

right angles to one another—called the axes of optical elasticity—such that the effect of the crystal on the luminous vibrations of the elastic ether is a maximum in one of these directions, a minimum in a second, and a maximum-minimum in the third. The length of these axes is chosen in terms of this action. In certain cases the direction of the axes of optical elasticity is different for light of different colours.

The position of these axes in relation to the crystallographic axes, and the ratios of their lengths, enable us to class all crystals as follows:—

1. Crystals of the cubic system. Here the three axes of elasticity are all equal. The refraction is simple.
2. Crystals of the tetragonal and of the rhombohedral systems. Two of the axes of optical elasticity are equal in these systems; the third is greater or less according as the crystals are negative or positive. The two equal axes lie in a plane perpendicular to the principal crystallographic axes; the third axis coincides with the principal axis.
3. Crystals of the right prismatic system. The direction of the three axes of optical elasticity coincides with the crystallographic axes, taken parallel to the diagonals of the base of the rhombohedron, and to the vertical edge of the prism (the primitive parallelepiped of Levy).
4. Crystals of the oblique prismatic system. Only one of the axes of optical elasticity coincides necessarily with the crystallographical horizontal axis, or the diagonally horizontal axis of the rhombic base, the direction of the two others not having any evident relation, *a priori*, with the inclined or diagonally inclined axis of the base, and with the vertical axis (or vertical edge of the primitive parallelepiped).
5. Crystals of the anorthic system. The three axes of optical elasticity have no relation that can be assigned *a priori* to the crystallographic axes, whatever position may be assigned to these in relation to the primitive solid.

In crystals belonging to the last three systems the three axes of elasticity are unequal. The axes of elasticity are in general such that a ray passing through the crystal in the direction of any one of them is divided into two, which follow that direction with different velocities depending on the lengths of the other two axes. To any other direction there will in general also correspond two different velocities; but their ratio will now depend in a more complex manner on all three axes. In two directions (and only in two, if the axes are all unequal) the ratio becomes unity, or the ray is not divided. These directions are the optic axes.

The displacement of the axes of elasticity for light of different colours, already mentioned, takes place for two axes in crystals of the oblique prismatic system and for all three axes in the anorthic (*i.e.*, doubly oblique) system. In the other systems it does not occur.

Colour phenomena.

In order to follow the distinctive features of the different systems farther, it is necessary to consider the colour phenomena which they display, when examined in a beam of polarized light. Various instruments have been devised for this purpose, as, *e.g.*, the polarizing apparatus of Norrenberg, fitted with a condensing lens below and above the crystal slice, or with a low-power (3-inch) eye-piece. The polariscope of Hoffman of Paris is more efficient, but the apparatus of Descloizeaux (fig. 240), who has made this mode of investigation a special study, has the widest scope of usefulness. In this apparatus a blackened mirror is employed for polarizing the light, taking the place of a tourmaline plate, a Nicol's prism, or a bundle of thin glass. The mirror is inferior to the other two in completeness of polarizing power, and in not admitting of rotation; while it shares this defect with the last. It is, however, superior to all in extent of field, while it does not, like the first, affect white light. A Nicol's prism is used for examining or analysing the light which passes.

The description of the many beautiful phenomena that may be observed with polarizing apparatus when applied to sections of crystals belongs to the subject of OPTICS (PHYSICAL), to which

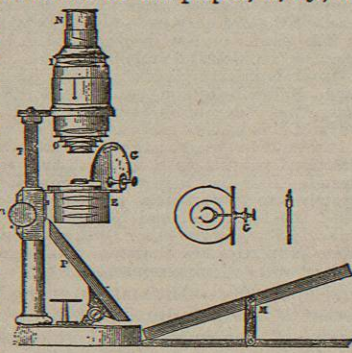


Fig. 240.—Apparatus of Descloizeaux.

heading also we must refer for the phenomena of circular polarization.

Double Refraction and Polarization of Composite Crystals.—In all the crystallized bodies whose action upon light we have been considering, the phenomena are identical in all parallel directions, the smallest fragment having the same property as the largest, from whatever part of the crystal it is taken. In the mineral world, however (and among the products of artificial crystallization), there occur crystals which are composed of several individual crystals whose axes are not parallel. These crystals sometimes occur in such regular symmetrical forms that mineralogists have long regarded them as simple forms; and it is probable that they would have still been so viewed if they had not been exposed to the scrutiny of polarized light.

