Philosophical Magazine Series 1

ISSN: 1941-5796 (Print) 1941-580x (Online) Journal homepage: http://www.tandfonline.com/loi/tphm12

XXII. On the optical properties of sulphuret of carbon, carbonate of barytes, and nitrate of potash, with inferences respecting the structure of doubly refracting crystals

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To cite this article: David Brewster LL.D. F.R.S. Edin. F.A.S.E. (1815) XXII. On the optical properties of sulphuret of carbon, carbonate of barytes, and nitrate of potash, with inferences respecting the structure of doubly refracting crystals , Philosophical Magazine Series 1, 45:202, 118-129, DOI: 10.1080/14786441508638398

To link to this article: http://dx.doi.org/10.1080/14786441508638398

Published online: 27 Jul 2009.

able defect, of *depth of pit*, (in situations where such are necessary,) cannot be substantiated.

Mr. Buddle has stated, that some pits not long opened, are subject to very destructive explosions; What then becomes of our Editor's alleged accumulation of gas *through ages*, in the works of the pit? Surely he must have blundered on the notion, that the deepest pits were also the oldest? though the reverse is the case.

The geognostical sketch furnishes us with this paragraph, viz. "both the *sand-stone* and slate-clay form the roof and *floor* of coal-beds, but *the latter* much more frequently than the former." Are we to understand from this too loose description, that *sand-stone*, properly so called, was ever observed by the writer as the immediate *floor* of a coal bed? If so, he will confer an obligation on myself and many others, who have never seen the like, if he will mention the particular pit and coal bed, in as many instances as he may be able.

Before I conclude, let me remark, that however clearly the learned Editor may have himself understood, and may have acquiesced in, the positions contained in the first twelve pages of his last number, and two plates, as to "rents;" to men of my standard of intellect, the language appears not less unintelligible, than the cases that I guess the writer meant to describe, are contrary to the real appearances of *faults* in coal mines.

I am, yours, &c.

Feb. 3, 1815. AN ENGINEER.

XXII. *On the Optical Properties of Sulphuret of Carbon, Carbonate of Barytes, and Nitrate of Potash, with Inferences respecting the Structure of doubly refracting Crystals.* By DAVID BREWSTER, *LL.D. F.R.S. Edin. and F.A.S.E.**— *Communicated by the Author.*

IN examining the changes which light undergoes during its passage through transparent bodies, we not only receive information respecting the properties of that mysterious agent; but we are in some measure made acquainted with the composition of the substances themselves, and with the manner in which their ingredients are combined. The optical phænomena, therefore, which bodies exhibit in their action upon light, are so many tests, to which the philosopher may have recourse, either in supplying the place of chemical analysis, or in correcting and modifying its results. A difference in the optical properties of two bodies, is generally an infallible indication of a difference in their elementary

* From the Transactions of the Royal Society of Edinburgh for 1814.

elementary principles; and whatever confidence we may place in the skill of the chemist, or in the accuracy of his methods, the mind can never rest satisfied with the results of an analysis which is directly opposed by optical phænomena.

It is highly desirable, therefore, that the chemical philosopher would avail himself more frequently of the agencies of light in the prosecution of his inquiries. The various products to which his attention is constantly directed, cannot always be preserved for subsequent examination, and can seldom be procured by the experimental philosopher. An opportunity is thus lost of confirming his own results, and of contributing most essentially to the progress of optical knowledge. It is by the alliance, indeed, of chemistry with optics, that great revolutions are yet to be effected in physics; and the time is probably not very distant, when, by their united efforts, we shall be able to develop those mysterious relations among the elementary principles of matter which hypothesis has scarcely ventured to anticipate.

In the following paper, I propose to describe the optical properties of sulphuret of carbon, carbonate of barytes, and nitrate of potash, and to illustrate the conclusions to which some of these properties lead, respecting the structure of doubly refracting crystals.

I. *Sulphuret of Carbon.*

This remarkable fluid was lately discovered by Lampadius. It is pure and colourless like water; has a specific gravity of 1·272; is remarkable for its extreme volatility; and is composed of 85 parts of sulphur, and 15 of carbon.

