SPECIAL OPTICAL CHARACTERS BELONGING TO CRYSTALS OF THE DIFFERENT SYSTEMS.

346. All crystallized minerals may be grouped into three grand classes, which are distinguished by their physical properties, as well as their geometrical form. These three classes are as follows:

A. *Isometric class*, embracing crystals of the isometric system, which are referred to three equal rectangular axes.

B. *Isodiametric class*, embracing crystals of the tetragonal and hexagonal systems, referred to two, or three, equal lateral axes and a third, or fourth, axis unequal to them at right angles to their plane. Crystals of this class have a fixed principal axis of crystallographic symmetry.

C. *Anisometric class*, embracing the crystals of the orthorhombic, monoclinic, and triclinic systems, referred to three unequal axes. Crystals of this class are without a fixed axis of crystallographic symmetry.

347. Isotropic Crystals.—Of the three classes, the ISOMETRIC CLASS includes all crystals which, with respect to light and related phenomena involving the ether, are *isotropic;* that is, those which have like optical properties in all directions. Specifically, a light-wave is propagated in them with the same velocity in all directions, and its wave-front is therefore a sphere. Hence, also, the sphere may be regarded as representing the optical structure of an isometric crystal. The geometrical property of the sphere that every cross-section is a circle corresponds to the optical property of the isotropic medium in which the velocity of light-propagation is the same in every direction, for this being true, the medium must have like properties of the ether in any plane normal to such a line.

It must be repeated here, however, that such a crystal is *not* isotropic with reference to those characters which depend directly upon the molecular structure alone, as cohesion and elasticity. (See Art. **254**.)

Further, amorphous bodies, as glass and opal, which are destitute of any oriented molecular structure—that is, those in which all directions are sensibly the same—are also isotropic, and not only with reference to light, but also as regards their strictly molecular properties.

348. Anisotropic Crystals; Uniaxial and Biaxial.—Crystals of the ISODIAMETRIC and ANISOMETRIC CLASSES, on the other hand, are in distinction *anisotropic.* Their optical properties are in general unlike in different directions, or, more particularly, the velocity with which light is propagated varies with the direction.

Further, in crystals of the isodiametric class that variable property of the light-ether upon which the velocity of propagation depends remains constant for all directions which are normal, or, again, for all those equally inclined to the vertical crystallographic axis. In the direction of this axis there is no double refraction; it is hence called the *optic axis*, and the crystals of this class are said to be *uniaxial.* The optical structure of uniaxial crystals can be represented by a spheroid, that is, an ellipsoid of revolution whose axis of revolution is the optic axis, or axis of crystallographic symmetry. The direction and properties of this optic axis will be seen to correspond to the geometrical property of the spheroid, a section of which normal to this axis is always a circle.

Crystals of the third or anisometric class have more complex optical relations requiring special explanation, but in general it may be stated that in them there are always two directions analogous in character to the single optic axis spoken of above, hence these crystals are said to be optically *biaxial.* Further, it will be shown that their optical structure may be represented geometrically by an ellipsoid with three unequal rectangular axes. Every such ellipsoid has two directions in which it can be cut yielding cross-sections which are circles; the optic axes spoken of will be seen later to be normal to these planes after the analogy of uniaxial crystals.

In crystals of the orthorhombic system the axes of the ellipsoid coincide in direction with the crystallographic axes. In crystals of the monoclinic system one of these ellipsoidal axes coincides with the axis of crystallographic symmetry, the other two lie in the plane of symmetry. In crystals of the triclinic system there is no necessary relation between the position of the ellipsoidal axes and those assumed to describe the crystallographic form.

All of these points require detailed discussion, but the above statements will partially serve to bring out the intimate connection between the molecular structure exhibited in the geometrical form and the optical characters depending upon the properties belonging to the light-ether within the crystal.

A. ISOMETRIC CRYSTALS.

349. It has been stated that crystals of the isometric system are optically *isotropic*, and hence light travels with the same velocity in every direction in them. Light can, therefore, suffer only single refraction in passing into an isotropic medium; or, in other words, there can be but one value of the refractive index for a given wave-length. If this be represented by n, while V is the velocity of light in air and v that in the given medium, then

$$n = \frac{V}{v}, \text{ or } v = \frac{V}{n}.$$

The wave-front for light-waves propagated from any point within such an isotropic medium is a sphere, and, as already stated, this geometrical figure may be taken as representing the optical structure of an isometric crystal.