A composite structure has been observed in the case of Brazilian topaz, sulphate of potash, and apophyllite. Bipyramidal sulphate of potash, which Count Bournon supposed to be a simple crystal, was found to be a tessellated crystal, composed of three pairs of crystals of the prismatic sulphate of potash combined so that each pair had their principal axes parallel. When exposed to polarized light, each pair gave the system of binaxial rings, and when held at a distance from the eye had the tessellated appearance shown in fig. 241, each opposite pair of the triangles having the same tint.

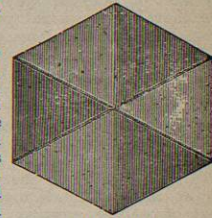


Fig. 241.

The most remarkable of this class of minerals is the tessellated apophyllite. The examination of this body by polarized light is due to Brewster. For his results the reader is referred to his paper in the *Edinburgh Transactions*, vol. ix. p. 323.

Figs. 242, 243 are representations of the figure produced in polarized light by an internal slice of the barrel or cylindrical

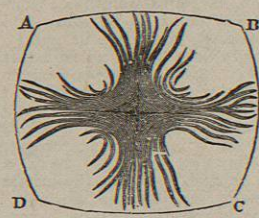


Fig. 242.

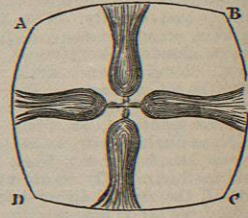


Fig. 243.

apophyllite from Kudlisaet, in Disco Island. The figures are from different specimens. The shaded part of them has only one axis of double refraction, while the four sectors have two axes. The mechanical structure of the cleavage planes resembles the optical figure even after the planes are ground.

The minerals stilbite, heulandite, chabasite, and many others, are similarly complex in structure.

Crystals with Planes of Double Refraction.—Analcime, a mineral ranked among the cubical crystals, was found by Brewster to be singular in its action upon light, and to exhibit the extraordinary property of many planes of double refraction, or planes to which the double-refracting structure was related in the same manner as it is to one or two axes in other minerals. It crystallizes most commonly in the form of the icositetrahedron. If we suppose a complete crystal of it to be exposed to polarized light, it will give the remarkable figure shown in fig. 244, where the dark shaded lines represent planes in which there is neither double refraction nor polarization, the double refraction and the tints commencing at these planes, and reaching their maximum in the centre of the space enclosed by three of the dark lines. When light is transmitted through any pair of the four planes which are adjacent to any of the three axes of the solid, it is doubly refracted, the least refracted image being the extraordinary one, and consequently the double refraction negative in relation to the axes to which the doubly-refracted ray is perpendicular. If we suppose the crystal to have the form of a

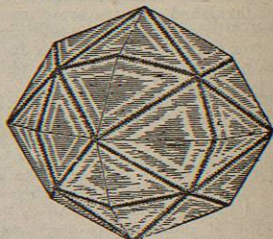


Fig. 244.



Fig. 245.

cube, the planes of double refraction will be, as in fig. 245, a plane passing through the two diagonals of each face of the cube. The tints vary as the square of the distance from the nearest plane of double refraction.

Pleochroism.—Closely connected with double refraction is that property of transparent minerals named pleochroism (of many colours), in consequence of which they exhibit distinct colours when viewed by transmitted light in different directions. Crystals of the cubic system do not show this property, whilst in those of the other systems it appears in more or less perfection,—in tetragonal and hexagonal minerals as dichroism (two colours), in the rhombic and clinic systems as trichroism (three colours). In most cases these changes of colour are not very decided, and appear rather as different tints or shades than as distinct colours. The most remarkable of dichroic minerals are the magnesian mica from Vesuvius, the tourmaline, and ripidolite; of trichromatic, iolite, andalusite from Brazil, diaspore from Schemnitz, and axinite.

In a specimen of yellow Iceland spar the extraordinary image is of an orange-yellow colour, while the ordinary image is yellowish white. Along the axis of double refraction the colour of the two pencils is exactly the same, and the difference of colour increases with the inclination of the refracted ray to the axis. This is the invariable law of the phenomena in uniaxial crystals. Sir John Herschel found several tourmalines to have a blood-red colour along the axis, and at right angles to it to be yellow-green. There can be little doubt that this property will be found in every crystal of sufficient refraction. Even if the crystal is colourless, a slight inequality in the intensity of the two images may be observed; and when it is distinctly coloured the difference of intensity is very easily seen, even when the two colours are not of a different kind.