Owing to the great length of spectrum which this substance produces, I found considerable difficulty in measuring the mean index of refraction. By taking the bisecting ray beyond the green rays, and very considerably advanced upon the blue space, I obtained the following results:

Angle of the prism	8° 10′
Angle of refraction	5° 38′
Refractive power	1·687

By considering the bisecting ray, as passing through the green space, and near its confines with the blue, the following measures were obtained:

Angle of the prism	8° 10′
Angle of refraction	5° 27′
Refractive power	1·6632

As the sulphuret of carbon has nearly the same action upon the red and green rays, as balsam of Tolu, I have no doubt but that the bisecting ray is considerably advanced upon the blue space, and that the mean index of refraction is nearly 1·680.

 A prism

A prism of flint glass, with a refracting angle of 20° 53′, corrects the colour produced by a prism of sulphuret of carbon, having a refracting angle of 8° 10′; the light being incident perpendicularly upon the fluid prism. Hence it follows, that the dispersive power of the sulphuret, or the value of $\frac{dR}{R-1}$ is 0·115, R being the index of refraction, and *d* the part of the whole refraction to which the dispersion is equal; and that the refractive power of the extreme red ray is 1·623, and the refractive power of the extreme blue ray 1·737.

From these experiments we conclude, that the *sulphuret of carbon exceeds all fluid bodies in refractive power, surpassing even flint-glass, topaz and tourmaline; and that in dispersive power, it exceeds every fluid substance, except oil of cassia, holding an intermediate place between phosphorus and balsam of Tolu.*

These relations will be better understood from the following short tables:

Refractive Powers.

Sulphur, native	2·115
Boracite	1·701
Sulphuret of carbon	1·680
Tourmaline	1·668
Blue topaz	1·636
Flint glass	1·616

Dispersive Powers.

Oil of cassia	0·139
Sulphur	0·130
Phosphorus	0·128
Sulphuret of carbon	0·115
Balsam of Tolu	0·103
Flint glass	0·052

Although oil of cassia surpasses the sulphuret of carbon in its power of dispersion; yet, from the yellow colour with which it is always tinged, it is greatly inferior to the latter, as an optical fluid, unless in cases where a very thin concave lens is required. The extreme volatility of the sulphuret is undoubtedly a disadvantage to which the oil is not liable; but as this volatility may be restrained, we have no hesitation in considering the sulphuret of carbon, as a fluid of great value in optical researches, and which may yet be of incalculable service in the construction of optical instruments. All other fluids are separated from these two, in their optical properties, by an immense interval; and hence we are of opinion, that oil of cassia will yet be found to consist of ingredients as remarkable as those which enter into the composition of sulphuret of carbon.

II. Car-

II. *Carbonate of Barytes.*

The native carbonate of barytes possesses, like the agate, the remarkable faculty of forming two images, one of which is bright, and the other nebulous. The shapeless appearance of the agate; its heterogeneous and imperfect structure, and its anomalous character in the mineral kingdom, corresponded well with the singularity of its optical properties, and discouraged the anticipation of analogous phænomena, in minerals of a more perfect structure. I was, therefore, surprised to find the same character in carbonate of barytes, a mineral which has a regular crystalline form, and possesses two distinct refractive powers. The index of refraction for the perfect or least refracted image is 1·540; and its dispersive power 0·0285.

In order to observe with accuracy the phænomena presented by the carbonate of barytes, I formed nine prisms, cut in different directions, from the same specimen. In one of these prisms, which was bounded by planes parallel to the striæ or longitudinal joints, the least refracted image was extremely distinct, while the other was a faint nebulous image, of a brownish-red hue. It was small and round, and the intensity of its light was inconsiderable, when compared with that of the bright image.

When the image of a candle polarized by reflection, was viewed through this prism, having the longitudinal joints parallel to the plane of reflection, the light which formed the bright image of the candle was wholly reflected, while the nebulous light alone penetrated the mineral. But when the longitudinal joints were perpendicular to the plane of reflection, the light image became extremely distinct, in consequence of the nebulous light having now refused to penetrate the prism.

In a second prism, the nebulous or most refracted image was more luminous than in the first, and approached to a definite form; the general shape of the candle being distinctly visible.

In a third prism, the nebulous image was more luminous than in the last case, and the form of the candle still more distinctly seen; but it had now the appearance of an assemblage of incoincident images.

