itons, predicted in the numerical calculation of the cold-ion–hot-electron fluid equations,[9] was not observed.

In conclusion, large-amplitude ion acoustic solitons have been generated from density steps, and the basic structure of such solitons bears a close similarity with recent computer simulation results. Interactions have been observed for Mach numbers up to 1.8. Two solitons approaching from opposite directions show linear behavior; two solitons of different amplitude moving in the same direction exhibit a nonlinear interaction.

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Measurements of the Rotational Viscosity Coefficient and the Shear-Alignment Angle in Nematic Liquid Crystals

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A method is described for the direct measurement of the shear-alignment angle in a nematic liquid crystal. Results of such measurements are reported for the nematic phases of three compounds: PAA (*p*, *p′*-azoxydianisole), MBBA (*p*-methoxybenzylidene-*p′*-*n*-butylaniline), and HBAB (*p*-*n*-hexyloxybenzylidene-*p′*-aminobenzonitrile). We also report measurements of the rotational viscosity coefficient for the same compounds. In contrast to a recent report by Gähwiller, no orientational instability was found in HBAB.

A hydrodynamic theory of nematic liquid crystals has been formulated by Leslie,[1] based on earlier work by Ericksen.[2] Alternative formulations and extensions of this theory have recently been published.[3-6] The theory characterizes the viscous properties of a uniaxial (nematic) liquid by five independent coefficients, with the dimension of a viscosity. Two of these coefficients, customarily[1,7] denoted by γ_1 and γ_2, determine the viscous volume torque on the molecules, and, as they have no counterpart in isotropic liquids, are of particular interest. The coefficient γ_1 characterizes the viscous torque associated with an angular velocity of the director (i.e., the unit vector along the direction of nematic alignment), while γ_2 gives the contribution to this torque due to a shear velocity in the liquid. The coefficients γ_1 and γ_2 are closely related to the flow-alignment angle θ defined as the angle between the direction of flow and the director under stationary shear flow[1,7]:

$$\cos 2\theta = -\gamma_1/\gamma_2. \tag{1}$$

It is clear from this equation that if $|\gamma_1| > |\gamma_2|$, no real solution for θ exists. Physically, this means that in this case the director will tumble under shear flow of the liquid.

In a recent Letter, Gähwiller[8] reported measurements of the flow-alignment angle in *p*-methoxybenzylidene-*p′*-*n*-butylaniline (MBBA) and in p-n-hexyloxybenzylidene-p'-aminobenzonitrile (HBAB). He reported that in the latter compound director tumbling occurs at the lower temperatures. Hardly any other quantitative results for the flow-alignment angle appear in the literature. The only ones known to us are (i) a reinterpretation by Helfrich[9] of dielectric constant measurements by Marinin and Tsvetkov,[10] obtaining $\theta \approx 10^\circ$ for p,p'-azoxydianisole (PAA); (ii) light-scattering experiments by the Orsay group,[11] which in principle can provide γ_1 and γ_2, but are of insufficient accuracy to allow definite conclusions as to a value for θ.

In the present Letter, we present measurements of the flow-alignment angle in PAA, MBBA, and HBAB. As discussed below, our results are at variance with those of Gähwiller.[8] We also report measurements of the rotational viscosity γ_1 in the same compounds.

The measurements of γ_1 were made by the method first described by Tsvetkov,[12] and used more recently by Prost and Gasparoux.[13] A sample of about 1 cm^3 volume is suspended from a quartz fiber and is positioned in the field of a permanent magnet (1600 G). The magnet is rotated slowly, and the resulting torque on the sample measured. The torque per unit sample volume per unit angular velocity (in radians per second) is the rotational viscosity coefficient γ_1. Our results are given in Fig. 1 in the form of Arrhenius plots. The slopes of the lines are characterized by the following activation energies (in kilocalories per mole): 11.3 (MBBA), 10.8 (HBAB), and 11.8 (PAA).

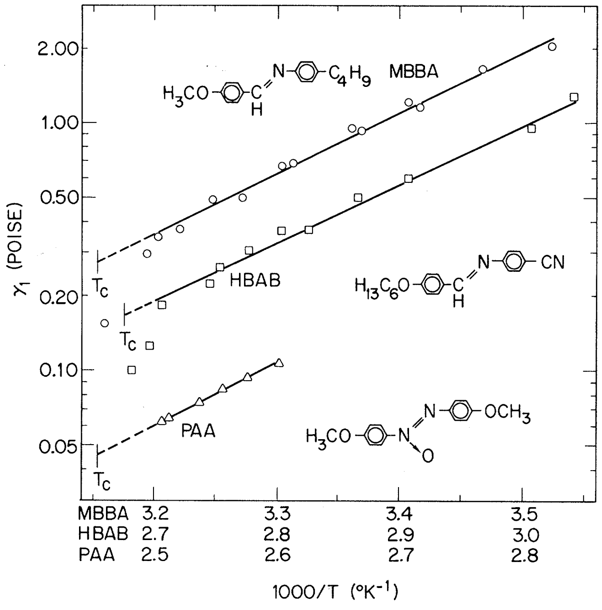

FIG. 1. Semilog plot of the rotational viscosity (γ_1) of three nematic liquid crystals as function of reciprocal temperature. Note that the labeling of the temperature axis differs for each of the curves. The nematic to isotropic transition temperatures of the samples are indicated by T_c.

