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Voltage Effects in Cholesteric Liquid Crystals

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Abstract—Liquid crystal mixtures were sandwiched between two transparent electrodes on glass and a direct or alternating potential was applied. The light scattering property of the liquid crystal changes upon application of voltage, the intensity varying from 1 to 10% of that scattered by a MgO diffuse surface. The maximum increase in intensity due to voltage was a factor of about six. The maximum wavelength shift was 40 nm to the blue by 80 V applied to a layer 10 μ thick. The response time varied from 0.03 to 0.5 sec.

Introduction

This report describes some measurements of the changes in the light scattering property of cholesteric liquid crystals which occur when an electric field is applied to them. The initial and preliminary work was done in this laboratory by J. L. Fergason. Recently Muller[1] reported on microscope observations of the electric field in cholesterol nonanoate. In the present work four mixtures of three compounds were examined; cholesterol chloride 20 to 30% by weight, cholesterol nonanoate 10 to 20%, and oleyl cholesterol carbonate about 60%. In the cells numbered from 1 to 4 the proportion of cholesterol chloride was increased in steps and that of cholesterol nonanoate decreased.

The volume resistivity of the cells was about 10^{13} Ω-cm and the dielectric constant about 3.

Structure of Cells

Cells were made by pressing the liquid crystals between glass plates coated with tin oxide and separated by a Mylar spacer. The active area of the cell was 2 cm^2. The thickness was measured by observing the separation of the glass edges with a microscope. Using a 7 μ Mylar spacer resulted in a thickness of 10 to 12 μ. Evaporated metal electrodes were tried but the light reflected by the metal masked the light scattered by the liquid crystal making visual inspection difficult.

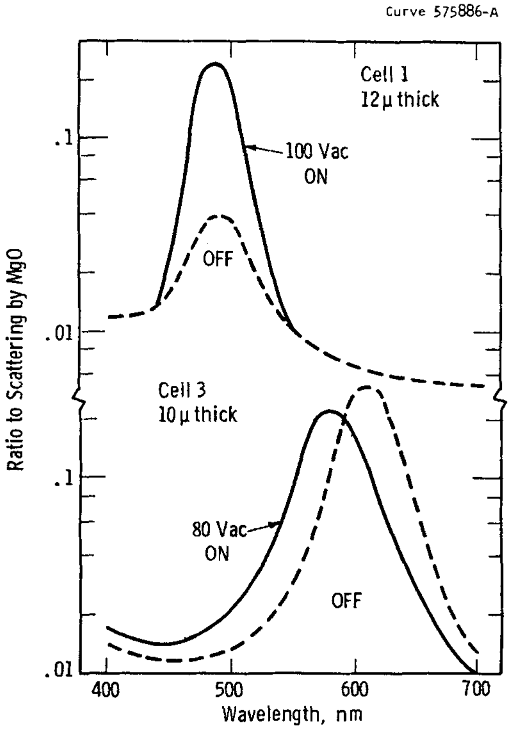

Figure 1. Effect on spectral scattering due to cycling a liquid crystal cell with voltage 5 sec ON, 5 sec OFF.

Most of the colored light scattered by the liquid crystal came from specks about 2 or 3 μ in size and from clusters about 30 to 50 μ in diameter. Some cells had fiber-like patterns which did not scatter strongly. Voltage caused the specks and the fiber patterns to disappear while the clusters changed color and form and sometimes moved around. With sufficient voltage and time the liquid crystal turned clear and ceased to scatter light.

Spectral Distribution

The color of the scattered light results from wavelengths that are scattered most strongly and this is determined by the wavelengths for which the optical activity changes sign. A general description of the phenomenon has been given by Fergason.[2] The color depends on the angles of illumination and scattering. For the results reported here the cell was illuminated at an angle of 45° with a parallel beam of light and observed from the same side in a direction

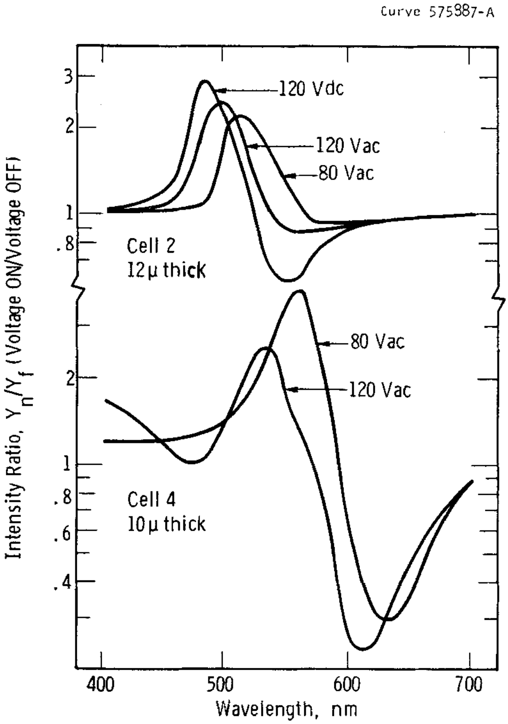

Figure 2. Spectral dependence of intensity ratio of scattered light from liquid crystal cell when voltage cycled 5 sec ON, 5 sec OFF.

