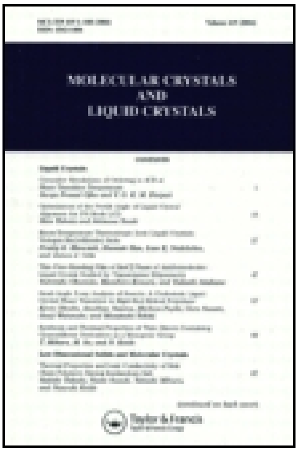

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Measurement of Electrical Conductivity in Two Cyanobiphenyls

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Measurement of Electrical Conductivity in Two Cyanobiphenyls

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We report the measurement of electric conductivity in two cyanobiphenyls 7CB and 8CB. The alignment has been achieved using an electric field. We report that for 7CB the anisotropy in conductivity is positive at all temperatures. For 8CB too, we find that $\Delta\sigma$ is positive both in the nematic and the smectic phase. This is in sharp contradiction with what has been found in most smectics and particularly with the work of Jadzyn and Kedziora[5] for 8CB.

Keywords: Nematics, electrical conductivity.

INTRODUCTION

Mircea-Roussel *et al.*[1] have reported the measurement of electrical conductivity in 8CB and 80CB both of which exhibit a smectic-A phase. According to these authors 80CB has $\sigma_{\|} > \sigma_{\perp}$ in the nematic phase and as the smectic phase is approached by cooling the nematic, $\sigma_{\|}/\sigma_{\perp}$ tends to 1. Although Mircea-Roussel *et al* did not publish the results for 8CB either in the form of a graph or a table, they mention that 8CB behaves in a similar manner. This behaviour does not agree with what is found in most smectics where the anisotropy $\Delta\sigma = \sigma_{\|} - \sigma_{\perp}$ changes sign and becomes negative in the smectic phase.[1–4] Jadzyn and Kedziora[5] have published the results of electrical conductivity measurements in 7CB and 8CB (among other cyanobiphenyls). Their data clearly shows that $\Delta\sigma$ changes sign as the smectic phase is reached from the nematic phase. This is not in agreement with the results of Mircea-Roussel *et al* for 8CB. Both Mircea-Roussel and Jadzyn and Kedziora used a magnetic field to align the samples.

In this paper we report the measurement of $\sigma_{\|}$ and $\sigma_{\perp}$ in 7CB and 8CB where the alignment has been achieved using an electric field. We show that in the nematic phases of both 7CB and 8CB $\Delta\sigma > 0$ and in the smectic phase in 8CB $\Delta\sigma$ tends to zero while always remaining positive. This behaviour, clearly contradicts with the work of Jadzyn and Kedziora.[5]

It will be pertinent to mention that the data on electrical conductivity found in literature are not always consistent. We site the example of HEPTAB which has been investigated by both Mircea-Roussel[1] and Jadzyn and Kedziora.[5] In Table 1, we compare the results published by these authors and find that they are not in any sort of agreement with one another. However, it is believed that the magnitudes of the

TABLE I

Comparison of conductivity data from References [1] and [5] at two temperatures HEPTAB

Temperature (T °C)	$\sigma_\perp$ (ns/m) (ref 1)	$\sigma_\perp$ (ns/m) (ref 5)	$\sigma_\parallel$ (ns/m) (ref 1)	$\sigma_\parallel$ (ns/m) (ref 5)
60	621.6 (S_A)	158.0	526.8	158.0
70	672.0(N)	173.0	1405.0	209.0

electrical conductivities characterize the purity of the samples and is essentially not a material parameter for liquid crystals. It may not be therefore, a matter of great surprise that different values of the conductivities – even orders of magnitude – are obtained in measurements with different samples. Nevertheless in our opinion there is still a need for more reliable measurements of electrical conductivity for compounds both in nematic and smectic phases.

