IP 제공 자료 [2014]

What is Liquid Crystals?

김 윤 호

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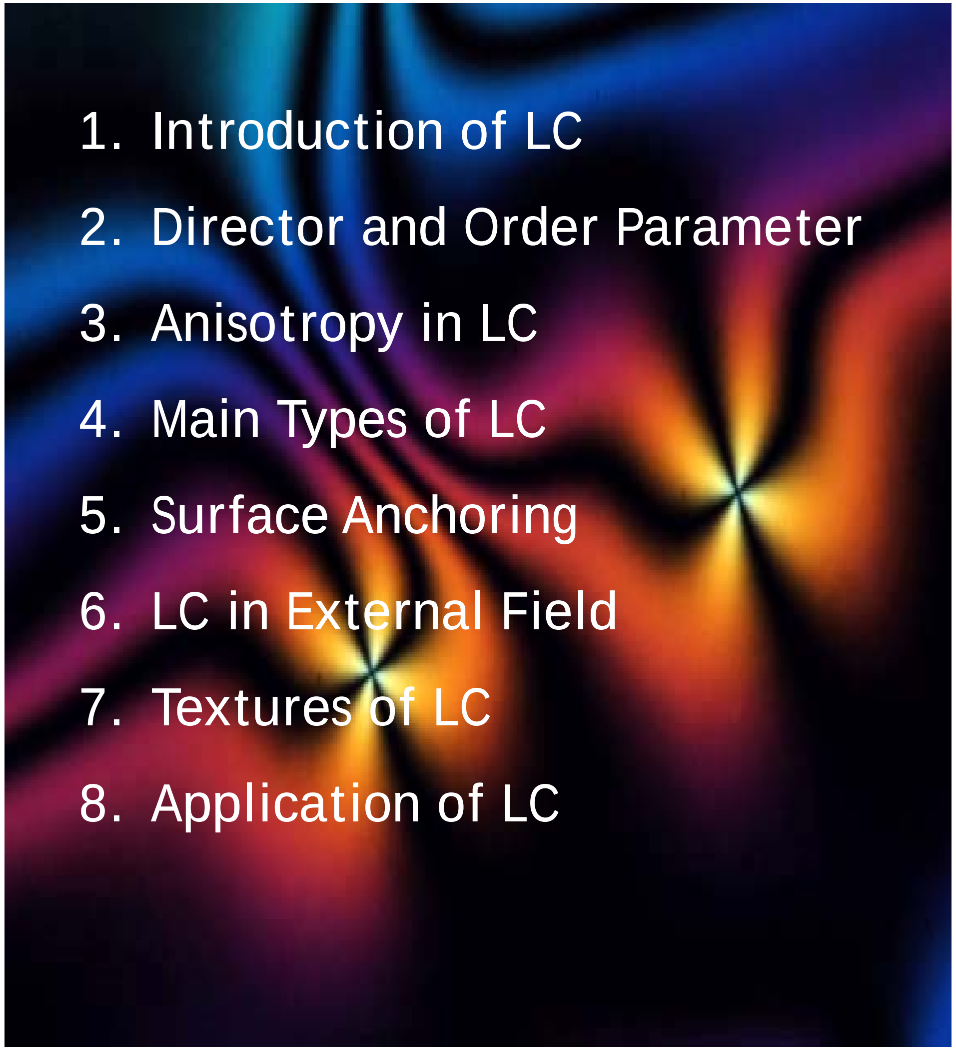
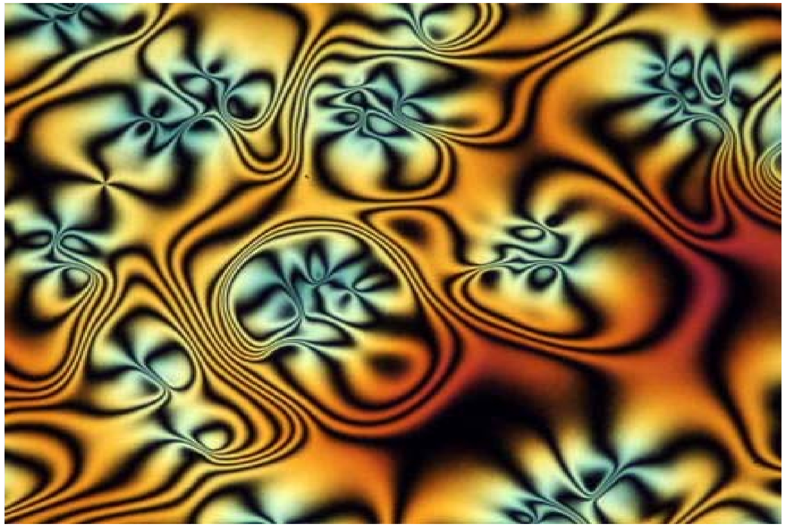
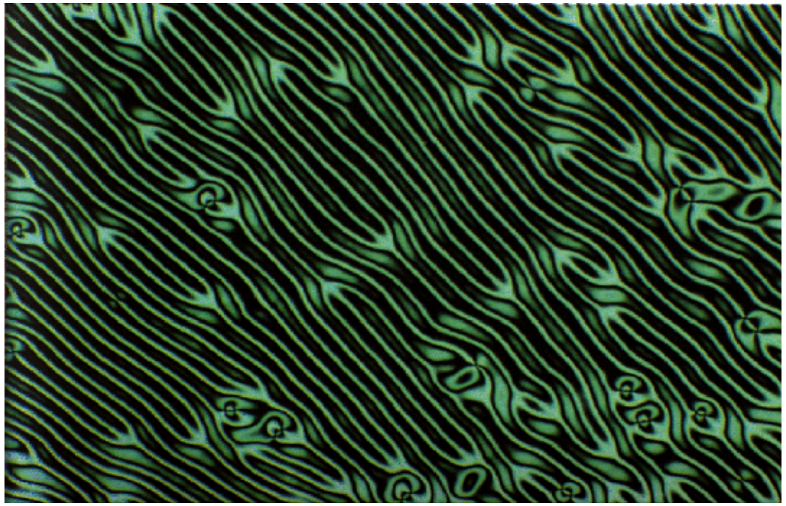
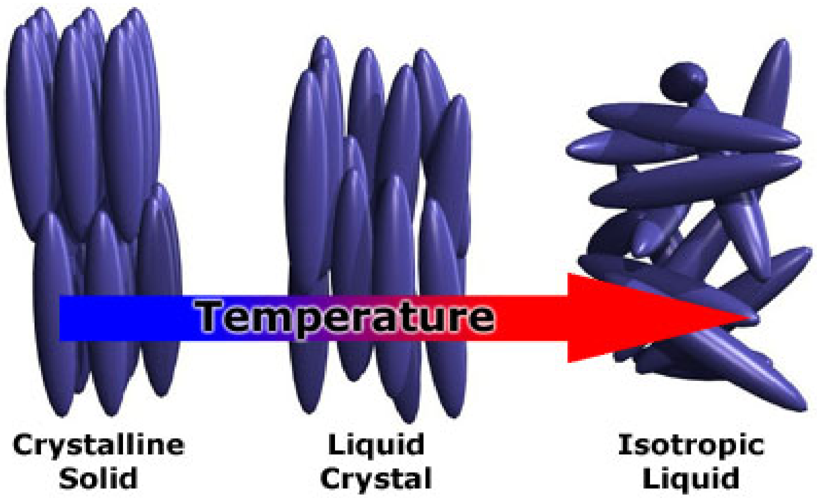






What are Liquid Crystals?



Liquid Crystals (LCs) are state of matter intermediate between that of a crystalline and an isotropic liquid. They possess many of the mechanical properties of liquid, e.g., high fluidity, formation, and coalescence of droplets. At the same time they are similar to crystals in that they exhibit anisotropy in their optical, mechanical, electrical, and magnetic properties.

- The quintessential property of a LC is its anisotropy. The optical, mechanical, electrical and magnetic properties of LC medium are defined by the orientation order of the constituent anisotropic molecules.

- Due to the anisotropy of the electrical and magnetic properties, the orientation of the LC molecules is effectively controlled by weak electric or magnetic fields.

A Brief History of LC

- The discovery of an intermediate, *liquid crystalline*, state of matter is credited to ***Friedrich Reinitzer***, an *Austrian botanist*. He described his experiment with the cholesteryl ester in a paper published in 1888.

