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András Balogh^a, Nándor Éber^a & Lajos Bata^a

^a Central Research Institute for Physics, P.O. Box 49, H-1525,
Budapest, Hungary

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Elements of the Biaxial Dielectric Tensor of a Smectic C Liquid Crystal†

ANDRÁS BALOGH, NÁNDOR ÉBER and LAJOS BATA

Central Research Institute for Physics, H-1525 Budapest, P.O. Box 49, Hungary

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The form of the biaxial dielectric tensor of smectics C is discussed. An experimental method and preliminary data on the tensor elements of a smectic C compound is presented.

INTRODUCTION

Biaxiality is one of the most interesting features of the smectic C phase. Dielectric measurements can serve as means for the investigation of this biaxiality. However there are only a few experiments^{1–4} in this field and the complete determination of the biaxial dielectric tensor is still missing.

In this paper we present some suggestions concerning the elements of the dielectric tensor of the S_c phase with some preliminary experimental results.

THE DIELECTRIC TENSOR OF SMECTICS C

In the smectic C phase there are four “crystallographic” directions; the layer normal n , the director d , its projection on the layer plane, the C-director c and the direction $n \times c$ which is perpendicular to all of them and corresponds to the only twofold symmetry axis of the phase. On the orthogonal base $n \times c$, n and c the general form of the dielectric permittivity tensor ϵ reads⁵

$$\epsilon_{ij} = \epsilon_1 \delta_{ij} + \epsilon_2 c_i c_j + \epsilon_3 n_i n_j + \epsilon_4 (c_i n_j + n_i c_j). \quad (1)$$

Since the dielectric tensor is symmetric, there is a co-ordinate system set out by the orthogonal eigenvectors e_a , e_b and e_c in which ϵ possesses only diagonal elements, i.e.

$$\epsilon_{ij} = \epsilon_a e_{ai} e_{aj} + \epsilon_b e_{bi} e_{bj} + \epsilon_c e_{ci} e_{cj}. \quad (2)$$

† This paper presented at the 8th Liquid Crystal Conference of Socialist Countries, August 28–Sept. 1, 1989, Krakow, Poland.

Now one has to relate these eigenvectors to the crystallographic directions. One of the eigenvectors, say e_a , must coincide with the symmetry axis ($n \times c$) of the medium. However in a biaxial system the other two eigenvectors should not coincide with any crystallographic direction. Thus e_b and e_c are co-planar with n , c and d (Figure 1a), but the angle ϕ made by the vectors e_b and n is theoretically different from the tilt angle θ of the director, moreover it may depend on the frequency as well. Nevertheless this difference is often neglected.¹⁻⁴

As a result we can draw the conclusion that in biaxial substances four parameters are needed for a complete description of the dielectric tensor.

The permittivity measured along an electric field E of arbitrary direction, $E = E_1 n \times c + E_2 n + E_3 c$, can be expressed by

$$\epsilon = \frac{E \epsilon E}{E^2} = \epsilon_1 + \frac{\epsilon_3 E_2^2 \epsilon_2 E_3^2 + 2\epsilon_4 E_2 E_3}{E_1^2 + E_2^2 + E_3^2} \quad (3)$$

Thus varying the direction of the electric field with respect to the crystallographic directions all four parameters can be determined.

EXPERIMENTAL

For the measurement of biaxiality a compound with negative dielectric anisotropy is preferred, so we have chosen the compound 4-pentyloxyphenyl-4'-decyloxybenzoate (obtained from the Halle group).³ This compound has a N , S_A and S_C phase which can be supercooled into an unidentified S_3 phase.

Permittivity was measured using a thermostated plane condenser in slow cooling from the N phase in magnetic field. The cell could be rotated around the axis parallel to the electrodes but perpendicular to the magnetic field (z -axis in Figure 1b), which allowed to adjust the angle α between the electric (E) and magnetic (H_0) fields in the nematic phase. The director and the layer normal in the S_A phase is parallel to H_0 . We pretended that cooling the sample through the S_A – S_C phase transition the layers remain fixed ($n = H_0$) and the director declines. In the S_C

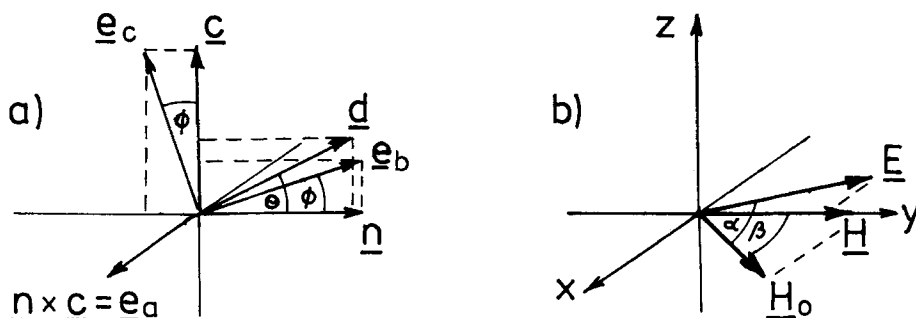


FIGURE 1a Orientation of the eigenvectors of the dielectric tensor with respect to the crystallographic directions. 1b, experimental geometry. E electric field, H_0 magnetic field in N and S_A phases, H magnetic field in S_C phase.

phase the cell is rotated by $\beta = 45^\circ$ so the magnetic field (H) fixes the director in a definite position on the cone. As a result the C-director lies in the xy plane, i.e. $E_1 = 0$, $E_2 = E \cos \alpha$ and $E_3 = E \sin \alpha$. From Equation (3) the measured permittivity can be expressed as

$$\varepsilon(\alpha) = a + b \cos 2\alpha + c \sin 2\alpha, \quad (4)$$

where a , b and c can be obtained by curve fitting yielding three equations for the parameters ε_1 , ε_2 , ε_3 and ε_4 . A fourth equation can be obtained if at $\alpha = 45^\circ$ the cell is tilted around the x -axis (Figure 1b) by 45° ($E \parallel n \times c$).

