

# THE FRESNEL TRIPRISM AND the circular polarization of light

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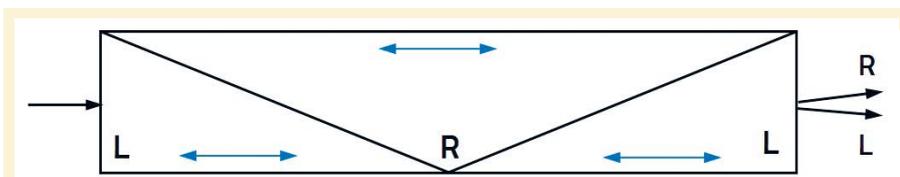
In 1822 Augustin Fresnel discovered the circular polarization of light with an experiment in which a plane polarized beam was resolved into its left- and right- circularly polarized components after refraction at slightly different angles at the interface between two different species of quartz that formed a composite prism, called the Fresnel triprism. Fresnel's landmark experiment, once popular, remains today a very little known method for producing circularly polarized light.

In a rapid sequence of discoveries made in France, starting in 1811 with the observation of optical rotation in quartz by François Arago [1], and roughly spanning over 10 years, most of our modern understanding about the polarization of light was established. The leading figure was the brilliant mathematical physicist Augustin Fresnel, often stimulated by preliminary experimental discoveries of Arago. By 1820 Fresnel had already realized that light could be understood as a transverse wave and the Fresnel-Arago laws of interference and polarization had been just published [2]. At that time however, circular polarization was still not fully understood and the property of “polarization of light” was, by default, associated only with linear polarization. Nonetheless, circular polarization was already a main ingredient of the experimental research as, for example, in 1817 Fresnel had already reported that after two total internal reflections in a glass prism light seemed “depolarized” [3].

Indeed this was the earliest description of a Fresnel rhomb, but it would take Fresnel a few years more to realize that the light was actually circularly polarized instead of being depolarized. The concepts of linear polarization, circular polarization and elliptical polarization in the wave picture of light were established by Fresnel in the conclusion of his memoir from 1822 [4]. The main subject of this memoir was the circular double refraction of light propagating along the optic axis of a quartz crystal (*cristal de roche*) in an experiment that is little known today, but that was crucial for Fresnel to understand circular polarization and its relation to optical rotation. Unlike the well-known double refraction phenomenon in calcite, already well understood by Fresnel in terms of polarization, light does not split by polarization in two different paths when propagating along the optic axis of a quartz crystal. However, Fresnel thought that the phenomenon of optical rotation, first observed by Arago in

1811, could be explained by a special form of double refraction and made an experiment to demonstrate it.

Fresnel took a very acute isosceles prism of right-handed quartz and cemented it in between two half prisms of left-handed quartz, forming a composite prism, named “Fresnel triprism” and schematically shown in *Figure 1*. In the experiment, light always propagated substantially parallel to the optic axes of the quartz prism components, so it could not be affected by standard double refraction but, at the exit facet, Fresnel still observed two beams emerging with a small angular separation. Fresnel used double refracting calcite to check that these emerging beams were not linearly polarized as in standard double refraction, yet he checked that when the beams were totally internally reflected in a glass prism, linear polarizations were recovered, each beam being orthogonal to the other. With this experiment Fresnel postulated the circular polarization of light and understood that the optical rotation of quartz and other materials was due to the different indices of refraction for left- and right-circular polarizations. To generate the angular divergence (i.e. the circular double refraction) interfaces between quartz prisms of different species were needed, since according to Snell-Descartes's law left- and right-handed waves refract with slightly different angles at such interfaces.



**Figure 1.** The Fresnel triprism. A prism made of quartz cemented in between two other half prisms made of quartz of opposite handedness splits the incident light into its right (R) and left (L) circularly polarized components. The double headed arrows indicate the directions of the optic axes of the crystals.

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**Figure 2.** Photo of the historical Fresnel polyprism composed of nine prisms. The inset shows the beam splitting of a laser beam. More details in Ref. [5].

Fresnel tripriprisms became popular optical devices in the XIX and the first part of the XX century as they were often used in teaching demonstrations that plane polarized light can be resolved into right- and left-circularly polarized components. However, Fresnel tripriprisms remain nowadays very little known optical devices and they are not available as commercial optical components. In our quest to find a Fresnel tripriprism we were lucky to discover that in the recently inaugurated museum of the École polytechnique (Palaiseau, France), institution where both Arago and Fresnel were trained, there is one of such composite prisms (see Fig. 2) manufactured by Henri Soleil some time before 1872. This unit held a surprise: instead of a tripriprism, it contained nine different prisms of alternating handedness, so it is better referred to as a polyprism, a feature that to our knowledge is unique of this unit. Essentially, each interface doubles the

angular separation between the emerging light beams, so with this device it is easy to achieve a large macroscopic separation between the right and left circularly polarized beams, something that we could test *in situ* in a series of experiments we performed with this historical polyprism during the summer of 2018 [5].

The Fresnel tripriprism, or more generally, polyprism can be regarded as the experimental culmination of what perhaps was the most fruitful decade in the history of polarization optics, started with Arago's observation of optical rotation also found in quartz. Beyond this historical significance, we think that this optical device, today almost forgotten, can be again of scientific relevance in the XXI century as methods to produce and detect circularly polarized light are becoming more and more important in today's research and technology. ■

#### FURTHER READING

- [1] D.F. Arago, "Mémoire sur une modification remarquable qu'éprouvent les rayons lumineux dans leur passage à travers certains corps diaphanes, et sur quelques autres nouveaux phénomènes d'optique". *Mm. Inst.* vol. 1, 93-134 (1811)
- [2] F. Arago and A. Fresnel, "Mémoire sur l'action que les rayons de lumière polarisée exercent les uns sur les autres". *Ann. Chim. Phys.* vol. 10, 288-305 (1819)
- [3] A. Fresnel, "Mémoire sur les modifications que la réflexion imprime à la lumière polarisée". *Ceuvres* vol. 1, 441-485 (1817)
- [4] A. Fresnel, "Mémoire sur la double réfraction que les rayons lumineux éprouvent en traversant les aiguilles de cristal de roche suivant les directions parallèles à l'axe". *Ceuvres* vol. 1, 731-751 (1822)
- [5] O. Arteaga, E. Garcia-Cauarel, and R. Ossikovski, "Stern-Gerlach experiment with light: separating photons by spin with the method of A. Fresnel". *Opt. Express* vol. 27, 4758-4768 (2019)