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## A REVIEW ON SMART APPLICATIONS OF LIQUID CRYSTALS

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### Abstract:

Liquid crystals (LCs) represent a unique state of matter exhibiting properties of both liquids and solids, enabling exceptional electro-optical behavior. Their ability to modulate light under applied electric fields has made them indispensable in modern technologies, particularly in flat panel displays, photonic devices, and smart systems. This article reviews the fundamental principles governing LC behavior, including molecular alignment, anisotropy, and phase transitions such as nematic, smectic, and cholesteric states. It highlights key classifications, including thermotropic and lyotropic liquid crystals, and discusses their structural and functional characteristics. Recent advancements in material design and device engineering have improved performance metrics such as response time, contrast, and energy efficiency. Furthermore, emerging applications in soft robotics, drug delivery systems, photonic crystal fibers, and smart windows demonstrate the expanding interdisciplinary relevance of LCs. Overall, liquid crystals continue to play a vital role in both fundamental research and innovative technological developments.

**Key Words:** Liquid Crystals, Electro-optical Properties, Phase Transition, Advanced Applications

### Introduction:

Liquid crystals (LCs) are a special kind of matter because they are both fluid and have a well-ordered molecular structure. This gives them amazing electro-optical qualities. Because they can change visual properties when an electric field is applied, they are essential in many fields, from advanced display technologies and holography to smart windows and light shutters. LC-based devices have become more useful as material synthesis, molecular design, and device layout keep getting better. This is because they can work with lower voltages, have better contrast ratios, and respond faster. This summary shows the newest developments and explains the basic ideas behind how they work electrically and optically. It emphasizes how important LCs are in both basic and applied research around the world [2].

Most people know liquid crystals (LCs) as the stuff that goes into flat panel displays, which can be small ones for pocket calculators or big ones for TVs. In theory, the technology is still mainly based on the original work that was done fifty years ago, though there have been many improvements and advances in materials, addressing, electrode patterns, alignment and processing. Since the turn of the century, good displays with wide viewing angles and video capabilities have been available. However, basic research into displays has slowed down and moved on to 3D vision, holographic displays, augmented and virtual reality (AV-VR) devices [3], and flexible displays. You can say that a substance is in a liquid crystalline state if its physical traits are somewhere between those of a solid and a liquid.

A lot of people are interested in liquid crystals because they have interesting physical and chemical qualities that could make them useful in many technological areas [4]. Liquid crystals may move like a liquid, but their molecular arrangements may be like those of a solid crystal. On top of that, liquid crystals can be made artificially or naturally [5]. In this case, the lyotropic phase of liquid crystal is found in large amounts in proteins and cell membranes, which are parts of living things. A lot of display apps use liquid crystals that have been synthesized. Liquid crystals are used in display technology because they are symmetrical and have a high electro-optic coefficient, which makes them very useful. Besides being used for displays, liquid crystals are also very useful for a number of different types of sensors. Lasers and medical diagnostics are two other places where it could be used [6]. The flat panel monitor, on the other hand, is the most well-known device that uses liquid crystals. Synthesized liquid crystals are needed in a lot of different areas besides just display screens.

People who study the basics of liquid crystals are now more interested in a wider range of questions that are connected to other areas of study, such as fundamental physics, optics and photonics, topology, biology, and nanotechnology. These



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questions are not as specific to ferroelectric and antiferroelectric LCs (FLC and AFLC), the Twist Grain Boundary Phase (TGB), or bent-shaped liquid crystals.

There is also more and more contact between the topics, which shows that there is more and more synergy and multidisciplinary. A good example is LC elastomers, which are made by mixing liquid crystals and polymers. They show promise for use in soft robots. [7].

### Types of liquid crystals:

The state of matter called Liquid Crystals (LCs) is unique because it has qualities of both liquids and solids. These things are anisotropic, which means that their features change based on the direction of measurement. The molecules that make up LCs arrange themselves in a specific way, usually along one or two chosen directions.

- **Thermotropic liquid crystals:** Liquid crystals in the thermotropic class change from a liquid to a solid state when heated [8]. Which means that a thermotropic type of liquid crystals can form when the temperature of a solid is raised and/or lowered. The cholesteric liquid crystal is a popular type of thermotropic liquid crystal. It has a helical shape. When light hits the helical structure, it specifically bounces back, which makes colors. The pitch of the helix determines the color that is mirrored, and this color can change as the temperature changes. The pitch of the helix changes as the temperature rises, which makes the color that is mirrored change.
- **Lyotropic liquid crystals:** The lyotropic class of liquid crystals shows changes caused by solvents [9], so they are naturally amphiphilic. What this means is that these liquid crystals are made up of both lyophilic (solvent-attracting) and lyophobic (solvent-repelling) materials. As we've already said, the nematic, smectic, and cholesteric phases of liquid crystals are separated by the way their molecules are arranged.
- **Nematic liquid crystals:** When molecules are in the nematic state, they don't have any positional order. Instead, they are lined up along the director, which shows the direction of molecular orientation. In the nematic phase, the molecules tend to be parallel, but their places are not set in stone [10].
- **Smectic liquid crystals:** It is only in the smectic phase that the molecules of the liquid crystal have a translational order. In the nematic phase, they don't have this. In this state, the molecules are lined up parallel, but their cores are stacked in parallel layers where they move around randomly. In the smectic phase, this basically means that the molecules of the liquid crystal can only move in the directions in which they are evenly spaced [11].
- **Cholesteric liquid crystals:** When liquid crystals are in the cholesteric phase, their molecules are arranged in a helicoidal pattern. This makes the cholesteric phase a twisted form of the nematic state, where molecules are arranged in a helical pattern around an axis. In the cholesteric phase of liquid crystals, it is clear that the director has a continuous spiral pattern around the axis that is perpendicular to the two-dimensional nematic layers (of molecules). In this case, the chirality of cholesteric liquid crystals holds a lot of promise for making a lot of different electro-optic parts, like sensors and display screens.

