Lec 2

C3A - Display Technology

Peter Raynes

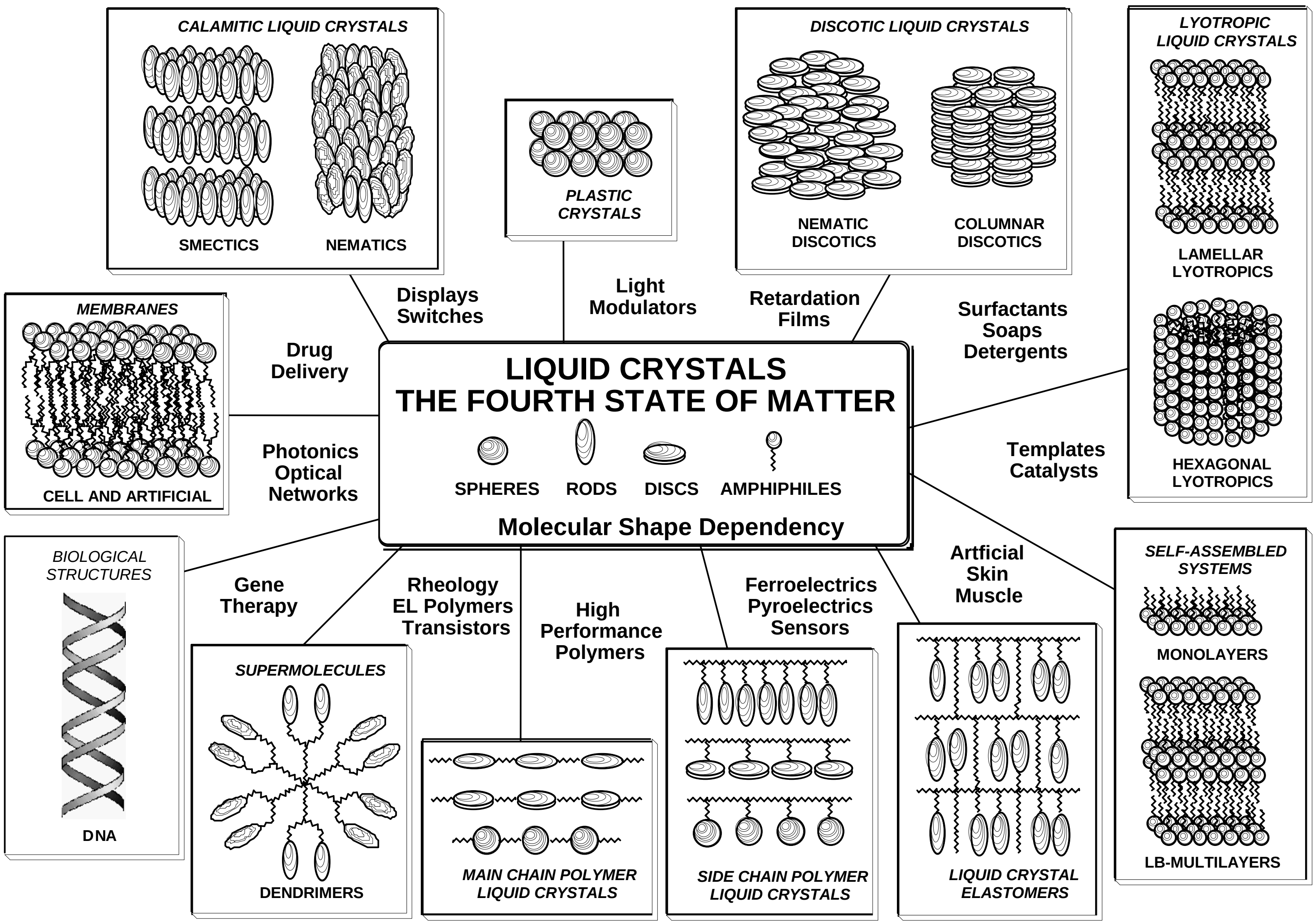
Lecture 2

- LC materials
  - The range of LC phases
  - Chemical structures of LC materials
  - Mixtures

- Physical properties
  - Spontaneous ordering
  - Anisotropic properties
  - Elastic constants

- Principles of LCDs
  - Surface alignment
  - Alignment by electric field
  - Competition between surfaces and electric field

