Prayogik Rasayan

Liquid Crystals: A Fascinating Fourth State of Matter

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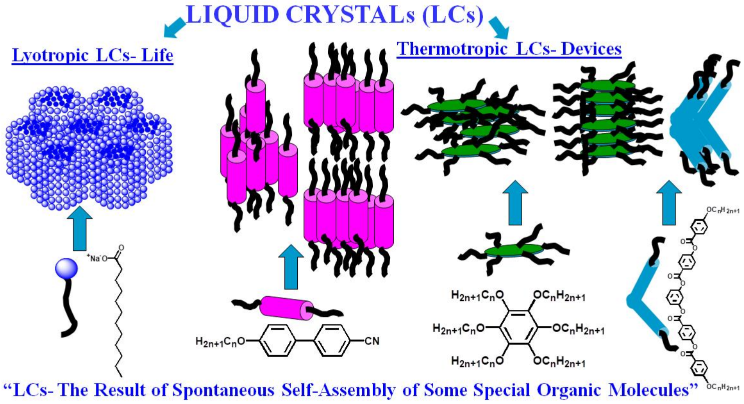
Abstract



Liquid crystals (LCs) are a distinct phase of matter whose structural order is intermediate between conventional liquids and solids. They have attracted considerable attention not only because they form the basis of every living being but also due to their ability to show a range of unique properties that are promising from the viewpoints of both fundamental research and applied science. LC phases formed by shape-anisotropic organic molecules such as rod-like and disk-shaped (so-called conventional mesogens) have been investigated exhaustively over the years. Consequently, they have been employed in different technological applications. However, during the last two decades or so, several new mesogenic motifs differing in their shape-anisotropy from conventional LCs have been realized not only to understand the structure-property correlations but also to widen their functional characteristics required for many other non-display applications, including their usage in the organic field-effect transistors, organic photovoltaics, light emitting diodes etc.

Keywords: Liquid crystals, discotics, calamatics, LCD, chirality

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1. Introduction

Conventionally, matter exists in one of the three distinct aggregation states: solid, liquid and gas. Crystalline solids possess both positional and orientational order in which the constituent molecules are constrained to occupy specific sites in a lattice and point their molecular axes in specific directions (Fig.1a). Due to this rigid arrangement of molecules, most of the crystalline solids are optically anisotropic. In liquids, the molecules diffuse randomly throughout the container with the molecular axes tumbling wildly and the state is optically isotropic (Fig.1d). In the gaseous state, the molecules move much more freely through the container's entire volume without any constraint.
Phases, having higher order than that of liquids but lower order than the solids exist in nature. Such states of matter have been grouped and called "liquid crystals" (LCs).[1] Figure 1b & c shows the liquid crystalline phases called nematic and smectic phases, in which molecules maintain a preferred orientational direction (known as the director and represented by the symbol "n").

The term "liquid crystals" is a well-accepted terminology used to describe these unique states of matter that are characterized by the properties of both solids and liquids. A molecule that exhibits the liquid crystalline state is called "mesogen" and exhibits the phenomenon of "mesomorphism."[2-8] the intermediate phase between the solid and liquid is referred to as a "mesophase." In LC phases, the constituent molecules diffuse similar to the liquid molecules; however at the same time, they maintain some degree of orientational order and in some cases positional order as well. It may be mentioned here that there is another phase of matter that possesses positional order but no orientational order and has been called "plastic crystals."

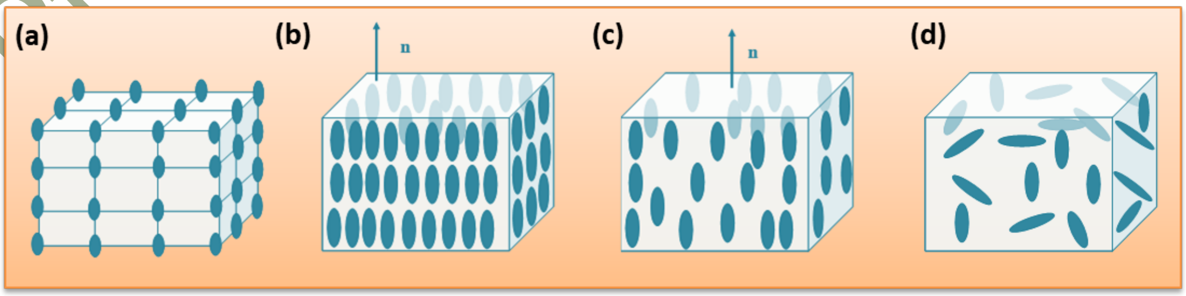

Figure1. Schematic representation of arrangement of molecules (a) solid-state (crystal) (b) & (c) liquid crystals and (d) liquid-state.

