AUSTRALIAN ALMANAC Vol.2 No 17

# The Extended Sensorium

## What is Polarized Light?

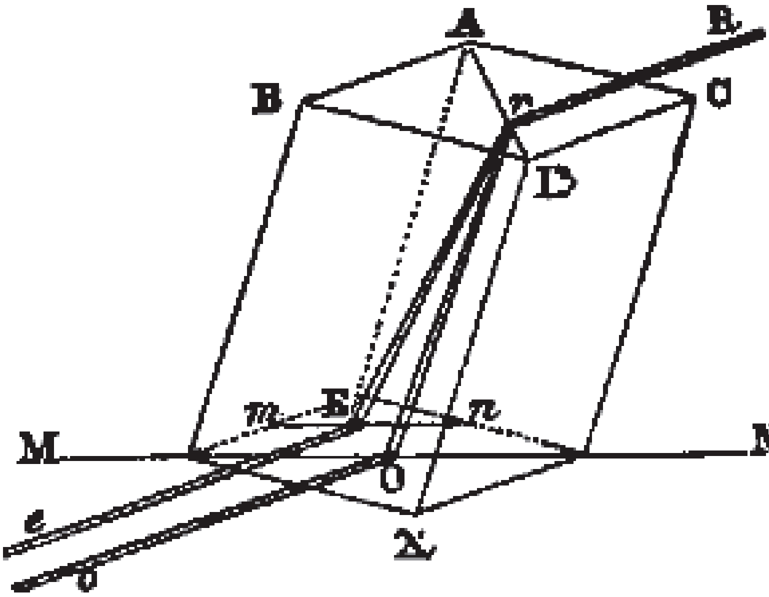
*by Jason Ross*

### Beginnings

When light passes from one substance into another, its direction is perceived to change. This phenomenon, known as refraction, was first understood by Pierre de Fermat as arising from the different speeds of light when moving through different media. These coefficients of resistance were successfully determined for a variety of different materials, but one particular crystal, a type of calcite known as Iceland spar, did not fit neatly into the theory. This crystal has the amazing property of not simply bending light's path, but of splitting it in two!

These two paths of light, known as the "ordinary" and "extraordinary" rays, are always of equal intensity, when usual sources of light are used. This is not the case, however, when rays refracted through Iceland spar, are directed to a second piece of the crystal. If the two pieces are parallel, the rays do not split again, but continue on as either ordinary or extraordinary rays. If the second crystal is rotated by 90 degrees, the once-ordinary light undergoes an extraordinary refraction, and the extraordinary light refracts as an ordinary ray. At 45 degrees, both rays split, giving a total of four rays exiting the second crystal. In between, there are four rays, but of unequal intensities: at zero and ninety degrees, two of the four rays vanish. Thus the rays of light refracted through Iceland spar are not of the same quality, but have additional *directions* associated with them (not just the direction of propagation), as revealed in their changing interaction with the crystal: they are thus said to be "polar."

In the early 19th century, Etienne-Louis Malus was studying Iceland spar, using beams of light reflected off the windows of a nearby building. To his surprise, the ray of light was not doubled, but refracted in the ordinary or extraordinary way, depending on how he held the crystal. Performing a further test with candlelight reflected off the surface of water, he found that at a shallow enough angle, the light reflecting from the water had a polarity, just like the light passing through Iceland spar. Similarly, the extraordinary ray passing through Iceland spar would not reflect at all off of water at this shallow angle. He discovered that almost all surfaces (except mirrored metal surfaces) can reflect polarized light.

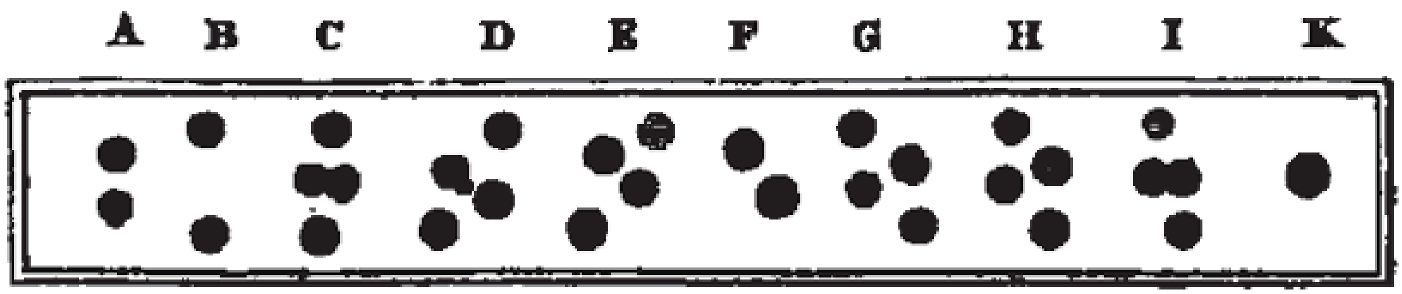



Double refraction of Iceland spar. (Illustration from François Arago's *Biographies of Distinguished Scientific Men*, p. 152)