In a fourth prism, in which the plane of refraction was parallel to the longitudinal joints, both the images were imperfect, and the most refracted image was extremely faint. By inclining the prism, an image appeared on each side of the least refracted image; but they were polarized in the same manner, and were probably analogous to the two images which are frequently seen in specimens of calcareous spar.

In a fifth prism, which was formed by planes nearly perpendicular to the longitudinal joints, *four* images were plainly visible, all of which were imperfect, and consisted of circular arches of nebulous

nebulous light. The two middle ones, which were the principal images, were equally luminous, and were polarized in an opposite manner, like all other double images; but each of the two outer images was polarized in the same manner as the bright image furthest from it. The *most refracted* of the two principal images was in this case the more perfect of the two, and exhibited a degree of prismatic colour so much greater than the other, that it obviously belonged to a higher dispersive power. When the light enters the prism, and emerges from it at equal angles, the four images are not distinctly separated, and are extremely imperfect. When the angle of incidence at the first surface of the prism is increased, the images become more and more distinct, and better separated; but, by diminishing the angle of incidence, all the images approach one another, and are confounded into one mass of nebulous light.

With a plate of carbonate of barytes, which was about two-tenths of an inch thick, and which had its surfaces at right angles to the direction of the longitudinal joints, the image of a candle was a large circular mass of light, when the incidence was perpendicular. By inclining the plate, this mass was changed into an annular image: by increasing the inclination, it assumed the form of a crescent; and at a considerable angle of incidence, it was separated into three imperfect images, or circular arches of nebulous light, similar to those which were seen with the fifth prism. The middle image, which was the brightest, consisted of the ordinary and extraordinary image, which were not separated, in consequence of the parallelism of the refracting surfaces. In one position of the plate, these arches were crossed by other three similar arches, inclined to the first at an angle of 10° or 12°.

The phænomena which have now been described, differ in several respects from those which are presented by the agate. In the *carbonate of barytes*, the two images are distinctly separated, and are, therefore, formed by two separate refractive powers; whereas in the *agate*, the bright image is placed in the centre of the nebulous mass. In the *carbonate of barytes*, the imperfect image occupies a small space; but in the *agate*, it is an elongated mass of light, extending about $7\frac{1}{2}°$ in length, and about 1° 7′ in breadth, on each side of the bright image. These differences, however, are probably owing to the different ways in which the two minerals have been cut; but it is not easy to submit this point to direct experiment, on account of the difficulty of procuring a mass of agate, from which a variety of transparent prisms could be obtained. It follows, however, from the theory of the depolarization of light, which I have explained in another place, and which is supported by all the evidence which

which any theory can possess, that the specimens of agate which depolarize light must necessarily form two distinct images,—a phænomenon to which we have found a rapid approximation in the carbonate of barytes.

The property which has now been explained, forms a simple and infallible mineralogical character of the striated carbonate of barytes; and is particularly valuable to those who have been perplexed by the numerous marks with which some writers have laboured to distinguish it from its kindred minerals. The assistance, indeed, which optics afford in discriminating minerals, is of the most extensive kind; and it is much to be wished, that mineralogists would exchange many of their vague distinctions for those unambiguous characters which bodies exhibit in the modifications they impress upon light.

The Abbé Haüy has, in some measure, begun this reformation, and has set a brilliant example of what may be effected by the aid of mathematical and physical acquirements. In his admirable work on Crystallography, which has never been duly appreciated in this country, he has created a new science, in which he has shown how to determine the integrant molecules of crystallized bodies; and how, from a few primitive forms, may be derived that endless variety of secondary crystals which adorn the mineral kingdom. The recent discoveries which have been made in optics, enable us to give a new direction to these interesting inquiries; to determine the forms and even the angles of crystals from their optical properties; and out of a mass of shapeless fragments, to reconstruct an artificial crystal, of which all the parts shall have the same relation as they had in nature to the axes and sides of the primitive crystalline form.

III. *Nitrate of Potash.*

This salt possesses the most remarkable optical properties of any crystal that is at present known, and its various actions upon light are of the most anomalous and instructive character.