The phenomena of dichroism are best seen in crystals with two axes of double refraction, and are well exemplified in iolite, a mineral which crystallizes in six- or twelve-sided prisms. These prisms are of a deep blue colour when seen along the axis, and of a yellowish brown colour when viewed in a direction perpendicular to it.

If *abcd* (fig. 246) is a section of the prism of iolite in a plane parallel to the axis of the prism, the transmitted light will be blue through the faces *ab* and *dc*, and yellowish brown through *ad*, *bc*, and in every direction perpendicular to the axis of the prism. If we grind down the angles *a, c, b, d*, so as to replace them with faces *m, n, m', n'* and *op, o', p'*, inclined $31^\circ 41'$ to *ad*, or to the axis of the prism, then, if the plane *abcd* passes through the optic axes, we shall observe, by transmitting polarized light through the crystal in the directions *ac, bd*, and subsequently analysing it, a system of rings round each of these axes. The system will exhibit the individual rings very plainly if the crystal is thin; but if it is thick, we shall observe, when the plane *abcd* is perpendicular to the plane of primitive polarization, some branches of blue and white light diverging in the form of a cross from the centre of the system of rings, or the poles of no polarization, as shown at *p* and *p'* (fig. 247), where the shaded branches represent the blue ones. The summits of the blue masses are tipped with purple, and are separated by whitish light in some specimens and yellowish light in others. The white light becomes more blue from *p* and *p'* to *o*, where it is quite blue, and more yellow from *p* and *p'* to *c* and *d*, where it is completely yellow. When the plane *abcd* is in the plane of primitive polarization, the poles *p, p'* are marked by spots of white light, but everywhere else the light is a deep blue.

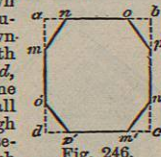


Fig. 246.

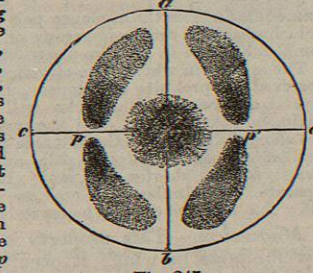


Fig. 247.

In the plane *cabd* (fig. 247) the mineral, when we look through it by common light, exhibits no other colour but yellow, mixed with a small quantity of blue, polarized in an opposite plane. The ordinary image at *c* and *d* is yellowish brown, and the extraordinary image faint blue, the former receiving some blue rays and the latter some yellow ones from *c* and *d* to *a* and *b*, where the difference of colour is still well-marked. The yellow image becomes fainter from *a* and *b* to *p* and *p'*, till it changes into blue, and the faint blue

image is strengthened by other blue rays, till the intensity of the two blue images is nearly equal. As the incident ray advances from *c* and *d* to *p* and *p'*, the faint blue image becomes more intense, and the yellow one, receiving an accession of blue rays, becomes of a bluish white colour. The ordinary image is whitish from *p* and *p'* to *o*, and the extraordinary is deep blue; but the whiteness gradually diminishes towards *o*, when they are both almost equally blue.

The principal axis of double refraction in iolite is negative. The most refracted image is purplish blue, and the least refracted one yellowish brown.

Brewster found that the dichroism of several crystals is changed by heat, and that in some cases this property may be communicated to them. Babinet found that all negative crystals, such as calcareous spar, corundum (including ruby and sapphire), tourmaline, and emerald, absorb in a greater degree the ordinary ray, with the exception of beryl, apatite, and some apophyllites; while positive crystals, such as zircon, smoky quartz, sulphate of lime, and common apophyllite, absorb in a greater degree the extraordinary ray. Babinet found also that certain crystals, such as red tourmaline and ruby, transmit rays of their peculiar colour without being polarized,—in which cases the black cross of their system of rings is coloured, and this unpolarized light exists both in the ordinary and extraordinary ray.

Haidinger devised an instrument for showing and for testing the pleochroism of minerals. In fig. 248, *p* is an oblong cleavage-rhombohedron of Iceland spar which has two glass prisms *uv*, of



Fig. 248.—Section of Dichroscope.

