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EXPERIMENTALLY PROVED POSSIBILITY OF GENERATING STABLE NONLINEAR DIRECTORY WAVES IN LIQUID CRYSTALS

Mihai PISCUREANU[1]

Abstract. *In this work we present an experimental attempt aiming at investigating the possibility of mechanical excitation of solitary directory waves. Thus, we have built an experimental set-up by means of which we excited with a compression wave a smectic liquid crystal (elaidic acid) placed inside a capillary tube at 46°C. After the first three excitations within the capillary tube we observed by help of a microscope, the occurrence of some dark transversal minims alternating with bright maxims zones, which have shown a tendency of motion. Afterwards, a soliton-like stable structure appeared and propagated during the next excitations along the tube. These results are repeatable and can be described by means of the effect of the shearing waves in liquid crystals. Using the Ericksen-like equations, which led to a damped driven sine-Gordon equation, we have shown that in the case of a strongly damped motion, we can get dark soliton-like solutions, in good agreement with the experimental results.*

Keywords: solitons, directory waves, liquid crystals

1. Introduction

Studies concerning directory waves in liquid crystals began since 1968 [1, 2]. More recently, several authors presented preliminary experimental studies on director waves [3]. In these experiments, the liquid crystal cell consists of two polished glass plates of dimensions $0.5\times5\times30$ cm^3, the cell thickness being of about 50µm, fixed by four spacers. As an exciter, they used a Mylar film 20 µm thick. As a substance with homeotropic texture, an MBBA-like liquid crystal was used, having the mesophase interval between 22 °C and 47 °C. Within the framework of these experiments, one has noticed the generation of several transverse dark lines and their propagation along the liquid crystal cell. These experiments have put into evidence the possibility to generate directory waves into nematics. These waves are incompressible since their velocities are much less than the ones usually encountered in the case of incompressible waves in fluids. These dark lines were interpreted as having a soliton-like behavior [4]

2. Experimental results.

In our study concerning the possibility of exciting soliton-like directory waves in liquid crystals, we used a flexible capillary tube with a 500 µm diameter.

[1]University "Politehnica" of Bucharest, Department of Physics II, Splaiul Independentei 313, Bucharest, 77206 Romania, piscureanu@physics.pub.ro.

In this tube, we have introduced an unsaturated fatty acid – the elaidic acid – at 40 °C. This system showed a smectic C liquid crystal behavior within some temperature values [5]. The tube was sealed at one end. As a mechanical exciter, we used a cylinder represented by the body of a syringe of 2 cm^3, which was attached to the free end of the capillary tube. The pressure waves were generated by means of the mobile piston of the syringe, driven by an asynchronous electric motor supplied at 100 V. When exciting the sample at 46°C we observed the formation of some dark minims in totally polarized white light. We have chosen this temperature in order to increase the elasticity of the smectic system and to achieve a more efficient excitation (Figure 1). These minims occurred after the first excitation, and have shown a tendency of motion. After three excitations, the number of minima reduced, and an aggregate-like structure aroused at one side of the tube (Figures 2 and 3), this one moving along during the fourth and fifth excitation.

3. Theoretical considerations

It is known that liquid crystals could be considered ordered fluids. In order to explain the above results we considered the liquid crystal as being under uniform shear, such that the velocity depends only on the y-coordinate, which corresponds to the thickness of the liquid crystal layer, and $\partial v / \partial y = const$.

Under the assumptions that the director vector can be written as

$$\bar{n} = (\sin\theta, \cos\theta, 0)\text{, and } \theta = \theta(x, t)$$

is the tilt angle in the smectic layer, we get the following equation [6]:

$$Md^2\theta / dt^2 = Kd^2\theta / dx^2 - \gamma_1 d\theta / dt + s / 2(\gamma_1 - \gamma_2 \cos 2\theta) \quad (1)$$

where M is the moment of inertia, K is the elasticity constant, γ_1 and γ_2 are viscosity coefficients, and:

$$d\theta / dt = \partial\theta / \partial t + v\partial\theta / \partial x \approx \partial\theta / \partial t$$

$\partial v / \partial y = s$ and θ is the angle between the director and the normal to the quasi-plane surface of the capillary tube.

