Additional Note on the Lamellar Structure of Quartz-Crystals, and the methods by which it is developed.

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IN a former communication to this Society,[1] I have demonstrated that quartz must now be added to the long list of minerals in which a lamellar structure can be set up by mechanical stresses. In that paper, a crystal of smoky quartz was described in which well marked lamellæ could be detected; the relations of these lamellæ to the parts of the crystal which had suffered mechanical deformation and crushing are such as to leave no possibility of doubt that the lamellar structure is not an original but a secondary one; while it is equally clear that the structure has been developed by the action of mechanical forces upon the crystal.

The manner in which these lamellæ in quartz terminate abruptly at accidental cracks or die out gradually, precisely resembles in fact what may be observed in the case of the twin-lamellæ of calcite, leucite, felspar, and many other minerals: and in all of these cases we can prove, by several different methods, that the structures in question have been developed subsequently to the formation of the crystals.

The position and relations of the lamellæ in the quartz-crystals in question were demonstrated by two different methods:—that of Des Cloizeaux, which consists in examining thick plates (cut equatorially from the crystal) in polarised light: and that of Leydolt, which is based on the study of faces and cut surfaces of the crystals that have been etched with hydrofluoric acid. In the case of some of the wider lamellæ, it was proved, by the use of convergent polarised light, that the alternate bands exercise opposite rotatory effects on the plane of polarisation, and that by the overlapping of the right- and left-handed quartz, Airy's spirals are formed. The "gliding-planes" of quartz were shown to be parallel to R (100) and $-R$ ($\bar{1}22$).

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[1] *Mineralogical Magazine*, Vol. VIII. (1888), pp. 1-8.

Although, as stated in my paper in 1888, an attempt was made to force quartz-crystals to yield along their gliding planes, firstly by alternately heating and cooling them, and secondly by crushing them in vices, yet neither of these methods afforded any very definite results. Quite recently, however, my attention has been called by Mr. F. H. Butler to some results accidentally obtained by him, which, because of their bearing upon this interesting question, I think are worthy of being described and discussed before this Society.

Mr. Butler, to whom I must acknowledge myself as indebted for much valuable assistance and information in connection with this investigation, has designed and employed a very powerful machine for breaking minerals and rocks in definite directions. It consists of two sharp steel-jaws which are capable of being moved in the same horizontal plane by means of a screw; a pressure amounting to many tons can thus be applied to a specimen, and under the powerful stresses set up in its midst the mass is eventually torn asunder.

In order to explain the phenomena detected by Mr. Butler in some of the quartz-crystals which he had crushed in his machine, I must call attention to the striking peculiarity in fracture, noticed long ago by Brewster, in quartz-crystals possessing a lamellar structure. As far back as 1819, Brewster pointed out that "the fracture across the veined portions" (of quartz-crystals) "exhibits a beautiful and sometimes a regular rippled structure, not unlike the engine-turning on the back of ornamental watches. This rippled structure is an infallible proof that the specimen is amethyst, whether it is *yellow*, *orange*, *olive-green*, *lilac*, or perfectly *colourless*."[1] Brewster, in short, proposed to separate the quartzes with lamellar structure from those without any such structure, and to call the former "amethyst"; and he suggested that in the "rippled fracture" we have a ready means of distinguishing "amethysts," whatever their colour, from common quartz. This proposal to separate amethyst from quartz as a distinct mineral species has not, it is scarcely necessary to say, been accepted by most mineralogists.

When the "rippled" fracture-surface of a laminated quartz ("amethyst") is carefully studied, the cause of the peculiarities which it exhibits becomes perfectly obvious. The different lamellæ yield in different ways to the force employed in producing the fracture, and the ordinary lines of the conchoidal fracture, which are often barely visible in the alternating lamellæ themselves, become frequently very strongly pro-

[1] *Trans. Roy. Soc. Edinb.* Vol. IX. p. 149.

nounced along the lines where the lamellæ meet. This appearance can be equally well seen in incipient fractures, and in those in which actual separation of the parts has taken place, and in it we find a striking proof of the want of homogeneity in the crystal. The fracture, in fact, affords us just the same kind of evidence concerning the differences in molecular structure in the alternating lamellæ, as is supplied by the etching of faces or cut surfaces of the crystal, with hydrofluoric acid.

