A NEW ELECTROSTRUCTURAL PHENOMENON

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Figure 1: structural formula of PAA

Abstract

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A NEW ELECTROSTRUCTURAL PHENOMENON

IN LIQUID CRYSTALS OF NEMATIC TYPE

(Presented by Academician A. V. Shubnikov, 26 III 1970)

For the liquid-crystalline state, an approximately parallel arrangement of molecules within certain regions is characteristic (1). As an object for investigating the influence of electric fields on the structure of liquid crystals, *n*-azoxyanisole (PAA) was chosen; analogous results were obtained for *n*-azoxyphenetole. This substance forms a nematic phase in the temperature interval 117.5°–136.5°. The side grouping $N \equiv O$ leads to the presence of a dipole moment in the molecule $\mu = 2.48 \cdot 10^{-18}$, making an angle of $57^\circ 31'$ with its long axis (2). The chemical formula of PAA is

The nematic liquid possesses anisotropy of the dielectric constant, magnetic susceptibility, and viscosity. The refractive indices for the ordinary and extraordinary rays at $t = 117^\circ$ are respectively equal to 1.561 and 1.849 (3). In contrast to an isotropic liquid, the nematic phase is readily oriented in external electric and magnetic fields, and is also oriented mechanically (by flow in a capillary, by the surface of a substrate, etc.).

As was described earlier, in oriented liquid-crystalline films a stable domain structure was observed at a certain electric-field strength. The domains are mutually parallel and perpendicular to the principal optical axis of the film. With a small increase in the voltage (5–10 V), the domains are destroyed and the entire nematic liquid enters a state of intense turbulent motion (4). The so-called phenomenon of dynamic scattering is observed (5).

However, for oriented liquid-crystalline films it proved possible to obtain conditions under which an increase in voltage, up to its breakdown values, did not lead to destruction of the domain structure, and the phenomenon of turbulent motion of the nematic liquid was not observed at all. This made it possible to

Fig. 1. Width of domains and diffraction of a monochromatic light beam by them for various values of the voltage across the liquid-crystal film

Figure 2: Fig. 1. Width of domains and diffraction of a monochromatic light beam by them for various values of the voltage across the liquid-crystal film

observe the action of the electric field "in pure form" on a nematic monocrystalline film, which allowed new properties of thin layers of a nematic liquid crystal to be discovered. It was found that, for domains to arise, a certain threshold voltage is required, independent of the film thickness and changing almost not at all with temperature throughout the entire region of existence of the liquid-crystalline phase. The threshold voltage is a constant for a liquid crystal of a given chemical composition. It represents a profound analogy to the threshold voltage necessary for half-wave displacement in solid electro-optical crystals in the case of the longitudinal electro-optical effect ([6]).

The width of the domains is a function of the voltage on the electrodes and decreases as the latter increases.

The bands of layer-domains extend through the entire liquid crystal parallel to the main optical axis of the film.

A parallel beam of rays passing through the film undergoes diffraction in the presence of an external electric field. Patterns of both ordered and disordered diffraction were observed. If the incident light is plane-polarized, the patterns of ordered diffraction consist of even and odd orders that are polarized in different directions. It has been established that the current at a voltage sufficient to change the width of the layers becomes saturated and, with a further increase in voltage (up to a certain limit), remains constant. Similar results were obtained for a mixture of the pure components.

Fig. 1. Width of domains and diffraction of a monochromatic light beam by them for various values of the voltage across the liquid-crystal film

The discovery of the fact that the mixture possesses the properties established for the pure components is very important. This makes it possible to substantially broaden the temperature range of existence of the liquid-crystalline phase and to obtain liquid crystals with the required properties at room temperatures. The experiment consisted in observing a collimated beam of light that had passed through the liquid crystal and the surface of the liquid crystal as a function of the magnitude of the voltage on the electrodes. In the absence of voltage and at small values of it, the specimen is transparent and transmits the beam of light without scattering.

