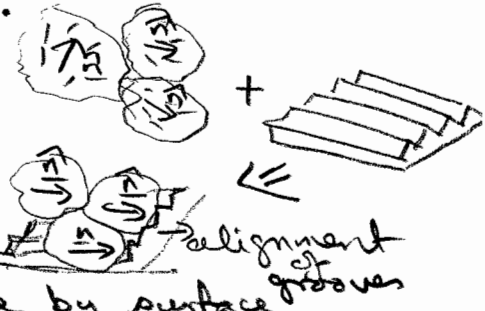
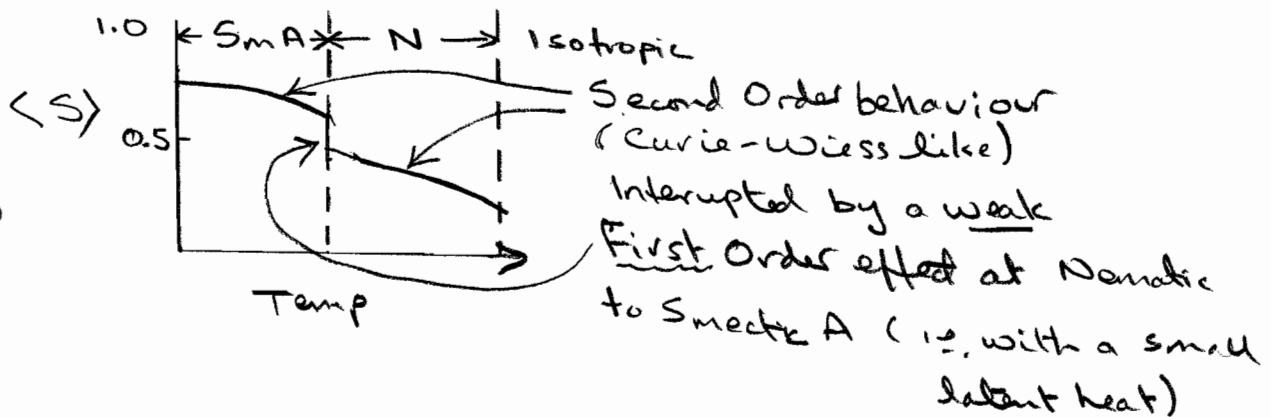


(a) Nematic phase has Oriental order only. Short range forces give structures with no regular organisation between centres of mass. Long molecular axes align on average in one direction denoted the director \hat{n} . Molecules free to slide past one another. The local director order extends over a range defined by short range forces to give local domains. Different domains point in different directions unless the one constrained at the surface by surface forces. Rubbed Polymer or microgrooves produces uniaxial directors \rightarrow uniform domain free structure - domains disappear since directors are indistinguishable



⑥

(b) Order Parameter $S = \frac{1}{2} \langle 3 \cos^2 \theta - 1 \rangle$, where θ is the angle between any molecular axis and \hat{n} averaged over the whole ensemble



②

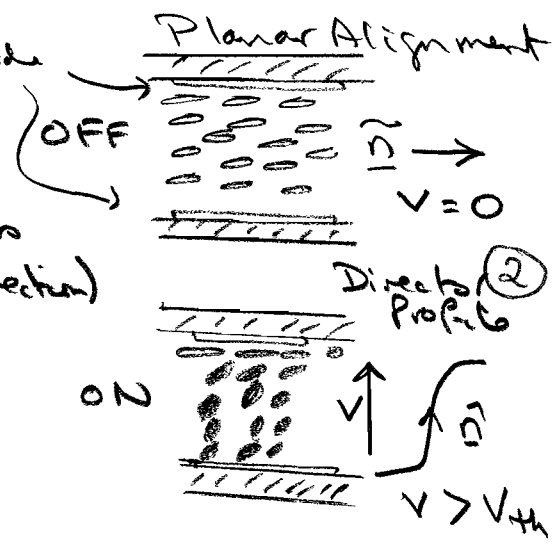
- The elastic constant defines the switching threshold voltage ($V_{th} = \pi \sqrt{\frac{k}{\Delta \epsilon \cdot \epsilon_0}}$) } k and $\Delta \epsilon$ both depend on S as a function of temperature
- Response time τ is a function of the viscosity which depends on $\langle S \rangle$

