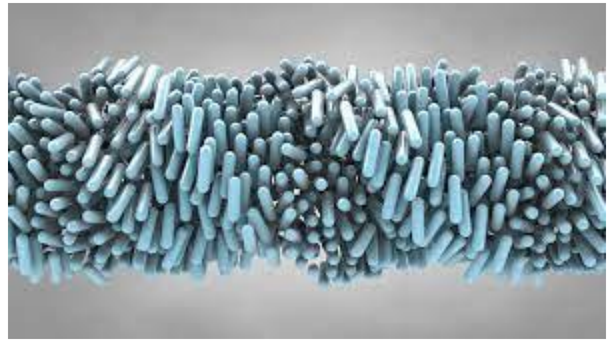
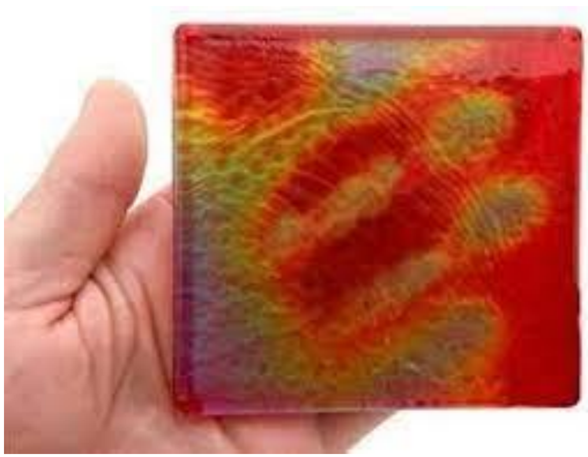
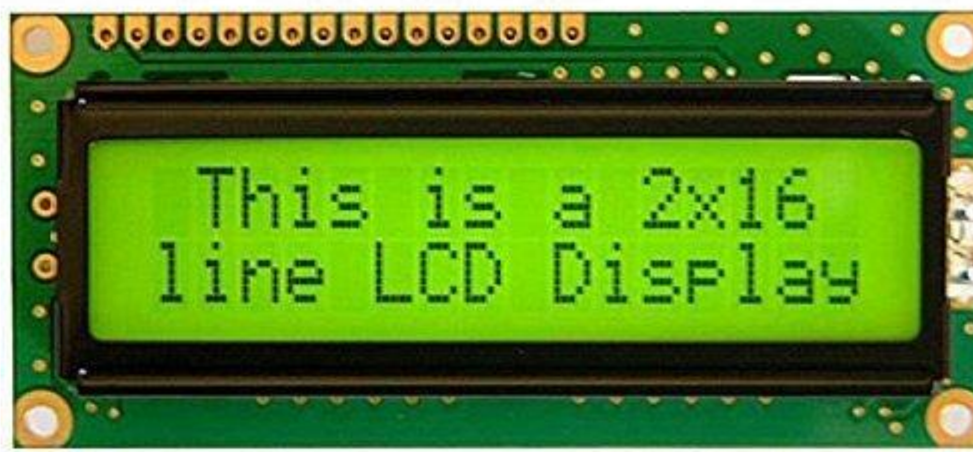
Liquid Crystals




4CFPB




This is a 2x16
line LCD Display

LIQUID CRYSTAL

A “double melting” behavior of cholesteryl benzoate.

The crystals of this material melted at 145.5^{o}C into a cloudy fluid, which upon further heating to 178.5^{o}C became clear.

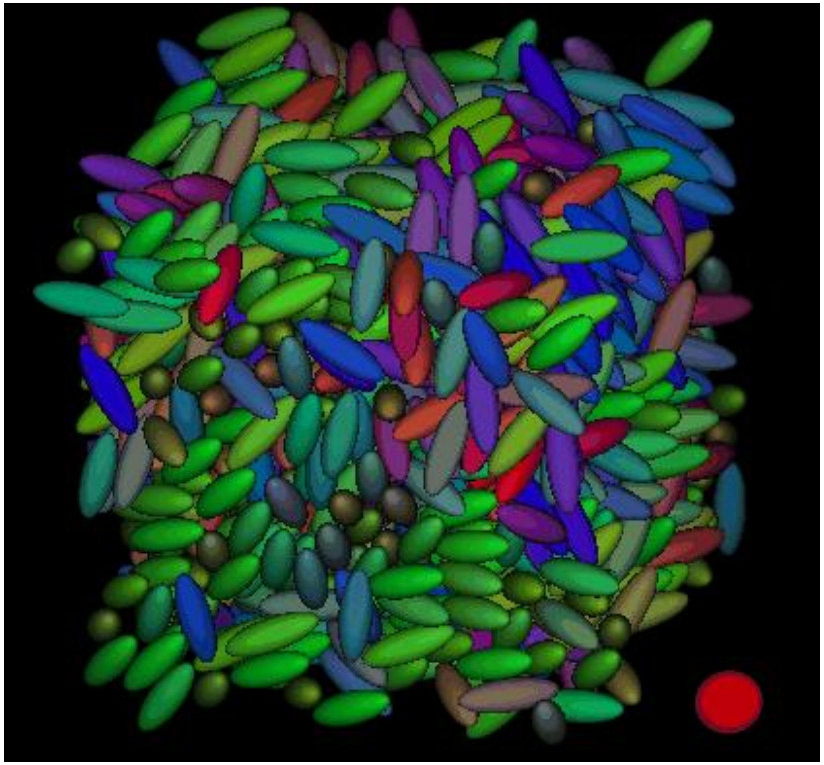
They undergo more than a single transition in passing from solid to liquid through different intermediate states on heating.

Intermediate state - mesophase

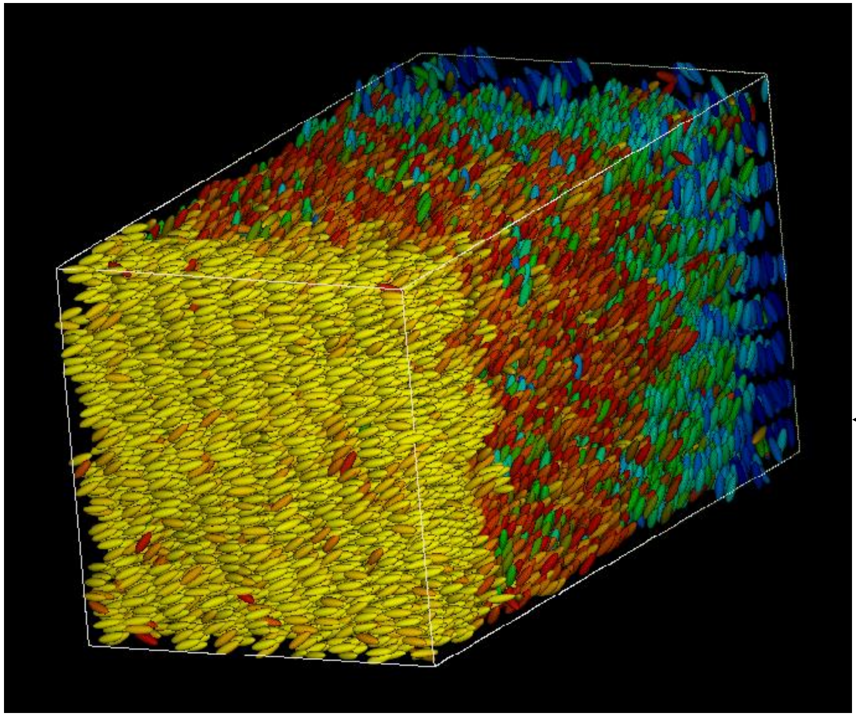
Liquid Crystal – a stable phase of matter characterized by anisotropic properties without the existence of a 3-dimensional crystal lattice – generally lying between the solid and isotropic ("liquid") phase.

Anisotropy: they exhibit different optical properties when the light is incident in different directions

Isotropy: Same properties in all directions



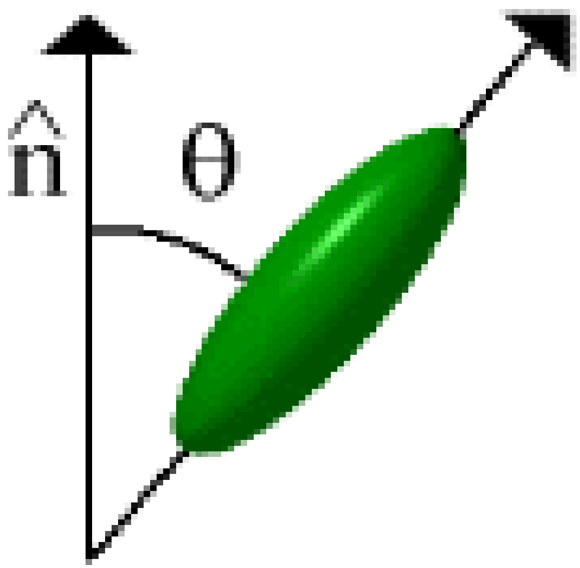
Liquids and gases
(uniform properties in all
directions).



LC state (mesomorphic state) is characterised by having a **long-range orientational order** and possible **partial positional order**

i.e., the tendency of the molecules (*mesogens*) to point along a common axis, called the *director.*

where ***theta*** is the angle between the director and the long axis of each molecule.



- In a liquid crystal, the molecules possess orientational order, i.e., the molecules tend to remain oriented in a particular direction.

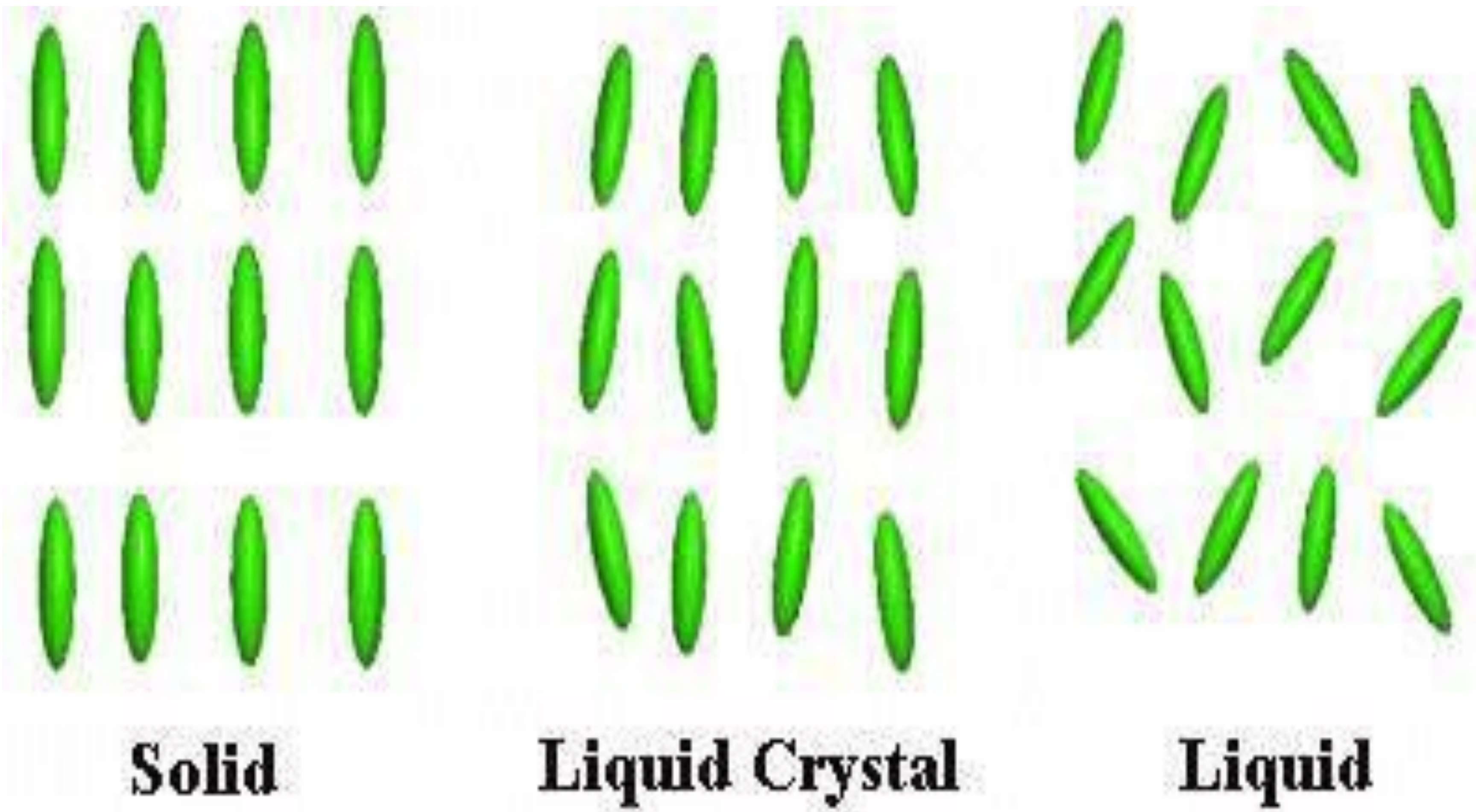
- **Director (n)**
- The direction of preferred orientation in a liquid crystal

- Since the molecules are in constant motion, in liquid crystal phase they spend more time pointing along the director than along any other direction.