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Compared to solids, the molecules in LC phases have greater intermolecular and intramolecular mobility.They are optically anisotropic simillar to crystals. The transmitted light has different velocities in different directions. Hence these are double refractive or birefringent and exhibit intense colour patterns upon observing through crossed polarizers. These patterns are reffered to as textures, the unique distinguishing feature of individual LC phases

To date, as we shall see in later sections, several liquid crystalline phases have been characterized and classified according to the molecular ordering they possess. The difference between the many LC phases is quite subtle. Several different techniques, along with good experience, are essential for identifying the LC phases. Polarizing optical microscope (POM) is the most important and widely used tool for identifying and characterizing LC phase by analyzing the optical textures. The samples are placed between two simple glass plates or between pre-treated glass plates for the desired alignment. The alignments can be of two types. One with director parallel to the substrate's surface called "homogenous" whereas the one with director normal to the surface is referred to as "homeotropic".Differential scanning calorimetry (DSC) is a complementary tool to POM studies that determine the exact temperature at which the phase transition occurs and provides the information regarding the associated enthalpy change. However, DSC studies cannot identify the LC phase. However, the magnitude of enthalpy change provides some information about the degree of molecular ordering present in the mesophase. A more sophisticated and powerful technique used to identify and classify mesophases is X-ray diffraction technique. It gives information regarding the extent of positional and orientational order present of the mesophase under examination. Hence, these techniques are extremely helpful for the classification of mesophases.

II.CLASSIFICATION OF LIQUID CRYSTALS

Materials exhibiting mesophases are classified into two categories, namely:

(i) Thermotropic LCs
(ii) Lyotropic LCs

II.1.Thermotropic Liquid Crystals

Liquid crystalline materials are referred to as thermotropic if they display phase transitions due to temperature changes. Generally, they are shape-anisotopic organic or metal-containing organic molecules (mesogens), and their self-assembly, caused due to the action of heat, yields thermotropic LC phases. Upon heating mesogen, at a given melting temperature, the solids sharply transform into LC (anisotropic) phase wherein, along with the molecular mobility, long-range order exists in at least orientation of mesogens. Upon further heating, at a given clearing (high) temperature, the long molecular axes of the mesogens randomly orient due to loss of the orientational order, resulting in the liquid (isotropic) phase. Indeed, on cooling from the isotropic state, these phase transitions can be reversed. The mesogens may show a series of LC phases essentially differing in their structural symmetries. Here, the disappearance in one, two, or three dimensions of long-range translation periodicity in the crystal may precede the long-range orientational order collapse. The LC phases observed above the melting point during the heating process are stable and known as **enantiotropic**, while those phases that occur below the melting point on supercooling the high-temperature phase are metastable and called **monotropic.**

Generally, organic and metal-organic compounds display the thermotropic LC behaviour. Among a vastnumber of known organic compounds, only a small fraction exhibit this property. The compounds with the rigid and flexible region are capable of exhibiting mesophase behaviour. The aromatic and non-aromatic cores provide the rigidity or stiffness, whereas paraffinic chains constitute the molecules' soft or flexible regions. A specific combination of these two distinct regions is the reason for the anisotropic molecular shape. Hence this molecular shape anisotropy plays a crucial role in deciding the formation of liquid crystalline and non-liquid crystalline phases. Anisotropic molecules that are rod-shaped are called calamitics while the ones having disc-shaped are discotics.

II.2.Lyotropic liquid crystals

Lyotropic LCs result from a solvent's action (water is a commonly used solvent) on individual molecules and are usually multi-component systems in which the individual component may or may not be mesomorphic. In thermotropic LCs, the mesophases appear entirely due to the effect of temperature. Specific amphiphilic molecules consisting of hydrophilic (polar) and lipophilic (non-polar) groups can form thermotropic mesophases in their pure form and show lyotropic mesophases upon addition of solvent; they are referred to as amphotropic LCs. Lyotropic LCs are frequently encountered in everyday life; the most common example is the dissolution of soaps and detergents in water that furnishes lyotropic LC phases. Another example is cell membranes, which result from lyotropic mesophase generated from the dissolution of phospholipids in water. Thus, our life itself critically depends upon lyotropic LC systems. However, thermotropic LCs, especially nematic LCs, have attracted a great deal of attention as they have been used as media in display devices; from simple wristwatch and calculator displays, to colour television displays.

III. CLASSIFICATION OF THERMOTROPIC LIQUID CRYSTALS

Thermotropic liquid crystals are further classified into:

(i) Conventional liquid crystals
(ii) Nonconventional liquid crystals

III.1. Conventional liquid crystals

Generally, thermotropic conventional LCs are constituted by shape-anisotropic molecules (mesogens), either rod-like[1-15] or disc-shaped.[16-23] Using these classical rod-like (calamitic) and disc-shaped (discotic) mesogenic cores, various monomers,[2-4] oligomers[5] and polymers[7] exhibiting thermotropic mesomorphism have been realized, and their properties have been investigated.[1,2] The incorporation of molecular chirality in the molecular architecture of such materials have yielded chiral mesogens that are known to display helical (chiral) superstructures and the frustrated LC phases.[24-36]

