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ELECTRIC FIELD INDUCED INSTABILITIES IN NEMATIC LIQUID CRYSTALS;

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BUDAPEST

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ELECTRIC FIELD INDUCED INSTABILITIES IN NEMATIC LIQUID CRYSTALS

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ABSTRACT

In the paper we discuss instabilities arising when a static or alternating electric field is applied to a nematic liquid crystall cell. The threshold voltage for inducing instability is presented as a function of the frequency. Regular structures observed at static and alternating fields are described in detail. We report also some observations connected with development of turbulence.

РЕЗЮМЕ

В работе описываются исследования нестабильностей, возникающих в нематических жидких кристаллах под действием постоянного и переменного напряжений. Описываются также некоторые новые черты турбулентности под влиянием напряжения, исходящие от порогового напряжения. Даются значения порогового напряжения нестабильностей в зависимости от частоты, структура завихрений, а также изменение этой структуры в зависимости от частоты.

KIVONAT

Ebben a cikkben a nematikus folyadékkristály-anyagokban egyen- és váltófeszültség hatására keletkező instabilitásokat vizsgáljuk. A feszültségek hatására egy küszöbfeszültségtől meginduló turbulencia néhány uj vonását ismertetjük. Megadjuk az instabilitások küszöbfeszültségét a frekvencia függvényében, továbbá a meginduló örvények szerkezetét, és a szerkezet változását a feszültség függvényében.

KEYWORDS, КЛЮЧЕВОЕ СЛОВО, KULCSSZÓK

LIQUID CRYSTALS

DINAMICAL SCATTERING

ELECTROHYDRODYNAMICAL INSTABILITIES

1. INTRODUCTION

In the last few years a number of electrooptic effects have been reported in connection with nematic liquid crystals, for example the formation of Williams domains [1], dynamic scattering [2], electrically controllable domains [3], electrically controlled birefringence [4, 5], etc.

Some features of these phenomena have been explained theoretically, however the mechanisms responsible for these effects are not yet fully understood.

In this paper we discuss Williams domain formation and dynamic scattering. We give a summary of well-known facts and describe some other features also.

2. NEMATIC LIQUID CRYSTALS IN ELECTRIC FIELD

Nematic liquid crystals consist of rod-shaped molecules which tend to lie parallel to each other, while their centre of gravity are completely disordered. The direction in which the molecules are aligned may be characterised by a unit vector, the so-called director. In macroscopic liquid crystal cells the director usually varies along the sample.

To study electrooptic effects the liquid crystal is placed between two transparent plane electrodes. The spacing between the electrodes is usually 10-100 µm. Let us apply an electric field to this cell. Two cases should be distinguished:

a; The liquid crystal has a positiv dielectric anisotropy, that is $\varepsilon_{\parallel} > \varepsilon_{\perp}$./$\varepsilon_{\parallel}$ denotes the dielectric constant parallel to the director, $\varepsilon_{\perp}$ is the perpendicular component./ In this case the electric field tends to align the molecules parallel to the field. If the field is strong enough a monocrystal arrangement will be formed in which the director lies parallel to the field throughout the whole sample. The details of this effect and the related optical effects will be discussed in another paper.

b; If the cell is filled with a liquid crystal that has negativ anisotropy /$\varepsilon_{\perp} > \varepsilon_{\parallel}$/ the electric field tends to orient the molecules perpendicularly to the field. One might assume that applying a sufficiently strong field the director would turn perpendicularly to the field, i.e. parallel to the electrodes throughout the whole cell. However this is not the case; above a threshold voltage a new arrangement develops in which the director varies periodically along the plane of the electrodes /Williams domains/. At higher voltages a turbulent motion arises which generates strong light scattering /dynamic scattering/.

This phenomenon as Carr [6] and Helfrich [7] have pointed out is due to the electric current induced in the sample by the field. As the conductivity is anisotropic space charges develop. The ponderomotoric force acting on these space charges generates internal motion in the liquid crystal cell and it is a well known fact in the theory of liquid crystals that this motion influences the molecular alignment. The details of this theory have been published by Helfrich [7], Orsay Liquid Crystal Group [8], Pikin [9], Penz and Ford [10].

