

Fig. 1.

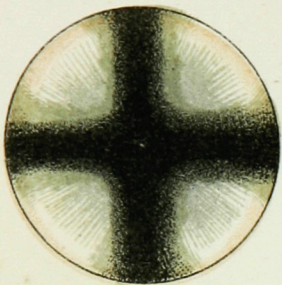


Fig. 2.

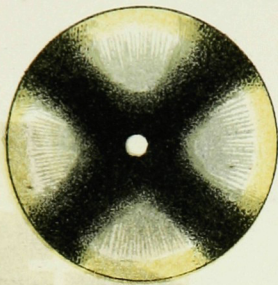


Fig. 3.

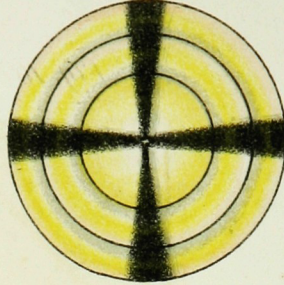


Fig. 4.

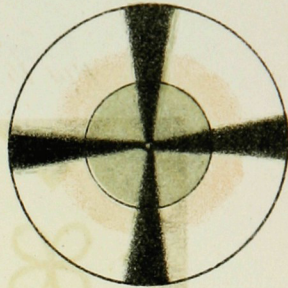


Fig. 7.

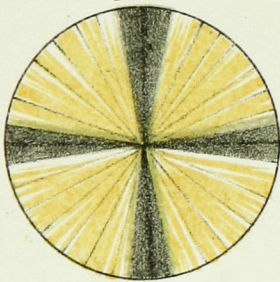


Fig. 8.

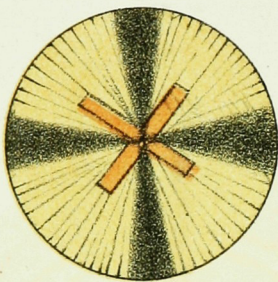


Fig. 9.

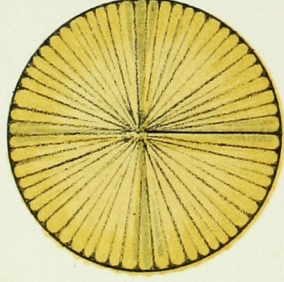


Fig. 10.

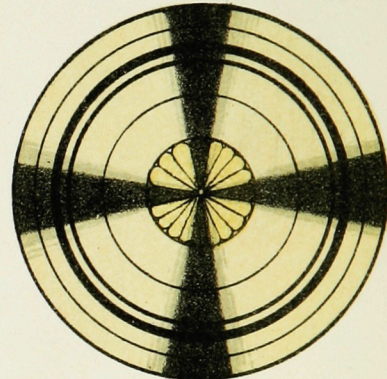


Fig. 6.

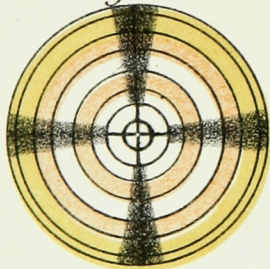


Fig. 13.

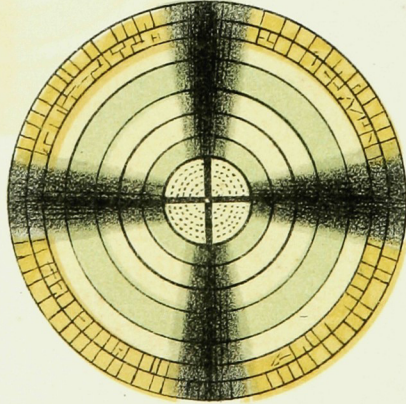


Fig. 11.

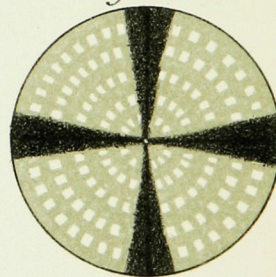


Fig. 5.

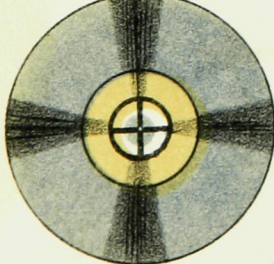


Fig. 14.

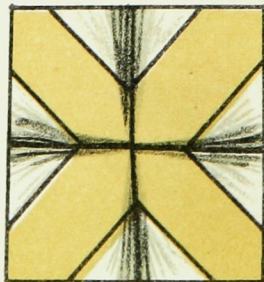


Fig. 12.

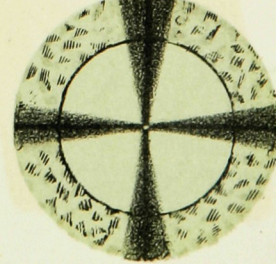


Fig. 15.



Fig. 16.

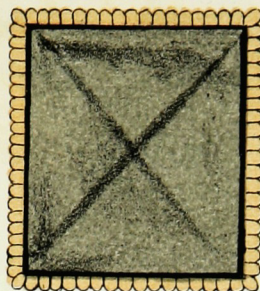


Fig. 17.

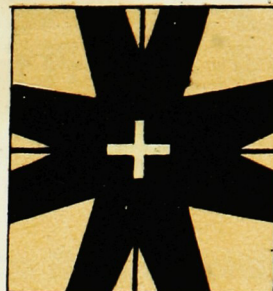


Fig. 18.

