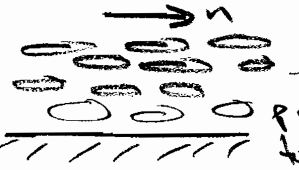
2007 IIB 4B17 Prof H Coles
hjc37@eng.cam.ac.uk

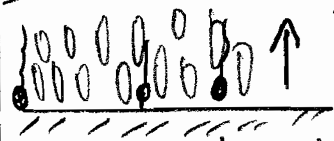
CRIB. (1)

Photonics of Molecular Materials – 4B17 – 2007

Q1(a) Nematic Phase has Orientational Order Only (1)
Short range forces – No correlation between
Centres of Mass (1). Long molecular axis
align on average in one direction ⇒ director $\underline{n}$ (1)
(6) Molecules free to slide / glide past each other
Local directors extend over 1–10 μm ⇒ domains (1)

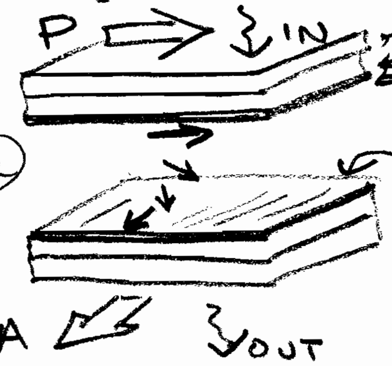


PLANAR (1)
– Surface aligned polymers rubbed to give axial alignment or microgrooves
PLANAR

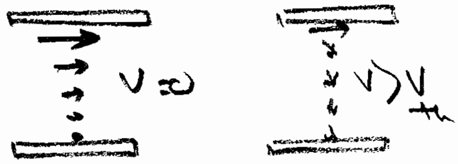


(1) Homeotropic
Produced by surfactants with polar head groups & alkyl chains into the bulk (or SiOx evaporation)

(b) Twisted Nematic Device



(2)



(a) Bright (b) Dark

(6) 'OFF' state alignment twisted by 1/4 turn by orthogonal surface alignment. Incoming light polarised in alignment direction. Helix 1/4 turn waveguides the polarisation to twist by 90°. Output light ∥ to Analyser ⇒ Transmission or Bright state (2)
ON state Application of $V > V_{th}$ (V_{th} to distort alignment near to surface) gives field induced Homeotropic alignment → Helix destroyed ∴ Waveguiding lost
∴ Polarisation NOT rotated and crossed with Analyser ⇒ Dark State (2)
Removal of Field and Planar Surface Alignment restores twist

1) < Surface Alignment → Threshold Voltage or Energy to overcome. Defines 1) OFF State and Helix, 2) Provides threshold for multiplexing. Restores Helix after field removal. (1)

(1)

(1) c). Response time $\tau = \frac{\gamma V_c^2 d^2}{(V^2 - V_{th}^2) k_{22}}$ or $\frac{\gamma d^2}{\Delta\epsilon V^2 - k\pi^2}$ (2)
continued.

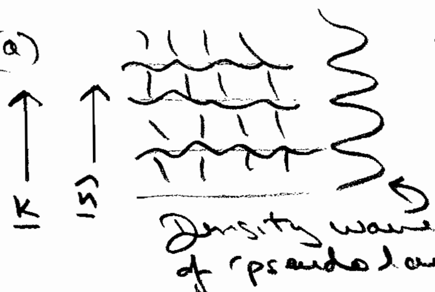
γ = twist viscosity
V_{TH} = Threshold Volts , k_{22} = twist elastic constant
d = display cell thickness | All under Mauguin limit.
Ideally $V \gg V_{th}$ to improve response time, high k_{22}
low γ, V_{th}, d. (2)

Delay time – due to the helix in centre of device flexing as V applied but not destroyed helix. ie. mid plane tilt – Switch observed as helix destroyed. Hence transmission switch delayed in time.