III.2. Nonconventional liquid crystals

There is yet another important class of thermotropic LCs, called nonconventional LCs, where the mesogens' anisotropic shape deviates significantly from conventional LCs. It has been well demonstrated over the years that the mesogens with such unconventional molecular structures also display liquid crystallinity. The combination of incompatible molecular fragments such as flexible units (tails and spacers) and rigid (anisometric) cores(s) is such that the resultant molecular architecture does not resemble classical structural design. Notably, they display complex/intriguing mesophases, besides conventional LC phases. Examples of nonconventional LCs include polyhydroxy amphiphiles,[24-26] taper shaped molecules,[24-26] rod-coil molecules, [24-26] oligoamides, [24-26] polycatenars, [24-26] bent-core (bananashaped &V-shaped) LCs,[27-36] oligomers (dimers, trimers, tetramers, etc.)[37-59] and soft-nano composites.[760-92]

III.1.1. Calamitic liquid crystals

The most common type of compounds that forms LC phases is a rod-shaped molecule in which one molecular axis is much longer than the other two. Such compounds represent a class of LCs called calamitics. Figure 2 shows a general template that can be used to describe the precise molecular structure of low molar mass (monomeric) calamitics.

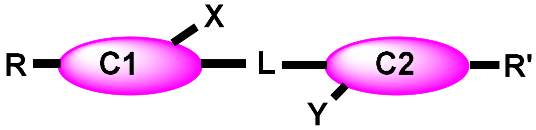

Figure 2. General molecular structure of calamitics

C1 and C2 are the rigid cores.They are generally aromatic such as 1,4-phenyl, 2,5-pyrimidinyl, 2,6-naphthyl etc. However, they can also be formed by alicyclic molecules like trans-4-cyclohexyl, cholesteryl etc. A covalent linkage can sometimes connect the two cores, and these cores can also be linked via a linking unit L. The linking units can be -COO -, -CH_2-CH_2, -CH=N-, -N=N- etc. The R and R' are the terminal tails are composed of alkyl and alkoxy chains. One or both the terminal units can possess polar substituents such as CN, F, NCO, NCS, NO_2. In some exceptional cases,the rigid cores might also contain lateral units denoted by X, and Y. Inclusion of molecular chirality in rod-like molecules furnishes chiral LCs and is known to exhibit various chiral structures.

IV. General liquid crystalline phases of calamatic liquid crystals

IV.1. Nematic (N) phase

It is the most uncomplicated LC phase, which occurs just below the isotropic phase. The surface conditions affect this mesophase's observation and give rise to schlieren, marble and pseudo-isotropic textures.[4,8] This mesophase is characterized by the absence of positional order and the existence of orientational order alone. As can be observed from Figure 3, molecules orient along a particular direction that is referred to as director (n).[93]

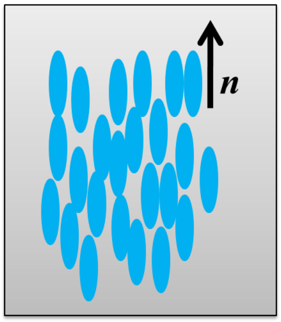

Figure 3. Schematic representation of theorganization of molecules in the nematic phase

IV.2. Cholesteric (N*) mesophase

The chiral variant of the normal nematic phase is referred to as chiral nematic or cholesteric phase. Generally, this phase is observed in the LCs formed by the chiral molecules. In this phase, adjacent molecules orient/tilt (Fig. 4.)concerning one another, which leads to the formation of a helix by the local director with a pitch. As can be seen from the image, the pitch represents one full turn of the helix.[3] The twist can either be clockwise or anticlockwise, which in turn depends on the molecular conformation. Similar to regular nematic phase, this phase is also surface dependent and gives rise to the focal-conic fan, fingerprint, droplet and oily streak (planar) textures based on the surface on which it is present.[12]

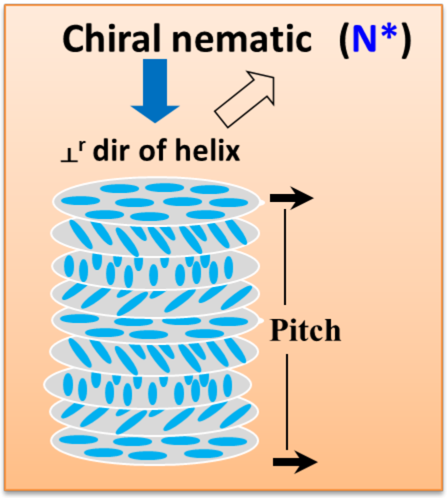

Figure 4.Helical structure of the chiral nematic phase.

IV.3. Smectic (Sm) mesophases

The smectic mesophases possess both orientational and positional order due to the equidistant arrangement of the molecules' centre of gravity. These are layered structures and are further classified depending upon intralayer arrangement and interlayer interactions into multiple types.[93] Letter codes A, B, C etc. are used to designate these phases based on the chronological order of detection. The chiral smectic mesophases are formed due to the chirality of the constituent molecule due to the titling of these molecules with respect to the layer normal. The following section discusses the significant smectic phases and their structural details.