The crystals which I employed were all equiangular hexaedral prisms; and the light was transmitted through two natural faces, separated by another face, so that they were inclined to each other at an angle of about 60°. This inclination is by no means convenient for measuring refractive and dispersive powers; but I attempted in vain to form artificial faces inclined at a less angle, and those means which I had found successful with other soft crystals, completely failed when applied to this salt.

When a candle was viewed through the nitrate of potash, I observed a double refraction very much greater than that of calcareous spar,—a phænomenon which gave me the more surprise, as the Abbé Haüy, who examined many splendid crystals of this salt, ascribes to it the property of simple refraction.

The

The least refracted image was a circular mass of white nebulous light, condensed at its centre into a very faint image of the candle, but without any strong prismatic tinge; while the light which had suffered the greatest refraction, formed a distinct and highly coloured image. The great interval between the two images; the achromatic nebulosity of the first, and the distinctness and deep colours of the second image, formed altogether a singular phænomenon, and, at the same time, afforded an *ocular demonstration of the existence of two dispersive powers in doubly refracting crystals.*

The following measures of the refractive powers of the two images were taken with the greatest care:

Angle of the prism	60° 21′
Angle of refraction for the 1st image ..	24° 8′
Angle of refraction for the 2d image ..	38° 54′
Index of refraction for the 1st image .	1·3374
Index of refraction for the 2d image ..	1·5156

In order to confirm these results, I formed a new prism, and obtained the following measures:

Angle of the prism	62° 12′
Angle of refraction for the 1st image ..	24° 48′
Angle of refraction for the 2d image ..	40° 39′
Index of refraction for the 1st image ..	1·3326
Index of refraction for the 2d image ..	1·5134

By taking a mean of these results, which are extremely near to each other, we obtain for the

Least refractive power	1·3350
Greatest refractive power	1·5145

Hence it follows, that the least refraction of nitrate of potash is almost exactly the same as that of *water* which is 1·3358, —a result of such an extraordinary nature, that I felt it necessary to confirm it by repeated observations.

In measuring the dispersive power of this salt, we cannot expect the same accuracy of result on account of the great angle of the prism. Owing to the nebulosity of the first image it is impossible to measure its dispersive power; but it evidently corresponds with its low power of refraction. In order to correct the dispersion of the second refraction, it requires a prism of flint glass with an angle of nearly 60°. With an angle of 66°, the dispersion is more than corrected; but with an angle of 56° the correction is not nearly completed. The dispersive powers due to these different angles are contained in the following table:

Angles of the flint glass prism	66°	Dispersive powers	0·0613
	60		0·0573
	56		0·0516

By

By taking a mean between the two extreme observations, we obtain 0·058 for the approximate dispersive power,—a result which could scarcely have been anticipated from the substances which enter into the composition of nitre. The following table will show the relation which this measure bears to the dispersive powers of other bodies:

Sulphate of lead	0·060
Nitrate of potash, 2d refraction	0·058
Flint glass	0·048
Water	0·035

In order to examine the character of the rays which form the two images, I polarized the light of a candle by reflection from glass, and viewed it through two of the parallel faces of a hexaedral prism of nitre. When the edges or common sections of its faces were parallel to the plane of reflection, a bright image of the candle was seen in the middle of a mass of nebulous light, exactly similar to what happens in the agate when its veins are parallel to the plane of reflection. But upon turning round the crystal of nitre, the bright image gradually vanished, while the nebulous light increased; and when the edges of the crystal were perpendicular to the plane of reflection, the bright image was extinguished, and the nebulous light a maximum. When the reflected image of the candle is viewed through two inclined faces of the nitre, the two images vanish alternately, like those formed by all doubly refracting crystals.

A prism of nitrate of potash, having its refracting surfaces equally inclined to the axis of the hexaedral crystal, possesses the faculty of depolarizing light ; and hence it follows, from the theory of depolarization, that the prism must, in this case, form two distinct images.

The two neutral axes of this salt are parallel and perpendicular to the sides of the hexaedral prism; and the depolarizing axes are parallel to the diagonals of the square base common to the two pyramids which compose its primitive rectangular octaedron. The least refracted image is that which is produced by the extraordinary law of refraction.

The beautiful coloured rings which I exhibited to the Society, as produced by the action of topaz upon polarized light, and which I have also discovered in the agate, and in a great variety of other bodies*, exist also, but in a very singular manner, in the nitrate of potash.