(7) Assume typical $\tau \sim 10ms$. (1)
T.V. has 25 Frames/sec or 40ms/frame
1028 lines ∴ ~ 38µs/line
or one frame (1)

Line by line addressing requires ~ 38µs per line and columns to be driven (1280) at same time which implies complex waveform addressing scheme. Hence prefer active matrix or TFT devices at each pixel (as effectively switching capacitors. (1)

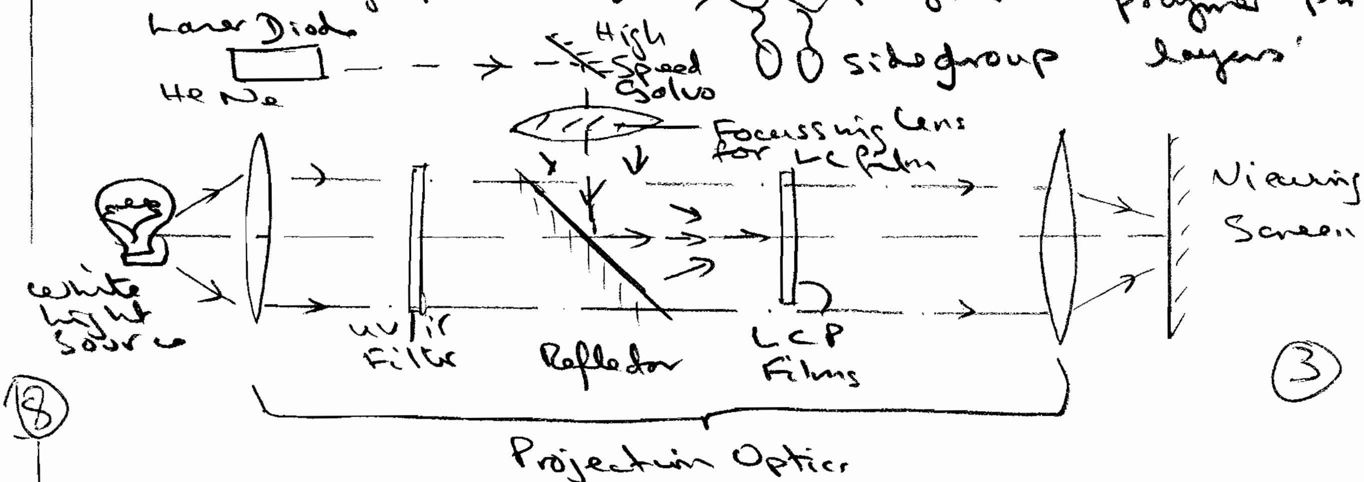
(2) (a)



Smectic (A) layer like structure
density waves (still or not).
In SmA $\underline{n} \parallel \underline{k}$. (1)
Layer "thickness" ~ 1 pendant group

polymer
sidegroup

polymer 'pins' layers'

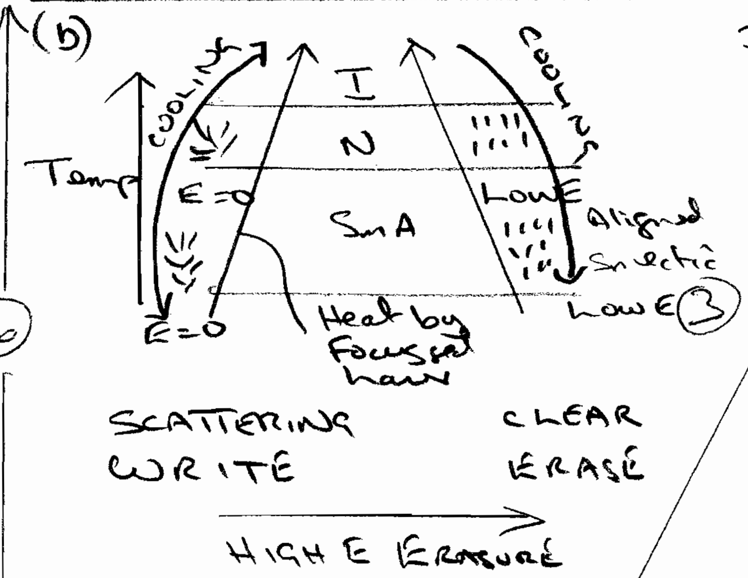


(3)

(8)

White light source (450–700nm); UV-IR filter to reduce unwanted degradation; Projection Optics to image LCP film on screen – Resolution near diffraction limit (hence white unpolarised light) ∴ tracks ~ 1–2μm. LCP film ~ 5–10μm thick includes blue dye (red absorbing) to increase write sensitivity / HeNe or Laser Diode as write source (~680nm) / Galvo deflector (high speed x-y motion) to give line by line scan ~ 2048 × 1024 + write times ~ 1–2s. (4)

(b)



(3)