- The name *liquid crystal* was first suggested by ***Otto Lehmann**, a German physicist. (the first to use hot stage on POM)*

- *A classification of LCs based on their structural properties was first proposed by **Georges Friedel**, a French mineralogist, in 1922.*

- ***Carl Oseen** in Sweden worked on elastic properties of liquid crystals and his results were used on the continuum theory by F.C. Frank. This theory became one of the fundamental theories in liquid crystals today..*

- ***V. Fredericks** in the 1930's. Transition from a homogeneous to a deformed structure at some critical value of applied field strength is named Fredericks transition due to his pioneering work in this area.→ **Liquid Crystal Display***

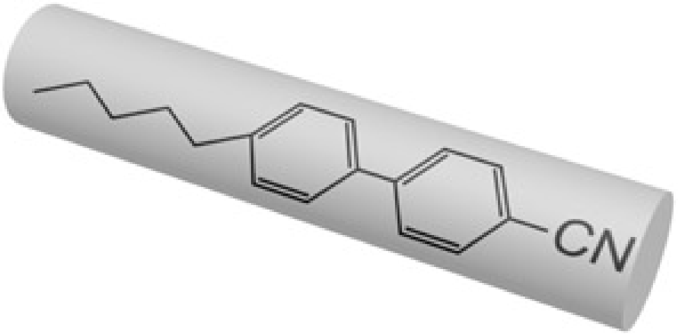
- *Since middle 1960 the entire theoretical and experimental development has been influenced by **Pierre-Gilles de Gennes**, a French physicist. (**Nobel Prize, 1991**)*

Classification of LCs

- Liquid Crystal
  - Molecular Shape
    - Spherical-like
    - Rod-like
    - Tapered-like
    - Disc-like
    - Banana shape
  - Molecular Ordering
    - Micelle
    - Vesicle
    - Nematic (1D)
    - Cholesteric (1D)
    - Lamellar (pseudo 2D)
    - HPL (2D)
    - Columnar (2D)
    - Cubic (3D)
  - Nature of Phase Transition
    - Thermotropic
    - Lyotropic
  - Type of Mesogenic Materials
    - Small Molecules
    - Polymers

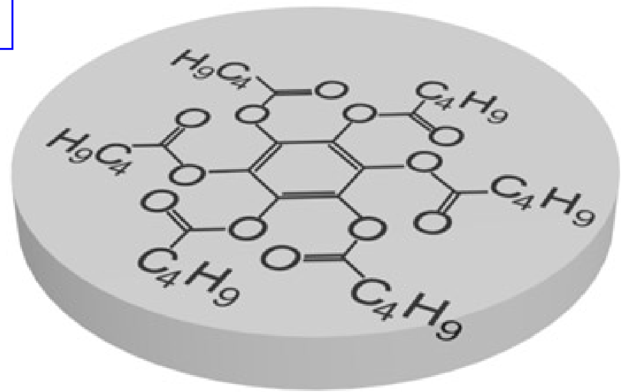
Building blocks

a) Rod-like LC



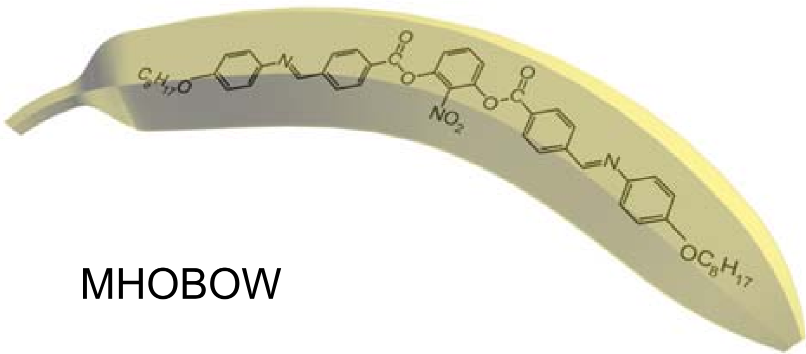
4-pentyl-4'-cyanobiphenyl (5CB)

b) Disk-like LC



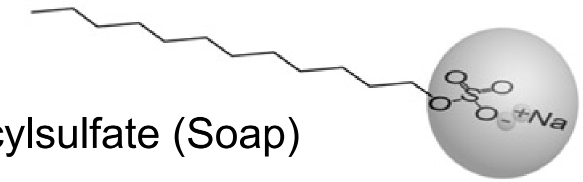
Benzene-hexa-n-alkanoate

c) Banana-like LC

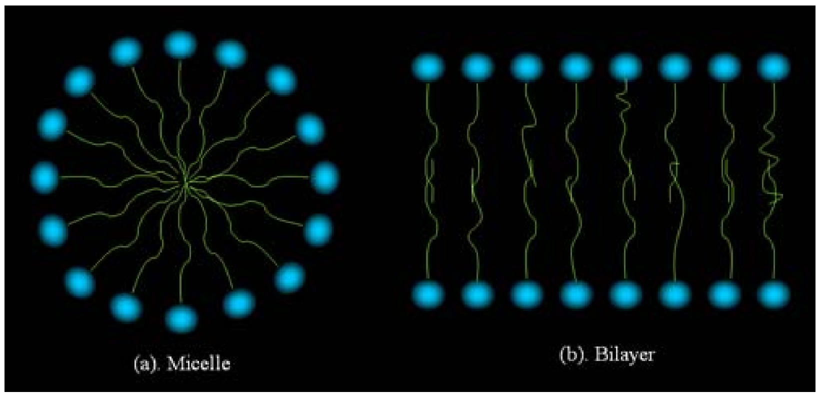


MHOBOW

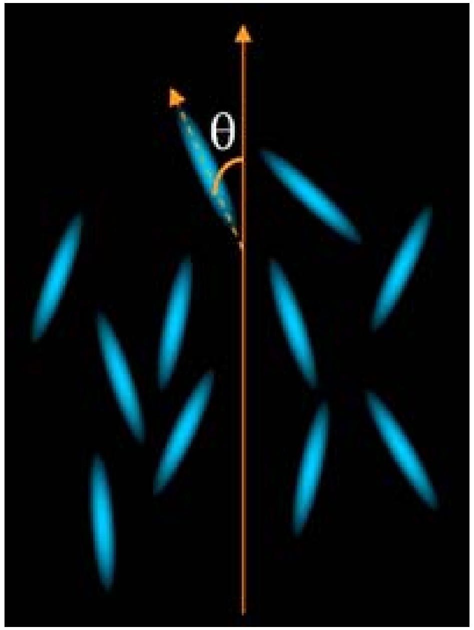
d) Lyotropic LC

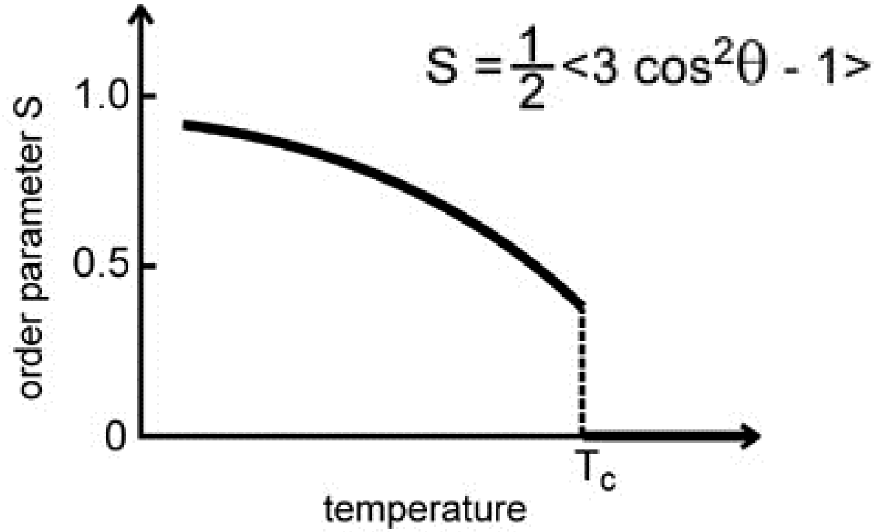


Sodium dodecylsulfate (Soap)



Director and Order Parameter





<Director>
The average direction of the molecular long axes in the LC phase defines the director **n**, which gives the direction of the preferred orientation of LC molecules.