18° cemented to its ends with Canada balsam. This combination is placed in a metallic case, which has a convex lens *l* at one end and a square hole *o* about the fifteenth of an inch in width at the other. The lens is of a focal distance which shows an object held about half an inch from the square hole.

On looking through the lens and prisms two images of the square hole are seen just touching each other. The light of the one image is polarized in the plane which intersects the short diagonal of the prism; that of the other is polarized in the plane of the longer diagonal. When a pleochroic crystal or fragment is held at focal distance and examined by transmitted light, then, on the turning of the instrument bringing the polarization of its planes into coincidence with those of the crystal, the two images of the square opening will show the colours of the oppositely polarized pencils of which the light transmitted by the crystal is composed; this constitutes its pleochroism. The dichroism is then seen by looking through the crystal in one direction only, and the contrast of the two colours is made more obvious.

Phosphorescence.—This is the property possessed by particular minerals of emitting light in certain circumstances, without combustion or ignition.

Thus some minerals appear luminous when taken into the dark, after being for a time exposed to the sun's rays or even to the ordinary daylight. Many diamonds, and also calcined barytes, exhibit this property in a remarkable degree; less so aragonite, calc-spar, and chalk. Many minerals, including the greater part of those thus rendered phosphorescent by the influence of the sun, also become so through heat. Thus some topazes, diamonds, and varieties of fluor-spar become luminous by the heat of the hand; other varieties of fluor-spar, and phosphorite, require a temperature near that of boiling water; whilst calc-spar and many silicates are only phosphorescent at from 400° to 700° Fahr.

Electricity produces phosphorescence in some minerals, as in green fluor-spar and calcined barytes. In others it is excited when they are struck, rubbed, split, or broken; as in many varieties of zinc-blende and dolomite when scratched with a quill, pieces of quartz when rubbed on each other, and plates of mica or needles of pectolite when suddenly separated.

The light emitted by phosphorescent minerals is of various tints. The variety of fluor called chlorophane emits, as its name expresses, a green light. The same particle may emit varying tints, as in the fluor from Aberdeenshire, which, as the heat falls, or the energy of the phosphorescence wanes, emits tints which pass from violet, through blue, green, and yellow, to dull purplish red. The yellow blendé from the same place is vividly phosphorescent when heated. Fluor generally phosphoresces with a tint of its own colour.

Too high a heat destroys the phosphorescence, which may, however, be restored by either exposure to sun's light or to electricity.

The mineral phosphoresces vividly when the discharge passes through it; it generally phosphoresces with a different colour after it has been thus recharged.

Fluorescence is the property whereby rays of light of a refrangibility higher than those ordinarily seen by the human eye are rendered visible. The substance when placed in the violet end of the spectrum, and carried beyond it into the invisible rays, becomes luminous, through "degrading" the rays of extreme refrangibility. This property is well marked in those varieties of fluorite which are pale green by transmitted light, and deep purple by reflected light. Ozocerite and some petroleum also exhibit the property.

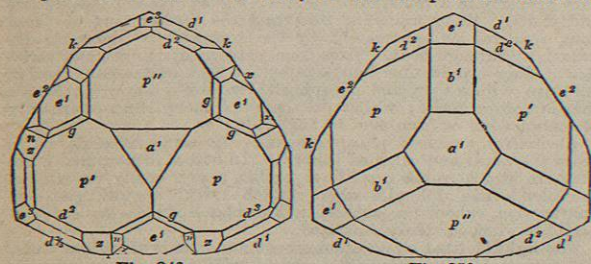
Electric, Magnetic, and Thermic Properties.

Electricity.—Friction, pressure, and heat may all excite electricity in minerals. To observe this property delicate electroscopes are required, formed of a light needle terminating at both ends in small balls, and suspended horizontally on a steel pivot by an agate cup. Such an instrument, can be electrified negatively by touching it with a stick of sealing-wax excited by rubbing, or positively by merely bringing the wax so near as to attract the needle. When the instrument is in this state, the mineral, if also rendered electric by heat or friction, will attract or repel the needle according as it has acquired electricity of an opposite or of a similar kind; but if the mineral is not electric it will attract the needle in both conditions alike.