By comparing in a rude manner the coloured rings formed by different bodies, with the thickness of the plates by which they were produced, I concluded that the conjugate diameters of the

* See Phil. Trans. Lond. 1814, part i. p. 218.

rings

rings were nearly as $\frac{1}{(m-1)^3}$, *m* being the index of refraction. In the nitrate of potash, however, their magnitude is quite anomalous, as it produces along the axis of the hexaedral prism a series of miniature rings, nearly *eight* times less than they should have been according to the preceding law. The beautiful generalization of the phænomena of coloured rings, which we owe to the genius of the celebrated Biot, may perhaps afford an explanation of this apparent anomaly.

The *carbonate of potash* forms also two images, one of which is bright, and the other nebulous. They are polarized in an opposite manner, like those formed by the nitrate of potash, but the nebulous image is more distinct in the carbonate. With a prism bounded by natural faces, and having a refracting angle of 49° 53′, I obtained the following measures of its mean refractive power:

Index of refraction for the nebulous image .	1·379
Index of refraction for the bright image ..	1·482

IV. *On the Structure of doubly refracting Crystals.*

Notwithstanding the numerous discoveries which have recently appeared respecting the polarization of light, no attempt has been made to apply them in solving the problem of double refraction. They furnish us, indeed, with a variety of beautiful phænomena, analogous to the polarization of light, which always accompanies the production of two images; but they afford no ground of conjecture respecting the separation of the pencil into two parts.

When I discovered the property possessed by the agate, of forming a bright and a nebulous image, and of polarizing them in an opposite manner, like all doubly refracting crystals, I was sufficiently aware of the conclusions which it authorized*; but as no other crystallized body exhibited analogous phænomena, I contented myself with stating these conclusions as mere conjectures, which required the sanction of numerous experiments.

In the carbonate of barytes, however, and in the nitrate and carbonate of potash, we are presented with properties analogous to those of the agate, and are therefore enabled to resume this subject, with that confidence which can only be derived from multiplied observations.

When we examine the two images formed by calcareous spar and other perfectly transparent crystals, we find that they have the same magnitude, and are equally luminous and distinct. There is, therefore, no circumstance which can lead us to suppose, that the light which forms the one image passes through a

* See Phil. Trans. Lond. 1813, part i. p. 101.

part

part of the crystal, having a different structure from that which transmits the light of the other image. In the carbonate of barytes, however, where the transparency of the crystal is imperfect, one of the images is nebulous and imperfect; and as the same phænomenon is exhibited in the agate and in the imperfectly transparent crystals of the nitrate and carbonate of potash, we are entitled to conclude, that the light which forms the imperfect image is transmitted through the imperfect structure; while the light which forms the bright image is transmitted through a structure of a more perfect kind. The imperfect transparency, therefore, of the crystal, and the nebulous character of one of the images, can be considered in no other relation than that of cause and effect.

From the optical properties of the agate, this conclusion derives a still higher degree of probability. The two images formed by this mineral are not similar to each other, like those of calcareous spar, though they possess exactly the same properties. One of them is bright and distinct, and the other is a mass of nebulous light. Now it happens that the agate possesses two different kinds of structure, corresponding to the characters of its two images, and distinctly perceptible even to the naked eye. One of these structures is composed of small serpentine lines like the figures 3333, resembling the surface of water ruffled by a gentle breeze; and I have a specimen in my possession, one-half of which has much larger serpentine lines than the other. The light which passes through the serpentine lines, is that which forms the nebulous image; while that which passes between them forms the distinct image. This may be demonstrated by a variety of experiments.

When the light is transmitted through a part of the agate that has the largest serpentine lines, the nebulous image has an appearance different from that which it has when the light is transmitted through the other part where the serpentine lines are smaller. If the agate is inclined in the direction of the serpentine lines, so as not to prevent the rays from passing between them, the bright image will be distinctly visible as before; but when the agate is inclined in a direction at right angles to this, so as to prevent the rays from passing between the serpentine lines, the whole of the transmitted light is nebulous. Hence it follows, that the nebulous image is produced by the imperfect structure of the agate, indicated by the serpentine lines; while the bright image is produced by a structure the same as that of all other transparent bodies.