This statement holds true of all the groups of isometric crystals. In other words, a crystal of maximum symmetry, as fluorite, and one having the restricted symmetry characteristic of the tetrahedral or pyritohedral divisions, have alike the same isotropic character. Two of the groups, however, namely the plagihedral and the tetartohedral groups, differ in this particular: that crystals belonging to them may exhibit what has already been defined (Art. **323**) as circular polarization.

350. Behavior of Sections of Isometric Crystals in Polarized Light.—In consequence of their isotropic character, isometric crystals exhibit no special phenomena in polarized light. Sections of transparent isometric crystals may be always recognized as such by the fact that they behave as an amorphous substance in polarized light. In other words, a section on the stage of the polarization-microscope, when the nicols are crossed, appears dark, and a revolution of the section in any plane produces no change in appearance. Similarly, it appears light in any position when placed between parallel nicols. Some anomalies are mentioned on a later page (Art. **411**).

The single refractive index may be determined by means of a prism cut with its edge in any direction whatever.

B. UNIAXIAL CRYSTALS.

General Optical Relations.

351. The crystallographic and optical relations of crystals belonging to crystals of the tetragonal and hexagonal systems have already been briefly summarized (Art. **348**); it now remains to develop their optical characters more fully. This can be done most simply by making frequent use of the familiar conception of a light-ray to represent the character and motion of the light-wave.

352. Optic Axis. Ordinary and Extraordinary Ray.—The study of a crystal belonging to this class shows, in the first place, that light-rays which pass in the direction of the vertical axis suffer no double refraction. This direction is that called the *optic axis*. Since the rays spoken of are propagated by vibrations at right angles to the vertical axis, that is, in the plane of the lateral crystallographic axes, this observed fact proves that for such rays there is but one value of the refractive index, and, further, that all the lateral directions must be identical so far as those properties of the ether are concerned upon which the velocity of light depends.

On the other hand, light which passes through the crystal in any other direction than that of the vertical axis suffers *double refraction*; in other words, it is separated into two rays, which are propagated with different velocities. This is true (see Art. 310) even when the rays follow the same path, as in the case of perpendicular incidence upon the given face.

Both of these rays are completely polarized, and that in planes at right angles to each other.

It is found, further, that for one of these two rays, namely, that propagated by vibrations normal to the vertical axis, there is a constant value of the refractive index, whatever its direction; moreover, this value follows the usual law as to the constant ratio between the sines of the angles of incidence and refraction (Art. **298**). It is hence called the *ordinary ray*, and the corresponding refractive index is uniformly represented by the letter ω.

For the other ray, on the other hand, it is found that the refractive index varies, and in general it does not obey the sine law. It is hence called the *extraordinary ray*. Further, if the direction of propagation changes progressively from that nearly coinciding with the vertical axis to that in the lateral plane normal to it, it is found that the value of the refractive index of the extraordinary ray deviates more and more widely from the constant value for the ordinary ray, and this difference becomes a maximum when the former is propagated in a lateral plane normal to the vertical axis, that is, by transverse vibrations in the direction of this axis. This last value of the refractive index is represented by the letter ϵ. These two indices, ω and ϵ, are called the *principal indices* of a uniaxial crystal. A *principal section* of a uniaxial crystal is a section passing through the vertical axis.

353. Positive and Negative Crystals.—Uniaxial crystals are divided into two classes. Those in which the refractive index of the extraordinary ray, ϵ, is greater than that of the ordinary ray, ω, are called *positive*. This is illustrated by quartz for which (for yellow sodium light):

$$\omega = 1{\cdot}544. \qquad \epsilon = 1{\cdot}553.$$

On the other hand, if ω is greater than ϵ, the crystal is said to be *negative*. Calcite is an example, for which (for sodium light):

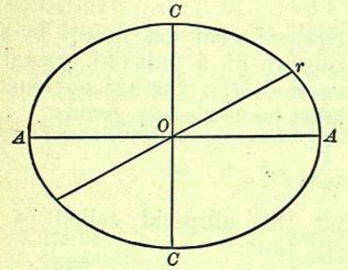
$$\omega = 1{\cdot}658. \qquad \epsilon = 1{\cdot}486.$$

Other examples are given later (Art **356**).

