XXV.—*Experiments on the Ordinary Refraction of Iceland Spar.* By WILLIAM SWAN, Esq. Communicated by Professor KELLAND.

(Read 19th April 1847.)

According to the theory devised by HUYGENS, to explain the phenomenon of double refraction in Iceland spar, a pencil of light transmitted through that substance is divided into two pencils; the index of refraction for the one being constant, while for the other it varies with the inclination of the transmitted light to the optical axis of the crystal.

Dr WOLLASTON, in 1802, verified the spheroidal form of the wave of light, which HUYGENS had assumed to account for the refraction of the extraordinary pencil, by a careful experimental investigation, conducted by means of his elegant instrument for "examining refractive and dispersive powers by prismatic reflection."* In 1810, MALUS, in his *Théorie de la Double Réfraction*, also demonstrated experimentally the accuracy of the Huygenian law for the extraordinary pencil. I have not had an opportunity of consulting the memoir of MALUS, so as to know the precise nature of his experiments, with reference to the refraction of the ordinary ray; but the object of Dr WOLLASTON's researches was simply to prove the law of extraordinary refraction, and the constancy of the index of refraction for the ordinary ray, is therefore tacitly assumed by him.

More recently, Professor MACCULLAGH of Dublin, in order to account for certain phenomena observed by Sir DAVID BREWSTER, in the reflexion of light from Iceland spar, was led to propose a law of double refraction, according to which the ordinary ray in that substance has a variable index of refraction; and at his request, Sir DAVID BREWSTER made an experiment to ascertain whether the ordinary refraction of Iceland spar is different at different inclinations to the axis. Two prisms were cut out of the same piece of spar, so that in one the transmitted ray was at right angles to the axis, and in the other, it was coincident with it; and both being cemented to a plate of glass, had their surfaces ground and polished together, so as to ensure the equality of their refracting angles. It was then found that the images of a narrow slit, illuminated by homogeneous yellow light, seen through the prisms, were perfectly coincident, which proved that the index of refraction for the ordinary ray was the same in both prisms, "within the limits of the errors of observation."†

* Philosophical Transactions, 1802, pp. 365 and 387.

† See Experiment on the ordinary refraction of Iceland spar, by Sir DAVID BREWSTER.—*Notices and Abstracts of Communications of the British Association*, 1843, p. 7.

Some time ago, Mr WILLIAM NICOL of Edinburgh, whose skill in cutting and polishing Iceland spar is well known, requested me to undertake the examination of the ordinary refraction of several prisms of Iceland spar, with which he had the kindness to entrust me, and which he had cut so that the transmitted light is inclined at various angles to the axis. The refractive power of these prisms was examined by means of an instrument devised by me for facilitating such inquiries, and described in the Transactions of the Royal Scottish Society of Arts for 1844, p. 293.* It will be sufficient here to explain that the prism is mounted in front of the telescope of a theodolite, with plates of sextant glass in accurate contact with its faces. The deviation of the refracted rays is then measured as in FRAUNHOFER's method of determining refractive powers; and the refracting angle of the prism is ascertained by measuring the deviation of rays that have suffered two reflexions at the surfaces of the sextant glasses. The prism being placed in its position of minimum deviation, the index of refraction is ascertained from the formula $\mu=\frac{\sin \frac{1}{2}(\theta+a)}{\sin \frac{1}{2}\theta}$ where θ is the angle of the prism, and a the minimum deviation of the refracted rays.

The theodolite I used in this investigation is made by TROUGHTON. The horizontal limb, measuring 6·5 inches in diameter, is furnished with two verniers reading 20″, and the telescope magnifies twelve times. As I had not the means of observing an object at a greater distance than 40 feet, and as the correction for parallax due to the distance of the prism from the centre of the theodolite could not be ascertained with sufficient accuracy, owing to the difficulty of finding the exact position of the pencil of incident rays, I determined to adopt a method for avoiding this correction.

This consisted partly in mounting the prism over the centre of the theodolite by means of a simple and ingenious arrangement suggested by Mr JOHN ADIE. A rod of well-seasoned mahogany, fitted to the *Ys* of the theodolite, was furnished at one end with temporary *Ys*, placed so as to shift the telescope out from the centre of the instrument; while, at the other, it carried a counterpoise to the weight of the telescope. To this I added stays of wire passing from the ends of the rod to the extremities of the horizontal axis of the theodolite, which were tightened by means of screws so as to prevent any lateral shake. The whole apparatus was mounted on a very firm portable tripod, and was sufficiently stable.