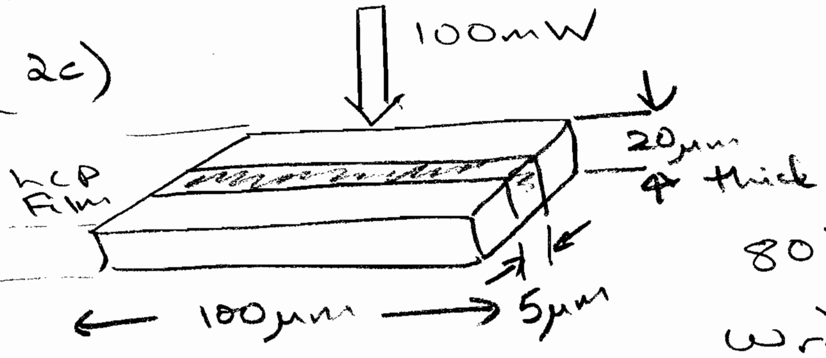
I = Isotropic Random
N = Nematic (Orientational Order)
S = Smectic (Ordered Layers)

(6)

<u>No Field</u> – Focussed laser → local temperature jump to isotropic – Cools rapidly to give random scattering or OPAQUE state (1)

<u>LOW FIELD</u> – Same process but E(low) applied aligns (1) nematic homeotropic (clear) ⇒ TRANSMISSIVE STATE, 1–10V/μm; E too low to distort smectic BUT total erasure for E ~ 100V/μm

2c)



80% Absorption

Write Speed = 5 m/s

$$\text{Write time} = \frac{\text{track length}}{\text{write speed}} = \frac{100 \times 10^{-6} \ (m)}{5 \ (m.s^{-1})}$$

$$= \underline{20 \mu s}.$$ (2)

(i) Therefore Pulse width at least $\overline{20 \mu s}$

(ii) Temperature Increase.

$$\text{Energy Absorbed} = \text{Power} \times \text{time}$$

$$= 100 \times 10^{-3} \times \frac{80}{100} \times 20 \times 10^{-6}$$

$$= \underline{1.6 \mu J}.$$ (2)

(6)

$$\text{Heat Energy Absorbed} = \Delta H = m.c_p.\Delta T$$

$$\text{or } \Delta T = \frac{\Delta H}{m c_p} = \frac{1.6 \times 10^{-6}}{\underbrace{120}_{\rho} \times \underbrace{100 \times 10^{-6} \times 5 \times 10^{-6} \times 20 \times 10^{-6}}_{V} \times \underbrace{60 \times 10^{3}}_{c_p}}$$

$m = \rho V$

$$= \underline{\underline{22 K}}.$$ (2)

③ (a) Chiral nematic (N*)
molecules in nematic like
layers – (one molecule thick
with director 'in plane"
Director traces out helix.

Planar – planes & ∴ molecules
parallel to substrate & $\hat{n}$ in plane
but ⊥r to $\underline{k}$ ③

<u>Reflection Properties</u>

⑧ (i) Constructive interference coupled with director fluctuation
→ narrow band of reflection colour.

(ii) Reflected λ follows "Bragg" law $\lambda = \bar{n} p$ for normal incidence
n = mean refractive index

(iii) Reflected light is circularly polarised same hand as helix rot^n

(iv) Opposite handedness transmitted. (50%)

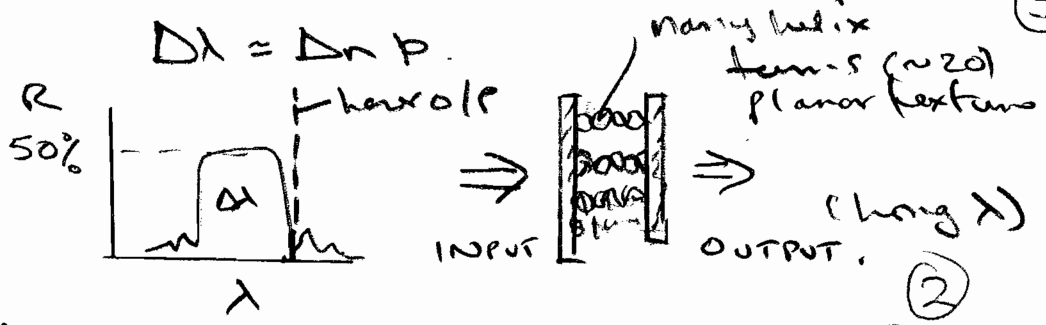
(v) For non normal incidence reflected light is elliptically polarised and $\lambda = \bar{n} p \cos\theta$ for θ = angle of incidence ⑤

<u>Resonator</u>

3(b)

$\Delta\lambda = \Delta n\, p$.