EXPERIMENTAL DETAILS

The sample cells were fabricated from optically flat Indium-Tin-Oxide coated borosilicate glass having antiparallel polyimide coatings to ensure planar orientation. The conductions was measured using a Hewlett-Packard impedance/gain-phase analyser HP4194A and an LCR meter HP4284A. The instruments were used in C_p-G mode. The former instrument could provide a probe voltage in the range 10 mV_{rms} to 1 V_{rms} while the LCR meter was capable of providing the same upto 20 V_{rms}. The reason for using the 4194A was its ability to provide an 1 mV resolution in discrete steps in its range upto 1 V. The probe voltage was used to align the liquid crystals and no external magnetic field was used in any case. The temperature of the sample cell was controlled using a PID temperature controller with a precision of ± 0.1 °C. A chromel-alumel thermo-couple along with a HP3458A DMM was used to measure the temperature. The measurements were carried out at a fixed frequency of 1 kHz. The samples were obtained from BDH and were used without further purification. The cell spacing was 30 micron and the cell area was 27.3 × 14.3 sqmm. To prevent contamination fresh samples were always used and the sample cells were sealed using a Teflon tape after filling.

RESULTS AND DISCUSSION

The conductance G and the capacitance C_p were monitored as the voltage across the cell was increased from a low value. Both the parameters exhibit fairly sharp Freedericksz threshold voltage (Fig. 1) and the value of V_{th} differs by less than 1% in all cases we have studied. As the aligning electric field is increased the slope of the G-V curve decreases and the alignment approaches a homeotropic configuration. The constant value of conductance G for $V < V_{th}$ will be called $G_\perp$ and the corresponding conductivity

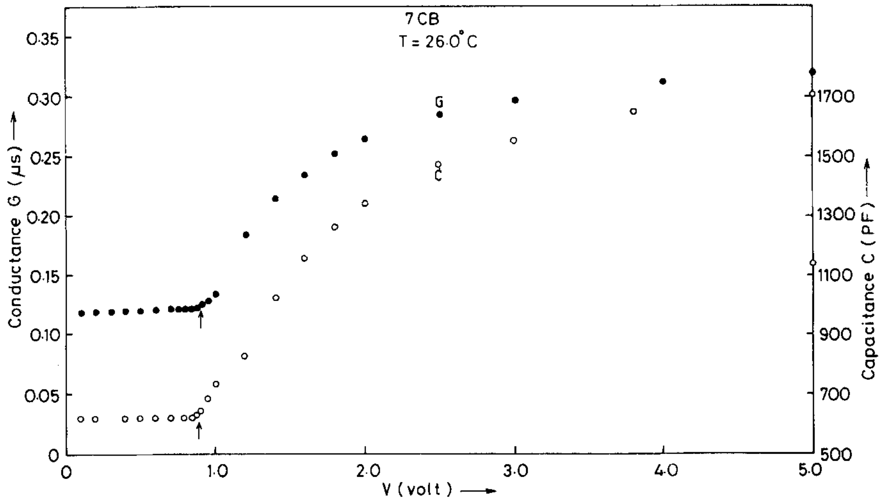

FIGURE 1 Voltage-conductance and voltage-capacitance curve for 7CB near threshold ($T = 26$ °C).

calculated from it $\sigma_\perp$. In Figure (2a, b) we have plotted G against $1/V$ for 7CB and 8CB respectively. Readings were taken up to 12 V for 7CB and 8 V for 8CB.

The G-$1/V$ plots exhibited a linear behaviour for $V > 4.0\ V_{th}$ and these were extrapolated to $1/V \rightarrow 0$ to obtain $G_\parallel$. The behaviour of the G-$1/V$ graphs closely

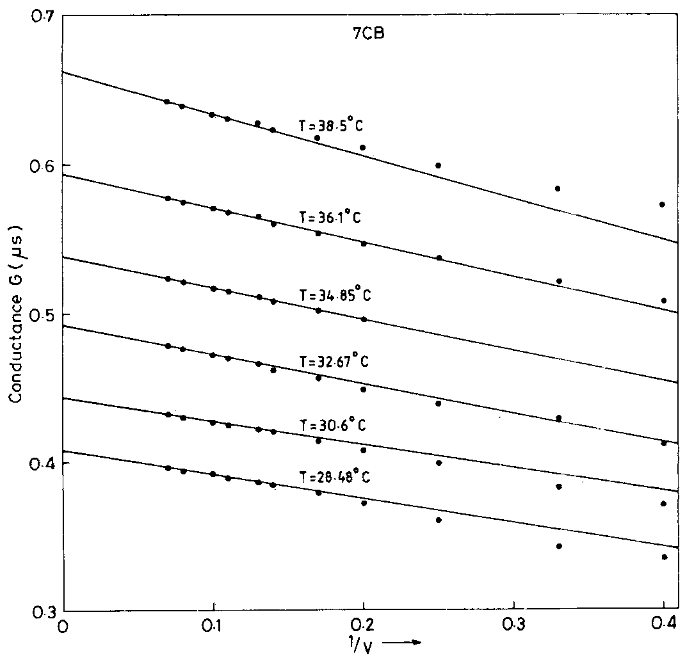

FIGURE 2a Conductance G Vs V^{-1} plot for 7CB at different temperatures.

