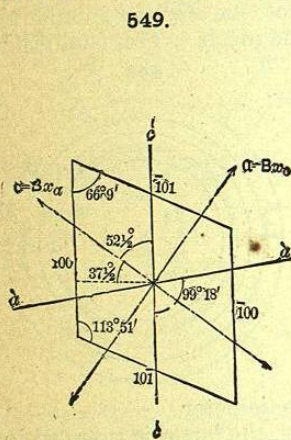
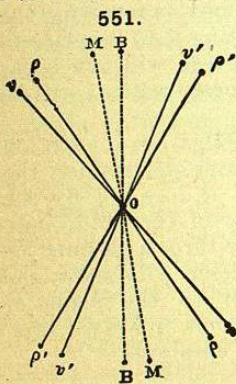


The position of the optic axial plane is described as  $\parallel b$  or  $\perp b$  according as it is parallel or normal to the plane of symmetry, that is, to the face  $b(010)$ . In the former case, the position of the bisectrices may be defined according to the angle which the acute bisectrix ( $Bx_a$ ) makes either with the normal to the face  $a(100)$  or that of  $c(001)$  or with the vertical axis  $\hat{c}$ . The last method is particularly convenient since the direction of the vertical crystallographic axis,  $\hat{c}$ , is that marked by the prismatic zone (e.g., in a section by cleavage lines), and still more since the extremity of  $\hat{c}$  is the middle point of the sphere of projection (Fig. 550) and the angle is either  $+$  (in front, toward 100) or  $-$  (behind, toward  $\bar{1}00$ ).

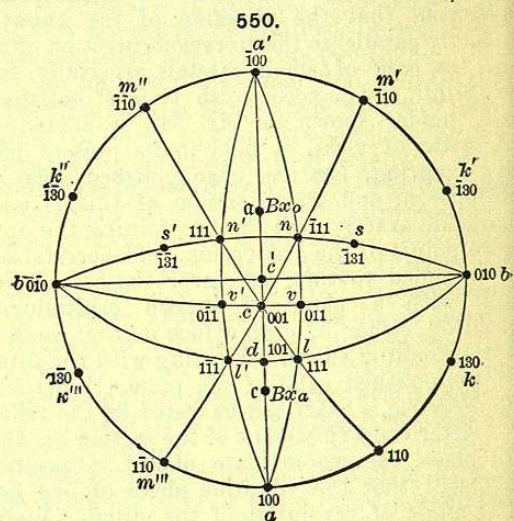
For example, gypsum is optically positive, hence the axis,  $c$ , is the acute bisectrix,  $Bx_a$ . Further (Figs. 549, 550), the position of  $Bx_a$  is defined by the angle  $Bx_a \wedge \hat{c} = +52\frac{1}{2}^\circ$ . But since the axial angle  $\beta$ , or  $ac(001 \wedge 100)$ ,  $= 80^\circ 42'$ , it is also true that the normal



angles between  $c$  or  $a$  and the planes  $c, a$  are as follows:  $ac = +43^\circ 12'$ ,  $ac = +37^\circ 30'$ , and  $ca = -46^\circ 48'$ . The positions of the bisectrices are shown in the section parallel to  $b(010)$  of Fig. 549, and also in the sphere of projection, Fig. 550.

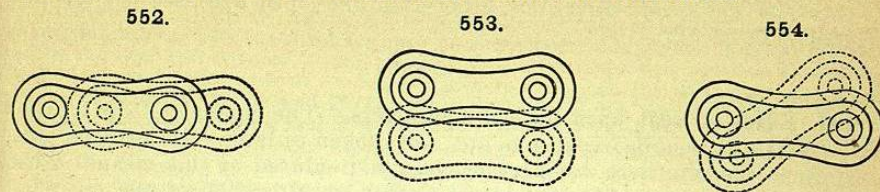


considerable, shows a distribution of colors illustrated by Figs. 4a and 4b of



**401. Dispersion of the Bisectrices.**—1. **INCLINED DISPERSION.**—In this first case the plane of the optic axes is parallel to the face  $b(010)$ ; in other words, the two bisectrices (the axes  $a$  and  $c$ ) lie in the plane of symmetry, and the mean axis  $b$  coincides with the orthodiagonal axis. The optic axes may here suffer a dispersion in this plane of symmetry, and, as already stated, they then do not lie symmetrically with reference to the acute bisectrix. This is illustrated in Fig. 551, where  $MM$  is the bisectrix for the angle  $vOv'$ , and  $BB$  for the angle  $\rho Op'$ . This kind of dispersion was called by Des Cloizeaux *inclined* (dispersion inclinée). The position of the two axial planes is further illustrated by Fig. 552 (from Schrauf), and corresponding to this axial interference-figure, when the dispersion is con-

the plate (frontispiece), which should be compared with the normal figures (Figs. 3a and 3b), where there is no dispersion of the bisectrices.



