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David Brewster LL.D. F.R.S. Edin. F.S.A. Edin.

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XLII. *On the Affections of Light transmitted through crystallized Bodies.* By DAVID BREWSTER, LL.D. F.R.S. Edin. and F.S.A. Edin. In a Letter to Sir HUMPHRY DAVY, LL.D. F.R.S.*

DEAR SIR,—IN a former paper† on “Some Properties of Light,” which I took the liberty of addressing to you, and which the Royal Society honoured with a place in their Transactions, I attempted to give a brief abstract of a set of experiments on the Properties of transparent Bodies in refracting, dispersing, and polarising the Rays of Light. An account of the instruments and methods employed in these experiments has since that time been published in my “Treatise on new philosophical Instruments.”

From the general object of these researches, however, I have been allured into a new field of inquiry, by the discovery of a singular property of light transmitted through the agate, and the prosecution of the views which it suggested has led to some very extraordinary results, which, while they seem to conduct us into the very mysteries of physical optics, exhibit at the same time a series of appearances which far surpass, both in splendour and variety, all the phenomena of light under its usual transformations. In again soliciting you to communicate these observations to the Royal Society, I trust I need offer no apology. They are closely allied with that science which you have so widely extended by the most profound and brilliant discoveries; and it is probably from the cultivation of this department of physics, that philosophy will be enabled to unfold the secrets of double refraction, to explain the forms and structure of crystallized bodies, and to develop the nature and properties of that ethereal matter, which, while it enlivens all nature by its presence, performs also a capital part in the operations of the material world.

The different subjects of which I mean to treat in the following letter may be included under five heads.

- I. On the polarizing power of the agate.
- II. On the structure of the agate as connected with its optical properties.
- III. On the peculiar colours exhibited by the agate.
- IV. On the depolarization of light.
- V. On the elliptical coloured rings produced by obliquely depolarizing crystals.

I. *On the polarising Power of the Agate.*

I have already shown, in a former paper, that a ray of light

* From the Philosophical Transactions for 1814, part i.

† Phil. Trans. for the year 1813, p. 101.—Phil. Mag. vol. xlii. p. 286.

transmitted through a plate of agate cut by planes perpendicular to the laminae of which it is composed, suffers polarization like one of the pencils formed by double refraction. If the light thus polarized is incident at a particular angle upon any transparent body, so that the plane of reflection is perpendicular to the laminae of the agate, it will experience a total refraction; if it is transmitted through another plate of agate, having its laminae at right angles to those of the plate by which the light is polarised, it will suffer total reflection; and if it is examined by a prism of Iceland crystal turned round in the hand of the observer, it will vanish and reappear in every quadrant of its circular motion.

The pencil of rays to which this remarkable property is communicated is surrounded by a large mass of nebulous light, which extends about $7^{\circ} 30'$ in length, and $1^{\circ} 7'$ in breadth on each side of the bright image*. This nebulous light never vanished with the bright image which it inclosed, but was obviously affected with its different changes, increasing in magnitude as the bright image diminished, and diminishing as the bright image regained its lustre. From this circumstance I was led to conjecture "that the structure of the agate was in a state of approach to that particular kind of crystallization which affords double images, and that the nebulous light was an imperfect image arising from that imperfection of structure."

On the supposition that this conjecture was well founded, I imagined, in conformity with the general analogy of all doubly refracting crystals, that the bright image and the nebulous light were produced by two different refractive powers, and I expected to separate the one from the other by forming the agate into a prism with a considerable refracting angle. Every attempt of this kind, however, was fruitless; no perceptible separation of the images was effected by any of the prisms which I employed, and I was therefore obliged to abandon this mode of investigation.

Having procured a plate of agate remarkably thin and transparent, I admitted a beam of light from the sky into a dark room through a narrow rectangular aperture. When this aperture was viewed through the agate, it was surrounded with a very considerable nebulosity; and by interposing a prism of Iceland spar between the agate and the eye, and giving it a motion of rotation, the nebulous light became very dense when the bright image vanished, and almost completely disappeared when

* On each side of the bright image I have observed a condensation of the nebulous light resembling two imperfect images of the luminous body. These imperfect images, which increase in number by inclining the agate, are slightly tinged with the prismatic colours, which evidently belong to that class of phenomena which have been so ably treated by Dr. Thomas Young, in his late work on Medical Literature.

the bright image had reached its greatest brilliancy. The bright and the nebulous images, therefore, comported themselves exactly like the two images formed by doubly refracting crystals; and the small portion of nebulous light, which surrounded the bright image at its maximum lustre, was obviously produced either by the imperfect polish of the agate, or by its not being cut exactly at right angles to the plane of its laminæ.