normal to the surface with a grating monochromator positioned for a half-angle aperture of 15° and with a pass band of 40 nm. The intensity of the scattered light was measured as a ratio to that scattered by a diffuse surface of MgO. Because the restoration of the scattering property of the cell depends on the voltage and the time since the voltage was removed, the spectral distribution was measured with the cells cycled on and off during measurement.

In Fig. 1, cell 1 shows an enhancement of intensity due to voltage with almost no shift in the wavelength of the spectral peak, while cell 3 shows an enhancement in the green and a quenching in the red. Another way of describing the latter effect is to say the spectral peak was shifted to the blue by about 40 nm by the application of 80 V a.c. (rms, 60 c/s) with no substantial change in intensity. However, intensity is affected by voltage. An alternate way of presenting the spectral change due to voltage is to show the ratio of intensity with the voltage on and off. The results for cells 2 and 4 are shown in Fig. 2. The intensity ratio Y_n/Y_f (voltage on to off) in cell 1 with the 10-sec cycling is about six but the ratio depends on the voltage and the length of the cycle, reaching a maximum for cycles of about 1 sec.

Intensity Waveforms

To obtain maximum brightness from a cell a momentary shear force was applied to the glass plates with the fingers and the cell allowed to rest at least a half hour to reach an equilibrium state before measurements were made. There is some dependence between the direction of shear and the angle of illumination and the angle and intensity of scattering. If a voltage is applied to such a cell, in general the cell will not revert to its original color and brightness when the voltage is removed. The intensity waveforms in Fig. 3 give some measure of the degree of restoration. Zero intensity is represented by the base line. The initial intensity with voltage off after restoration by shearing is shown by the short horizontal line. The waveform then shows the intensity with voltage on for 30 sec and off for 30 sec for the first and tenth cycles.

The cells did not reach a state of equilibrium in the 30 sec except at low voltages where the intensity ratio is small.

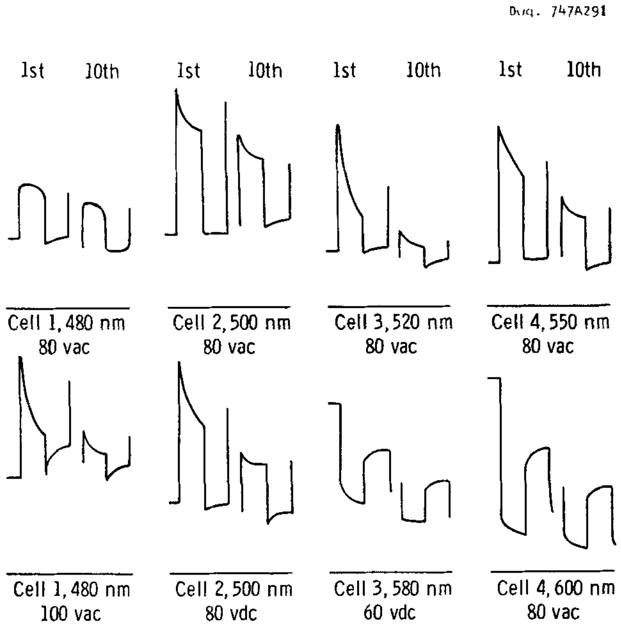

Figure 3. Intensity waveforms of scattered light from liquid crystal cells due to cycling with voltage 30 sec ON, 30 sec OFF, showing the first and tenth cycles after restoration.

Speed of Response

The cells were cycled at a faster rate to determine their speed of response as the voltage is applied and removed. Some results are given in Fig. 4 and Table 1. In Fig. 4 the upper curve represents light intensity, the lower one voltage. The speed of response is measured by the time required for the change in intensity to reach 63% of its maximum value and, in Table 1, is represented by t_n and t_f for the voltage going on and off respectively. However, the time required for the light intensity to reach equilibrium is usually much greater than the speed of response figures would imply.