Self-organising Soft Matter

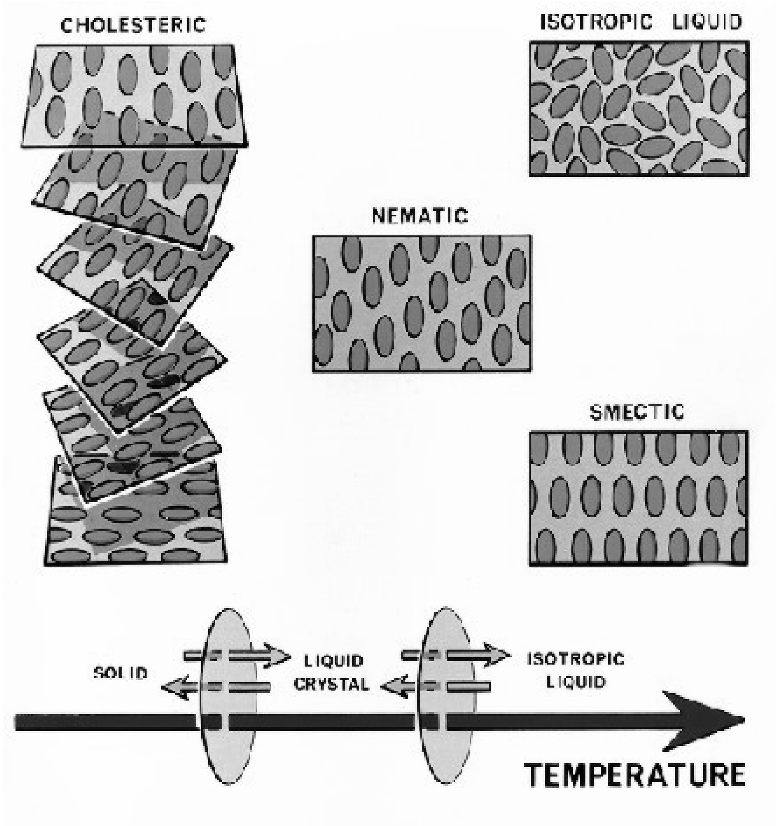


Liquid Crystal Phases

- Occurence
  - Thermotropic (temperature)
  - Lyotropic (concentration)
- Constituent molecules
  - Small molecules
  - Big molecules (polymers)
  - Rods (calamitic)
  - Disks (discotic)

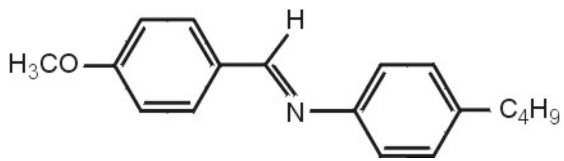
Thermotropic Calamitic LCs

- Finite temperature range
- Isotropic (I)
- Nematic (N)
  - Molecular axes ordered
  - No positional order
- Chiral Nematic (N*)
  - (Cholesteric)
  - Helical rotation (pitch)
- Smectic (S_A, S_B etc)
  - Positional order
  - Many smectic phases

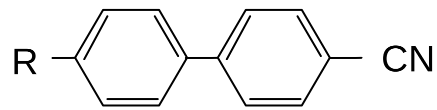


Typical LC Materials

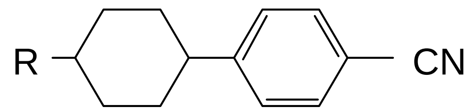
- MBBA
  - First room temperature material
  - 20 °C to 47 °C
  - Totally unstable



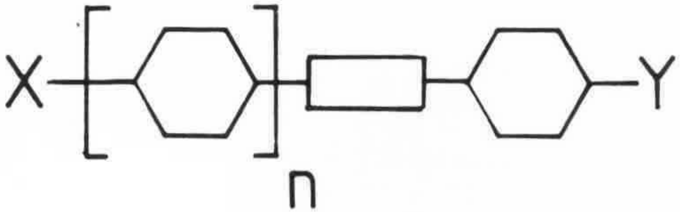
- Cyanobiphenyls (CB)
  - First useful LC material
  - Chemically & photochemically stable
  - Colourless
  - Excellent performance in displays
  - LC at room temperature but narrow range
    - eg 5CB (R = C_5 H_{11}- : 23 °C to 35 °C)

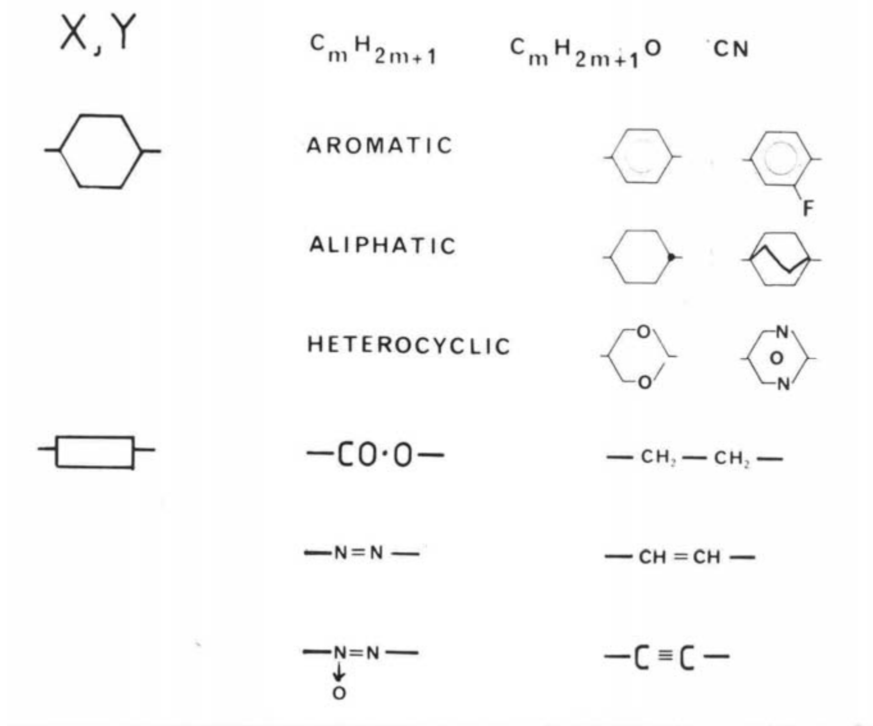


- Phenyl cyclohexanes (PCH)
  - Second useful LC
    - eg 5PCH (31 °C to 55 °C)