IV.4. Smectic A (SmA) and Chiral SmA mesophases

In the case of smectic A phase, the director lies in the direction of layer normal. Within the layer, the liquid-like packing is observed, and the long-range positional correlation is absent.As can be seen from Fig. 5 the layers are not well defined due to the disorder present within the layers, and formally SmA phase can be explained as a one-dimensional density wave.[93-98] The SmA phase is also known to exhibit subphases such as SmA_2(bilayer phase),SmA_d (a partially-bilayer phase) and SmÃ (a modulated phase).Likethe biaxial nematic phase, the SmA phase can also have biaxial symmetry known as biaxial smectic A (SmAb).

Consequently, when an electric field applied orthogonalto the layer normal in SmA phase,there will be a coupling of the electroclinic susceptibility to the field and the tilting of long molecular axes for the layer planes are observed. At lower electric fields, the tilt angle variation is linear with the field. This linear relation is referred to as the electroclinic effect. SmA phase shows characteristic focal-conic texture in the slides that are treated for planar

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orientation. On the slides treated for homeotropic orientation, a dark field view is observed.

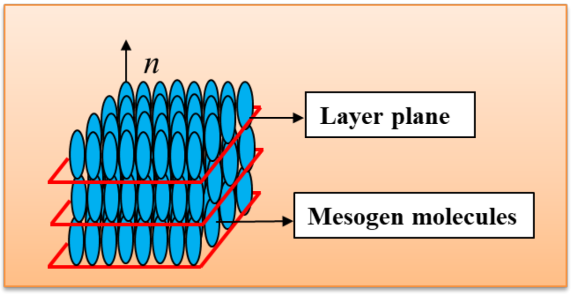

Figure 5. Schematic representation of the SmA phase formed by rod-like anisometric molecules.

IV.5.Smectic C (SmC) and chiral smectic C (SmC*) phases:

The smectic C phase differs from the SmA phase in aligning constituent molecules to the layer normal. In the SmC phase, molecules will be inclined at an angle to the layer normal, and this angle of inclination is the same for all the layers (Fig. 6a). It has been observed that this angle varies monotonically with temperature. Whereas the chiral/optically active molecules form chiral smectic C or SmC* phase. Unlike the SmC phase, the inclination of molecules in the SmC* varies gradually with respect to each layer which traverses a helix and gives a helical structure to the SmC* phase (Fig. 6b). Due to the presence of a chiral molecule, the symmetry of the SmC* phase is reduced to C_2 symmetry. This generates inequivalence in the dipole moment along the C_2 axis normal to the tilt direction leading to the spontaneous polarization (*Ps*) in each layer. But, due to the formation helix, the *Ps* among each layer averages out to zero.[94] However, to observe macroscopic *Ps*, the helix will be unwounded by applying an electric field or by surface interactions.[95]

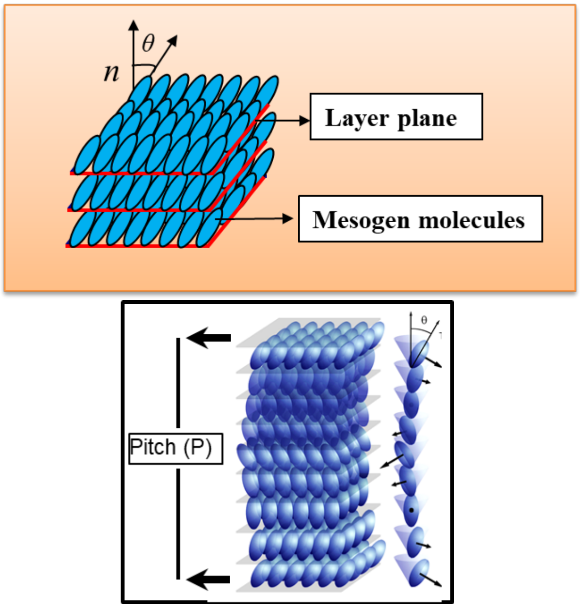

Figure 6.(a) Structure of the SmC phase, (b) the representation of the precession of a single chiral molecule in the consecutive layers indicating the formation of SmC* phase.

IV.6.Chiral frustrated phases

The molecular symmetry will be reduced due to chirality, and it will considerably modify the mesomorphic behaviour.The unequal packing of the chiral molecules throughout leads to the stabilization of many frustrated mesophases.[1,99-102] Few of them are discussed below.

IV.6.1.Blue phases (BP.)