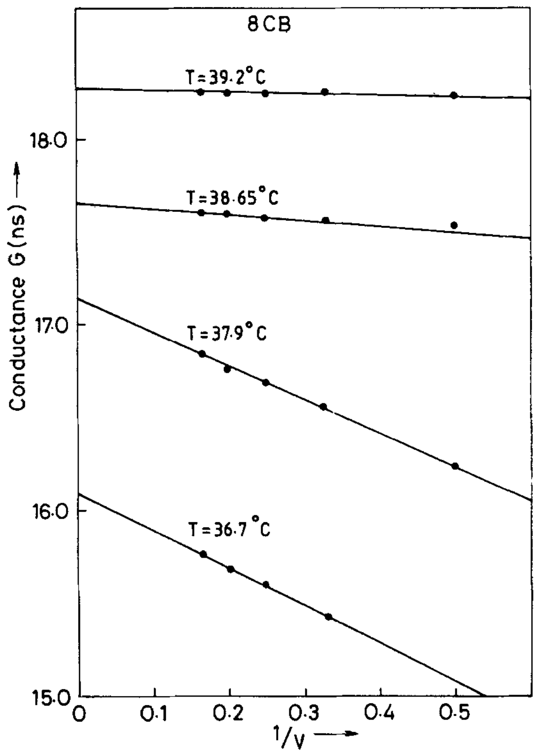

FIGURE 2b Conductance G Vs V^{-1} plot for 8CB at different temperatures.

resembles that of C-$1/V$ which may be used to obtain the ratio of the bend to splay elastic constants K_{33}/K_{11}.[6]

Figure (3a) exhibits the values of the conductivities $\sigma_{\parallel}$ and $\sigma_{\perp}$ for 7CB as well as the anisotropy of the conductivity $\Delta\sigma = \sigma_{\parallel} - \sigma_{\perp}$. The anisotropy $\Delta\sigma$ increases as the $N \rightarrow I$ transition temperature is approached and sharply falls to zero at T_{NI}. Figure (3b) shows the plot of the ratio $\sigma_{\parallel}/\sigma_{\perp}$ for 7CB. The ratio changes from about 3 to 1 as $T_{NI} - T$ changes from about 16 °C to zero.

In Figure (4a) we have plotted the values of $\sigma_{\parallel}$ and $\sigma_{\perp}$ for 8CB as a function of temperature for both the nematic and smectic phases. To obtain $G_{\perp}$ in the smectic phase the sample was first heated to $T > T_{SN}$ and then cooled with the voltage across the cell either zero or less than V_{th}, the Freedericksz threshold voltage, while for obtaining $G_{\parallel}$ in the smectic phase the sample was cooled from nematic to smectic phase with the voltage across the cell ranging from 8 V to 12 V. No variation in the value of $G_{\parallel}$ in the smectic phase with the applied voltage under which cooling took place was found for voltages in excess of 8 V. Tables II and III show the results of our conductivity measurements for 7CB and 8CB respectively.

Figure (4b) shows the plot of $\Delta\sigma$ and $\sigma_{\parallel}/\sigma_{\perp}$ against $T_{NI} - T$ for 8CB. One noteworthy feature is that the ratio $\sigma_{\parallel}/\sigma_{\perp}$ is close to unity over the entire smectic phase. Our results