②

- Dielectric Anisotropy $\Delta \epsilon$ and Birefringence D_r are derived from the polarisability anisotropy which depends on $\langle S \rangle$ i.e. $\Delta \alpha = (\alpha_{11} - \alpha_{\perp}) \langle S \rangle$ (molecular values)

③

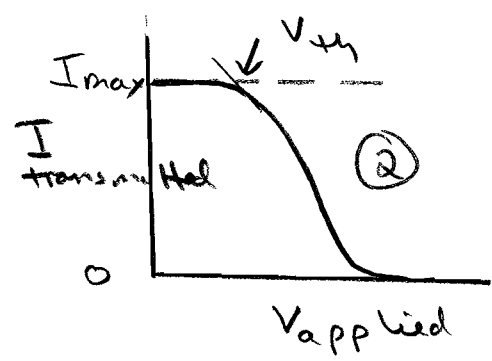
transparent electrode
 (C) Splay elastic constant k_{11} . Use planar surface alignment and place cell between crossed polarisers (normally at 45° to rubbing direction)



In OFF state $V=0$ the cell has a birefringence Δn in ON state $V > V_{th}$ $\Delta n \rightarrow 0$ i.e. homeotropic alignment. for $\Delta \epsilon > 0$ dielectric anisotropy V_{th} defines energy need to produce splay deformation.

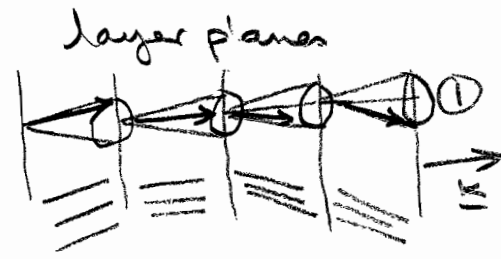
$$V_{th} = \pi \sqrt{\frac{k_{11}}{\epsilon_0 \Delta \epsilon}}$$

Monitor $I_{transmitted}$ as a function of V .



(The candidates could draw a schematic of the apparatus with light source, crossed polarisers and detector)

2(a)

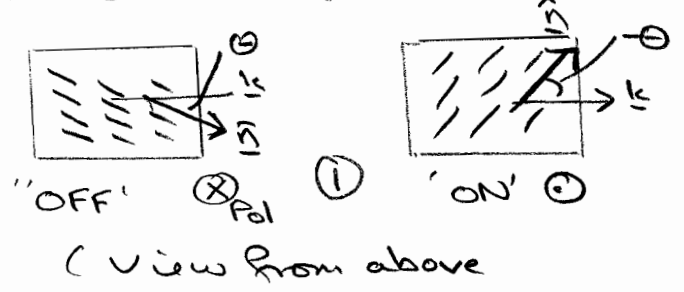
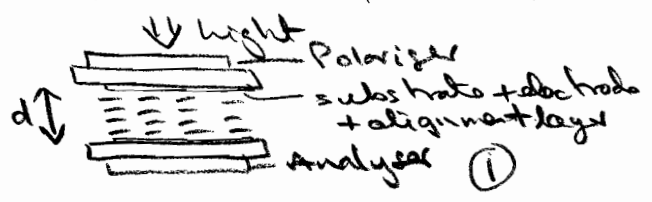


In the Smectic C* phase the director tilts at an angle θ to the layer normal k and \hat{n} of each layer precesses around k . Since each molecule has a transverse dipole



the dipoles also precess around the 'cone' and if one end averages to zero $\therefore \sum p = 0$. Thus the phase is not ferroelectric. Unwinding the helix leads to two states $\pm \theta \Rightarrow \pm P_{ferro}$.

(b) To produce an SSFLC surface forces are used to align \hat{n} in the horizontal (planar) plane. Typical device thickness $d \approx 1-2 \mu m$ which constrains \hat{n} to $\pm \theta$. The dipoles then sum to give a resultant polarisation 'up' or 'down' i.e. the device becomes ferroelectric with 2 stable states ($+\theta$ or $-\theta$).

