IV. *Further Observations on the Optical Phenomena of Crystals.*

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§ 1.

In my former paper on this subject I have described the remarkable circular mode of crystallization which sometimes occurs when borax crystallizes from a solution in phosphoric acid.

I have stated that when examined by the polarizing microscope, a black cross and four sectors of light are seen upon each crystal; and upon that kind which is most easily and frequently obtained, there are seen in addition one or more rings of vivid colour. Some deviations, however, from this usual form occur occasionally; one of which, being extremely beautiful as a microscopic object, deserves a separate mention. This variety of crystalline circles differs from the one first described in the following particulars.

1. The circles are much larger, attaining the diameter of $\frac{1}{10}$th of an inch; whereas those first observed did not exceed $\frac{1}{200}$dth of an inch in diameter.

2. They are flat, whereas the former ones were convex, and frequently I believe of a spherical form.

3. In consequence of which probably, they are seen to exhibit no coloured rings, but only a cross.

4. The cross is brightly coloured, red, green, blue, &c. upon a white ground (the polarizers being supposed to be parallel to each other). This has a beautiful appearance, especially when several circles seen at once have crosses of different colours.

5. When the polarizers are placed at right angles, the phenomenon complementary to the above is seen. For instance, the circle which presented a red cross upon a white ground now presents a black cross upon a green ground.

6. In an intermediate position of the polarizers, the circle just mentioned presents a red cross alternating with a green one, thus dividing the circle into eight sectors of coloured light.

Other circles present other colours, but they all follow the same analogy, and the crosses upon all the crystals are in a parallel position.

7. These crystals last longer than the former ones. I have found some of these retain their structure for two months; the former kind seldom last in perfection more than a day.

8. It sometimes happens that their circumference is imperfect, and presents a

notched or jagged outline. These have a very beautiful appearance, and have been almost universally compared by those who have looked at them to highly coloured flowers with four petals; the cross upon them being so dark as to have the appearance of being a division between the petals.

All the circles, when viewed by common light, appear transparent, white, and very uniform. If they are composed of acicular crystals diverging from a point, these latter must be exceedingly slender and numerous, and in perfect optical contact, since a high magnifying power does not render them separately visible.

§ 2.

With respect to the chemical nature of these crystals, it appears to me evident that they consist of boracic acid. They are obtained by dissolving borax in phosphoric acid; and it may be inferred that this latter substance unites with the alkali and isolates the boracic acid. In order to see if this supposition were correct, I dissolved boracic acid in alcohol, and I found that a drop of this solution evaporated on a plate of glass frequently yielded an abundant crop of the crystalline spherules. But these are generally exceedingly small, requiring a high power to display in them the cross and four sectors of light, and they speedily grow opake; for which reason they are not so well suited for observation as those prepared by the former method. They establish the fact, however, that this mode of crystallizing is a property of the boracic acid. It is highly improbable that it should be peculiar to that substance, but I have not yet met with it in any other.

§ 3. *Explanation of some of the Optical appearances.*

1. When any doubly refracting crystal is examined with the polarizing microscope, (the polarizers being transverse to each other, and the field of view consequently dark,) if it be turned round in one plane, it is seen to grow four times *luminous* and four times *dark* in the course of one revolution. This I have found to be universally the case with all the substances which I have tried, and it also is in accordance with theory.

2. In the case of an acicular crystal, one of the optical axes always coincided with the axis of figure, or length of the crystal; so that if a crystal of this sort appears unilluminated, all the others that are either parallel to it or perpendicular to it are likewise dark.

3. It results from the above that a circle composed of acicular crystals diverging from a point, must present the appearance of a black cross, and that the crosses on all the circles will be parallel.

4. With respect to the rings of colour, they are a consequence of the variable thickness of the crystalline circle at different distances from its centre. Their being visible, and indeed very conspicuous, upon a body of such small diameter, arises from the very energetic action of boracic acid upon polarized light.

§ 4.

I have remarked that the circular crystallization of boracic acid is frequently entirely superseded by other modes of crystalline formation; which circumstance appears to be chiefly owing to the presence or absence of combined water. Some of these variations deserve to be particularly specified.

1. Instead of circles there often occurs a formation of crystals resembling *two opposite sectors of a circle combined.* This form may be traced in different crystals, from its commencement when the angle of the sector is small, through all degrees of increase, until at length the opposite sectors unite and form a complete circle.

2. The crystals are frequently of a very irregular elongated shape, which does not approximate either to a prismatic or a cylindrical form. This stem, as it may be termed, subdivides itself *at both extremities* into an immense multitude of diverging fibres, giving it the appearance of a bundle of elastic filaments firmly held together in the central part, but with its extremities left at liberty to diverge*.