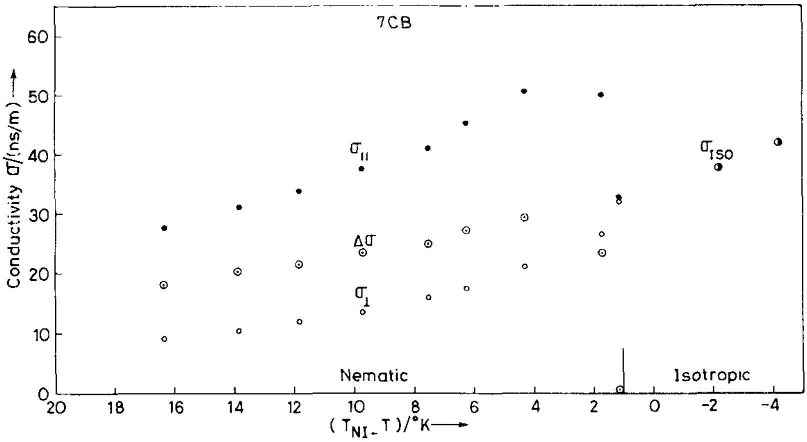

FIGURE 3a The conductivities $\sigma_\perp$(○), $\sigma_\parallel$(●), $\Delta\sigma$(⊙) and σ_{iso}(◑) plotted against $(T_{NI} - T)$ for 7CB.

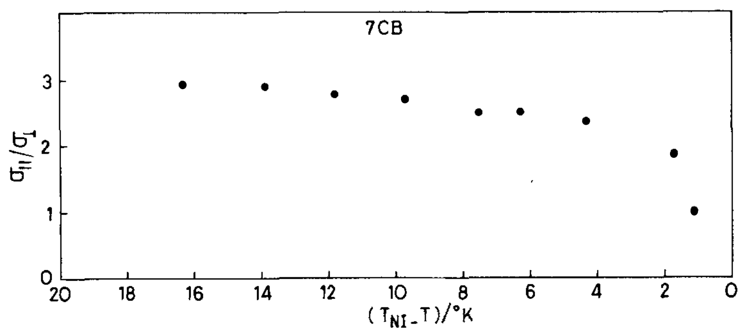

FIGURE 3b The ratio $\sigma_\parallel/\sigma_\perp$ plotted against $(T_{NI} - T)$ for 7CB.

for 8CB are in sharp contradiction with that reported by Jadzyn and Kedziora[5] who achieved the alignment using a magnetic field and has shown that $\Delta\sigma$ changes sign at the $N \rightarrow S$ transition point. However Mircea-Roussel *et al.*,[1] who also used a magnetic field reported the conductivity of 80CB and 8CB among other compounds. According to them in 80CB $\sigma_\parallel/\sigma_\perp$ approaches unity in the smectic phase from a higher value in the nematic phase. These authors did not report the values of the ratio $\sigma_\parallel/\sigma_\perp$ or $\Delta\sigma$ for 8CB (for which they carried out measurements) but say that 8CB behaved in a manner similar to 80CB and this is in close agreement with our finding.

Coming to the comparison of our results in say 7CB with that of Jadzyn and Kedziora[5] it may be noted that there is an order of magnitude difference between the two sets of results. For example in 7CB at 35 °C we observed that $\sigma_\perp$ is about 16.5 ns/m whereas Jadzyn *et al.*,[5] gives a values of about 692 ns/m. We attribute this discrepancy to sample contamination and presence of ionic impurities in the work of those authors.

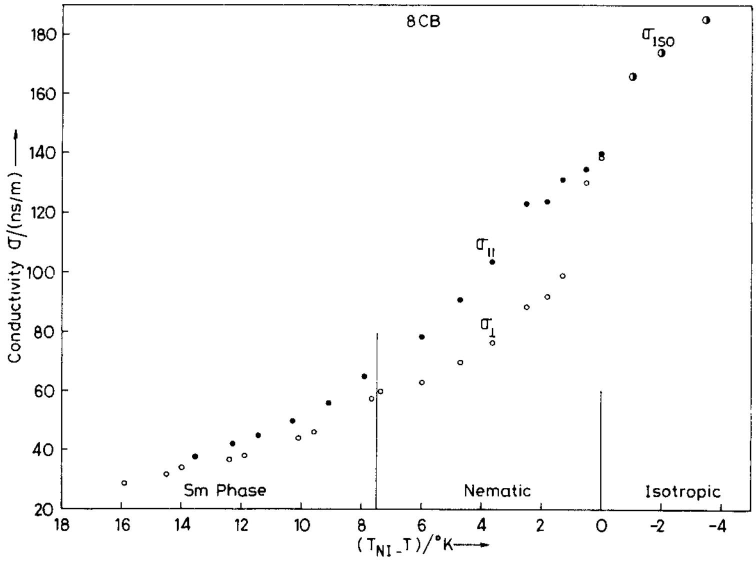

FIGURE 4a The conductivities $\sigma_{\perp}$(○), $\sigma_{\parallel}$(●), σ_{iso}(◑) plotted against $(T_{NI} - T)$ for 8CB.