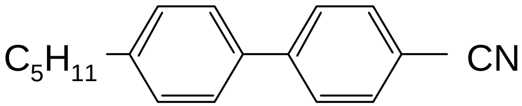
Summary of LC Chemistry





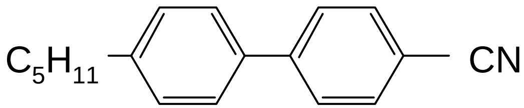
Wider Temperature Range

- Single compounds have narrow LC range

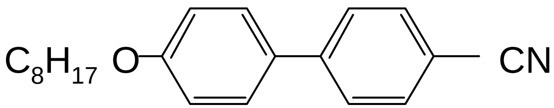


23°C to 35°C

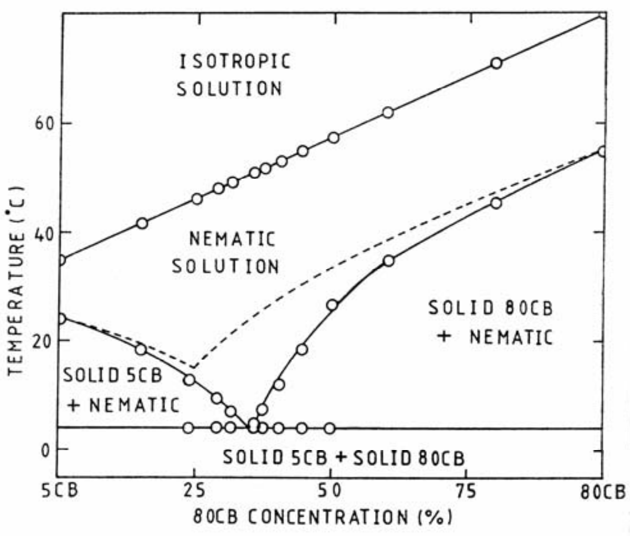
- Eutectic binary mixtures have broader LC range



5°C to 50°C



- Binary phase diagrams
  - Easy to find eutectic



Multi-component Eutectic Mixtures

- Must be close to eutectic composition

- Schroder - van Laar Equation $$\ln(X_i) = \frac{\Delta H_i}{R}\left(\frac{1}{T_i} - \frac{1}{T}\right)$$
  where:

ΔH_i	is latent heat of melting of i
T_i	is melting point of component i
R	gas constant

- Solubility equation $$\ln\left(c_i\right) = a_i\,T_i + b_i$$
  where:

c_i	is concentration (wt %) of i
T	is temp.,

  a_i and b_i are constants

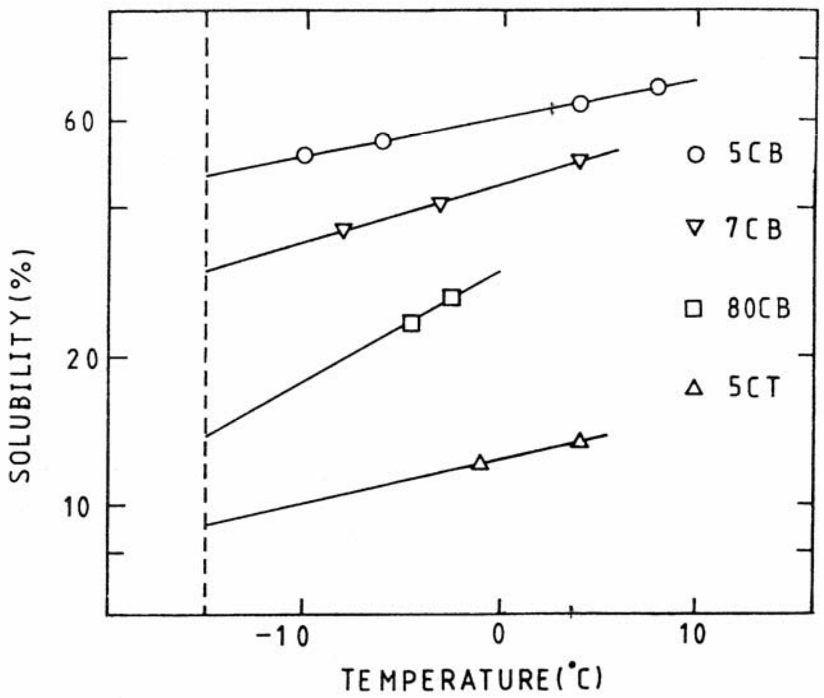
E7 Cyanobiphenyl Mixture

- 4 Components
  - 5CB 24 $\Rightarrow$ 35 °C
  - 7CB 30 $\Rightarrow$ 42 °C
  - 80CB 54 $\Rightarrow$ 80 °C
  - 5CT 130 $\Rightarrow$ 240 °C

- First generation
  - (-15 to -10) $\Rightarrow$ 60 °C

- Second Generation
  - (-15 to -13) $\Rightarrow$ 60 °C
  - Not wanted my manufacturer!