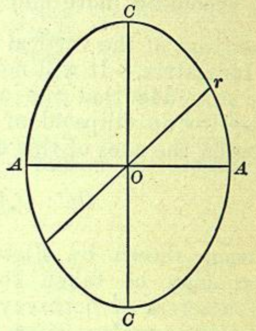
354. Wave-surface.—Remembering that the velocity of light-propagation is always inversely proportional to the corresponding refractive index, it is obvious that the velocity of the ordinary ray for all directions in a uniaxial crystal must be the same, being uniformly proportional to $\frac{1}{\omega}$. In other words, the wave-front of the ordinary ray must be a sphere.

For the extraordinary ray, however, the velocity varies with the direction, being proportional to $\frac{1}{\epsilon}$ in a lateral direction and becoming sensible equal to $\frac{1}{\omega}$ when nearly coincident with the direction of the vertical axis. The law of the varying change of velocity between these values, $\frac{1}{\omega}$ and $\frac{1}{\epsilon}$ is given by an ellipse whose axes (OC, OA, Figs. 518, 519) are respectively proportional to the above values.

518.



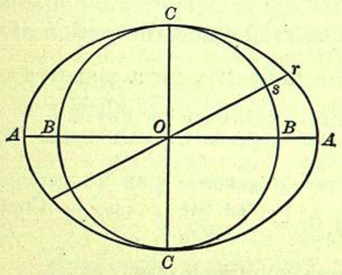
519.



$$OC : OA = \frac{1}{\omega} : \frac{1}{\epsilon} = \epsilon : \omega.$$

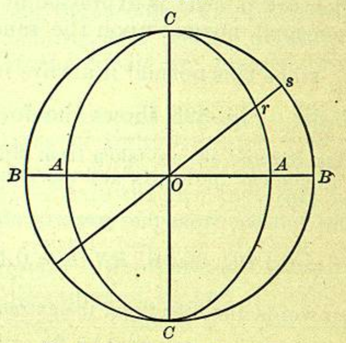
This law, suggested by Huygens, has since been verified by accurate experiments by several observers for typical substances, as calcite and soda niter; hence it is accepted without question as a law of nature. The wave-front of the extraordinary ray is then a spheroid, or an ellipsoid of revolution whose axis coincides with the vertical crystallographic axis, that is, the optical axis. In the direction of the vertical axis it is obvious that the two wave-fronts coincide.

520.



Negative crystal, $\omega > \epsilon$.

521.

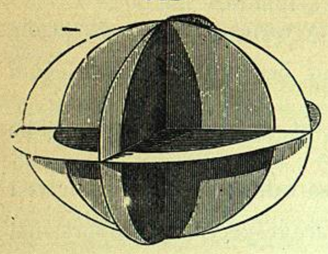


Positive crystal, $\epsilon > \omega$.

Figures 520 and 521 represent vertical sections of the combined wave-surfaces for both rays. Fig. 520 gives that for a *negative* crystal like calcite

($\omega > \epsilon$); Fig. 521 that of a *positive* crystal like quartz ($\epsilon > \omega$). Fig. 522 is an attempt to show the relations of the two wave-fronts of a negative crystal in perspective.* The constant value of the velocity of the ordinary ray $\left(\frac{1}{\omega}\right)$, whatever its direction in this plane, is expressed by the radius of the circle ($= OC$). On the other hand, the velocity of the extraordinary ray in the lateral direction is given by $OA\left(\frac{1}{\epsilon}\right)$, while in a direction as Osr, Fig. 520 (Ors, Fig. 521), it is expressed by the length of this line, becoming more and more nearly equal to $OC\left(\frac{1}{\omega}\right)$ as its direction approaches that of the vertical axis.

522.

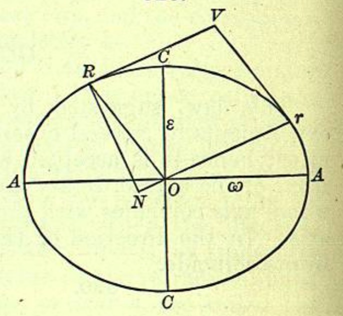


355. Indicatrix.—It will now be understood what was meant by the statement in Art. **348** that the optical structure of a uniaxial crystal may be represented by an ellipsoid of revolution, and it is further obvious that the ratio between the axes of this ellipsoid must be as already given:

$$OC : OA = \frac{1}{\omega} : \frac{1}{\epsilon}, \quad \text{or} \quad \epsilon : \omega.$$