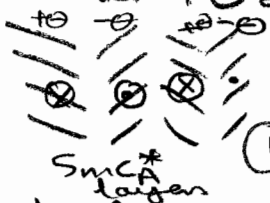


In OFF state device is arranged such that \hat{n} is parallel to the input light polarisation. This polar is crossed with the Analyser to give a dark or non-transmissive state. If in this state the resulting dipole polarisation was pointing down, then application switches the polarisation into the 'up' state. The director \hat{n} precesses around the cone to the $-\theta$ position. Thus in projection for the two end states \hat{n} has switched through 2θ . Since the materials are birefringent ($\Delta n = n_{||} - n_{\perp}$) this corresponds to a phase plate and provided $2\theta \neq 90$ light (I_t) is transmitted. Both end states $+\theta, -\theta$ are bistable.

Continued over

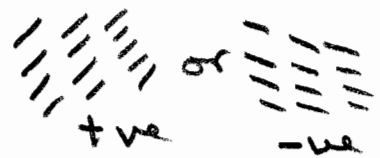
2(b) cont. For optimum transmission $\Theta = 22.5^\circ$

In an antiferroelectric material alternate layers are tilted at $+\Theta$ and $-\Theta$. (i.e. a herringbone structure.)

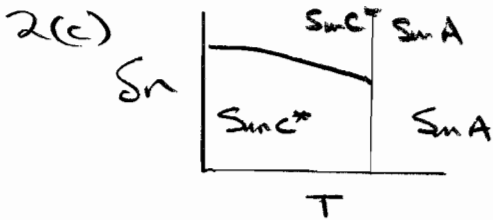
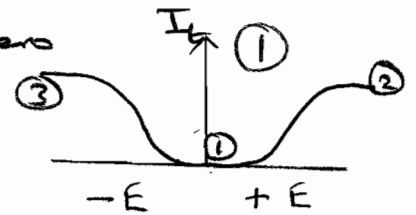


Here the off state has P from each layer cancelling the next layer and on application of a $+E$ or $-E$ switches half of the layer in turn.

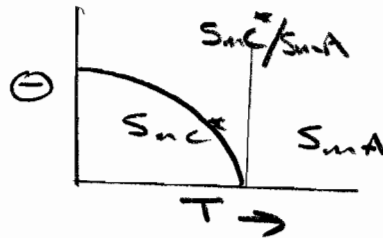
thus leading to a 3 state switch.



The optimum tilt is then $+45^\circ$ or -45° and the device switches around the zero field 'off' state. Polariser aligned parallel to the layer normal.



n varies slowly as the orientational order parameter varies.



Θ follows a Curie Weiss dependency and drops to zero at the transition.

$$I_t = I_0 \sin^2 4\Theta \sin^2 \left(\pi \frac{\delta n d}{\lambda} \right)$$

Optimum values of $4\Theta = 90^\circ$ i.e. tilt angle $\Theta = 22.5^\circ$ and one polariser aligned parallel to \hat{n} at this angle.

For a $\lambda/2$ plate Phase retardation $= \pi$

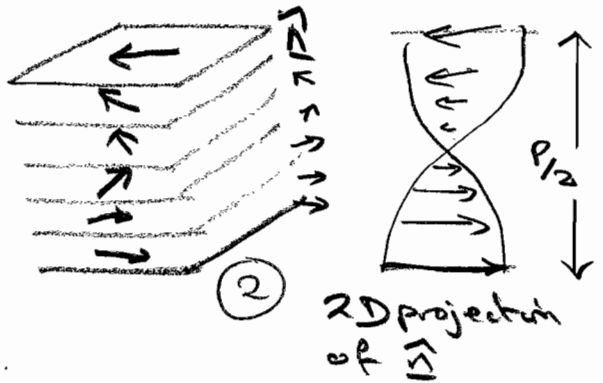
$$\pi = \pi \frac{\delta n d}{\lambda} = \pi \rightarrow \delta n = \frac{\lambda}{2} = \frac{600 \times 10^{-9}}{3 \times 10^{-6}}$$

$$\delta n = \underline{\underline{0.2}}$$

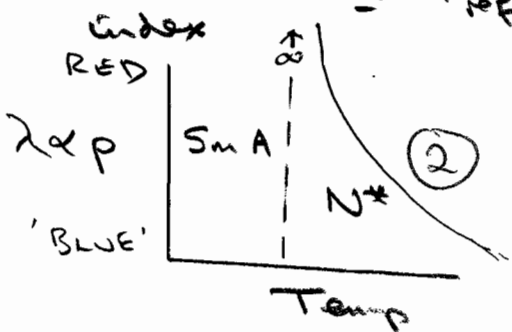
Q3(a)