- Most common LC mixture in LCDs during 1975-1985



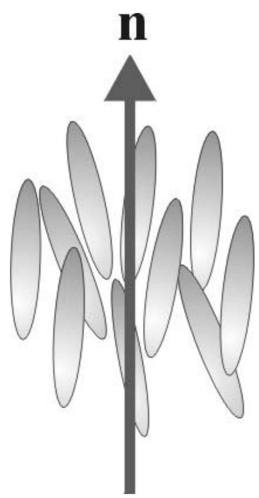
Spontaneous Ordering

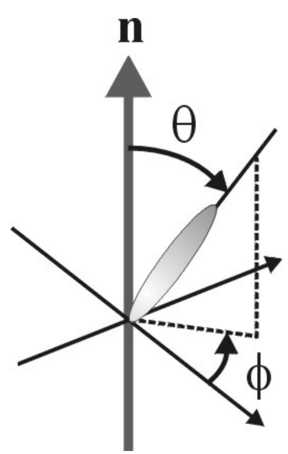
- Director **n** is a unit vector describing average orientation
- Average over:
  - time at a point in space
  - space at a snapshot in time
- Distribution function $f(\theta, \phi)\, d\Omega$:
  - probability of finding the molecule pointing in the small

    solid angle $d\Omega = \sin\theta\, d\theta\, d\phi$ around the direction (θ, ϕ)
- Nematics have cylindrical symmetry about **n**

  $\Rightarrow \quad f(\theta, \phi) = f(\theta)$
- **n** and **-n** are equivalent

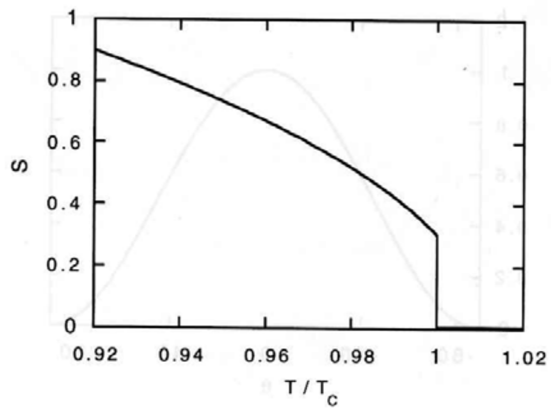
  $\Rightarrow \quad f(\theta) \equiv f(\theta - \pi)$ symmetry





Nematic Order Parameter

- Definition $$S = \frac{1}{2}\left\langle 3\cos^2\theta - 1 \right\rangle \equiv \frac{\int \frac{1}{2} f(\theta)\left(3\cos^2\theta - 1\right) d\Omega}{\int \frac{1}{2} f(\theta) d\Omega}$$
- Perfect order $f(\theta) = 1$ at $\theta = 0$ and $\theta = \pi$, but $f(\theta) = 0$ when $0 < \theta < \pi$
$$\Rightarrow \; S \sim \frac{1}{2}\left\langle 3\cos^2\pi - 1 \right\rangle = 1$$
- Total disorder $f(\theta) = 1$ for the whole range of angles $0 \le \theta \le \pi$
$$\Rightarrow \; S \sim \int_0^{2\pi} d\phi \int_0^{\pi} \frac{1}{2}\left(3\cos^2\theta - 1\right)\sin\theta \, d\theta = 0$$
- Typical nematic LC
  - S = 0.3 to 0.4 at N-I
  - Weakly second order
  - S increases as T lowered
  - S results in anisotropic properties

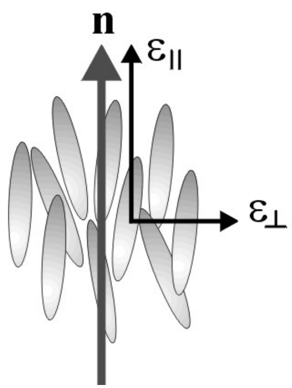


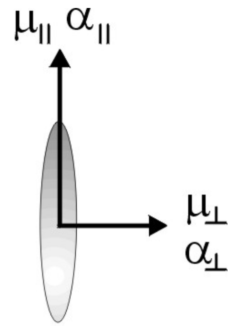
Anisotropic Physical Properties

- Dielectric permittivities
- Refractive indices
- Elastic constants
- Viscosities

Dielectric Permittivities - Molecular Contributions

- Two polarisation contributions:





1. Anisotropic molecular polarisabilities (α)
   $\Rightarrow$ contribute up to optical frequencies

2. Permanent molecular dipole moments (μ)
   $\Rightarrow$ field skews molecular distribution
   $\Rightarrow$ net polarisation
   $\Rightarrow$ contributes to permittivity
   but only at low frequencies