Most precious stones become electric from friction, and are either positive or negative according as their surface is smooth or rough. All gems become positive when polished; the diamond even when unpolished is positive. Pressure between the fingers will excite distinct positive electricity in pieces of transparent double-refracting calc-spar. Topaz, aragonite, fluor-spar, carbonate of lead, quartz, and other minerals show this property, but in a much smaller degree. Some bodies remain excited much longer than others, topaz for a very long time. Heat or change of temperature excites electricity in many crystals; as in tourmaline, calamine, topaz, calc-spar, beryl, barytes, fluor-spar, diamond, garnet, and others; these are hence said to be thermo- or pyro-electric. Some acquire polar pyro-electricity, or the two electricities appear in opposite parts of the crystal, which are named its electric poles. Each pole is alternately positive and negative, the one when the mineral is heating, the other when it is cooling. Hankel's investigations of these phenomena are specially noteworthy.

As already noticed, many polar electric minerals are also remarkable for their hemimorphic crystal forms. Tourmaline, calamine, and boracite are among the species thus affected. The polarity continues so long as the temperature is increasing, and becomes reversed when it commences to decline; and when the heat is stationary it disappears.

Rose and Reiss name one of the poles the analogue electric pole, and the other the antilogue electric pole. The former becomes positive while the crystal is heating, and negative while cooling; the latter negative while heating, and positive while cooling. Becquerel found that in tourmaline at 80° C. electrical polarity was sensible; it continued unchanged to 150°, as long as the temperature continued to rise; if the temperature remained



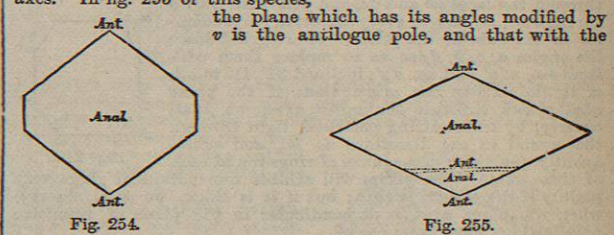
stationary an instant, the polarity disappeared, but shortly manifested itself reversed, when the temperature commenced to decline. If but one end of the crystal was heated the crystal was unpolarized, and when two sides were unequally heated each acquired an electrical state independent of the other. In tourmaline the extremities of the prism are dissimilarly modified, and that end which presents the greater number of planes is the antilogue pole; or, if the

number of planes is the same, the secondary rhombohedrons of the antilogue pole have (one or more of them) longer vertical axes than those of the analogue pole. Fig. 249 (tourmaline) is the antilogue pole (negative under increasing heat), and fig. 250 the analogue pole. The pyramid of the analogue end is more flattened by its facets than that of the antilogue end; thus e^2 and d^2 of the antilogue end are more acuminating than e^1 and d^1 of the analogue end. The same is the case with the other two crystals (figs. 251, 252).

Pyro-electricity has been observed in the following substances:—tourmaline, topaz, axinite, boracite, scolecite, prehnite, electric calamine, sphene, rhodizite, heavy spar, rock-crystal.

Pyro-electricity is of two kinds, either terminally polar or centrally polar. In the former the extremities are opposite poles. In the latter two sides of a prism are of the same name, and the opposite pole to each is intermediate between the two.

The examples of the first kind are tourmaline, calamine, and scolecite, which are uniaxial; axinite, binaxial; boracite and rhodizite, with four axes. Calamine, like tourmaline, has the sharper extremity the antilogue end, and the more flattened the analogue. Compound crystals from Altenberg have both ends analogue, and the portion which lies between the twins antilogue electric; the pyro-electric axis corresponds with the vertical axis of the prism, as in tourmaline. Boracite, which crystallizes in cubic forms, with the opposite solid angles differently modified, has four pyro-electric axes, corresponding to the four octahedral axes. In fig. 253 of this species,



the plane which has its angles modified by v is the antilogue pole, and that with the unmodified angles the analogue pole; and, generally, the antilogue pole has either more numerous or larger facets. Rhodizite resembles boracite in its pyro-electricity.

The species in which pyro-electricity of the second kind has been observed are prehnite and topaz. If fig. 254 represent a tabular crystal of prehnite, the poles will be situated as marked, the analogue being central, and the antilogue at either extremity of the shorter diagonal of the rhombic prism. Topaz has in a similar manner a central analogue pole, and an antilogue at either extremity of the shorter diagonal. In some instances there is a separate set of similar poles near one or the other angle, as in fig. 255; this must be due to the crystals being of a composite nature.