552. 1. Inclined. Ax. pl.  $\parallel b(010)$ .  
553. 2. Horizontal. Ax. pl.  $\perp b$ ;  $Bx_o \perp b$ .  
554. 3. Crossed. Ax. pl.  $\perp b$ ;  $Bx_a \perp b$ .

**2. HORIZONTAL DISPERSION.** In the second case the acute bisectrix and  $b$  lie in the plane of symmetry, and the optic axial plane is hence normal to it. In other words, the plane of the optic axes for all the colors lies parallel to the orthodiagonal axis, but these planes may have different inclinations to the vertical axis. This was called *horizontal* dispersion by Des Cloizeaux.

The relative positions of the axial planes is illustrated by Fig. 553, and the resulting interference-figure is shown in Fig. 5 of the plate.

**3. CROSSED DISPERSION.** In the third case the obtuse bisectrix and  $b$  lie in the plane of symmetry, that is, the plane of the optic axes is normal to this plane and the acute bisectrix coincides with the orthodiagonal axis  $\hat{b}$ . This was called *crossed* dispersion by Des Cloizeaux (dispersion tournante or croisée). The relative positions of the axial planes is illustrated by Fig. 554 and the corresponding interference-figure is shown in Fig. 6 of the plate.

**402. Axial Angle, Dispersion, etc.**—The method of measuring the axial angle has been already explained, and if this is determined for the different colors it will determine the dispersion of the axes  $\rho \leq v$ .

The dispersion of the bisectrices has been shown to be in general indicated by the character of interference-figures; its amount, where considerable, may be determined by making the stauroscopic measurements for different colors.

The remaining points to be investigated, the refractive indices, the  $+$  or  $-$  character of the crystal, etc., need no further explanation beyond that which has been already given.

*Special Optical Characters of Triclinic Crystals.*

**403.** The crystals of the **TRICLINIC SYSTEM** are characterized by the absence of a plane of crystallographic symmetry, the position and inclination of the axes being thus arbitrary. It follows from this that there is no necessary connection between them and the rectangular ether-axes. More than one of the three kinds of dispersion mentioned in Art. 401 may occur in a single crystal, and the interference-figures will indicate the existence of both.

The practical investigation of triclinic crystals optically involves considerable difficulty; in general a series of successive trials are required to determine the position of the axes. When these are found, the axial sections can be prepared and the axial angle determined, and the other points settled as with other biaxial crystals. Cf. Fig. 341, p. 109, of chalcantite, where  $S$  repre-

sents approximately the position of  $Bx_a$ , or in other words is the pole or normal to the plane at right angles to the acute bisectrix. On the general relation between the extinction-directions, ether-axes and optic axes, see the authors referred to on p. 212.

**404. Effect of Heat upon Optical Characters.**—The general effects of heat upon crystals as regards expansion, etc., are spoken of later. It is convenient, however, to consider here, briefly, the changes produced by this means in the special optical characters. It is assumed that no alteration of the chemical composition takes place and no abnormal change in molecular structure. The essential facts are as follows:

(1) *Isotropic* crystals remain isotropic at all temperatures. Crystals, however, which like sodium chlorate ( $\text{NaClO}_3$  of Group 5, p. 51) show circular polarization, may have their rotatory power altered; in this substance it is increased by rise of temperature.

(2) *Uniaxial* crystals similarly remain uniaxial with rise or fall of temperature; the only change noted is a variation in the relative values of  $\omega$  and  $\epsilon$ , that is, in the strength of the double refraction. This increases, for example, with calcite and grows weaker with beryl and quartz. It is, further, interesting to note that the rotatory power of quartz increases with rise of temperature, but the relation for all parts of the spectrum remains sensibly the same.

