

International Journal of Multidisciplinary Trends

E-ISSN: 2709-9369

P-ISSN: 2709-9350

Impact Factor (RJIF): 6.32

www.multisubjectjournal.com

IJMT 2025; 7(11): 135-137

Received: 10-09-2025

Accepted: 15-10-2025

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From television screens to medical applications: The journey of liquid crystals

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DOI: <https://www.doi.org/10.22271/multi.2025.v7.i11b.835>

Abstract

Liquid crystals (LCs) have undergone a remarkable evolution, shifting from their initial role in flat-panel display technologies to becoming promising functional materials in biomedicine. Their unique physicochemical characteristics—including anisotropy, high sensitivity to external stimuli, and self-organizing behavior—make them highly suitable for the design of smart medical systems. In recent years, liquid crystals have been extensively explored in bio sensing, where their orientation changes enable label-free, real-time detection of biomolecules such as proteins, DNA, and toxins. They have also demonstrated potential in medical imaging, enhancing diagnostic precision through their optical and structural properties. Furthermore, liquid crystal phases serve as efficient platforms for drug delivery, offering improved stability, biocompatibility, and controlled release triggered by physiological conditions. This review highlights the transition of liquid crystals from display technology to advanced biomedical applications, emphasizing their role as a bridge between material science, physics, and modern medicine. Such developments position liquid crystals as key enablers of next-generation smart healthcare solutions.

Keywords: Liquid crystals, bio sensing, medical imaging, drug delivery, smart biomaterials, biomedical applications

Introduction

Between conventional solids and liquids exists an intermediate state of matter known as liquid crystals. They play a crucial role in biological systems, as many essential components of living organisms such as cell membranes and metabolic fluids exhibit liquid or crystalline properties. Liquid crystals are typically composed of organic molecules that are elongated and possess an uneven distribution of electrical charges along their axes. These structures display anisotropy, meaning they have direction-dependent optical and physical properties, combining both solid- and liquid-like characteristics ^[1].

Due to their anisotropic nature, liquid crystals exhibit birefringence, resulting in double refraction with two distinct refractive indices. The formation of liquid crystalline phases fundamentally requires molecules with anisometric shapes and polarizability ^[2]. Unlike crystalline solids, liquid crystals lose some or all of their positional order while maintaining orientational order among their constituent molecules ^[3]. This orientational order can persist even in the solid state, providing mechanical stability to the material.

Typical properties of liquid crystals include birefringence, responsiveness to electric and magnetic fields, optical activity in chiral nematic phases, and sensitivity to temperature changes ^[4]. Biological examples of liquid crystals include DNA, lipids, cellular proteins, and membrane structures.

Liquid Crystal Phases

The various liquid crystal phases, called mesophases, can be the type of ordering. Most thermotropic liquid crystals will have an isotropic phase at high temperature. That is heating will eventually drive them into a conventional liquid phase characterized by random and isotropic molecular ordering, and fluid-like flow behavior ^[5].

The scheme of classification of liquid crystals and phases exhibited by the thermotropic liquid crystals made by rod like molecules is shown in Figure (1) ^[6].

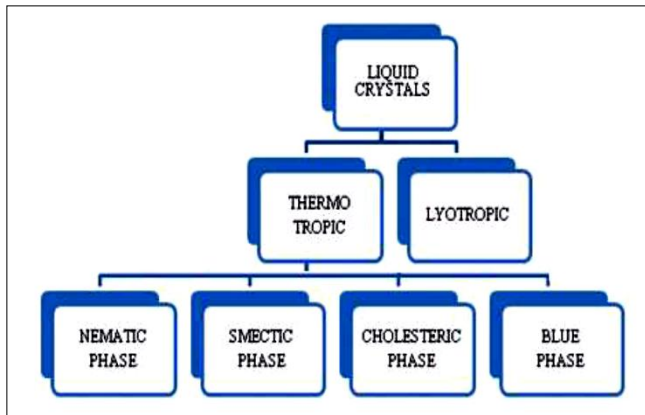


Fig 1: Classifications of liquid crystalline materials ^[6].

Characterizing Liquid Crystals

The following parameters describe the liquid crystalline structure ^[7]:

- 1. Orientational order:** Measure of the tendency of the molecules to align along the director on a long-range basis.
- 2. Positional order:** The extent to which the position of an average molecule or group of molecules shows translational symmetry.
- 3. Bond orientational order:** Describes a line joining the centers of nearest-neighbor molecules without requiring a regular spacing along that line. Thus, a relatively long range order with respect to the line of centers but only short range positional order along that line.