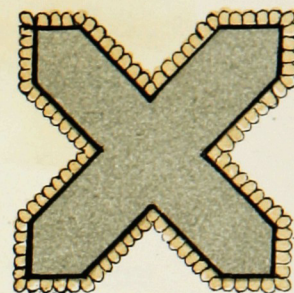


Fig. 20.

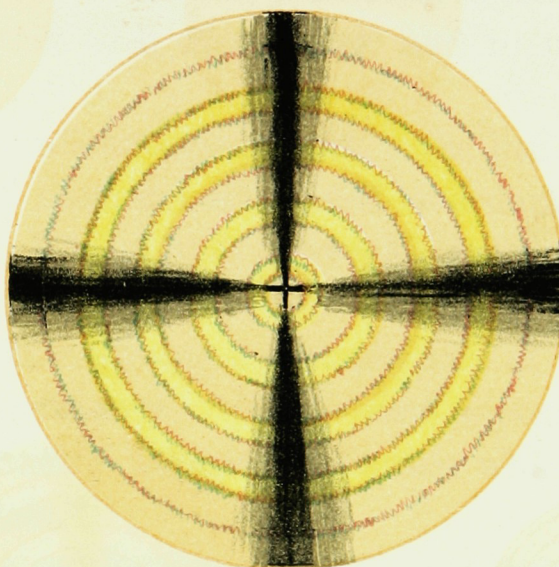


Fig. 19.

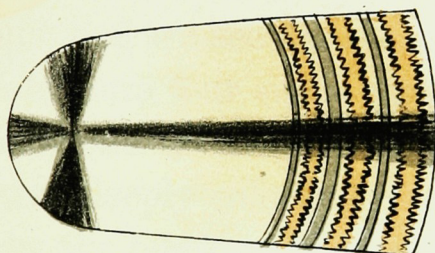


Fig. 21.

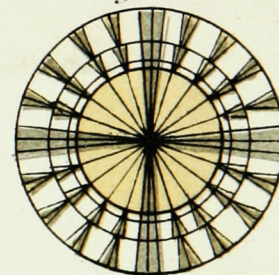


Fig. 22.

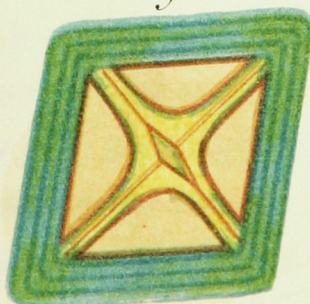


Fig. 23.

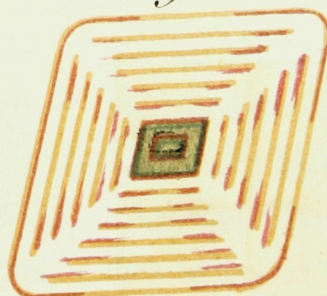


Fig. 24.

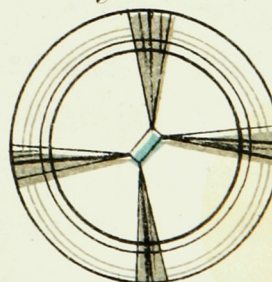
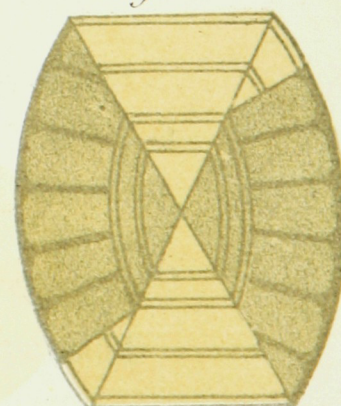


Fig. 25.



XLIII.—*On Circular Crystals.* By Sir DAVID BREWSTER, K.H., D.C.L., F.R.S.,
V.P.R.S. Edin., and Associate of the Institute of France. (With Two Plates.)

(Read 21st March 1853.)

In 1836, Mr FOX TALBOT communicated to the Royal Society a paper “On the Optical Phenomena of certain Crystals” which he obtained by dissolving a crystal of Borax in a drop of somewhat diluted Phosphoric acid. When the acid and the salt are in proper proportions, “the field of view of the microscope is seen covered with minute circular spots, each of which is like a tuft of silk radiating from a centre, and is composed of a close assemblage of delicate acicular crystals forming a star.” Among these crystals are seen interspersed “a number of circular transparent bodies, which are tufts or stars of acicular crystals, in such close assemblage as to be in optical contact with each other, and to produce the appearance of a single individual.”

When the field of the polarising microscope is dark, “the little circles become luminous, and we see upon each of them a well-defined and dark cross, dividing the crystal into four equal parts.” With a high power, Mr TALBOT observed upon each circle one or more coloured rings arranged concentrically; the innermost, which was deeply coloured or black, enclosing a central space of white light, traversed by the black cross already mentioned. “The general appearance,” he adds, “resembles the Fig. 98* in BREWSTER’S Treatise on Optics, which is a representation of the rings in uniaxal crystals.”

About twenty years† before the publication of Mr TALBOT’S paper, I had produced minute circular crystals in *Oil of Mace*,—in a mixture of *Oil of Mace* and *Rosin*, and also in *Tallow*, when these substances were melted between two plates of glass, and cooled under pressure. The crystals thus produced were not themselves visible in the microscope, but, in polarised light, they exhibited their existence and their structure, in the formation of four luminous sectors traversed by a black cross.