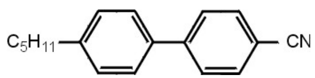
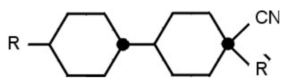
- Langevin theory for an isotropic fluid $\Rightarrow$ $P = N\mu^2 E / 3k_B T$

Dielectric Permittivities – Ordering Effects

- Theory extended to anisotropic fluids (LC) by Maier and Meier

defining $\Delta\varepsilon = \varepsilon_{\parallel} - \varepsilon_{\perp} \; and \; \bar{\varepsilon} = \frac{1}{3}\left(\varepsilon_{\parallel} + 2\bar{\varepsilon}\right)$

$$\Rightarrow \quad \Delta\varepsilon \propto \left[\Delta\alpha + \frac{F}{k_B T}\left(\mu_{\parallel}^2 - \frac{\mu_{\perp}^2}{2}\right)\right] S \quad \text{and} \quad \bar{\varepsilon} \propto \bar{\alpha} + \frac{F}{3k_B T}\left(\mu_{\parallel}^2 + \mu_{\perp}^2\right)$$

molecular structure	$\mu_{\|\|}$	$\mu_{\perp}$	$\Delta\varepsilon$
	4.8	0.0	+15
	0.0	4.0	-5

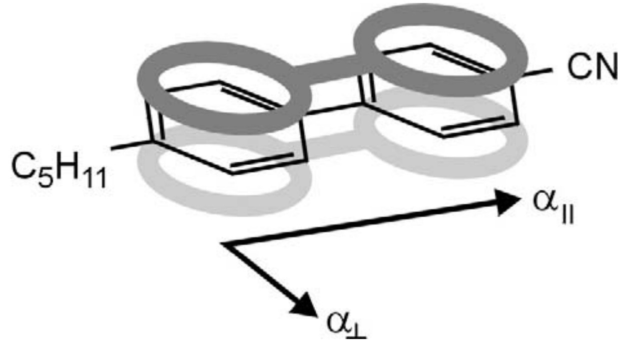
- $\Delta\varepsilon$ dominated by dipole moment

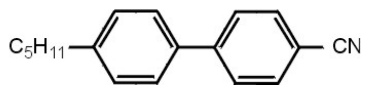
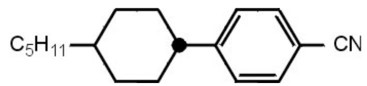
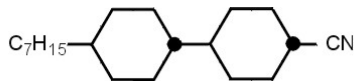
- Relaxation at medium frequencies

Refractive Indices – Molecular Contributions

- Polarisability anisotropy
  $\Delta\alpha = \alpha_{||} - \alpha_{\perp}$
- Delocalised electron clouds in phenyl rings enhance α
- Roughly coplanar phenyl rings in 5CB
  $\Rightarrow$ large $\alpha_{||} \Rightarrow$ large $\Delta\alpha$ and Δn
- Cyclohexane ring
  - No delocalised electron cloud
  - Less planar

  $\Rightarrow$ smaller $\alpha_{||} \Rightarrow$ smaller $\Delta\alpha$ and Δn



Molecular structure	$\Delta\alpha$	Δn
	19.4	0.194
	16.0	0.125
	11.1	0.045

Refractive Indices – Ordering Effects

- No dipole contributions at optical frequencies
- Use Maier and Meier equations with no diploes

$$\Rightarrow \qquad \Delta\varepsilon \propto \Delta\alpha\, S \quad \text{and} \quad \overline{\varepsilon} \propto \overline{\alpha}$$

- From definition of the refractive index $\quad n = \dfrac{c_{vacuum}}{v_{medium}} = \sqrt{\varepsilon}$

$$\Rightarrow \qquad \left(n_{\parallel}^2 - n_{\perp}^2\right) \propto \Delta\alpha\, S \quad \text{and} \quad \overline{n^2} \propto \overline{\alpha}$$

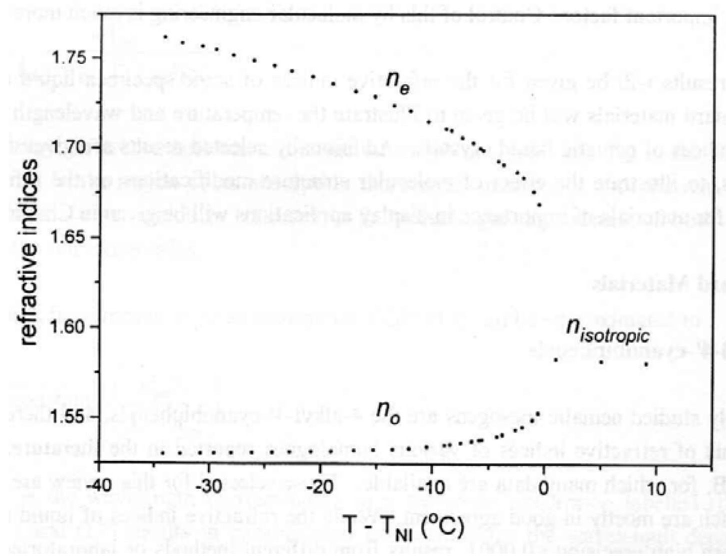
$$\Rightarrow \qquad S\,\Delta\alpha \Big/ \overline{\alpha} = \left(n_{\parallel}^2 - n_{\perp}^2\right) \Big/ \left(\overline{n^2} - 1\right)$$

