 2005 IIB 4B17 Prof H Coles hjc37@eng.cam.ac.uk

Exam Cribs — marks ex 20 in red

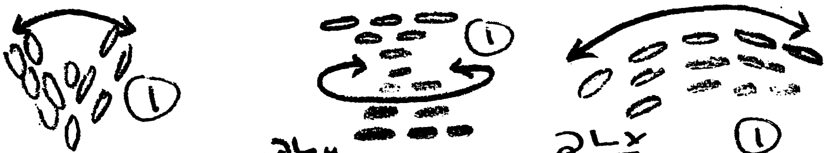
Q1 • Start with continuum theory for director field (nematic) (i.e. not molecular). Frank continuum Free energy equation (1)

where $F = \frac{1}{2}\left[k_{11}(\mathrm{div}\,\underline{n})^2 + k_{22}(\underline{n}\cdot\mathrm{curl}\,\underline{n})^2 + k_{33}(\underline{n}\wedge\mathrm{curl}\,\underline{n})^2\right]$

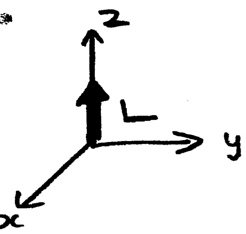
SPLAY — TWIST — BEND

$\underline{n}$ = director = $\underline{n}$

Deformation



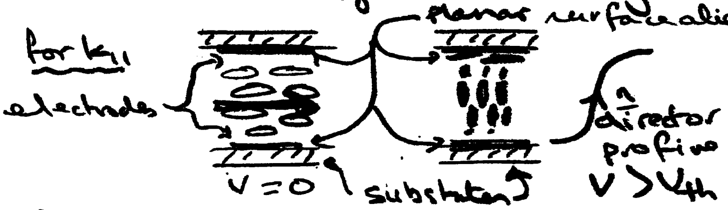
Splay: $\frac{\partial L_x}{\partial y}$, $\frac{\partial L_y}{\partial y}$ (1) — Twist: $-\frac{\partial L_y}{\partial x}$, $\frac{\partial L_x}{\partial y}$ (1) — Bend: $\frac{\partial L_x}{\partial z}$, $\frac{\partial L_y}{\partial z}$ (1)



where $\underline{L}$ is a unit vector describing local director.

A Freedericksz transition occurs when an external voltage (energy) is applied to induce a (splay, twist or bend) director deformation to overcome align induced by surface forces. (8)

for k_{11}

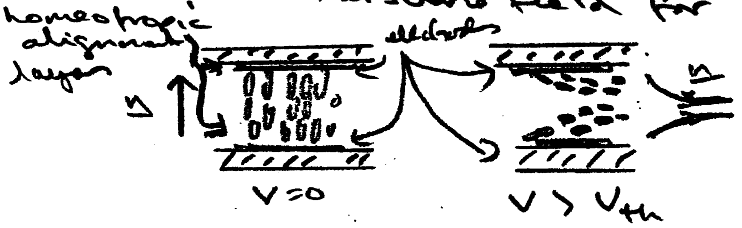


i.e. a splay Freedericksz Transition (1)

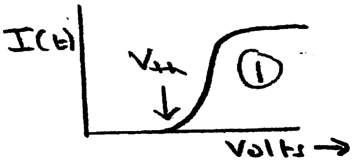
$V_{th} = \pi\sqrt{\frac{k_{11}}{\varepsilon_0 \Delta\varepsilon}}$ planar to homeotropic for $\Delta\varepsilon > 0$

for k_{22} use orthogonal alignment layers i.e. a twisted nematic cell and in plane field ($\underline{E}$ or $\underline{H}$) (1)

for k_{33} use homeotropic alignment and in plane field (for $\Delta\varepsilon > 0$) or transverse field for $\Delta\varepsilon < 0$. (1)