<Order Parameter>
To specify quantitatively the amount of the orientational order in the LC phase, the scalar order parameter **S** is commonly used ($0 < \mathbf{S} < 1$)

The order parameter of the LC decreases as the temperature increases and typical values are in the range 0.3-0.9

Anisotropy in LC -1

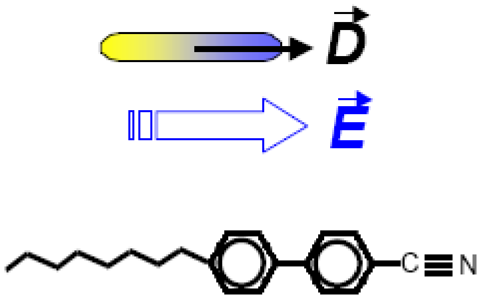
Birefringence: $\Delta n = n_e - n_o$

Dielectric Anisotropy: $\Delta \varepsilon = \varepsilon_e - \varepsilon_o$

$n_o \;\; \varepsilon_o \qquad n_e \;\; \varepsilon_e$

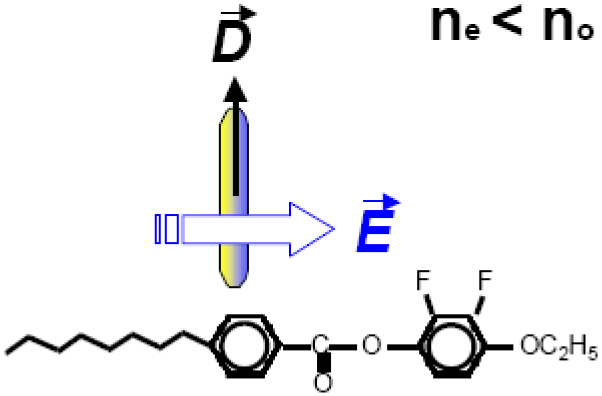
p-type ($\Delta n > 0$)

$n_e > n_o$



n-type ($\Delta n < 0$)

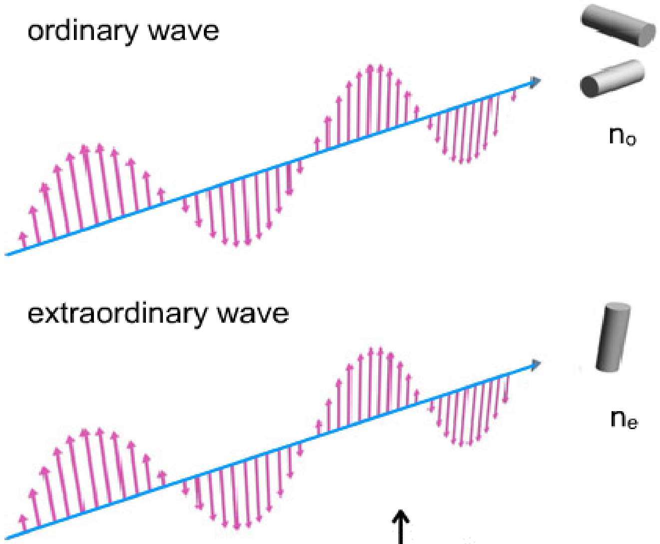
$n_e < n_o$

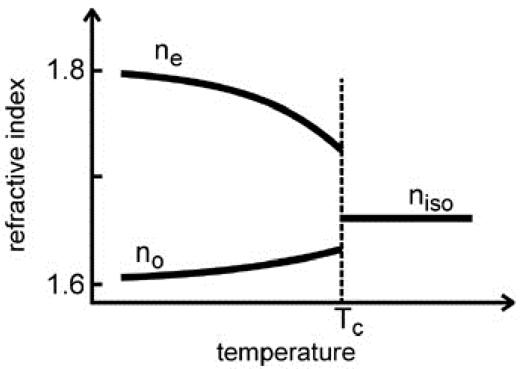


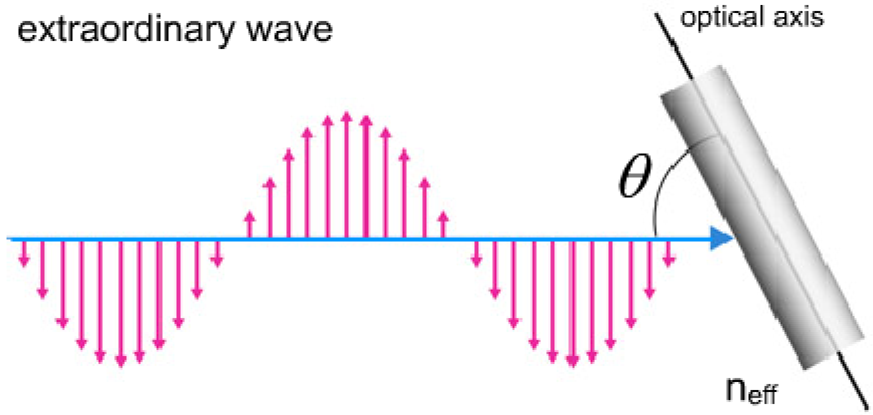
Anisotropy in LC -2

<Dielectric Anisotropy of LC>

The anisotropy of LCs causes light polarized along the director **n** to propagate at a different velocity than light polarized perpendicular to it. Therefore, LCs are **birefringent**. A uniaxial LC has two principal refractive indices, ordinary refractive index $\mathbf{n_o}$ and extraordinary refractive index $\mathbf{n_e}$.





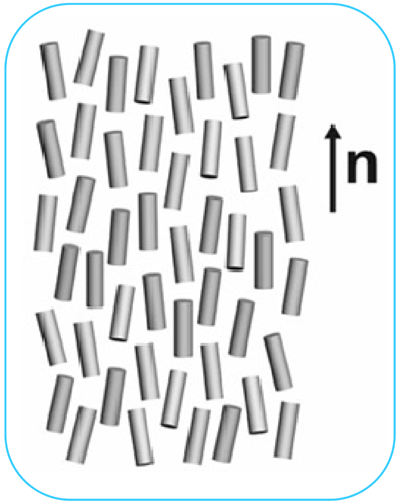


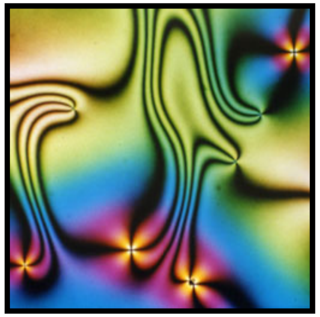
$$n_{eff}^2 = \frac{n_e^2\, n_o^2}{n_e^2 \cos^2\theta + n_o^2 \sin^2\theta}$$