(3) With *Biaxial crystals*, the effect of change of temperature varies with the system to which they belong.

The axial angle of biaxial crystals may be measured at any required temperature by the use of a metal air-bath. This is placed at  $P$  (Fig. 544), and extends beyond the instrument on either side, so as to allow of its being heated with gas-burners; a thermometer inserted in the bath makes it possible to regulate the temperature as may be desired. This bath has two openings, closed with glass plates, corresponding to the two tubes carrying the lenses, and the crystal-section, held as usual in the pincers, is seen through these glass windows. Suitable accessories to the refractometer also allow of the measurement of the refractive indices at different temperatures.

In the case of *orthorhombic* crystals, the position of the three rectangular ether-axes cannot alter, since they must always coincide with the crystallographic axes. The values of the refractive indices, however, may change, and hence with them also the optic axial angle; indeed a change of axial plane or of the optical character is thus possible.

For example, Des Cloizeaux gives the following values for barite:  $2E_r = 63^\circ 5'$  at  $12^\circ \text{C}$ .,  $69^\circ 49'$  at  $95.5^\circ$ ,  $74^\circ 42'$  at  $195.8^\circ$ . Further, Arzruni obtained the following measurements of the refractive indices of the same species for the  $D$  line:

	$\alpha$	$\beta$	$\gamma$	$2E$	$2V$
At $20^\circ$	1.63609	1.63712	1.64795	$64^\circ 1'$	$37^\circ 28'$
" $50^\circ$	1.63575	1.63678	1.64726		$38^\circ 43'$
" $100^\circ$	1.63512	1.63612	1.64643	$68^\circ 51'$	$40^\circ 15'$
" $200^\circ$	1.63344	1.63474	1.64426	$77^\circ 16'$ ( $204^\circ$ )	$44^\circ 18'$

With *monoclinic* crystals, one ether-axis must coincide at all temperatures with the axis of symmetry, but the position of the other two in the plane of symmetry may alter, and this with the possible change in the value of the refractive indices may cause a variation in the degree (or kind) of dispersion as well as in the axial angle.

With *triclinic* crystals, both the positions of the ether-axes and the values of the refractive indices may change. The observed optical characters may therefore vary widely.

A striking example of the change of optical characters with change of temperature is furnished by gypsum, as investigated by Des Cloizeaux. At ordinary temperatures, the dispersion is inclined, the axial plane is  $\parallel b$  and  $2E_r = 95^\circ$ . As the temperature rises this angle diminishes; thus at  $47^\circ$ ,  $2E_r = 76^\circ$ ; at  $95^\circ$ ,  $2E_r = 39^\circ$ ; and at  $116^\circ$ ,  $2E_r = 0$ . At this last temperature the axes for blue rays have already separated in a plane  $\perp b$ ; at  $120^\circ$  the axes for red rays also separate in this plane ( $\perp b$ ) and the dispersion becomes *horizontal*. The motion toward the center of one red axis is more rapid than that of the other, namely between  $20^\circ$  and  $95^\circ$ ,  $33^\circ 55'$  and  $22^\circ 38'$ , respectively; thus  $Bx_r$  moves  $5^\circ 38'$ .

Another interesting case is that of glauberite. Its optical characters under normal conditions are described as follows: Optically —. Ax. pl.  $\perp b$ ,  $Bx_{ar} \wedge c = -31^\circ 3'$ ,  $Bx_{a,y} = -30^\circ 46'$ ,  $Bx_{a,bl} \wedge c = -30^\circ 10'$ . The optical character (—) and the position of the axes of elasticity remain sensibly constant between  $0^\circ$  and  $100^\circ$ . The ax. pl., however, at first  $\perp b$  with horizontal dispersion and  $v < \rho$  becomes on rise of temperature  $\parallel b$  with inclined dispersion and  $v > \rho$ . The axial angle accordingly diminishes to  $0^\circ$  at a temperature depending upon the wave-length and then increases in the new plane. In white light, therefore, the interference-figures are abnormal and change with rise in temperature. Axial angles, Laspeyres:

	red (Li)	yellow (Na)	green (Ti)	blue
At $5^\circ$	$2E = 16^\circ 6'$	$14^\circ 8'$	$11^\circ 42'$	$8^\circ 51'$
$22^\circ$	" = $13^\circ 30'$	$11^\circ 8'$	$8^\circ 14'$	$0^\circ$ (at $18^\circ$ )
$36^\circ$	" = $11^\circ 1'$	$8^\circ 9'$	$0^\circ$	$8^\circ 42'$
$46^\circ$	" = $8^\circ 40'$	$0^\circ$	$7^\circ 8'$	$11^\circ 8'$
$58^\circ$	" = $0^\circ$	$7^\circ 14'$	$10^\circ 32'$	$13^\circ 2'$
$85^\circ$	" = $10^\circ 47'$	$13^\circ 14'$	$15^\circ 15'$	$17^\circ 7'$