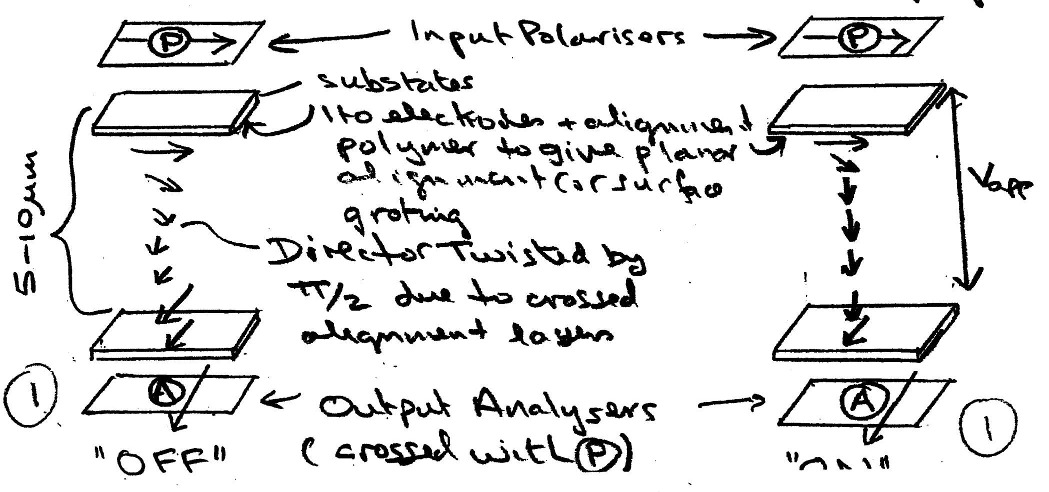


$V_{th} = \pi\sqrt{\frac{k_{33}}{\varepsilon_0 \Delta\varepsilon}}$



(1)

In all three experiments apply gradually increasing field and measure optical change through crossed polarisers (all materials birefringent i.e. $\Delta n > 0$)



$V_{app} > V_{th}$ gives homeotropic alignment except at immediate surface i.e. no bulk twist

(1) (1) (description)

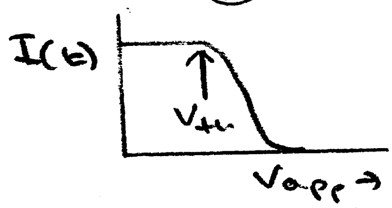
Pg 2

Q 1 Continued.

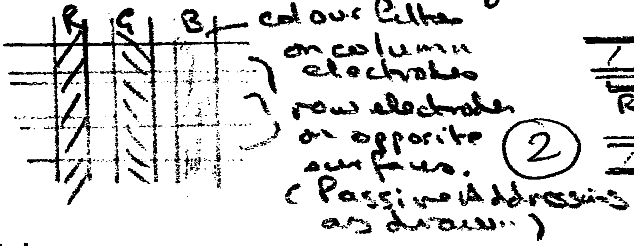
TN cell based on light polarisation guiding down the twisted structure induced using "crossed" alignment directions (+ chiral additive to ensure 1/4 twist to minimise optical bounce). Thus the light leaving the LC cell is polarised in the same direction as the Analyser ⇒ Transmission.

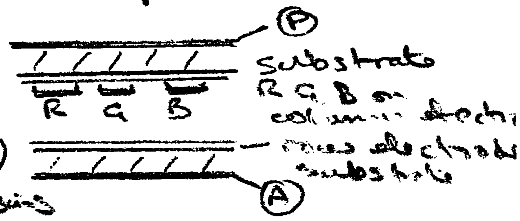
(6) For $V_{app} > V_{th}$ and $\Delta\varepsilon > 0$ the helix unwinds to homeotropic alignment. Therefore Twist ($\pi/2$) dissappears and polarisation guiding is lost.
∴ the optical polarisation of the input light (P) is maintained. Therefore (P) and (A) are crossed leading to extinction of light ie dark state. (2)

On removal of Vapp the surface pinned molecules and chiral twist returns the directors back to the $\pi/2$ twist or original "off" state

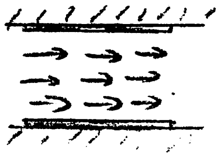


To construct colour display use Red, Green, Blue filters at each pixel - normally arranged in stripes - Trinitron Mode

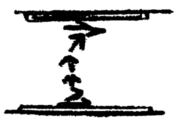




Problem



(1)