The first observation of the blue phase has been attributed to Reinitzer. These extremely short temperature range phases appear over a very narrow temperature range between isotropic and chiral nematic phases. Generally, the LCs exhibiting short pitch chiral nematic phases have shown the ability to stabilize the blue phases. These can be observed in a variety of mesogens such as rod-like,[103] disc-like,[104&105] as well as in dimers.[106]

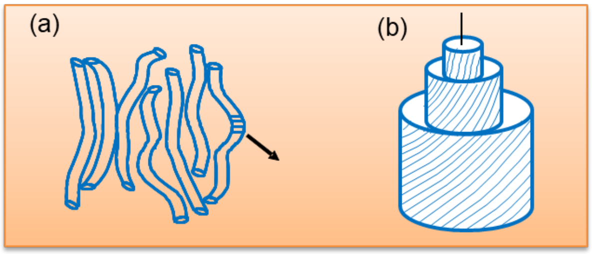

Figure 7. (a) Schematic representation of the theoretical spaghetti model of BPIII; having randomly oriented squirming double twist tubes (b).

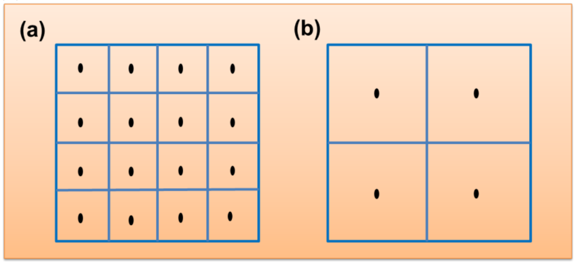

Figure 8. Schematic representation of the theoretical model of (a) BPII& (b) BPI

The structure of these BPsdepends upon the radial twist of director referred to as a **double cylinder**. In the absence of an electric field, the BPs can be classified into three types BP-I and BP-II; both have a cubic symmetry (Fig. 8); and BP-III (Fig. 7) has the same symmetry as that of the isotropic phase, which is known as the **fog phase.**

IV.6.2.Twist grain boundary (TGB) phases

These are the mesophases in between the isotropic/N* and smectic phases (SmA/SmC*).[1,107-117] They generally appear in the short-pitched chiral materials due to the competition between molecules to form a helical structure due to the chiral packing requirements (N*) and the need to form a layered structure (smectics). (Fig. 9.)Thus, forming a twist grain boundary phase, the frustration generated will be relieved, consisting of smectic blocks. Here, the successive smectic block will rotate at a particular angle to generate a helical structure which is orthogonal to the layer normal directions.Since twisting of smectic layers cannot be continuous, they are separated from each other by screw

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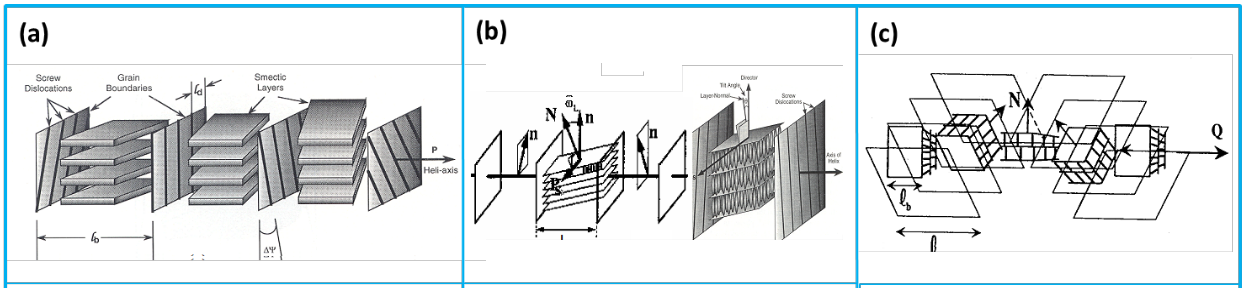
dislocations giving rise to grain boundaries that are periodic; leading to the presence of layering as well as helical twists.



d = smectic layer spacing, l_b = smectic slab thickness, l_d = distance between neighbouring screw dislocations

ωL = tilt angle of the layers, n = direct, N = layer normal, PS = spontaneous polarization

Q = helical wave vector, l_b= distance between the grain boundaries, l_H = thickness of helislabs

Figure 9. (a) Structure of TGBA phase, (b) structure of TGBC phase and (c) structure of TGBC* phase

Based on the nature of smectic blocks, TGB phases, TGBA, (Fig.9a) TGBC (Fig.9b) and TGBC* (Fig.9c) are possible and are seen experimentally.The TGBC* phase has a much-complicated structure as compared with the other two TGB phases. This phase exhibits a regular grid pattern which is superimposed over the planar structure.