The curvature of the nebulous light, in some specimens of agate with incurvated veins, and its constant parallelism to the laminæ,

laminæ, and to the direction of the serpentine lines, give additional probability to this conclusion.

Here, then, we have a case of the most unequivocal kind, in which one image of a doubly refracting crystal is produced by one structure, or by one part of the crystal, while the other image is produced by another structure, or another part of the crystal; and hence we are led to conclude, in general, that the two images exhibited by all doubly refracting bodies, are formed by two different structures, related to some axis or fixed line in the primitive crystal. Whether this difference of structure is produced by a difference in the arrangement of the elementary molecules, or is owing to a combination of different ingredients, is a point which still remains to be determined.

The phænomena presented by the agate and the carbonate of barytes, convey still further information respecting the structure of these imperfect crystals. In one direction, the light transmitted by the agate is wholly nebulous; the perfect image being converted into a shapeless cloudy mass, and confounded with the nebulous image. In another direction, one of the images is distinct and perfectly formed; and in one specimen, which has the faculty of depolarization, there must necessarily be two perfect images. In a prism of the carbonate of barytes, both the images were imperfect. In a second prism, the one image was nebulous, and the other distinctly formed; while, in other prisms, there was a rapid approximation to two perfect images. Hence it follows, that the imperfect structure, which, in general, transmits only a mass of nebulous light, allows a distinct image to be formed, when the rays are incident in one particular direction; while the perfect structure, which in general gives a distinct image, allows an imperfect image to be formed, when the light penetrates it by a particular path.

These inferences, which I conceive to be irresistible, have a higher degree of importance than we may at first be disposed to attach to them. They form a real step in the explanation of double images, and indicate a part of that structure which is necessary to their formation. The other phænomena of double refraction are still involved in obscurity. The opposite polarization of the two pencils may be explained by supposing the crystal to consist of laminæ inclined in various directions; and, as I have shown in another place *, the same phænomena may be actually produced by an artificial crystal composed of bundles of glass plates. The most perplexing point, however, is the extraordinary refraction which takes place at a perpendicular incidence. Whether this phænomenon is the result of an extraor-

* Phil. Trans. Lond. 1814, part i. p. 230.

dinary

dinary law of refraction, as Huygens and Newton supposed, or is produced by forces dependent on the elementary structure of the crystal, is a question which still remains to be determined. The extraordinary reflection and refraction arising from the last of these causes, which I have discovered in mother of pearl*, present an analogy, by no means remote, to the phænomena of double refraction.

XXIII. *Of the Physiology of certain Disorders of Health founded on a Knowledge of the proportionate Development and Functions of the special Organs of the Mind.* By Thomas Forster, *Esq.*

To Mr. Tilloch.

Sir,—In a former paper I endeavoured to point out some of the practical applications of the new discoveries into the structure and functions of the brain, with a view to show the various means in which it might become useful to society. For I consider every inquiry as to the particular utility of any science to be merged in the general question, Whether or no it be the illustration of truth? Yet it is of use to particularize the special purposes for which it may be employed. I proceed to mention briefly a few curious facts relative to the history of certain kinds of aberration of mind, and to their connexion with particular organization.

It seems to me, that we cannot obtain any accurate knowledge of the nature of this mental disorder, till we have first become acquainted with the mind in its healthy state. Insanity consists in the erroneous or inordinate energy of the functions of the mind in general, or of some of the faculties in particular. To learn the physiological history of these, we must previously know what are the primitive faculties of the mind in a healthy condition; we must first know the passions, learn what are the results of primitive and uncompounded organs, and what are compounded

* This substance, whose remarkable optical properties I have explained in another place, resembles the agate, the carbonate of barytes, and the nitrate and carbonate of potash, in giving a bright and a nebulous image, when the light is transmitted in one direction, and two bright images, when the light is transmitted in another direction; but it possesses this property under circumstances of such an extraordinary nature, that I could not with propriety have introduced any account of it into this paper.

A number of soft substances, of animal and vegetable origin, have likewise the faculty of forming a bright and a nebulous image, under various singular modifications. A full account of the results which I have obtained with this class of substances, will be found in another paper.

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