- An average of 0° indicates perfect orientation and can be expected in solids.
- An average of greater than 45° indicates no orientational order and found in liquids.

- liquid crystals a smaller average angle with the director is observed which indicates orientational order.

A distinct state of matter in which the degrees of molecular ordering lie intermediate between the ordered crystalline state and the completely disordered isotropic liquid state



Characteristics of LC

a. Liquid crystalline nature should be at room temperature and the entire temperature range of the device operation

b. Chemically, electrochemically, photochemically and thermally stable

c. Permanent electric dipole, hence either a positive or negative dielectric anisotropy.

d. Should possess easily polarizable substituents

Types of LCs

- **Thermotropic LCs**, LC substances undergo transition by variation in temperature

  Mesophase formation is temperature dependent

  Ex: p-azoxy anisole

- **Lyotropic LCs**, LC substances undergo transition by the influence of solvent

  Mesophase formation is solvent dependent

  Ex: sodium stearate

Amphotropic LCs- exhibit both thermotropic and lyotropic mesophases

Thermotropic LCs

Classification

Based on the molecular phase structure

Nematic:

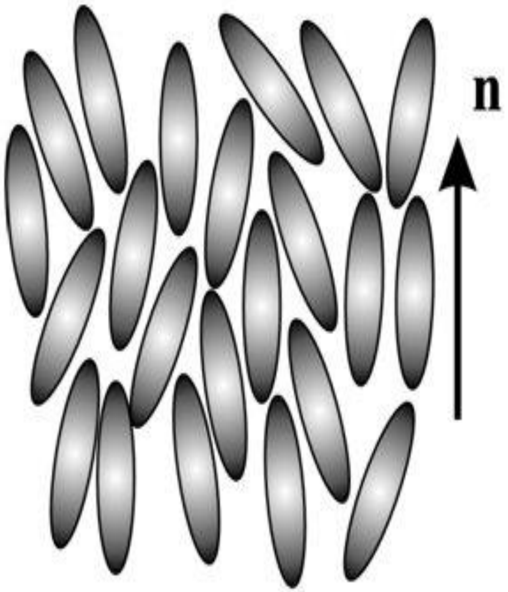
Smectic

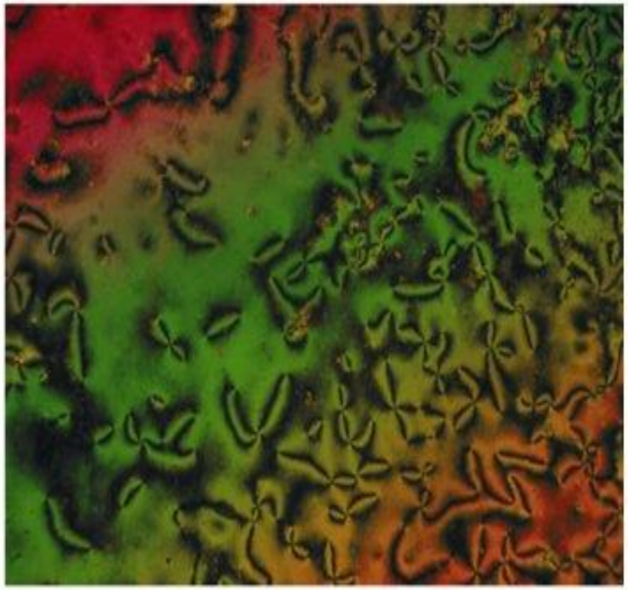
Columnar

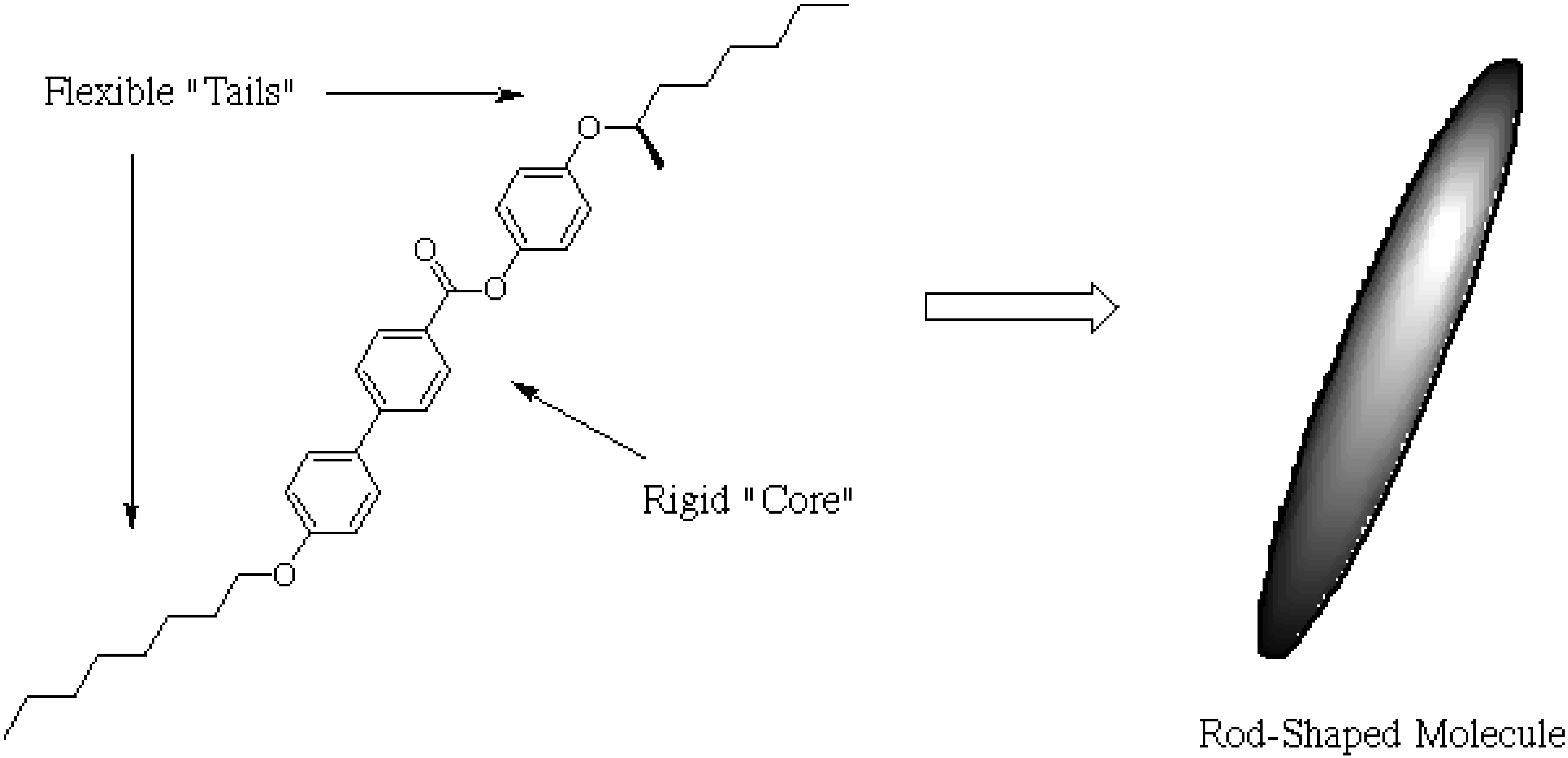
Cubic

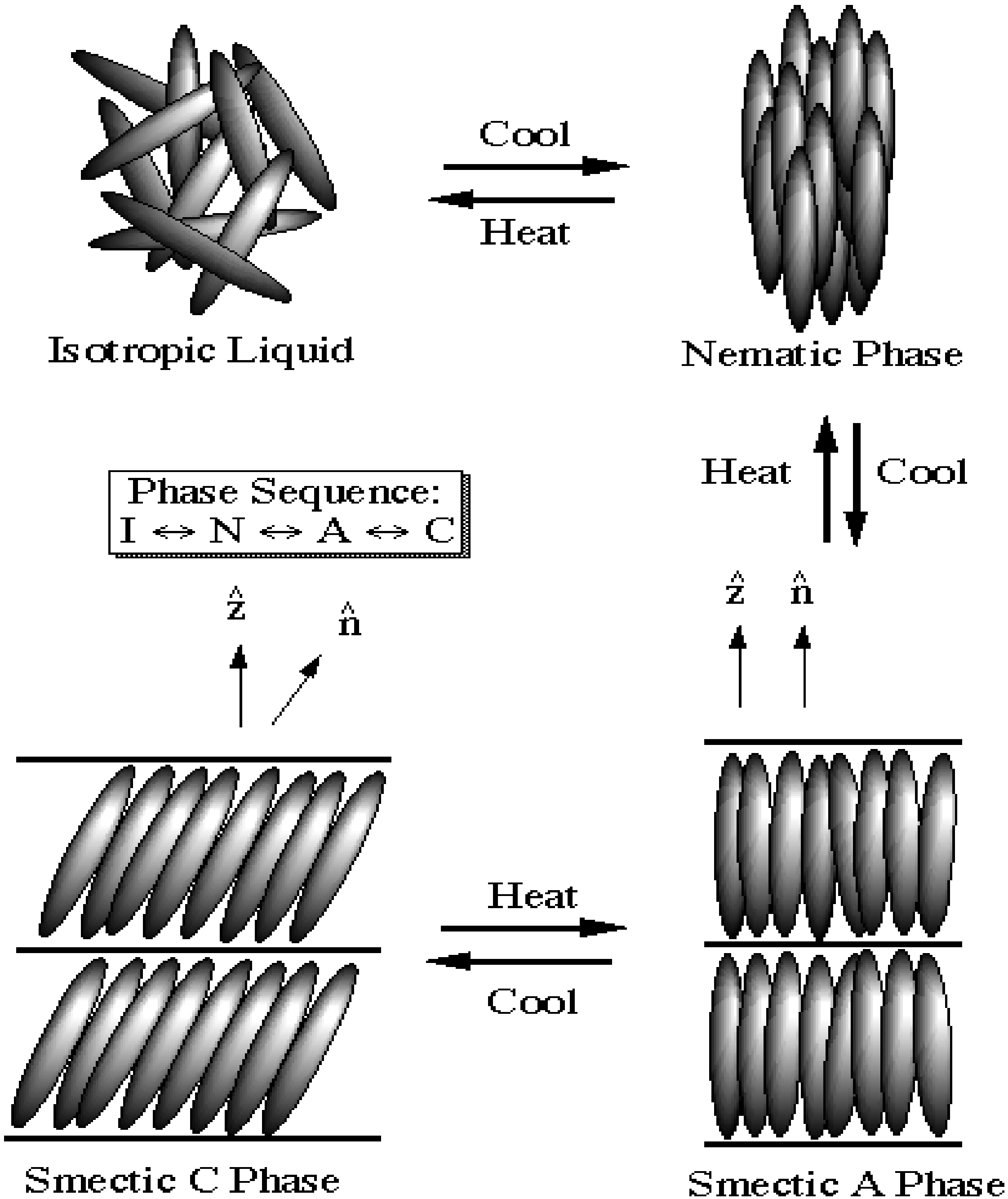
Nematic phase:

The least ordered mesophase (the closest to the isotropic liquid state) is the nematic (N) phase, where the molecules have only an orientational order



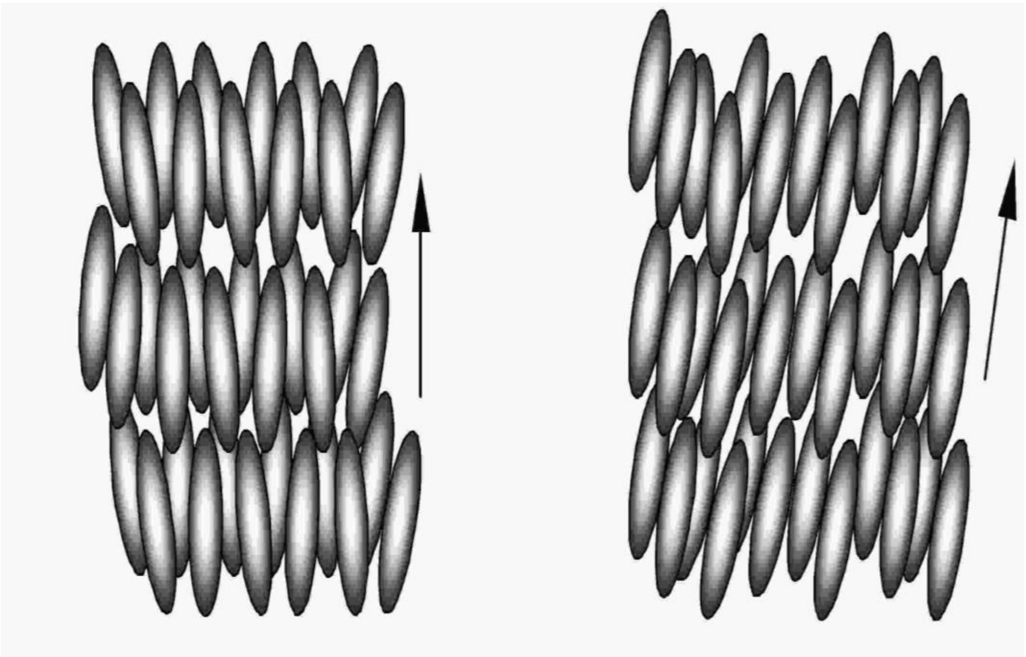


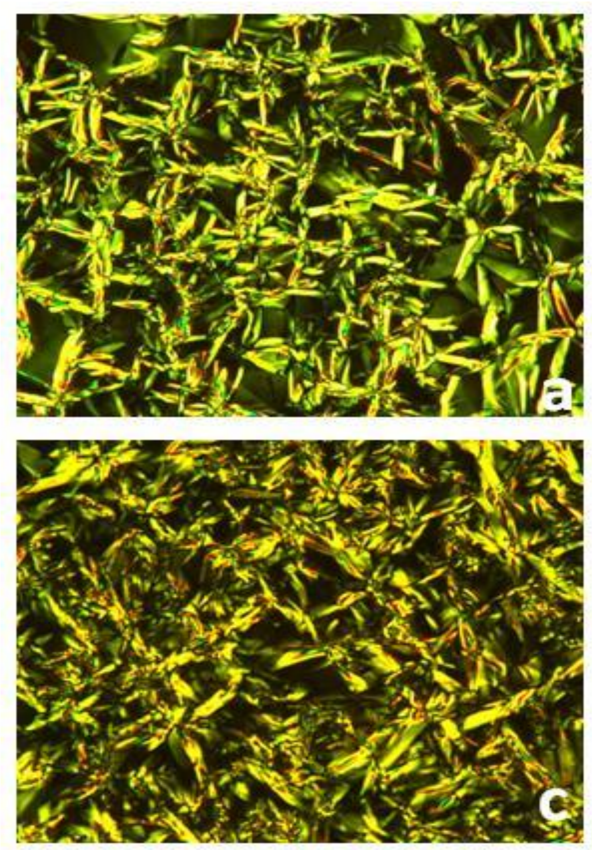

Flexible "Tails"
Rigid "Core"
Rod-Shaped Molecule

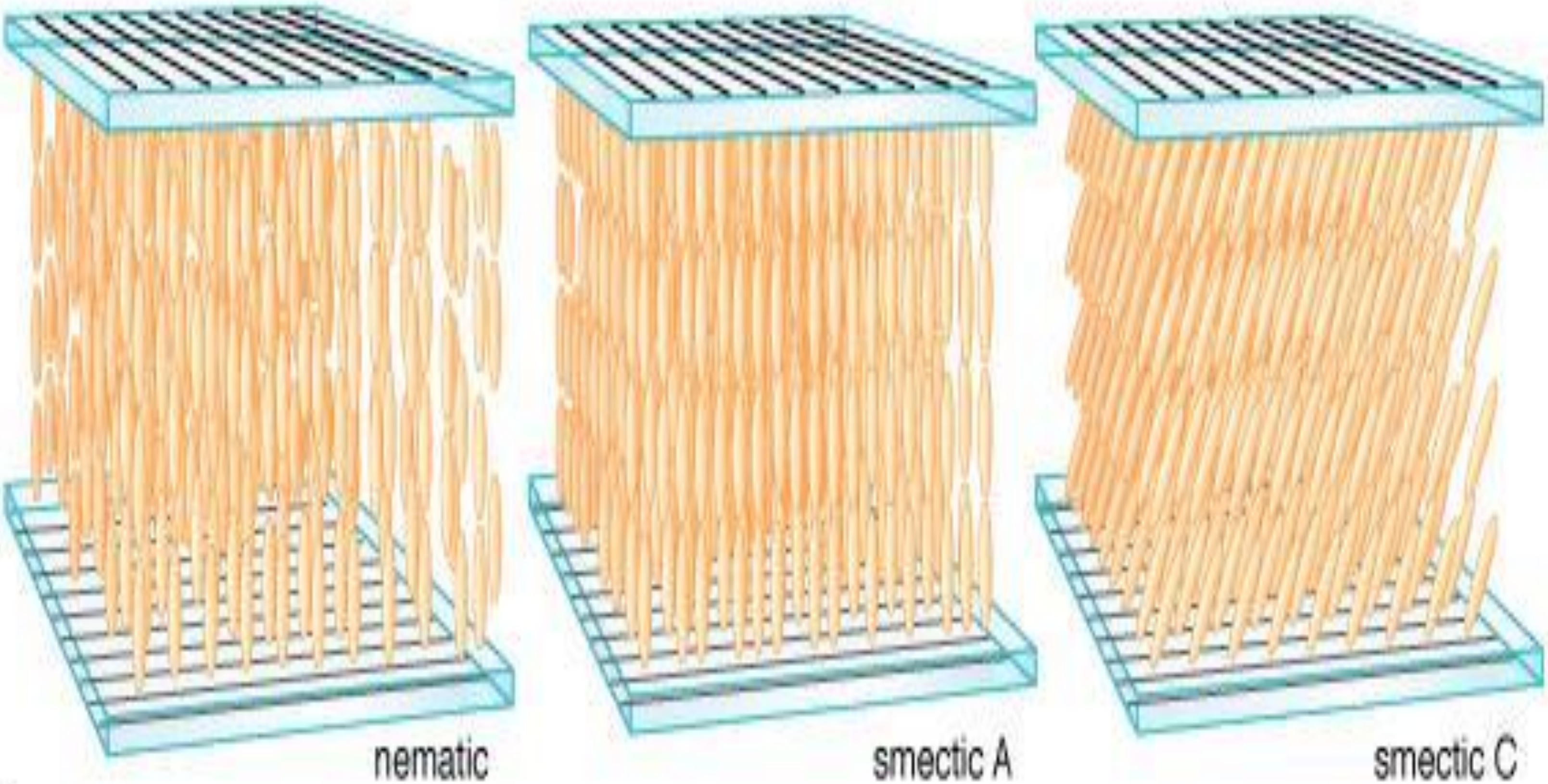

Cool
Heat
Isotropic Liquid
Nematic Phase
Heat
Cool
Phase Sequence:
I ↔ N ↔ A ↔ C
$\hat{z}$
$\hat{n}$
$\hat{z}$
$\hat{n}$
Heat
Cool
Smectic C Phase
Smectic A Phase

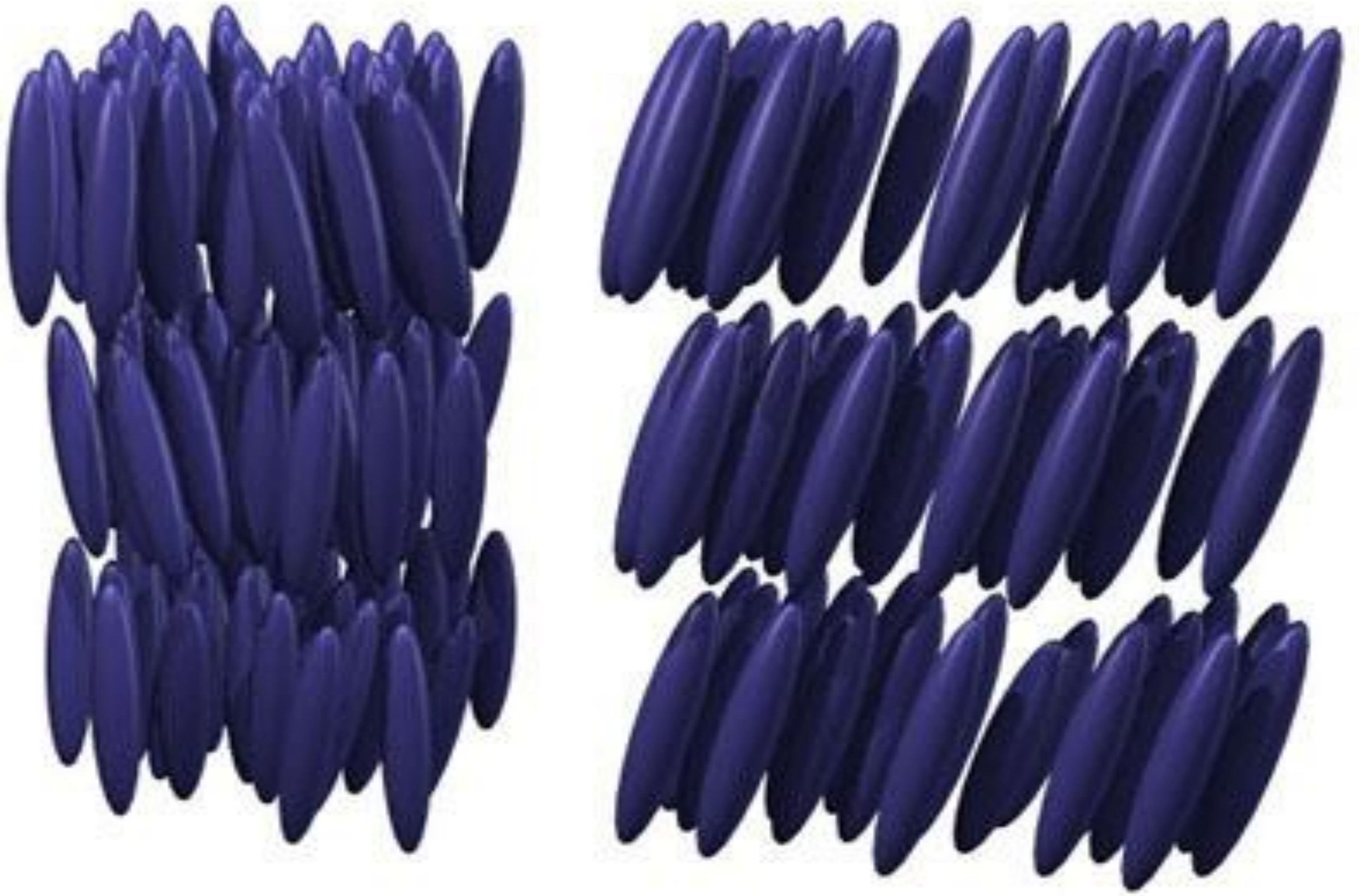
Smectic phases

In smectic (S) phase, in addition to the orientational order the molecules possess less or more positional order, such that the molecules organize in layered structures.