In the next sections we describe this effect in detail. In our experiments we used methoxybenzilidene butylanilin /MBBA/ /$\varepsilon_{\parallel} = 4.72$; $\varepsilon_{\perp} = 5.25$/, the spacing of the electrodes was usually 12 μm. The molecules were initially uniformly aligned in a direction parallel with the electrodes by rubbing the surfaces of the walls and introducing the liquid crystal into the cell by capillarity. The formation of monocrystal arrangement /with an optic axis parallel to the walls/ was checked with a polarising microscope.

3. THRESHOLD VOLTAGE

Most of the theoreticall works refer to cells in which the molecules are aligned initially as described above. Such an arrangement is stable below a threshold voltage, above this threshold Williams domains are formed. It is a well established fact, that this instability occurs at a threshold <u>voltage</u>, which is independent of sample thickness. This threshold is a few volts for static fields. In the case of MBBA we found it to be 5.3 V. Penz and Ford |10| deduced theoretically a value of 6.9 V. The deviation of the theoretical and the experimental value may be due to the following:

a; There is some uncertainty in the values of the material constants applied in the theory.

b; Theory neglects charge injection on the boundaries, which may play a role when static field is applied. Indeed, as we shall see some differencies exist between the structures obtained at d.c. and a.c. fields.

When a.c. field is applied the threshold voltage increases as the frequency is increased. The relation between threshold and frequency is given theoretically as [8]

$$V_{th}^2 = V_o^2 \quad \frac{1 + \omega^2\tau^2}{1 - \alpha^2\omega^2\tau^2} \qquad /1/$$

V_o denotes the static threshold, α is a parameter of the liquid crystal and

$$\tau = \frac{\varepsilon_{\parallel}}{4\pi\sigma_{\parallel}}$$

where $\sigma_{\parallel}$ is the conductivity parallel to the director. According to eq. /1/ a critical frequency exists above which instability does not occur:

$$\omega_{cr} = \frac{1}{\alpha\tau} \qquad /2/$$

To check the validity of eq. /1/, we transform it as follows:

$$\frac{y^2 - 1}{\omega^2} = \tau^2 + \frac{y^2}{\omega_{cr}^2} \; ; \qquad y = \frac{V_{th}}{V_o} \qquad /3/$$

According to eq. /3/ if $\frac{y^2-1}{\omega^2}$ is plotted against y^2 we should get a straight line. Our experimental result is shown on fig. 1. We got

$$\frac{1}{\sigma} = 5.6 \cdot 10^8 \; \Omega cm; \qquad \omega_{cr} = 2\pi \cdot 570 \text{ Hz}$$

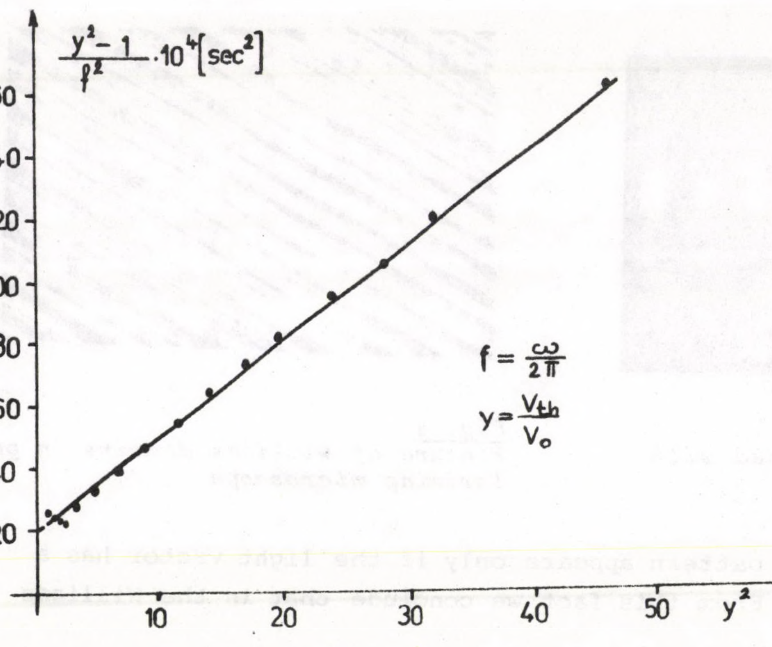

Fig. 1

Check of the theoretical relation between threshold voltage and frequency

It should be mentioned that $\sigma_{\parallel}$ is rather a characteristic of the purity of the liquid crystal than a material constant. Its value, deduced from the threshold voltage-frequency relation is in good agreement with the value obtained from the volt-amper characteristic.