It will be seen from a subsequent section of this letter, that light polarized by the agate, or by any other means, is depolarized, or partly restored to its original state, by being transmitted in a particular direction through a plate of mica, or any other crystallized body. I therefore interposed a plate of mica between the agate and the Iceland spar when the nebulous light had nearly disappeared, and having adjusted it to the depolarizing position, the nebulous light was instantly revived round the bright image, while the other bright image which had disappeared resumed its place in the middle of the other nebulous mass.

When a pencil of light polarized and afterwards depolarized, in a manner to be afterwards described, is transmitted through a plate of agate, the *red** rays go to the formation of the bright image, while the *green* rays compose the nebulous light, so that we have a *red bright image* enveloped in a *cloud of green light*. By turning round the agate 90° the bright image is formed by the green rays, while the nebulous image consists of the red rays, so that we have a *green bright image* encircled by a mass of *nebulous red light*. If in the place of the agate we substitute a doubly refracting crystal, it will always be found that the ordinary image is green when the extraordinary one is red, and that they assume these colours alternately during the motion of the prism round the axis of vision.

From these experiments, we may consider it as demonstrated, that the nebulous light has the same relation to the bright image, as the first has to the second image of all crystals that have the property of double refraction†. It does not appear, however, that the nebulous image is produced by a greater refractive power than that by which the bright image is formed. There is on the contrary every reason to conclude, in opposition to the analogy of all doubly refracting‡ crystals, that the agate

* The *red* and the *green* are complementary to each other. The same result is obtained if the *blue* and *yellow*, or any other two complementary colours are used.

† See Edinburgh Trans. vol. vii. part ii.

‡ It will be seen from a subsequent paper, that many other bodies both of mineral, animal, and vegetable origin, have the property of forming two images, polarized in an opposite manner, but not produced by two different refractive powers.

gives two images and polarizes them like other crystallized bodies, while the one image is placed exactly in the centre of the other.

II. On the Structure of the *Agate* as connected with its optical Properties.

When we examine a piece of transparent and well polished agate, we perceive a number of bands or stripes, which are the sections of a succession of laminae that are sometimes parallel, but in general concentric. These laminae are often of a milky white colour when seen by reflected light, and sometimes nearly as transparent and colourless as glass, and the white laminae commonly alternate with the transparent ones. The laminae which are white when seen by reflected light, are brown by transmitted light, and the intensity of this brown colour increases with the thickness of the plate of agate. The transparent laminae exhibit three varieties of structure.

The *first variety*, which appears to be the coarsest, consists of a number of small serpentine lines like the figures 333 333, lying parallel to each other, and closely resembling the surface of standing water when ruffled by a gentle breeze, or the sandy bottom of a slow moving stream. These serpentine lines are always arranged in a direction parallel to the laminae, and are seen very distinctly even when the agate is so thin as the 150th part of an inch.

The *second* variety of structure differs from the first, only in the serpentine lines having a much smaller size; and the laminae which have this structure appear the finest and most transparent.

The *third* variety has no serpentine lines, and does not appear to differ from other semi-transparent bodies. It admits the light more copiously in all directions than any of the other structures; and as it does not polarize it in a similar manner, we may consider it as possessing, in a different way, that kind of crystallization which polarizes the incident light by separating it into two pencils.

The white veins sometimes exhibit the first variety of structure; but in several specimens the veins appear to be fibrous in their structure, the fibres stretching at right angles to the laminae through the whole of their thickness.

These different structures will be better understood from fig. 1 and 2 of Plate IV. Fig. 1, represents the specimen of agate with incurvated veins which I have noticed in a former paper*. It is composed of two veins, AB, CD, and three transparent portions AEB, ABDC, and CFD. The transparent portions ex-

* See Phil. Trans. 1813, part i.—Phil. Mag. vol. xlii.

