Applications of Liquid Crystals: Special Emphasis on Liquid Crystal Displays (LCDs)

*Laxmi Shankar Awasthi, and Karuna Shankar Awasthi**

Deptt. of Computer Science, Lucknow Public College of Professional Studies, Lucknow.

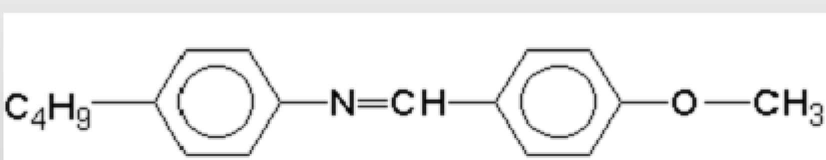
**Corresponding Author:ka7052@gmail.com*

Abstract: Liquid Crystals are beautiful and extremely useful, thus providing scientists and engineers' one of the most active and fascinating fields of scientific and industrial research. Their dual nature and easy response to electric, magnetic and surface forces have generated innumerable applications, which continue to grow both in money and diversity. The most common use of liquid crystals in technology is in the display industry, and this is especially true in the last several years. Interestingly, liquid crystals are also found in other everyday objects such temperature sensors with various applications and smart windows. More recently liquid crystals have been studied for their potential in photorefractive devices, spatial light modulators and optical limiters.

Keywords: Liquid Crystal Displays (LCDs), Twisted Nematic LCDs and Temperature Sensors.

An Overview of Liquid Crystals and its Historical Perspective: Materials in nature can be divided into different phases, also called states of matter, depending on the mobility of the individual atoms or molecules. The obvious states of the matter are the solid, the fluid and the gaseous state. In the solid state, intermolecular forces keep the molecules close together at a fixed position and orientation, so the material remains in a definite shape. In the fluid state, the molecules are still packed closely together, but they are able to move around. Hence a fluid does not have a rigid shape, but adapts to the contours of the container that holds it. Like a liquid a gas has no fixed shape, but it has little resistance to compression because there is enough empty space for the molecules to move closer. Whereas a liquid placed in a container will form a puddle at the bottom of the container, a gas will expand to fill the container. Although the three categories seem very well defined, the borders between the different states are not always clear. Apart from the three familiar states, there exist a large number of other intermediate phases. A simple example is a gel. A gel is not quite solid, neither it is a liquid. **LIQUID CRYSTALS** (LCs) are another important intermediate phase which exhibits features from both the solid and the fluid state. LCs are neither quite liquid nor quite solid. Physically, they are observed to flow like liquids, but they have some properties of crystalline solids. LCs can be considered to be crystals which have lost some or all of their positional order, while maintaining full orientational order. Under certain circumstances, LCs phases have a liquid-like behavior and during others they have the opposite behavior. They represent thermodynamically stable phases existing between isotropic liquid and crystalline solid phases. There are many different types of LC phases, which can be distinguished based on their different optical properties (such as birefringence). When viewed under polarized light microscope, different LC phases will appear to have a distinct texture. The contrasting areas in the texture each correspond to a domain where the LC molecules are oriented in a different direction. Within a domain, however, the molecules are well ordered. LC materials may not always be in an LC phase (just as water is not always in the liquid phase: it may also be found in the solid and gaseous phase). In 1888, Austrian botanical physiologist Friedrich Reinitzer (1858–1927), working at the Charles University of Prague, was extracting Cholesterol from carrots to establish its chemical formula. Reinitzer examined the physico-chemical properties of various derivatives of the Cholesterol. Other researchers had observed distinct color effects on cooling Cholesterol derivatives just above the solidification temperature. Reinitzer himself found the same phenomenon in Cholesteryl Benzoate [**1**], but the colors near the solidification of Cholesteryl Benzoate were not the most peculiar feature. Reinitzer found that Cholesteryl Benzoate does not melt like other compounds, but had two melting points. At 145.5°C, it melted into a cloudy liquid, and at 178.5°C, it melted again and the cloudy liquid became clear. The phenomenon was found to be reversible. In 1890 the German physicist Otto Lehman [**2**] with his self-constructed polarized light microscope coupled with hot stage, observed the optical properties of other materials that also showed some anomalous melting characteristics. Lehman suggested the name “Liquid Crystals” because of the crystal-like molecular structure of these liquids. The name ‘Liquid Crystals’ originates from the fact that the phases are both liquid-like such as they flow and the shape is usually determined by the container it fills, and crystal-like, such as there is a degree of orientational ordering of the molecules. There are some materials like N-(4-Methoxybenzylidene)-4-butylaniline (MBBA)and4'-pentyl-4-cyanobiphenyl (5CB) (see **Figure 1**) which when heated from their crystalline phase, completely lose their positional ordering but have some sort of the orientational ordering in the sense that their molecules are slightly oriented in a preferable direction as compared to the other directions.

