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The Acousto-Optic Effect in Nematic Liquid Crystals

J.S.Sandhu, W.G.B.Britton and R.W.B.Stephens.

Chelsea College(Univ. of London), London, S.W.6.

Introduction

The rheological properties of liquid crystals were first investigated through acoustically-excited flow by Kapustina and Statnikov (1). In the present investigation surface acoustic waves (S.A.W.) are generated on a piezoelectric substrate (lithium niobate). The S.A.W. interact with a liquid crystal nematic contained within a shallow cell set-up on the substrate within the acoustic surface beam from an interdigital transducer. Only a small volume of liquid crystal is required thus permitting the use of a polarising microscope for observations of the fluid phenomena. The acousto-optic effect is studied by the variation in the intensity of the light which has been reflected from the liquid-crystal layer, using a photo-multiplier to receive the reflected light.

Experimental System

The general schematic lay-out of the experimental system is given in Fig. (1) and it shows the liquid-crystal test-cell (Fig. 2) (described fully in (2)) and the interdigital transducer which is deposited on a lithium niobate crystal substrate. The observing microscope is vertically disposed above the cell or alternatively an image of the probed liquid-cell area may be projected onto the window of a photo-multiplier. The output of the latter is measured by a digital voltmeter or, for dynamic measurements, is displayed on a chart-recorder.

Observed Phenomena due to Acoustic Field Application

Using thin liquid nematic layers the sequence of events resulting from the application of an S.A.W. of increasing intensity have been reported by a few workers (1,2,3). The generally accepted explanation of the acousto-optic effect is in terms of acoustic streaming arising from the radiation pressure of the acoustic field (2,3,4,5). At low acoustic intensities the (Fig 3,4) 'stripe-domain' pattern is observed (1,2,3), which arises from the development of the Rayleigh-Bénard type of cellular vortices that have a definitive spatial period with their rotational axes perpendicular to the direction of wave propagation.* This ordered type of fluid-flow becomes turbulent at higher acoustic intensities, the degree of disturbance being dependent both on the thickness and breadth of the cell and on acoustical intensity (6). As the cell thickness is increased from 12 μm to 254 μm there is a continuous decrease in the acoustic intensity required to initiate acoustic streaming. At the largest thickness no

The Acousto-Optic Effect in Nematic Liquid Crystals.

stripe domains were observed and the clarity of the observed acoustic flow pattern enabled an estimate to be made of the flow velocity from a study of the projected screen image of a cine film of the phenomena. The film was recorded at 16 frames per second and the flow velocity deduced by noting the movement of some trapped dust particles, or easily distinguishable disinclination lines, between successive frames of the film.

Since the radiation pressure is proportional to the acoustic wave intensity then, for a given cell, the acoustic streaming is expected to vary as the wave intensity. By assuming a constancy of the energy transduction process it follows that to a first approximation the streaming velocity should be proportional to the acoustic intensity as measured by the square of the applied transducer voltage (V^2). This deduction appeared to be verified for lower acoustical intensities i.e. before strong turbulence occurred (Fig. 6).

Transient Measurements

In liquid crystal applications the times taken to reach a new state or to return to the initial condition are usually of prime importance. These rise (τ_R) and decay (τ_D) times were evaluated respectively by displaying the output of the photo-multiplier on the chart-recorder consequent upon applying and removing the applied transducer voltage. τ_R is defined as the time taken to rise from 10% to 80% of the steady-state optical transmission while τ_D is the time to decay to 80% of the steady-state optical transmission. Typical observations are shown in Fig. , where L denotes the liquid layer thickness. The effect of increased acoustic intensity is to produce a decrease in τ_R but an increase in τ_D. The latter is seen (Fig. 7) to be very sensitive to liquid crystal layer-thickness.

References

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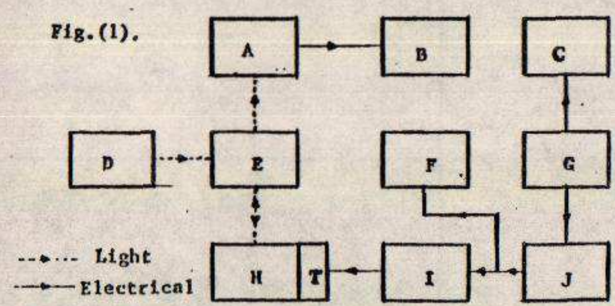
* see also Fig 5.

The Acousto-Optic Effect in Nematic Liquid Crystals.

BLOCK DIAGRAM OF THE SYSTEM

Fig.(1).



A-Photomultiplier or Cine Camera; B-Digital Voltmeter or Chart Recorder; C-Timer-Counter; D-Light Source; E-Microscope(Vickers M74); F-R.F.Voltmeter or oscilloscope; G-C.W.Signal generator; H-Liquid crystal cell; T-Transducer; I-Switch; J-R.F.Amplifier:

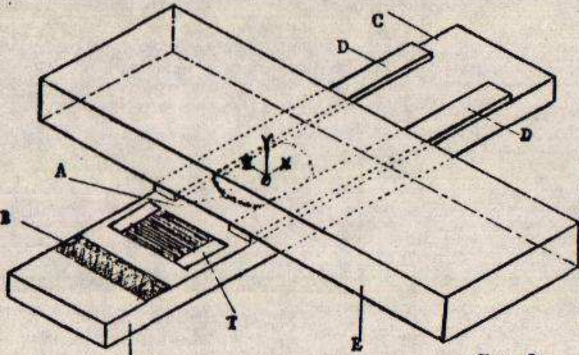


Fig.2

THE LIQUID CRYSTAL CELL

A-Liquid Crystal; B-Acoustic Absorber; C-Lithium Niobate Substrate; D-Melinex Film Separators; E-Glass Cover Plate; T-Transducer:

The coordinate axes indicated in the diagram are such that the vertical Oy is the optic axis of a homeotropically aligned cell.

'a'

'b'

'c'

Fig. 5 (a,b and c) above are three records from a ciné-film illustrating the development, with increasing acoustic intensity, of a domain system and its subsequent disruption.

Fig.3 shows the 'field pattern' along the central axis of the transducer with the existence of streaming, the lower boundary of the figure being the feeding-edge.

The Acousto-Optic Effect in Nematic Liquid Crystals.

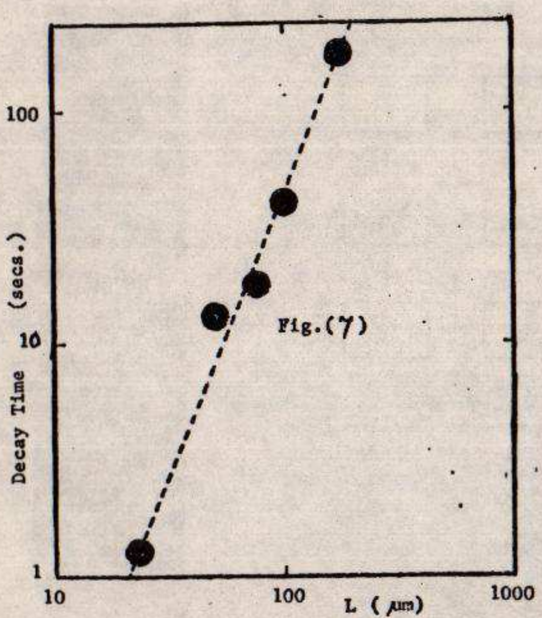


Fig.4 ,above, shows vortex motion near the boundary of the liquid crystal cell.