Effect of chirality and applications of liquid crystals engineering essay

Engineering

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Abstract:

To those who know that substances can exist in three states, solid, liquid, and gas, the term " liquid crystal" may be puzzling. How can a liquid be crystalline? However, " liquid crystal" is an accurate description of both the observed state transitions of many substances and the arrangement of molecules in some states of these substances. Many substances can exist in more than one state. For example, water can exist as a solid (ice), liquid, or gas (water vapour). The state of water depends on its temperature. Below 0°C, water is a solid. As the temperature rises above 0°C, ice melts to liquid water. When the temperature rises above 100EC, liquid water vaporizes completely. Some substances can exist in states other than solid, liquid, and vapour. For example, cholesterol myristate (a derivative of cholesterol) is a crystalline solid below 71°C. When the solid is warmed to 71°C, it turns into a

cloudy liquid. When the cloudy liquid is heated to 86°C, it becomes a clear liquid. Cholesterol myristate changes from the solid state to an intermediate state (cloudy liquid) at 71°C, and from the intermediate state to the liquid state at 86°C. Because the intermediate state exits between the crystalline solid state and the liquid state, it has been called the liquid crystal state.

Introduction:

" Liquid crystal" also accurately describes the arrangement of molecules in this state. In the crystalline solid state, the arrangement of molecules is regular, with a regularly repeating pattern in all directions. (Molecules of substances with a liquid crystal state are generally oblong and rigid, that is, rod-shaped.) The molecules are held in fixed positions by intermolecular forces. As the temperature of a substance increases, its molecules vibrate more vigorously. Eventually, these vibrations overcome the forces that hold the molecules in place, and the molecules start to move. In the liquid state, this motion overcomes the intermolecular forces that maintain a crystalline state, and the molecules move into random positions, without pattern in location or orientation. Liquid crystals (LCs) are a state of matter that have properties between those of a conventional liquid and those of a solid crystal. For instance, an LC may flow like a liquid, but its molecules may be oriented in a crystal-like way. There are many different types of LC phase, which can be distinguished by their different optical properties (such as birefringence). When viewed under a microscope using a polarized light source, different liquid crystal phases will appear to have distinct textures. The contrasting areas in the textures correspond to domains where the LC molecules are oriented in different directions. Within a domain, however, the molecules are well ordered. LC materials may not always be in an LC phase (just as water may turn into ice or steam).

Structure and Forces Involved in Crystal Liquid:

Liquid crystals can be divided into thermotropic, lyotropic and metallotropic phases. Thermotropic and lyotropic LCs consist of organic molecules. Thermotropic LCs exhibit a phase transition into the LC phase as temperature is changed. Lyotropic LCs exhibit phase transitions as a function of both temperature and concentration of the LC molecules in a solvent (typically water). Metallotropic LC is composed of both organic and inorganic molecules; their LC transition depends not only on temperature and concentration, but also on the inorganic-organic composition ratio. Examples of liquid crystals can be found both in the natural world and in technological applications. Most modern electronic displays are liquid crystal based. Lyotropic liquid-crystalline phases are abundant in living systems. For example, many proteins and cell membranes are LCs. Other well-known LC examples are solutions of soap and various related detergents, as well as tobacco mosaic virus. Arrangement of molecules in a liquid. Arrangement of molecules in a liquid crystal. In materials that form liquid crystals, the intermolecular forces in the crystalline solid are not the same in all directions; in some directions the forces are weaker than in other directions. As such a material is heated, the increased molecular motion overcomes the weaker forces first, but its molecules remain bound by the stronger forces. This produces a molecular arrangement that is random in some directions and regular in others. The arrangement of molecules in one type of liquid crystal is represented in Fig. The molecules are still in layers, but within each layer, they are arranged in random positions, although they remain more or less parallel to each other. Within layers, the molecules can slide around each other, and the layers can slide over one another. This molecular mobility produces the fluidity characteristic of a liquid.