When we look through a plate of Oil of Mace properly prepared at a bright and small disc of light, the light is generally surrounded with a single halo, though sometimes with two. When the disc of light is polarised and subsequently analysed, the halo is divided into four luminous sectors, separated by a rectangular black cross, which, from the divergency of its branches, had the appearance of four dark sectors. The arms of the black cross were always parallel

* Fig. 120 in the New Edition, just published.

† *Phil. Trans.*, 1815, p. 49, 38; and 1816, p. 97.

and perpendicular to the plane of primitive polarisation, and the disc of bright light disappeared at their point of intersection. In the opposite position of the analyser, the luminous disc appeared at the point of intersection, and the two luminous sectors that were horizontal were brighter than the two vertical ones. These phenomena are shewn in Figs. 1 and 2, Plate XVI.

In some cases, the circular space enclosing the sectors was very small, and in others large, and frequently when two halos were produced, there were two sets of luminous sectors, separated by an interval equal to that between the halos.

It is very obvious that the halos were produced by the crystals of the *Oil of Mace*, the smaller halo by the larger crystals, and the larger halo by the smaller crystals existing among the larger ones. In order to explain the luminous sectors, I inferred that each halo was composed of two, the one lying above the other, and having every alternate sector polarised in opposite planes; or, in other words, that these two halos were the two images formed by the double refraction of the elementary crystals, and were oppositely polarised, as all such images are. But though this inference was correct, as I afterwards proved, yet I could not see with the microscope the actual form of the circular crystals by which the double refraction and polarisation were produced.

After the publication of Mr TALBOT's paper, I repeated the experiment with oil of mace, and having adopted different methods of cooling it under pressure, I soon discovered with the microscope, and by the aid of polarising films when the microscope could not alone detect the structure, that the phenomena which I have described were produced by circular crystals varying from invisibility to the 200th or 300th of an inch in diameter, and exhibiting, when of this size, distinct and beautiful sectors in polarised light.

Having thus discovered a method* of distinguishing true quaquaversus polarisation, or that which is produced by invisible crystalline particles with their axes lying in all directions, from that *apparent* quaquaversus polarisation which is produced by the same class of particles combined in circular crystals, I was anxious to prosecute the subject of circular crystallisation, by examining a great number of doubly-refracting substances.

With this view I received from Mr TALBOT the preparation of Borax and Phosphoric acid which he had found to give the best circular crystals, and from Dr DOWLER of Richmond a quantity of the *Lithoxanthate of Ammonia*, which yields circular crystals with more certainty and less trouble than the preparation of

* This method consists in placing a film of selenite (sulphate of lime) between the polariser and the substance to be examined. If the polarising structure is produced by circular crystals, it will appear covered with spots, or minute sectors, of two different colours, the one being a tint a little lower, and the other a tint a little higher, than that of the selenite. The higher tint is the sum of the tints of the two substances, and the lower their difference, the tint of the selenite being increased by that of two of the sectors, and diminished by that of the other two.

Borax. I was thus enabled to study the phenomena which they exhibit in their formation, their structure, and their subsequent decomposition.

In the expectation of obtaining a greater variety of structure, and discovering new phenomena, I submitted to examination about 300 doubly-refracting substances, and among these I discovered nearly *seventy* that give circular crystals, about *thirty* of which are *positive*, like *Zircon*, and *forty negative*, like *Calcareous spar*.

In the course of these experiments, which have occupied much of my time, I have observed many new and splendid phenomena, which lay open an extensive field of research, and promise to throw much light on those abnormal crystallisations which take place under the constraining influences of heat and pressure, and also on their subsequent decomposition and return to their molecular state.

In submitting to the Society an account of these experiments, I shall begin with the *Lithoxanthate of Ammonia*, as it exhibits a greater variety of phenomena, and is more easily converted into circular crystals than any other salts with which I am acquainted.

1. *Lithoxanthate of Ammonia*.—This substance, under ordinary circumstances, crystallises in minute prisms, often in beautiful dendritic forms, and in spherical groups of crystals in which the prisms are not in optical contact, and yet sufficiently united to exhibit the black cross at the centre of the sphere.

When the circular crystals are produced, and are transparent, they have very different aspects in different specimens. In their simplest form, they are united in a continuous film, each circular crystal exhibiting four luminous sectors separated by a black cross, the arms of which are, of course, always parallel and perpendicular to the plane of primitive polarisation. The light polarised by the sector is the *blue* of the first order, often rising to the *white*, and sometimes to the *yellow*, of the same order.

When we look at a small and bright luminous disc through a film of such crystals, we see a halo, and sometimes two halos, the diameter of the halo diminishing as the circular crystals increase in size. When the film is placed in the polariscope, the halo is converted into four luminous sectors, and into eight when it is double, exactly the same as those produced by oil of mace, and shewn in Figs. 1 and 2.

When the circular crystals are separate, their structure is more complex, and their appearance more beautiful. In one of these, shewn in Fig. 3, I have observed, but only once, the *three* first orders of colours of thin plates, exactly like the uniaxal system of rings in regular crystals; and consequently, the thickness of the spicular crystals which composed them must have increased from the centre outwards, according to the law in NEWTON'S Table of Periodical Colours. This result was so remarkable, that I determined the character of the three

orders of tints, by compensating them with the corresponding tints of plates of selenite.

