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LIQUID CRYSTALS

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An introduction to Liquid Crystals

"What does the oxymoronic phrase liquid crystals mean?!" – I have been asked this question many times over the years.

On one occasion, one of my colleagues, who had just returned after giving a lecture on liquid crystals at a high school, received in the mail a bottle of finely ground quartz suspended in water. The accompanying note asked if the sender had succeeded in making a new type of liquid crystal!

These and many similar instances show that even non-scientists find liquid crystals fascinating and they want to know more. Liquid crystals instantly fire up people's curiosity and imagination. Of course, the presence of liquid crystal displays (LCDs) in every home as flat panel televisions, in notebook computers, cell phones, and a myriad of other electronic devices, has also fuelled people's interest in these mystical materials.

Indeed, even researchers in chemistry, physics, biology, polymers, and optical engineering have been fascinated, puzzled, and awed by liquid crystals for over a century. Liquid crystal research has proceeded in a very collaborative manner with exchange of ideas and sharing of results among synthesis chemists, physicists, and device engineers. Consequently, this field has remained vibrant for a very long time and has continually presented to us new materials, phases, and phenomenology. Liquid crystals possess anisotropic elasticity, dielectric and diamagnetic susceptibilities, viscosity, and optical and (de)wetting properties. It is these anisotropies that make liquid crystals responsive to external applied electric, magnetic, and flow fields. Understanding of the interactions of liquid crystals with surfaces is essential for making LCDs and other electro-optical devices. Applications relying on surface modifications by chemical and biological agents are being developed for the detection of radiation, nerve gases, viruses, and bacteria.

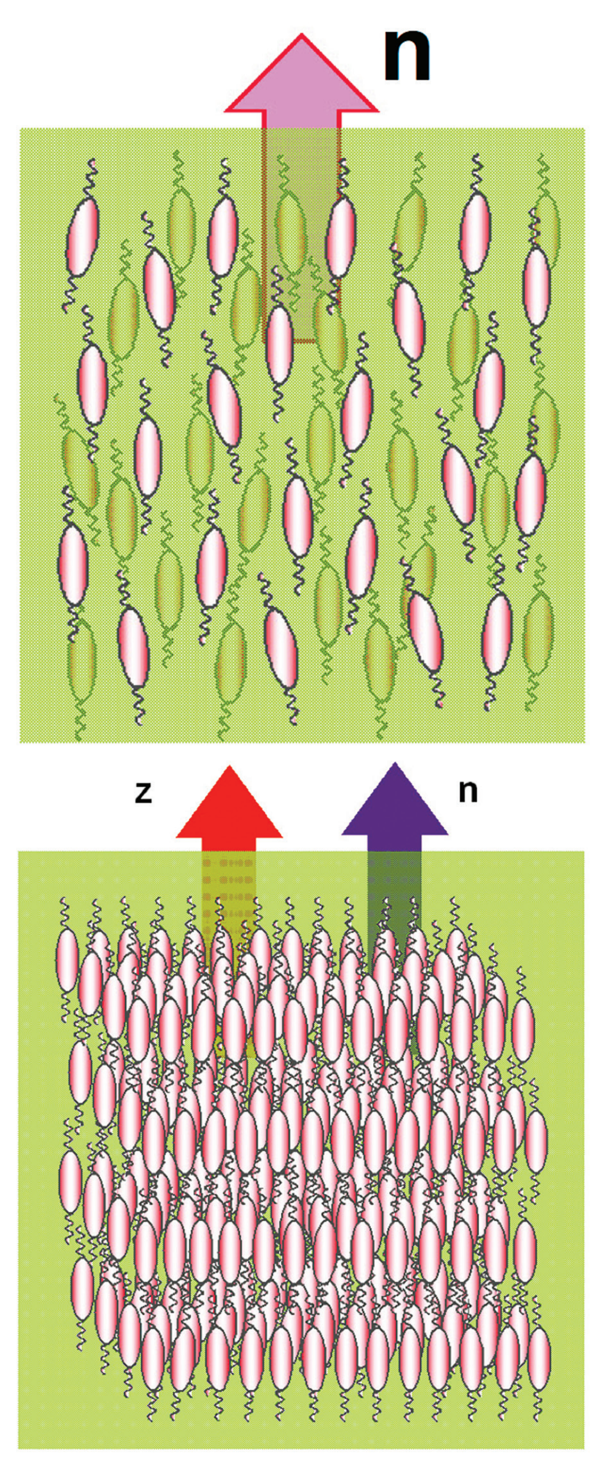

Figure 1: (Top) Orientational ordering of molecules parallel to the direction of the director n in the nematic phase. (Bottom) One dimensional positional order along the z-direction results in 2D liquid-like layers of the smectic phase. Here ellipses and wiggly lines represent the rigid core and flexible hydrocarbon chains of liquid crystal molecules.