V. Discotic liquid crystals

It was a general belief for a long time that, only the rod-like molecules are capable of exhibiting mesomorphism. But in 1977Chandrasekhar *et al.*[16] demonstrated that the disc-like molecules exhibit the mesomorphic behaviour. Such disc-like molecules capable of exhibiting mesomorphic behaviour are called "**discotics**". A crucial structural requirement for such a molecule is the presence of rigidity at the molecular centre.[16,118-124] A general molecular structure of the discotic molecule is shown in Figure. 10. They possess a rigid core composed of either aromatic or alicyclic moiety surrounded radially by the flexible groups linked by various functional groups, as shown in Figure. 10. Two different mesophases are stabilized by the achiral discotic LCs: nematic (N) and columnar (Col) phases. The nematic (N) phase (Fig. 11a, 12a) similar to the one observed in rod-like molecules possessing only the orientational order. However, the most general mesophase exhibited by the discotic LCs is the columnar phase which consists of discs that stacked one above the other to form the columns. Columnar mesophases exhibit a rich polymorphism and are classified at three levels; based on the symmetry of two-dimensional array, the orientation of core to the column axis and degree of order within the column. The mesophases can be classified into three major categories based on the two-dimensional array's symmetry. The three classes are hexagonal, rectangular and oblique[16b]. The hexagonal phase(Fig. 11c) has the substituent molecules arranged in the aperiodic arrangement or long-range positional order. Columnar rectangular (Col$_r$) (Fig. 12d) or columnar oblique (Col$_{ob}$) phases (Fig. 11d, 12c) are characterized by the molecular order similar to that of liquid along with the columns. The column is packed in is either a rectangular or oblique fashion, respectively.

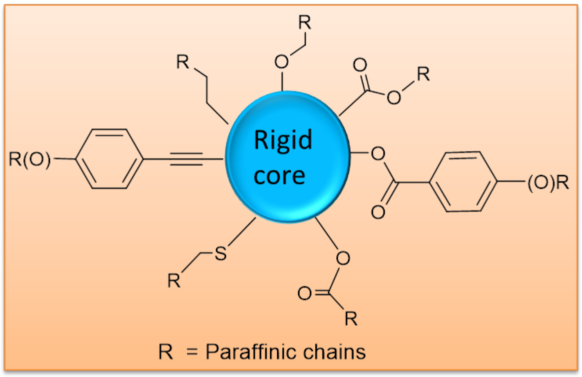


Figure 10. A general template for discotics

The derivatives of triphenylene and phthalocyanines have been workhorses in the research area of discotic liquid crystals.[119]

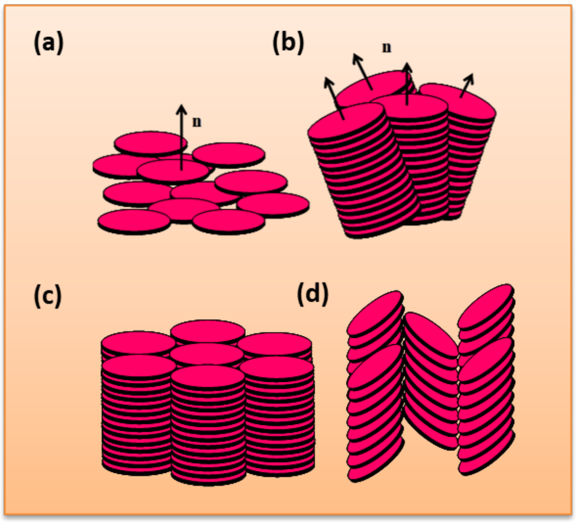


Figure 11. (a) The nematic phase, (b) columnar nematic phase (c) columnar hexagonal phase with ordered molecular stacking (d) columnar rectangular phase

Many hexabenzocoronene, tricycloquinazolines, macrocycles with large holes, metallo-discogens containing copper, molybdenum, nickel and palladium etc.are added to the list of new discogens.[118-124] The guidelines framed for the formation of mesophases in achiral discotics have been followed to realize chiral discotic systems by introducing one or several chiral chains around the periphery of discotic core known to exhibit either a chiral nematic (N*) or columnar phase. The blue phase has been rarely observed in some discotics.[121] The chiral discotic nematic phase has a structure

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analogous to that of the chiral nematic phase exhibited by calamitics.

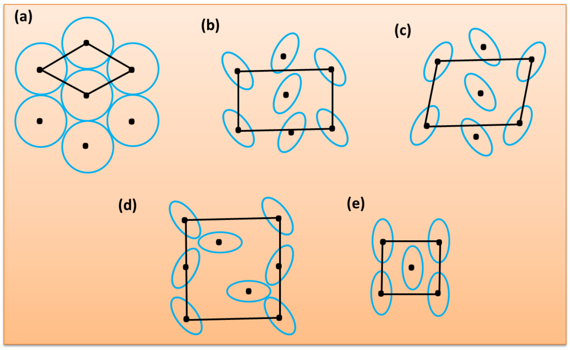

Figure 12. Plan views of the two-dimensional lattice: (a) hexagonal symmetry, (b) rectangular symmetry, (c) oblique symmetry (d) rectangular symmetry, (e) rectangular face-centered symmetry

Interestingly, the ferroelectric switching phenomenon was observed by the columnar phase formed by some of the chiral molecules. This provides some advantages over the tilted smectic counterparts that are used in electro-optical displays. The least ordered discotic nematic is recently considered a better medium for display applications, mainly to address theviewing angle problems. The potential use of discotic materials, especially those exhibiting columnar phases, as quasi-one-dimensional conductors, photoconductive systems, ferroelectrics, light-emitting diodes, photovoltaic solar cells, optical storage devices, hybrid computer chips for molecular electronics etc.are attracting considerable attention.[120]

VI. Liquid crystal dimers

Among all the different liquid crystals (LCs) classes, one of the new recently discovered systemsis oligomeric liquid crystals (OLCs).[37&38] Depending upon the number of linking groups, they can be subdivided into dimers, trimers, tetramers etc. The first members, dimers, are formed by attaching two calamatic mesogenic cores through a flexible spacer. The first example of the dimer synthesis can be traced back to Daniel Vorlander[125] in the early 1930s where he synthesized the first series of LC dimers: α,ω-bis(4-alkyloxyphenyl-4'-azophenyl)alkanedioates.

