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Double Refraction

The operation of liquid crystal displays is founded on the phenomenon of the double refraction of light as first recorded in Denmark by Erasmus Bartholinus in 1670. A piece of translucent calcite apparently divides incident light into two streams, producing a double image. This is depicted in Figure 1.1, as shown by the offset of the word "calcite." At about the same time in the Netherlands, Christian Huygens discovered that the light rays through the calcite could be extinguished by passing them through a second piece of calcite if that piece were rotated about the direction of the ray; this is depicted in Figure 1.2. This may be observed by taking two pairs of polarizing sunglasses and rotating them relative to each other.

One hundred and thirty-eight years later, in 1808, a protégé of the famous French mathematician Fourier, Etienne Louis Malus, observed that light reflected from a window, when passing through a piece of calcite also would change intensity as the calcite was rotated, apparently showing that reflected light was also altered in some way. The intensity of the light changed in both cases because the molecules of calcite have a crystal order that affects the light in an intricate but very understandable way called *polarization*.

Liquid Crystal Displays, First Edition. Robert H. Chen.

Figure 1.1 Double refraction in calcite. From http://www.physics.gatech.edu/gcuo/lectures.

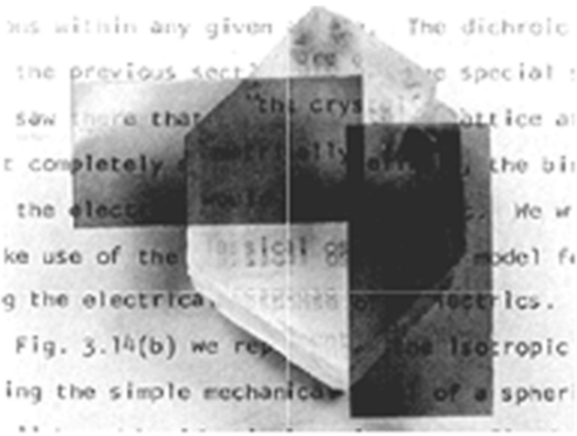

Figure 1.2 Two pieces of calcite at an angle. From http://www.physics.gatech.edu/gcuo/lectures.

It would be another 80 years later in Austria that double refraction, also called *birefringence*, and light polarization would be observed, not in crystalline rocks, but in a viscous liquid, later to be called a "liquid crystal." Although no doubt intriguing to natural scientists, intensive investigation of liquid crystals had to wait for yet another 80 years, when commercial interests provided the impetus for further study.

Briefly, a liquid crystal display can reproduce an image of a scene through the use of a video camera that, upon receiving the light reflected from the scene through its lens, in accord with the photoelectric effect first explained by Einstein, an electric current is generated in a metal when struck by light of sufficient energy, the current being proportional to the intensity of that light. That current is then transmitted to transistors that control an analog voltage that is applied to a pair of transparent electrode plates. Those plates enclose a thin layer of liquid crystal between them, and the voltage on the plates generates an electric field that is used to control the orientation of the electric dipole moment of the liquid crystal molecules, causing them to turn. Then light from a light source placed behind the liquid crystal layer, after being linearly polarized by a polarizer, will have its polarization states altered by the different orientations of the liquid crystal molecules, in accord with the liquid crystal's degree of birefringence. The beauty of the liquid crystal display is that the birefringence effected by a liquid crystal is precisely controllable by that electric field. The different polarization states of the light in conjunction with a second polarizer changes the brightness of the light emanating from the backlight source, and that modulated brightness can represent the light intensity of the original scene; the millions of picture elements so produced then combine to form an image that replicates the original scene.

Liquid crystal displays thus are based on an optical phenomena of electrically controlled birefringence and polarization, which can only be understood through knowledge of the interaction of light and matter.

However, light may be familiar to everybody, but Samuel Johnson succinctly observed that [1]*

> We all know what light is, but it is not easy to tell what it is.

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* Samuel Johnson (1709–1784), English lexicographer, critic, poet, and moralist who completed the *Dictionary of the English Language* in 1755; Johnson is one of the preeminent authorities on the English language.

The understanding of light can gainfully begin at the outset with an appreciation of light as described by the Maxwell equations.

Reference

[1] Johnson, S. 1755. *Boswell's Life; Dictionary of the English Language*; quoted in Clegg, B. 2001. *Light Years*. Piatkus, London.