4. WILLIAMS DOMAINS

When the voltage is increased above the threshold a periodic structure is formed in the liquid crystal cell. We studied this structure by light diffraction and by a polarising microscope. The experimental setup for light diffraction investigation is shown in Fig. 2. First we describe structures connected with a.c. fields.

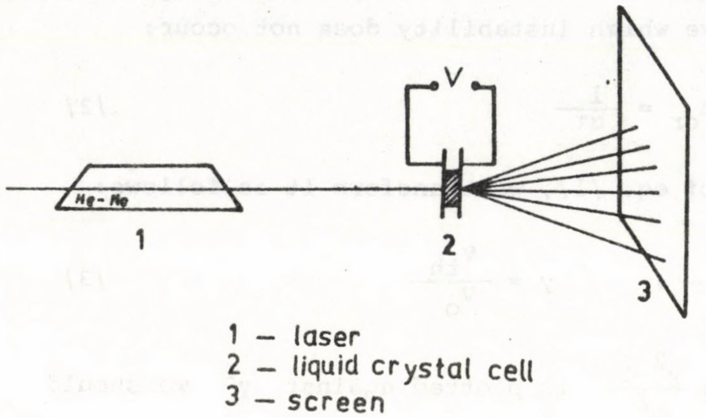

Fig. 2.
Experimental setup for investigation of light scattering

The diffraction pattern obtained at voltages just at threshold is shown in Fig. 3. This pattern corresponds to diffraction on a linear optical grating. The structure observed in the polarising microscope is displayed in Fig. 4. The wave-vector of the structure is in the direction of the original molecular alignment /x direction/, its magnitude is approximately equal to the sample thickness.

Fig. 3
Diffraction pattern obtained with a.c. field at threshold

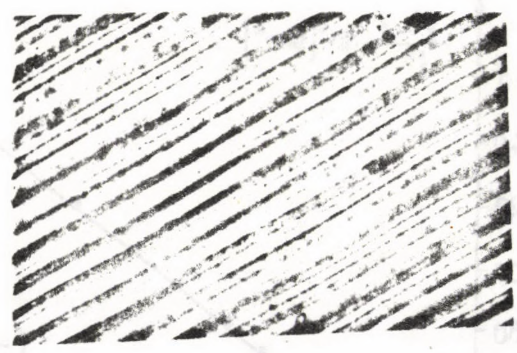

Fig. 4
Picture of Williams domains in polarising microscope

This diffraction pattern appears only if the light vector has a component parallel to x. From this fact we conclude that in the Williams domains the director lies in the x, z plane /z is the directon perpendicular to the electrodes/. If this holds then for light polarised perpendicularly to x /i.e. in the y direction/ the sample seems to be homogeneous, therefore light scattering should not occur.

Theory describes Williams domains as stationary vortices, the axis of which is parallel to y. In adjacent vortices the liquid crystal streams in opposite directions. The director has a maximum z component at the centres of the vortices /Fig. 5/.

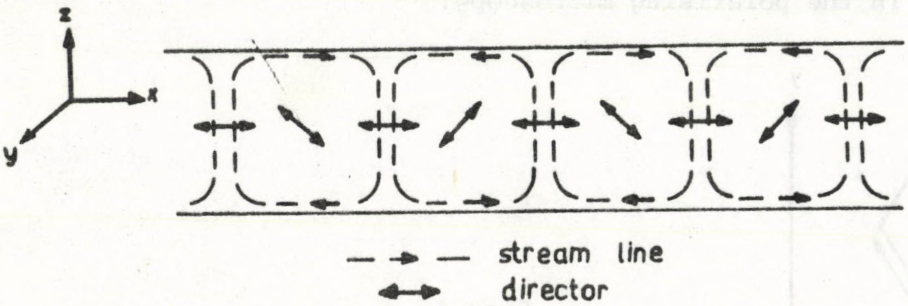

Fig. 5
Stationary vortices in the liquid crystal cell

5. INSTABILITY OF WILLIAMS DOMAINS

When the voltage is increased the Williams domains become instable. In the optical grating-like structure "defects" appear. These defects are illustrated in Fig. 6. Near these the original structure is strongly deformed, which results in the widening of the diffraction spots into y direction.