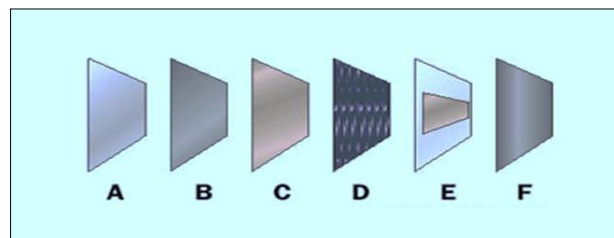


Fig 2: An arrangement constituents layers for the display screen ^[10].

Medical Applications of Liquid Crystals

Liquid crystals have been researched as an innovative drug delivery mechanism. Their resemblance to colloidal systems found in living beings is the reason behind this. They have distinguished as superior to conventional, dermal, parenteral, and oral dosage forms. Liquid crystals (LC) have a long shelf life and are thermodynamically stable ^[12]. Liquid crystal-based drug delivery is a vast area of study. The use of liquid crystals, particularly lyotropic liquid

Applications of Liquid Crystals

Liquid Crystal Displays Devices

The term liquid crystal is used to describe a substance in a state between liquid and solid but which exhibits the properties of both. Molecules in liquid crystals tend to arrange themselves until they all point in the same specific direction. This arrangement of molecules enables the medium to flow as a liquid ^[8].

Depending on the temperature and particular nature of a substance, liquid crystals can exist in one of several distinct phases. Liquid crystals in a nematic phase, in which there is no spatial ordering of the molecules, for example, are used in LCD technology. One important feature of liquid crystals is the fact that an electrical current affects them. A particular sort of nematic liquid crystal, called twisted nematics (TN), is naturally twisted. Applying an electric current to these liquid crystals will untwist them to varying degrees, depending on the current voltage ^[9].

LCDs use these liquid crystals because they react predictably to electric current in such a way as to control the passage of light. The working of a simple LCD is shown in Figure (2) ^[10]. It has a mirror (A) in the back, which makes it reflective. There is a piece of glass (B) with a polarizing film on the bottom side, and a common electrode plane (C) made of indium-tin oxide on top. A common electrode plane covers the entire area of the LCD. Above is the layer of liquid crystal substance (D). Next comes another piece of glass (E) with an electrode in the shape of the rectangle on the bottom and on the top, there is another polarizing film (F), at a right angle to the first one ^[11].

crystals, as nanoparticles (cubosomes and hexosomes) for drug delivery applications has seen a significant increase in interest in recent years. Liquid crystals have prolonged release effects which serves as its main characteristics. In recent years, research has concentrated on strengthening the synthesis and characterization of loaded therapeutic molecules, controlling drug release, and increasing their efficacy ^[13]. The table (1) shows its most important applications in medicine ^[14].

Table 1: Medical Applications of Liquid Crystals ^[14].

Medical Application	Key LC Properties	Advantages	Recent Examples / Techniques
Bio sensing	Molecular orientation or phase change upon interaction with biomolecules	Real-time detection; High sensitivity; Label-free detection	LC-based detection of HER-2 protein (breast cancer); LC sensors for hydrogen peroxide detection
Medical Imaging	Birefringence, response to electric/magnetic fields, temperature and pressure sensitivity	Enhanced contrast and resolution; Dynamic tissue measurement; Compatible with multiple imaging systems	LC nanoparticles for MRI or fluorescence imaging; LC films for thermal sensing in tissues
Drug Delivery	Formation of ordered phases (Cubosomes, Hexosomes); Responsive to temperature, pH, or enzymes	Controlled drug release; Increased drug stability; Targeted organ delivery	Cubosomes for cancer therapy; LC films for ocular drug delivery (glaucoma, infections)
Natural Biological Examples	DNA, lipid membranes, proteins	Partial ordering mimics LC; Supports cellular functional organization	Cell membranes and biological fluids exhibiting LC-like behavior

Conclusion

The journey of liquid crystals from conventional display technologies to advanced biomedical applications reflects the dynamic evolution of functional materials in science and technology. Their intrinsic responsiveness to external stimuli, coupled with their structural versatility, has enabled breakthroughs in biosensing, medical imaging, and drug delivery systems. While challenges remain regarding long-term biocompatibility, stability under physiological conditions, and large-scale integration into clinical practice, ongoing research continues to expand the biomedical potential of these materials.

Ultimately, liquid crystals represent more than just a milestone in display technology; they embody a transformative platform that bridges physics, chemistry, and medicine. With continuous innovation, liquid crystals are poised to play a pivotal role in shaping the future of personalized and smart healthcare solutions.

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