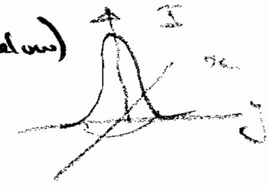
Transverse



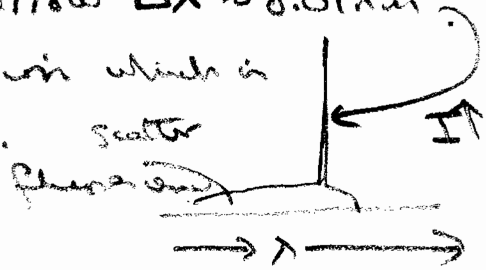
②

The N* phase sets up Photonic Band Gap for CP light for planar alignment.
Gain Medium add Fluorescent dye to N* phase (DCM) Pump with frequency doubled YAG laser (λ ~ 530nm). Choose dye that absorbs near 530nm. Upconversion to longer λ for fluorescence. Light internally reflected until infinite density of states at band edge and emission occurs (~ 600nm) [Dotted as shown] ②
Can give Energy level diagram for typical dye

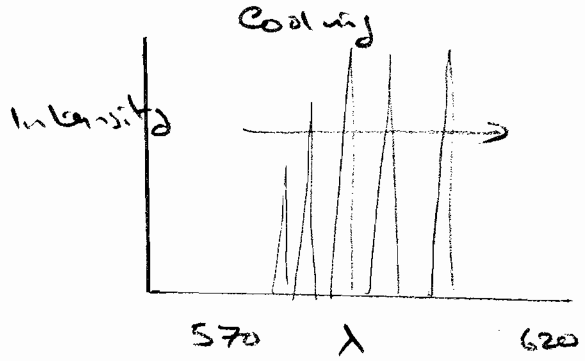
3bi Threshold & Slope Efficiency. (see below)
Beam profile ~ Gaussian (~ TEM_{00})

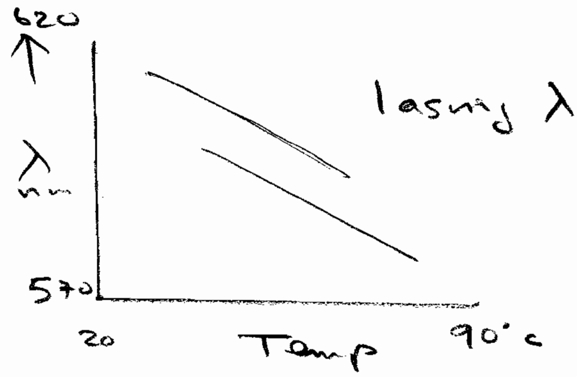


Directional, Coherent.
For well aligned planar film — narrow $\Delta\lambda \sim 0.01$nm.
∴ Differentiates from other emission which is broad band & multi directional.
Short ~ns pulse width ④
Efficiency ∝ ⟨S⟩.

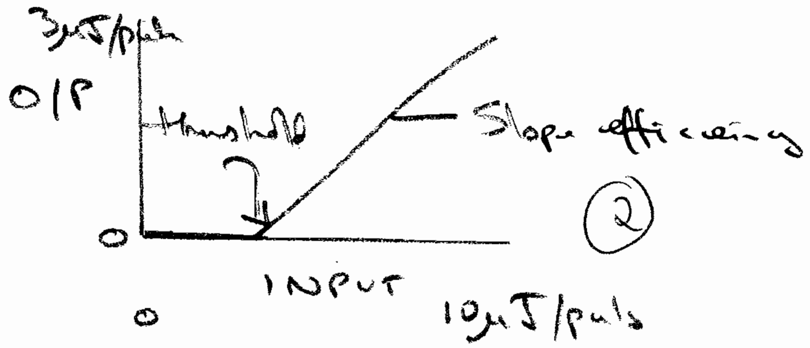


⑫





Can choose N* material in which p is a f(T) ②
then gradually change temp. Helix distorts and
(λ = np) starts to unwind ∴ sets up different
resonant conditions as shown. Pitch jumps at surface give different modes
[Can describe E field tuning



4(a)

$$F(P_s, T, E) = -EP_s + g_0 + \frac{g_2}{2} P_s^2 + \frac{g_4}{4} P_s^4 + \ldots \quad (1)$$

$g_n = f(T)$ g_0 independent of T

Thermal Equilibrium then $\left(\frac{\partial F}{\partial P}\right)_{\text{const } T} = 0$