The first specimen which I received from Mr. Butler exhibiting noteworthy peculiarities of fracture, was a quartz-crystal from Brazil about 60 millimetres in diameter, and very free from included cavities or foreign minerals. I satisfied myself by repeated trials that, when fractured by a blow from a hammer, this quartz-crystal shows no tendency to exhibit the peculiar rippled surfaces, and it has therefore no claim to be regarded as a "white amethyst." But I found that when crushed in the powerful vice and broken across a plane which traversed the crystal in a nearly equatorial direction, the surfaces of fracture exhibit the "engine-turned" appearance in a much more pronounced manner than any natural "amethyst" which I had ever seen. Mr. Butler has since shown me other Brazilian quartzes exhibiting the same peculiarities in a very striking manner.

A second series of very interesting specimens was obtained by Mr. Butler during the breaking up of a great mass of quartz, consisting of interpenetrant crystals, which, it is believed, came from Madagascar. The quartz in question presents many very interesting features. It is remarkably full of cavities of various sizes, which all contain a liquid with moveable bubble. The most noticeable feature about these cavities is that, while some of them are of very irregular form, the great majority are clearly *negative crystals* differing greatly in the development of their several faces, but all arranged with their axes parallel to those of the enclosing positive crystal. As the liquids in these cavities can be heated far above the critical temperature of carbon dioxide without undergoing appreciable change, it is probable that they are aqueous solutions. Besides the liquid-cavities, this quartz contains acicular crystals of blue tourmaline (indicolite), sometimes forming matted tufts; and in addition we find hexagonal plates, often 6 to 8 millimetres across, of a muscovite with tolerably wide separation of the optic axes. These muscovite crystals appear to be confined to the outer part of the quartz-crystals, which by the symmetrical disposition of their foreign inclusions thus come to exhibit a markedly zoned structure.

Now, as in the case of the Brazilian quartzes, I satisfied myself that fractures of the Madagascar specimens made in the ordinary way show no trace of the "rippled" surfaces. Nevertheless the specimens broken in the powerful vice exhibited, when the plane of separation was along a nearly equatorial direction, remarkable examples of the "engine-turned" surfaces referred to by Brewster, the appearances being even more strongly pronounced than in the case of the Brazilian specimens.

By the kindness of Mr. Butler, I have been enabled to witness the actual operations by which these peculiar fractures are produced. It has already been remarked that the "rippled" surfaces arise when the quartz-crystals are placed in such a position in the machine that fracture takes place nearly at right angles to the principal axis of the crystal. It was found, in fact, that when crystals are placed so that the plane passing through the two steel jaws of the machine coincides with an equatorial plane of the crystal, "rippled" surfaces of fracture could nearly always be obtained. As strong pressure is applied, a series of crackling sounds is heard, and then, after the grip has been maintained for some seconds, the mass gives way, often with a loud report. It is evident that before the actual rupture occurs a number of violent strains are set up within the mass, and that under the influence of these strains it finally yields.

A study of the fractured surfaces revealed the following results:—The ridges and furrows are very much more prominent than those seen in fractured "amethysts," the height from the bottom of a furrow to the top of a ridge being sometimes as much as 0·5 millimetre, though usually it is much less than this. The width of the ridges and furrows is very varied, occasionally reaching as much as 1 millimetre, but being usually from 0·2 to 0·5 millimetre, and sometimes much less. Usually two sets of ridges and furrows can be traced, mutually intersecting and thus giving an appearance exactly resembling "cross ripple-marks" or "engine-turned" surfaces.

In some cases a fortunate fracture nearly parallel to the principal axis of the crystal enables us to study the direction in which the lamellæ (whose existence is revealed by the fracture) intersect the equatorial plane. In these cases we see a "rippled" surface, quite similar to those of "amethyst," gradually dying out at distances varying from 2 to 20 millimetres from the equatorial fractures, which are so strongly marked by ridges and furrows. These ripplings seen on vertical fractures traversing the crystal, taken in conjunction with those which are exposed in the horizontal fractures, with which they are evidently continuous, enable us to determine that the planes which they follow are really those of R (100) and $-R$ ($\bar{1}22$).

When the ridges and furrows exposed on the fracture at right angles to the principal axis are carefully studied, two very striking circumstances are impressed on the mind of the observer. In the first place it is manifest that the two sets of lamellæ are sometimes accurately parallel to the rhombohedral faces of the crystal. But in the second place it is equally clear that these lamellæ are very often deflected from their proper directions, that they assume curved and twisted forms, that they not unfrequently become merged in the ordinary lines of the conchoidal fracture, and sometimes die out in an apparently capricious manner.

