Liquid Crystals Revisited

As I described in the April *Light Touch* column (page 58), liquid crystal materials are beginning to be used in an ever-increasing number of applications. I started with the properties of liquid crystals in general, and then quickly discussed the most common liquid crystal application—twisted nematic displays. These displays are used in many applications, ranging from clocks and watches to portable laptop computers. This column describes a different kind of liquid crystal—the kind used to make unbreakable fever thermometers.

So, what is a liquid crystal? Liquid crystals are materials that show some of the properties of liquids, while at the same time showing other properties that we normally think of as belonging to solid crystals. In particular, liquid crystal materials flow, like normal liquids. They can be poured from one bottle to another. But they also have long-range order. Liquid crystal molecules are typically long-chain organics; I like to think of them as looking like pencils or cigars. The best analogy I know for a liquid crystal material is a box that is partially full of pencils. If you shake the box from side to side, the pencils "flow" inside the box. However, the average orientation of pencils is not random. Rather, most pencils will tend to be aligned by the walls of the box and by bumping into other pencils so that their long axes are all pointed in the same direction. So a liquid crystal is a liquid in which there is a long-range order—in which the orientation of the molecules is not random, but ordered.

Even though all liquid crystals have long-range order, different materials (or often the same material in different temperature ranges) have different amounts of order. Just as one can stack pencils in a variety of different ways, so too can liquid crystal molecules be arranged.

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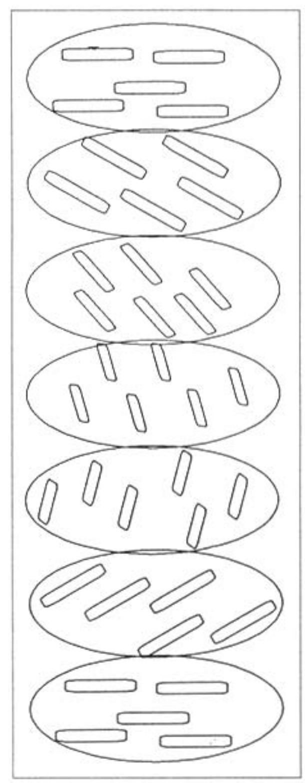
One class of liquid crystals is called cholesteric liquid crystals. They get their name from the fact that some of the original members of the class are related chemically to cholesterol. In cholesteric liquid crystal materials, the molecules can be thought of as being in layers. The molecules in any one layer are all pointed in the same direction. However, the molecules in the next layer are pointed in a different direction, at some small angle from the direction of the first layer. This results in an inherent twist in the material, similar to the twist that is artificially imposed on the molecules in the twisted nematic displays I described last time.



▲ FIGURE 1. SCHEMATIC VIEW OF A CHOLESTERIC LIQUID CRYSTAL MATERIAL. NOTE THAT THE DIRECTION OF ORIENTATION FOR THE LIQUID CRYSTAL MOLECULES IN SUCCESSIVE LAYERS ROTATES THROUGH A FIXED ANGLE.

One example of this twisting of alternate layers is the way that the logs in a log cabin are put together. In a log cabin, the logs in each layer make a 90° angle with the logs in the previous layer. In a normal cholesteric material, the angle between the molecules in successive layers is typically much smaller than 90°, however, so that one cycle represents many layers of liquid crystal. Figure 1 illustrates this cholesteric material structure.

TRY IT WITH PENCILS

Kids might enjoy exploring the different types of order that can be illustrated with a box of pencils or crayons. You can obviously model a nematic liquid crystal easily by putting the pencils loosely in a larger box and shaking it from side to side. The pencils will end up with their long axes mostly aligned, but with no limitation as to their positions in the other two directions. For a cholesteric liquid material, you could stack the pencils, with each layer being at some angle with respect to the ones in the layer below and above them. By varying the angle between the layers, you can vary the number of layers required until the pencils again line up with the pencils in the bottom layer. This characteristic length is called the pitch of the cholesteric.

So how does this produce a visible effect? Liquid crystal materials are strongly birefringent; they have different indices of refraction along different axes of the molecules. Thus, in a cholesteric liquid crystal material, there is a periodic variation in the index of refraction, corresponding to the pitch of the material. When the pitch is comparable to the wavelength of incident light, this spiralling variation results in the separation of the incident light into left-handed and right-handed circularly polarized portions. The polarization whose handedness matches that of the liquid crystal is transmitted, whereas the other polarization is diffracted according to the usual Bragg condition. This gives an intense iridescent metallic appearance to the film. In addition, this color varies as the temperature of the liquid crystal changes. It turns out that the pitch of a cholesteric material is a strong function of the temperature. The spiral unwinds as the temperature decreases. This changes the wavelength of the light that is reflected from red at low temperatures to blue at higher ones. The effect is most noticeable when the liquid crystal material is placed over a black background, since the amount of light that is reflected by the liquid crystal is relatively limited.

Several characteristics of this effect should be noted. First, the diffracted color does not depend on the total film thickness as it does in interference, but only on the characteristic pitch of the liquid crystal film as in a diffraction grating. Thus, this effect, though similar in appearance, is different from the iridescence of soap films. The colors also vary with the viewing angle, as described by the Bragg condition. Finally, Nassau[1] points out that the iridescent colors of some beetles originate from twisted structures of chitin in the outer layer of their shells!

TAKING YOUR TEMPERATURE

This optical phenomenon has been applied to a variety of products, including fever thermometers. In a fever thermometer, there are typically several different windows. Each one contains a liquid crystal with a slightly different pitch, so that they become colored sequentially as the temperature of the strip increases. A spectrum of materials has been formulated, covering temperatures from −30°C to 100°C and above. Any one mixture will be colored only over a small (0.5°C) temperature range.

Fever thermometers are available from most drug stores. Kids will be intrigued by watching the changing colors of the thermometer as they hold it in their hands, especially if they have seen brilliantly iridescent beetles in the garden. I have a stress gauge, which was given to me at a trade show, that uses this principle to indicate your individual stress level. (Obviously, the surface temperature of our hands must vary, depending on stress level.) By combining some wave optics with the image of a stack of pencils, maybe you can further feed a kid's curiosity about the world!

REFERENCE

1. Nassau, Kurt, *The Physics and Chemistry of Color*, Wiley and Sons, New York, N.Y. 1983.