Main types of LC -1

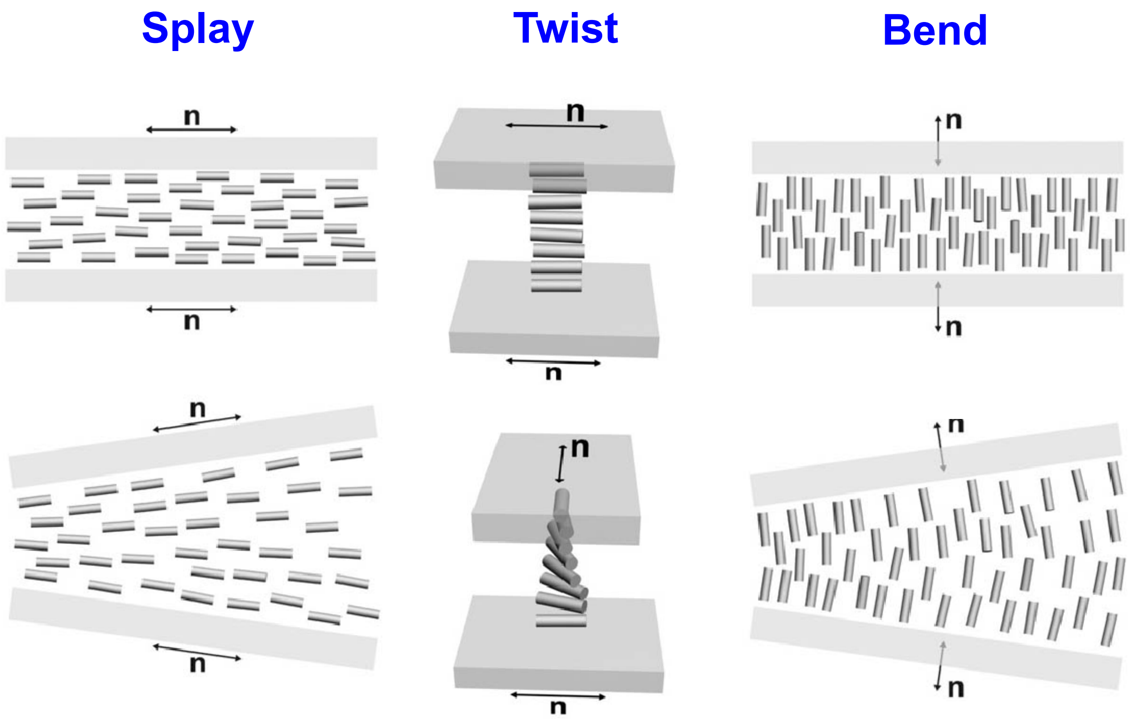
<Nematic Liquid Crystal>

The simplest mesophase is a nematic LC. In nematics, the long molecular axes are preferably oriented in one direction, defined as the director **n**. *Long-range orientational order, but no long-range positional order.*





Schlieren Texture

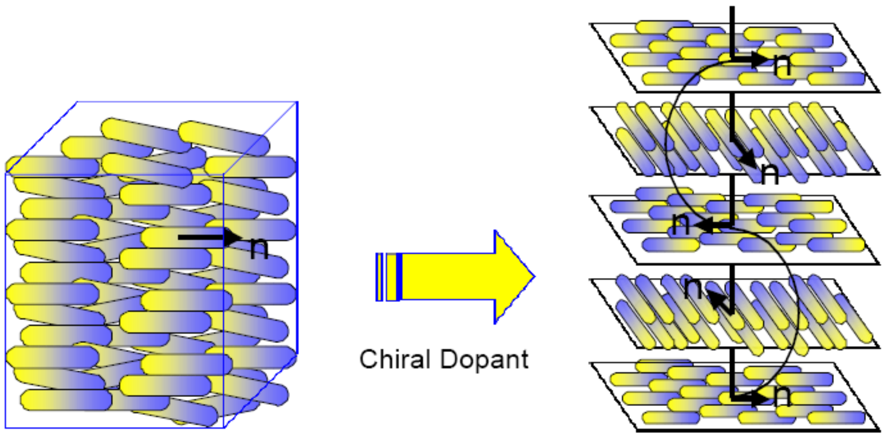


$$F_d = \frac{1}{2}K_1(\mathrm{div}\,\mathbf{n})^2 + \frac{1}{2}K_2(\mathbf{n}\bullet\nabla\times\mathbf{n})^2 + \frac{1}{2}K_3(\mathbf{n}\times\nabla\times\mathbf{n})^2.$$

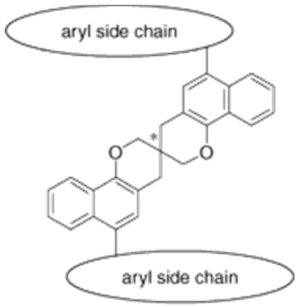
Main types of LC -2

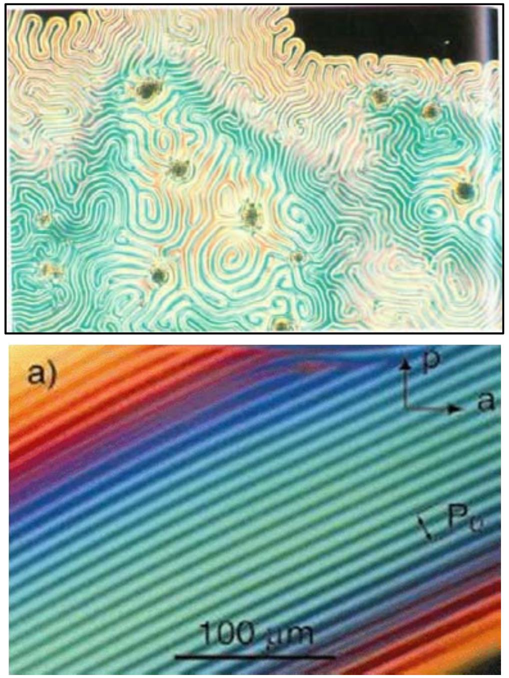
<Cholesteric Liquid Crystal – Chiral Nematic, Twisted Nematic>

Chiral molecules cause a twist in the nematic structure. Such a helical phase is called a *cholesteric* LC. Locally, the cholesterics are very similar to the nematic LCs. The layers turned by an angle of 2π are equivalent; the distance between these two defines the pitch ***p*** of the helical structure. The helical pitch can be controlled by temperature and concentration of chiral dopant. It is inducing *selective reflection* property with photonic bandgap.

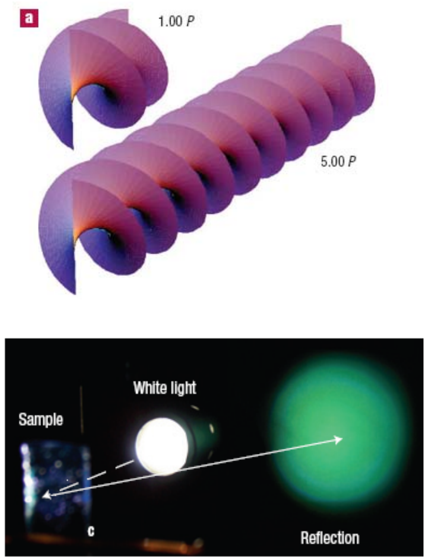


Nematic   Cholesteric





Fingerprint texture

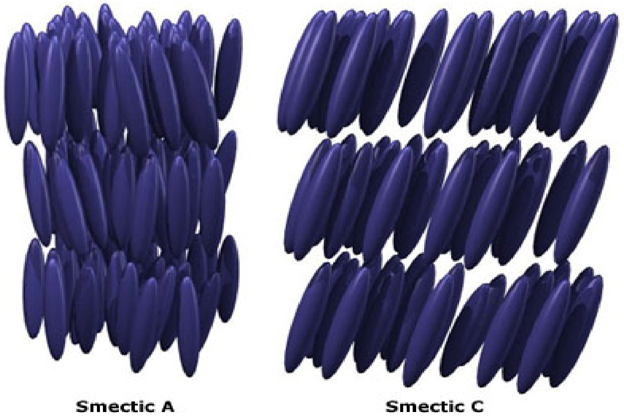


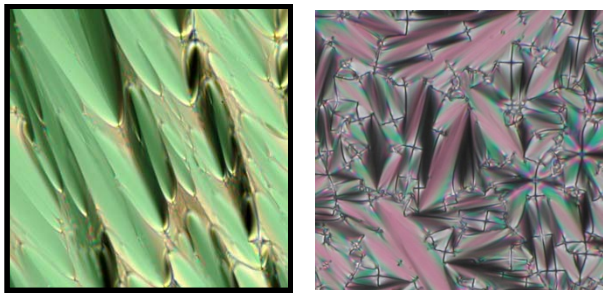
Selective Reflection

Main types of LC -3

<Smectic Liquid Crystal>

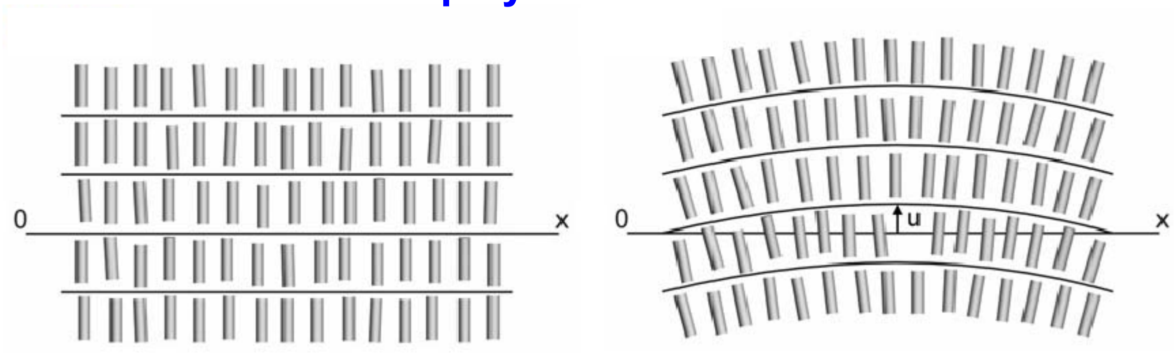
In smectic A (SmA) phases, on average, the molecules are parallel to one another and are arranged in layers, with the long axes perpendicular to the layer plane. Within the layers, the centers of gravity of the molecules are ordered at random. Thus, smectics A possess the one-dimensional quasi *long-range positional order* and within the layers molecules show a relatively high mobility. The layer thickness is equal to the molecule length. The bend and twist deformations of the director field in the SmA structure are prohibited.





