L. M. Blinov. *Electro-optics of liquid crystals.* The popularity of liquid crystals is due primarily to their numerous applications in microelectronics. The dial indicators of watches and of calculators (first generation), television screens and electronic computer displays (second generation), modulators and devices for the optical processing of information (third generation)—are all examples of devices utilizing electro-optical effects in liquid crystal materials. These effects are exceptionally varied[1], but in all cases the same general scheme is at work. In the first stage the electric field is in some way "coupled" with one of the order parameters of the liquid crystal (here the "solid-state" nature of the material is manifested). In the second stage, in order to minimize its energy under the action of the field the liquid crystal flows, rearranges itself and changes its molecular orientation characterized by a unit director-vector **L** (here the "liquid" nature of the medium manifests itself). Finally, due to its optical anisotropy again resulting from the presence of nonzero order parameters (just as in a solid) the entire rearrangement is accompanied by a sharp change in the optical properties of the specimen (absorption, refraction, scattering of light). Thus, in the electro-optics of a liquid crystal the "crystal" passes the baton to the "liquid", and the latter again back to the "crystal". It is precisely due to this that the effects under consideration are absent both in ordinary liquids and in solids, since the baton itself is absent. The technique of the experiment is also common for all the effects. Usually all the investigations are carried out in a thin layer of liquid crystal confined between two glass plates covered with transparent electrode-films (cf., Fig. 1). Let us discuss the most interesting of the electro-optical effects.

1. In a Fredericks transition induced by an electric field a nematic liquid crystal tends to become so oriented that the direction along which its permittivity is a maximum ($\varepsilon_{\parallel}$ or $\varepsilon_{\perp}$ with respect to the director), would coincide with the line of action of the field regardless of its sign. The effect is qua-

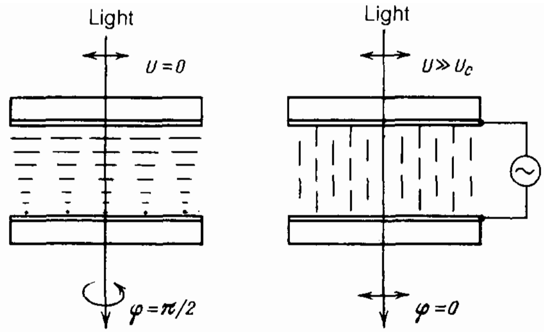

FIG. 1.

dratic in the field and is characterized by the interaction energy $W^2 \sim \varepsilon_a E^2$, where $\varepsilon_a = \varepsilon_\parallel - \varepsilon_\perp$. The reorientation is accompanied by a change in the birefringence of the medium and this is utilized for the modulation of monochromatic light. The threshold voltage of the corresponding effect is $U_c \sim \varepsilon_a^{-1/2}$, while the time of response to the field is $\tau \sim \gamma_1/\varepsilon_a E^2$, where γ_1 is the coefficient of viscosity for the reorientation of the director.

There are several variants of the Fredericks transition which differ by the geometry of the initial orientation of the director and the sign of ε_a. Of particular interest is the so-called twist-effect. In the latter case an orientation of the director twisted by 90° is produced artificially by a special treatment of the cell walls. Such a structure rotates the polarization vector of the light by an angle of $\pi/2$, and upon the application of a field $\varepsilon_a > 0$ the effect of the rotation disappears (see Fig. 1). Using two polaroid films one can produce a light shutter, and this is used in the majority of the displays.

The Fredericks effect in nematics has been well studied both theoretically and experimentally, and at the present time the focal point of research has shifted into the range of practical applications (optimization of materials, development of methods of orienting the director on a solid surface, etc.)

One of the interesting variants of new applications is the supertwist-cell in which the initial direction of the director has been twisted through an angle of π or $3\pi/2$. In this case the switchover occurs exceptionally sharply, it is in fact of a bistable nature.

2. The presence of an electrical current leads under certain conditions to the flow of a liquid crystal.[2,3] This flow may be laminar or turbulent. Laminar flow is accompanied by spatial-periodical distortions of the distribution of the director, and this is observed optically in the form of various domain patterns. Turbulent motion leads to intensive scattering of light. The threshold voltages of EHD-processes are determined, as a rule, by the anisotropy of the electrical conductivity of a medium $U_c \sim \sigma_a^{-1/2}, \sigma_a = \sigma_\parallel - \sigma_\perp$. Although the mechanisms of the various EHD instabilities (in different liquid crystal phases, at different frequencies, etc.) have been studied quite thoroughly, still many unsolved problems remain. In particular, the process of transition from laminar to turbulent flow, the behavior of instabilities in spatially-periodic fields, etc., deserves serious study.

3. Recently considerable amount of attention is being devoted to the study of electro-optical effects due to the linear interaction of the field with the electrical polarization of the medium **P** (the corresponding energy is $W^{(1)}\mathbf{P}\cdot\mathbf{E}$). The polarization can be induced by the deformation of the field of the director even in centrally-symmetric phases (the flexoelectrical effect). Of the greatest interest are ferroelectric phases (particularly the mirror-asymmetric smectic C* phase), which are characterized by the presence of a spontaneous polarization P_c. The threshold and the time of the field-induced switchover of the director are in this case inversely proportional to the polarization $U_c \sim (P_c)^{-1}$, $\tau \sim \gamma_1/P_c E$.[4] At the present time the greatest attention is devoted to the study of the interrelationship between the molecular structure and the magnitude of the spontaneous polarization of liquid crystal ferroelectrics, to the search for new switching regimes (fast modes, spiral structures), to the study of specific properties of thin layers, and to the special features of electro-optics near phase transitions, etc.

The liquid crystal phases are very varied, and for many of them the electrical effects have not been studied at all. This refers, in particular, to discotic, lyotropic and low-temperature smectic phases, the investigations of which will be developing in the near future.

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