It has been shown by Fletcher† that this ellipsoid, called by him the indicatrix, may be taken to represent the optical characters of both rays without reference to the wave-surface, since it can be proved geometrically‡ that for a given direction, as Or, the velocity of the extraordinary ray is expressed not only by Or but also by the inverse of the normal upon it from the point R (determined by the tangents to the ellipse), that is, by $\frac{1}{RN}$; also this normal fixes the plane of polarization which is perpendicular to RN. Further, the velocity of the ordinary ray, having the same direction (cf. p. 195), is expressed by the inverse of the second normal upon the same line, that is, $\frac{1}{OA}$, since this normal is always in the equatorial plane, the section of which is a circle. Fig. 523 shows the form of the indicatrix for a negative crystal

523.



---

* Figs. 522 and 538 are taken from Müller-Pouillet's Lehrbuch der Physik.

† The Optical Indicatrix and the Transmission of Light in Crystals, by L. Fletcher, London, 1892.

‡ This follows, from the property of the ellipse in general, since the parallelogram

$$ORVr = OA.OC, \text{ that is, } RN.Or = OA.OC \text{ and } Or = \frac{OA.OC}{RN}. \quad \therefore Or = \frac{\text{Constant}}{RN}.$$

In other words, the velocity of the extraordinary ray (v_ϵ) varies inversely as $\frac{1}{RN}$

Similarly, v_ω is represented by Or_2, that is, in the indicatrix by

$$\frac{1}{OA}\left(\text{since } Or_2 = OC = \frac{OA.OC}{OA} = \frac{\text{Constant}}{OA}\right).$$

like calcite ($\omega > \epsilon$); that for a positive crystal, like quartz ($\epsilon > \omega$) would be a prolate spheroid.

356. Examples of Positive and Negative Crystals.—The following lists give prominent positive and negative uniaxial crystals, with the values of the refractive indices, ω and ϵ, for each, corresponding to yellow sodium light.* The difference between these, $\omega - \epsilon$ or $\epsilon - \omega$, is also given; this measures the birefringence or *strength* of the double refraction.

It may be remarked that in some species both + and − varieties have been observed. Certain crystals of apophyllite are positive for one end of the spectrum and negative for the other, and consequently for some color between the two extremes it has no double refraction. The same is true for some other species (*e.g.*, chabazite) of weak double refraction. It is to be noted also that while eudialyte is positive, the related eucolite is negative.

NEGATIVE CRYSTALS.

	ω	ϵ	$\omega - \epsilon$
Proustite	3·0877	2·7924	0·2953
Calcite	1·6585	1·4863	0·1722
Tourmaline	1·6397	1·6208	0·0189
Corundum	1·7675	1·7592	0·0083
Beryl	1·5894	1·5821	0·0073
Nephelite	1·5416	1·5376	0·0040
Apatite	1·6461	1·6417	0·0034
Vesuvianite	1·7235	1·7226	0·0009

POSITIVE CRYSTALS.

	ω	ϵ	$\epsilon - \omega$
Rutile	2·6158	2·9029	0·2871
Cassiterite	1·9966	2·0934	0·0968
Zircon	1·9313	1·9931	0·0618
Phenacite	1·6540	1·6697	0·0157
Brucite	1·5590	1·5795	0 0205
Quartz	1·5442	1·5533	0·0091
Apophyllite	1·5337	1·5356	0 0019
Leucite	1·508	1·509	0·001

Examination of Uniaxial Crystals in Polarized Light.

357. Section Normal to the Axis in Parallel Polarized Light.—Suppose a section of a uniaxial crystal to be cut perpendicular to the vertical axis. It has already been shown that light passing through the crystal in this direction suffers no double refraction; consequently, such a section examined in *parallel* polarized light in the instrument called an orthoscope (Fig. 515), or in the polarization-microscope (Figs. 516, 517), behaves as a section of an isometric crystal, or of an amorphous substance. If the nicols are crossed it appears *dark*, and remains so when revolved.