In other discs the rings 2 and 3 have each the same colour throughout,—the one generally *red* and the other *green*, and having no relation, either to the central tint at 1, or to one another. In some cases the order of colours is completely inverted, as in Fig. 4, where the central tints are a *blue* of the second order, gradually passing through *red* and *yellow* to a brilliant *white* of the first order. In other crystals I have found the central tints *red*, *green*, and *yellow*, of high orders; but in these cases the discs are not regularly formed, and the elementary crystals not wholly in optical contact.

The most perfect circular crystals are those in which the central tints are the *blue* and *white* of the *first* order. This arises from the extreme minuteness of the crystals, which thus form a more uniform disc, and cause the *black cross* to have a degree of sharpness, which it requires a considerable magnifying power to exhibit. In such crystals, the central portion is surrounded with a black and narrow ring, beyond which there is another annulus of sectors, sometimes *white* like the inner ones. This is again terminated by a black circle, beyond which is a third series of sectors, sometimes *white* and sometimes a *blue* of the first order. This structure is shewn in Fig. 5, where the black cross starts into different breadths, in passing from one set of sectors to the others,—an effect which is produced by an inferior degree of optical contact in the elementary crystals of the outer sectors.

An interesting structure is shewn in Fig. 6, where all the tints are *white*, the central ones terminating in a dark circle, beyond which are four large sectors, whose tint is the *bluish white* of the first order, lower than the central tint. Each of these sectors, however, is divided into four portions by very faint circular lines, which scarcely depolarise the incident light, the tint being there a minimum, and increasing to the middle point between them.

In Figs. 7 and 8, we have represented structures consisting of crystals, shooting out, as it were, from the centre, and all of a *golden-yellow* colour. In Fig. 7, the black cross is seen, but in Fig. 8 there is such imperfection of contact between all the radial crystals, that the darkness of those under the black cross is scarcely visible.

In discs like Fig. 7, a very singular effect is sometimes produced, as shewn in Fig. 9, where the black cross is so divergent and wide, that the golden-coloured crystals half-way between its branches, have the appearance of a yellow rectangular cross.

Under favourable circumstances, the discs assume a very interesting and complex appearance, as shewn in Fig. 10. Beyond the central golden-yellow radiations is a broad annulus of *pale blue* of the first order, divided by a faint, dark, and narrow band, scarcely luminous. This annulus is surrounded by a sharp and broad line, perfectly black, which is succeeded by a similar line separated from

the other by a faint line of light, which, in some crystals, reaches the *yellow* of the first order. Beyond this is another annulus of pale blue light, divided, like the first, by a faint line. In some discs this annulus is divided into three, by two faint bands. Each sector of this annulus is subdivided by dark radial lines, into four or five spaces, and, sometimes, beyond this there is another annulus similarly divided, the tint of both being a *white* of the first order.

The interesting fact in this description, and which will afterwards occupy our attention, is, that the two sharp black circular lines, or spaces, are *wholly devoid of matter*, and that the interior part of the disc is separated by them from the exterior part.

Among the almost infinite variety of crystallisations which this substance presents to us, I shall describe only another which, though we shall afterwards find it fully developed in other substances, occurs only in circular sectors of 30° or 45° . It is represented in Fig. 11, in its complete state, and consists of a series of concentric circles, composed of crystalline patches, which generally polarise tints not higher than the *yellow* of the first order. Each concentric circle appears at first to be separated from its neighbour, and each crystalline patch from those adjacent to it; but though this is in some crystallisations the case, yet in general, we can observe between the patches, in all directions, crystalline matter so exceedingly attenuated, that its existence is not made visible by its action on polarised light.

2. *Salicine*.—In this substance, whether dissolved in water or in alcohol, I have found the most splendid circular crystallisations. They are generally very large, and their character is *negative*, like the rings in calcareous spar. When the crystals are small, and require a considerable power to be seen, their tint is the palest *blue* of the first order, but when their diameter is between the one-fifth and the one-thirtieth of an inch, and their tints those of the *first* and *second* orders, they form, in the estimation of all who have seen them, one of the finest objects for the polarising microscope.

One of the smaller crystals is shewn in Fig. 12, where the tint of the four sectors is *bluish-white*, while that of the circular rim is absolutely black, arising from the great thinness of the crystals which compose it. That they are transparent crystals and not opaque matter is proved in this, and in all similar cases, by turning round the analyser when the light freely permeates the rim, and has a slightly yellow tinge, being complementary to what NEWTON calls, in his Table of Periodical Colours, the *Beginning of Black*.

A larger disc of Salicine is shewn in Fig. 13, where there is a sharp black cross in the centre, surrounded with five or six narrow and concentric *black* rings, which become *white* by turning the analyser; or we shall in future express it, in the white field. Beyond these central sectors, the black cross is wide and divergent.

The whole of this annulus, which forms the greater part of the disc, is composed of crystals radiating from the centre, and of unequal thickness in their breadth, so that we have the luminous sectors not of one colour, as in the Lithoxanthate of Ammonia, but of various tints from *white* of the first to *blue* of the second order. The radiating crystals are sometimes sectors of 10° or 15° , of uniform thickness, and giving the same colour; and hence, the black cross is composed of sectors of different degrees of blackness as they are brought into the plane of primitive polarisation. Beyond this annulus, the disc terminates in a rim, like that of a carriage-wheel, composed of two or more concentric circles, between which the crystals are disposed in radial lines, sometimes not in optical contact, but exhibiting the same colours as those in the larger annulus. In discs of a considerable size, there are seen exceedingly minute and dark circles, about ten or twelve in number, which I have found to be cracks or lines of cleavage, and which are accompanied with short lines of cleavage, passing radially from the one to the other.