But although the prism, from its position at the centre of the instrument, did not suffer any material displacement on turning round the telescope, it was still desirable to get rid of any remaining uncertainty as to the direction of the incident light. The method I devised for effecting this object, was to use a collimator so as to obtain a beam of sensibly parallel rays, and thus to place

* Also in the Edinburgh New Philosophical Journal, January 1844.

the luminous object I observed, virtually at an infinite distance. Having fitted a pair of cross fibres of silk* in the anterior focus of the object-glass of a telescope, I carefully adjusted it to distinct vision on a star, so that, on moving the eye up and down, its image remained fixed on the wires. The eye-piece being then cautiously removed, the wires were illuminated by a lamp; and the beam of rays issuing from the object-glass having been directed upon the prism, the optical axis of the collimator was made parallel to the horizontal limb of the theodolite by means of adjusting screws. A common oil-lamp was used in ascertaining the angles of the prisms; but when the deviation of the refracted rays was observed, the wires were illuminated with the homogeneous yellow light of a spirit-lamp with a salted wick: and it must be regarded as a remarkable proof of the perfect homogeneity of this light, that the refracted image of a single fibre of silk was always distinctly visible with a good prism.

I shall now give the results of the examination of Mr NICOL's prisms, to which I shall refer according to the numbers he has attached to them. The angle of the prism was generally determined by four, and the deviation of the refracted rays by six observations.

The prism marked No. 1 is cut out of the crystal, so that in the position of minimum deviation the transmitted rays are parallel to the axis; and Mr NICOL has worked with such accuracy, that the images produced by the ordinary and extraordinary rays coincide almost exactly in this position. The angle of this prism was found to be 60° 8′ 8″, the deviation of the refracted rays 52° 14′ 36″, and consequently $\mu = 1{\cdot}658367$.†

The plane of refraction in the prism No. 2 is perpendicular to the axis. Its angle was found to be 44° 29′ 20″, and the deviation of the refracted rays 33° 17′ 8″. From which $\mu = 1{\cdot}658366$.

Two other prisms, No. 3 and No. 4, were also examined, in which the transmitted rays are perpendicular to the axis; but in either case the prism is cut so that the plane of refraction differs from that of No. 2.

For No. 3, the angle of the prism was found to be 59° 36′ 32″, the deviation of the refracted rays 51° 25′ 25″, and $\mu = 1{\cdot}658384$.

For No. 4, the angle of the prism was found to be 44° 55′ 24″, the deviation 33° 42′ 34″, and $\mu = 1{\cdot}658361$.

In No. 5, the transmitted rays are inclined 45° to the axis; the refracting angle of the prism was found to be 45° 3′ 51″, the deviation of the refracted rays 33° 50′ 58″, and $\mu = 1{\cdot}658385$.

* Silk is not the most suitable material for the purpose, owing to its transparency; but I could procure no better at the time.

† I have also examined another prism, No. 1, and have found $\theta = 44°\ 23'\ 2''$, $\delta = 33°\ 11'\ 0''$, and $\mu = 1{\cdot}658362$.

In No. 6, one of the faces is a cleavage plane, and the principal section of the prism is in the same plane with the axis. Therefore, since the cleavage plane is inclined 45° 23′ 25″ to the axis, it follows that the inclination of the transmitted rays in the position of minimum deviation is nearly 66° 51′. The angle of this prism was found to be 44° 28′ 29″, the deviation of the refracted rays 33° 16′ 22″, and $\mu = 1{\cdot}658389$.

These results are combined in the following Table :—

Prism.	Inclination of the plane of incidence, or of the principal section of the prism to the optical axis of the crystal.*	Inclination of the transmitted rays to the optical axis.	Index of refraction for the ordinary ray (μ).	Difference of each result from the mean value of μ.
No. 1.	0°	0°	1·658367	−0·000008
2.	90°	90°	1·658366	−0·000009
3.	0°	90°	1·658384	+0·000009
4.	45°	90°	1·658361	−0·000014
5.	0°	45°	1·658385	+0·000010
6.	0°	66° 51′	1·658389	+0·000014
Mean			1.658375	0·000011

From this summary it will be seen, that the greatest difference between the observed index of refraction of any prism and the mean of the whole results is only ·000014; while the difference of the greatest and least results is less than ·00003. So close an agreement in six essentially different cases, seems to render it very probable that the index of refraction is really constant; and the result of the investigation thus confirms the accuracy of the Huygenian law.

* As the term, principal section, is employed in more than one sense, it may be proper to observe, in order to avoid ambiguity, that I use it to denote a plane perpendicular to both faces of the prism.—See Sir John Herschel's Treatise on *Light*, in the *Encyclopædia Metropolitana*, p. 370, art. 197.