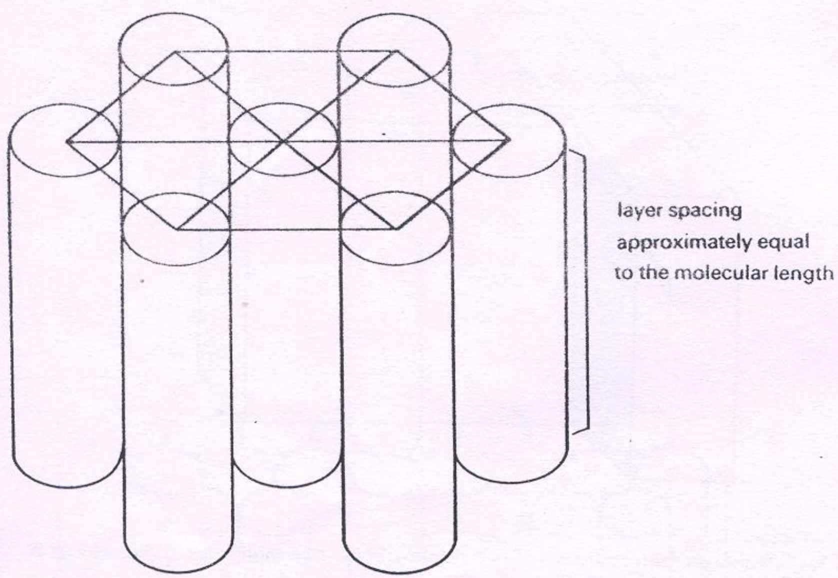

nematic
smectic A
smectic C



Schematic of alignment in the smectic phases. The smectic A phase (left) has molecules organized into layers. In the smectic C phase (right), the molecules are tilted inside the layers.

Smectic B

Smectic B phase has the molecules arranged within the layers in a hexagonally close-paced array with the molecular long axes perpendicular to the layer planes

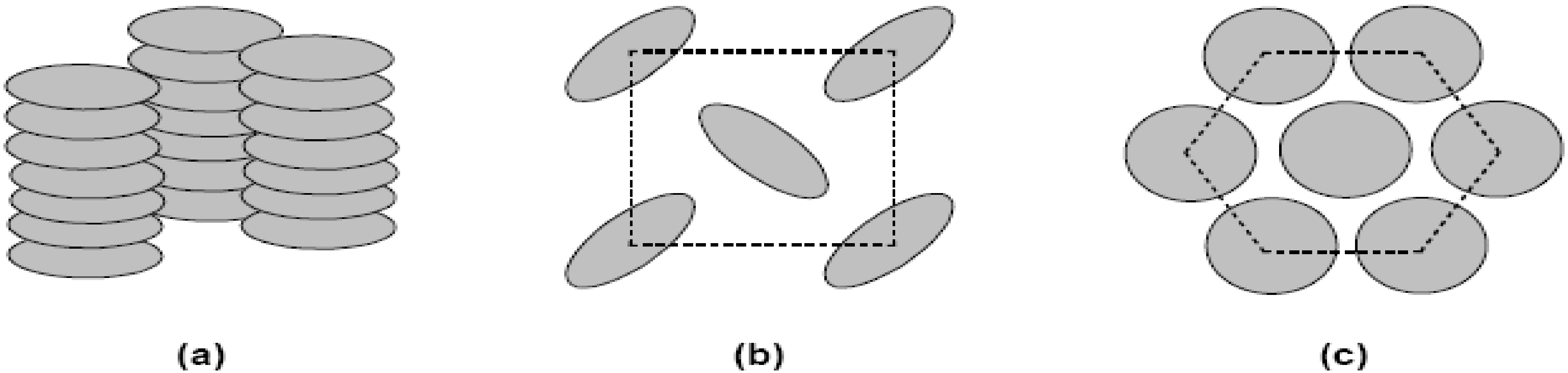


hexagonally close-packed smectic B phase

Columnar Phases

Columnar (Col) phases are more ordered. Here the disc-shaped cores have a tendency to stack one on the top of another, forming columns

Arrangement of these columns into different lattice patterns gives rise to a number of columnar mesophases, namely columnar rectangular (Col_r) and columnar hexagonal (Col_h)



(a) the general structure of Col phases, where the molecules are aligned in the same orientation and, in addition, form columns,

(b) representation of Col_r, and (c) representation of Col_h.

Cubic Phase of LCs

This phase exhibited by lyotropic LC

Structures with micellar lattice units

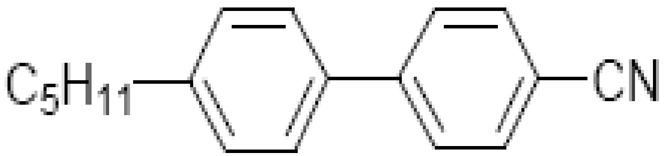
Thermotropic LCs

The essential requirement for a molecule to be a thermotropic LC is a structure consisting of a **central rigid core** (often aromatic) and a **flexible peripheral moiety** (generally aliphatic groups).

1 . Calamitic LCs
2. Discotic LCs
3. Banana shaped LCs
4. Polycatenar LCs

Calamitic LCs

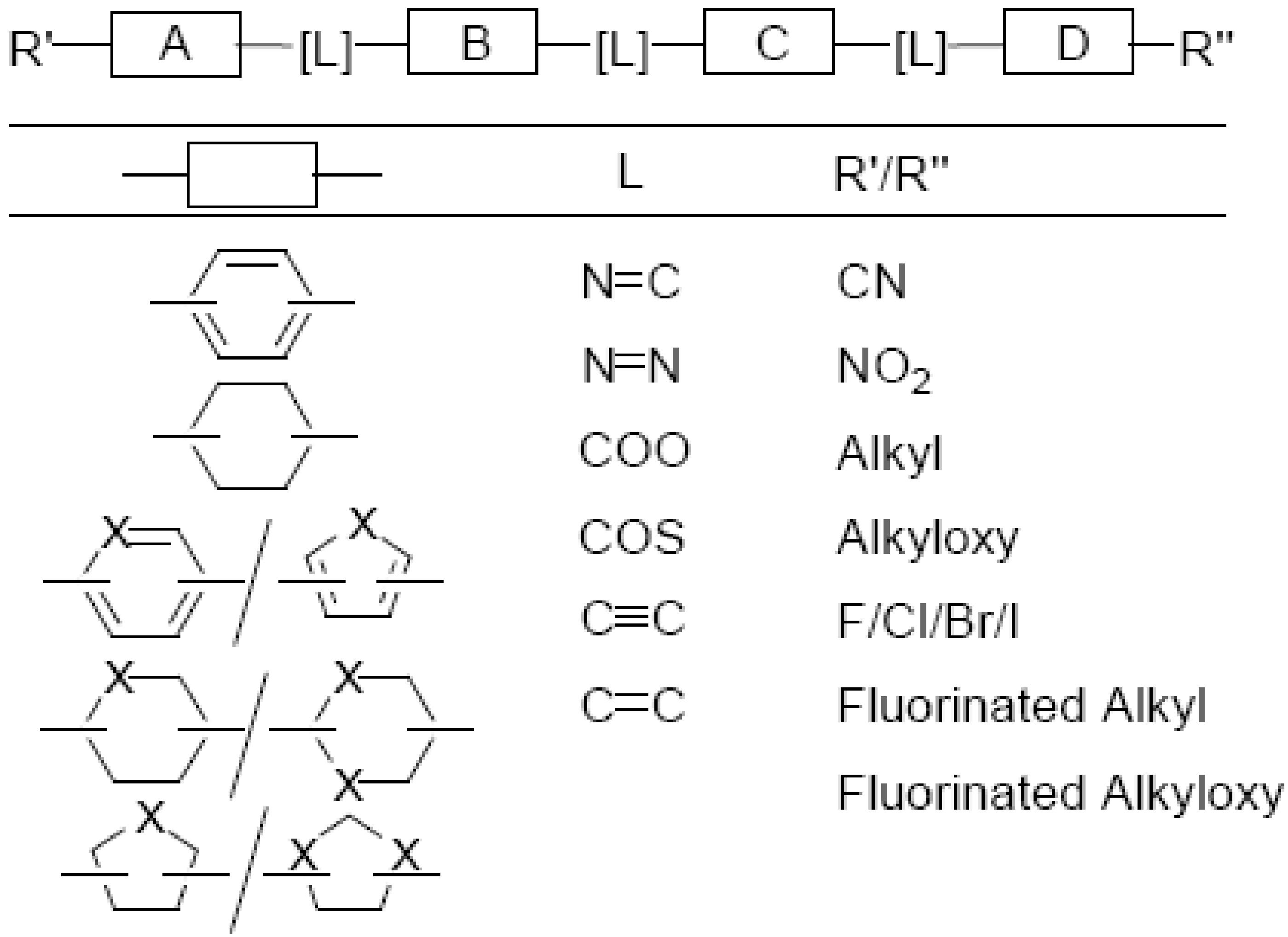
Calamitic or rod-like LCs are those mesomorphic compounds that possess an elongated shape, molecular length (l) being significantly greater than the molecular breadth (b).