The curvature, distortion and abrupt dying out of the twin-lamellæ of calcite, plagioclase-felspar and other minerals is a phenomenon very familiar to mineralogists, and especially to petrologists. But in quartz-crystals it can easily be shown that this disturbance of the lamellæ from their normal positions is often carried to an extreme.

This remarkable phenomenon is admirably illustrated by the section of a very beautiful "amethyst," which I owe to the kindness of Professor A. H. Church, F.R.S. The section is believed by Professor Church to have been one of those originally in the possession of Sir David Brewster, and it admirably exemplifies what that investigator regarded as "the most general structure of well crystallised amethyst.[1]" There is also a close agreement between this amethyst and the one so carefully investigated by Böklen[2] in 1883.

The section to be described is about 2·5 millimetres thick, and in ordinary light exhibits the lamellar structure in certain parts, by the distribution of the colouring matter, the limits between the lamellæ being marked with faint purple lines. The width of the lamellæ seldom exceeds 0·3 millimetre, and is often much less. In plane polarised light the lamellar structure becomes very distinctly apparent, the alternate bands appearing in violet and yellow tints, and the lines separating them being nearly black, as described by Brewster. These characters remain constant when the section is rotated between the crossed nicols, but, when one of the nicols is rotated, the colours of the lamellæ change alternately to the complementary tints.

By the kindness of my colleague, Professor A. W. Rücker, F.R.S., I have been able to place this section (which is about 50 millimetres in diameter) between the large nicol prisms which the late Mr. Spottiswoode presented to the Physical Laboratory of the Royal College of Science.

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[1] *Trans. Roy. Soc Edinb.* Vol. IX, pp. 146-152, Pl. X. f. 12.

[2] *Neues Jahrb. für. Min. &c.* 1883, Vol. I. pp. 62-73, Pl. V.

An image of the whole section could thus be thrown on a screen, showing the distribution of the lamellæ in the minutest detail. Mr. R. Chapman has obtained for me very beautiful silver-print photographs of this image, the best results being obtained when mono-chromatic (green) light is employed. From the negatives thus obtained Messrs. Waterlow have succeeded in producing a block for printing by their half-tint process. This, though far inferior in the reproduction of minute detail to the silver prints, will serve to illustrate the position and relations of the lamellæ in this very interesting quartz-crystal (see Plate IV.). Referring to the key-plate (Plate III.) it will be easy to identify the structures referred to in the following description.

From the centre of the crystal (O) there radiate three bands of a pale yellow tint, at angles of 120°. At distances of 7, 18, and 16 millimetres from the centre of the crystal, these bands expand into sectors, (x, y, z) with an angle of almost exactly 60° and having the same pale yellow tint. Now, although the largest of these sectors (x) is clearly double, and consists of right- and left-handed quartz which are superposed along the line x_3 giving Airy's spirals, the whole of those portions of the crystal which have a pale yellow tint show no trace whatever of lamellar structure. The remainder of the crystal, however, which has the usual purple tint of amethysts, exhibits the lamellar structure in a most striking manner. The sectors AOB, BOC, and COA are seen to be perfectly distinguishable, the lamellæ in one sector meeting the neutral bands in the adjoining sector, when the section is viewed by polarised light. All these appearances have been admirably described by Brewster and Böklen; but what is particularly noticeable in this crystal is the amount of disturbance in the *position* of the lamellæ in the exterior portions of the crystal. In the centre of the crystal there is the most perfect regularity and symmetry; but, as we pass outwards, curved and rippled forms make their appearance, till at the outer limits of the crystal the whole of the lamellæ break up into a multitude of twisted and interrupted bands. Still more striking is the circumstance that when the lamellæ meet the three yellow sectors x, y, z, they can be seen to be deflected from their former course by an angle of about 30°.