V = 0 | V_{th} = 1 V

(6) Planar Sample | Deforms to Homeotropic

Planar Sample, $\Delta\varepsilon > 0$

∴ Splay (1) Freedericksz Transition

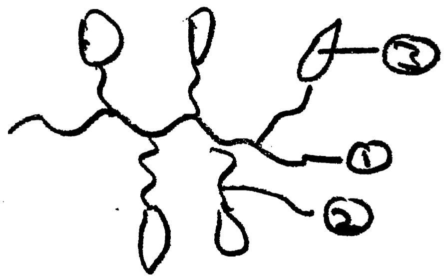
$$V_{th} = \pi \left[\frac{k_{11}}{\varepsilon_0 \Delta\varepsilon} \right]^{1/2} \quad (1)$$

$$\text{or } k_{11} = \frac{V_{th}^2 \cdot \varepsilon_0 \cdot \Delta\varepsilon}{\pi^2} \quad (1)$$

$$= \frac{1 \times 8.854 \times 10^{-12} \times 12}{\pi^2}$$

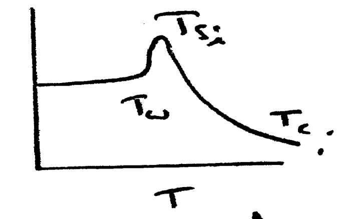
$$k_{11} = 10.8 \times 10^{-12}\ N \quad (2)$$

(Q2) Side Chain Polymer LC composed of semi flexible backbone ① linked via spacers ② to liquid crystal functional group ③

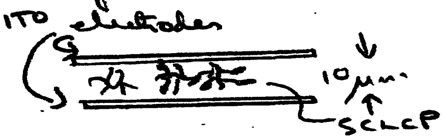


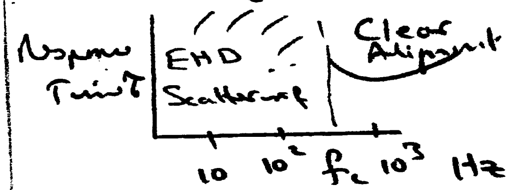
For optical data storage one needs a polymer capable of giving optical contrast between two alignment states that are well controlled. (4)

Smectic A polymer with high viscosity storage at T_w or T_g (glass)



On state clear - formed by heating
(12) into isotropic phase and rapid quenching (or cooling). Heat local regions and allow to cool slowly i.e. normally to give scattering domains. Electric fields can be applied equally during the heating process to realign clear (high f) or scattering (low f) i.e.



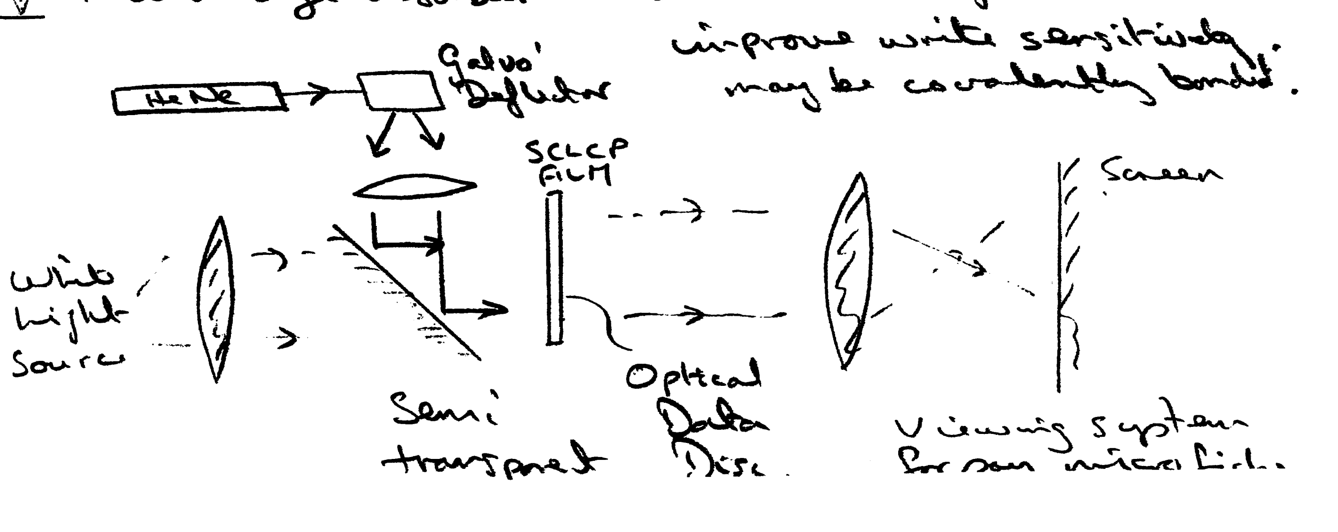


At low frequencies ionic turbulence at high frequencies dielectric alignment

The turbulence leads to random local directors and high scattering. The dielectric alignment (for $\Delta\varepsilon > 0$) leads to homeotropic or clear textures.