Molecular structure of 4-pentyl-4'-cyanobiphenyl

(perfluorodecyl)-decane

The general molecular formulae of Calamitic LC s

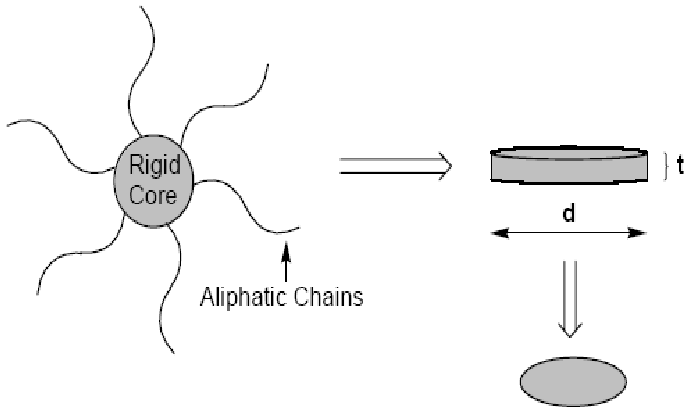


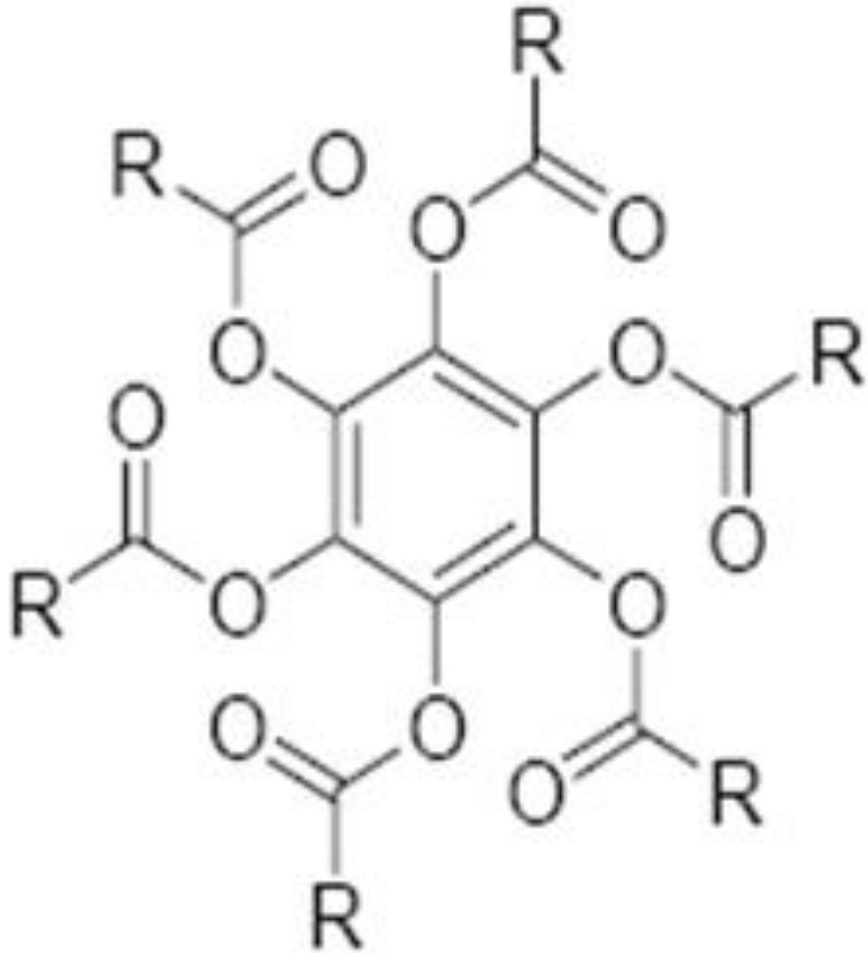
Discotic LCs

A second type of mesogenic structure, based on discotic (disc-shaped) molecular structures.

The first series of discotic compounds to exhibit mesophase belonged to the hexa-substituted benzene derivatives.

Structure comprising a planar (usually aromatic) central rigid core surrounded by a flexible periphery, represented mostly by pendant chains (usually four, six, or eight),





R = C_4H_9 to C_9H_{19}

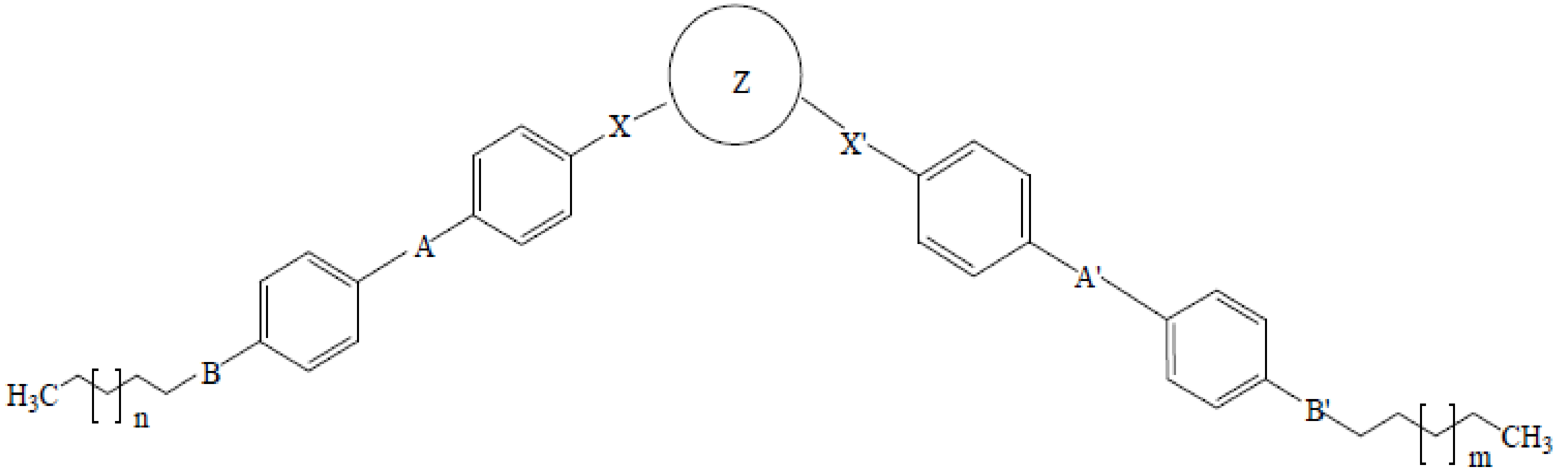
Molecular structure of first series of discotic LCs discovered

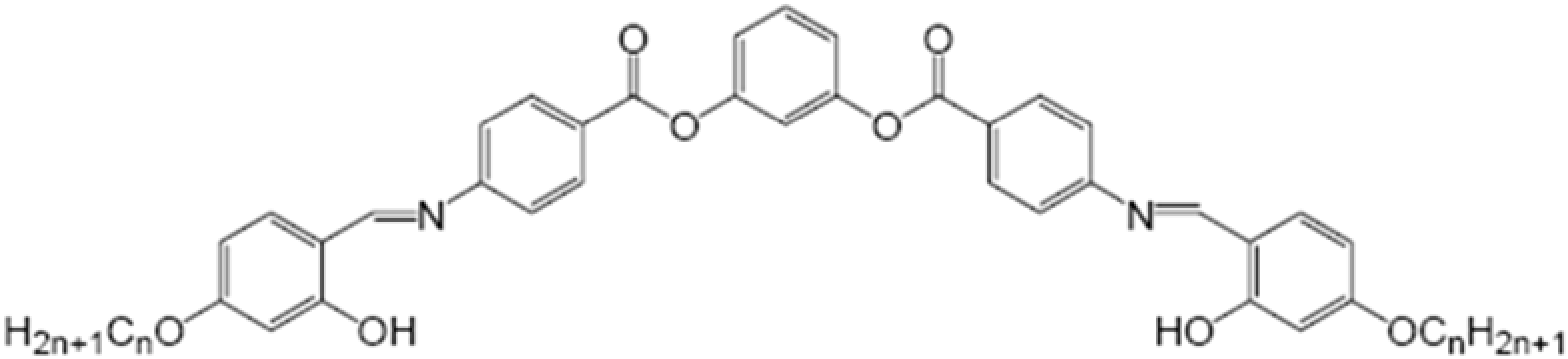
Benzene hexa n-alkanoate derivatives

Bent shape or Banana shaped LCs

- Mesomorphic compounds characterised by bent molecular structures
- It exhibit both nematic and/or smectic phase.
- It consist of two mesogenic groups linked through a rigid core so as to form bent shaped molecule but not linear.

Examples of bent LCs





Polycatenar Liquid crystals

- Hybrid class of thermotropic LCs
- Described with intermediate molecular features between rod-like and disc-like mesogens.
- the central core of polycatenar LCs comprises a calamitic region.
- It exhibit both calamitic (nematics/smectic) and discotic (columnar) depending on the specific molecular structure of the components

E.g., the tetracatenar mesogens

The numbers of the flexible end chains of the core can be indicated by using the term, *m*,*n*– polycatenary mesogen.

2,2-polycatenary mesogen

3,1-polycatenarymesogen

Lyotropic LCs

Lyotropic LCs are two-component systems where an amphiphile is dissolved in a solvent. Thus, lyotropic mesophases are concentration and solvent dependent.

The amphiphilic compounds are characterized by two distinct moieties, a hydrophilic polar “head” and a non polar hydrophobic “tail”.

Examples of these kinds of molecules are soaps and various phospholipids like those present in cell membranes

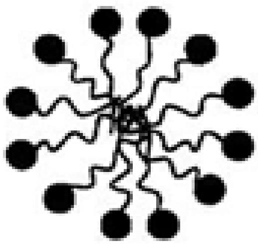
Soap + polar solvent like water- micelle formation

Soap + non polar solvent like hexane – inverted micelle

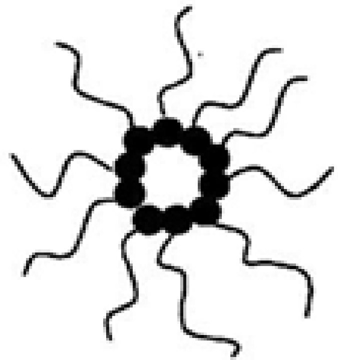
where the hydrophobic tails shield the hydrophilic head groups from the non-polar environment. Under certain conditions, these micelles further aggregate to form more complicated assemblies, such as lamellar and hexagonal phases, which generate lyotropic liquid crystal phases.

Lamellar phases are particularly significant as they form the structural basis for biological membranes

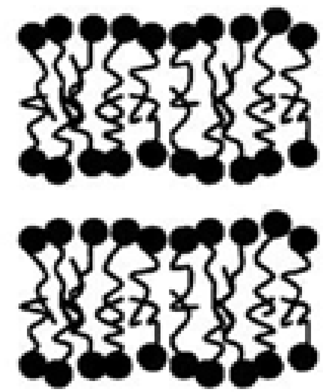
Micellar aggregates and phases formed by Lyotropic liquid crystals



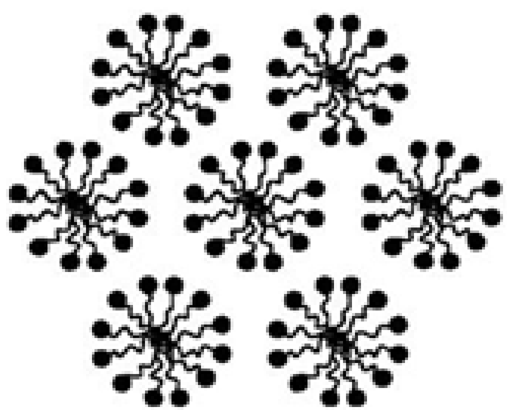
a.) micelle



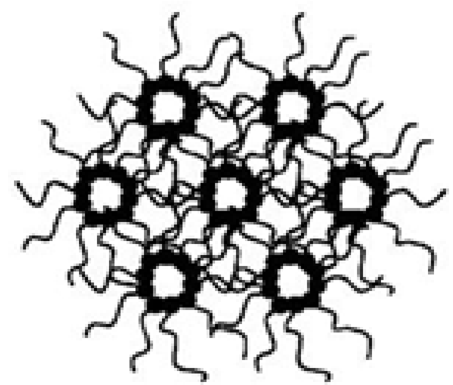
b.) inverse micelle



c.) lamellar



d.) hexagonal phase (H_1)



e.) inverse hexagonal phase (H_2)