While the yellow portions (x, y, z) of the crystal exhibit the ordinary circular polarisation of quartz, the purple portions AOB, BOC, COA, which are traversed by these fine lamellæ, exhibit *no trace of such circular polarisation* when studied in convergent polarised light. In the central parts of the crystal, where the symmetrical disposition of the lamellæ is preserved, the quartz behaves like an ordinary *uniaxial crystal*, showing the usual rings and black cross, while in the outer portions, where the position of the lamellæ is interfered with, we find the rings and hyperbola of a *biaxial crystal*, aud often of one with a considerable separation of the optic axes. Where the lamellæ are much broken up and interfered with, we often find that the interference figures exhibit curious irregularities and much distortion.

Now it is impossible not to recognise in the position of the lamellæ of this quartz-crystal a close analogy with the curious rippled fracture ("engine-turning") of the crushed quartzes already described. In both alike we see the tendency of the lamellæ to lose their regular and symmetrical arrangement, and to become curved, twisted and interrupted in a very remarkable manner. Nor is there any difficulty in understanding how the difference in molecular structure of the alternating lamellæ, which makes itself apparent in equatorial sections when etched with hydrofluoric acid, also gives rise to the curious differences in fracture.

The distribution of colour in the remarkable amethyst we are describing is another and very suggestive indication of the peculiarities of molecular structure in different parts of the crystal. Among the numerous very interesting observations made upon amethyst by Brewster, none is more remarkable than that on the effects of heat on these quartzes with lamellar structure. Brewster showed that the purple colour of the amethyst can be removed by heating it, "but when the colour is removed by heat, neither the veins nor their optical actions suffer any change."[1]

It is thus seen that there is no necessary connection between the lamellar structure and the distribution of colour, though the latter has been clearly determined by the former. That slight changes in the state of oxidation of the iron and manganese, which appear to be present in very minute quantities in these amethysts, give rise to the yellow and purple tints, is almost certain. The way in which such changes take place in mixtures of silicates through the action of changes of temperature or even in consequence of passage of light through them, is well known from experiments on topazes and other minerals, and also on artificial silicates like window-glass. That these chemical changes should be determined and controlled by the molecular structure of the crystals, is in perfect accordance with what we know from the study of the etched surfaces, weathered faces, and "solution-planes" of crystals. It is perfectly conceivable, and indeed there are not wanting facts to support the suggestion, that the distribution of colour in these amethysts has been

[1] *Loc. cit.* p. 143,

brought about subsequently both to the growth of the crystal and the development of the lamellar structure in certain parts of it.

There is one curious and seemingly anomalous circumstance which comes into prominence when these artificially fractured quartzes are compared with the so-called amethysts with natural "rippled" fracture. It has already been pointed out that in the fractured surfaces the ridges and furrows of the crushed crystals are much more pronounced than in the natural "amethysts." If the peculiar fracture in both cases be due to the existence of a lamellar structure in the crystals, it might be expected that this structure, as exhibited in polarised light, would be more marked in the crushed crystals than in the natural "amethysts." But this is certainly not the case. When a section is made from one of the crushed quartzes, immediately below the rippled surface of fracture, the lamellar structure can be faintly detected, but is far less distinct than in sections of the same thickness cut from many natural amethysts.

The following considerations will, I think, afford a satisfactory explanation of this apparent anomaly. When by Baumhauer's method, a knife-blade has been introduced into a cleavage-rhomb of calcite, so as to develop the lamellar structure parallel to $-\frac{1}{2}R(110)$, it is possible to push back the parts of the crystal over the "gliding-planes," and thus to restore the crystal to its original condition, as is seen if we examine it by polarised light. In the same way, crystals of leucite, tridymite, boracite, and other minerals lose their lamellar structure when heated to certain temperatures; the portions of the crystal appearing to move over the gliding-planes, so as to restore the original optical characters of the mass. It is perfectly possible to conceive the lamellar structure being developed in part of a crystal of quartz, in consequence of the mechanical stresses to which it has been subjected, but the natural elasticity of the quartz causing the mass to return to its normal state when the condition of strain is removed. In the case of the crystal of smoky quartz which I described on a previous occasion, the stress which produced the lamellar structure was probably applied very gradually, and was long continued; consequently we are not surprised to find its effects permanent. In the case of the artificially crushed crystals, the stress, though so intense as to lead to a more marked disturbance of the molecules, which endured during the period before rupture and determined the nature of the fracture, was maintained only for a few seconds, and when the mass was relieved by the occurrence of the rupture, the molecules might return almost to their original position. It is quite in conformity with many other observations on the comparative effects of such stresses to find that when long continued they produce permanent results, while when they are short and sudden their consequences are only of a temporary character.