3. Another variety resembles in the same way irregular stems or branches, which, however, instead of being subdivided, are abruptly truncated at both extremities perpendicularly to the general line of their direction.

4. Sometimes, on the contrary, the ramification is much more developed, and then resembles two plumes united by a common stem.

5. Crystals of regular geometric form. These appear to require the presence of combined water.

Whichever of these formations occurs, it is for the most part seen in all the crystals at once, to the exclusion of any of the other forms.

§ 5.

These crystals generally undergo a spontaneous change in the course of one or two days after they have been formed. Those (No. 4) resembling plumes usually break up and resolve themselves into small rhombs and other geometric forms. The elongated crystals (Nos. 2, 3) undergo a remarkable change. They become traversed with innumerable fissures transverse to their length, and thus break up into thin plates, which either cohere loosely or separate entirely.

§ 6.

All these forms are very pleasing objects for the polarizing microscope. This arises from the very high depolarizing power of boracic acid, which enables its thinnest plates to exhibit colours of great variety and brilliancy, and causes even its dust or smallest particles to appear luminous. The more energetically any substance acts upon polarized light, the closer and more crowded are the bands and lines of

* This appearance is not very uncommon in the crystallization of other substances, though I believe it has not yet been described. The divergence of the filaments suggests the idea of electrical repulsion as being at least its primary cause.

colour which appear upon its crystals. These isochromatic lines, of which there are frequently many alternations, denote lines of equal thickness in the crystal. In the case of boracic acid, when anhydrous or nearly so, these lines are more crowded than in any other crystal that I have yet examined, insomuch that to exhibit them distinctly is as fine a test of the performance of a microscope as to resolve the more difficult lines on the scales of a butterfly's wing, or any other of the known test-objects. And in many cases the microscope only indicates the existence of a still more delicate structure, which, at least in its present state, it has not power distinctly to exhibit.

§ 7. *On Analytic Crystals.*

I now come to describe a property of crystals which I met with while employed in pursuing the above investigation. This is the power which certain crystals have of analysing polarized light in a manner analogous to the tourmaline; for which reason I shall propose for them the name of *Analytic Crystals.*

If I am not mistaken, this property has been hitherto confined to the tourmaline and a few other natural minerals; and it has not been known that their effects could be imitated, much less surpassed, by crystals artificially made. I trust, therefore, that it will be of some interest to describe a method of procuring such crystals.

In the following experiments it will be understood that the *analysing plate* of the microscope (or the polarizer next the eye) is removed.

1. A good example of this kind of crystal is obtained by dissolving the sulphate of chromium and potash in tartaric acid by the aid of heat. A drop of this solution placed on a plate of glass soon yields by evaporation filmy crystals, which very frequently have the characteristic property of tourmaline: that is to say, that if polarized light is transmitted through them, in one position they suffer it to pass freely, but if they are turned round 90°, they arrest and absorb it entirely.

When the experiment has been successfully conducted, the crystals will not in this position allow the smallest portion of light to pass.

If now we consider the extreme thinness of these crystalline films, it will appear how energetic must be their action upon light: since although white and transparent, they are able to produce an absorption equalling that of the best tourmalines, notwithstanding that the effect of the latter is aided by their natural dark colour.

But if these crystals are analogous to the tourmaline, they must have the power which that substance has of analysing the light that has been transmitted through other crystals.

Accordingly, if we place in the path of the polarized ray a plate of sulphate of lime of a proper thickness, the crystal, which before absorbed the light and appeared black, becomes splendidly coloured with that colour which the sulphate of lime produces, and which a tourmaline would show if it were employed as an analysing plate.

On reversing the polarization of the ray (or turning round the crystal), the complementary tint appears. The same results occur if the crystal is employed in the first place to polarize the light, and tourmaline or calcareous spar is used to analyse it: so that the analogy or rather identity of effect with the tourmaline is complete.

I will now mention some other crystals which possess the analysing property, but not in such a high degree.

2. *Boracic acid.*—If dissolved in boiling water, it yields in cooling irregular crystals which have considerable analytic power. A crystal which in one position is so translucent as to be hardly distinguishable from the water in which it floats, is in the transverse position very strongly defined. It does not become dark all over, but *only in its outline.*

If now we employ it to analyse the tints of sulphate of lime, its *outline* becomes beautifully coloured. Nothing can exceed the delicacy of colouring which a number of these crystals exhibit when viewed together: those which lie in one direction appearing, for instance, *green*; those in a transverse direction *red.* The appearance is very unlike any other optical phenomenon that I know of, in consequence of two colours being seen in strong contrast, and without any intermediate tints; and also from the *outline* only of the objects being coloured, while their interior remains without colour. It is only when the crystals have a fibrous or striated structure that the tint extends over all their surface.