Twisted nematic liquid crystals:

There are other molecular arrangements in liquid crystals. Many liquid crystals of technological significance have the arrangement represented in Figure. Liquid crystals with this arrangement are called twisted nematic liquid crystals. In this arrangement, the layers contain the long axes of the molecules. Furthermore, the long axes rotate by a small angle from one layer to the next. Twisted nematic liquid crystals are used in temperature-sensing devices that change colour. They are also the most common type used in the liquid crystal displays (LCDs) found in calculators and watches. Both of these applications depend on the way liquid crystals interact with light. When light strikes a twisted nematic liquid crystal, some of the light is reflected. Only light with a wavelength equal to the spacing between layers of similar orientation is reflected. Therefore, the reflected light will appear colored. As the temperature of the liquid crystal changes, the spacing between layers also changes. The change in spacing changes the wavelength of the reflected light and its observed color. Therefore, the color of the reflected light is an indication of the temperature of the liquid crystal. Arrangement of molecules in a twisted nematic liquid crystal. Different substances form twisted nematic liquid crystals over different temperature ranges, and so a wide temperature range can be covered by using several substances. When polarized light passes through a twisted nematic liquid crystal, the plane of polarization rotates. The degree of rotation depends on the number of layers of molecules the light encounters in the liquid crystal. If the axes of the molecules in the layer from which the light exits are at an angle of 90 degrees to those in the layer of entry, then the plane of polarization of the light rotates by 90 degrees. The ability of twisted nematic liquid crystals to rotate the plane of polarized light are exploited in LCDs. Figure 5 is a schematic diagram of an LCD. Ambient light enters from the right and is polarized by a polarizing filter. The polarized light passes through the front glass wall of the display, then through a transparent, electrically conductive coating on the glass, and into the liquid crystal. The thickness of the liquid crystal is sufficient to rotate the plane of the polarized light by 90 degrees. At the back of the display, the light passes through another electrically conductive coating, glass plate, and polarizing filter. This rear polarizing filter is placed with its axis at 90 degrees to the front filter. The polarized light passes through this rear filter, because its polarization was also rotated by 90 degrees by the liquid crystal. At the back of the LCD is a mirror that reflects the light back through the cell. The light retraces its path, and an observer sees the display as relatively bright. When an electric potential is applied between the two conductive coatings, the resulting electric field affects the positions of molecules in the liquid crystal. The molecules tend to turn so they align with the electric field. When this happens, the plane of polarized light passing through the cell is no longer rotated by 90 degrees, and it cannot pass through the rear filter. Therefore, it is no longer reflected back to an observer, and the area appears dark. By the selective charging of areas of the conductive coating, patterns of dark digits or letters against a bright background are formed.

Liquid crystal phases

The various LC phases can be characterized by the type of ordering that is present. One can distinguish positional order (whether or not molecules are arranged in any sort of ordered lattice) and orientational order (whether or not molecules are pointing in the same direction), and moreover order can be either short-range (only between molecules close to each other) or long-range (extending to larger, sometimes macroscopic, dimensions). Most thermotropic LCs 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 (little to no long-range order), and fluid-like flow behavior. Under other conditions (for instance, lower temperature), an LC might inhabit one or more phases with significant anisotropic orientational structure and long-range orientational order while still having an ability to flow. The orientational order may be quasicrystalline. One of the most common LC phases is the nematic, where the molecules have no positional order, but they do have long-range orientational order. Thus, the molecules flow and are randomly distributed as in a liquid, but they all point in the same direction (within each domain). The smectic phase is one where in addition to orientation order, the mesogens are grouped into layers, enforcing long-range positional order in one direction. In the smetic A phase, the molecules point perpendicular to the layer planes, whereas in the smectic C phase, the molecules are tilted with respect to the layer planes. The ordering of liquid crystalline phases is extensive on the molecular scale. This order extends up to the entire domain size, which may be on the order or microns, but usually does not extend to the macroscopic scale as often occurs in classical crystalline solids. However, some techniques (such as the use of boundaries or an applied electric field) can be used to enforce a single ordered domain in a macroscopic liquid crystal sample. The ordering in a liquid crystal might extend along only one dimension, with the material being essentially disordered in the other two directions.

Mesogens

Liquid crystal mesogens are divided into two groups depending on the shape of the molecules. Calamitic liquid crystals consist of rod-like molecules and have order in the direction of the longer axes of the molecules. In contrast, discotic liquid crystals are composed of flat-shaped molecules which align in the direction of the shorter axes of the molecules. Important types of calamitic liquid crystals includenematics (most nematics are uniaxial but biaxial nematics are also known)smectics (smectic A , smectic C , and hexatic)cholesterics (which can have spiral and quasicrystalline orientational order)Important types of discotic liquid crystals includediscotic nematicscolumnar phasesBiological membranes are a form of liquid crystal. Their rod-like molecules (e. g., phospholipids) are organized perpendicularly to the membrane surface, yet the membrane is fluid and elastic. It can also host important proteins such as receptors freely " floating" inside, or partly outside, the membrane. Fig.: Rodlike molecules in the nematic phase (N), the smectic A phase (SmA) and in the smectic C phase (SmC). The director is denoted as n.