Initial interest in this LCs originated from their ability to act as model compoundsfor semi-flexible main chain liquid crystal polymers.[127] Due to their application potential andunusual liquid crystalline propertiessuch as dependence of their transitional properties on the flexible spacers' length and parity, the occurrence of unique smectic phases etc. As hypothesized by Griffin and Britt in semiflexible main-chain liquid crystal polymers, the basic repeating unit possesses two mesogenic units connected via a flexible spacer. Hence, itproposed anew approach to study these polymers by investigating the monodispersive dimers.[127] It proved that the dependence of thermal behaviour on the length and parity of the flexible spacer. LC dimers are the lowest possible class of oligomers exhibiting characteristic properties such as thermal behaviour, glass transitions etc., of polymers while still retaining the fluidity,viscosity etc., of low molar mass LCs. They hence are promising systems for many practical applications.

The general structure of a dimer is shown in Fig. 13, As mentioned earlier dimers are composed of two promesogenic units linked together by a flexible spacer. As can be seen from the image, the segments A and B represent the conventional mesogenic segments. These can be possessing aromatic or alicyclic rings; they can also have heteroatoms. The R and R' depict the terminal groups. Generally, the linking and the terminal groups are composed of flexible alkyl or alkoxy chains. The lateral substituents often present of the mesogenic segments are denoted by the letters M and N.

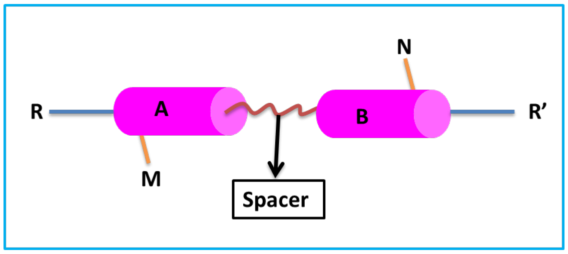

Figure13. General representation of an LC dimer

Based on the mesogenic segments' nature, the dimers can be classified into two classes: (a) symmetric dimers and (b) non-symmetric dimers. Symmetric dimers consist of two chemically identical mesogenic segments linked together via a flexible spacer while the mesogenic segments linked in asymmetrical dimers are chemically non-identical. Furthermore, these two broad groups can be subdivided based on the mesogenic segment's molecular arrangements. Some of the major divisions are (i) symmetric calamitic dimers,[1] (ii) non-symmetric calamitic dimers, (iii) symmetric discotic dimers, (iv) non-symmetric discotic-calamitic dimers, (v) supramolecular non-symmetric dimers etc.(Fig. 14)

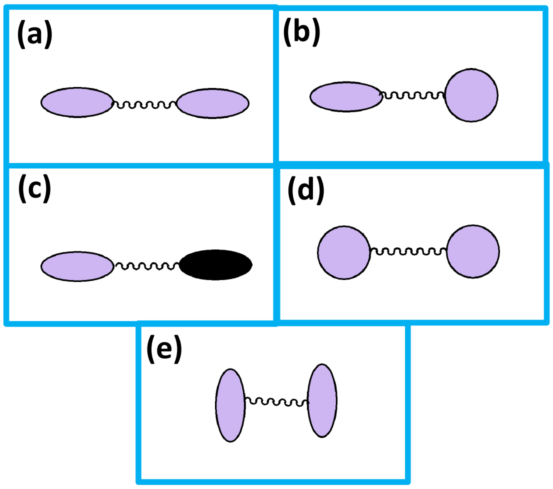

Figure 14. Schematics showing the molecular architectures of the different LC dimers; (a) symmetrical calamitic dimer, (b) unsymmetrical calamitic dimer, (c) unsymmetrical discotic-calamitic dimer, (d) symmetrical discotic dimer, (e) symmetrical calamitic dimer that is linked Ellipses laterally represent the rod-like molecules; the discotics are denoted by circles and the flexible spacer by the wavy bond.

It is a well-known fact that the mesomorphic behaviour of LCs is greatly affected by the molecular chirality.[24] Similarly, the dimers which posses the chiral molecules are no exception.[24,37-43] The molecular chirality can be introduced into the dimers via chiral mesogenic core, chiral terminal or space. The effect of spacers parity on the transitional properties and on the formation of chiral phases has been well documented and studies. However, other than the mesogenic core, the molecular structure also plays a vital role in determining the chiral dimer's overall thermal behaviour.In most cases, the differing mesogenic cores have been chosen to exhibit a specific molecular interaction. For example, in recent years, it is well demonstrated that non-symmetrical chiral dimers formed by covalently linking pro-mesogenic cholesterol with the aromatic rod-like core through an alkylene spacer exhibit a range of unique liquid crystalline behaviour originating from the complex intermolecular interactions among the cores, terminal chain and the spacer.