Focal conic domain

Splay Deformation

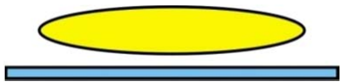


$$F_d = \frac{1}{2}K\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)^2 + \frac{1}{2}B\left[\frac{\partial u}{\partial z} - \frac{1}{2}\left(\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial u}{\partial y}\right)^2\right)\right]^2,$$

Surface anchoring

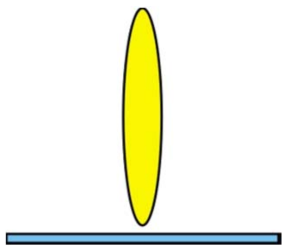
I. Planar alignment

- Molecules orient parallel to a surface
- Hydrophilic surface (low water contact angle)
- Chemically clean glass
- Spin coated polymer (Polyimide, Polyamide, Nylon, PVA, GLYMO,…)



II. Homeotropic alignment

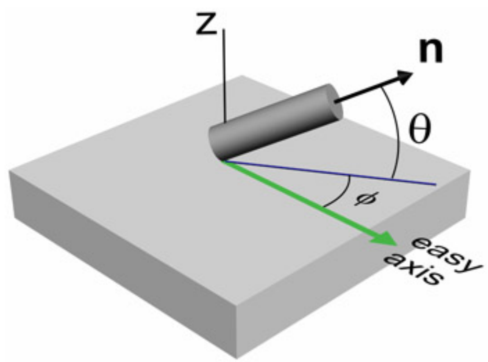
- Molecules or layer normal orient perpendicular to a surface
- Hydrophobic surface (high water contact angle)
- Organo-siloxyane self-assembled monolayer (SAM)
- Specially designed polymer (Polyimide, RN1211…)
- LC-air interface



III. Surface anchoring

- Due to the deformations of LC, there are deviations of the director from the easy axis in the areas adjacent to surfaces.
- The distortion free energy should be added term related to the excess surface energy.

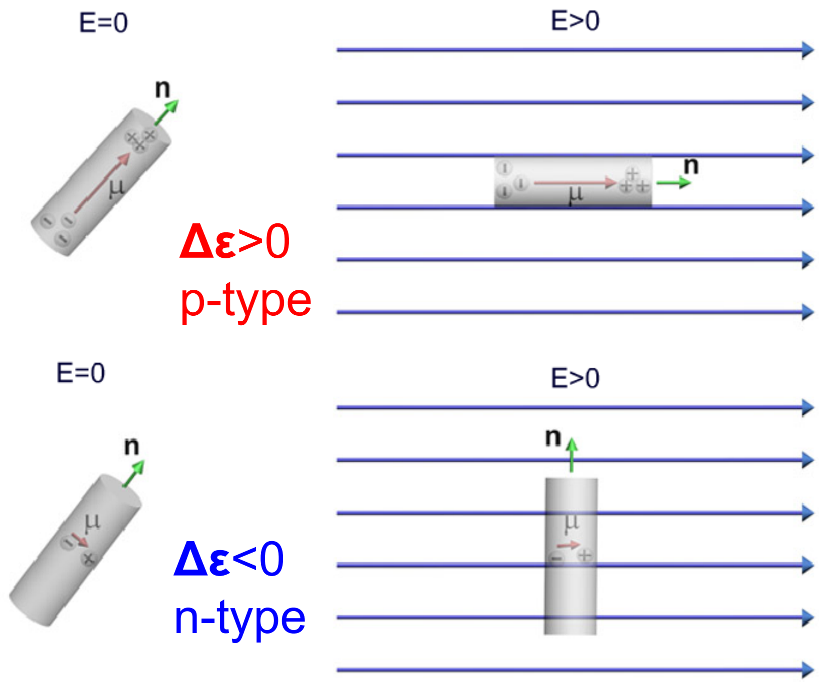
$$F_s = 1/2\ W_{\theta o}\sin^2(\theta - \theta_o) + 1/2\ W_{\varphi o}\sin^2(\varphi - \varphi_o),$$



LC in External Field -1

<LC in Electric Field>

The LC molecules can possess the permanent or induced dipole along or across the long molecular axis. The electric field causes the director n reorientation. If the dipole moment is parallel (or nearly parallel) to the long molecular axis then **Δε**>0 and the molecules tend to orient along the electric field direction.



$$F_e = -\ 1/2\ \varepsilon_o \Delta\varepsilon\ (\mathbf{E}\cdot\mathbf{n})^2$$

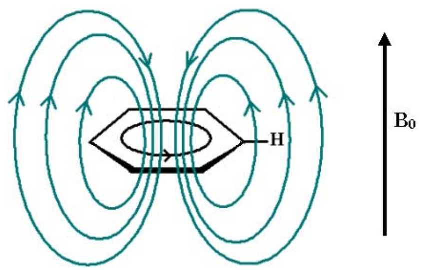
- E: Electric field
- n: Director of LC
- ε_o: Electric permittivity of Vac.
- Δε: Dielectric anisotropy

- The electric field causes the director **n** reorientation.
- The larger the dielectric anisotropy the smaller electric field is needed to reorient the LC molecules.

LC in External Field -2

<LC in Magnetic Field>

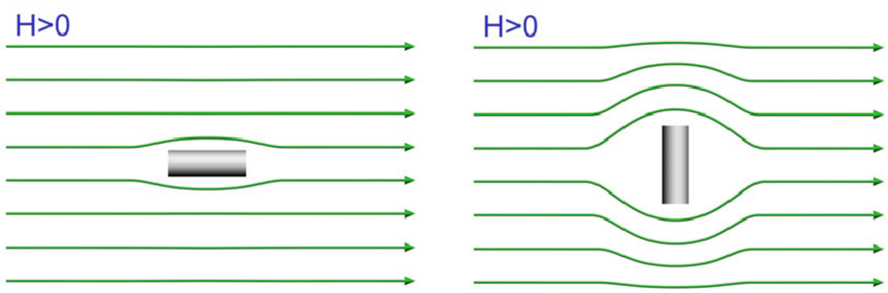
Most LC organic molecules are diamagnetic. The induced magnetic dipoles are responsible for the reorientation of the LC molecules in a magnetic field **H**. The LC molecules tend to orient themselves parallel to the magnetic field decreasing the distortion of the magnetic field flux when they are perpendicular to **H**. Comparing the relative efficiencies of the electric and magnetic fields should be noted that, roughly, the torque exerted on the LC molecules by one Volt/μm is equivalent to the magnetic torque exerted by 10,000 Ga (=1 Tesla).