If we carefully study the section of amethyst-quartz which I have been describing (see Plate IV. and the key Plate III.), we shall see that it is built up of two modifications of quartz, each possessing its own distinctive properties. We may assume that the quartz-crystal began to grow by the formation of the nucleus O, and that a skeleton crystal was formed by the extension of three plates radiating from it at angles of 120°. This nucleus and the plates radiating from it are composed of quartz, which has now assumed a yellow tint and shows no tendency to acquire a lamellar structure. Between these radiating plates, however, the other modification of quartz was developed, a form of quartz which shows the most marked tendency to acquire a lamellar structure, and is now of a purple tint, the colour being most intense along the bands separating the lamellæ. At a certain point, one of the radiating plates of the skeleton crystal showed a tendency to expand and form the wedge-shaped mass x, which almost immediately divided, along a nearly vertical plane, into the portions x and x_2, the former being right-handed and the latter left-handed in its circular polarisation; at a somewhat later stage in the development of the crystal the plate oz expanded into a wedge z of right-handed quartz and the plate oy into the wedge y of left-handed quartz—none of these portions showing any tendency to the development of a lamellar structure. The plane which separates x from x_2 is evidently not absolutely at right angles to the equatorial plane, and thus we get an overlapping of right-handed on left-handed quartz giving rise to Airy's spiral along the band x^3.

Let us now turn our attention to the sectors which lie between the plates and wedges of yellow, non-lamellar quartz. These are composed of quartz which is now of a purple tint and exhibits the most striking tendency to assume the lamellar structure. It is evident, from the way in which the lamellæ meet one another, that the purple quartz really forms the three sectors AOB, BOC, COA, each of which is divided into two portions by the radiating plates that eventually expand into wedges. Now, in the central parts of the crystal, the most beautiful regularity and symmetry is maintained in the disposition of the lamellæ, but as we proceed outwards perturbations and minute ripplings begin to make their appearance, and these increase in number and complexity as we approach the edge of the section. What is most remarkable, however, is the fact that the lamellæ which were parallel to the yellow plates, are at once deflected from their normal position when the latter expand into wedges—the amount of the deflection reaching in some cases 30°. All of these phenomena can be clearly followed in the photograph of which Plate IV. is a reproduction and in the key Plate III.

A question which naturally suggests itself when we study this interesting crystal is that of the period at which the lamellar structure was developed in what is now the purple quartz. Are we to regard the lamellæ as arising in the quartz at the time of its deposition, or have they been developed long subsequently to the formation of the crystal? Although most of the accidental cracks which traverse the crystal, and are well seen in the photograph, are clearly of later date than the development of the lamellar structure, there are one or two which seem to me to have influenced the position and arrest of the lamellæ. If this be the case it affords a clear proof that, as in calcite, felspar and other minerals, the lamellæ of this amethyst have been developed subsequently to the formation of the crystal.

It is conceivable that the remarkable disturbance in the position of the lamellæ of this quartz-crystal originated during the growth of the crystal, when the quartz, which is now of a purple tint, was confined between the growing wedges of the quartz, now exhibiting a yellow tint. It is, however, equally possible that in consequence of the expansion and contraction of the whole mass and of stresses produced by external forces on the crystal long after its complete growth, the lamellæ were forced from their normal position and came to acquire their irregular distribution. I believe the balance of probability, considering what has been proved in analogous cases, is in favour of the latter view.

I cannot help thinking that the development of the purple tint, its concentration in the neutral bands between the lamellæ, and the acquirement by the three plates and wedges of their yellow tint, must be regarded as due to actions going on after both the growth of the crystal and the development of the lamellar structure in certain parts of it.

It is, I believe, impossible to maintain with Brewster that the laminated quartzes (amethysts) constitute a distinct group, as distinguished from quartzes without lamellar structure. The observations of DesCloizeaux and many other mineralogists prove that many quartz-crystals include portions in which a lamellar structure is developed. But the study of forms, like that described in this paper, point to the conclusion that there is a curious kind of dimorphism in the mineral. There is a variety of quartz, which we may designate as *stable* quartz, which may be right-handed or left-handed in its circular polarisation, but shows no tendency to assume the lamellar structure. On the other hand, there is another type of quartz, which we may call *unstable* quartz, in which mechanical stresses at once develop a lamellar structure. Both of these varieties may be, and in many cases certainly are, included in the same crystal, the relations of the portions of the crystal composed of either type being very variable, but always apparently governed by the symmetry of the crystal. Both of these varieties may be perfectly colourless, but, when coloured, the stable quartz tends to assume yellow tints and the unstable quartz to acquire a purple colour. Further than this, it may be noticed that the purple colouring matter tends to be concentrated in the bands separating the alternating lamellæ of right- and left-handed quartz.

