# A polarizing oriented smectic beam splitter

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A beam of *unpolarized* light is shown to be split into three distinct *polarized* beams when it passes through the core region of a smectic liquid crystal which is oriented so that its planes form concentric cylinders. In *N-p*-cyanobenzylidene-*p*-octylozyaniline (CBOOA) the angle between two adjacent exit beams is $\sim 22°$, whereas for *N-p*-cyano-*p*-octylbiphenyl (COB) it is $\sim 14°$. Knowing this angle, we are able to deduce the ratio of the extraordinary to ordinary index of refraction, $n_e/n_o$, for CBOOA and COB.

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Earlier results[1,2] have shown that treating a glass cylinder with the appropriate surfactant[3] can result in the growth of an oriented smectic in which the smectic layers form cylinders concentric with the glass container and for which there is a clearly visible threadlike core running down the axis of the cylinder. Sometimes, in the case of cylinders which are very long compared to their diameter, this core has been observed to exhibit a bead structure.[1] We have been making a systematic study of such oriented smectics in glass cylinders ranging in diameter from 50 $\mu$ to 1 cm and have found that on the larger cylinders (diameter greater than 1 mm) when we shine a laser beam of diameter somewhat less than the cylinder diameter (but a little larger than the core) on the core of the oriented smectic, three exit beams result. The angle between the exiting beams is independent of the cylinder diameter but does depend upon the liquid crystal. Two of these beams are polarized in a direction perpendicular to the cylinder axis and the third, middle beam, is polarized parallel to the cylinder axis. In these large tubes, we almost always observe a diffraction pattern associated with the bead structure of the core. By measuring the spacing of this diffraction pattern we found that the core diameter depends upon the tube diameter, $2R$. By measuring the angle between the exit beams and using Grandjean's analysis of the optical path for the extraordinary ray when confronted with a "structure rayonnée plane" we deduce the ratio of the extraordinary to the ordinary index of refraction, $n_e/n_o$. As far as we know, this is the first quantitative verification of the validity of this analysis made many years ago.

Figure 1 shows our experimental arrangement. A Spectra Physics He-Ne "unpolarized" laser shines on the core of the cylindrically oriented smectic and is observed to split into three polarized beams. When the

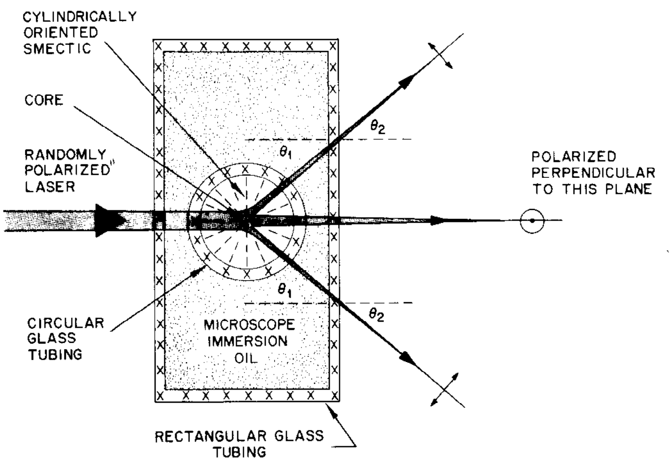


FIG. 1. The circular glass tube is contained in a rectangular glass tube. Microscope immersion oil, which is heated for CBOOA, flows between the two cylinders. The smectic orients as shown in the figure. We measure $\theta_2$ and deduce $\theta_1$ knowing the index of refraction of the microscope immersion oil and using Snell's law. An actual photograph is shown in Fig. 2. The polarization of the exit beams is shown by the arrows on the exiting beams.

FIG. 2. An "unpolarized" laser shining on the core of a cylindrically oriented smectic results in three distinct polarized exit beams. Slightly focusing the incoming laser beam results in a finer central beam.

  

TABLE I. Results of the measurements on the diffraction pattern associated with the headed core.

| Tube diameter (2$R$) (cm) | Core diameter (CBOOA) ($\mu$) |
|---|---|
| 0.81 | 26 ~ 33 |
| 0.5 | 26 |
| 0.3 | 7–9 sometimes 14–18 |
| 0.18 | 22–26 |
| 0.007 | 2 |

incoming beam is shifted slightly off the core axis, only two beams result. By placing a polarizer before the specimen we observe that when the polarizer is parallel to the cylinder axis and the beam is shining on the core, only the central beam appears and when turned by 90°, the central beam is extinguished and the two flanking extraordinary beams appear. By placing the polarizer after the sample we are able to verify the respective polarization of the exiting beams. Thus, this configuration, due to the large birefringence of liquid crystals has enabled us to sort the originally unpolarized light into three distinct polarized beams which are separated from each other by a large angle. Further, since the liquid crystal absorbs very little of the incoming light (in fact, COB is a clear transparent room-temperature smectic, when so oriented) very little (if any) attenuation results in the polarizing sorting process (see Fig. 2).

Since our tube is contained in a rectangular tube, the space between the two tubes being filled with microscope immersion oil, in order to deduce the actual angle of the beams emerging from the inner circular cylinder, we need to correct our measured angle for the additional refraction of the light at the glass-air interface. Doing this we find that in the case of CBOOA ($N$-$p$-cyanobenzylidene-$p$-octyloxyaniline) and COB ($N$-$p$-cyano-$p$-octylbiphenyl) the room-temperature smectic, this angle is $\alpha = 22°$ and 14°, respectively. According to Grandjean[4]

$$\frac{n_e}{n_o} = \frac{\pi}{\pi - \alpha} \qquad (1)$$

which gives for CBOOA $n_e/n_o = 1.139$ and for COB $n_e/n_o = 1.084$. In the case of CBOOA we have the independent measure (for a wavelength of 6328 Å) of this ratio[5] of $1.75/1.53 \approx 1.144$. This good agreement quantitatively verifies Grandjean's analysis of the optics of this configuration.

In the nematic phase, except very near the smectic transition, so much of the laser light is scattered that we cannot discern three exit beams but rather only a single diffuse beam. Also we note that in the nematic phase, we no longer expect the "structure rayonnée plane" to be a stable one[6] for most nematics and it is usually replaced be a more complicated configuration.[1,6]

We mention here, briefly, our measurements on the diffraction pattern associated with the beaded core. The main result is that the bead diameter depends upon the diameter of the sample but not in a simple manner. Table I shows the results so far of our measurements. We note that the bead sizes are approximately given by $r_c \approx [2R(K_1/B)^{1/2}]^{1/2}$ where $K_1$ is the elastic constant of splay and $B$ is the elastic constant associated with a dilation of the smectic layers.

In conclusion, therefore, we have shown that by orienting a smectic liquid crystal so that its planes form concentric cylinders, we are able to construct a low-loss polarizing beam splitter. In addition, knowing the ratio $n_e/n_o$, one should be able to predict the angles between the three out-going beams.

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