Figure 2 shows preliminary data determined by the above method. After diagonalization we can find (Figure 3) that the dielectric properties of the S_C phase are definitely biaxial.

We have to mention however, that we could not check the orientation of the sample in the S_C phase, so it may happen that instead of a monodomain structure pretended above we have obtained a polydomain sample,^{1,3,4} where the layer normals are on a cone around H_0 . This question should be discussed in more detail in a forthcoming paper. However it can be stated that Equation (5) holds even in a polydomain sample, but the parameters a , b and c then depend on β and on the tilt angle of the layer normals. So there is a hope that from dielectric measurements at various β angles all four tensor elements as well as the tilt of the layers can be determined.

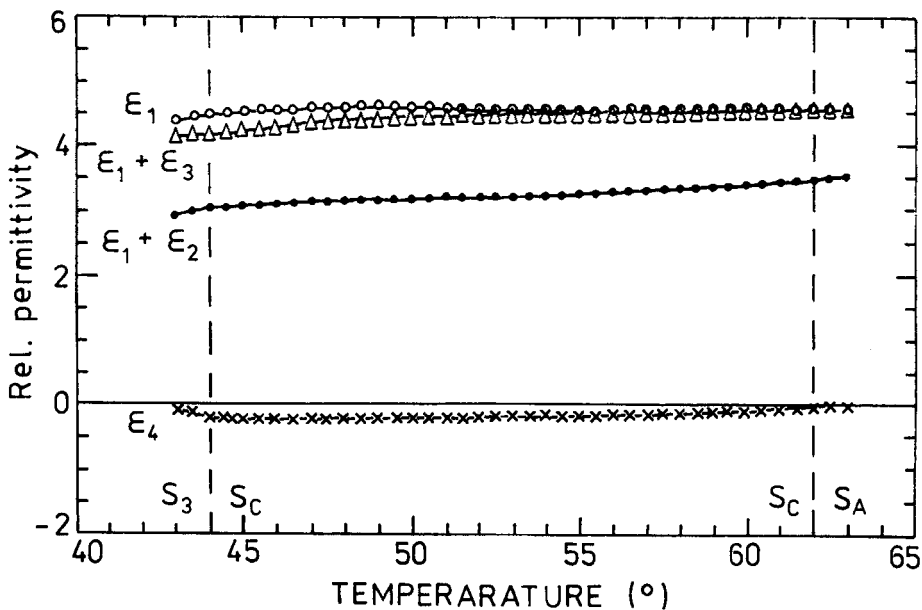


FIGURE 2 Temperature dependence of the elements of the dielectric tensor in the smectic C phase (cf. Equation (1)). The measuring frequency is $f = 100$ kHz.

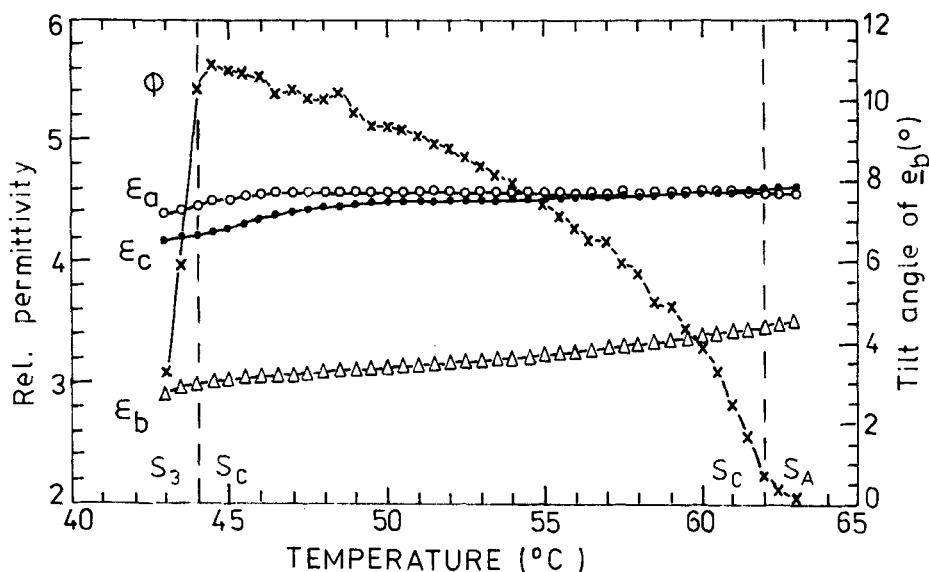


FIGURE 3 Temperature dependence of the eigenvalues of the dielectric tensor (cf. Equation (2)) and the tilt angle ϕ of the eigenvector e_b in the smectic C phase (calculated from data in Figure 2). The measuring frequency is $f = 100$ kHz.

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