### Applications of liquid crystals:

Their high electro-optic coefficients make them promising for a wide range of photonic uses [12]. There are a number of benefits to using liquid crystals in flat panel electronic displays (LCDs) [13] as opposed to more conventional displays that use cathode ray tubes (CRTs). Less weight and reduced power consumption are two of LCD's most appealing features. Additionally, LCDs have a shorter lifetime and a narrow viewing angle, which are disadvantages.

Soft robots may benefit from LC elastomers, a material that combines liquid crystals with polymers. Liquid crystal



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elastomers (LCEs) and networks (LCNs) are used in soft robotics as smart actuators that produce large, reversible, and programmable shape changes (bending, twisting, contracting) in response to stimuli like heat, light, or electric fields. Functioning as artificial muscles, these materials allow for biomimetic locomotion—such as crawling, swimming, and gripping, making them ideal for flexible, safe, and precise microrobotics and soft robotic component

Thermochromic liquid crystals change color based on temperature, allowing for use in medical thermometers, fever strips, and non-destructive testing to detect structural stress or defects. Some liquid crystals are capable of displaying different colors at different temperatures. This change is dependent on selective reflection of certain wavelengths by the crystalline structure of the material, as it changes between the low-temperature crystalline phase, through anisotropic chiral or twisted nematic phase, to the high-temperature isotropic liquid phase. Only the nematic mesophase has thermochromic properties. Mixtures with 3–5 °C span of temperatures and ranges from about 17–23°C to about 37–40°C can be composed from varying proportions of cholesteryl oleyl carbonate, cholesteryl nonanoate, and cholesteryl benzoate. For example, the mass ratio of 65:25:10 yields range of 17–23 °C, and 30:60:10 yields range of 37–40 °C [14].

Lyotropic liquid crystalline (LLC) nanoparticles have gained significant attention as drug delivery systems owing to their unique self-assembly properties, biocompatibility, and ability to encapsulate both hydrophilic and hydrophobic drugs. [15]

Liquid Crystal Photonic Crystal Fibers (LC-PCFs), also referred to as Photonic Liquid Crystal Fibers (PLCFs), are advanced specialty optical fibers formed by integrating passive photonic crystal fiber microstructures with active liquid crystal materials. This hybrid configuration gives rise to a wide range of novel and unconventional spectral, propagation, and polarization characteristics applicable in highly tunable photonic devices as: attenuators, broadband filters, polarizers, waveplates and phase shifters [16]

There is a lot of promise in using cubosomes for medication encapsulation, transport, and delivery [17]. Lipid molecules' cubic phases give rise to these crystalline formations in liquid form. An appropriate structure for the transport, distribution, and release of individual pharmaceuticals can be developed through the selection of a wide range of parameters, including lipid and amphiphile types, liquid crystalline phase, alky-chain length, stabilisers, and many more.

With the advent of more advanced methods for creating patterned substrates, such as photo-patterned substrates for liquid crystal alignment in photonic applications, the practice of aligning liquid crystals on surfaces appears to have undergone a renaissance [18].

Smart windows, which can regulate light transmittance as needed, are regarded as a highly significant and promising technology for reducing building energy consumption by managing the indoor lighting environment [19, 20]. LC smart windows, which transition between transparent and opaque states, serve multiple purposes beyond building energy conservation. They can also function effectively in private spaces, car sunroofs, airplane portholes, greenhouses, and augmented reality displays. [21].

## Conclusions

Liquid crystals represent a unique and versatile state of matter combining fluidity with molecular order, enabling exceptional electro-optical properties. Their ability to respond to external stimuli, particularly electric fields, has made them indispensable in modern display technologies and emerging photonic applications. Advances in material design and alignment techniques have significantly enhanced device performance, including faster response and lower power consumption. Beyond displays, liquid crystals show strong potential in sensors, smart windows, soft robotics, and biomedical applications such as drug delivery. Their multidisciplinary relevance and adaptability ensure that liquid crystals will continue to play a crucial role in future scientific research and advanced technological innovations.



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