1 (a)



1 (b)

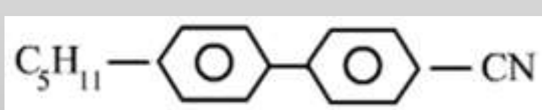


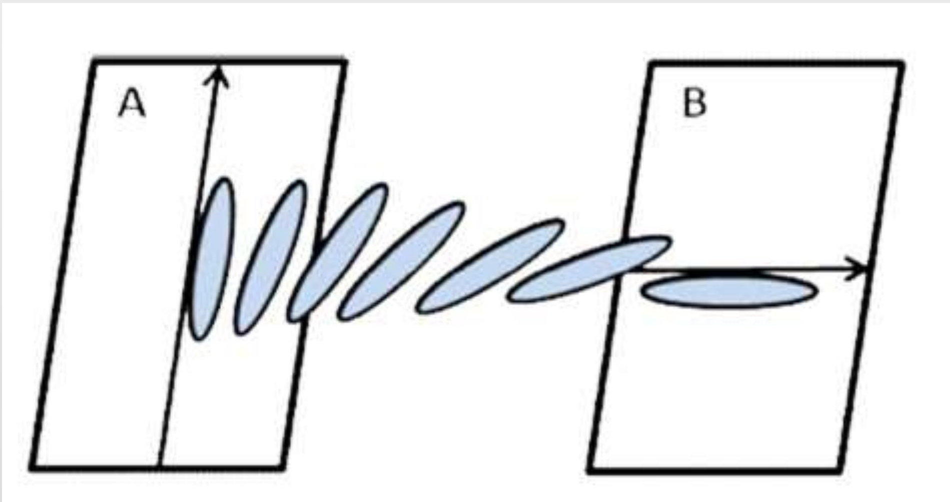
Figure 1: Important liquid crystal discoveries: Molecular structure of: (a) N-(4-Methoxybenzylidene)-4-butylaniline (MBBA) and (b) 4'-pentyl-4-cyanobiphenyl (5CB).

The LC phases are also known as the crystalline liquids, mesophases or mesomorphic phases. Subsequently, Daniel Vorlander [**3**] began a systematic synthetic study to find correlations between molecular structure and the occurrence of the liquid crystalline state. In 1906, he discovered the phenomenon of polymorphism in LCs, i.e. a given compound can exhibit more than one liquid crystalline phase. He also established the rule that liquid crystallinity occurs most frequently with a rod-like shape. LCs were not popular among scientists in the early 20th century and the material remained a pure scientific curiosity for about 80 years. In 1969, Hans Kelker succeeded in synthesizing a substance that has a nematic phase at room temperature, MBBA, the well-known "fruit-fly" of liquid crystal research [**4**]. The invention of the twisted nematic cell by Schadt and Helfrich in 1971 [**5**], lead to the development of liquid crystal display (LCD) technology and since then number of studies on liquid crystalline state increased considerably, due to applications of LC material in electro-optical (EO) switching devices. Now, there are thousands of compounds, both naturally occurring and synthesized, that exhibit one or more LC phases. In 1991, when LCDs were already well established in our everyday life, Pierre-Gilles de Gennes (1932-2007) received the Nobel Prize in Physics for discovering that methods developed for studying order phenomena in simple systems can be generalized to more complex forms of matter, in particular to LCs and polymers.