Diamagnetism of benzene ring

$$F_B = - 1/2\ \mu_o^{-1} \Delta\chi\ (B\cdot n)^2$$

- B: Magnetic field
- n: Director of LC
- μ_o: Magnetic permittivity of Vac.
- $\Delta\chi$: Diamagnetic anisotropy

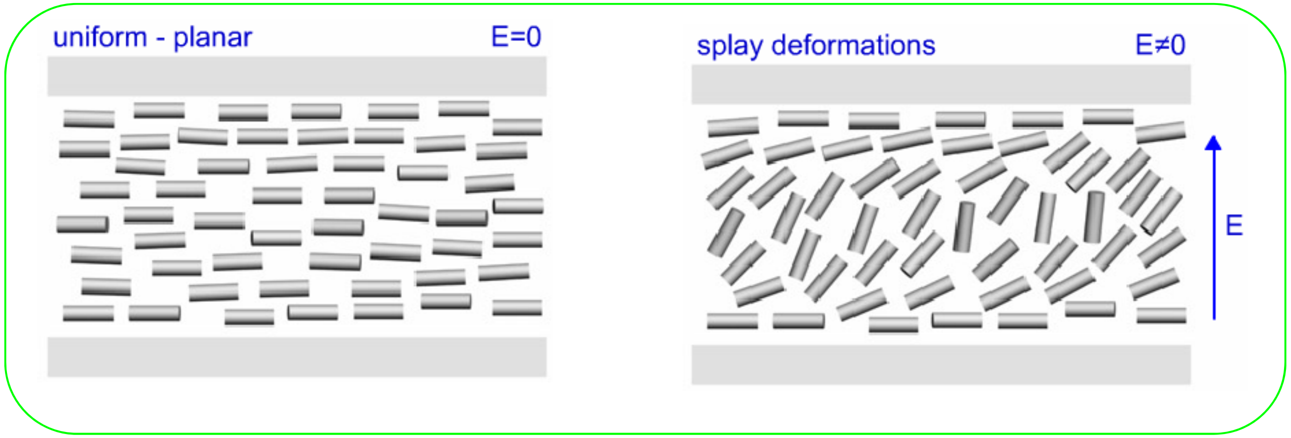


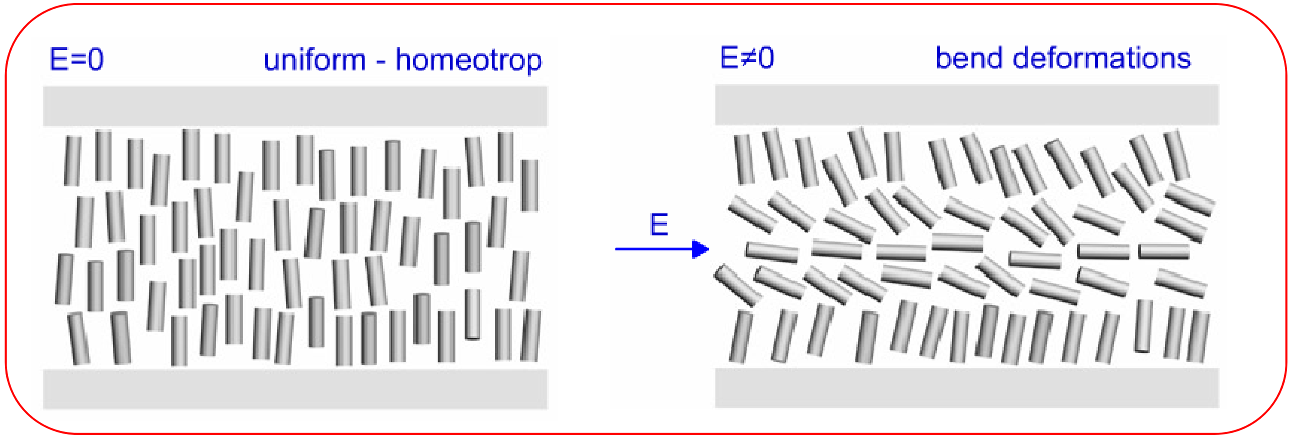
- In nematics, the positive anisotropy of susceptibility proportional to the number of aromatic rings is expected.

LC in External Field -3

<Frederiks Transition>

The Frederiks transition means the deformation of a uniform director pattern in an external field. If the external, electric or magnetic, field is applied to the LC sample with some uniform director structure, there is a gradual change of the director structure once the field strength exceeds some threshold or critical value.





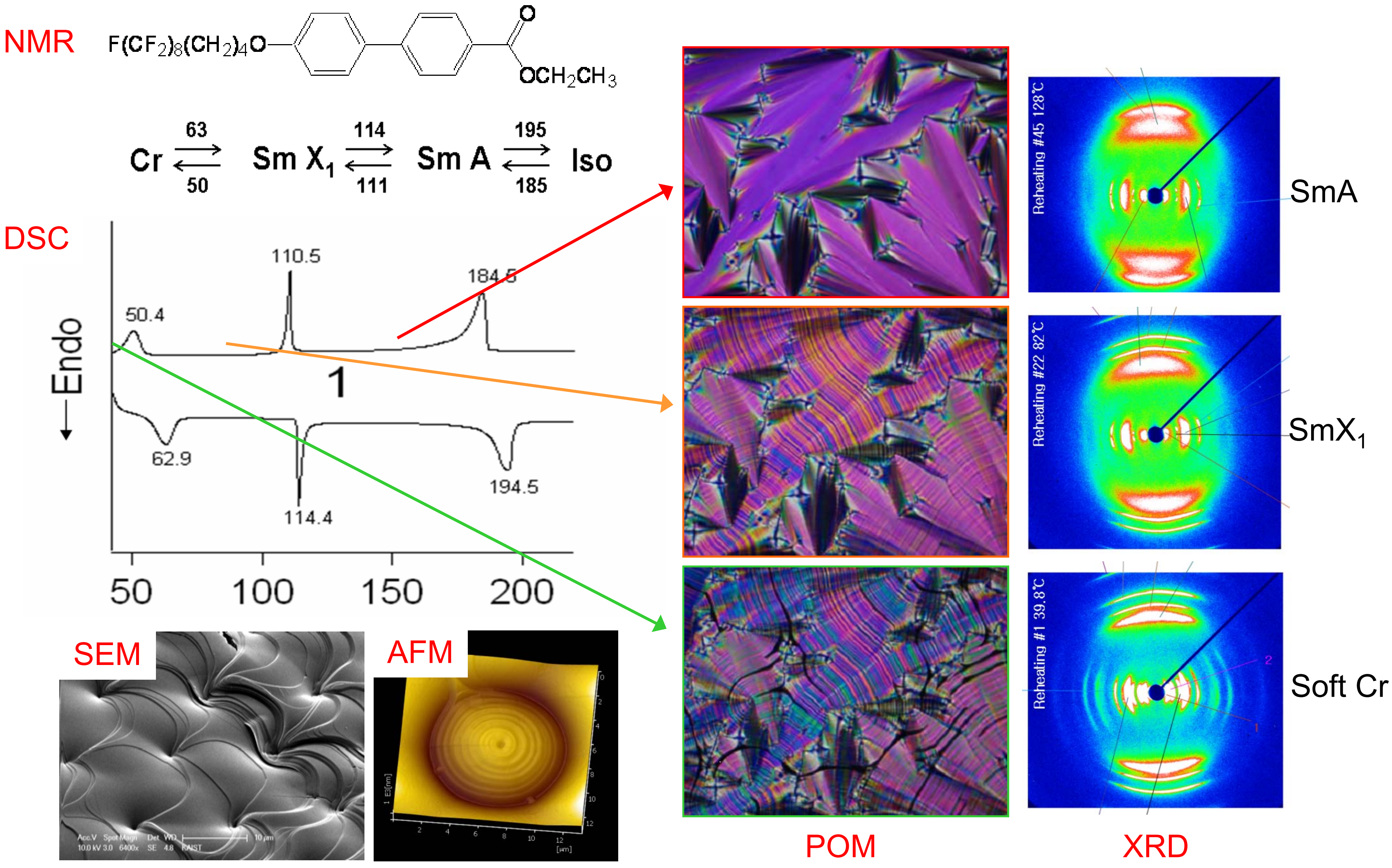
$E_{ci} = \pi/d\ (K_i/\varepsilon_o \Delta\varepsilon)^{1/2}$

This phenomena opens LCD technique.