Des Cloizeaux found that the feldspars, when heated up to a certain point, suffer a change in the position of the axes, and if the heat becomes greater and is long continued they do not return again to their original position, but remain altered.

In addition to the typical cases referred to, it is to be noted that when elevation of temperature is connected with change of chemical composition wide changes in optical characters are possible. This is illustrated by the zeolites and related species, where the effect of loss of water has been particularly investigated.

Further, with some crystals, heat serves to bring about a change of molecular structure and with that a total change of optical characters. For example, the greenish-yellow (artificial) orthorhombic crystals of antimony iodide ( $\text{SbI}_3$ ) on heating (to about  $114^\circ$ ) change to red uniaxial hexagonal crystals. Note also the remarks made later in regard to the effect of heat upon leucite and boracite (Art. 411).

**405. Some Peculiarities in Axial Interference-figures.** \*—In the case of uniaxial crystals, the characteristic interference-figure varies but little from one species to another, such variation as is observed being usually due to the thickness of the section and the birefringence. In some cases, however, peculiarities are noted. For example, the interference-figure of apophyllite is somewhat peculiar, since its birefringence is very weak, and it may be optically positive for one part of the spectrum and negative for the other.

In the case of biaxial crystals, peculiarities are more common. The following are some typical examples:

Brookite is optically + and the acute bisectrix is always normal to  $a(100)$ . While, however, the axial plane is  $\parallel c$  for red and yellow, with  $2E_r = 55^\circ$ ,  $2E_y = 30^\circ$ , it is commonly  $\parallel b$  for green and blue, with  $2E_{gr} = 34^\circ$ . Hence a section  $\parallel a$  in the conoscopic shows a figure somewhat resembling that of a uniaxial crystal but with four sets of hyperbolic bands.

Titanite also gives a peculiar interference-figure with colored hyperbolas because of the high color-dispersion,  $\rho > v$ ; thus Des Cloizeaux gives  $2E_r = 55^\circ$  to  $56^\circ$ ,  $2E_r = 24^\circ$ ; the dispersion of the bisectrices is, however, very small.

The most striking cases of peculiar axial figures are afforded by twin crystals (Art. 407).

**406. Relation of Optical Properties to Chemical Composition.**—The effect of varying chemical composition upon the optical characters has been minutely

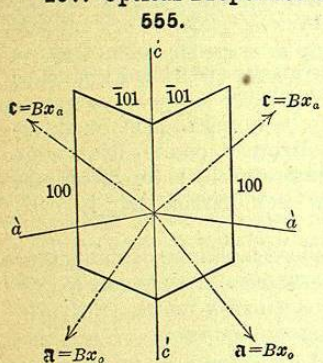
\* Variations in the axial figures embraced under the head of optical anomalies are spoken of later (Art. 411).

studied in the case of many series of isomorphous salts, and with important results.\* It is, indeed, only a part of the general subject of the relation between crystalline form and molecular structure on the one hand and chemical composition on the other, one part of which has been discussed in Art. 302. It was shown there that the refractive index can often be approximately calculated from the chemical composition.

Among minerals, the most important examples of the relation between composition and optical characters are afforded by the triclinic feldspars of the albite-anorthite series. Here, as explained in detail in the descriptive part of this work, the relation is so close that the composition of any intermediate member of this isomorphous group can be predicted from the position of its ether-axes, or more simply from the vibration-directions on the fundamental cleavage-directions,  $\parallel c$  (001) and  $\parallel b$  (010).