Applications of Liquid Crystals: Liquid Crystals are attractive and tremendously useful, thus providing scientists and engineers' one of the most vigorous and charming arenas of scientific and industrial exploration. Their dual nature and relax response to electric, magnetic and surface forces have produced countless applications, which sustain to grow both in money and diversity. The utmost collective use of liquid crystals in technology is in the display industry, and this is particularly true in the last several years. Fascinatingly, liquid crystals are also found in other everyday objects such temperature sensors with various applications and smart windows. More recently liquid crystals have been studied for their potential in photorefractive devices, spatial light modulators and optical limiters.

Liquid Crystal Displays: The most successful application are LIQUID CRYSTAL DISPLAYS (LCDs) well known from wrist watches, pocket calculators, cellular telephones, iPods, portable DVD players, digital cameras, projectors, portable color televisions or flat screens of laptop computer which take advantage of electro-optical effects. Portable displays are now found in an abundance of electronic devices and serve entertainment, educational, and business needs. One technology, the liquid crystal display, has proven to provide clear images with high contrasts and viewing-angles, but continues to face demands to improve efficiency and lower costs. Projection displays based on high resolution micro displays are also becoming increasingly popular due to their small size and large image. Although each of the previously mentioned displays is different in detail and application, the basic principle behind their operation is similar. Accordingly, liquid crystals are ideal for display devices because (i) the mesophase is fluid and therefore the molecules are easily moved by the application of an electric field, (ii) the phases are structured, and the alignment of the molecules in a thin film of mesophase can be controlled either by boundary conditions (treatment of the glass plates) or by the application of a small electric field. Although early displays utilized either a guest-host effect between a dichroic dye and a liquid crystal or exploited a cholesteric nematic transition, the first twisted nematic liquid crystal display (TN-LCD) was reported in the early 70's [**6**]. This type of display is composed of a thin liquid crystal material sandwiched between a set of polarizers as shown in **Figure 2**.

2 (a)



2 (b)