hibit the *second* variety of structure, though the small serpentine lines are not so distinctly marked as in other specimens. The two veins AB, CD, are both white when seen by reflected light. The breadth of AB is one-tenth of an inch, and its radius of curvature $1\frac{1}{2}$ inch, and it consists of *four* smaller veins *mn*, *op*, *qr*, *wx*. The light reflected by *mn* is a paler white, and the light transmitted by it a lighter brown than in the other parts of the vein. The light which *op* reflects is of a brighter white, and that which it transmits of a deeper brown than in the other parts of the vein, and at the junction of *mn* and *op* there are several tufts of fibres of the same character as *op*. The other divisions of the vein *qr* and *wx* are of an intermediate character between *mn* and *op*. The vein CD resembles the division *mn*, and possesses, like AB, the fibrous structure already described. The thickness of the plate AEDC is one-fiftieth part of an inch; AC is three-tenths of an inch; and a line AC forms an angle of about 25° with a plane perpendicular to the laminae.

Figure 2, represents another specimen of agate of a different character. It consists of transparent portions AB, BC, CD, DE, EF, separated from each other by white veins Bb, Cc, &c. and distinctly exhibiting the *second* variety of structure; and of other transparent portions FG, GH, HI, IK, KL, separated by similar veins Gg, Hh, &c. but exhibiting the *first* variety of structure. All the veins possess a structure approaching to that of the first variety, Gg, Kk exceeding the rest in the intensity of the light which they reflect and transmit.

If we measure the quantity of light transmitted through a plate of agate containing veins, it will be found to be a maximum when the direction of the incident rays is parallel to the interior surfaces of the veins. When the light, however, is transmitted through a part of the agate of an uniform transparency, and perfectly free from veins, the same result will be obtained, the intensity of the light being a maximum when its direction is parallel to that of the laminae.

If AB, fig. 3, be a section of the specimen of agate represented in fig. 1, and *mn*, *op*, the direction of the laminae inclined 25° to the surfaces of the plate, rays of light incident in the direction RS parallel to *mn* are more copiously transmitted than when they are incident in any other direction. When the pencil of light falls in the direction TV, its lustre suffers a great diminution: the light gradually assumes a red colour, and vanishes altogether when the obliquity is considerable. But if the pencil is incident at the same angle on the opposite side, as PQ, its lustre suffers very little diminution, and its colour is not sensibly altered.

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These facts admit, to a certain extent, of an easy explanation, if we suppose that the plate of agate consists of laminae *mn*, *op* imperfectly transparent, alternating with laminae *cd*, *ef*, which are more pervious to light, a structure which is indicated by the existence of a bright and a nebulous image. In this case the intensity of the light will obviously be maximum when the ray RS is parallel to *mn*, and a ray PQ will, within certain limits, suffer less diminution of lustre than a ray TV falling with the same angle of incidence on the other side of RS.

When RS and *mn* are perpendicular to the surfaces of AB, and when PQ and TV form equal angles with the perpendicular RS, their intensity should be equal; but this is by no means the case, for the transmitted light which is incident on the side T of RS appears to have a different character from that which is incident on the other side. We must therefore suppose that there is some other peculiarity of structure in the agate, connected probably with that particular kind of crystallization which polarizes light, to which this curious fact must be ascribed*.

The intensity of the light transmitted by the agate is likewise affected by its polarizing property. If a ray Rr, Plate IV., fig. 4, is incident upon a piece of agate AB, so as to be polarized by reflection from the second surface, then, since it is polarized during its passage from r to E, the bright image will suffer total reflection at E, while the nebulous image will be transmitted like common light in the direction EG. If the agate is now turned round 90°, the nebulous image will suffer total reflection at E, while the bright image will penetrate the second surface at E like common light. When the incident ray Rr has different obliquities and the agate intermediate positions, the intensity of the transmitted light will be more or less affected by its polarizing power.

The preceding observations on the laminated structure of the agate enable us to give a satisfactory explanation of some singular appearances exhibited by that mineral.

In the specimen shown in Plate IV. fig. 5, the black lines represent the veins, and consequently the direction of the laminae, and the dotted lines *ab*, *ac*, *cm*, *ck*, &c. are drawn through the vertices of the angles made by the veins; and consequently by the laminae whenever they change their direction. When light is transmitted through a piece of agate of this description, the planes *Aacm*, *mck*, *ngf*, *nhg* have the appearance of being differently inclined to one another, and transmit different quantities of light. If the veins and the laminae preserved the same inclination to the surface of the plate of agate when they changed

* See Edinburgh Transactions, vol. vii. part ii.

their direction at the lines *ac*, *cm*, *de*, the phænomenon which has been mentioned could not take place; but whenever the laminae change their direction, their inclination to the surface likewise changes, and therefore the intensity of the transmitted light experiences a corresponding variation as the rays have to traverse different lengths of the imperfectly transparent laminae.