The apparatus built to measure the shear-alignment angle θ has a cylindrical configuration, similar to a Couette viscosimeter. A brass cylinder, of diameter 18 mm and height 19 mm, can rotate inside a glass tube, with an inner diameter of 22 mm. The gap between cylinder and glass is thus 2 mm, and is filled with the liquid crystal. This large gap was chosen to minimize the effect of surface alignment. The orientation of the director of the liquid crystal is monitored by measuring changes in the dielectric constant. For this purpose, two metal-foil electrodes, 5 mm by 13 mm, are glued to the outside of the glass tube at two diametrically opposite positions and with their long dimension parallel to the axis. The two electrodes are connected together, and form one side of the measuring capacitor, the other one being the grounded inner cylinder. Capacitance is measured at 100 kHz with a Boonton type 118 capacitance bridge, modified to accommodate a Princeton Applied Research type JB5 lock-in amplifier as the detector. The output of the lock-in drives a recorder. Also glued to the glass, and surrounding the measuring electrodes, are a set of guard electrodes. They are connected to a point in the capacitance bridge having the same potential as the measuring electrodes, and thus ensure a radial electric field configuration under the latter. The following items complete the apparatus: a variable speed motor, which rotates the inner cylinder at rates between about 1 revolution/min and 1 revolution/sec; a cylindrical enclosure with an electric heater and a cooling coil, providing an adjustable temperature between 0 and 150°C; a thermocouple and potentiometer for measuring sample temperature; and, finally, a magnet on a rotating base, capable of giving a field of 5 kG in the measuring volume.

The method of observation found most convenient was to have the inner cylinder rotate at a constant speed of a few revolutions per minute, and then find the orientation of the magnet for which, on reducing the magnetic field from maximum to zero, no change in the balance of the capacitance bridge occurs. In this situation the

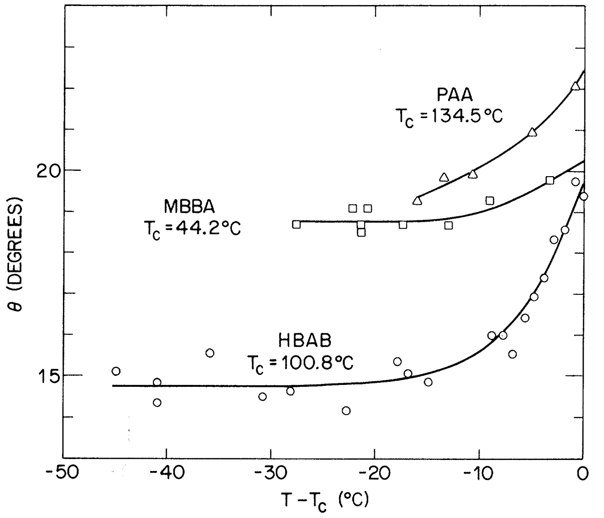

FIG. 2. Flow alignment angle (θ) of three nematic liquid crystals as function of $T - T_c$, where T is the temperature and T_c the nematic-to-isotropic transition temperature. The values of T_c for the samples measured are indicated in the figure.

direction of the magnetic field is parallel to the direction of shear alignment in that part of the liquid-crystal sample directly under the measuring electrode. (Because of the finite width of the measuring electrodes, and the cylindrical geometry, this statement is only approximately true. In the actual calculations a correction to allow for the cylindrical, rather than plane, geometry is made.[14]) The measurements were repeated with the reverse rotation sense. The angle between the magnet orientations for the two cases gives (after the correction mentioned above) 2θ directly. The measurements give consistent results for a range of rotational speeds between less than 1/min to about 20/min. The sensitivity is such that angles could be reproduced to better than 1 deg.

Our results are summarized in Fig. 2, which gives θ as a function of temperature for the three compounds studied. Clearly, the results are very different from the ones reported by Gähwiller[8]: We find neither the strong temperature dependence for MBBA, nor the even more dramatic dependence for HBAB at high temperatures, and the director instability at lower ones.

We can only speculate on possible reasons for these discrepancies, but the following may be relevant. An analysis of what happens to the director orientation in the cylindrical geometry of our apparatus on removal of the magnetic field shows that two 180° inversion walls should form at an angular position $180° - 2\theta$ away from the center of the measuring capacitor (where the director orientation is preserved). These walls will accordingly move into the measuring volume after a rotation of $180° - 2\theta$. In the case of HBAB at temperatures below about 90°C, a strong disturbance in the bridge output is indeed observed, starting very nearly half a revolution after switching off the magnetic field. This disturbance is not observed in HBAB well above 90°C, nor in PAA and MBBA. We conclude that in the latter cases an effective mechanism exists for relaxing the inversion walls, while in HBAB the walls are much more persistent. We tentatively suggest that Gähwiller's results are due to the presence of inversion walls, the formation of which may be hard to avoid in a flowing sample and which are slow to relax in HBAB.

We wish to thank Dr. Zeev Luz for the synthesis of HBAB.

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