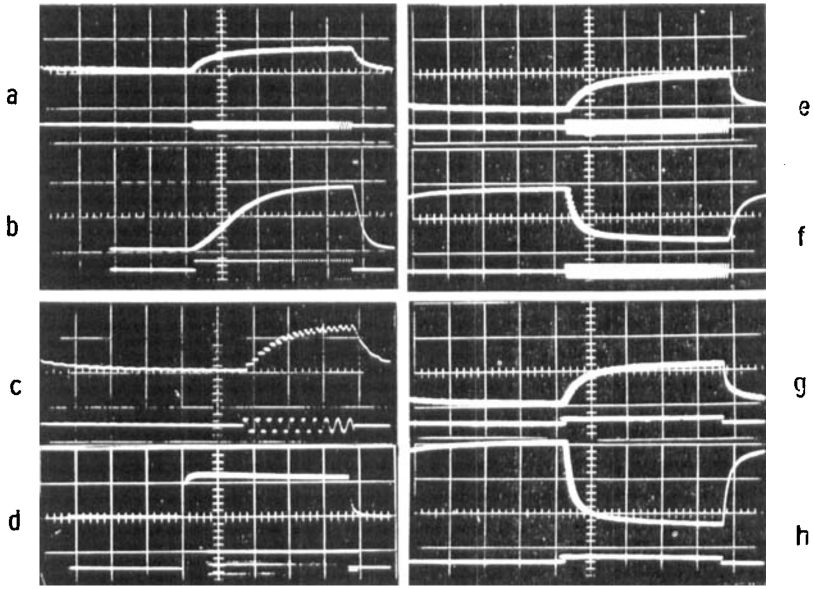

Figure 4. Response of liquid crystals cells to voltage cycling. The parameters for the figure are given in Table 1.

Table 1 Parameters for Fig. 4

Fig.	Cell	Voltage	Wave-length nm	Cycling rate c/s	Sweep ms/div	Intensity ratio Y_n/Y_f	Response time	
							t_n sec	t_f sec
a	1	40 a.c.	480	0.5	200	1.1	0.15	0.10
b	1	120 a.c.	480	0.5	200	8.1	0.40	0.05
c	3	80 a.c.	520	2.0	50	2.1	0.05	0.04
d	3	80 a.c.	520	0.2	500	2.2	0.05	0.05
e	4	80 a.c.	520	0.5	200	1.5	0.15	0.05
f	4	80 a.c.	620	0.5	200	0.5	0.07	0.10
g	4	80 d.c.	520	0.5	200	1.4	0.15	0.06
h	4	80 d.c.	620	0.5	200	0.5	0.06	0.06

In each of the four cells the speed of response varied from about 0.03 to 0.5 sec. In a cell 125 μ thick it was about 1 sec. The voltage-off time t_f was usually smaller than t_n. A variety of experiments was done to determine the dependence of the response time on voltage, both direct and alternating, on the cycling rate and on the wavelength, but there were exceptions to almost every conclusion that could be made. It is believed that there are conditions in the liquid crystal or in the cell as yet unrecognized that have an influence on the response time and the rate of recovery.

Effect of Thickness

The results given above are for cells of thickness 10 to 12 μ. Six cells were made with thickness 10 to 170 μ using the liquid crystal mixture of cell 4. The correlation between thickness and the intensity of scattered light with no voltage was poor and the maximum intensity ratio was 5. The wavelength peaks differed by a maximum of 30 nm with the thicker cells and those scattering more strongly being more red. Only the 10 μ cell gave a pronounced ON to OFF ratio in intensity, all the others were poor by comparison. At 620 nm the thicker cells showed some enhancement with voltage while the thinner ones showed quenching. When the voltage was increased in 10 V increments until the liquid crystal became clear there was no correlation between the clearing voltage and the thickness of the cell. The results indicate it is necessary to distinguish between field effects and voltage effects in such cells.

To prepare cells a few microns in thickness the liquid crystal was dissolved in ether or chloroform and the solution sprayed or cast and the deposit dried. Cells of thickness about 3 μ did not scatter enough light to show color until they were sheared and then the intensity was weak. When an evaporated electrode was used on such thin layers there was difficulty with pin-holes unless an insulating layer was provided. If the dilution of the liquid crystal was not too great (1 to 100 by weight), layers of even 20 μ had no color after deposition and drying until they were sheared or smeared. When the dilution was large (1 to 1000) mechanical manipulation produced no color in the scattered light. The results indicate that the degree of disorientation of the molecules is related to the degree of dilution.

Acknowledgments

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