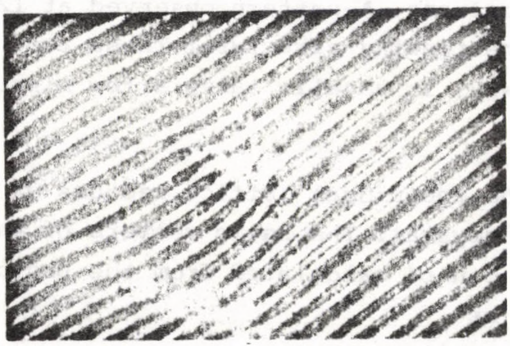

Fig. 6/a
Appearance of defects in Williams domains

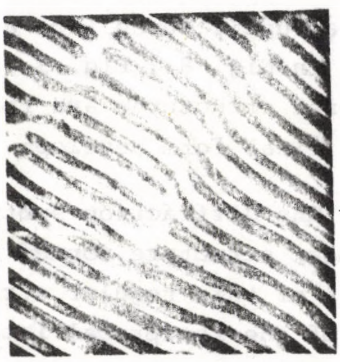

Fig. 6/b
Distortion of the linear structure by the motion of a defect

The defects are not stationary, they wander, usually perpendicularly to the vortex axis, i.e. in x direction. Increasing the voltage the number of defects and the speed of their motion increases also. Finally a turbulent motion develops, which smears out the diffraction pattern and causes large fluctuations in the scattered light.

However, before the diffraction peaks disappear completely a two-dimensional diffraction pattern can be distinguished from the background. We have found that this pattern corresponds to a hexagonal unit mesh. The unit cell is shown in Fig. 7. $\underline{a}$ and $\underline{b}$ denote the basic vectors of the unit cell. The strong movement of the liquid crystal makes it difficult to observe this structure in the polarising microscope.

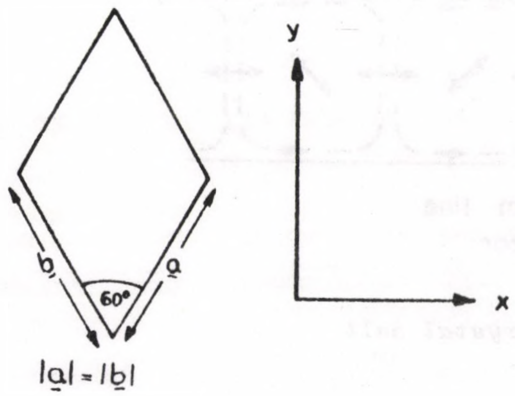

Fig. 7
Two-dimensional unit cell at a.c. field. $\underline{a}$ and $\underline{b}$ denote the basic vectors of the unit cell. x is the initial direction of the molecular alignment

6. STRUCTURES OBSERVED AT STATIC FIELDS

Williams domains appear also when a static field is applied, however, in this case the linear structure is fairly imperfect. The diffraction peaks are rather lines parallel to y than spots. At about 8 V the diffraction pattern abruptly turns into a two-dimensional one. A pattern observed at 12 V is shown in Fig. 8., Fig. 9. shows the corresponding structure. These two-dimensional structures are formed very slowly, it usually takes a few minutes till the final form develops.

The diffraction spots determine the reciprocal lattice vectors of the regular structure formed in the liquid crystal. The basic vectors of the unit cell of this regular structure $/\underline{a},\underline{b}/$, can be calculated from the basic vectors of the reciprocal lattice $/a^*, b^*/$ as

$$\underline{a} = \frac{\underline{b}^* \times \hat{\underline{z}}}{|\underline{a}^* \times \underline{b}^*|} ; \qquad \underline{b} = \frac{\underline{a}^* \times \hat{\underline{z}}}{|\underline{a}^* \times \underline{b}^*|} \qquad /4/$$

where z is a unit vector perpendicular to the electrodes.

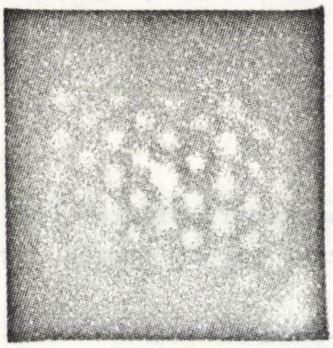

Fig. 8
Diffraction pattern obtained with d.c. field at 12 V.