The effect of varying amounts of iron protoxide (FeO) is illustrated in the case of the monoclinic pyroxenes, where, for example, the angle  $Bx_a \wedge c$  is  $36^\circ$  in diopside (2.9 p. c. FeO) and  $48^\circ$  in hedenbergite (26 p. c. FeO). This is also shown in the closely related orthorhombic species of the same group, enstatite,  $MgSiO_3$  with little iron, and hypersthene,  $(Mg, Fe)SiO_3$  with iron to nearly 30 p. c. With both of these species the axial plane is parallel to  $b$  (010), but the former is optically + ( $Bx_a = c$ ) and the dispersion  $\rho < v$ ; the latter is optically - ( $Bx_a = a$ ) and dispersion  $\rho > v$ . In other words, the optic axial angle increases rapidly with the FeO percentage, being about  $90^\circ$  for FeO = 10 p. c. In the case of the chrysolites, the epidotes, the species triphylite and lithiophilite, and others, analogous relations have been made out.

407. Optical Properties of Twin Crystals.—The examination of sections of twin crystals of any other than the isometric system in polarized light serves to establish the compound character at once and also to show the relative orientation of the several parts. This is most distinct in the case of contact-twins, but is also well shown with penetration-twins, though here the parts are usually not separated by a sharp line.

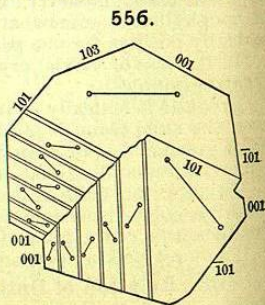


Thus the examination of a section parallel to  $b$  (010) of a twin crystal of gypsum, of the type of Fig. 555, makes it easy not only to establish the fact of the twinning but also to fix the relative positions of the ether-axes in the two parts. The measurement can in such cases be made between the extinction-directions in the two halves, instead of between one of these and some definite crystallographic line, as the vertical axis.

The polysynthetic twinning of certain species, as the triclinic feldspars, appears with great distinctness in polarized light. For example, in the case of a section of albite, parallel to the basal cleavage, the alternate bands extinguish together and assume the same tint when the quartz section is inserted. Hence the angle between these directions is easily measured, and this is obviously double the extinction-angle made with the edge  $b/c$ . A basal section of microcline in the same way shows its compound twinning according to both the albite and pericline laws, the characteristic grating structure being clearly revealed in polarized light. Fig. 556 of a section of chondrodite (from Des Cloizeaux) shows how the compound structure is shown by optical examination; the position of the axial plane is indicated in the case of the successive polysynthetic lamellae. The complex penetration-twins of right- and left-handed crystals of quartz (see the description of that species) also have their character strikingly revealed in polarized light.

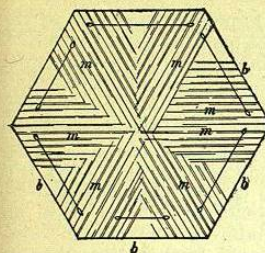
Still again, the true structure of complex multiple twins, exhibiting pseudo-symmetry

\* See a recent paper by Pockels, Jb. Min., Beil.-Bd., 8, 117, 1898.



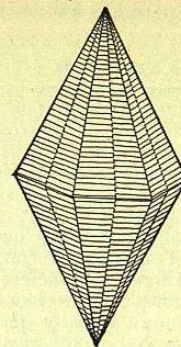
in their external form, can only be fully made out in this way. This is illustrated by Fig. 557, a basal section of an apparent hexagonal pyramid of witherite (cf. Fig. 400, p. 128). The analogous six-sided pyramid of bromlite (Fig. 558) has a still more complex structure,

557.



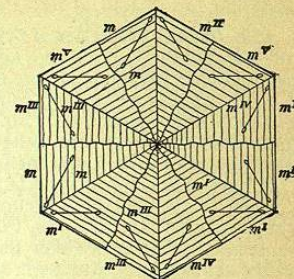
Witherite.

558.



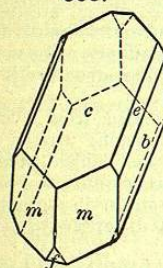
Bromlite (Des Cloizeaux).

559.

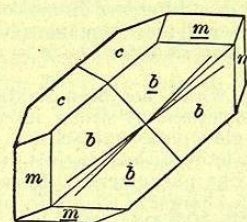


as shown in Fig. 559. Fig. 560 shows a simple crystal of stilbite; Fig. 561 is the common type of twin-crystal, and Fig. 562 illustrates how the complex structure ( $\parallel b$  010) is revealed in polarized light. Other illustrations are given in Art. 411. It will be understood that

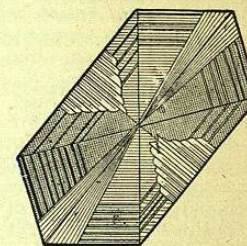
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561.