Refractive Indices – Variation with Temperature

- Order parameter dominates

$$n_{\parallel} \propto \left(1 + \overline{\alpha} + \tfrac{2}{3}\Delta\alpha S\right)^{1/2}$$

$$n_{\perp} \propto \left(1 + \overline{\alpha} - \tfrac{1}{3}\Delta\alpha S\right)^{1/2}$$



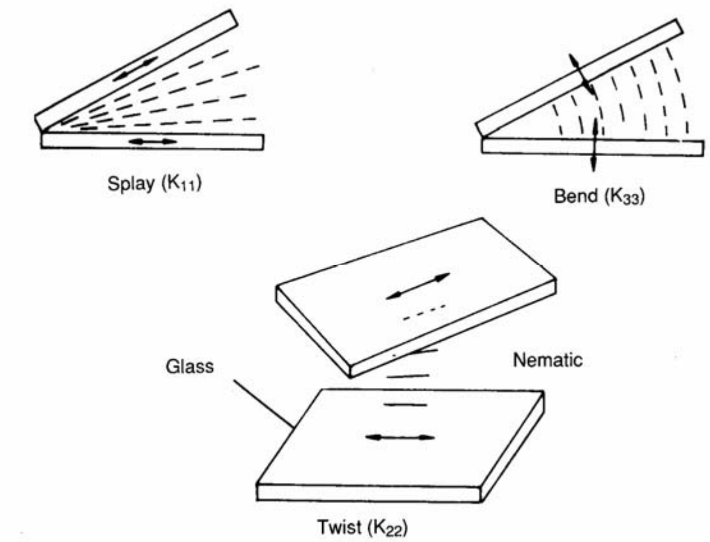
- Haller plot assumes $S = \left(1 - \dfrac{T}{T_{NI}}\right)^{b}$

- Plot log $\left(\dfrac{n_{\parallel}^2 - n_{\perp}^2}{n^2 - 1}\right)$ versus log $\left(1 - \dfrac{T}{T_{NI}}\right)$

$\Rightarrow$ Measurement of order parameter

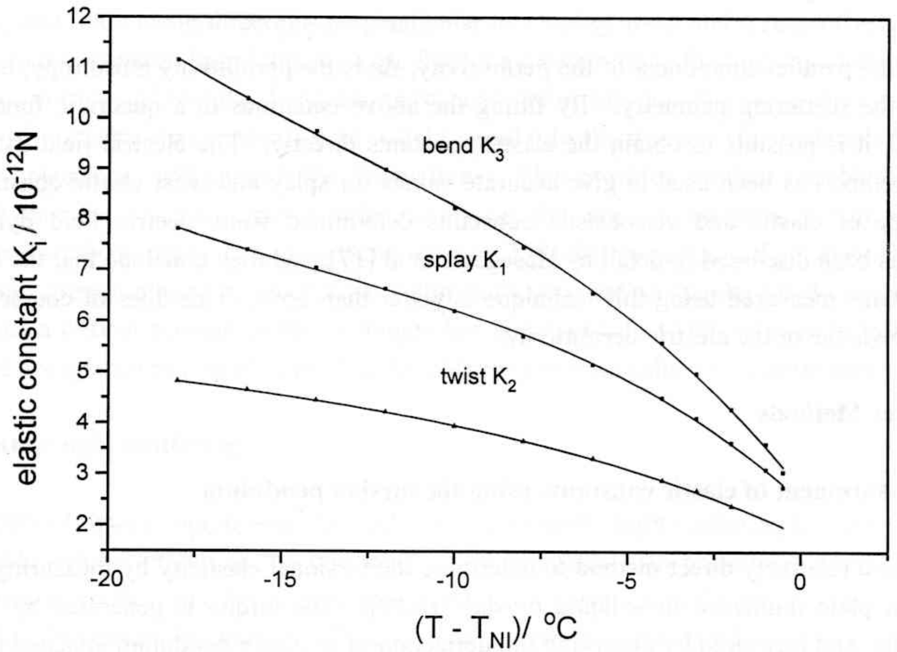
Elastic Constants - Definition

- With no forces applied
  $\Rightarrow$ no spatial variation of director
- Elastic torques oppose any distortions
- Long range distortions
  - do not change order S
  - length scale >> molecular length
- 3 elastic constants describe distortion e
  - splay (K_{11}), twist (K_{11}) and bend (K_{33})
- Used to calculate distortion energy