Characterization of LCs

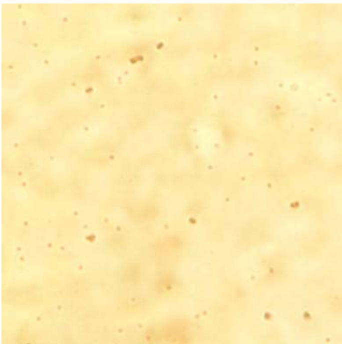
- OM (POM) : Texture of LC phase (Optical Retardation)
- DSC : Transition temperature- thermotropic mesophase transition
- Scattering : LS, XRD, NS, ED - LC ordering
- Microscopy : AFM, STM, TEM, SEM – ordering, defects,
  Sub- microscale structure
- Spectroscopies : IR, NMR – chemical structure, ordering

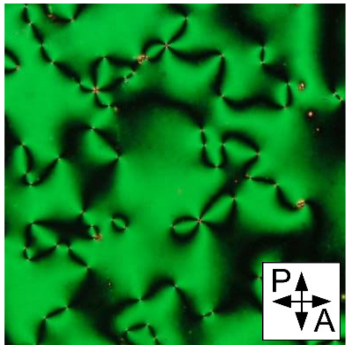
Characterization of LCs

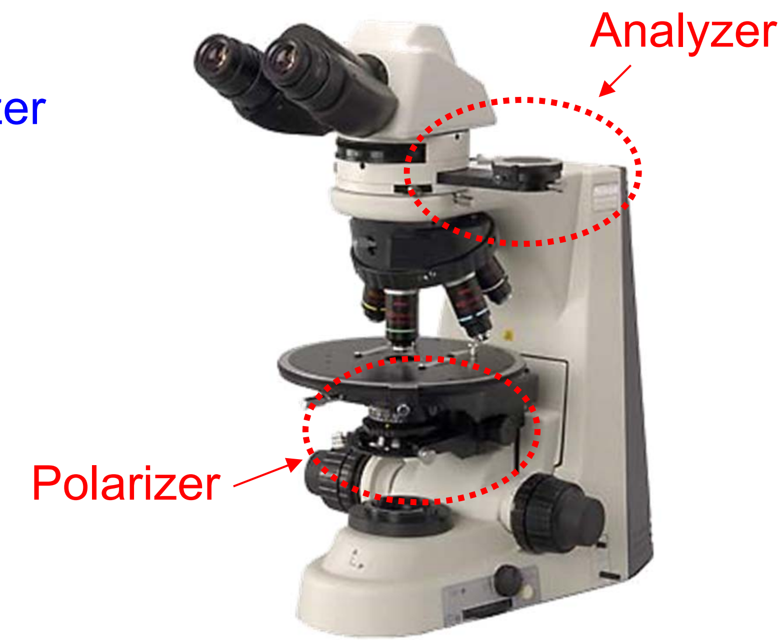


Texture by POM

- Polarized Optical Microscope
  → Optical Microscope + Polarizer and Analyzer
  → Shape of object + Birefringence

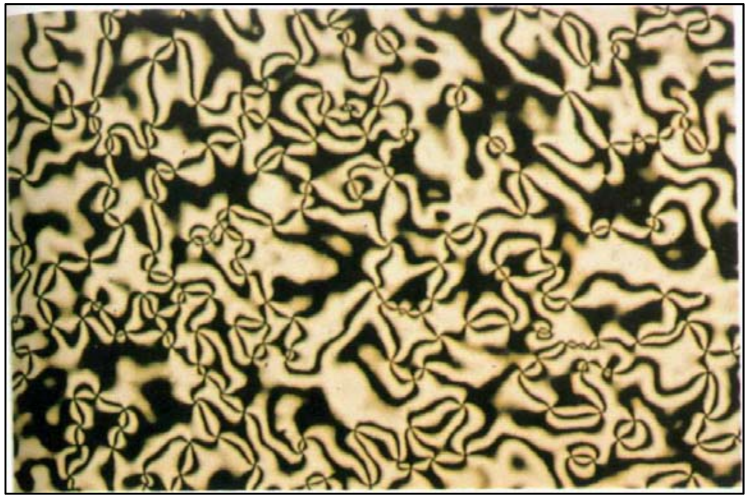




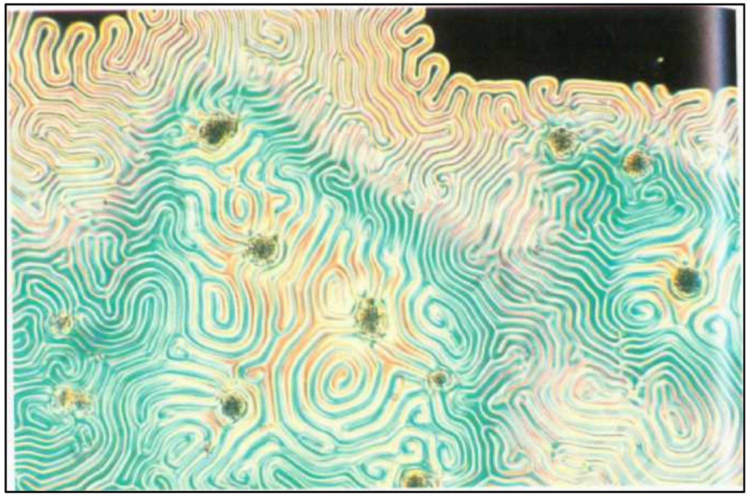


- Nematic : schlieren (typical), threaded, marbled texture
- Cholesteric : focal conic, oily streak or fingerprint texture
- Smectic : S_A : focal conic (typical)
  S_C : schlieren texture (only four point schlieren)
- Columnar : focal conic
- Cubic: Optically Isotropic

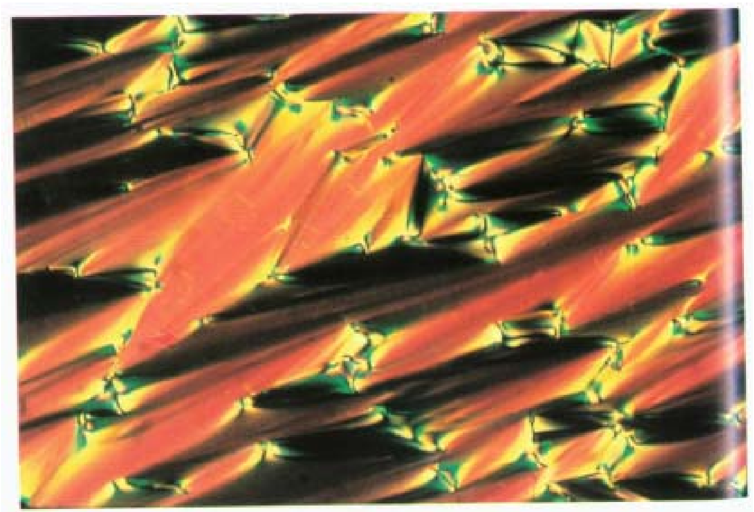
Typical Texture of LCs



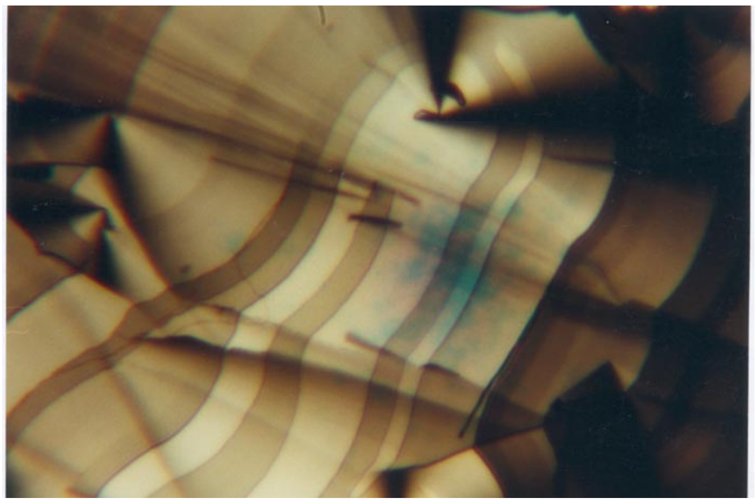
Nematic (schlieren)



Cholesteric (fingerprint)