Application of liquid crystal

Liquid crystal display

Liquid crystal thermometers

In medicine

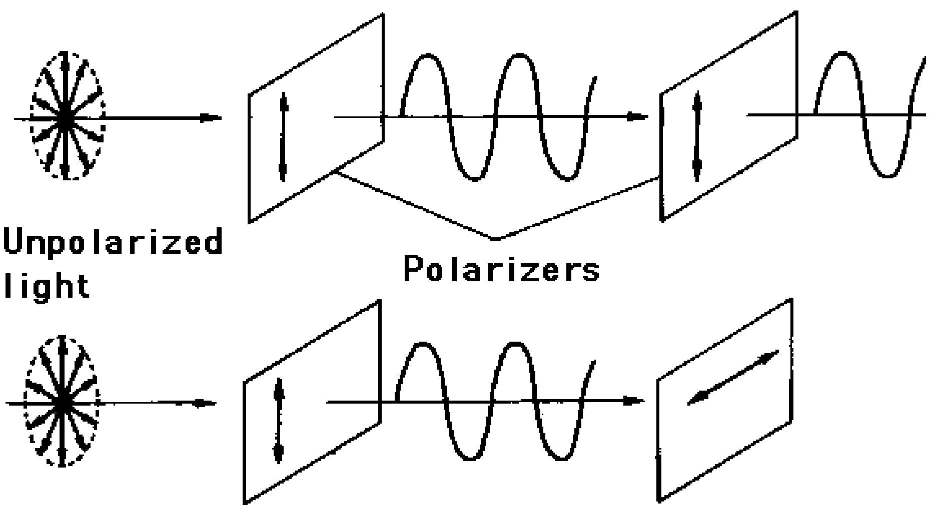
Optical imaging and recording

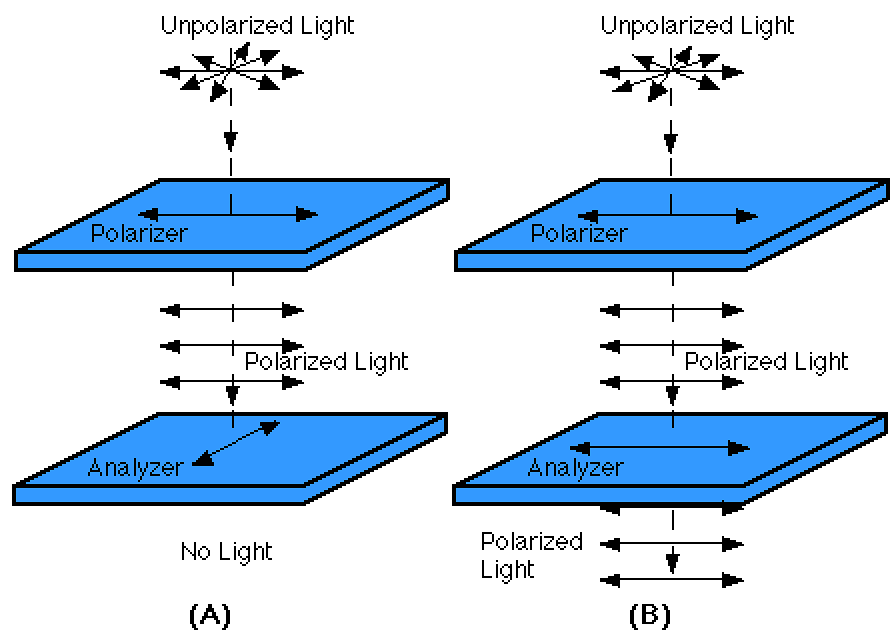
Non destructive mechanical testing

Polarization of light

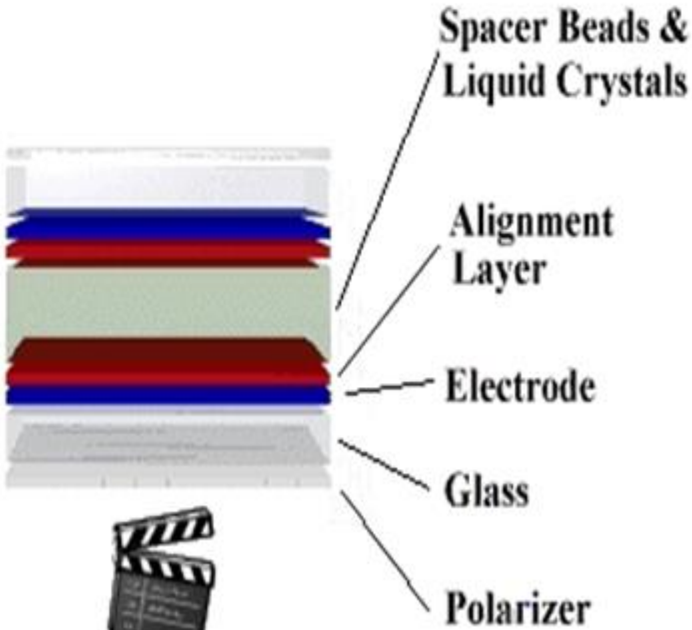
Polarization of light

- When unpolarized light passes through a polarizing filter, only **one plane of polarization is transmitted**. Two polarizing filters used together transmit light differently depending on their relative orientation.





Online Offline

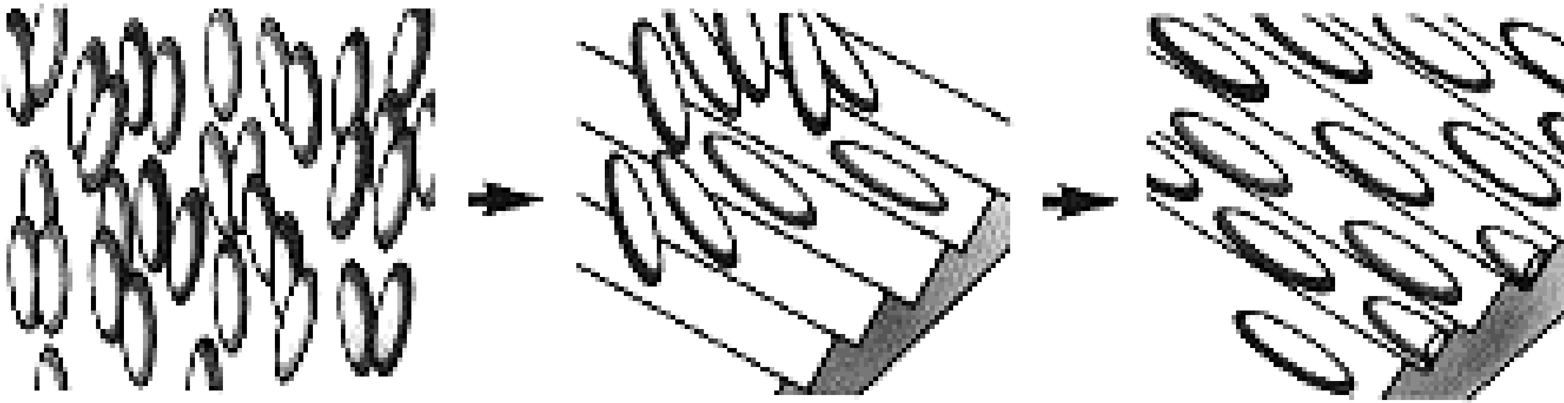


Construction of Liquid Crystal Display

- Two bounding plates (usually glass slides), each with a transparent conductive coating (such as indium tin oxide) that acts as an electrode;
- A polymer alignment layer- undergoes a rubbing process as grooves.
- Spacers to control the cell gap precisely

- Two crossed polarizers (the **polarizer** and the **analyzer**);

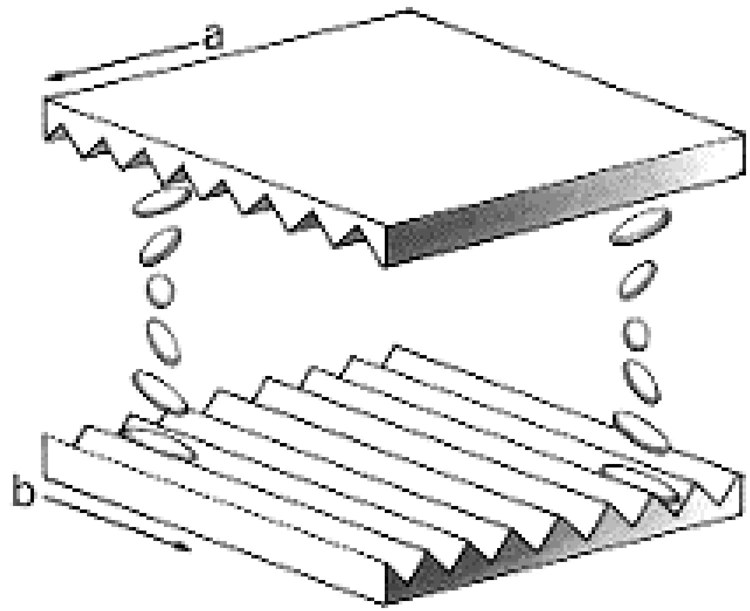
LCD Alignment



When coming into contact with a finely grooved surface (alignment layer), LC molecules line up parallel along groove due to their rod-like shape.

[Coating ITO glass with a layer of PVA and rubbing repeatedly creates these grooves.]

LCD Orientation

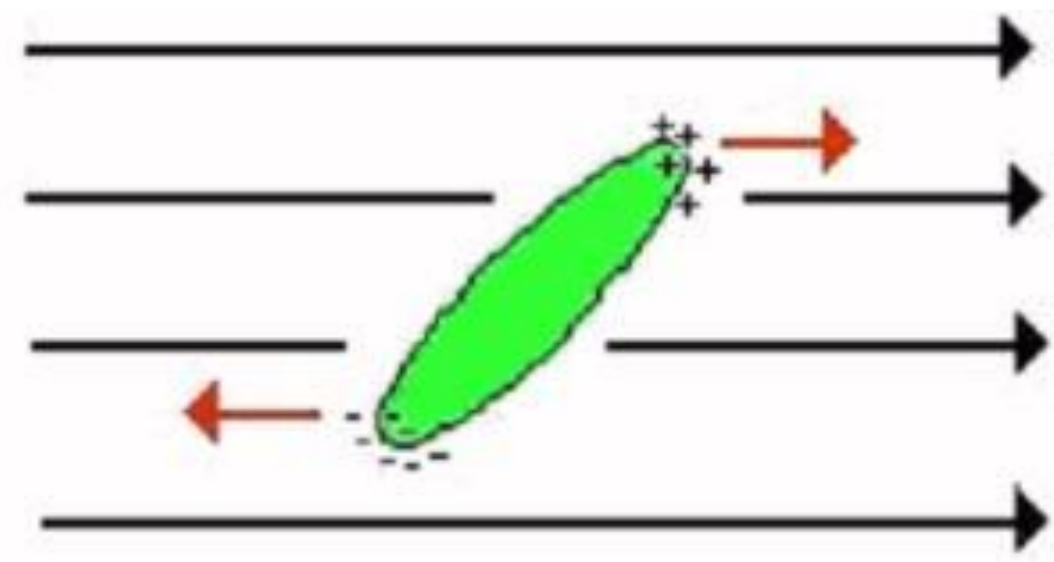


The molecules along the upper plate point in direction 'a' and those along the lower plate in direction 'b,' thus forcing the liquid crystals into a twisted structural arrangement./ (figure shows a 90-degree twist) (TN type liquid crystal)

Unique Properties of Liquid Crystals

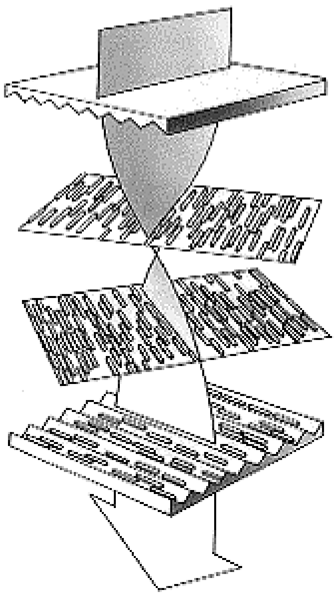
The orientation of Liquid Crystals can be affected by…