The boracic acid has the same analytic property and precisely the same appearance when it crystallizes from a solution of borax in phosphoric acid. The plumose crystals of it (No. 4. *suprà*) are very delicately coloured with the two opposite tints.

I obtained a very beautiful result by placing a drop of phosphoric acid upon a group of circular crystals. This caused a fresh deposition of boracic acid upon them as nuclei, which assumed the form of very delicate cilia, spreading in all directions as from a centre. These fringed circles showed the analytic property in an admirable manner, exhibiting four quadrants coloured alternately with complementary colours of great vivacity.

3. Another instance which is worthy of mention is the *oxalate af potash and chromium*, a salt whose optical properties have been investigated by Sir DAVID BREWSTER*. If some gum arabic is added to a solution of this salt, and a drop of it put between two plates of glass, it abandons its usual mode of crystallization for another, which resembles a microscopic vegetation composed of minute prisms growing one out of another, and variously arranged in sprigs and branchlets; while in other places it assumes an undulating capillary form, much resembling in miniature the tufts or locks of a species of *conferva* which is seen growing in pools of water or in the sea. Now these objects are possessed of a high analytic power, insomuch that when a plate of sulphate of lime is placed beneath them they assume a colour of great intensity and splendour, which is changed for the complementary tint when the polarization of the incident ray is reversed.

4. *Nitre.*—If nitre and gum arabic are dissolved together in hot water, a drop of

* Philosophical Transactions for 1835, p. 91.

the solution put on a glass plate yields very good analytic crystals. These have a branched or plumose appearance, and assume beautiful colours in polarized light when a plate of sulphate of lime is placed beneath them. The microscope shows the colour to reside principally in the outline, but to the naked eye the whole film appears coloured. As these films may be obtained of large size, the phenomenon can be well seen by the unassisted eye.

A very interesting experiment, and one which throws much light upon the cause of these appearances, is to transmit a beam of polarized light *very obliquely* through a small prism of nitre immersed in gum, and viewed with the microscope. Its outline then generally exhibits two colours instead of one: for while the edge of the prism which is on that side from whence the ray of light comes is, for instance, of a red colour, the opposite edge will appear green. Reverse the polarization of the light, and these colours are exchanged one for the other. This observation enables us to explain the origin of the phenomenon in a satisfactory manner, and to show why it only occurs in crystals possessing strong double refraction, like nitre, in which the refractive indices of the two rays are materially different.

When a ray of common light is incident upon such a crystal, and therefore divides itself into two rays oppositely polarized, both rays are transmitted through the central parts of the crystal, which are bounded by parallel planes, or by planes approaching to parallelism. But when the bounding planes of the crystal are much inclined to each other, and therefore refract the light in the manner of a prism, the refractive indices of the rays may differ so much, that while one of them passes freely through such a prism, the other cannot pass at all, but suffers total internal reflexion, and is thereby dispersed; just as if the prism had a larger refracting angle with respect to that ray than to the other. Therefore if two oppositely polarized rays are presented successively to such a crystal, as in our experiment, one of them will be transmitted, and the other not. That this is the true explanation appears from this, that when the oblique planes are well formed and clearly defined by the microscope, the colour also is accurately limited by the same boundary: so that while this part analyses the tints of a plate of sulphate of lime, the rest of the crystal is inactive.

It may be inferred by analogy, that the same cause produces the analysing power of striated or fibrous surfaces, and of those in which the striæ are too minute to be discernible (as in No. 1. *suprà*, page 32): for it is not the property of all crystals with striated surfaces to have the analytic power, but only of such as are doubly refractive in a high degree.

I have said that the capillary crystals (No. 3.) possess the analytic property, although their diameter is often evanescent even with a microscope. An important inference may be drawn from this, viz. that a ray of light, *immediately* on entering one of these crystals, subdivides itself into two rays of different refractive indices, or at least that the thickness of crystal which is requisite to produce this effect is insensible to observation.

When nitre is made to crystallize in gum, it often shoots into prismatic crystals, which are very interesting objects, the more so, that they are of a permanent nature, and not liable to spontaneous change. When examined by polarized light, these prisms, in one position of their axis, frequently disappear completely. This arises from the refractive power of the gum being equal to that of one of the two rays in the crystal. Reverse the polarization of the ray, and the crystal appears, as it were, to start into existence, acquiring great strength and blackness of outline, and, not unfrequently, entire opacity. Again, when the sulphate of lime is interposed, this opacity disappears, and the crystal becomes brightly coloured.

Since it is probable that many better methods may be found of obtaining this kind of crystals than have hitherto presented themselves, I have hopes that it will be possible to obtain large and permanent artificial crystals, which may possess the advantages of the tourmaline without the inconvenience resulting from its dark colour.