VII. APPLICATIONS AND PROSPECTS OF LIQUID CRYSTAL

VII.1. Display applications

Due to the fluidic nature, the LCs can be processed into thin films and even in the thin film state the optical properties such as the ability to rotate the plane-polarized light are retained. It is a well-known fact that the LC molecules' orientation can be modified and controlled upon applying the electric field. This orientational tweaking ability makes it a suitable candidate for the application of display devices.[51,54] When the LC material is placed between the two crossed polarizer, the variation of its orientation caused by the electric field's action makes it switch between an on and off state. Generally, liquid crystal displays (LCDs) prepared consists of twisted nematic or super twisted nematic systems.

VII.2. Thermal sensors

Its pitch characterizes the helix of the chiral nematic phase. The mesophase reflects the light, and the reflected light's wavelength is proportional to the magnitude of the pitch. Since the pitch is temperature-dependent, the reflected colour also exhibits the temperature dependence. Hence the cholesteric LCs can gauge the temperature effectively just by observing the colour variation closely.This property has been exploited for various practical applications[127-129] in diverse areas such as medicine, packing industry and electronics. A device to measure any temperature range can be built by a careful mixing of different cholesteric LCs. Cholesteric liquid crystals are used as disposable thermometers referred to as 'fever strips'.These thermal stips are attached to the skin to obtain the thermal map. This is immensely helpful because the pathological conditions such as tumours have a significantly different temperature than the rest of the body.LC temperature sensors can even find bad connections in a circuit board by detecting the characteristic higher temperature.

VII.3. Columnar fluid phases as a promising media for modern applications

Discotic mesogens' ability to self assemble to form the columnar mesophases is primarily driven by the π-π interactions between the aromatic cores.[16-23] The columnar mesophase acts as a molecular wire by providing the one-dimensional electron charge migration pathway. The central aromatic acts as a conducting unit while the peripheral chains act as an insulating mantle. This LC state's importance arises mainly due to its ability to combine various physical properties such as optical, conductive, etc. with an orientational control of molecular order, ability to self-heal, and ease of processability. Hence the columnar phase promises to be a media for various device applications such as solar cells, OFET (organic field-effect transistors), OLED (organic light-emitting diodes) etc.

VII.4. Other applications

Liquid crystals polymers are the vital subclass of LC materials, and they occur in natureas solutions of some biopolymers and play a key role in processing the high-modulus materials like Kevlar.[130] The liquid crystals are used as the anisotropic solvents to probe different physiochemical properties.[2131-132] In the nematic mesophase, the molecules can be homogeneously oriented by a magnetic field to have the optic axis aligned parallel to the field. Hence these are used as anisotropic solvents in NMR spectroscopy.[133] It provides information regarding the chemical shift anisotropy and molecular symmetry. Since the mesophases have an inherent ability to control solutes' orientation, constraint their mobility and randomness in the molecular orientations., which makes the mesophases suitable solvents for altering the rates of uni- or bi-molecular thermal and photochemical reactions.[134] Cholesteric LCs are also used for chiral recognition. Lyotropic LCs areused in commercialdetergents and cosmetics. Recently, LCsare probed for their ability to acts as a medium for controlled drug release.

VIII. **Conclusion**

To summarise, liquid crystals, the metastable intermediate phases between solid and liquid, are fascinating materials that have attracted both fundamental scientists and technologists' attention. The variety of mesophases and their close association with the molecular design is one of the LC systems' key feature. Mesophases that are chiral due to the self-assembly of the organic molecules present a new window of opportunity to examine the phenomena of self-assembly as well as to use this property for different applications such as plasmonics, sensing etc. The discotic mesophases are front runners in the area of organic electronics. These self-assembled systems formed by the stacking of disc-like molecules via π-π interaction act as molecular wire and are being probed for their potential usage in OFETs, OLEDs, photovoltaics etc. Overall, the area of liquid crystals that studies a rather unconventional state of matter provides a plethora of opportunities to undertand its basic phenomenons of that state as well as cater to the modern world's technological need.

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7. About the author(s)

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- Optically active, non-symmetrical dimers derived from cholesterol
- Gold nano-particles coated with liquid crystalline organic ligands
- Metal organic frameworks derived from bi-dentate and tetra-dentate ligands
- Materials for renewable energy

Chemical sensing

Madhu Babu Kanakala
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- Cholesterol based non-symmetric liquid crystals
- Metal nano-particles decorated with chiral/achiral mesogens
- Achiral bent, rod liquid crystals
- Optically active mesomorphic dimers derived from cyano biphenyl

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- h-index 36: Citations over 4000

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