In these discs, there is another peculiarity which deserves to be noticed. In the coloured sectors, there are often circular spots and rings, in which the tint descends to *zero*, as if a drop of some solvent had fallen upon the crystal: and there are spots of an opposite kind, where the tint rises from that of the sector to higher tints, an effect probably produced by a particle of the crystal forming around itself, while dissolving, a thicker film, becoming thinner as it recedes from the particle.

In some of the circular discs of Salicine, I have found the outer rim as wide as the interior portion, and in this case it polarises a *bluish-white* of the first order; but, what is peculiarly worthy of notice, this rim is subdivided by faint concentric rings of different degrees of darkness, into, sometimes, twelve or fifteen annuli of different degrees of brightness. This seldom takes place in the interior portion of the disc, but when it does occur, and the tints are brilliant, the subdivision of the annulus into a number of concentric circles of different colours is singularly beautiful.

3. *Asparagine*.—The circularly polarising discs which this substance displays, resemble very much those of *Salicine*. They are more varied in their structure, and more beautiful in their tints. The rims of the discs are more highly coloured, and more uniform in their texture; and the concentric tints, whether they are all of different degrees of whiteness, or of higher orders of colours, are so perfectly regular, and so sharply defined, that the observer stands before them in mute admiration, and feels himself unable either to describe or to draw them. There are two peculiarities, however, which deserve to be noticed; the one, the existence of discs in which there is no circularly polarising structure; and the other, of discs exactly resembling, in the succession of black and white narrow rings, the systems

of rings seen round the star Capella, with annular apertures, and drawn by Sir JOHN HERSCHEL.*

4. *Manna*.—This substance gives fine circular crystals, which are negative, whether obtained from fusion or an aqueous solution. The crystals obtained by melting the Manna are the most perfect and beautiful. The intersection of the arms of the black cross is so sharp that it sometimes requires a considerable power to develope it, and the four minute sectors around it. Beyond this the crystals radiate uninterruptedly till they are stopped by meeting with other crystals, and the whole of them are joined together in a hexagonal mosaic pavement. The colours are very bright, varying from the *white* of the first to the *blue* and *green* of the second order, and there is a uniformity in the tints, and consequently in the shading of the black cross, which indicates great equality in the elementary prisms, and in the forces which keep them in optical contact. The discs are seldom found separate, and they have no rims, no annuli, and no concentric cracks.

5. *Disulphate of Mercury*.—This salt, dissolved in nitric acid, gives no circular crystals by rapid cooling; but, when the solution is cooled slowly, it yields positive circular crystallisations of a square form, as shewn in Fig. 14, which undergo interesting variations. The rectangular cross is sometimes wanting, and is, as it were, replaced by black lines, which meet at the centre. These lines are sometimes black in the white field, and are then junction lines where the optical contact is imperfect. The greater number of the crystals in which these lines are more or less perfectly seen are rounded at the angles. Sometimes they are nearly circular, and the tint which they polarise is very little above the *beginning* of black of NEWTON's Table.

When the crystals are thicker, they exhibit a singular variety of forms, of which I have given a specimen in Figs. 15, 16, 17, and 18, the relation of which to Fig. 14, will be easily recognised. The crystals shewn in Figs. 16 and 18 were obtained from a weak solution of the salt, and are very interesting. In the dark field of the microscope, we see only the brilliant golden-yellow border, and it requires a strong light and a very high power to discover, in the black interior of the square, minute specks of light equally diffused over its surface. By a slight turn of the analyser, we perceive the slightly darker diagonal cross shewn in Fig. 16. These squares are often wholly and uniformly filled up with crystals of the same tint as their outline; and occasionally only part of the square is thus occupied. The small and often shapeless crystals (occasionally oval and pear-shaped), which form the outline of the square in Fig. 16, and of the cross in Fig.

* *Treatise on Light*, § 770, Figs. 155, 156, 157, Plate IX.

18, have placed themselves in these positions after the interior crystal has been formed; that is, they are not increments deposited by the solution, but have been formed at a distance from the crystal, and carried to their new position. This is proved by the fact that sometimes a mass of them surround several of the square crystals, while individual ones take their place at random upon the face of the square. When the crystals are deposited from a strong solution, the square ones become almost opaque, and the irregular ones highly coloured, and of exceedingly various shapes. I have not been able to obtain any square crystals of the disulphate of mercury from its solution in muriatic acid.*

6. *Parmeline*.—This substance, dissolved in water, has a tendency to give circular crystals. In alcohol it gives very fine ones, producing, when small, beautiful halos like oil of mace, with blue light in their centre.

7. *Asparagine and Salicine mixed*.—After standing several months, this mixed salt produced small circular crystals, apparently of asparagine. These crystals gave brilliant halos of red and green light, of such a diameter that the individuals were only $\frac{1}{7500}$ th of an inch in diameter. Among these small crystals were placed large circular discs, with curved sectors and black crosses, which gave them the appearance of the corolla of a flower with party-coloured petals.

8. *Palmic Acid*.—This substance, when melted by heat, gives very fine negative circular crystals like those in the hexagonal mosaic of manna. The insulated discs have a rim sometimes divided by broad black bands, where the substance was too thin to polarise the light. When the rim is broad and single, it is composed of narrow luminous sectors, radiating from points in the circumference of the disc. The rims are sometimes of a different colour from the principal sectors, and the latter are often subdivided by numbers of black and equidistant concentric circles.