TABLE II

Temperature dependence of conductivities and their anisotropy obtained in 7CB
7CB $T_{NI} = 42.37\,°C$

Temperature (T °C)	$\sigma_{\parallel}$ (ns/m)	$\sigma_{\perp}$ (ns/m)	$\Delta\sigma$ (ns/m)	$\sigma_{\parallel}/\sigma_{\perp}$
26.0	27.75	9.42	18.33	2.95
28.5	31.44	10.85	20.58	2.90
30.6	34.13	12.30	21.83	2.78
32.7	37.82	13.93	23.90	2.71
34.9	41.35	16.33	25.00	2.53
36.1	45.66	17.96	27.70	2.54
38.1	50.96	21.42	29.54	2.38
40.7	50.42	26.75	23.67	1.88
41.3	32.51	32.36	0.15	1.00

It may be commented that even the relative anisotropy $(\sigma_{\parallel}/\sigma_{\perp})$ can depend on the amount and nature of the ionic impurities. The story is about the same for 8CB too. More recently Winkler *et al.*,[7] have reported the measurement of electrical conductivity in 5CB at 22.0 °C. According to them $\sigma_{\parallel} = 90$ ns/m and $\sigma_{\perp} = 60$ ns/m. These are of about the same order as we have observed in 7CB and 8CB and this gives more confidence in our results. We believe our results to be accurate to, within 2%.

We conclude with a remark of the sample thickness used in the different experiments. In our electric field method we have used a 30 micron cell while Mircea-Rossel *et al.*,[1] and Jadzyn and Kedziora[5] both used magnetic field with sample thickness of 75 micron

TABLE III

Temperature dependence of conductivities and their anisotropy obtained in 8CB
8CB $T_{SN} = 33.05\,°C$ $T_{NI} = 40.7\,°C$

Temperature (T °C)	$\sigma_\parallel$ (ns/m)	$\sigma_\perp$ (ns/m)	$\Delta\sigma$ (ns/m)	$\sigma_\parallel/\sigma_\perp$
27.2	38.18	34.00	4.18	1.12
28.4	42.38	36.50	5.88	1.16
29.3	45.65	39.00	6.65	1.17
30.4	50.66	43.00	7.66	1.17
31.6	56.76	49.00	7.76	1.16
32.8	65.20	55.50	9.70	1.17
34.7	78.78	63.20	15.58	1.24
36.0	91.85	70.10	21.75	1.31
37.1	104.38	77.21	27.17	1.35
38.2	123.75	89.30	34.45	1.38
38.9	124.05	92.84	31.21	1.34
39.4	131.74	99.73	32.00	1.32
40.2	135.66	130.90	4.76	1.06

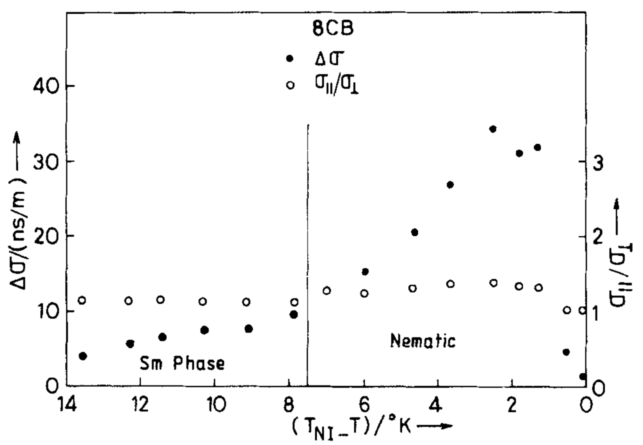

FIGURE 4b The anisotropy $\Delta\sigma$(●) and the ratio $\sigma_\parallel/\sigma_\perp$(○) plotted against ($T_{NI} - T$) for 8CB.

and 1 mm respectively. Our sample thickness is much smaller than those used by the two other groups and this may appear to be one possible reason for the discrepancy between our results and those in.[5] But a rough estimation of the thickness of the non-aligned layers (~ coherence length) at both electrodes in high aligning fields show that this does not exceed 2 to 4% of the sample thickness in our case and is perhaps too small to account for the large difference in the conductivity results.

Acknowledgments

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