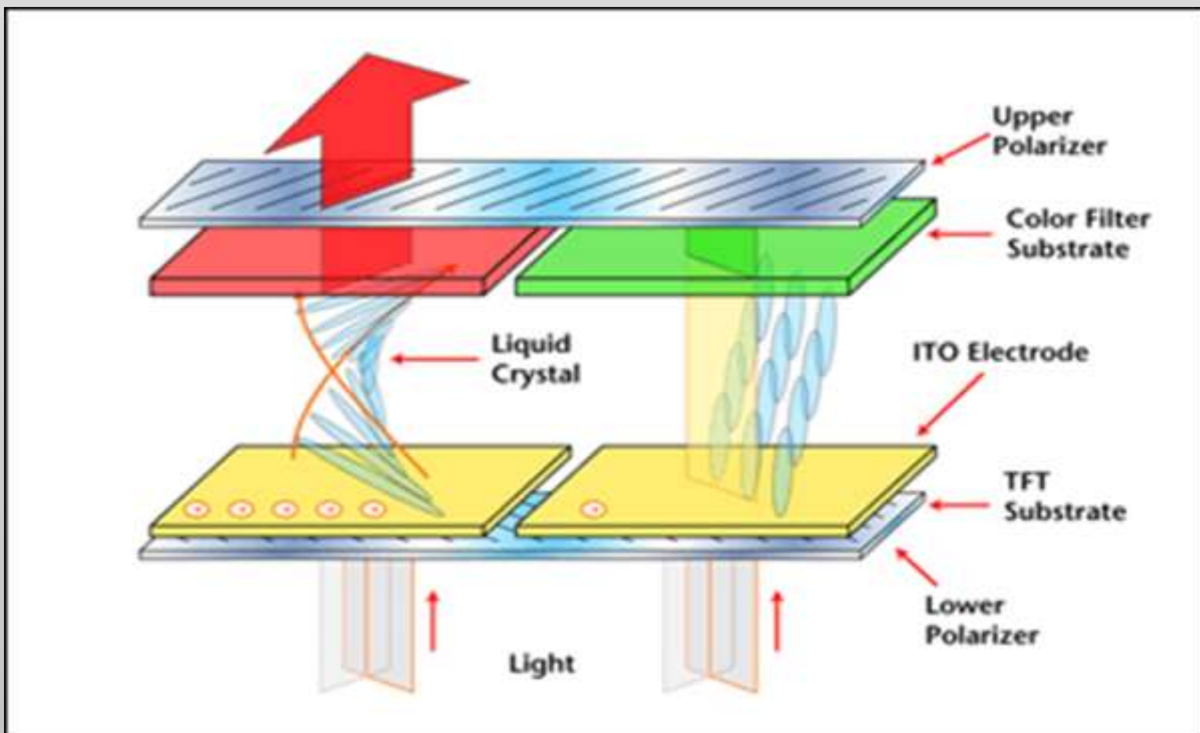


Figure 2: A schematic of the basic elements of a liquid crystal display, a liquid crystal material sandwiched between two polarizers.

The most important features of LCDs are the fast switching speed (ms-micros) and the low power consumption (mW). Accordingly, they can be small and compact and hence used where portable displays are desirable or essential for example in aircraft, cars and caravans. In fact more recently displays have been developed for use inside helmets (head-up displays) for fighter pilots and racing drivers. The surface of the glass confining the liquid crystal material is treated in such a way so as to induce a parallel alignment at either surface but with the director twisting by 90 degrees between the two surfaces. Polarizer A is aligned such that it is parallel to the liquid crystal director at the surface of the cell. Because of the adiabatic following of light, the polarization state of light incident at side A will exit side B with a polarization state that has followed the twist of the director of the liquid crystal. Using an applied electric field, the molecules may be untwisted causing the polarization state of the light to remain unchanged. The alignment of Polarizer B is crucial to the operation of the device. Two different configurations can be created known as normally white (NW) or normally black (NB) in which the polarizer is parallel and perpendicular to the director at side B, respectively [**7**]. **Figure 2 (a)** shows the basic elements for a NW mode. The elongated liquid crystal molecules are surface aligned in one direction and give one optical property and when an electric field is applied, the fluid molecules reorient to give a different optical property hence the use in displays. Consumers are now asking for more compact methods to view information, while still maintaining high contrasts and brightness. A schematic illustration of a TN-LCD is shown in **Figure 3**.

Temperature Sensing: Chiral nematic (N^*) materials are of great technological importance, as their ability to selectively reflect light of a wavelength equal to that of the pitch length. So if the pitch length is of the order of the wavelength of colored light then colored light will be reflected. Additionally, the pitch length of the helix of a chiral nematic phase changes with temperature. At high temperature, the pitch becomes wound up and short and hence the light reflected is blue but a lower temperature the pitch unwinds and becomes long which causes the reflection of red light. Accordingly, a chiral nematic material with a suitable pitch can be used as a thermometer which reflects different colors at different temperatures. Such materials can be encapsulated into a polymer or an ink and can be used in great variety of items. For example, the polymers can be used to make decorative items, clothing and paints that changes color with temperature. The inks can be used for printing onto paper or clothing that changes color with temperature. However, chiral nematic liquid crystal mixtures can be used to make accurate thermometers that consist of a plastic strip with a fixed legend. These thermometers are very convenient for use in fish tanks, display refrigerators in supermarkets, in the home or office. They also give an accurate indication of body temperature. Other areas of use include the detection of structural flaws, the detection of hot spots in electronic circuits and in aerodynamic testing for the cooling of engine parts.