$\therefore$ from (1) $0 = -E + g_2 P_s + g_4 P_s^3 + g_6 P_s^5$ —— (2)

(8)

For ferroelectric state $g_2 \to 0$ at T_0 & Assume $g_2 = \gamma(T - T_0)$ (2)

For second order transition g_4, g_6 positive but order $\to 0$ so ignore high order terms (2)

From (2) for $E = 0$

$$\gamma(T - T_0) P_s + g_4 P^3 = 0 \quad (2)$$

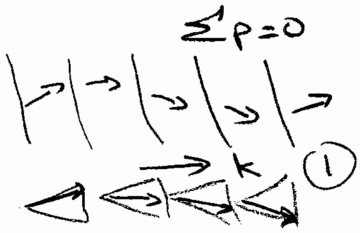
$\therefore P_s = 0$ or $P_s^2 = \frac{\gamma}{g_4}(T_0 - T)$ for $T < T_0$

(for $T > T_0$ $P_s = 0$)

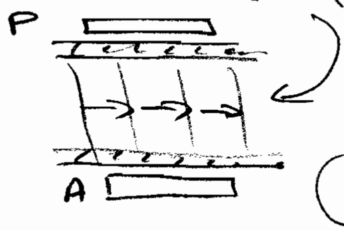
$\therefore T < T_0$ $|P_s| = \left(\frac{\gamma}{g_4}\right)^{1/2} (T_0 - T)^{1/2}$ (2)

where T_0 = Curie temperature.

(b) In chiral smectic C phase (SmC^*) molecules spiral in helix around layer normal (tilt in layer $= \Theta$). Surface Forces unwind helix into "bookshelf geometry SmC^*" to give two states + or − Θ in plan view.

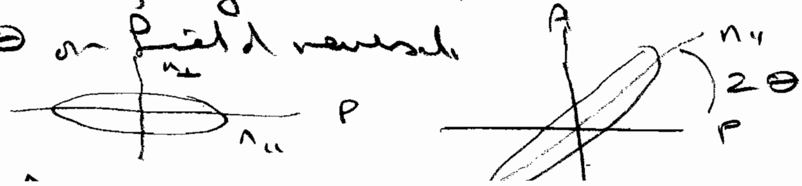


(1)



(2)

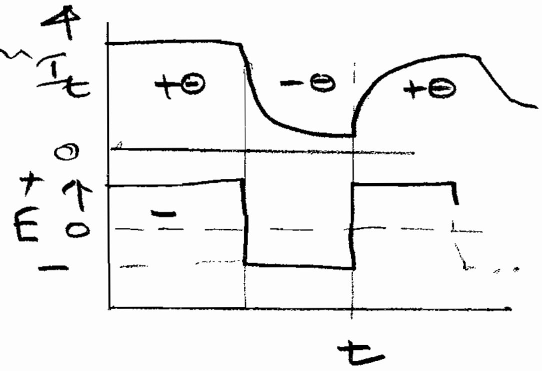
Molecules have $\Delta\varepsilon < 0$ $\therefore$ Application of E poles molecule to + or − Θ state. Since molecules are birefringent this rotates the indicatrix through 2Θ on field reversal.



Align P or A parallel to one switched state (1)

(6)

4(b) then



(2)

$\Delta\varepsilon = \varepsilon_{\parallel} - \varepsilon_{\perp} < 0$

$\Delta n = n_{\parallel} - n_{\perp} > 0$

Two stable states at +θ or −θ. Bistable device.

Transmission after 2θ switch as drawn.

(6)

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

Optimum value of $4\theta = 90°$ or $\theta = 22.5$ & PrA aligned parallel to + or − θ. (2)

a) λ/4 plate Phase $= \pi/2$ (linear → circular polarist)