358. Section Parallel to the Axis.—A section cut parallel to the vertical axis, as already explained, has two directions of light-vibration, one parallel to this axis and the other at right angles to it. A ray of ordinary light falling upon such a section at right angles is divided into the two rays, ordinary and extraordinary, which, however, in this special case of perpendicular incidence travel on in the same path through the crystal, but one of them retarded relatively to the other. In parallel polarized light between crossed nicols such a section will appear dark if the directions of its two vibration-planes coincide with the vibration-planes of the nicols. Thus in Fig. 524, AA being

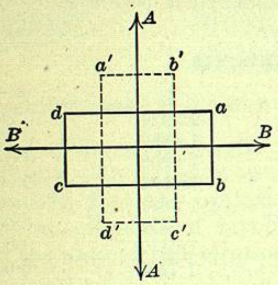
---

* For authorities, see Dana's System, 1892. For corundum and brucite the values of ω_r and ϵ_r are given.

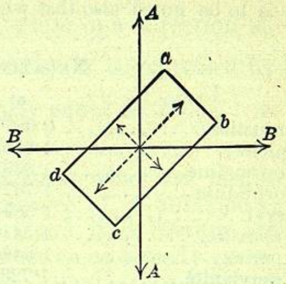
the vibration-plane of the lower nicol (polarizer) and *BB* of the upper nicol (analyzer), the light that has passed through the polarizer has its vibrations limited to the plane *AA*; these, therefore, pass through the section *abcd*, but they are arrested or extinguished by the second nicol. The same will be true if the section is turned at right angles to the first position, that is, into the position *a′b′c′d′*, represented by the dotted lines.

If the section stand obliquely, as *abcd* in Fig. 525, it will appear light to the eye (and usually colored). For the vibrations parallel to *AA* that have passed through the polarizer have upon resolution a component in the direction of each of the vibration-planes of the section. Again, each of these components can be resolved along the direction of the vibration-plane of the upper nicol, *BB*. Therefore, two rays will emerge from the analyzer, both having the same vibration-plane, but one more or less retarded with reference to the other, the amount of retardation increasing with the birefringence and the thickness of the section. In general, therefore, these rays will interfere, and if the thickness of the section is sufficient (and not too great) it will appear colored in white light and, supposing the thickness uniform, of the same color throughout.

524.



525.



Any section whatever of a uniaxial crystal appears dark between crossed nicols if its principal section (Art. **352**) coincides with the vibration-plane of either nicol.

359. Color of a Section in Parallel Polarized Light. Birefringence.—The interference-color of a section under examination depends (Art. **320**) upon its thickness and upon the birefringence; this birefringence has a maximum value, equal to $\omega - \epsilon$ or $\epsilon - \omega$, if the section is cut parallel to the optic axis (*i.e.*, $\parallel \dot{c}$).

The following table[*] gives the thickness (in millimeters) of sections of a few uniaxial crystals which yield *red* of the first order:

	Birefringence ($\omega - \epsilon$) or ($\epsilon - \omega$).	Thickness in Millimeters.
Rutile	0·287	0·0019
Calcite	0·172	0·0032
Zircon	0·062	0·0089
Tourmaline	0·023	0·0240
Quartz	0 009	0·0612
Nephelite	0·004	0·1377
Leucite	0·001	0·5510

---

[*] See further, Rosenbusch (Mikr. Phys. Min., 1892, p. 166), from whom these are taken. Compare also remarks made in Art. **320**.

Again, as another example, it may be noted that with zircon ($\epsilon - \omega = 0.062$), a thickness of about 0·009 mm. gives red of the first order; of 0 017 red of the second order; of 0·026 red of the third order.

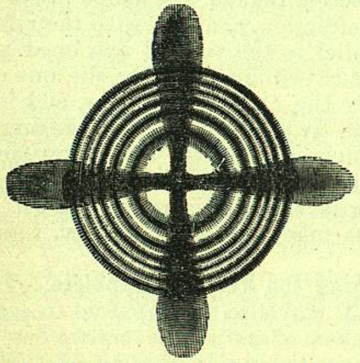
The methods ordinarily used to determine the birefringence of a section (not $\perp \dot{c}$) of a uniaxial crystal, as also to fix the relative value of its two vibration-directions, are the same as those employed for biaxial crystals, and the discussion of them is postponed to a later page (Art. **384**).

360. Uniaxial Interference-figure.—If an axial section, that is, one cut normal to the vertical axis $\dot{c}$, of suitable thickness, be viewed in *converging* polarized light in a polariscope, *e.g.*, the conoscope (Art. **327**, Fig. 514), or the tourmaline tongs (Fig. 513), or again in the microscope[*] arranged for the purpose, it no longer appears dark. On the contrary, a beautiful phenomenon is observed: a symmetrical black cross—when the nicols or tourmaline plates are crossed—with a series of concentric rings, dark and light in monochromatic light, but in white light showing the prismatic colors in succession in each ring. This is represented without the colors in Fig. 526, and with the colors in Fig. 1 of the plate forming the frontispiece to this volume.

