Liquid crystal research

# Far-From-Ordinary Crystals

Professor Wojciech Kuczynski is a physicist studying the structures and physical properties of liquid crystals

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**Liquid crystals have recently found their way into many everyday applications. Indeed, they are now employed in numerous devices without which contemporary life seems difficult to imagine**

Liquid crystals are found in digital watches, computer monitors and TV sets. Without liquid crystal displays, the current rapid expansion of mobile telephones would not be possible. The total area of such liquid crystal displays produced every year is nowadays best measured in terms of square kilometers. Such enormous development of such liquid crystal devices has been facilitated by the findings of scientific research into the nature of liquid crystals. Nevertheless, public understanding of liquid crystals has not kept pace with the vast progress in the science and technology of these materials; they are still widely considered to be some sort of miraculous objects. Children learn in school that there are three states of matter: solid, liquid and gaseous - a classification that leaves no place for liquid crystals. So what are liquid crystals, really?

As a rule, the melting of a solid produces a liquid. In some cases, however, the melting process might be quite complex and occur in two or more stages. Such intermediate phases between the solid and the liquid state are called mesophases, or liquid crystals.

Solid crystals are characterized by long-range translational order. This means that the molecules or atoms constituting the crystal are located in precisely defined positions within the three-dimensional crystal lattice. Liquids and gases do not exhibit such order, being fluid instead. Mesophases, as states intermediate between solids and liquids, possess both long-range order and fluidity. However, the order is not as perfect as in crystals. The simplest liquid crystals called nematics possess one-dimensional orienta-

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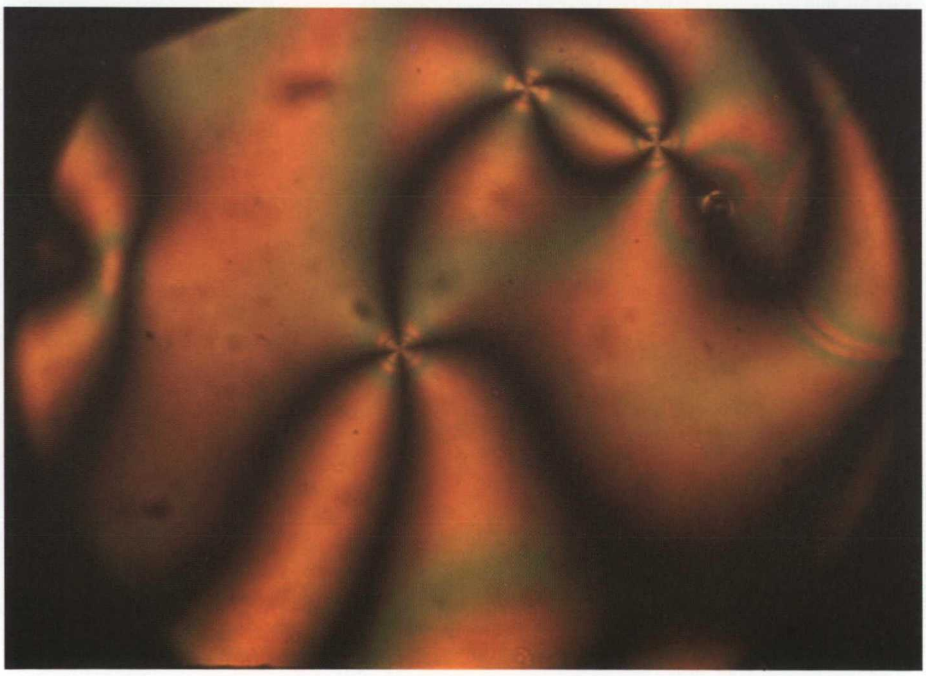
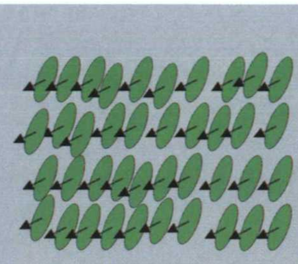
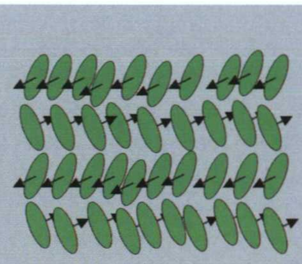


Effects caused by optical anisotropy observed using polarized light in the simplest (nematic) liquid crystal phase

In some smectic liquid crystals, molecules are tilted with respect to the layer plane. If the molecules are chiral, i.e. they differ from their own mirror image (like one's left hand differs from one's right hand), the transversal components of their dipoles (visualized by black arrows) are ordered. A net polarization appears in each smectic layer parallel to the layer plane and perpendicular to the tilt direction. If tilt





directions in all layers are the same or nearly so (as in the left-hand drawing above), the material exhibits ferroelectric properties.

In the case of antiparallel tilt directions in consecutive layers (as in the right-hand drawing), the polarization of each couple of smectic layers is compensated and the material shows antiferroelectric properties.

tional order only. Nevertheless, this order means that many of their physical properties are anisotropic (i.e. depend on the direction of measurement). For instance, striking effects caused by optical anisotropy can be observed using polarized light.