Magnetism.—This property is very characteristic of the few minerals in which it occurs,—chiefly ores of iron or nickel. Some magnetic iron ores possess polar magnetism, or are natural magnets; while the common varieties of magnetite, meteoric iron, magnetic pyrites, precious garnet, and other minerals, are simply magnetic. Most minerals are only attracted by the magnet, but do not themselves attract iron.

Minerals, as other substances, have also been divided into magnetic and diamagnetic. See MAGNETISM.

The ordinary mode of testing whether a mineral is magnetic or not is to bring it near a pole of a delicately suspended magnetic

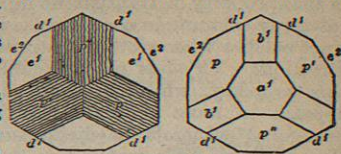


Fig. 251.

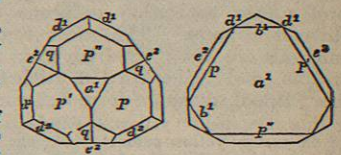


Fig. 252.

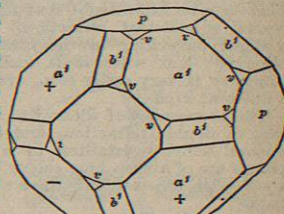


Fig. 253.

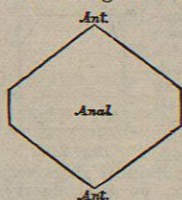


Fig. 254.

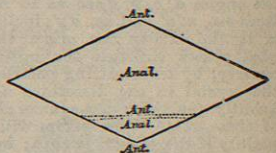


Fig. 255.

needle, and observe whether it causes it to vibrate. Another mode is to apply a strong magnet to the mineral in powder. These are sufficient for the mineralogist. Delesse has experimented extensively upon the magnetic force of minerals, and has determined the relative amount for numerous species. Calling this force for Styrian steel 100, the following are some of his results:—

Native platinum.....	2-173 to 3-047
Magnetic iron ore.....	15-00 to 65-00
Franklinite, from the United States.....	1-032
Chromic iron.....	0-136 to 0-065
Spinel (pleonaste), from Monzoni, Tyrol.....	0-078
Titanic iron (rhombohedral), often magnetipolar.....	5-764
Specular iron, sometimes magnetipolar.....	0-14 to 2-35
Graphite.....	0-016 to 0-040
Sphatic iron (epherosiderite, the highest).....	0-092 to 0-257
Iron pyrites.....	0-039 to 0-057
Vivianite.....	0-027 to 0-075
Columbite of Bodenmais and Haddam.....	0-151
Pyrochlore.....	0-010
Chrysoprase (quartz is diamagnetic, but many varieties are magnetic).....	0-004
Felspar, sometimes feebly magnetic.....	
Labradorite of an antique green porphyry.....	0-077
Hornblende.....	0-012 to 0-057

Crystallomagnetic Action.—The magnetic polarity thus far alluded to belongs to the mass, and has no relation to crystalline form. There is also a kind of polarity directly related to the crystalline or optic axes of minerals. A crystal of cyanite, suspended horizontally, points to the north, by the magnetic power of the earth only, and is a true compass needle, from which even the declination may be obtained; and the line of direction is the line of the optic axes. Other crystals, which are called negative, take a transverse or equatorial position. The latter are diamagnetic crystals.

Conductivity for Heat.—Senarmont found that the conducting power of colloids and of crystals of the cubic system is equal in all directions, but that it varies in different directions in crystals belonging to all the other systems, exhibiting characters analogous to those deduced from their double refraction, conformable with the optic axes of the crystal, and referable, as in the latter case, to axes of elasticity, or unequal compression of the molecules.

The fundamental fact is easily shown by taking two slices of rock-crystal, one cut transverse to the axis and one parallel to it. Through the centre of each plate a small hole is drilled for the reception of a bent wire, which by insertion into the hole sustains the plate. The other end of the wire is to be heated, and the rate of the conduction of the heat is rendered visible by the amount of a thin coating of beeswax, with which the plate has been previously coated, which is melted round the central hole. It will be seen that in the transverse slice the wax is melted in a circular form, while in the longitudinal slice the form is elliptical (fig. 256). The conduction is equal in all directions, as regards the transverse axes of the hexagonal prism, but more rapid in one direction in the longitudinal slice, and that direction is the line of its optic axis. In the case of quartz the two diameters of the ellipse are as 1000 to 1312.

