THE

TRANSACTIONS

OF THE

MICROSCOPICAL SOCIETY

OF

LONDON.

VOL. II.

"Minimus partibus, per totum Naturæ campum, certitudo omnis innititur; quas qui fugit pariter Naturam fugit."—*Linnæus.*

LONDON:
JOHN VAN VOORST, 1, PATERNOSTER ROW.
M.DCCC.XLIX.

XV.—*On the Application of Polarized Light in Microscopic Investigations.* By M. S. Legg, Esq.

(Read December 9, 1846).

It has been truly and eloquently observed by Sir David Brewster, that "the application of the principles of double refraction to the examination of structures is pregnant with a very high interest. The chemist may perform the most dexterous analyses; the crystallographer may examine crystals by the nicest determination of their forms and cleavages; the anatomist and the botanist may direct the dissecting-knife and use the microscope with the most exquisite skill; but there are still structures in the mineral, the vegetable, and the animal kingdoms, which defy all such methods of examination, and which will yield only to the magical analysis of polarized light. A body which is quite transparent to the eye, and which appears upon examination to be as monotonous in its structure as in its aspect, will yet exhibit under polarized light the most exquisite organization, and will display the result of new laws of combination, which the imagination even could scarcely have conceived. Like the traveller who has visited an unknown land, polarized light emerges from bodies bearing with it the information it has acquired during its passage, and indicating the structures through which it has passed, when put to the question of optical analysis. As an example of the utility of this agent in exploring mineral, vegetable, and animal structures, I may refer to the extraordinary organization of Apophyllite and Analcime; the symmetrical and figurate depositions of siliceous crystals in the epidermis of Equisetaceous plants; and to the wonderful variations of density in the crystalline lenses and the integuments of the eyes of animals." *

In order, therefore, to facilitate the application of this principle, and to render the subject interesting to those who may be disposed to adopt it in microscopic investigation, or who may already have the necessary apparatus fitted to their instruments, as well as for the information of those whose avocations may have debarred them from the study of this branch of natural philosophy, it is proposed to describe a series of apparatus, and to detail some experiments which, although well known to a few, are not generally understood by mere microscopic

* Report on Optics, Brit. Ass. 1832.

observers, and which may generally be adapted to almost any instrument.

In conducting experiments on this subject it is usual to employ one of three methods of producing polarized light, viz.—

1st. *A bundle of plates of crown glass* (see Pl. XII. fig. 1), from which the light is to be reflected at an angle of 56° from the perpendicular, a portion of the light being reflected from the surfaces of the glass, and another portion being transmitted, each of these portions is found by analysis to consist of rays of light polarized in opposite planes. This method is employed when it is required to illuminate a large object, as in the single or doublet microscope, and in the oxy-hydrogen apparatus.

2nd. *A plate of tourmaline* (see fig. 2), cut parallel to the crystalline axis of the crystal: it is necessary to be careful in the selection of tourmalines; they should be as free from colour as possible, and dark-coloured ones to be avoided as almost useless in investigations of colours. Tourmalines are, however, seldom used as polarizers, in consequence of the difficulty of obtaining them of sufficient magnitude.

3rd. *A Nicol's or single-image prism* (see fig. 3), which is a portion of a crystal of Iceland spar cut and combined with a piece of glass, so as to throw out of the field of view one of the two images produced by the double refraction of the crystal. This is the most eligible for the compound microscope, in being perfectly free from colour, and requiring no adjustment beyond transmitting the light, either direct or reflected from the mirror; it may be fitted into the diaphragm, and also be adapted to the achromatic condenser, to be employed with high powers in the examination of minute structures.

As a test of polarized light, it is necessary to employ analyzers of the most convenient form; they consist of apparatus possessing the same properties as the polarizers, that is, of causing light to pass in only one plane of vibration: the polarizer and analyzer should, when superposed, allow the light to pass freely in one position, and produce a dark field when turned one-fourth of a revolution; for this purpose either of the two last-named pieces of apparatus can be employed: the tourmaline will be found useful for ascertaining if the object under examination possess the property of polarization, as it may be placed over the eye-piece without cutting off any part of the field of view; but if the analyzer be required as a test of colour, the Nicol's prism should be employed, and placed in the body of the instrument, and as near to the back of the object-glass as possible.