562.

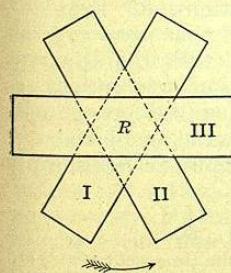


Stilbite (Lasaulx).

the axial interference-figures of twin crystals, where the parts are superposed, often show many peculiarities; the Airy spirals of quartz (p. 203) will serve as an illustration.

408. A particularly interesting case, related to the subject discussed in the preceding article, is that of the special properties of superposed cleavage-sections of mica, as developed by Reusch.\*

563.



If three or more of these, say of rectangular form, be superposed and so placed that the lines of the axial planes make equal angles of  $60^\circ$  ( $45^\circ$ , etc.) with each other the effect is that polarized light which has passed through the center suffers circular polarization, with a rotation to right or left according to the way in which the sections are built up. The interference-figure resembles that of a section of quartz cut normal to the axis. This is illustrated in Fig. 563.

If the sections are numerous and very thin the imitation of the phenomena of quartz is closer. As shown by

\* Reusch, Pogg. Ann., 138, 628, 1869; Sohneke, ibid., Erg.-Bd., 8, 16, 1876, and Theorie der Krystallstruktur, 1879.

Sohncke and others, these facts throw much light upon the ultimate molecular structure of a crystallized medium showing circular polarization. Further, it is easy from this to understand how it is possible to have in sections of certain crystals (*e.g.*, of clinoclone) portions which are biaxial and others that are uniaxial, the latter being due to an intimate twinning after this method of biaxial portions.

**409. Optical Properties of Crystalline Aggregates.**—The special optical phenomena of the different kinds of crystalline aggregates described on pp. 142, 143, and the extent to which their optical characters can be determined, depend upon the distinctness in the development of the individuals and their relative orientation. The case of ordinary granular, fibrous, or columnar aggregates needs no special discussion. Where, however, the doubly refracting grains are extremely small, the microscope may hardly serve to do more than to show the aggregate polarization present.

A case of special interest is that of spherulites, that is, aggregates spherical in form and radiated or concentric in structure; such aggregates occur with calcite, various chlorites, feldspars, etc. If they are formed of a doubly refracting crystalline mineral, or of an amorphous substance which has birefringent characters due to internal tension, they commonly exhibit a dark cross in the microscope between crossed nicols; further, this cross, as the section is revolved on the stage, though actually stationary, seems to rotate backward.\*

A distinct and more special case is that of spherical aggregates of a mineral optically uniaxial (or biaxial with a small angle). Sections of these (not central) in parallel polarized light show more or less distinctly the interference-figure of a uniaxial crystal.† The objective must be focussed on a point a little removed from the section itself, say on the surface of the sphere of which it is a part. In such cases the + or - character of the double refraction can be determined as usual.

**410. Change of Optical Character Induced by Pressure.**—As the difference between the optical phenomena exhibited by an isometric crystal on the one hand and a uniaxial or biaxial crystal on the other is referred to a difference in molecular structure modifying the properties of the ether, it would be inferred that if an amorphous substance were subjected to conditions tending to develop an analogous difference in its molecular structure it would also show doubly refracting properties.

This is found to be the case. Glass which has been suddenly cooled from a state of fusion, and which is therefore characterized by strong internal tension, usually shows marked double refraction. Further, glass plates subjected to great mechanical pressure in one direction show in polarized light more or less distinct interference-curves. Gelatine sections, also, under pressure exhibit like phenomena. Even the strain in a glass block developed under the influence of unlike charges of electricity of great difference of potential on its opposite sides is sufficient to make it doubly refracting.

In an analogous manner, as shown by Klein, Bücking, and others,‡ the double refraction of a crystal may be changed by the application of mechanical force. Klein found that pressure exerted normal to the vertical axis of a section of a tetragonal or hexagonal crystal which has been cut  $\perp c$ , changes the uniaxial interference-figure into a biaxial, and with substances optically positive, the plane of the optic axes was parallel, and with negative substances normal, to the direction of pressure.

