tfrac{1}{3}) \tag{3}$$

E_i is the field within the droplet and is related to the applied field by the expression

$$E_i = E_o/[1 + \lambda_3(\epsilon - 1)] \tag{4}$$

in which λ_3 is the depolarization factor for the axis of symmetry of the spheroid. For a prolate spheroid of eccentricity e

$$\lambda_3 = [(1 - e^2)/2e^3]\{\ln [(1 + e)/(1 - e)] - 2e\} \tag{5}$$

The result is that the electric field induces a hydrostatic compression ($P_E < 0$) in an oblate spheroid ($\lambda_3 > \frac{1}{3}$) and a tension ($P_E > 0$) in a prolate spheroid ($\lambda_3 < \frac{1}{3}$). That is, a spheroidal drop will tend to become less oblate, or more prolate. This now ellipsoidal droplet has its long axis in the direction of the electric field; directions other than this would produce a torque on the droplet tending to align it with the field.

What is seen in the case of the N–I transition (on cooling) is that a droplet of nematic material condensing out of the melt gets stretched in the direction of the field lines. With many such events, the material would appear turbulent. If this turbulent phenomenon occurring at the N–I transition in 7CB is characteristic of a broader class of nematics with high dielectric anisotropy, then a search for the critical point by monitoring a decrease in the discontinuity of the electric field induced birefringence will be made very difficult. Efforts using magnetic fields would prove more useful.

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