When the veins and the laminae are incurvated like those in the portion *Aacm*, their inclination likewise changes; but as this change is gradual and not sudden, as in the former case, the intensity of the transmitted light suffers a gradual variation, and the portion *Aacm* has the appearance of being concave. When the laminae therefore are arranged in a circular form, they will resemble a number of dimples, the apparent concavity of which will in some cases depend on the curvature of the laminae, and will exhibit the phænomenon of the *hammered agate*.

III. On the peculiar Colours exhibited by the *Agate*.

In my former letter on the polarizing power of the agate, I noticed the existence of a coloured image which appeared on each side of the common colourless image, and which was polarized in a similar manner. I have since observed the same phænomenon in other specimens; and though I have not been able to discover its cause, I trust the following observations will be of some service to future inquirers.

In the specimen represented in Plate IV., fig. 2, the colours appear only when the rays of light are transmitted through the veins *B*, *C*, *D*, *E*, *F*, *G*, *H*, *I*, *K*, or through the coarse grained portions *Fg*, *Gh*, *Hi*, *Ik*, *KkL*, and when these parts are covered no colour is perceived. If the eye, therefore, is placed behind any of the coarse grained parts, and close to the agate, a colourless image of a candle will be visible, and on each side of it a highly coloured image forming an angle of $10\frac{1}{2}^{\circ}$ with the colourless image. The colours, which are extremely brilliant, are blue, green, yellow, and red, reckoning from the common image. A second image coloured in a similar manner, but considerably fainter, is distinctly seen, forming with the colourless image an angle of about 21° . When the agate is held some inches distant from the eye, the colours appear diffused over the surface of the coarse grained portions, and when the light is strong, the phænomenon is uncommonly brilliant. When the vein *Bb* is a pale blue, at a certain distance from the eye, *Cc* and *Dd* are of the same colour, *Ee* is greenish, *Ff* is yellowish, *FGgf* is pale red, and the red colour is more intense towards *Lk*. By a gentle motion of the agate the colours of these portions instantly change, a particular colour being always produced in the same portions.

portions at a particular angle of incidence. The veins *Eg*, *Hh*, *Ii*, and *Kk* are, however, green when the surrounding portions are red, and red when the surrounding portions are green; from which it follows that these veins produce a particular colour at a different angle of incidence from the adjacent portions. In another specimen of agate, very like the preceding, the same phenomena are distinctly visible, and the coloured image forms the same angle with the common image. In a third specimen, belonging to Robert Ferguson, Esq. of Raith, the colours are exhibited in the most splendid manner. A semi-transparent and irregularly elliptical zone, about six inches and a half in circumference and three-tenths of an inch broad, has the *first* variety of structure, and forms the coloured image at a distance of $13\frac{1}{2}^{\circ}$ from the common image.

In the specimen represented in Plate IV., fig. 1, the colours are visible only in the vein *AB*; but here the angle of the first coloured image with the common image is 23° , while that of the second image, which is very faint, is only a little greater. The other vein *CD*, which to all appearance has the same structure as *AB*, and which differs from it only in being a little thinner, exhibits no colours; but there is a small stripe *st* at its edge where the colours are very distinct. This circumstance induced me to think that the colours depended on the thickness of the plate, as well as upon its structure; but upon grinding a hollow place *mnw* in the vein *AB*, so as to make the agate remarkably thin, I found that it gave the same colours as before. A similar experiment was made with another piece of agate, and the result was the same, though the thickness of the plate could not exceed the 400th part of an inch. The colours indeed were rendered more brilliant by the increased transparency of the agate, but in other respects they experienced no change. In another specimen, of which it is unnecessary to give a particular description, the coloured image formed an angle of about 34° with the colourless pencil, and the different veins produced the same colour at different angles of incidence.

In attempting to explain these appearances, I at first imagined that the colours arose from the polarization of the transmitted rays, and that they were analogous to the colours of plates of mica and topaz which I have described in another place. I found, however, from several experiments, that the coloured image is equally distinct in every position of the agate; that it is alike produced by polarized or depolarized light, and that it suffers no change either when examined by a plate of agate or by a doubly refracting crystal.