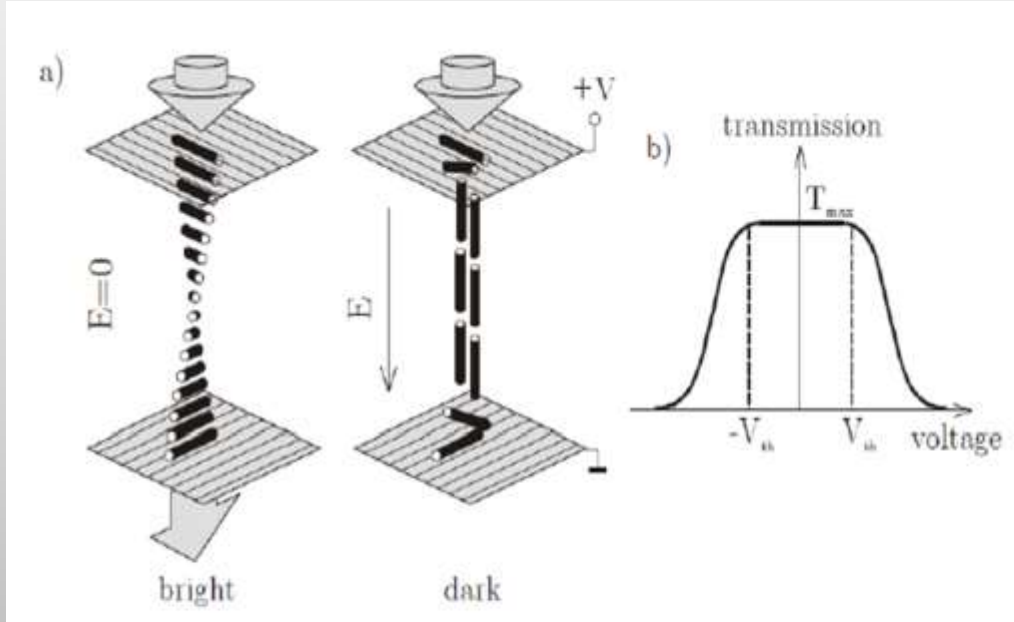


Figure 3: A schematic illustration of a TN-LCD.

Other Applications of Liquid Crystalline Materials: Liquid crystal polymers are still very much in the research stage but some liquid crystal polymers are in commercial use. If a polymer is extruded in the liquid crystal phase, the anisotropic ordering of molecules confers an extremely high strength to the polymer. Kevlar is a good example of such a high strength liquid crystal polymer and is used in bullet-proof vests and for car body panels. Liquid crystal polymers are also useful as a data storage medium. For example, a laser beam can be used to 'write' onto an ordered liquid crystal phase and produce an isotropic liquid which on cooling gives a scattered liquid crystal ordering. The written area can be changed simply by cooling the ordered liquid crystalline phase from the isotropic liquid but applying an electric field during the cooling process. This type of technology can produce both erasable and write once only devices. Liquid crystals is an exciting and unique field that draws upon the skills of scientists from a wide range of disciplines, including chemistry, physics, engineering, biology, mathematics and computation. Liquid crystals are very special materials and their research and development is of great technological importance.

Conclusions: The LCD display is commonly used in electronic digital watch displays because of its extremely low electrical power and relatively low-voltage requirements. The heart of an LCD is a special liquid that is called a twisted nematic liquid crystal. LCDs are commonly used for portable electronic games, as viewfinders for digital cameras and camcorders, in video projection systems, for electronic billboards, as monitors for computers, and in flat-panel televisions. Liquid crystal display technology works by blocking light. At the same time, electrical currents cause the liquid crystal molecules to align to allow varying levels of light to pass through to the second substrate and create the colors and images that you see. LCDs are known for their energy-efficient properties. They still require power to illuminate their respective pixels, but LCDs consume less power than non-

LCD devices. When compared to cathode-ray tube (CRT), for example, a typical LCD will use about 25% less power. Lighter in weight with respect to screen size. Energy efficient because of lower power consumption. Brightness range is too much wider produce very bright images due to high peak intensity. Some of the technological achievements include LCDs' response time and color clarity, making them faster and able to handle a wide range of computing work such as editing, gaming and design. The monitors vary in durability, power consumption and safety measures.

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