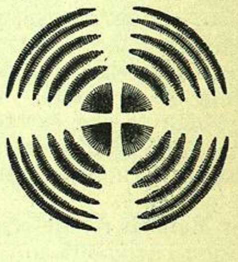
This cross becomes white when the nicols or tourmalines are in a parallel position, and each band of color in white light changes to its complementary tint (cf. Fig. 527). These interference-figures, seen[†] in this form only in a plate cut perpendicular to the vertical axis, mark the *uniaxial* character of the crystal.

The explanation of this phenomenon, so far as it can be given in a brief statement, is as follows: All the rays of light perpendicular to the plane of the section, that is, those whose vibrations coincide sensibly with the vibration-planes of either of the crossed nicols, must necessarily be extinguished. This gives rise to the black cross in the center, with its arms in the direction of the planes mentioned. Obviously this cross will be darkest along its central axis, while it fades out on the sides. All other rays passing through the given plate *obliquely* are doubly refracted, and after passing through the second nicol, thus being referred to the same plane of polarization, they *interfere*, and give rise

526.



527.



---

[*] After the section is in position on the stage, and properly focused, the eye-piece is removed and a condensing lens inserted over the lower nicol. It is important to use a relatively high-power objective. It is also possible to see axial figures without removing the eye-piece by using a magnifying glass above the latter. Cf. Klein. Jb. Min., Beil.-Bd., **3**, 540, 1885; also Bertrand, Bull. Soc. Min., **1**, 22, 96, 1878; **3**, 97, 1880.

[†] Uniaxial crystals which produce circular polarization exhibit an axial interference-figure (Fig. 2 of the plate referred to above) which differs somewhat from that described, as noted in Art. **366**. Some anomalies are mentioned later. (Art. **411**.)

to a series of concentric rings, light and dark in monochromatic light, but in ordinary light showing the successive colors of the spectrum. The phenomenon is closely analogous to that of the Newton's rings mentioned in Art. **313**. A cone of converging rays passes through the crystal and, having traversed the second nicol, each is divided into two rays with common vibration-planes, but one of them (the ordinary ray in positive crystals) slightly *retarded* with reference to the other. When the amount of retardation is equal to a wave-length (supposing monochromatic light to be employed) the effect of the interference is to destroy the light and the plane section of the cone, or circle, appears dark. Other dark rings are seen at distances which correspond to a retardation of $\frac{3}{2}$, $\frac{5}{2}$, $\frac{7}{2}$, etc., of a wave-length. If, however, the retardation amounts to a whole wave-length or any multiple of this, the two rays unite to strengthen each other and give rise to a light ring. If ordinary white light is employed, the relations are similar but the retardation cones overlap because of the different values of the refractive indices (*i.e.*, velocities) for the different wave-lengths, and the series of colored circles is the result.

The distance of each successive ring from the center obviously depends upon the birefringence, or the difference between the refractive indices for the ordinary and extraordinary ray, and also upon the thickness of the plate. The stronger the double refraction and the thicker the plate, the smaller the angle of the light-cone which will give a certain amount of retardation, or, in other words, the nearer the circles will be to the center. Further, for the same section the circles will be nearer for blue light than for red, because of their shorter wave-length. When the thickness of the plate is considerable, only the black brushes are distinctly seen.

361. Determination of the Refractive Indices.—A single prism suffices for the measurement of the indices of refraction, ω and ϵ, with the refractometer. Further, its edge may be either parallel to the vertical axis or at right angles to this direction. Such a prism yields two images of the slit, one corresponding to the ordinary and the other to the extraordinary ray, and for each the angle of minimum deviation is to be determined, that is, the angle δ in the general formula of Art. **304**. Which of the two rays corresponds to the ordinary and which to the extraordinary ray can be easily distinguished by means of a nicol, the position of whose vibration-plane is known. This will extinguish that ray whose vibrations take place in a plane at right angles to its own vibration-plane.

