Further Experiments on the Phænomena presented by Light in its Passage along the Axes of Biaxal Crystals. By the Rev. Humphrey Lloyd, *A.M. M.R.I.A. Fellow of Trinity College, and Professor of Natural and Experimental Philosophy in the University of Dublin*.*

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I stated in a former communication†, that by a new development of the undulatory theory of light, in its application to the laws of double refraction, Professor Hamilton had arrived at the remarkable conclusion, that in two cases of refraction in biaxal crystals, a single incident ray ought to be divided into an infinite number of rays, constituting a refracted cone. The first of these cases of conical refraction will take place at the emergence of the ray into air, when it has proceeded from a point on the surface of, or within, the crystal, and in the direction of the line‡ joining two opposite cusps in the wave. The second takes place within the crystal, when a single ray has been incident externally in such a manner, that one of the refracted rays may coincide with the normal to the circular section of the surface of elasticity, or the optic axis§.

In the article alluded to, I have entered into an account of some experiments, undertaken at the request of Professor Hamilton, which establish the existence of the first case of conical refraction; and go far, therefore, to support the theory of which it is a consequence. I have only to add, on this part of the subject, that additional measurements, taken since that paper was written, indicate a nearer agreement between the observed and computed cones than was at first obtained.

I have since succeeded in observing also the second species of conical refraction; and I now propose to give a brief sketch of the results of my experiments, referring for further detail to the forthcoming volume of the Transactions of the Royal Irish Academy.

It has been already mentioned, that the existence of this phænomenon depends on the mathematical fact,—that the wave surface is touched in an infinite number of points, constituting a small circle of contact, by a single plane parallel to one of the circular sections

* Communicated by the Author.

† Page 112, et seq.

‡ It is much to be desired that these lines,—the normal to the circular section of the *surface of elasticity*, and the normal to the circular section of the *ellipsoid* of Fresnel's theory,—were distinguished by some appropriate nomenclature. Fresnel calls the former, the *optic axis*, when he is defining the term; but he subsequently applies the same name to the other. I fear that I have also made the same double application of the term in my former communication on this subject; though I have generally, with Professor Hamilton, used the word *cusp-ray* to designate the latter.

§ See last note.

of the surface of elasticity. When a ray is incident upon the crystal externally, in such a direction that one refracted ray may be normal to the plane just mentioned, it will be divided into a cone of rays within the crystal, determined by lines connecting the centre of the wave with the points of the periphery of the circle of contact. The angle of this cone $= \text{tang}^{-1} \dfrac{\sqrt{a^2 - c^2}\sqrt{c^2 - b^2}}{c^2}$, c being the mean axis; and its value in the case of arragonite, calculated from the elements of this crystal as determined by Professor Rudberg, is $1^\circ\, 55'$.

Since the rays which compose this cone will be refracted at emergence in a direction parallel to the incident ray, they will form a small cylinder of rays in air; the base of the cylinder being the section of the cone formed by the second surface of the crystal. This cylinder is in all cases extremely small, and the experiments necessary to detect its existence and ascertain its magnitude require more care than those hitherto described.

The light first employed, was that of a lamp placed at some distance; and in order to procure an incident ray as minute as possible, this light was made to pass through two small apertures; one of which was in a screen placed near the flame, and the other perforated in a thin plate of metal close to the first surface of the crystal. Observing the two rays into which the incident ray is generally divided, I turned the crystal slowly, so as to alter the incidence very gradually. After some trials, in which I was partly guided by the changes in the relative position of these rays, I at length succeeded in obtaining an incidence at which the two rays were seen to spread into a continuous circle; the diameter of which was apparently equal to the interval between them when near the ultimate position.

The emergent light in this instance was received directly by the eye, assisted by a lens. On repeating the experiment with the sun's light, I was enabled to receive the emergent cylinder upon a small screen of silver paper, and to see that there was no sensible difference in the magnitude of the section at different distances from the crystal.

When the adjustment was perfect, the light of the entire annulus was white, and of equal intensity throughout. But on a very slight deviation from the exact incidence, two opposite quadrants of the circle appeared more faint than the two others; and the two pairs were of complementary colours.

The theoretical incidence is easily calculated. The ray which proceeds within the crystal in the direction of the optic axis being a normal to the wave-surface, the direction of the corresponding incident ray will be given by the ordinary law of the sines, assuming as the refractive index the mean index of the crystal. The angle which the optic axis makes with the axis of x, or with the perpendicular to the surface of incidence, is equal to $= \text{tang}^{-1} \sqrt{\dfrac{c^2 - b^2}{a^2 - c^2}}$; and its value in the case of arragonite is $9^\circ\, 1'$, assuming the values of the three indices as determined for the ray E by Professor Rudberg. The corresponding angle of incidence is $15^\circ\, 19'$, the refractive index being $1 \cdot 6863$. Now the *observed* angle of incidence, which was obtained by measuring the angle between the incident and reflected rays, was $15^\circ\, 40'$; differing from the computed angle by $21'$.

In order to determine the angle of the cone, I measured the diameter of its section made by the second surface of the crystal; and found it to be ·016 of an inch. The thickness of the crystal was ·49 of an inch, and the inclination of the conical pencil to the perpendicular about 9°. The angle of the cone, computed from these data, was found to be $1^\circ\, 50'$; differing by $5'$ only from that assigned by theory.

Examining the emergent rays with a tourmaline plate, I found that they were polarized, and according to the law already observed in the former case of conical refraction. The result was in this case predicted by theory; in the former instance it was first discovered by observation.