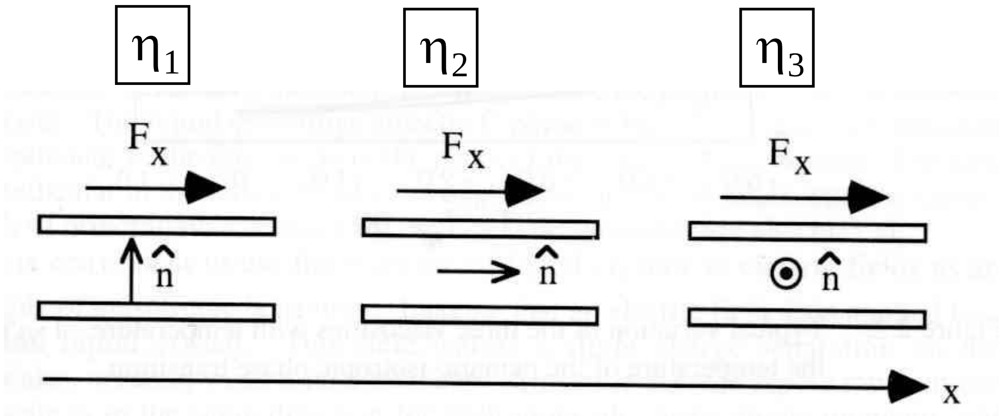
Elastic Constants – Typical Values

- Typically K_{ii} ~ 10 pN
  - 5 pN < K_{11} < 20 pN
  - K_{22} / K_{11} ~ 0.5
  - 0.5 < K_{33} / K_{11} < 3.0
- Temperature dependence
  - theory suggests K_{ii} ~ $\mathcal{S}^2$