A further increase in voltage up to a certain threshold value leads to sharp scattering of the light beam in the form of a narrow band perpendicular to the main optical axis of the liquid crystal. Then the band breaks up into a sequence of spots along the same direction. The diameter of the spots corresponded to

Fig. 2. Change in the light intensity of the zero-order diffraction maximum for $\lambda = 536$ mµ as a function of the voltage on the specimen

Figure 3: Fig. 2. Change in the light intensity of the zero-order diffraction maximum for $\lambda = 536$ mµ as a function of the voltage on the specimen

the diameter of the collimated light beam.

Simultaneous microscopic observation of the surface of the liquid crystal showed that it consists of alternating light and dark bands. The bands are parallel to one another and perpendicular to the direction outlined by the image of the beam. This confirmed that, in the given case, diffraction of light by the layered structure of the liquid crystal takes place (Fig. 1).

The emergence and formation of the layered structure occurs when the threshold voltage is reached. Apparently, the initial abrupt

the deflection of the beam of natural light without decomposing it into a spectrum is caused by reflection and scattering of light by this structure at the moment of its formation, since in this case considerable gradients of the refractive index arise in the film as a result of the influence of the electric field on the arrangement of spontaneously oriented regions of molecules possessing a considerable total dipole moment. An increase of the voltage above the threshold value leads to an increase in the distance between the diffraction maxima and to a redistribution of the light intensity in them. At the same time the width of the bands in the liquid crystal decreases, and their number increases (Fig. 1).

Fig. 2. Change in the light intensity of the zero-order diffraction maximum for $\lambda = 536$ mµ as a function of the voltage on the specimen

One of the mechanisms of this phenomenon consists in the formation of lenticular and wedge-shaped layer nuclei on defects of the substrate. Their further growth between the bands along them is observed as the voltage on the electrodes is increased. Quantitative measurements of the angle of deflection of the diffraction maxima as a function of the voltage on the specimen showed that the angle of deflection is directly proportional to the voltage, beginning with the threshold voltage,

$$\varphi = \varphi^0 + nkV, \tag{1}$$

where φ^0 is the angle of deflection of the diffraction maximum for the given wavelength, n is the order of the maximum, k is the proportionality coefficient, and V is the voltage on the electrodes.

It should be noted that over the entire voltage range the greatest light intensity falls on the maxima of the first and even orders. The odd orders are weak.

Observation of the film surface in linearly polarized light without an analyzer

Fig. 3. Current-voltage characteristic of a liquid-crystal film

Figure 4: Fig. 3. Current-voltage characteristic of a liquid-crystal film

showed that, if the plane of vibration of the light is perpendicular to the bands, then the bands and the diffraction pattern are hardly observed. If the plane of vibration of the transmitted polarized light is parallel to the bands, then the bands are clearly observed and the diffraction maxima have the greatest intensity. The zero-order diffraction maximum in this case periodically changes its intensity. This is connected with the redistribution of the light energy among maxima of different orders, as in the case of an ordinary phase grating (Fig. 2).

It should further be noted that, probably as a result of diffraction of light by the domains, the liquid crystal in natural transmitted light changes its color. The brightness and intensity of the color increase with increasing voltage on the liquid crystal, and the position of the light and dark bands also depends on the focusing of the microscope.

Direct measurement of the dependence of the band width on voltage showed that the band width, beginning with a certain value of the voltage, obeys the following dependence:

$$d = a/V, \tag{2}$$

where d is the domain width in microns, α is the proportionality coefficient, and V is the electric-field voltage across the film in volts.

The current passing through the liquid crystal reaches saturation when the stripe width changes.

The current-voltage characteristic of the liquid-crystal film is shown in Fig. 3. Some of the observed effects can be explained by considering the influence of the electric field on the position of the optical indicatrix of the liquid single crystal. Another part of the phenomena requires a deeper investigation for its explanation. The study of the phenomena discovered is continuing.

Fig. 3. Current-voltage characteristic of a liquid-crystal film

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Note: Figure translations are in progress. See original paper for figures.