The quartz crystals in rocks, which have been subjected to great pressure, are often found to be in an abnormal state of tension, showing an undulatory extinction in polarized light.

**411. Optical Anomalies.**—Since the early investigations of Brewster, Herschel, and others (1815 *et seq.*) it has been recognized that many crystals exhibit optical phenomena which are not in harmony with the apparent symmetry of their external form. Crystals of many isometric species, as analcite, alum, boracite, garnet, etc., often show more or less pronounced double refraction, and sometimes they are distinctly uniaxial or biaxial. A section examined in parallel polarized light may show more or less sharply

\* Cf. Rosenbusch, *Mikr. Phys.*, 68 *et seq.*, 1892.

† Bertrand, *C. R.*, 94, 542, 1882; Mallard, *Bull. Soc. Min.*, 4, 67, 1881.

‡ This subject has been discussed by various authors, among whom (in recent years) are the following: Klocke, *Jb. Min.*, 2, 249, 1881; Bücking, *Zs. Kryst.*, 7, 555, 1883; Brauns, *Jb. Min.*, 1, 232, 1886; Klein, *Ber. Ak. Berlin*, 724, 1890; Pockels, *Wied. Ann.*, 37, 144, etc., 1889; 39, 440, 1890; *Jb. Min., Beil.-Bd.*, 3, 217, 1893. See also literature on p. 231.

defined doubly refracting areas, or parallel bands or lamellæ with varying extinction. Occasionally, as noted by Klein in the case of garnet, while most crystals are normally isotropic, others show optical characters which seem to be determined by the external bounding faces and edges; thus, a dodecahedron may appear to be made up of twelve rhombic pyramids (biaxial) whose apices are at the center; a hexoctahedron similarly may seem to be made up of forty-eight triangular pyramids, etc.

Similarly, crystals of many common tetragonal or hexagonal species, as vesuvianite, zircon, beryl, apatite, corundum, chabazite, etc., give interference-figures resembling those of biaxial crystals. Also, analogous contradictions between form and optical characters are noted with crystals of orthorhombic and monoclinic species, *e.g.*, topaz, natrolite, orthoclase, etc. All cases such as those mentioned are embraced under the common term of *optical anomalies*.

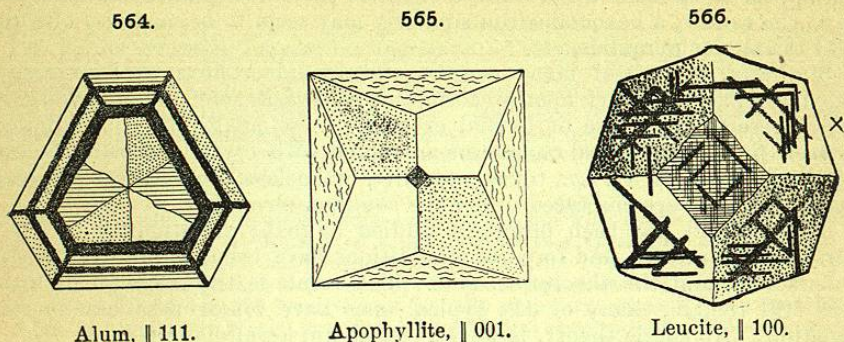
This subject has been minutely studied by many investigators in recent years (see literature), and important additions have been made to it both on the practical and the theoretical side. The result is that, though doubtful cases still remain, many of the typical ones have found a satisfactory explanation. No single theory, however, can be universally applied.

The chief question involved has been whether the anomalies are to be considered as secondary and non-essential, or whether they belong to the inherent molecular structure of the crystals in question. On the one hand, it has been urged that internal tension suffices (Art. 410) to call out double refraction in an isotropic substance or to give a uniaxial crystal the typical optical structure of a biaxial crystal. On the other hand, it is equally clear that twinning often produces pseudo-symmetry in external form, and at the same time conceals or changes the optical characters. From the simplest case, as that of aragonite (Fig. 397), we pass to more complex cases, as witherite (Figs. 400, 401, and 557), bromlite (Figs. 558, 559), phillipsite (Figs. 362, 422-424), which last is sometimes pseudo-isometric in form, though optical study shows the monoclinic character of the individuals.\* Reasoning from the analogy of these last cases, Mallard was led (1876) to the theory that the optical anomalies could in most cases be explained by the assumption of a similar but still more intimate grouping of molecules which themselves without this would unite to form crystals of a lower grade of symmetry than that which their complex twinned crystals actually simulate.