In chiral nematic phase molecules arranged in nematic like layers the director of which is rotated w.r.t. each adjacent layer i.e. the director (in plane) traces out a helix of pitch p .

chiral nematic 'pseudo' layer



If $p \approx \lambda$ then the layers selectively reflect light through 'Bragg' like interference i.e. constructive interference from layers with like \vec{n} . $\lambda_{ref} = \bar{n} p$ where \bar{n} is the mean refractive index



For such materials, as $N^* \rightarrow SmA$ transition is approached the pitch diverges to ∞ due to the second order phase transition ($p = \infty$ in SmA phase)

\therefore the reflected colour = fct. Since the and since λ may be chosen to be anywhere in the visible spectrum the colour change (blue to red) makes an excellent thermal sensor as T is reduced. Sensitive over $0.1^\circ C$ to $50^\circ C$ and reflected spectra may be resolved on the nm level. Hence $\Delta\lambda$ is very sensitive to ΔT .

embossed or photolithographic voids filled with N^* material



black background to absorb non reflected light

The N^* material is aligned in a planar or grandjean texture to give maximum reflection at normal incidence.

Could use 'double' device to reflect L Hand R H circular polarisations.

(2) $\lambda(\theta) = \bar{n} p \cos \theta$

3(b). Reflecting mirror in laser cavity

therefore assume normal incidence

$$\lambda_{\text{peak}} = \bar{n} \cdot p \quad \text{--- (1)}$$

\bar{n} ← mean ref index
 p ← pitch of helix

$$\bar{n} = \frac{1}{2}(n_{11} + n_{22}) \quad \Delta n = n_{11} - n_{22}$$

Differentiate (1)

$$\therefore \Delta \lambda = \Delta n \cdot p$$

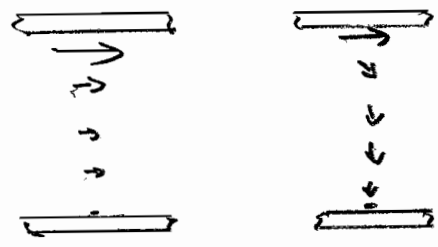
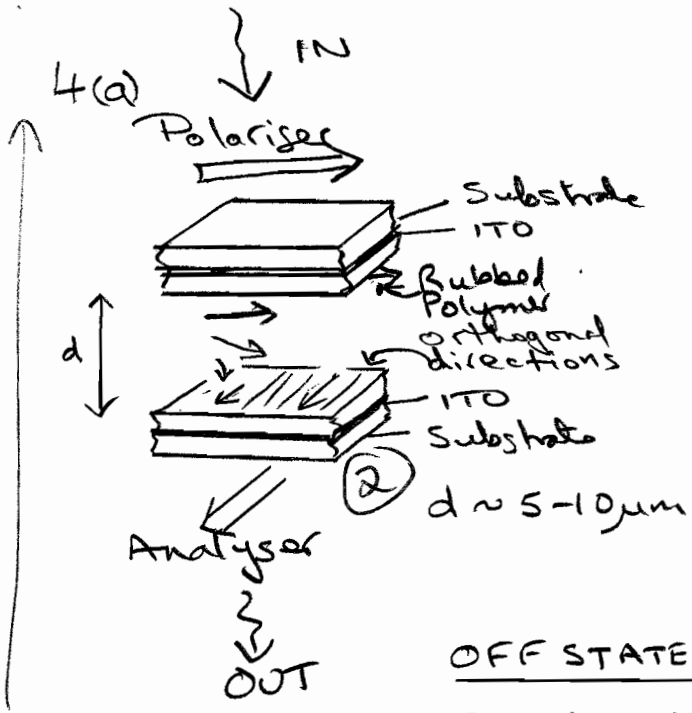
$$\text{or } \frac{\Delta \lambda}{\lambda_p} = \frac{\Delta n}{\bar{n}} \quad \text{(1)} \quad \Delta \lambda = \frac{\Delta n \lambda_p}{\bar{n}}$$

$$\lambda_p = 1.5 \times 300 \times 10^{-9} = 450 \text{ nm} \quad \text{(2)}$$

$$\Delta \lambda = \frac{450 \times 10^{-9} \times 0.03}{1.5}$$

$$= \underline{\underline{9 \text{ nm}}} \quad \text{(2)}$$

Polarisation state will be circular with same handedness as the chiral helix. (2)