When the lamellæ of right- and left-handed quartz are of sufficient breadth, then overlapping gives rise to Airy's spirals in convergent polarised light; but when, as in the example before us, the lamellæ are very narrow, the circular polarisation is entirely neutralised and quartz behaves in convergent polarised light like an ordinary uniaxial mineral; where, however, as in the outer part of the crystal described, the lamellæ are much disturbed and distorted, the quartz assume the characters of a biaxial mineral, the interference figures in some cases showing very singular anomalies.

The interesting researches of Des Cloizeaux[1] Tschermak,[2] Melville, and Lindgren,[3] have shown that cinnabar crystals are sometimes built up of alternating lamellæ of right- and left-handed material, and in this mineral we appear to have a remarkably parallel series of phenomena to those which we have been discussing in the case of quartz. We do not propose to enter upon the interesting theoretical questions raised by Mallard and Wyrouboff as to the dependence of the circular polarisation in such crystals on the existence of binary and ternary arrangements of biaxial plates of ultramicroscopical dimensions.

Summary of Conclusions.

1. There appears to be a curious kind of *dimorphism* presented by quartz—in virtue of which the two forms of the substance exhibit very different properties in relation to their behaviour when subjected to mechanical stresses.

2. One of those forms of quartz, which we have designated *stable*

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[1] *Comptes Rendus*, Vol. XLIV. p. 876.

[2] *Min. u. Petrog. Mitth.* Vol. VII. 1886, pp. 361-2.

[3] *Bulletin of the U. S. Geol. Surv.* No. 61, 1890.

quartz, shows no tendency to assume a lamellar structure. This stable quartz may be either right-handed or left-handed in its circular polarisation; it is often quite colourless, but when coloured shows a tendency to assume yellow tints.

3. The other form of quartz, which we distinguish as *unstable quartz*, constantly shows a tendency to have a lamellar structure developed in it. The lamellæ, which in their thickness vary between wide limits, are composed of right- and left-handed quartz, arranged alternately. The unstable quartz, though often colourless, shows a great tendency to assume the purple tints of amethyst.

4. The difference in the molecular structure of these two forms of quartz may be demonstrated in three different ways :—

(*a*) When thick sections, cut equatorially, are examined between crossed nicols, the alternate bands of the lamellar quartz polarise in pale grey tints ; or in some cases in complementary tints of a low order in Newton's scale ; the boundaries between the lamellæ sometimes appear nearly black.

(*b*) When faces or cut sections of quartz crystals are etched with hydrofluoric acid, the forms and distribution of the etching figures afford a ready means of distinguishing between the lamellar and non-lamellar quartz.

(*c*) When the crystals are broken, a curious rippling of the surfaces of fracture is very characteristic of the lamellar quartz, and when two sets of crossing lamellæ are present, a very striking appearance, similar to the "engine-turning" of watches, is exhibited.

5. The lamellæ of quartz are normally parallel to R (100) and $-R$ (122). Though sometimes very symmetrical in their position and constant in their direction, they at other times display a great tendency to be diverted from their normal positions, being deflected through angles of 30° or upwards, and not unfrequently bent into curves or twisted to an extraordinary extent. The dependence of these perturbations in the position of the lamellæ on the mechanical forces to which the crystals have been subjected is sufficiently obvious.