The following experiments, if carefully performed, will illustrate the most striking phenomena of double refraction, and form an useful introduction to the practical application of this principle.

The apparatus necessary is —

- A Nicol's prism to be adapted under the stage;
- A double refractor adapted to the eye-pieces;
- A film of selenite, of uniform thickness, adapted according to its crystalline axis; and
- A plate of brass, 3 inches by 1, perforated with a series of holes, from about the $\frac{1}{16}$th to $\frac{1}{4}$th of an inch in diameter: the diameter of the smallest hole should be regulated according to the power of the object-glass and the separating property of the double refractor.

Exp. 1. Place the piece of brass so as for the smallest hole to be in the centre of the stage of the instrument, employing a low power (about 1¼ inch) object-glass, and adjust the focus as for an ordinary microscopic object; place the doubly-refracting crystal over the eye-piece, and there will appear two distinct images; then by revolving the eye-piece the images will describe a circle, the circumference of which cuts the centre of the field of view; the one is called the ordinary, and the other the extraordinary ray. By passing the slide along, so as for the larger orifices to appear in the field, the images will not be completely separated, but will overlap as in fig. 4.

Exp. 2. Screw the Nicol's prism into its place under the stage, still retaining the double refractor over the eye-piece; then by examining the object there will appear in some positions two, but in others only one image; and it will be observed that at 90° from the latter position this ray will be cut off, and that which was first observed will become visible; at 180°, or one half of the circle, an alternate change will take place; at 270° another change; and at 360°, or the completion of the circle, the original appearance (see fig. 6).

Before proceeding to the next experiment, it will be as well to observe the position of the Nicol's prism, which should be adjusted with its angles parallel to the square parts of the stage (see fig. 10), in order to secure the greatest brilliancy in the experiment: the proper relative position of the selenite may be determined by noticing the natural fractures or flaws in the film, which will be observed to run parallel to one another: these flaws should be adjusted at about 45° from the square parts of the stage (see fig. 11) to obtain the greatest amount of depolarization.

Exp. 3. If we now take the plate of selenite thus prepared, and place it under the piece of brass on the stage, we shall see, instead of the alternate black and white images, two coloured images (as in fig. 7), composed of the constituents of white light, which will alternately change (by revolving the eye-piece) at every quarter of the circle; then by passing the brass along, so as to bring the larger orifices in succession into the field, the images will overlap, and where they overlap white light will be produced (see fig. 5). If by accident the prism should be placed at 45° from the position just indicated (see fig. 12), no particular colour will be observed, and it will then illustrate the phenomenon of the neutral axis of the selenite, because when placed in that relative position no depolarization takes place.

The phenomena of polarized light may be farther illustrated by the addition of a second double-refractor, and a film of selenite adapted between the double-refractors.

Exp. 4. By placing the apparatus as described in the first experiment (that is, removing the Nicol's prism and plate of selenite, but retaining the brass plate), we shall observe the two images as shown in fig. 4; then by placing the second double-refractor over the first, so as for all the faces of the one to be parallel to all the faces of the other, as if they formed but one piece, the eye will perceive two distinct images, but at twice the original distance from each other (see fig. 8). If we now turn the crystal nearest the eye, from left to right, two faint images will appear; continuing the turn, the four images will be all equally luminous; and when the crystal has turned round 90°, there will be only two images of equal brightness. Continuing the turn, other two faint images will appear; further on the four images will be equal; still further they will be unequal; and at 180° of revolution they will all coalesce into one bright image.

Exp. 5. The above results will be rendered more interesting by interposing between the doubly-refracting crystals the film of selenite. Place the doubly-refracting crystals and the selenite upon the brass mountings, so that the marks upon the brass mountings (as in figs. 13, 14 and 15) shall correspond. Instead of the two white images, as in the preceding experiment, we shall see three, of which the two outer ones will be one colour (say green), and the middle its complementary colour or red; by turning the crystal nearest the eye, the middle image will gradually divide, until the completion of a quarter revolution, when four images will appear, of equal brilliancy, two of each colour; revolve the crystal until the completion of the half circle, and the three images will reappear, but with different properties, the outer images being red and the middle green; at another quarter revolution, four images, but with opposite colours, will be observed, and at the completion of the revolution the original appearance (see fig. 9).