(a) Bright 90° twist (b) Dark homeotropic

OFF STATE (BRIGHT)

Director alignment twisted by $\frac{1}{4}$ turn by orthogonal surface alignment agent (polymer).

① Incoming light polarised in alignment direction. + the helix $\frac{1}{4}$ turn waveguides the polarisation to twist by 90°. The output light is then polarised parallel to the analyser to give a transmissive or BRIGHT state. ②

ON STATE Application of $V > V_c$ (V_c = threshold for distortion of alignment) gives field induced homeotropic alignment i.e. the helix is destroyed and the waveguiding is lost. ∴ the Polarisation is not rotated and the light is polarised orthogonal to the analyser to give a dark state. ②

On removal of the field the surface forces restore the original twisted or off state. This surface energy is much less than V_c so the process is relatively slow.

$$V_c = \pi \sqrt{\frac{k_{11} + \frac{1}{4}(k_{33} - 2k_{22})}{\Delta \epsilon \epsilon_0}} \quad \text{where } k_{11}, k_{22}, k_{33} \text{ are the splay, twist and bend elastic constants}$$

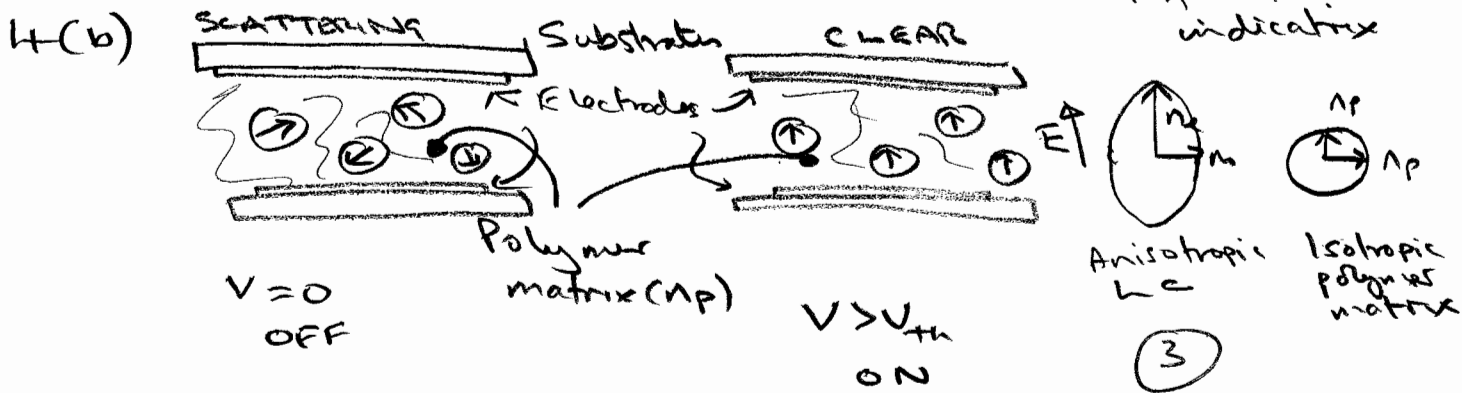
$\Delta \epsilon$ = relative dielectric anisotropy

$$\tau_{on} = \frac{\eta d^2}{\Delta \epsilon V^2 - k \pi^2} \quad \text{①} \quad \tau_{off} = \frac{\eta d^2}{k \pi^2} \quad \text{①}$$

η is a bulk viscosity \approx twist viscosity, V = Applied voltage & d = cell thickness

cont. inv. ↓

4(a) cont. In a dual frequency material a mixture is used with $\Delta\epsilon > 0$ at low frequencies and $\Delta\epsilon < 0$ at high frequencies thus it is possible by switching frequencies to drive the cell 'off' to speed up the τ_{off} (1)



(4) Droplets of LC suspended in isotropic polymer matrix with ref. index n_p equal in all directions. The LC is birefringent i.e. $n_e = n_o = n_o$ but chosen s.t. $n_o = n_p$.