6. When the lamellæ are of sufficient width they give rise, by their overlapping, to the phenomenon of Airy's spirals, when viewed in convergent polarised light. But when the lamellæ are very thin, the result is that the circular polarisation of the quartz is completely neutralised. In such cases quartz is found to behave like an ordinary uniaxial mineral without circular polarisation. When the fine lamellæ are greatly bent and disturbed we find that the quartz crystals give the interference-figures

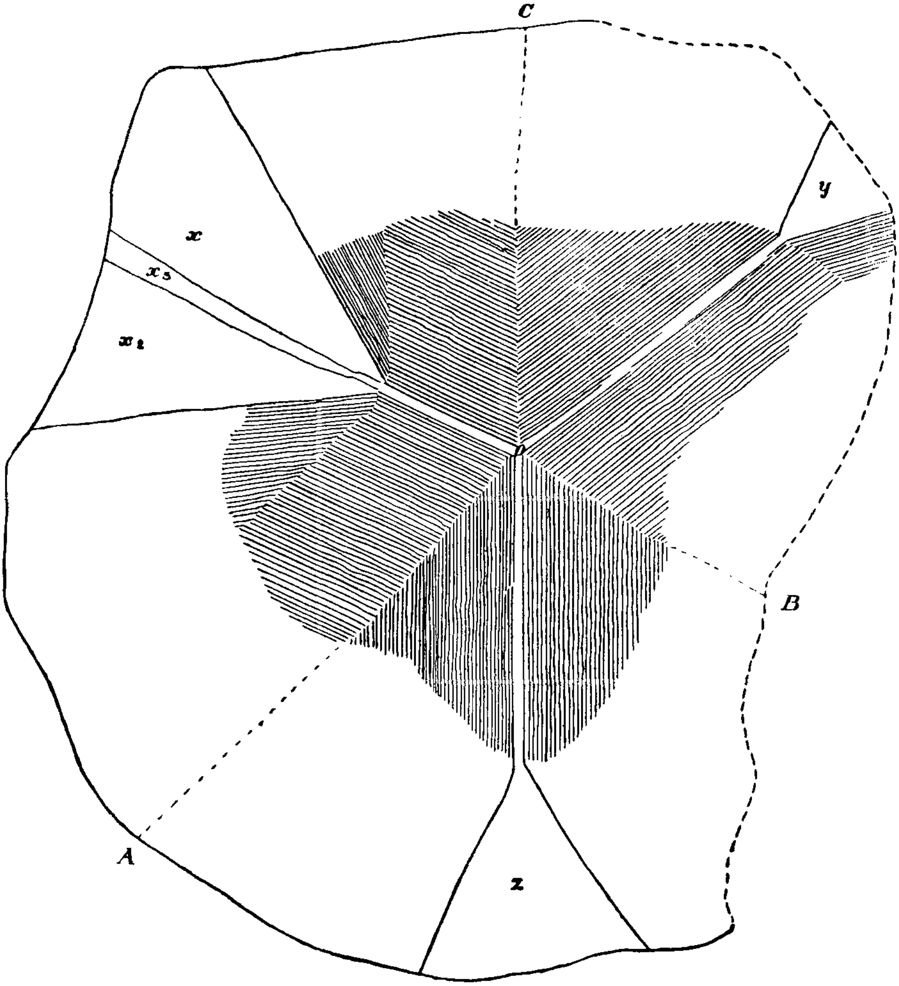
of a biaxial substance; and where excessive changes in the position of the lamellæ have occurred, very abnormal and unsymmetrical interference figures result.

7. Many quartz crystals are composed of portions of stable quartz combined with unstable quartz. The proportions and relative positions of these two forms of quartz in the crystals vary greatly in different cases, but always show some relation to the symmetry of the crystal.

8. When quartz crystals, composed wholly or in part of unstable quartz, are subjected to great mechanical stresses, the lamellar structure is induced in their mass; under the influence of this molecular disturbance the fractures often show very marked ridges and furrows and sometimes the complicated appearance of "engine-turning." The relief of the stresses by fracture, however, permits of the almost complete recovery of the crystal from the molecular disturbance, under the influence of which the fracture took place; and optical tests show only a slight residual trace of the effects produced by the pressure.