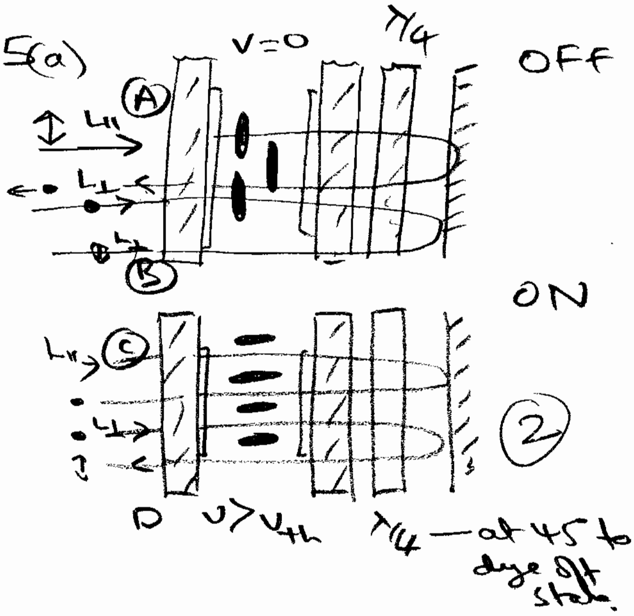
$\frac{\delta n \pi d}{\lambda} = \pi/2$ or $\delta n = \frac{600 \times 10^{-6}}{2 \times 2 \times 10^{-6}}$

$\delta n = 0.15$ (2)

b) λ/2 plate → linear → linear phase $= \pi$

$\therefore \delta n = 0.30$ (2)

5(a)



In DGH absorbing dyes marked ▬. +ve dyes ∴ $\varepsilon_\parallel > \varepsilon_\perp$, $\varepsilon_\perp \simeq 0$

Incorporated into N matrix so that absorption axis follows $\hat{n}$

→ matches λ peak absorption

In OFF state PLANAR alignment. For unpolarised light consider $L_\parallel$ & $L_\perp$ to absorption direction.

(8) Route (A) – $L_\parallel$ absorbed traversing cell along ($\varepsilon_\perp$) transmitted near λ/4 plate → Circular Polarisation of one handedness reversed on reflection (π phase change). After reflection & passage through λ/4 again passes back out (2)

(B) $L_\perp$ to $\hat{n}$ $L_\perp$ not absorbed on initial pass – follows same process as (A) but reenters N with polarisation rotated by 90° (i.e. ⊥ to $\hat{n}$ or $L_\parallel$) after λ/4 plate ∴ Absorption by planar dye. Thus in OFF state All polarisations absorbed → Dark state. (2)

(C) & (D) In ON state $L_\parallel$ & $L_\perp$ always in direction of $\varepsilon_\perp$ ∴ No absorption.

For white incident light the OFF state is coloured (1) (by 'subtraction') and on state is white. Patterned electrodes → characters (Can use RGB or R+G+B dyes)

Wavelength specific because of λ/4 plate & spectra of dye. (1)

5(b) $\lambda_{peak} = 550nm$

$DR = 15:1$

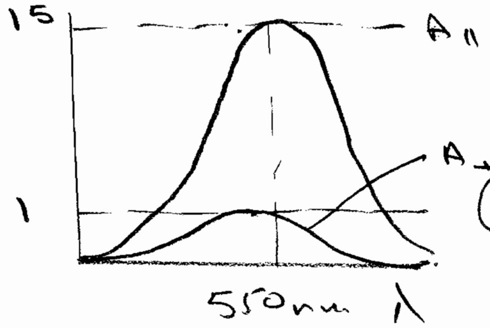
Dichroic Ratio $= \dfrac{Abs_{\parallel}}{Abs_{\perp}} = \dfrac{1+2S}{1-S} = DR$ (2)

where S = Order Parameter

6

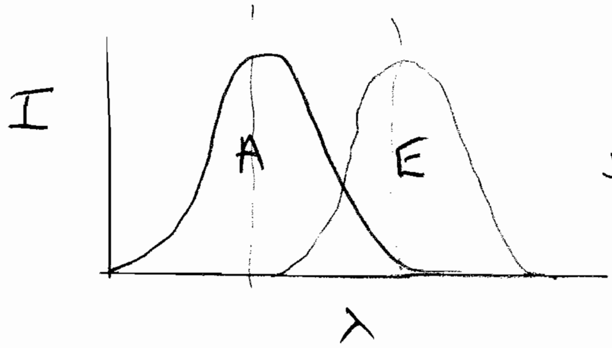
$\therefore 15 = \dfrac{1+2S}{1-S}$

$\rightarrow \underline{S = 0.82}$ (2)



(2)

5(c)



Use fluorescent dye to emit at longer λ

(Blue / uv absorption (A) & Green / Red emission

6

Can use similar construction to part (a) except off state would be emissive & on state black / blue. Fluorescence emitted at all angles.

Parameters of importance λ_A, λ_E, Order Parameter of N & of dye.

Conversion efficiency.

Response time,

Applied Field,

Elastic Constants etc

For max intensity maximise absorption of all polarisation ∴ White Taylor or scattering "off" state. [focal conic]