If instead of the relative positions of the crystals and selenite, as indicated in this experiment, the positions be changed, so that the selenite shall be at 45° from its former position, the ventral axis of the selenite will be parallel or perpendicular to the plane of polarization, and as in that position no depolarization takes place no colours will be produced, and the results will appear as if no selenite were interposed.

The systems of coloured rings, in crystals cut perpendicularly to the principal axis of the crystal, are best seen by screwing the Nicol's prism under the stage and employing the lowest object-glass; place the crystal over the eye-piece, and use either a short prism or a tourmaline as an analyzer.

The above remarks are submitted to the notice of the Microscopical Society in the hope of directing the attention of scientific observers to this branch of optical science, in which so much scope still exists for the determination of the laws of various phenomena in natural history. According to the opinion of the eminent author first quoted, "There is scarcely any branch of the subjects of double refraction and polarization which does not afford the richest fields of discovery. Even the theory of undulations, with all its power and all its beauty, is still burdened with difficulties, and cannot claim our implicit assent. It has not yet brought under its dominion the phenomena of elliptic polarization in all its varieties, from the rectilineal polarization of transparent bodies to the almost circular polarization of pure silver. It has not yet explained the singular influence of the force of double refraction over the force which polarizes light, and it has great difficulties to struggle with in accounting for certain phenomena of absorption.

"The determination of the physical data of these departments of science constitutes a new and almost untrodden field, which may be successfully cultivated by almost every variety of talent. The refractive indices of the two pencils in all crystallized bodies, measured in reference to fixed points of the spectrum, as has been lately done by Rudberg; the angles at which light is polarized by reflexion from crystallized and uncrystallized surfaces; the inclination of the resultant axes of crystals having double refraction, for different rays of the spectrum; the dimensions of the ellipse which regulates the polarization of metals and their alloys; the circularly polarizing forces of fluids and solutions; and the refractive and dispersive powers of ordinary solid and fluid bodies, measured according to the method of Fraunhofer,—are some of the points to which we would call the attention of young and active observers."

EXPLANATION OF PLATE XII.

Fig. 1 represents a bundle of plates of crown glass, in which a ray of common light, having two or more planes of vibration, is reflected at an angle of 56° from the perpendicular, the portion which is reflected having one plane of vibration, and that which is transmitted vibrating in a plane at right angles to it.

Fig. 2. A plate of tourmaline: the light which emerges after transmission is found to consist of polarized light, vibrating in a plane corresponding to the axis of the crystal.

Fig. 3. A Nicol's prism: a ray of light, on entering the prism, is divided into two pencils, one of which is transmitted, and the other is so refracted, by means of the glass, that it is thrown out of the field.

In these figures, the arrows indicate the direction of the ray of light; the circles with crossed lines represent common light; and those with only one line polarized light, with its plane of vibration.

Fig. 4 represents the complete separation of the images by the double-refractor, and the effect of passing the larger orifices of the brass plate along the stage.

Fig. 5 shows the effect of adding a Nicol's prism and plate of selenite, with the decomposition and recomposition of white light.

Fig. 6 gives the appearance of revolving the double-refractor, and the alternate cutting off of each image, at every quarter of a revolution (as in Exp. 2).

Fig. 7. The same as before, with the addition of a plate of selenite.

Fig. 8. The effects produced by two double-refractors, in separating the images to twice the distance from each other, compared with those in fig. 4, and the appearances presented at every quarter revolution of the second crystal.

Fig. 9. The same as above, with the interposition of the plate of selenite.