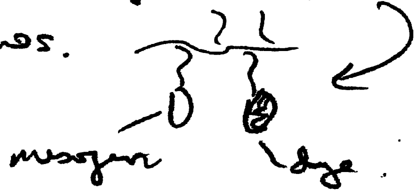
Local heating (as required) for diffraction limited 'spots'
∴ Possible to write, locally heat to erase and re write.

Include dye absorbent at laser wave length to improve write sensitivity. May be covalently bonded. (8)



(Pg4)

(8) Scan image onto SCLCP film (dye containing)
and read many times.



Laser temp jumps
write region to produce
image scanned using galvo deflector + explanation (6)

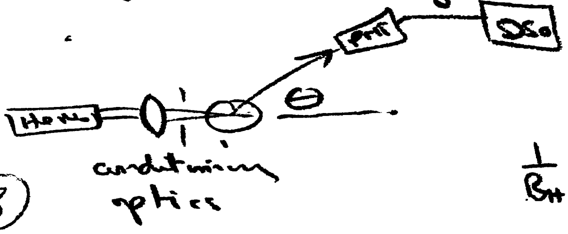
Typical parameters – laser powers ~100mW or densities
~10nJ/µm

write times ~ $1ms^{-1}$ Track dimensions $\lesssim$ 10µm.

Temp jump ~ 20°C (2)

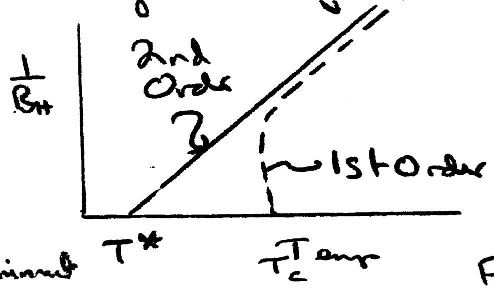
(Q3) For a weakly first order phase transition - smooth beha the there is a small discontinuity in the bulk properties such as density due to the heat of transition. This corresponds to an abrupt change in say order parameter or smectic lattice. i.e. $\langle S \rangle = 0$ in isotropic phase but jumps to $\sim 0.3-0.4$ in nematic phase. In a 2nd Order phase transition the macroscopic parameters change continuously on approaching the transition N → Smectic A for example. There is no latent heat of transition. (4)

Light scattering is a good technique here.



Depolarised signal indicates growth of order. (Plot $1/R_H$ Rayleigh signal

(8)



For 2nd Order $R_H \propto \frac{1}{(T-T^*)}$

Describe static or dynamic L.S. experiment

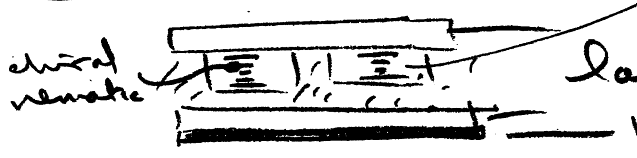
For 1st Order Discontinuity at Transition at T_c

[OR chiral Nematic → SmA] and 'Bragg' reflection

[Would also get bonus for writing out Landau expansion etc]

Couple with Scanning Calorimeter to confirm 1st (weak) or 2nd Order (1)

Construction

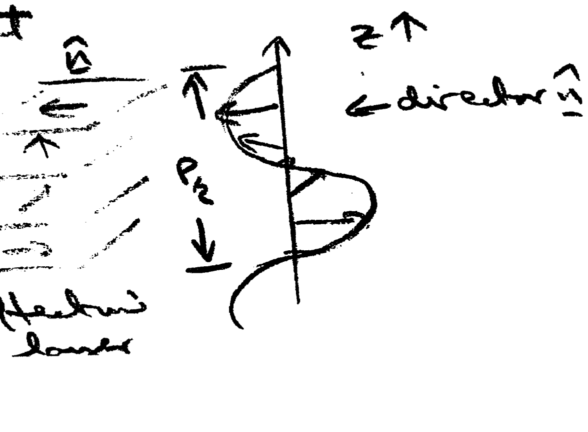


encapsulated regions with planar surface alignment

laminated polymer sheets,

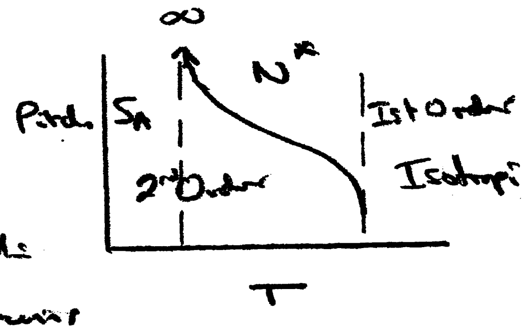
black backing to absorb non reflected and scattered light (4)