In OFF state LC director pattern is random \therefore refractive index mismatch at interface (Snell's law) \Rightarrow reflection + refraction \Rightarrow SCATTERING

In ON state ($V > V_{th}$) LC director aligns along E and since $n_o = n_p$ at normal incidence the refractive indices match & there is no scattering \therefore CLEAR state. (NB No polarisation) (2)

off axis light would give some mismatch and haze.

OPTIMISATION (5)

- Droplet size chosen to maximise scattering (i.e. $d \approx \lambda$)

However small droplets give faster off time due to surface interactions & forces but lower scattering whilst larger droplets give more scattering but slower response

- V_{th} is higher for small droplets, lower for large and a dispersion in sizes gives a broad threshold curve \therefore choose uniform size.

- Use materials with large n_e w.r.t. $n_o \rightarrow$ better interface scattering
- Add black dyes to optimise contrast i.e. scattering and absorption in off state but neither in on state if dichroic dye

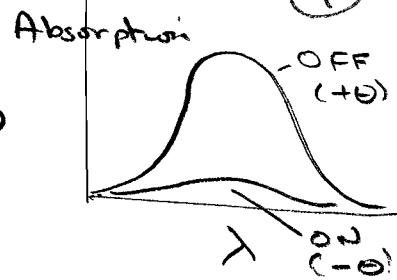
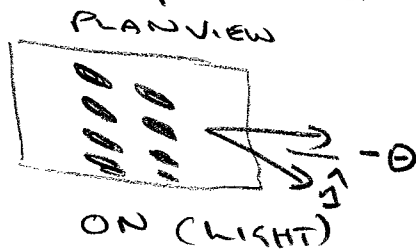
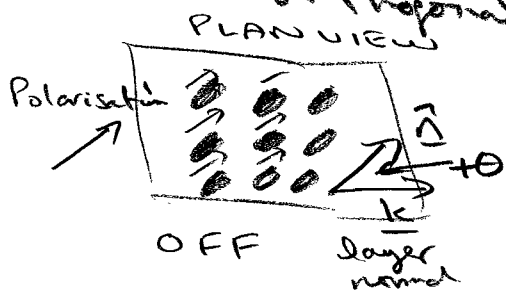
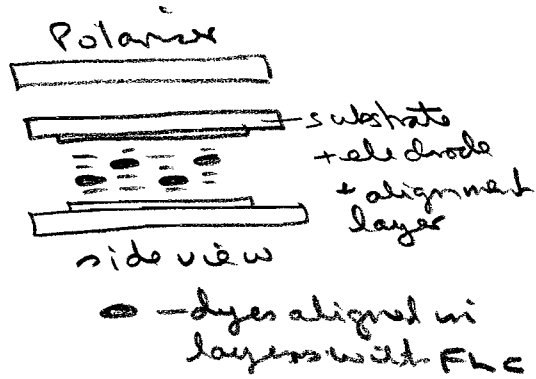
- Minimise field losses in isotropic polymer by improving ϵ & ρ .

Q 5(a) In dye guest host effect

the dye co-aligns with the ferroelectric host so that for a dichroic dye the major absorption axis follows \hat{n} the director. To produce a device we

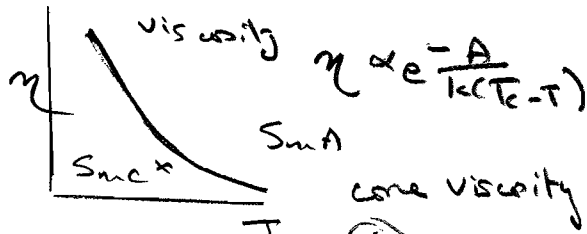
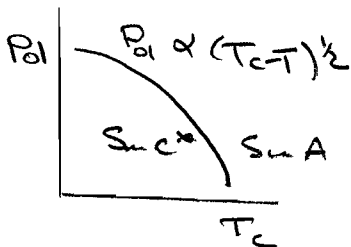
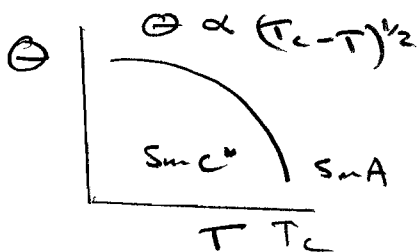
surface forces to align \hat{n} in the plane of the device so that in plan view the absorption axis switches from $+\theta$ to $-\theta$ in a surface stabilised device. So for light polarised along