Viscosities - Definitions

- Shear (or Miesowicz) viscosities η_1, η_2 and η_3

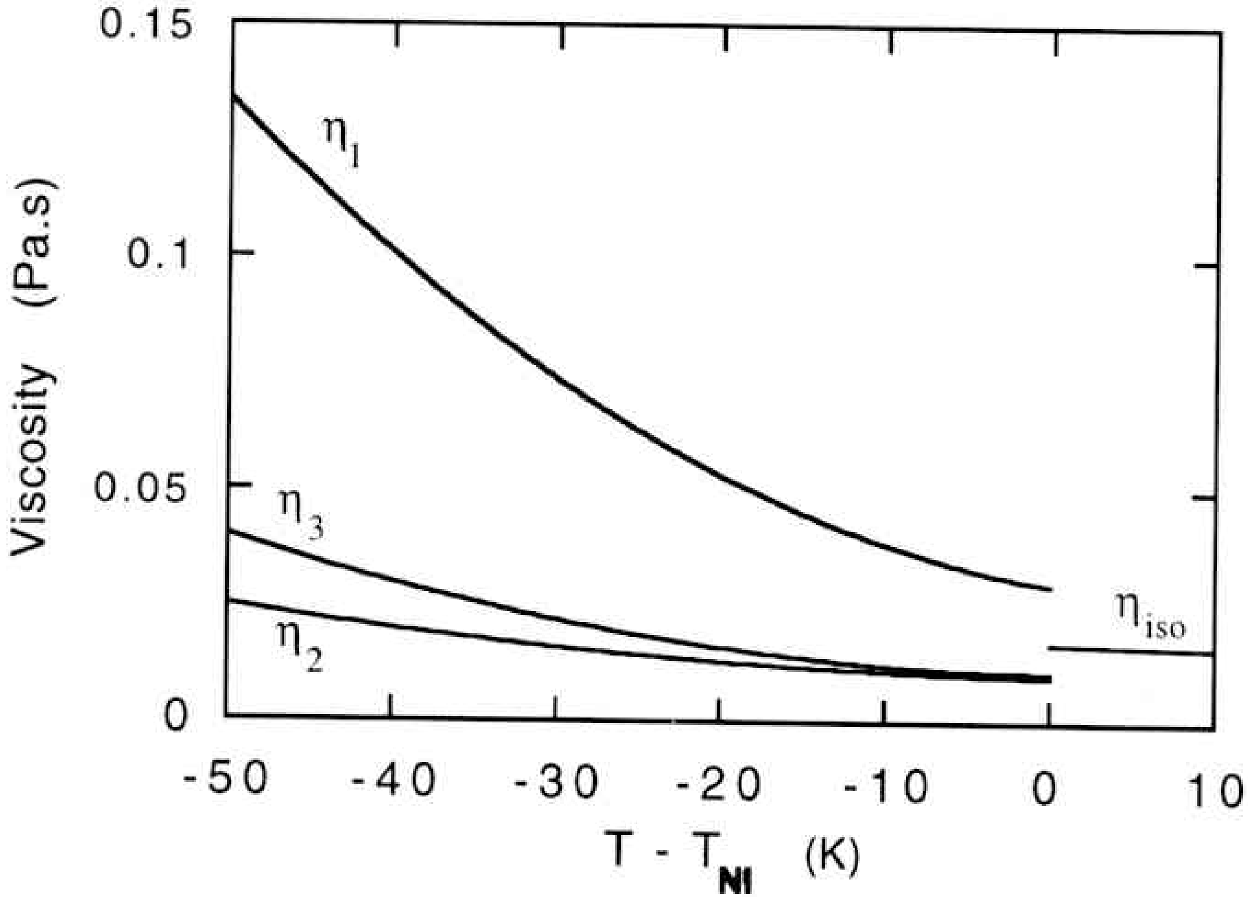


- From force required to move top plate

- 6 (5) Leslie viscosities for nematics

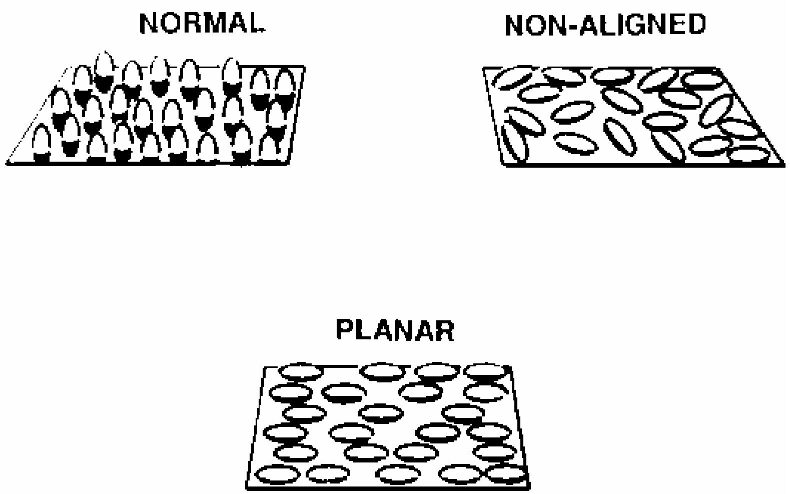
- Shear viscosities are combinations

Viscosities – Some Results



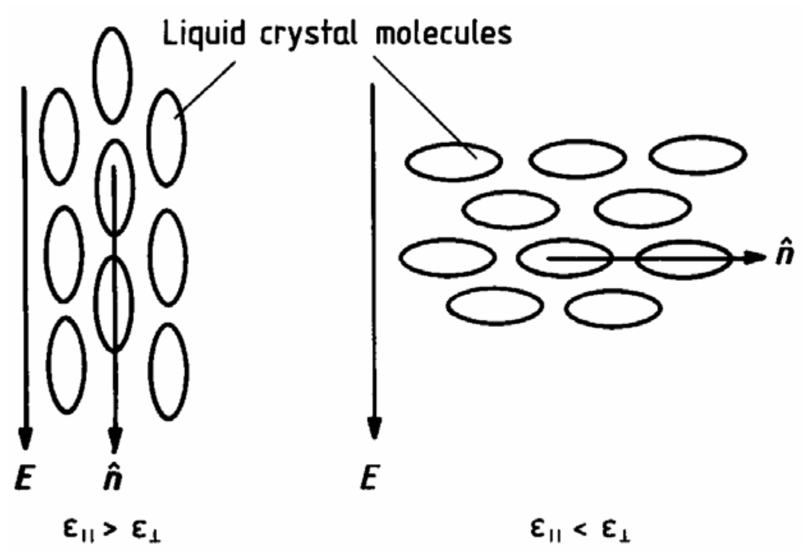
Alignment on Surfaces

- Two types of surface alignment
  - Normal (homeotropic)
    - Surfactants
  - Planar (homogeneous)
    - Oblique evaporation
    - Rubbing polymer coating
- LC between two surfaces
  - Uniform alignment
  - Controlled alignment
  - 'Single crystal' of LC



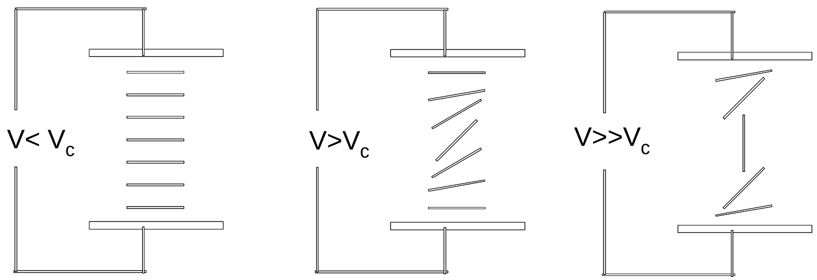
Alignment in Electric Field

- Electric permittivity
  - $\Delta\varepsilon = \varepsilon_{||} - \varepsilon_{\perp}$
  - Dielectric anisotropy ($\Delta\varepsilon$)
- Alignment type
  - Sign of $\Delta\varepsilon$
- Alignment strength
  - Magnitude of $\Delta\varepsilon$



Competition Between Fields and Surfaces

- Fundamental to most LCDs



- Threshold voltage Vc
  - V< Vc: nothing happens
  - V>Vc $\Rightarrow$ small reorienation
  - V>>Vc $\Rightarrow$ strong reorienation

- Vc depends on k_{ii} and $\Delta\varepsilon$ and is typically ~ 1V

Next Lecture

- Twisted nematic (TN) LCD
  - Device structure
  - Defects
  - Properties
- Passive addressing
  - RMS addressing
  - Alt & Pleshko analysis
- Continuum Theory
  - Static continuum theory
  - Application to switching mechanisms
  - Analytical calculations
  - Numerical calculations