Micro encapsulated regions ensure planar alignment so that the chiral nematic director spirals in a controlled direction (3)



(P06)

(3) continued



In thermometric devices based on chiral nematic phase N* the circularly reflected wavelength
(12) λ depends on the "bragg" reflections from the director alignment and fluctuations. p chosen to give visible reflection and to be temp. dependent. On approaching S_A phase, through a 2nd order transition p diverges → ∞.
∴ Monitors temp through λ back reflected. Colour goes blue to red on decreasing Temp. Can control 'strength' of 2nd Order transition to limit range of colour play to ~0.1°C or 50°C (i.e. p goes from 300nm → 1μm). Spectrum resolved to 1nm ∴ very sensitive thermometric device. (calibration needed)

$$\lambda_{peak\ refl} = \bar{n}\,P$$

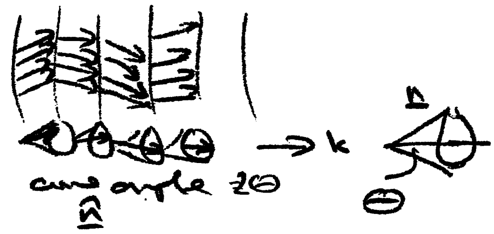
mean ref index ($\bar{n}$), P — helix pitch

$$\frac{\Delta\lambda}{\lambda_p} = \frac{\Delta n}{\bar{n}}$$

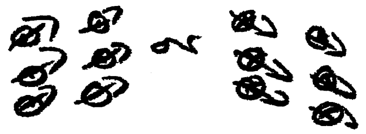
(5)

Pg 7

4 (a) Molecules in chiral smectic C^* phase trace out helicoidal director pattern layer to layer as the tilted director (Θ) spirals around $\underline{k}$.

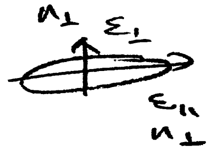


Constrained in a thin cell ($d \sim 1$-$2\mu m$) the surface forces unwind the helix and force the molecules to tilt up or down. (SSFLC).



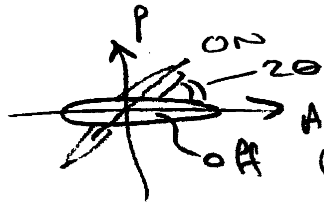
(4)

The molecule has $\Delta\varepsilon < 0$ at low frequencies due to transverse dipole

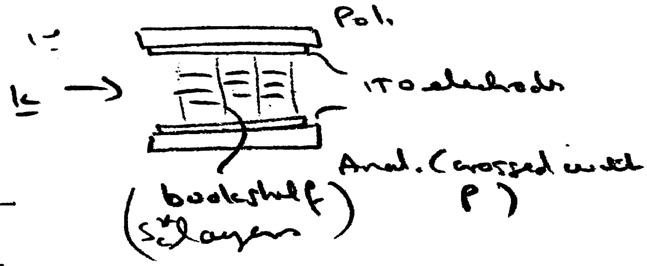


$\therefore \Delta\varepsilon = \varepsilon_{||} - \varepsilon_\perp$

(8) Application of a field into/out of plane gives either tilt up or down, field reversal reverses this effect. Molecules have birefringence Δn $\therefore$ Optics equivalent to rotating ellipsoid from $-\Theta$ to $+\Theta$. Place device between crossed polarisers & gives optical switching or shutter.

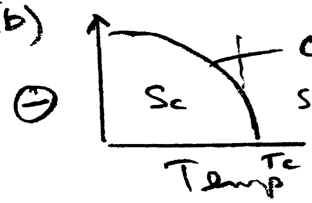


(4)



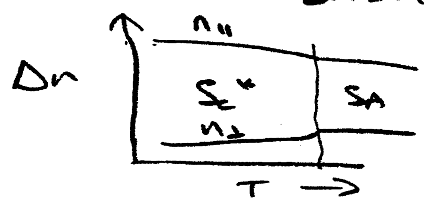
Two stable states $\pm\Theta$.