If the regular disposition of the molecules of amorphous bodies be interfered with by unequal tension or compression, the regularity of their power of conducting heat is destroyed, and they also show elliptical forms of melted wax; and the shorter axis of the ellipse is in the line of pressure or undue packing of the molecules. The heat thus does not travel so fast in this direction,—partly because it is spent in the heating up of the greater number of molecules. Hence we might conclude that along the main axis of quartz a smaller number of molecules are packed in an equal space than along the transverse. The following are the more important of Senarmont's results.

1. Crystals of the tetragonal and rhombohedral systems have one axis of conductivity which is either greater or smaller than the others, and this axis coincides with the main crystallographic axis. The isothermal surfaces are ellipses which lie in the line of this axis, and these ellipses may be either elongated or flattened in the direction of this line.

2. In crystals of the right prismatic system the isothermal surfaces have three unequal axes, which coincide with crystallographic axes drawn parallel to the edges of the rectangular prism.

3. In crystals of the oblique rhombic system the isothermal

surfaces have three unequal axes, one of which coincides with the horizontal diagonal of the base, while the other two have directions which are not referable to any law.

4. In crystals of the anorthic system the isothermal surfaces have three unequal axes, all with indeterminate positions.

In crystals of a single axis there appears to exist no constant relation between the axis of optic elasticity, whether maximum or minimum, and the axis of the greatest or of the least calorific conductivity. Thus, of the minerals examined by Senarmont, quartz (+), calcite (-), cassiterite (+), rutile (+), and calomel (+) have all their greatest axis of conductivity parallel to the principal axis; idocrase, beryl, tourmaline, and corundum, all optically negative, have on the contrary their smallest axis of conductivity parallel to the axis.

In crystals belonging to the oblique rhombic system there is rarely coincidence between the thermic axes and the axes of optic elasticity. In gypsum and in felspar these lie apart to a marked extent.

Dilatation by Heat.—In crystals of those systems in which the molecules are arranged unequally as regards their axes, the amount of their dilatation when heated is unequal in the direction of their axes. Our knowledge of this subject is chiefly due to Mitscherlich.

In crystals of cubic symmetry the expansion is equal in all directions. The dimetric systems—the pyramidal and hexagonal—are brought together as regards this quality, inasmuch as the axes of volumetric change are in these the same; for, while these in the pyramidal correspond with the crystallographic axes, in the hexagonal the three axes are the vertical, one lateral axis, and an axis lying intermediate to the other two and at right angles to the first lateral axis. The expansion along the principal axis may be either greater or less than along the others; and in some minerals there is even contraction along one axis.

In the right prismatic system the axes of dilatation correspond to those of form. In the oblique prismatic one axis corresponds with the orthodiagonal, but the others make angles not only with the other crystallographic axes but, strange to say, with the axes both of thermic conductivity and of optic elasticity. We are as yet ignorant of the properties of anorthic crystals in this respect.

As a consequence of this unequal expansion along different axes, the angles of crystals, other than those of the cubic system, are altered under the influence of heat. The alteration is extreme in the case of calcite, where, through elongation along the vertical axis, with some concomitant contraction of the transverse, the angle of the rhombohedral faces is, when the crystal is heated from 32° to 212° F., diminished from 105° 5' to 104° 56' 23",—the form thus approaching that of a cube, as the temperature is raised.

Dolomite, in the same range of temperature, diminishes 4' 46". In some rhombohedrons, as of calc-spar, the vertical axis is lengthened (and the lateral shortened), while in others, like quartz, the reverse is true. The variation is such, either way, that the double refraction is diminished with the increase of heat; for calc-spar possesses negative double refraction, and quartz positive. According to Fresnel the same is true of gypsum. The dilatation for calc-spar, according to experiment, is 0.001961.

Kopp has shown that in the carbonates of lime, magnesia, iron, manganese, and zinc, which are nearly the same in the angle of their crystals, the vertical axis is shorter the greater the atomic volume. And since heat diminishes the density, and therefore necessarily increases the volume, the axis a should be lengthened by an increase of temperature, as is actually the case. He has determined by calculation that the change of angle from 32° to 212° should be 7' 37".