## Challenges of smectic crystals

Smectic liquid crystals exhibit a more complicated structure. Besides the orientational order, they also exhibit various kinds of low-dimensional positional order. There exist many kinds of smectic liquid crystals, which differ in terms of inter- and intra-molecular correlations. Some of them (with molecules tilted with respect to the normal layer) may adopt a helical structure, when the molecules are chiral (i.e. different from their own mirror image) or contain chiral admixtures. The period of the helical structure is often comparable to the wavelength of visible light. In this case, due to the selective reflection phenomenon, the liquid crystal layer is colored in reflected light. We took advantage of this effect to achieve the visualization of smectic layers. The layers' thickness is about 3nm ($3\times10^{-9}$m, i.e. far below the wavelength of light) and, in principle, cannot be resolved by any optical microscope. In our experiments we used a wedge-shaped measuring cell with very small edge angle (on the order of $10^{-4}$ radian). Some edge dislocations appear in such a cell when the thickness gradient is parallel to the smectic layers. The distances between dislocations connected with every smectic layer is 10,000 times larger than the layer thickness. If the anchoring of molecules at the cell boundary is strong, the regions between dislocations are differently colored in reflected light because the helical period is not constant (its multiple must match the sample thickness). As the dislocations are well separated (by about 30 μm) they can be observed even under a simple optical microscope in polarized light.

We employed this method to investigate the structure of phases and subphases of antiferroelectric liquid crystals. The applied method clearly revealed the alternation of tilt direction in adjacent smectic layers.

## Applied crystals

Tilted smectic liquid crystals composed of chiral molecules exhibit order among the dipoles within each smectic layer. The resulting spontaneous polarization of neighboring layers can be either parallel or antiparallel. In the first case the material shows ferroelectric properties, and in the second - antiferroelectric properties. Due to the presence of local polarization, both kinds of smectic liquid crystals demonstrate a fast switching phenomenon, what makes them good candidates for use in electrooptic devices. Ferroelectric liquid crystals have already found application in TV screens and light switches; antiferroelectric liquid crystals will probably find similar or even wider application. In some antiferroelectric liquid crystals a so-called "threshold-less switching" is observed. This phenomenon can be used for producing a gray scale in information display devices, e.g. TV screens and computer monitors. Although this phenomenon is of large application potential, the physical mechanism involved is not yet fully understood. Our experiments have shown that this kind of switching is caused by extensive frustration between ferroelectric and antiferroelectric interactions acting among smectic layers. This research has contributed to a better understanding of the "threshold-less switching" phenomenon.

## Order composed of defects

Some chiral smectic liquid crystals create a so-called "twist grain boundary" (TGB)-phases. These are the liquid-crystalline analogs of the "Abrikosov phase" that occurs in superconductors. TGB phases are characterized by a helical structure with an axis lying in the smectic layer plane. The existence of such a structure is possible due to the creation of large number of defects. These defects are in fact screw dislocations, ordered in parallel arrays separated by a few dozen molecules. In this way a two-dimensional lattice of defects is created, which separate smectic grains consisting of about a thousand molecules. Locally, the grains possess an ordinary smectic A or smectic C structure. During our studies we observed, for the first time, a new kind of twist grain boundary phase. The grains in this phase possess a helical smectic C* structure. This apparently slight modification introduces significant changes in the structure of the discovered phase. Namely, there are two different helicoidal systems present in this phase: the local helix of the ordinary smectic C* in each grain and the helix arising through the rotation of dislocation arrays in adjacent grains. This gives rise to a long-range order of defects in three dimensions. The presence of such three-dimensional order means that we are dealing with a crystal, yet such a crystal is quite uncommon - its structural elements are neither atoms nor groups of atoms, but rather defects. This is not a defected crystal, but a crystal of defects. The lattice constant of this crystal is on the order of 1μm. Such a structure can be observed using polarized light under a regular optical microscope.

As the distances between lattice planes are on the order of the wavelength of visible light, such a crystal of defects possesses unusual optical properties. It reflects light of a given color under precisely defined angles, which fulfill the Bragg condition. Many optical experiments known from X-ray techniques can be performed with such crystals, such as the Laue or Debye-Scherrer experiments. Such experiments help ascertain the peculiarities of the structure of TGB phases, and can also be useful in teaching.

As this short review demonstrates, liquid crystals are not just materials of vast application potential - they also possess intriguing physical properties. These two features, attracting the attention of both engineers and physicists, mutually support and stimulate each other. Cooperation between scientists and technicians has resulted in the frequent announcement of both new application possibilities and new discoveries in liquid crystal research. To be sure, this process is far from finished. ■

**Further reading**

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**Edge dislocations in a liquid crystal reveal the smectic layers - visible under a simple optical microscope using polarized light**

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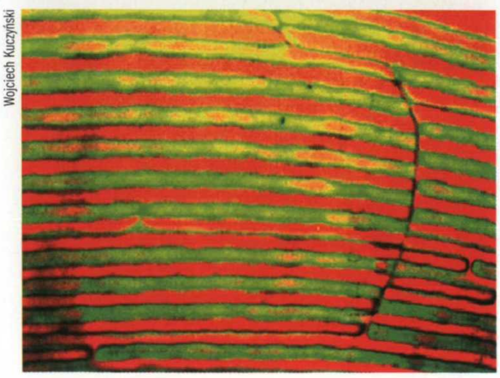

**Edge dislocations in the antiferroelectric phase. Different colors reveal a different direction of molecular tilt**