(b)



$\Theta \propto (T_c - T)^{\frac{1}{2}}$

$\Delta n = n_{||} - n_\perp$



v. small dependency due to increased order with decreasing T.
$\therefore \Delta n \sim$ constant.

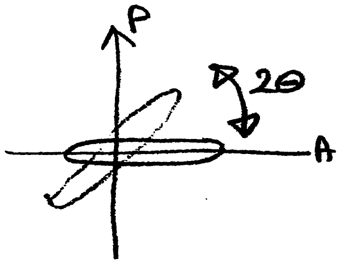
(4) $\therefore$ Tilt angle important for device. now external polarisers fixed during fabrication. If Θ varies then contrast decreases.
$-\Theta$ (say) set parallel to Analyser at fabrication. This fixed $\underline{k}$ relative to A.

$d \sim$ constant so any changes in Θ affect $\sin^2 4\Theta$ term (4)

" " " " δn -- $\sin^2 \left(\frac{\pi \delta n . d}{\lambda}\right)$ term

4 Continued

(c) In birefringence device 2 polarisers and optimum tilt angle = $22\frac{1}{2}°$



λ dispersion problems due to $\sin^2\left(\frac{\pi \Delta n . d}{\lambda}\right)$ term.

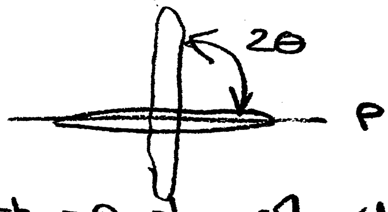
Low transmission

(8).

In dye guest host dye in solution in FLC host.

1 polariser & optimum tilt angle = 45°

Detail reqd

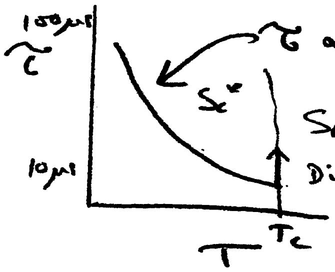


At −θ strong colour due to absorption moment ∥ to P

At +θ no absorption ∴ dye in FLC host acts as rotatable polariser. No λ dispersion problems just λ abs.

Higher brightness

(6)



$\tau \propto \eta \propto \exp\frac{-A}{k(T_c - T)}$

↑ viscosity

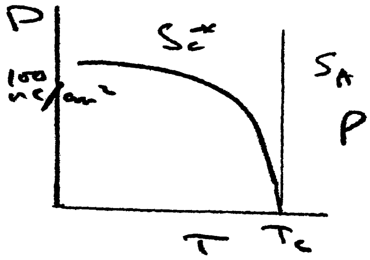
= 0 in S_A phase

Diff. process in S_A phase

$\tau \propto \frac{\eta}{PE}$

Important for device scheme

$E = V/d$.



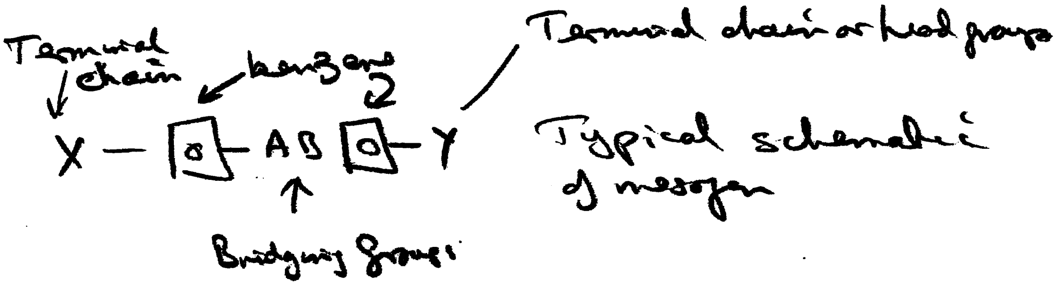
S_A

$P \propto (T_c - T)^{\frac{1}{2}}$

Important for device volts.