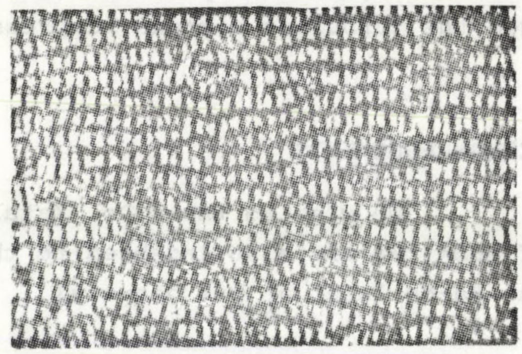

Fig. 9
Two-dimensional structure observed at d.c. field in polarising microscope

As it is shown in Fig. 10, a and b depend strongly on voltage. The lattice generally cannot be considered to be hexagonal, and it is interesting that the original direction of molecular alignment /x axis/ is not a symmetry axis. However, we have found, that if the polarity of voltage is changed the diffraction pattern is reflected to the x axis.

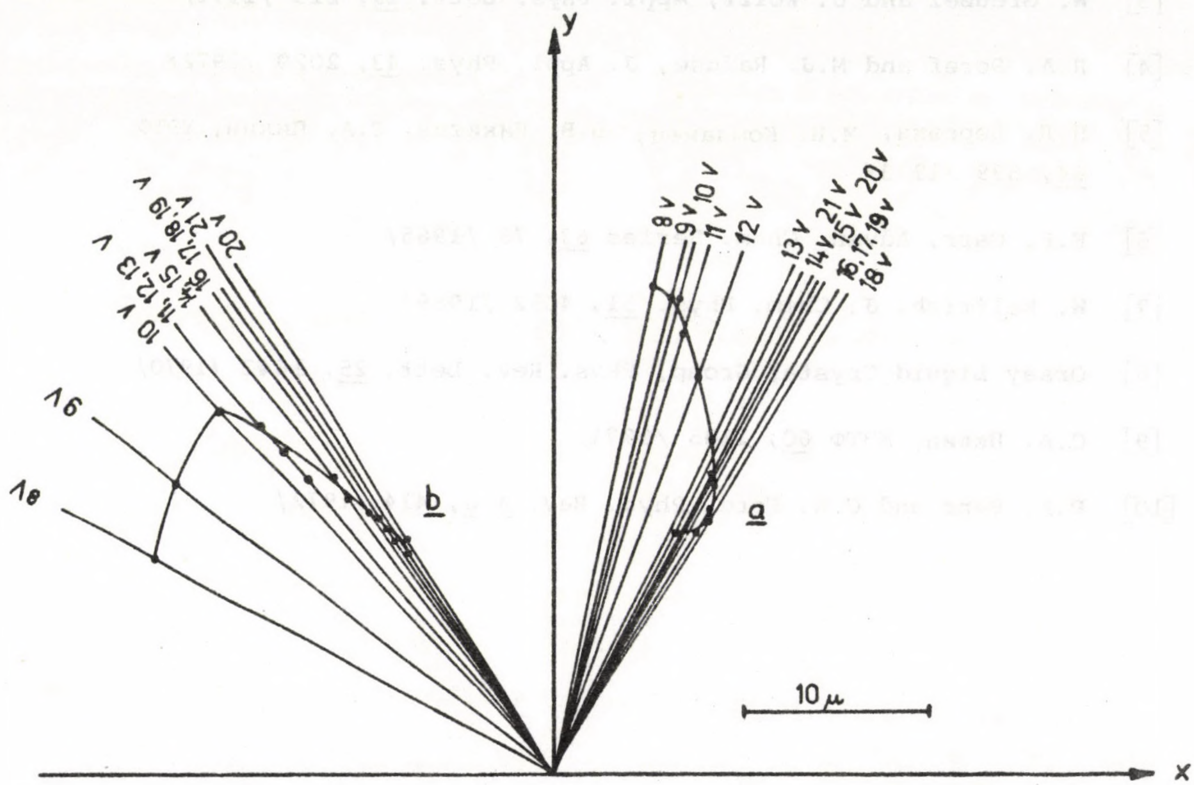

Fig. 10
Length and direction of the basic vectors, a and b as a function of static voltage. x is the initial direction of the molecular alignment

Diffraction pattern can be observed up to 20-25 V, at higher voltages the turbulent motions suppresses it.

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