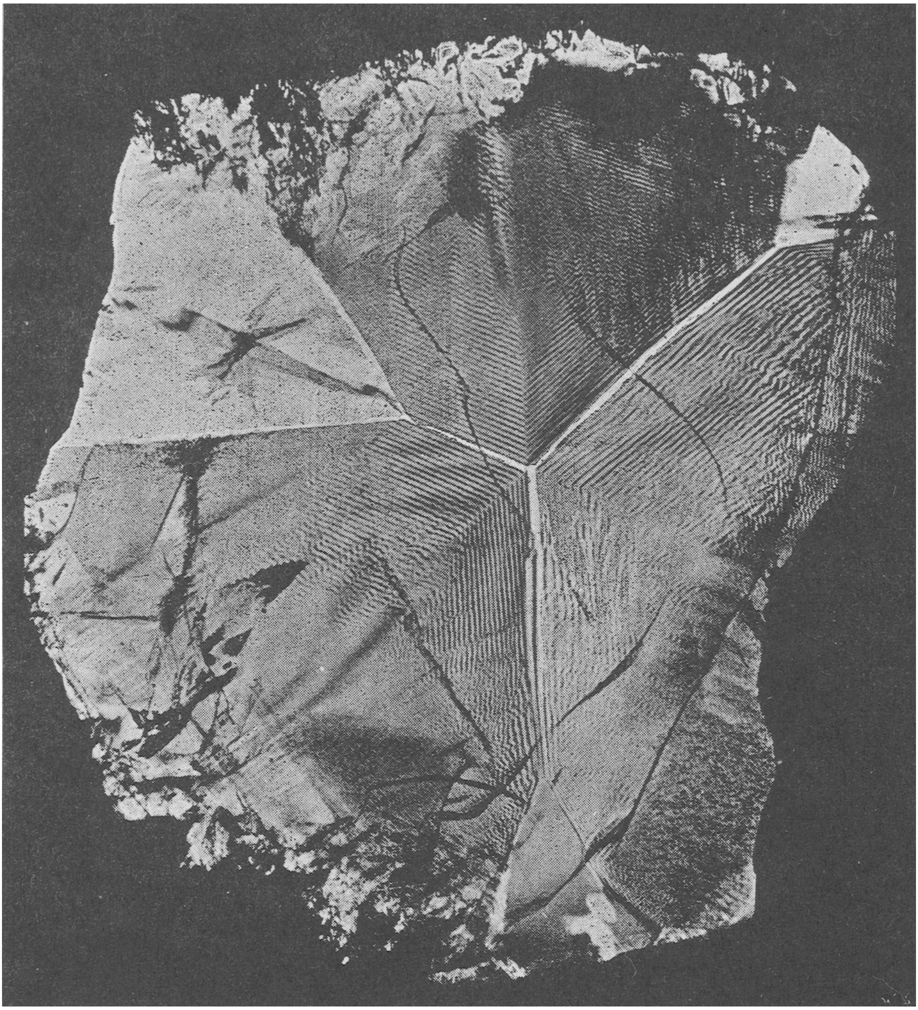
9. When chemical changes, resulting in the production of colour, take place in a quartz crystal, not only do we find the stable and unstable quartz assuming different tints, the former yellow and the latter purple, but the distribution of the colour in the unstable quartz appears to be determined to some extent by the lamellar structure. Thus we find the purple tint concentrated along the lines separating the lamellæ, and the peculiar structure of the quartz is rendered visible in ordinary light.

10. By heating, the colour of both varieties of quartz may be destroyed, while the peculiarities of molecular structure remain.



Key to the Section of Quartz represented in opposite Plate.

The wedges marked x, y, z are of a pale yellow colour, as are also the three plates proceeding from these wedges and meeting in the centre of the crystal O. This yellow quartz is stable quartz, and shows no sign of lamellar structure. The wedge y exhibits left-handed circular polarisation, while the wedge z shows right-handed polarisation. In the large wedge x we have both right- and left-handed quartz, x being right-handed and x_2 left-handed; the plane of junction of these two varieties of quartz is evidently not normal to the plane passing through the lateral axes, and where the one variety overlaps the other (x_3) we have beautiful Airy's spirals exhibited in convergent polarised light.



Equatorial Section of a Quartz (Amethyst) Crystal (magnified $2\frac{1}{2}$ times), as seen between crossed nicols and photographed in mono-chromatic (green) light.

The section shows very clearly the distinction between the stable (non-lamellar) quartz, and the unstable (lamellar) quartz.

While the yellow parts of the crystal exhibit the ordinary circular polarisation (with Airy's spirals locally) characteristic of quartz crystals, the remaining sectors of the crystal (which are divided along the lines *OA*, *OB*, *OC*, where lamellæ of opposite character meet) exhibit no trace whatever of circular polarisation. In the centre, where the lamellæ are in their normal position, the section gives the interference-figures of an uniaxial crystal, but nearer to the sides of the crystal biaxial interference-figures are given, and these become greatly disturbed where the disturbance in the position of the lamellæ is excessive.