(2)

Q5 (a)

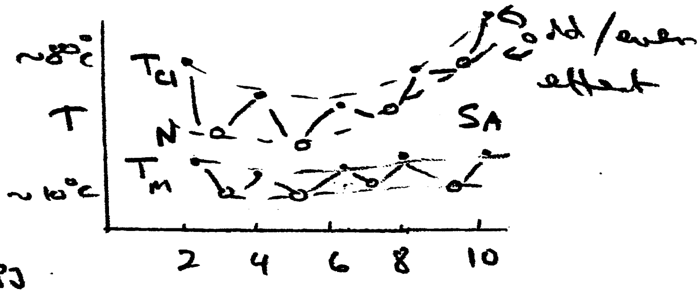


Typical schematic of mesogen

Change in X, Y, AB alter Geometrical, Electrical, Optical Polarisability and Phase Ranges. All will alter phase type.

(a) Increasing the chain length X, Y tends to lead to smectic phases above a critical length. For short chains the clearing points tend to decrease with increasing chain length.

Odd – even effect due to chain conformation increasing or decreasing shape, polarisability anisotropy



(10)

even } series follows their own smooth dependence
odd

SA rare with short chains. For long chains Tc → ≥100°c.

Increasing AB by further benzene rings increases the transition temps markedly

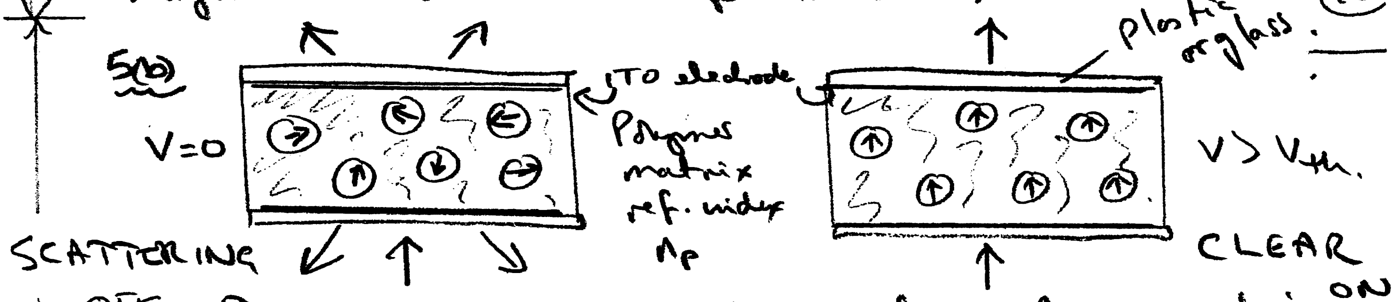
e.g. C_5H_{11}–[o]–[o]–CN C_5H_{11}–[o]–[o]–[o]–[o]–[o]–CN

Tc ~35°c   Tc ≅ 450°c.

Flexible AB reduces Tcl and tends to produce N phases
Rigid AB increases Tcl .. .. .. S or higher order phases.
Changing Polarity ↑ leads to ↑ transition temps.
Longer chains decrease crystallisation.

(10)

5(b)

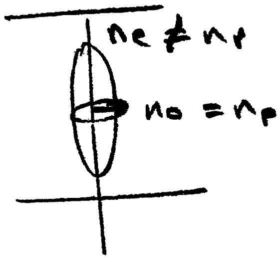


Droplets of nematic dispersed in polymer matrix

Q 5(b) continued

In Scattering 'OFF' state the nematic droplets are randomly aligned ∴ the indicatrix of the droplet and polymer mismatch and give scattering

In Clear 'ON' state the n_o of the l.c. droplet matches that of the polymer n_p so that normally incident light no longer experiences the mismatch.

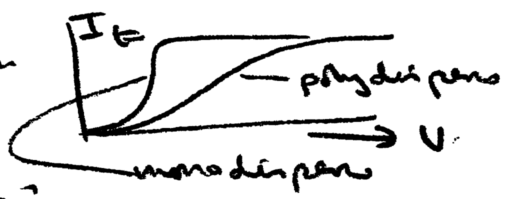


For other angles $n_p \neq f(n_o + n_e)$ ∴ scattering occurs increasingly with increasing viewing angle ⇒ Haze at wide angles.

10

a) PDLC's need high voltage due to different ε, ρ, σ of matrix + droplet ∴ match these to reduce voltage loss

b) Homogenise droplet size to sharpen threshold curve



(c) use anisotropic polymer matrix with same indicatrix as l.c. to match ellipsoids at all angles in ON state. OFF state will still give mismatch.

10