362. Other Methods for Determining the Refractive Indices.—The method of total reflection (Arts. **303** and **325**) may also be employed to determine the values of ω and ϵ. The section taken of a uniaxial crystal has its surface most conveniently parallel to the vertical axis. It is so placed that the direction normal to the optic axis is horizontal. The light is here separated into two rays, having separate limiting surfaces, and with a nicol prism it is easy to determine which of them corresponds to the vibrations parallel and perpendicular, respectively, to the optic axis.

Again, it is possible to obtain the refractive indices with considerable accuracy from measurements, in the plane of the axes, of the distances between the black rings in the interference-figures as seen in homogeneous light. The relation between these distances and the optical "axes of elasticity" was established by Neumann (Pogg. Ann., **33**, 257, 1834). Bauer has also developed the same method as applied to uniaxial crystals, and employed it in the case of brucite (Ber. Ak. Berlin, 1877, 704, and 1881, 958).

With the polarization-microscope the most simple method is that of the Duke de Chaulnes, explained in Art. **326**; this requires, however, that the two quantities measured should be determined with a considerable degree of accuracy, if the result is to be more than an approximation. (Cf. further, Rosenbusch, Mikr. Phys., p. 155 *et seq.*, 1892.)

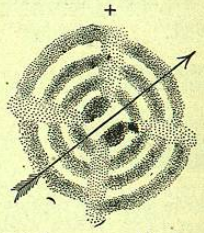
363. Determination of the Positive or Negative Character.—The most obvious way of determining the character of the double refraction ($\epsilon > \omega$ or $\omega > \epsilon$) is to measure the refractive indices in accordance with the principles explained in the preceding articles. It is not always possible, however, to obtain a prism suitable for this purpose, and in any case it is convenient to have a more simple method of accomplishing the result.

In the case of uniaxial crystals, the method which is practically the most simple is that suggested by Dove—the use of a cleavage plate of muscovite of such thickness that the two rays in passing through suffer a difference of phase which is equal to a quarter wave-length, or an odd multiple of this. It is often called a quarter-undulation plate (see Art. **322**).

Suppose that the section of the crystal to be examined, cut perpendicular to the axis, is brought between the crossed nicols in the polariscope; the black cross and the concentric colored rings are of course visible. Let now, while the given section occupies this position, the mica plate be placed over it, with the plane of its optic axes (determined beforehand, and the direction marked by a line for convenience) making an angle of 45° with the vibration-planes of the nicols. The interference-figure is completely transformed. The colored rings are broken by two more or less distinct hyperbolic brushes which pass through two black spots near the center, while the rings in the corresponding quadrants are pushed out from the center, and in the two remaining pushed in.

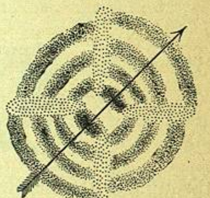
529.

+



530.

−



If now the line joining the two dark spots is at right angles to the axial plane of the mica (shown in the figures by the arrow) the crystal under experiment is opposite in refractive character to the mica, that is, *positive* (Fig. 529); if this line coincides with axial direction, the crystal is like the mica, *negative* (Fig. 530).

364. With the microscope the above method may also be employed, the mica plate, usually in the form of a narrow strip whose elongation is that of the plane of the optic axes, being introduced through a slit in the tube between the section and the analyzer. Here, however, the field of view is smaller than in the polariscope, and the black dots are not always distinctly observed; this is particularly true if the section be very thin or the mineral of low birefringence. In such cases a selenite plate is conveniently employed. This is of such thickness as to give a red of the first order, and the direction of elongation usually corresponds to the axis $\mathfrak{a}$ (Art. **373**). The plate is inserted in the tube with its axes inclined 45° to the vibration-planes of the nicols. This serves to increase the retardation between the two rays traversing the sections in two alternate quadrants and to diminish this in the others; the effect being shown by the rise or fall of the interference-colors, as compared with the usual scale (Art. **320**). For example, two blue areas (second order) may be seen in two opposite quadrants and two yellow (first order) in the others The blue areas here correspond in position to the black dots in Figs. 529 and 530; hence if the line joining them is transverse to that of the axis ($\mathfrak{a}$) of the selenite plate the mineral is positive; if it coincides with it the mineral is negative.

365. Absorption Phenomena of Uniaxial Crystals. Dichroism.—In uniaxial crystals it has been seen that there are two distinct values for the velocity of light transmitted by them, according as the vibrations take place *parallel* or at *right angles* to the vertical axis. Similarly the crystal may exert different