9. *Nitrate of Uranium*.—This salt gives fine negative circular crystals in water, alcohol, and ether. The crystals formed in the alcoholic solution deliquesced in an instant, forming hemispherical bells, which polarised the light by oblique refraction, giving four luminous sectors, and a black cross very wide at the centre, like the sectors and cross produced by the hemispherical cups of de-

* In making these observations, and on many other occasions, I have felt the great inconvenience of the present, and in general, perhaps the best, arrangement of the compound microscope. High powers being always obtained by object-glasses of short focal length, it is almost impossible, in transparent structures, to develop them, when they consist of lines or parts of different thickness. Vision is destroyed by the refractions and diffractions of the intromitted light. The only remedy for this is to use $\frac{1}{2}$ -inch, or even 1 or 2-inch object-glasses, and obtain the power that is required at the eye-piece, by means of grooved and other lenses of diamond, garnet, &c.

composed glass. After the deliquescence of the crystals, I attempted to make another crop, but having failed, I set the piece of glass aside. In the course of half-an-hour, however, I found it covered with a fine and splendidly-coloured set of circular crystals, which dissolved wholly when placed in castor-oil with the view of preserving them. The light polarised by the bells above mentioned, formed a double ring, *red* on one side, and *green* on the other, with a black space between.

Upon examining the solution in castor-oil, after having stood upwards of four years, I find that circular crystals of three different kinds have been formed, some small and very perfect, with four sectors and no rim; others with broad rims, with quaquaversus polarisation; and a third set in which the structure has been entirely decomposed, and the circular form of the disc preserved.

10. *Palmine*.—This substance melts like tallow into a uniformly luminous film, apparently with quaquaversus polarisation; but upon examining it with a high power in the polarising microscope, it exhibits millions of circular crystals, each bearing its little black cross. These crystals are so minute as to produce splendid halos, which, in the polariscope, give four luminous sectors exactly like those in oil of mace.

11. *Chromic Acid*.—The circular crystals of this substance, dissolved in water, are of a very peculiar kind. They are negative, and are very imperfectly represented in Fig. 11, where the circular disc is composed of a great number of concentric circles, whose tint is the *blue* of the first order, rising, in some cases, to the *yellow* of the same order. These circles may be described as rippled lines consisting of minute crystals, separated by others still more minute, and incapable of polarising the light. The system of concentric rings is traversed by the usual black cross. This salt gives another kind of crystals, in which are separate concentric rings without the black cross, and consequently with quaquaversus polarisation.

12. *Berberine*.—This salt gives very fine circular crystals which are negative, and form beautiful halos like those in oil of mace. The ordinary crystals often form a number of crystalline rings in contact, each of which contains circular crystals of different sizes, and occasionally prismatic crystals along with them.

13. *Sulphate of Cadmium*.—The sulphuret of cadmium, dissolved in nitric acid, is converted into sulphate, which gives beautiful negative circular crystals, varying from the 800th of an inch to the 3000th. After the sulphuret is melted, and the acid driven off, no crystallisation is seen, but in an hour or two a deliquescence takes place, and the circular crystals gradually appear. There are many of them so small and thin, that they have no action on polarised light.

Other three rings follow in succession, the *white* tint rising to the *yellow*, and again falling to its original colour. Each of these five rings have precisely the same tints throughout their circumference, and when a number of such crystals appear in the dark field, they form objects of singular beauty.

In some specimens, the discs have the appearance of cones, as in *Mannite*. They have, in the centre of the black cross, another cross whose arms bisect the sectors, having sometimes a *white*, or *yellow*, or *green* tint. This cross is surrounded with a faint ring, which separates it from large sectors of a bright *pink* colour.

The circular discs are often composed of radial lines of different thicknesses, and in imperfect optical contact. Their tints consequently vary throughout the disc, and have a remarkable appearance. When the crystals are very small, they produce the polarised halos given by oil of mace.

19. *Hippuric Acid*.—This salt gives imperfect discs when melted. With water, it gives good circular crystals, but very fine ones with alcohol. They have a great variety of forms and tints, depending on the strength of the solution; but they differ from other circular crystals in two points. The radial lines are often separated from one another by black spaces of the same breadth as the luminous radial lines, and the whole disc is covered with almost invisible concentric black circles, at equal distances from one another. They are seen most distinctly in the white field. The four central sectors are often surrounded with a ring separated from them by a black space entirely free from matter. In some specimens, the discs consist of eight or ten sectors of uniform thickness and tint, which become black when in the plane of primitive polarisation. In other specimens, the crystallisations are large, irregular, and highly coloured.

Having thus described the phenomena exhibited by some of the more important circular crystals, I shall give a tabular list of the other substances in which I have found the property of giving circular crystallisations, arranging them under the heads of *Positive* and *Negative*, as formerly explained.

Positive Circular Crystals.

Sulphate of ammonia and magnesia.	Sulphate of iron and ammonia.
... red oxide of manganese.	... potash.
Hydrate of potash.	... manganese and ammonia.
Citrate of potash.	... magnesia and ammonia.
Muriate of morphia.	... zinc and potash.
... magnesia.	Disulphate of mercury.
Almond soap.	Mannite.
Starch.	Citrate of ammonia.
Substance in garnet.	Myristic acid.
... mica.	Cuprose sulphate of potash.
Chloride of strontian.	Kreatinine.
Sulphate of cobalt and ammonia.	