the director direction there is a strong absorption or dark state (say along $+\theta$) when the field is reversed the dye precesses through 2θ to the bright state where the major absorption axis is orthogonal to the polarisation (LIGHT STATE)



(i) For a polariser free device two such cells are placed back to back to switch in opposite directions so that a dark state is obtained when the absorption axes are at 90° to each other and a light state is obtained when the axes are parallel ($\theta = 22.5^\circ$) or use in reflection mode with a waveplate + mirror

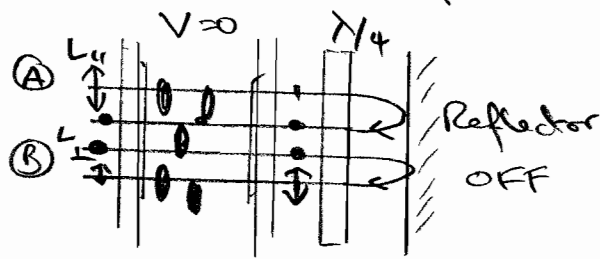
(ii) For a light emissive device use a fluorescent dye with a near uv dichroic absorption. Then in 'OFF' state the dye absorbs and fluoresces at longer visible wavelengths whilst in the 'ON' state the dye is rotated so that there is no absorption & hence no fluorescence $\theta = 45^\circ$



$\tau \propto \frac{\eta}{D^2}$

(4)

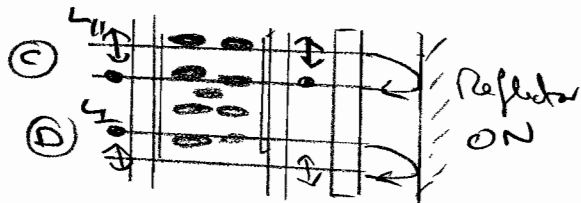
5(b) ~~Fredericksz transition~~ \therefore use a planar cell in incorporating dichroic dye. Dye co-aligns with the nematic director. Polarizer free is unpolarized light. Dye has anisotropic absorption (1)



$$S_{\parallel} - S_{\perp} = \Delta F$$



$\lambda/4$ plate matched to max of absorption spectrum



$v > v_{th}$
 $\lambda/4$ plate at 45° to dye axis (2)
 +ve dye
 +ve $\Delta \epsilon$

Consider off state and two components L_{\parallel} & L_{\perp} to director

For route (A) L_{\parallel} absorbed partially traversing dye to $\lambda/4$ plate, L_{\parallel} changed to circular polarisation by $\lambda/4$ plate to one handedness that is reversed on reflection. π phase change after reflection and passage thro $\lambda/4$ plate the weak component is rotated to L_{\perp} direction

and passes back out thro the device. For route (B) the L_{\perp} not absorbed at return after $\lambda/4$ plate polarised along the director \vec{n} (i.e. parallel to L_{\parallel}). This component is then absorbed by dye. Thus in OFF state all polarisations, L_{\parallel} & L_{\perp} are absorbed. In ON case L_{\parallel} & L_{\perp} are always in direction of S_{\perp} due to uniaxial symmetry. \therefore No absorption. (1)
 So for white light the OFF state is highly coloured (by subtraction) & the ON state is white, can use R.S.B dyes or complimentary colours.

By definition the Dichroic Ratio = $\frac{A_{\parallel}}{A_{\perp}} = \frac{1+2S}{1-S} = DR$ (2)

where S = order parameter.

A_{\parallel} = Absorption for planar alignment.

A_{\perp} = " " " on homeotropic state

$$\therefore 10 = \frac{1+2S}{1-S}$$

$$\Rightarrow \underline{\underline{S = 0.75}} \quad (1)$$