This equation is a sine-Gordon-like one and - as it is well known - it has soliton type solutions. When θ is a traveling wave of velocity *c*, equation (1) becomes:

$$m\ddot{\theta} = -\eta\dot{\theta} - \partial U / \partial\theta \quad (2)$$

where

$$\theta = \theta(Z),\ Z = X - \eta T,\ X = x/\lambda,\ T = t/\tau,$$

$$\lambda = (2K/|\gamma_2|s)^{1/2}, \tau = 2\gamma/s, \eta = c\tau/\lambda,$$
$$m = 1 - Ms\eta^2/(2\gamma^2|\gamma_2|) \quad (3)$$
$$\gamma = \gamma_1/|\gamma_2| U = \gamma\theta + (1/2)\sin 2\theta \dot{\theta} = d\theta/dZ.$$

The equation (2) describes the damped motion of a particle with mass m in an apparent potential U. The damping coefficient is η, and Z plays the role of time. Taking into account the fact that the elaidic acid has a high viscosity, it is of great interest to study the strongly damped case of $\eta \gg 1$. In this case, the equation (2) becomes:

$$\ddot{\theta} = -(\gamma + \cos 2\theta)/\eta - 2(\sin 2\theta)\dot{\theta}/\eta^2 \quad (4)$$

which has been solved analytically [7].

A solution of the equation (4) is:

$$\theta = \tan^{-1}\{wth[(\gamma - 1)wZ/\eta]\} \quad (5)$$

where

$$w = [(1+\gamma)/(1-\gamma)]^{1/2}$$

As we can notice, θ decreases monotonically from θ_0 at $Z \to -\infty$ to $-\theta_0$ at $Z \to +\infty$ ($\gamma < 1$, $m = 1$), where $\theta_0 = (1/2)\cos^{-1}(-\gamma)$. The two limits of θ_0 correspond to the two uniform states allowed by the shearing forces. These theoretical considerations on the traveling waves are applicable only in the case when in the time interval under consideration the velocity of the dark lines is almost constant.

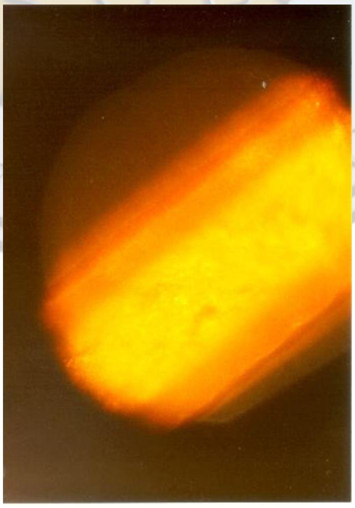
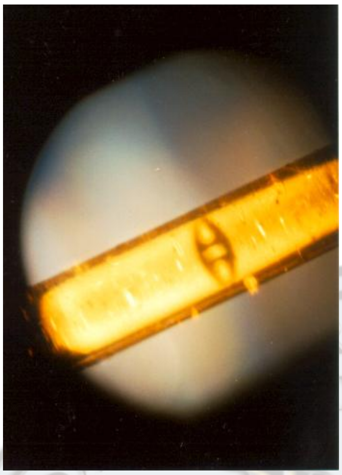


Foto 1.



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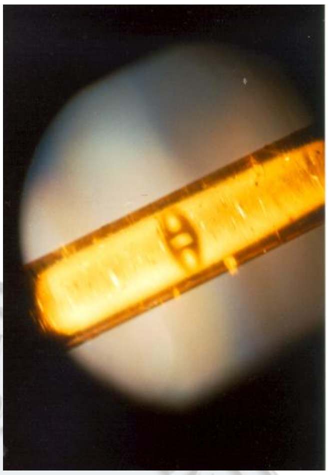

Foto 3.

4. Conclusions

In our work we have experimentally shown the possibility of exciting solitary-like director waves in a liquid crystal by a mechanical method. Thus, by means of a pressure wave, a smectic liquid crystal (elaidic acid) was excited inside a capillary tube, at 46°C. After the first three excitations, we observed the apparition of some dark minims alternating with bright maxims which presented a tendency of motion. Then a stable soliton-like structure occurred, and began to propagate, during the next excitations of the smectic system, along the tube. The propagation of such structures could be described by considering the effect of the shearing waves in liquid crystals. A damped driven sine-Gordon-like equation was derived. Finally, we have shown that in a strong damping case, corresponding to the large values of the viscosity coefficients for the elaidic acid, dark soliton-like solutions are obtained.

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