Negative Circular Crystals.

Borax in phosphoric acid.	Sulphate of copper and iron.
Lithoxanthate of ammonia. zinc.
Salicine. magnesia.
Asparagine. magnesia of potash.
Manna. copper of ammonia.
Parmeline. zinc of ammonia.
Palmic acid. zinc.
Palmine.	Substance in garnet.
Esculine.	Stearine.*
Berberine.	Stearic acid.
Cinchonine.	Palmitic acid.
Theine.	Acetate of strontian.
Oil of mace. quinine.
Cacao butter.	Chloride of zinc.
Hatchetine.	Oxide of uranium.
Animal fat.	Protoxide of nickel.
White wax.	Phosphate of nickel.
Chrysopleinic acid.	Carbonate of nickel.
Succinate of zinc.	Substance in mica.
Chromic acid.	Adipocire.
Citric acid.	Margaric acid.
Nitrate of uranium.	Ethal.
... .. urea.	Oxalurate of ammonia.
... .. brucine.	Kreatine.
... .. strychnine.	Carbazotate of potash.
Gallic acid.	Sulphuret of potassium.
Thianuret of ammonia.	Hippuric acid.
Sulphuret of cadmium.	Santonine.

To this list of substances which, under certain favourable conditions of crystallisation, after solution or fusion, give circular crystals, the perfection of which depends on causes over which the observer has little control, I may add the following animal substances, in which the circular phenomena are produced, and in which, with one exception, the structure is negative, as the greater number of such structures seem to be.

Hoof of horse, both transverse and vertical.	Hoof of rhinoceros.
... .. ass, transverse section.	Horn of rhinoceros, transverse and vertical.
Transparent aperture in the wing of the beetle. antelope.
	Hairs of animals, sections of.

In examining the crystallisations of the *Chromate* and *Protochloride* of *Mercury*, and of the *Sulphuret* of *Bismuth*, I found that they exhibited the hemispherical

* Stearine gives the same polarised halos as oil of mace.

bells already described, in which oblique refraction and the thinness of the film combine to produce beautiful coloured rings, with a black cross.

In other crystals, such as *Muriate* and *Citrate* of *Quinine*, *Codeine*, and *Nitrate* of *Codeine*, I have observed the luminous sectors, and the black cross round the air-bubbles, which are formed after fusion, a phenomenon exactly the same as that which takes place round cavities in diamonds, amber, and other substances.

Having thus described the principal phenomena of circular crystals, I shall now proceed to make a few observations on their formation and decomposition. Circular crystals are abnormal aggregations, which owe their existence to some disturbing cause. The natural tendency of the elementary molecules of the most perfect of them, is to combine with their homologous axes parallel to one another, and to form regular crystals; and it is only when this tendency is counteracted by the quick application of heat or cold, by pressure, or by the nature of the solvent or of the combined ingredients, as in the case of borax and phosphoric acid, that the molecules are constrained to arrange themselves round a centre, not merely in radiating prisms, as in *Wavellite* and some other minerals, but according to laws which could not have been anticipated from any known principles of crystallisation. If, owing to any disturbing cause, two molecules should be deposited with their axes at right angles to each other, or four with their similar poles directed to the same point, this will lead to the formation of a circular disc, which will be of limited thickness, if the crystallisation takes place between two plates of glass pressed together, or to the formation of a spherical crystal, as in the Lithoxanthate of Ammonia, when there is room for its growth in all directions. The disc, or the sphere, might thus increase to a considerable size, if there was only one centre of crystallisation, but as the same causes have been operating all around, the size of the circular crystal is limited by the number of molecules within its sphere, or by its junction with the other discs around it. In this last case, they form a sort of mosaic, in which their shape is not circular, but hexagonal, as in manna, oil of mace, and many other substances.

In the greater number of circular crystallisations, the tints are a minimum at the centre of the disc, and increase outwards,—that is, the molecules form a thinner film at the centre, which increases in thickness towards the circumference; but in other cases the reverse of this takes place, and in the disc represented in Fig. 3, where the tints are those of NEWTON'S rings, some cause, which we cannot even conjecture, must have determined the atoms to unite according to the complex law which connects these tints with the thicknesses at which they are produced. A cause of an opposite kind must have given birth to the disc shewn in Fig. 4, where the molecules form a thick film at the centre, which diminishes in thickness from nine to three as the tint passes from the central *blue* to the *white* at the circumference.

It is equally difficult to assign any reason for the production of the concentric bands of a uniform tint, which suddenly pass to another tint belonging to a different order of colours, and produced by a different thickness of material. A circular ring of *green*, for example, will pass *per saltum*, to a *red* of the next order, from a thickness of 9 to a thickness of 18; and this, according to a law which operates at every point of the circumference of the ring. Nor is this phenomenon less remarkable when the transition takes place in the very lowest order of tints, and at the smallest thickness of the film, as shewn in Figs. 6, 10, and 13, where the tint passes in repeated alternations from the pale *blue* to the beginning of *black*, rising to a *maximum* of *blue*, and again descending to the *minimum* of *black*.