### Fresnel's Discoveries

The shimmering colours of soap bubbles or of thin films of oil on water, arise from a phenomenon known as *interference*. Augustin Fresnel brought this phenomenon to a greater level of understanding by demonstrating the complete elimination of a beam of light by shining another upon it. Not just any two rays of light can interfere in this way: Fresnel showed that the two beams had to be of exactly equal colour to interfere. If red light is made to interfere with white light, then blue-green light will remain. By setting up two paths of light, differing only slightly in their length, Fresnel could determine the least difference in lengths that could give rise to interference, and determined these characteristic lengths for a variety of colours. Colour and distance are not the only factors, however: two rays of light, having the same origin and colour, but being polarized at right angles to each other, *will not interfere*.

Fresnel, a proponent of the wave theory of light who composed devastating attacks on the emission theory, conceived of these waves not as Huygens did – as longitudinal waves,




Representation of refraction through two pieces of Iceland spar. (A) represents the double-refraction through one piece. (B) represents the result when the two crystals are aligned, moving to 45 degrees at (D), with four equally bright spots. The four coalesce into two at 90 degrees (F), and then continue on, as the crystal is further rotated. *(Illustration from Arago,p. 150)*

Fresnel's method for producing interference. The two path lengths are very slightly different, and path differences that are multiples of a determined minimum distance result in interference–the brightness is eliminated. *(From Arago, p. 205)*

compressing and expanding in the direction of propagation, as do sound vibrations – but as transverse waves, having an oscillation perpendicular to the propagation direction. That is, like ocean waves, where water moves up and down as the wave moves horizontally, light has a perpendicular oscillation. This oscillation, having all different directions in a typical source of light, is split into its perpendicular components by passing through Iceland spar or by appropriate reflection. Thus, the rays polarized at right angles did not interfere, since they act in different planes.

Fresnel then created a new kind of polarized light, which he called *circularly polarized light.*[1] This new light would split in two when passed through Iceland spar like unpolarized light, but, unlike normal light, would display interference colours if it were passed through substances like mica before passing through Iceland spar. To produce this circularly polarized light, Fresnel used an apparatus that produced two rays, polarized at right angles to each other, and with one retarded by a quarter-wavelength. Together, they act as one ray of light, whose plane of polarisation rotates: circular polarisation. The secret to this special quality of light, quite useful now in microscopy and a variety of other applications, already existed in the tail of the lowly mantis shrimp!

The colours in this image of olivine and pyroxene appear from the polarized light used in the microscope.

**Footnotes**

[1] To distinguish it from the previous, simpler kind, now known as linearly polarized.

# Insects and Infrared

*by Oyang Teng*

Entomologist Philip S. Callahan dedicated his life's work to a field he termed "reverse bionics"—examining the properties of human invention to understand the means employed by nature for similar ends. In this case, it was his experience as a U.S. Army Air Force radio operator working with the electronics of antennas and tuned circuits during World War II that led him to the conclusion that insect antennae sensilla (the tiny micrometer structures covering what we typically call the antennae) were themselves functional electromagnetic antennae, allowing insects to utilize infrared frequencies, and not chemical scents per se, to "find their way around nature."

According to Callahan, the infrared portion of the electromagnetic spectrum, comprising some 17 octaves and therefore the largest region, provides fertile ground for study of the regulation of the biosphere:

"In terms of the overall universe, of course, all radiations are natural because they come from the sun and stars. In terms of our living environment, however, the radiation that is natural to our bodies is the huge sea of visible light and infrared radiation in which we begin, live, and end our lives, and which surrounds us day and night alike. Natural night light is just as important to our bodies and to all living things as is daylight, for as we can see from the spectrum of Earthly radiation, nighttime—as well as daytime—is primarily an infrared environment."[1]

Infrared ("below red") radiation was discovered during refraction experiments by the astronomer John Herschel in 1800, establishing for the first time the existence of "invisible light." Any object above absolute zero (0° K), i.e. every object, emits infrared radiation. So, for example, NASA's Spitzer Space Telescope is able to detect the infrared signatures of distant celestial bodies, by peering through dust clouds which trap visible light, but which are transparent to certain bands of infrared.