- Pressure
- Temperature
- Electrical Field



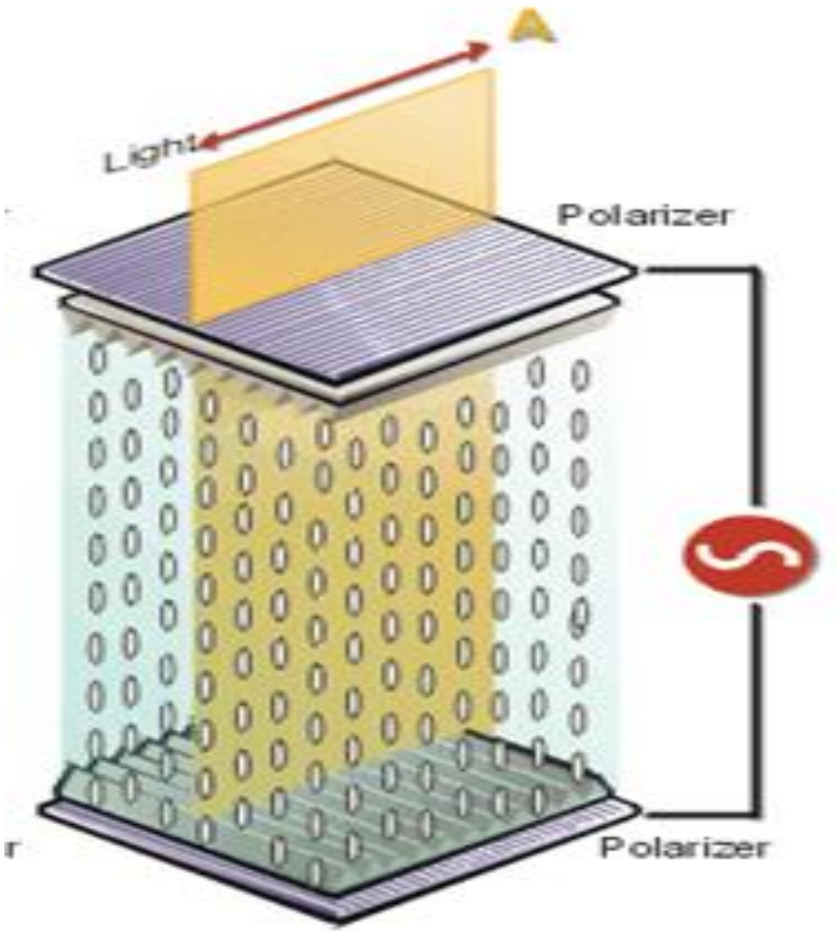
Light movement
Offline (no voltage is applied)

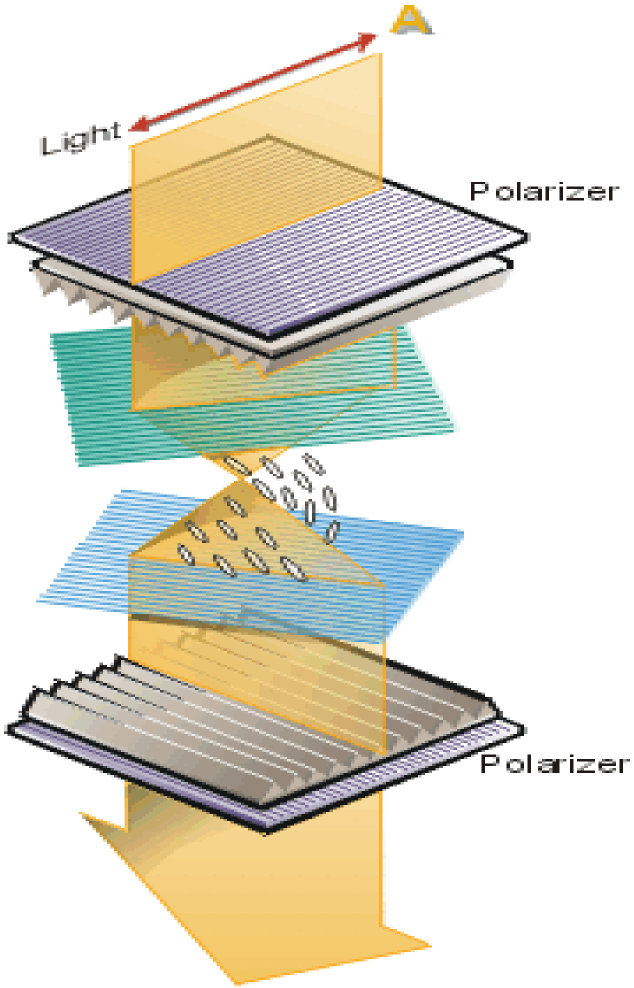
- Light travels through the spacing of the molecular arrangement.
- The light also "twists" as it passes through the twisted liquid crystals.
- Light bends 90 degrees as it follows the twist of the molecules.
- Polarized light pass through the analyzer (lower polarizer).

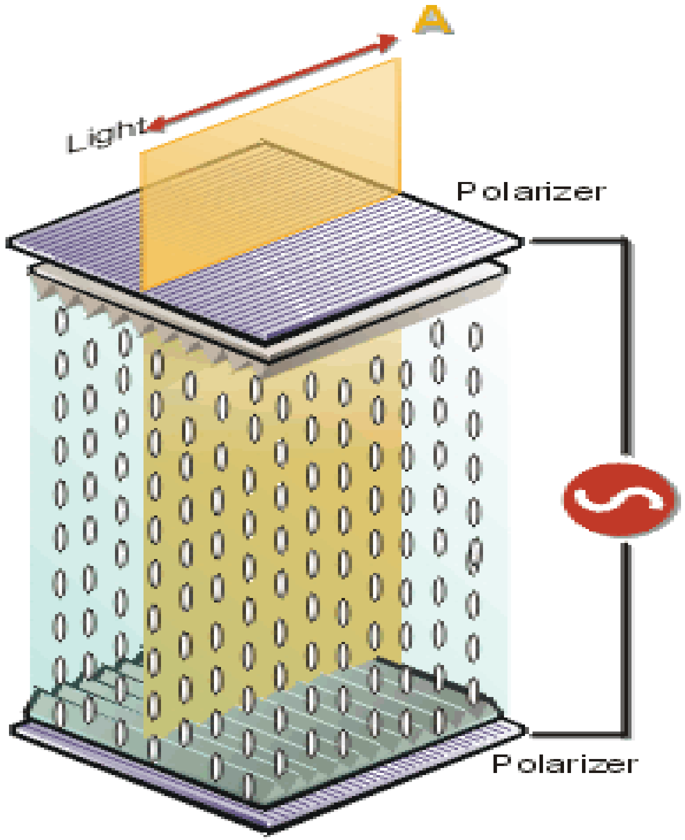


Molecules movement
Online (voltage is applied)

- Liquid crystal molecules straighten out of their helix pattern
- Molecules rearrange themselves vertically (Along with the electric field)
- No twisting thoughout the movement
- Forcing the liquid crystals into a straight structural arrangement. (Electric force)



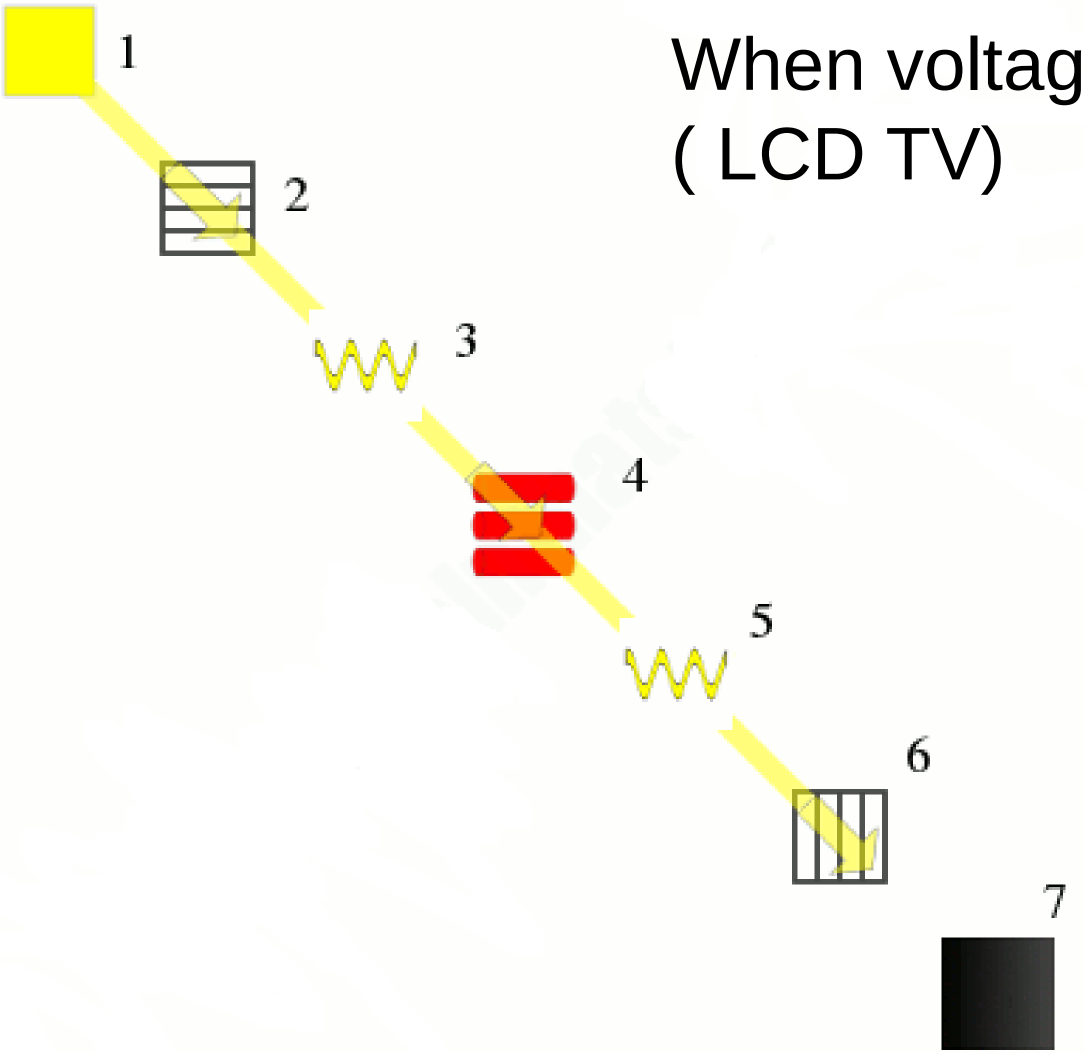




Screen appear dark

Screen appear bright

When voltage is switched on
(LCD TV)



1.Light travels from the back of the TV toward the front from a large bright light.

2.A horizontal polarizing filter in front of the light blocks out all light waves except those vibrating horizontally.

3.Only light waves vibrating horizontally can get through.