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Liquid crystal phases [1] can be distinguished on the basis of the presence/absence of long-range (a) orientational order, (b) bond-orientational order, (c) positional order, and (d) chirality in one, two and three dimensions. Because the spectrum of liquid crystal phases represents almost continuously varying symmetry, and type and degree of order, many of them exhibit scientific phenomena analogous to those found in other unrelated materials. Several of them are the only physical embodiments of theoretically predicted structures and phases. For example, Landau-Pierrels instability has been confirmed [2] in the smectics-A phase and in its lyotropic counterpart, the L_α phase. In the smectics-A phase, the quantity $\nabla \times \boldsymbol{n}$ is excluded just as the magnetic field ($\nabla \times \boldsymbol{A}$) is expelled from the type-I superconducting phase. This analogy [3] between the smectics-A and the superconducting phase engendered much interest in the study of critical phenomena at the nematic to smectics-A phase transition, and comparisons with the normal metal to superconducting phase and normal fluid to superfluid helium phase transition. Primarily for this and other pioneering work, Peirre-Gilles de Gennes was awarded the 1991 Nobel Prize in physics. A few decades after de Gennes' work, Lubensky *et al.* [4] predicted the existence of a smectics phase corresponding to the type-II superconducting phase which was almost simultaneously discovered by Pindak *et al.* [5].

The transformations from smectics-A to hexatic-B and hexatic-B to smectics-B phases are examples of 2D and 3D melting [6] transitions. Theoretically described by the Kosterlitz-Thouless theory [7] (and its subsequent extensions), the physics of these transitions is similar to that of adsorbed films [8] of noble gases on exfoliated graphite. The effect of random field and confinement on the development of order over finite dimensions has also been investigated in liquid crystals. The chiral phase phenomenology ranging from ferroelectric to ferrielectric to antiferroelectric smectics-C* phases is one of the richest condensed matter systems to challenge both theoreticians and experimentalists.

In addition to the mesophases formed by rod-like (calamitic) and disc-shaped molecules, bent-core (or banana shaped) molecules exhibit a number of phases with different symmetry and molecular packing. In particular, chiral phases formed by non-chiral molecules – the B2 conglomerate [9], the B7, and the biaxial nematic [10] phases – are very intriguing. These have generated much activity and discussion among scientists since their discovery in 1996 [11]. Liquid crystal phases are ubiquitous; many biological systems rely on their proper functioning on liquid crystal properties. Structures of cell membranes, cationic liposome complexes, bacteria, and viruses possess liquid crystalline structures. Liquid crystal based systems are now being developed as fast and portable

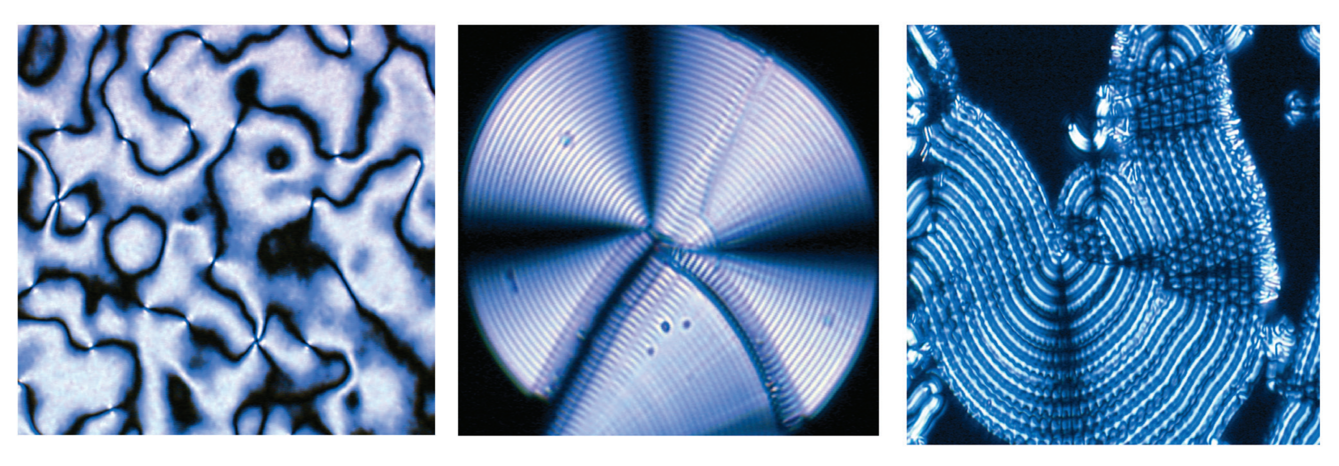

Figure 2: Characteristic textures of different liquid crystal phases as observed under a polarizing microscope. (Left) Schlieren texture of the nematic phase with two- and four-brush defects visible where two and four dark lines emanate from a point. (Middle and Right) Striations in the texture of the banana B7 phase confirm the chiral nature of the phase.

detectors for various chemical contaminants, nerve gases, and bio-agents. A multitude of polymers, elastomers, and macromolecules invariably possess liquid crystal properties. In the past 5-6 years very interesting effects have been observed when nano-particles are dissolved in different liquid crystalline phases.

Liquid crystal structure and knowledge of how to control molecular organization and growth is used to prepare defect-free films and 3D custom structures for use in organic semiconductors, organic photovoltaics, and organic lighting applications. Attempts are being made to increase the lifetime of excitons in organic materials so that solar energy harvesting efficiency can be increased. There are a number of issues to be resolved on the path to their effective use in flexible organic electronics.

Evidently, much interesting physics is yet to emerge from materials that can generally be classified as liquid crystals. I am sure we all will be looking for the best way to disseminate our scientific discoveries in high-impact and respected journals. EPL is an excellent place to publish your best results. EPL's impact factor has seen a dramatic increase in recent years and we are doing everything possible to render it even a more established journal of choice.

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