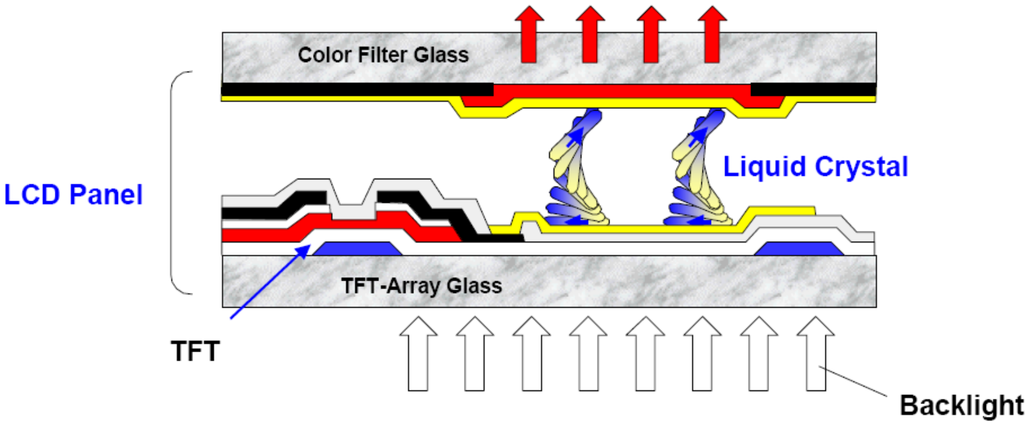
Smectic (fan shape focal conic)

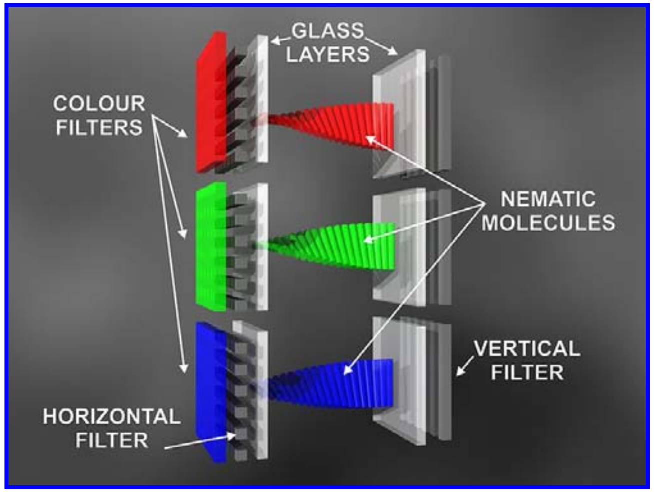


Columnar (focal conic)

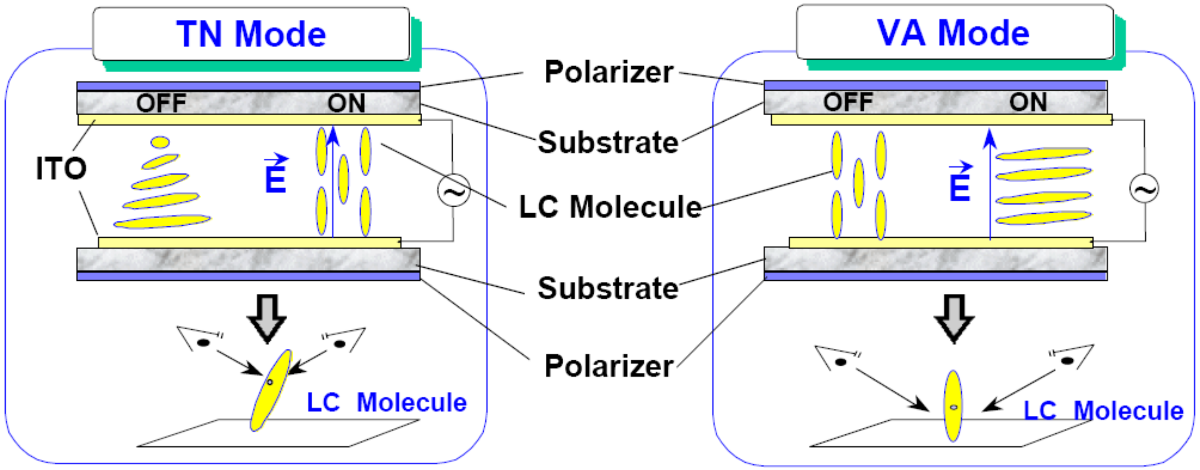
LCD application

❖ Basic structure of LCD



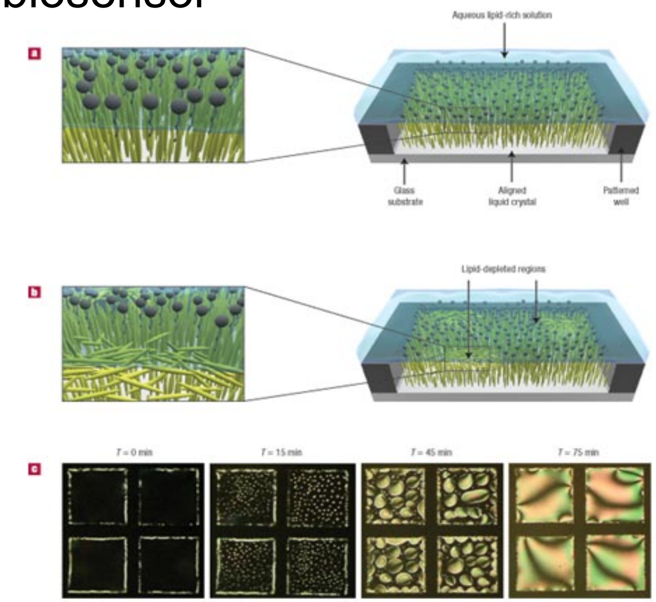


❖ Typical LCD mode as LC alignment

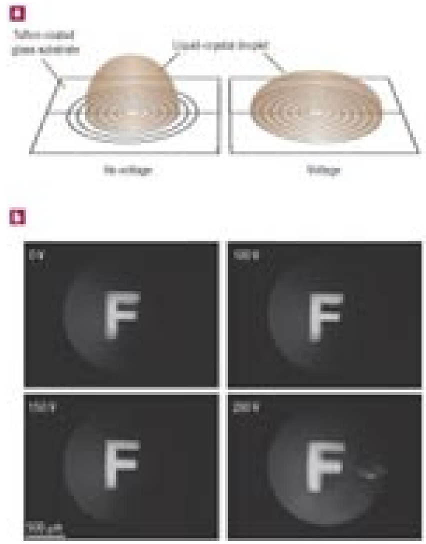


New applications of LCs for Future

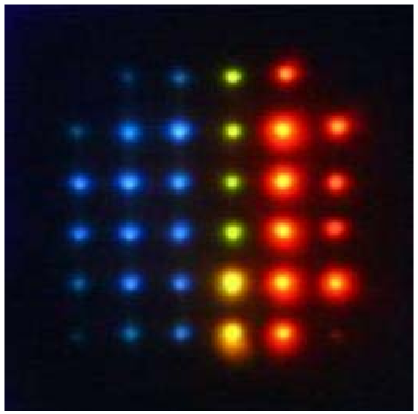
❖ LC biosensor



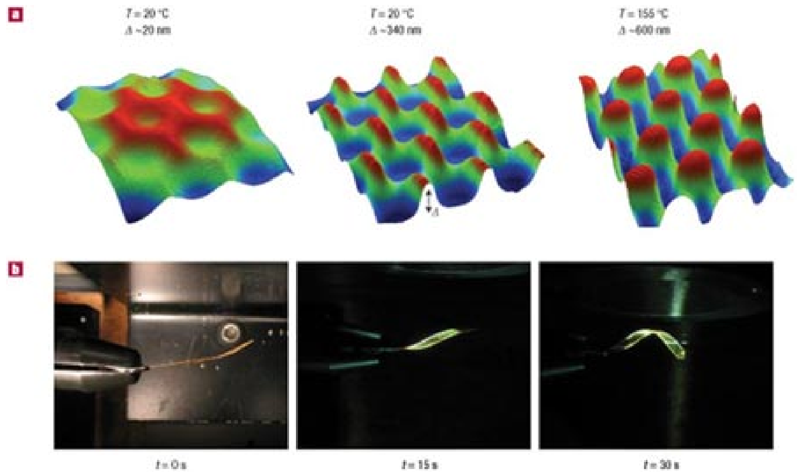
❖ LC microlens



❖ LC laser



❖ LC actuator



References & Related links

- International Liquid Crystals Society
- Liquid Crystals Group at University of Colorado at Boulder
- Liquid Crystal Institute at Kent State University
- Liquid Crystal Group at University of Hamburg
- Nikon (Polarized Optical Microscopy)
  http://www.microscopyu.com/articles/polarized/index.html