One of the central features of our unseen environment on earth, is the stimulation of gas molecules in the atmosphere by ambient infrared, visible, and ultraviolet (UV) radiation. This pervasive environmental radiation "stimulates them to oscillate at many unknown frequencies of colours—not visible colours of red or blue or green, but infrared "colours" of much longer wavelengths. If we had infrared eyes, we would give names to these colours—these auras of beautifully psychedelic infrared frequencies, as easily tuned to by an antenna as are the visible colour by the rods and cones of our eyes."[2] These subtle fluorescences, are a key component of insect communication and navigation, a discovery pioneered by Callahan through lab experiments in which he irradiated pheromones and other organic gases with low-intensity UV light and measured the response of insects like moths (which can also see in the UV spectrum). Insightfully, he remarks that "it is just such unknown mysteries of nature as these that space research will uncover for us. The entomologist and the space scientist must form a new and firm partnership to study nature's secrets together."[1] Airborne molecules can emit unique and subtle electromagnetic infrared "colours" as coherent, low-intensity, laser-like radiation. "The word laser refers to light because visible light lasers are the ones most commonly used by man. It is far easier,

The Trifid Nebula as revealed in a false-colour infrared photograph from NASA's Spitzer Space Telescope. The nebula is located 5,400 light-years away in the constellation Sagittarius. Image Credit: NASA.

The antennae of the saturnid moth. Micrometer sensilla arrays, not visible in this photograph, cover the spines of the antennae and act as electromagnetic waveguides. Image Credit: Elizabeth A. Sellers, NBII Catalogue.

however, to lase molecules that have absorption bands in the infrared portion of the spectrum, and, as a matter of fact, there are far more possibilities for lasing infrared than visible radiation. This is true because it is easier to stimulate low-energy wavelengths than high-energy ones. X-ray and UV lasing require extremely high-energy pumping sources, whereas infrared usually requires only visible or near-UV pumping radiation... Scent, in my mind, is a fleeting-floating world of vapors that luminesce in many, many different infrared colours and can be amplified and collected by a scent organ such as the insect antenna. The antenna sensilla are tuned as a resonating system to these infrared frequencies. Accordingly, I coined the term "maser-like frequencies" for the scent infrared colours that we could not detect until the early 70s."[3]

So, how do insects receive these frequencies? Oscillating gas molecules, be they pheromones or other organic scent molecules, disperse through the atmosphere and accumulate on or near the insect antennae (which have a static electric charge due to their waxy covering), transmitting their specific infrared frequencies down the sensilla antennae/waveguides. The frequency of the emitted infrared changes depending on the concentration and temperature of the gas (which cools as it disperses), thereby giving information about direction and distance to the emitting source, whether that source is a plant, a rotting carcass, or potential mate. Apparently, insects are also able to modulate the incoming frequencies through the beating of their wings and the attendant vibration of their antennae, and their constant rubbing of legs and antennae serve to improve their receptivity to the infrared frequencies, by clearing away debris and water moisture.

The implications of Callahan's work for pest control, especially for agriculturally vulnerable places like Africa, are enormous. But so too the potential for advancing our understanding of the fundamental nature of electromagnetic radiation itself. For, while there is a close analogy between the man-made antennae used in electronic communication and those utilized in the insect world, the direct comparison extends only so far, given that living organisms are not simple tuned circuits. Further work on the interaction of infrared and other radiation with specifically biological processes will revolutionize our understanding of such radiative phenomena, which are currently defined solely according to measurements by abiotic instruments. However, Callahan's discoveries already point to a partial reconciliation of "chemical" and "electromagnetic" effects, showing that the distinction—as in the case of scents—may not be as sharp as normally assumed.

**Footnotes**

[1] Callahan, Philip S., Tuning into Nature, Acres 1974

[2] Callahan, Philip S., Exploring the Spectrum, Acres 1994

[3] Callahan, Philip S., "Insects and the Battle of the Beams," Fusion Magazine, Septemper-October 1985, pp. 27-3 7. http://wlym.com/~basement/fusion/fusion/19850910-fusion.pdf.