The black rings or circles shewn in Figs. 5, 6, 10, and 13, require to be carefully studied, and with the finest microscopes. In most cases they seem to be spaces devoid of crystalline matter; but they have in general another origin. A line often appears perfectly black, when it corresponds with the *violet* of the *second* order, which separates the *indigo* of the same order from the *red* of the *first* order. Another set of lines appear black, from their being the junction lines of crystals not in perfect optical contact. A third set of black circles are produced by the extreme thinness of the substance, which is not capable of polarising the *very black* of NEWTON'S scale, and the existence of which upon the glass plate can be ascertained only by the highest powers of a fine microscope. But though in all these examples there is no breach of continuity in the circular disc, yet there are cases, as in the double black ring in Fig. 10, where *the corresponding space is devoid of all crystalline matter*. The crystallisation of the disc had been completed at the inner margin of the first black ring, and by some repulsive power the molecules in the solution were kept at a distance from the completed disc, and deposited themselves in a scarcely visible ring around the outer margin of the first black ring. The repulsive power again came into play; and another black ring intervened, the molecules being deposited at the same distance as formerly from the last-formed ring. What repulsive power this is, if it is not electrical, and how it operates, if it is electrical, we cannot even conjecture.

Another remarkable peculiarity in circular crystals is shewn in Figs. 11 and 12, where, as in chromic acid, the disc consists of alternations of dark and luminous circles, equidistant from each other. The dark circles are composed of the acid in particles too small to polarise light, and the luminous ones of separate patches of crystalline matter thick enough to give the *blue* and sometimes the *white* of the first order, and separated from one another by matter too thin to polarise light. In some rare cases, the spaces between the circles and between the patches are, like the black rings formerly described, devoid of crystalline matter. The separation of the patches in this case, is no less remarkable than the separation of the luminous circles. In the Adipocire from Paris, the tint of

the patches sometimes reaches the *yellow* of the first order, and its crystallisation has a very singular appearance.

When the molecules of the same body, or those of different bodies, are combined under the influence of disturbing causes, we may reasonably expect that their union will neither be strong nor permanent. When regular crystals are melted by heat, either alone or along with other bodies, their molecules are forced into positions of unstable equilibrium, and the natural tendency of similar poles to unite is aided by every mechanical vibration, and every variation of temperature to which they are exposed. Different kinds of glass, for example, in which earths, alkalies, and metals may have been combined by fusion, are thus completely decomposed by time, and the elementary particles, liberated from their constrained position, resume their place in crystals regularly formed. The specimens of ancient glass found at Nineveh, and in various parts of Italy and Greece, have undergone the most remarkable decomposition, and some of it converted into a sort of indurated mass, which can be broken between the fingers. The character of these decompositions, and the process by which they are effected, I have had occasion to describe in the *Appendix* to Mr LAYARD'S new work on Nineveh and Babylon.* The same principles operate in the decomposition of circular crystals, and the same phenomena are exhibited in their restoration to their original state.

In circular crystals the decomposition takes place in different ways. In those from borax and phosphoric acid, which I have had occasion to watch month after month for several years, the decomposition generally begins at the centre, which is dissolved, or occupied by a number of minute prisms, with their axes lying in every direction. These prisms sometimes are arranged in a ring round the centre, and I have seen them like a St Andrew's cross. In other crystals, the decomposition goes on in radial lines or streaks, where the optical contact has not been complete; but in the more perfect crystals it takes place in concentric circles, sometimes double, the colours between each pair of circles being different. Numerous cavities are formed,—pieces of the crystal separate, and irregular crystals are often formed in the solution. Decomposition sometimes takes place without solution: the crystal preserves its form, the black circles are granulated, and the colours wholly disappear. In one of the specimens in my possession, every crystal has vanished, and their elements converted into beautiful prisms, united like a bunch of straw tightened at the middle. Between these groups there are numerous flat crystals, of considerable size, and of a perfectly uniform tint. All these decompositions have been the work of several years; and in the course of one year more there will not be found a vestige of the original crystals.

In *Manna* the transformation of the circular into their component crystals

* Discoveries in the Ruins of Nineveh and Babylon. By AUSTEN H. LAYARD, M.P. Appendix, p. 674–676.

goes on more slowly, and in a more singular manner. It commences at the hexagonal junctions of the discs, all of which become *black* by transmitted, but *white* by reflected light. These minute crystals, which are transparent when separate, diffuse themselves around, as if they had fallen in a shower. The same kind of decomposition goes on in radial lines, and a granular decomposition takes place over the coloured sectors, commencing at their centre, obliterating the black cross, and destroying the tints of all orders.

In *Oil of Mace*, the decomposition is effected in a single night. The area of the disc is filled with drops of fluid and atoms of solid matter which have no action upon light, while an opaque ingredient occupies its circular margin.

In *Palmerine* and some other crystals, the film decays in spots, where the tint descends from that of the film to *zero* in concentric circles, while in other spots the tint rises in similar rings, as if the atoms, liberated from one spot, had been deposited in another.

Such are the details respecting the nature, formation, and decomposition of circular crystals, which I wish to submit to the Society. Lengthened as they are, they are but a brief abstract of the numerous observations, which, during the last ten years, I have made on this class of bodies. Their bearing upon unsettled questions in the molecular philosophy cannot be doubted. If it is in the agency of its ordinary laws that we recognise the beauty and harmony of the material universe, it is in the abnormal phenomena which so often perplex us, that Nature discloses her mysteries and reveals her laws.

ST LEONARD'S COLLEGE, ST ANDREWS,
15th March 1853.