The phenomenon which we have described must therefore
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be considered as a new case of the production of colour; and though we do not pretend to point out its cause, yet it obviously depends upon a particular structure which is possessed only by some portions of the agate, and admits of such variations as to produce the same colours at different angles of incidence.

IV. On the Depolarization of Light.

In the fourth book of my Treatise on new Philosophical Instruments, I have already shown that almost all transparent crystals possess in two positions the singular faculty of depolarizing light, or of depriving it of the property which it acquires by transmission through the agate, while in other two positions of the depolarizing crystal, the polarity of the light suffers no change. Thus in Plate IV., fig. 5, let $ABDC$ be a piece of mica or of any other crystallized body interposed between a plate of agate and a prism of Iceland spar when one of the images has vanished, and let GH be parallel or perpendicular to the laminæ of the agate when the vanished image continues invisible. This line I have called the *neutral axis*, as no effect is here produced upon the polarized light. By turning the mica round, the vanished image will gradually appear; and when the line AD comes into a vertical position, it will be restored to its full lustre, and will never again vanish, whatever be the position of the Iceland spar. The line AD I have therefore called the *depolarizing axis*, as the light in passing through it has been deprived of the polarity communicated by the agate, and which prevented it from penetrating the rhomboid of Iceland spar.

By continuing the motion of the mica, it will be found that EF is also a neutral axis, and BC a depolarizing axis. The depolarizing axes are common to almost all crystallized substances; and what is very singular, I have discovered them in horn, gum arabic, glue, tortoise-shell, caoutchouc, goldbeater's skin, amber, mother of pearl, camphor, spermaceti melted and cooled, bees' wax melted and cooled, adipocire melted and cooled, manna, oil of mace, acetate of lead melted and cooled, human hair, bristles of a sow, human cornea, cornea of a fish, cornea of a cow, and imperfectly in some pieces of plate glass.

Plates of mica, however, while they possess the properties of all depolarizing crystal, exhibit phenomena peculiar to themselves. If the neutral axis GH of a plate of mica is inclined forwards so as to make a considerable angle with the horizon, the image that was formerly invisible will start into existence, and therefore the neutral axis GH is accompanied with an oblique depolarizing axis Nn . This oblique axis is also possessed by topaz, rock crystal, and many other crystallized bodies. In making the same experiment with the depolarizing axis of the

the mica, I observed the image to vanish in the direction Mm and Pp , which I considered as oblique neutral axes; but I have since found that this was owing to the polarization of the pencil by oblique transmission, a property of light which I had not then discovered.

We have hitherto considered the depolarization of light as effected by two separate bodies, one of which polarizes the incident rays, while the other deprives them of the polarity which they have thus acquired; but in all bodies that possess oblique depolarizing axes, light may be polarized and depolarized by the same crystal. Thus if $ABab$, Plate IV., fig. 7, be a plate of topaz having DE for its oblique depolarizing axis, and if a ray RR' of common light is incident at R' with such an obliquity that it is polarized by being reflected at C from the posterior surface ab , then the ray rr' will be depolarized in its passage from C to r along the oblique axis of depolarization, and the emergent ray rr' will be depolarized light. Hence it follows that the angle DCb , which the oblique depolarizing axis makes with the posterior surface ab , is nearly equal to the complement of the angle OCr , at which light is polarized by reflection at C .*

[To be continued.]

XLIII. *New Outlines of Chemical Philosophy.* By EZ. WALKER, Esq. of Lynn, Norfolk.

[Continued from p. 350, vol. xliii.]

THE causes from whence arise all those various phenomena of our atmosphere, commonly called meteors, have never been investigated in a satisfactory manner. It is probable, however, that they are the effects of some universal cause. It is already

* Since the preceding section was written, I have performed a very extensive series of experiments on the depolarization of light, and have thus been led to a satisfactory generalization of the phenomena. In this theory the phenomena are referred to the general principle of polarization: such bodies as have neutral and depolarizing axes are supposed to form two images polarized in an opposite manner, and either produced by the same or by different refractive powers; while those which depolarize light in every direction, like gum aratic, caoutchouc, &c. are composed of films or layers, each of which is a doubly polarizing crystal, the neutral and the depolarizing axes of one film not being coincident with the neutral and depolarizing axes of the rest. In a separate memoir, which I have drawn up for the consideration of the Royal Society, I have given a full account of this theory, of the experiments on which it is founded, and of the new views to which it leads respecting the formation and structure of organized matter.

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