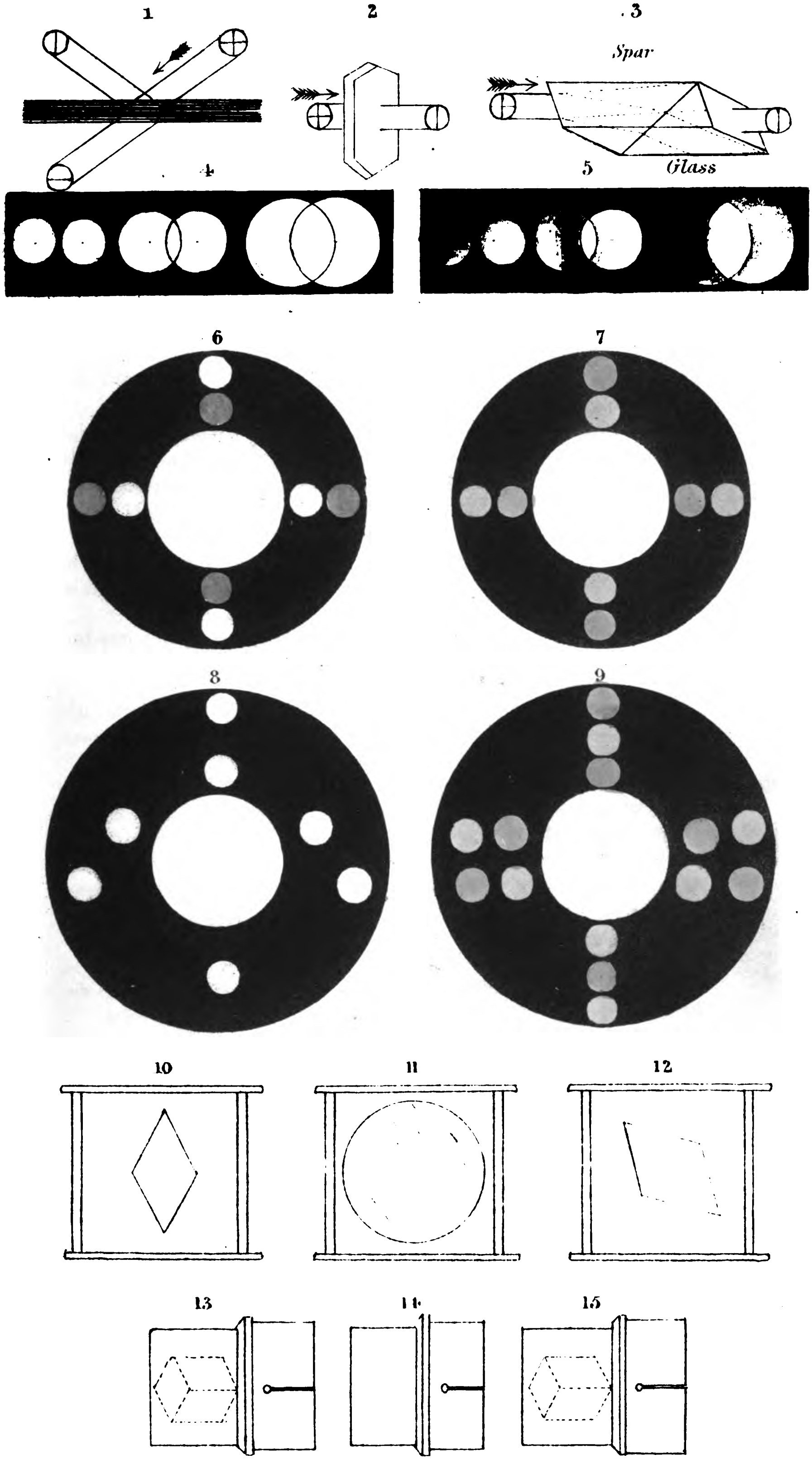
Fig. 10. The most suitable position for the Nicol's prism in investigations where a plate of selenite is employed.

Fig. 11. The proper position of the selenite, in relation to the polarizer, to produce the best effects.

Fig. 12. The Nicol's prism, turned about 45° from its former position, which should be carefully avoided in using the selenite plate.

Figs. 13, 14 and 15. The brass mountings of the double-refractors and plate of selenite. The crystals and selenite should be adjusted to the relative positions indicated in figs. 10 and 11, and the slits in the mounting placed in a line, to produce the appearances in fig. 9.

Plate XII.



M. S. Legg. del. Lens Aldous, Zinc

Day & Son Lith^rs to the Queen.