Effect of Chirality:

Chiral LC molecules usually give rise to chiral mesophases. This means that the molecule must possess some form of asymmetry, usually a stereogenic center. An additional requirement is that the system not be racemic: a mixture of right- and left-handed molecules will cancel the chiral effect. Due to the cooperative nature of liquid crystal ordering, however, a small amount of chiral dopant in an otherwise achiral mesophase is often enough to select out one domain handedness, making the system overall chiral. Chiral phases usually have a helical twisting of the molecules. If the pitch of this twist is on the order of the wavelength of visible light, then interesting optical interference effects can be observed. The chiral twisting that occurs in chiral LC phases also makes the system respond differently from right- and left-handed circularly polarized light. These materials can thus be used as polarization filters. It is possible for chiral LC molecules to produce essentially achiral mesophases. For instance, in certain ranges of concentration and molecular weight, DNA will form an achiral line hexatic phase. An interesting recent observation is of the formation of chiral mesophases from achiral LC molecules. Specifically, bent-core molecules (sometimes called banana liquid crystals) have been shown to form liquid crystal phases that are chiral. In any particular sample, various domains will have opposite handedness, but within any given domain, strong chiral ordering will be present. The appearance mechanism of this macroscopic chirality is not yet entirely clear. It appears that the molecules stack in layers and orient themselves in a tilted fashion inside the layers. These liquid crystals phases may be ferroelectric or anti-ferroelectric, both of which are of interest for applications. Chirality can also be incorporated into a phase by adding a chiral dopant, which may not form LCs itself. Twisted-nematic or super-twisted nematic mixtures often contain a small amount of such dopants.

Applications of Liquid Crystals

Liquid crystal technology has had a major effect many areas of science and engineering, as well as device technology. Applications for this special kind of material are still being discovered and continue to provide effective solutions to many different problems. Liquid Crystal DisplaysThe most common application of liquid crystal technology is liquid crystal displays (LCDs.). This field has grown into a multi-billion dollar industry, and many significant scientific and engineering discoveries have been made. Liquid Crystal ThermometersAs demonstrated earlier, chiral nematic (cholesteric) liquid crystals reflect light with a wavelength equal to the pitch. Because the pitch is dependent upon temperature, the color reflected also is dependent upon temperature. Liquid crystals make it possible to accurately gauge temperature just by looking at the color of the thermometer. By mixing different compounds, a device for practically any temperature range can be built. The " mood ring", a popular novelty a few years ago, took advantage of the unique ability of the chiral nematic liquid crystal. More important and practical applications have been developed in such diverse areas as medicine and electronics. Special liquid crystal devices can be attached to the skin to show a " map" of temperatures. This is useful because often physical problems, such as tumors, have a different temperature than the surrounding tissue. Liquid crystal temperature sensors can also be used to find bad connections on a circuit board by detecting the characteristic higher temperature. [Collings, 140-142]Optical ImagingAn application of liquid crystals that is only now being explored is optical imaging and recording. In this technology, a liquid crystal cell is placed between two layers of photoconductor. Light is applied to the photoconductor, which increases the material's conductivity. This causes an electric field to develop in the liquid crystal corresponding to the intensity of the light. The electric pattern can be transmitted by an electrode, which enables the image to be recorded. This technology is still being developed and is one of the most promising areas of liquid crystal research. Other Liquid Crystal ApplicationsLiquid crystals have a multitude of other uses. They are used for non destructive mechanical testing of materials under stress. This technique is also used for the visualization of RF (radio frequency) waves in waveguides. They are used in medical applications where, for example, transient pressure transmitted by a walking foot on the ground is measured. Low molar mass (LMM) liquid crystals have applications including erasable optical disks, full color " electronic slides" for computer-aided drawing (CAD), and light modulators for color electronic imaging. As new properties and types of liquid crystals are investigated and researched, these materials are sure to gain increasing importance in industrial and scientific applications.