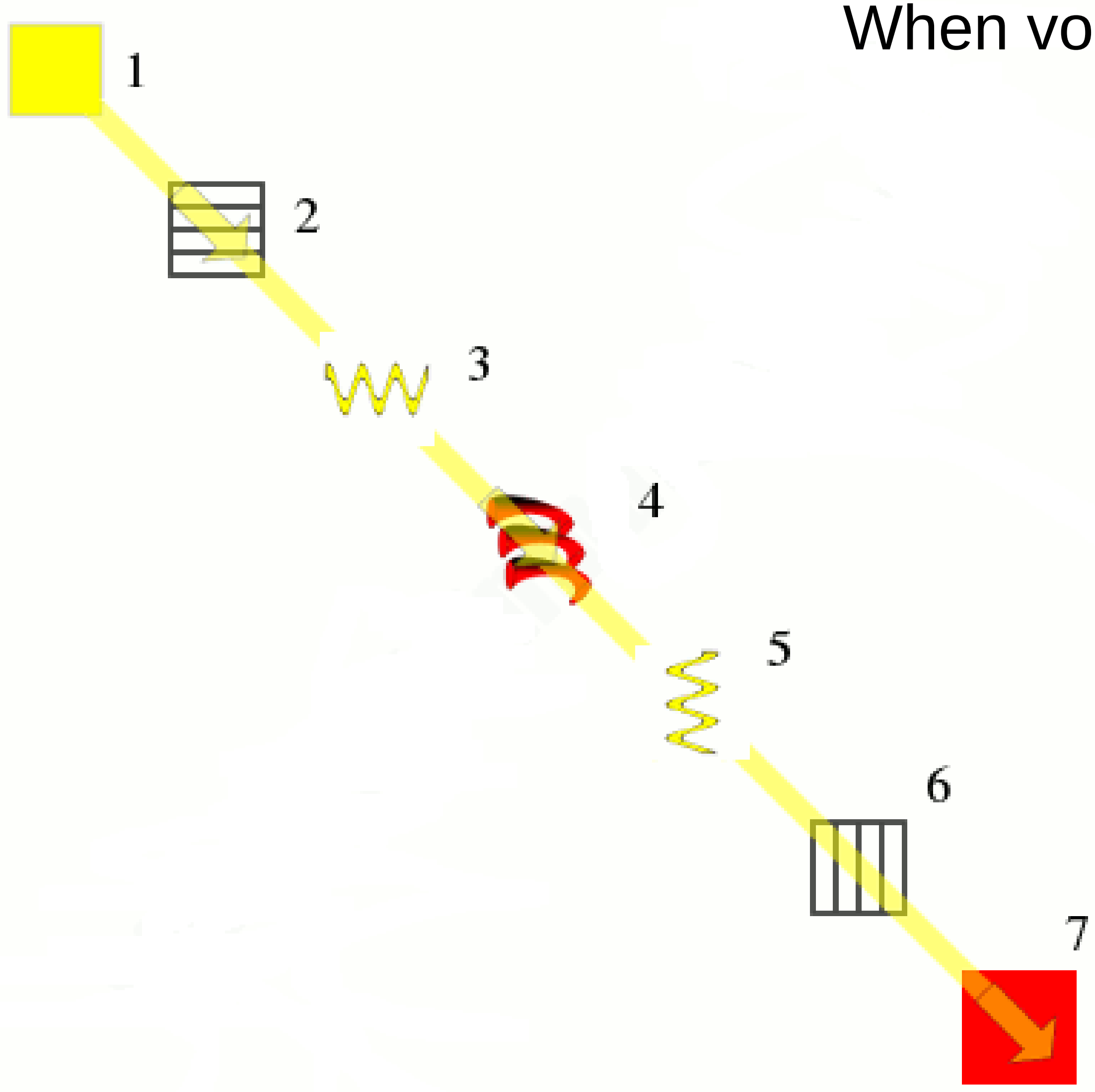
4.A transistor switches off this pixel by switching *on* the electricity flowing through its liquid crystals. That makes the crystals straighten out (so they're completely untwisted), and the light travels straight through them unchanged.

5.Light waves emerge from the liquid crystals still vibrating horizontally.

6.A vertical polarizing filter in front of the liquid crystals blocks out all light waves except those vibrating vertically. The horizontally vibrating light that travelled through the liquid crystals cannot get through the vertical filter.

7.No light reaches the screen at this point. In other words, this pixel is dark.

When voltage is switched off



1.The bright light at the back of the screen shines as before.

2.The horizontal polarizing filter in front of the light blocks out all light waves except those vibrating horizontally.

3.Only light waves vibrating horizontally can get through.

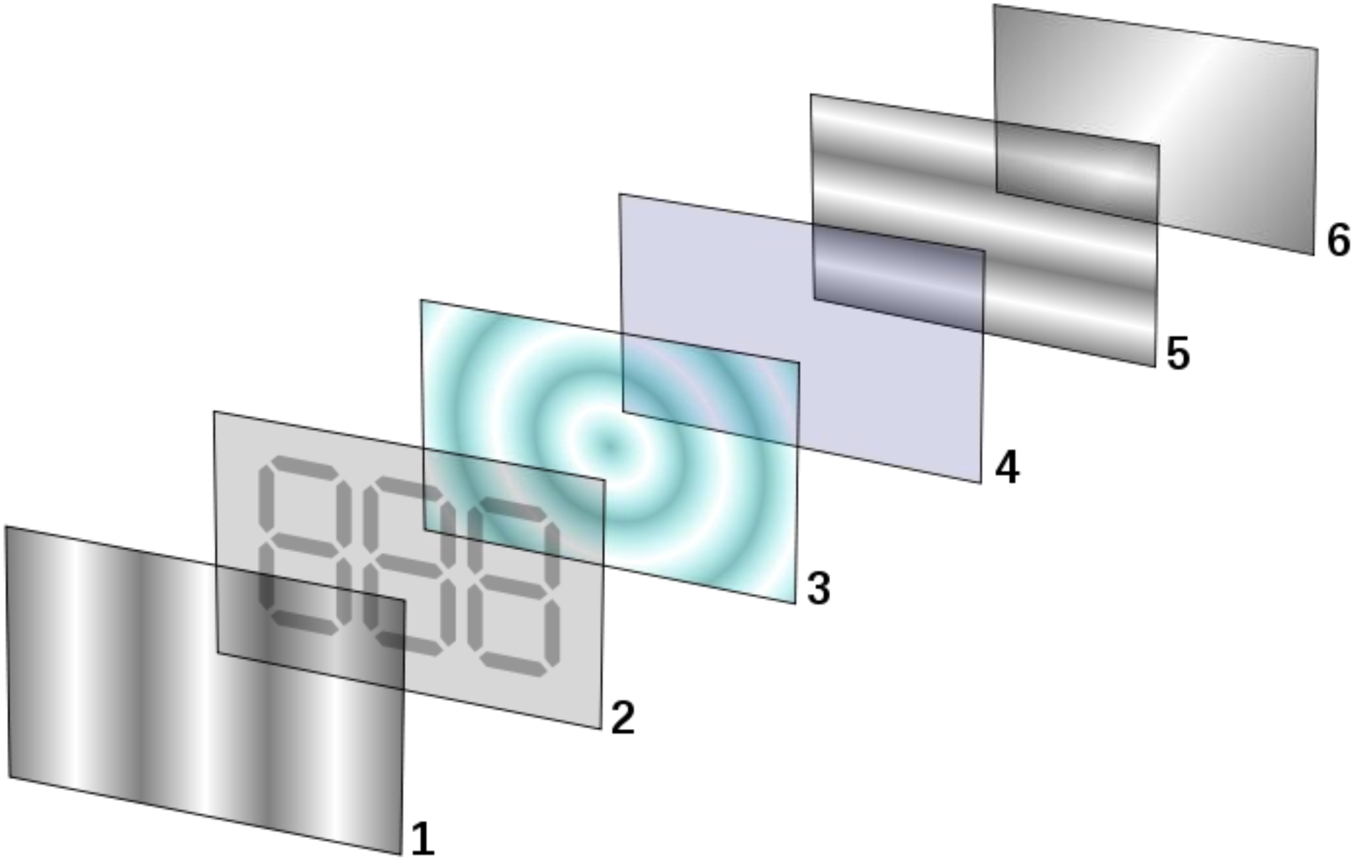
4.A transistor switches on this pixel by switching *off* the electricity flowing through its liquid crystals. That makes the crystals twist. The twisted crystals rotate light waves by 90° as they travel through.

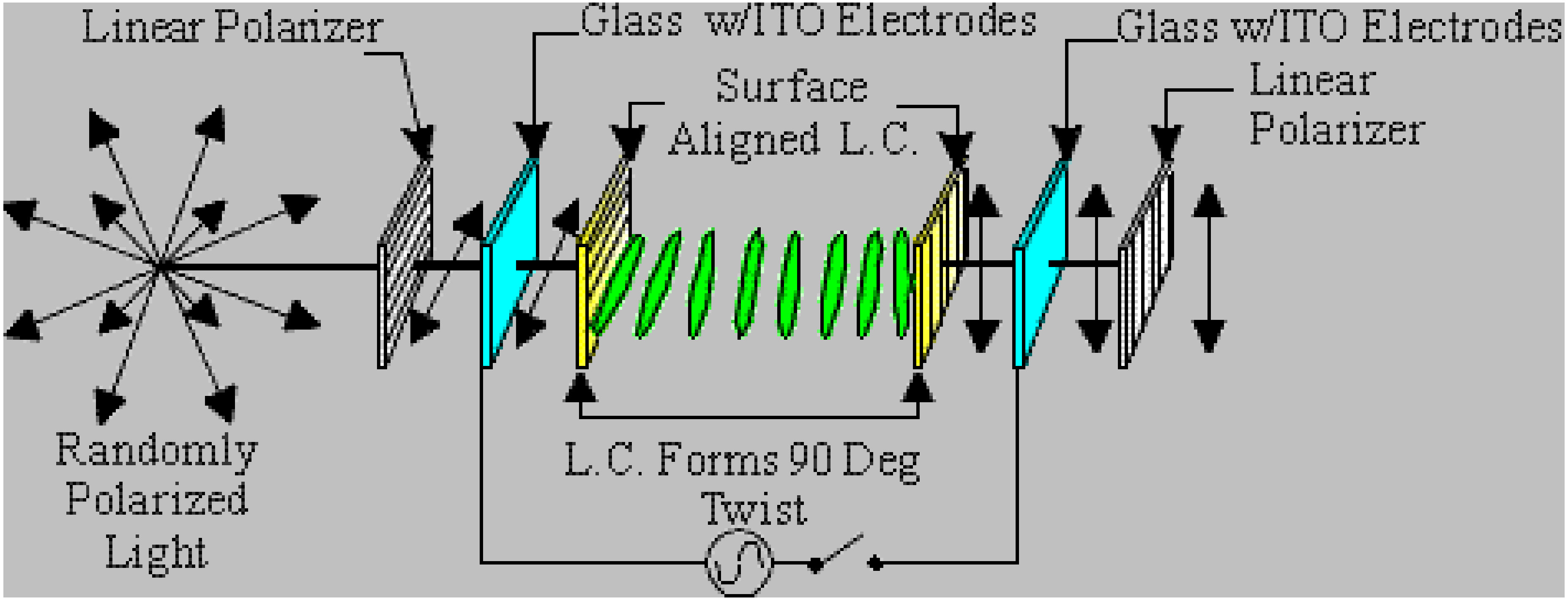
5.Light waves that entered the liquid crystals vibrating horizontally emerge from them vibrating vertically.

6.The vertical polarizing filter in front of the liquid crystals blocks out all light waves except those vibrating vertically. The vertically vibrating light that emerged from the liquid crystals can now get through the vertical filter.

7.The pixel is lit up. A red, blue, or green filter gives the pixel its color.

Structure of liquid crystal display: 1 – vertical polarization filter, 2,4 – glass with electrodes, 3 – liquid crystals, 5 – horizontal polarization filter, 6 – reflector




Linear Polarizer
Glass w/ITO Electrodes
Glass w/ITO Electrodes
Surface
Aligned L.C.
Linear
Polarizer
Randomly
Polarized
Light
L.C. Forms 90 Deg
Twist