In regard to the two points of view mentioned, it seems probable that internal tension (due to pressure, sudden cooling, or rapidity of growth, etc.) can be safely appealed to to explain the anomalous optical character of many species, as diamond, halite, beryl, quartz, etc. Again, it has been fully proved that the later growth of isomorphous layers of varying composition may produce optical anomalies, probably here also to be referred to tension. Alum is a striking example. The peculiarities of this species were early investigated by Biot and made by him the basis of his theory of "lamellar polarization," but the present explanation is doubtless the true one. Fig. 564 (from Brauns) shows the appearance in polarized light of a section  $\parallel o$  (111) from a crystal in which the successive layers have different composition. Further, according to Brauns the optical peculiarities of many other species may be referred to this same cause. He includes here, particularly, those cases (as with some garnets) in which the optical characters seem to depend upon the external form, as

\* Crystals showing pseudo-symmetry of highly complex type are called *mimetic* crystals by Tschermak.

noted above. Here belongs also apophyllite, a section of which (from Golden, Colo., by Klein) is shown in Fig. 565. The section has been cut  $\parallel c(001)$  through the center of the crystal and is represented as it appears in parallel polarized light.

Alum,  $\parallel 111$ .Apophyllite,  $\parallel 001$ .Leucite,  $\parallel 100$ .

Another quite distinct but most important class is that including species such as boracite and leucite, which are *dimorphous*; that is, those species which at a certain elevation of temperature ( $300^\circ$  for boracite and  $500^\circ$  to  $600^\circ$  for leucite) become strictly isotropic. Under ordinary conditions, these species are anisotropic, but the fact stated makes it probable that originally their crystalline form and optical characters were in harmony. The relations for leucite deserve to be more minutely stated.

Leucite usually shows very feeble double refraction:  $\omega = 1.508$ ,  $\epsilon = 1.509$ . This anomalous double refraction, early noted (Brewster, Biot), was variously explained. In 1873, Rath, on the basis of careful measurements, referred the seemingly isometric crystals to the tetragonal system, the trapezohedral face 112 being taken as 111, and 211, 121 as 421, 241, respectively; also 101, 011 as 201, 021. Later Weisbach (1880), on the same ground, made them orthorhombic; Mallard, however, referred them (1876), chiefly on optical grounds, to the monoclinic system, and Fouqué and Lévy (1879) to the triclinic. The true symmetry, corresponding to the molecular structure which they possess or tend to possess at ordinary temperatures, is in doubt, but it has been shown (Klein, Penfield) that at  $500^\circ$  to  $600^\circ$  sections become isotropic; and further (Rosenbusch), that the twinning striations disappear on heating, to reappear again in new position on cooling. Sections ordinarily show twinning-lamellæ  $\parallel d(110)$ ; in some cases a bisectrix (+) is normal to what corresponds to a cubic face, the axial angle being very small. The structure corresponds in general (Klein) to the interpenetration of three crystals, in twinning position  $\parallel d$ , which may be equally or unequally developed; or there may be one fundamental individual with inclosed twinning-lamellæ. Fig. 566 shows a section of a crystal ( $\parallel a, 100$ ) which is apparently made up by the twinning of three individuals.

Still again, in a limited number of cases it can be shown that the intergrowth of lamellæ having slightly different crystallographic orientation is the cause of the optical peculiarities. Prehnite is a conspicuous example of this class.

After all the various possible explanations have been applied there still remain, however, many species about which no certain conclusion can be reached. This is true, for example, of perovskite. To many of these species the theory of Mallard may probably be applicable. Indeed it may be added that much difference of opinion still exists as to the cause of the "optical anomalies" in a considerable number of cases.

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## IV. CHARACTERS DEPENDING UPON HEAT.

412. The more important of the special properties of a mineral species with respect to heat include the following: Fusibility; conductivity and expansion, especially in their relation to crystalline structure; change in optical characters with change of temperature; specific heat; also diathermancy, or the power of transmitting radiation, that is, ether-waves. The full discussion of these

\* A complete bibliography is given in the memoir by Brauns (1891), see below.