Although in the greater number of cases the variations are so small as to be scarcely measurable, yet they may be sufficient for establishing a difference between substances which have identical geometric form while belonging to different systems of crystallization. The angle of a rhombohedron might at a certain temperature be 90°, and so coincide with a cube; but that angle would in a rhombohedron change whenever the temperature altered, while the angle of a true monometric cube is constant at all temperatures. The increase in volume and diminution in density which generally result from heating are always accompanied by a change in optical properties. In trimetric crystals, where the principal indices alter unequally, the change affects the amount of divergence of the optic axes. The amount of alteration in gypsum, when the divergence is diminished, is extreme. At the ordinary temperature the angle of the divergence of the optic axes which lie in the plane of symmetry is about 90° for red light; when heated to 177° it is diminished to 0°, and for the moment the crystal appears to be uniaxial. When more highly heated, the axes again diverge, but in a plane at right angles to the original one, and in cooling these changes take place in reverse order. In barytes and celestine again, the alteration in the angle of the optic axes is a divergence when heated.



Fig. 256.

Characters depending on Cohesion.

These characters are of five kinds:—(1) hardness, (2) tenacity, (3) elasticity, (4) cleavage, (5) fracture. All may be considered as related to the power of resisting attempts to separate one part from another.

1. *Hardness*.—A harder body is distinguished from a softer, either by attempting to scratch the one with the other, or by trying each with a file. Each of these methods is used by the mineralogist in determining the hardness of the species, though the latter is in most cases to be preferred. Both methods should be employed when practicable.

Certain varieties of some minerals give a low hardness under the file, owing either to impurities or imperfect aggregation of the particles, while they scratch another mineral upon which a file would have no effect, showing that the particles of the first are hard, though loosely aggregated. Chastolite, spinel, and sapphire are common examples of this. When the mineral is too hard to be impressed by a file, the peculiarity of the grating sound will suffice for the practised ear.

Mohs introduced a scale of hardness, consisting of ten minerals, which gradually increase in hardness from 1 to 10. The intervals between 2 and 3 and 5 and 6 are larger than the others. Breithaupt has therefore introduced another degree of hardness between each of the above, and thus his scale consists of twelve minerals.

The scale is as follows:—

1. Talc, common laminated light green variety.
2. Gypsum, a crystallized variety.
- 2.5. Mica (muscovite).
3. Calcite, transparent variety.
4. Fluor-spar, crystalline variety.
5. Apatite, transparent variety.
- 5.5. Scapolite, crystalline variety.
6. Felspar (orthoclase), white cleavable variety.
7. Quartz, transparent.
8. Topaz, transparent.
9. Sapphire, cleavable varieties.
10. Diamond.

If the file abrades the mineral under trial with the same ease as No. 4, and produces an equal depth of abrasion with the same force, its hardness is said to be 4; if with more facility than 4 but less than 5, the hardness may be $4\frac{1}{2}$ or $4\frac{3}{4}$, written in decimals 4.25, 4.5. Several successive trials should be made to obtain certain results.

The use of the file is acquired with very little experience; usually a single trial is sufficient. Care must be taken to apply the file to edges of equal obtuseness. That part also of the specimen should be selected which has not been altered by exposure, and has the highest degree of transparency and compactness of structure. The pressure for determination should be rather heavy, and the file should be passed three or four times over the specimen.

Where the scale of hardness is wanting, or a first rough determination is sought, the following experiments may serve:—

Every mineral that is scratched by the finger-nail has H. = 2.5 or less. Minerals that scratch copper have H. = 3 or more. Polished white iron has H. = 4.5. Window-glass has H. = 5 to 5.5. Steel point or file has H. = 6 to 7; hence every mineral that will cut or scratch with a good penknife has H. less than 6. Flint has H. = 7, and only about a dozen minerals, including the precious stones or gems, are harder.

Many specimens present different degrees of hardness on dissimilar faces; as an example of which we mention cyanite and mica. This is confined to the inequilateral primary forms, and like the similar difference of colour, lustre, &c., finds a ready explanation in the theory of their formation; unlike faces are the result of the action of the polar force acting along unlike axes.

This difference in faces parallel to unlike axes may be perceived in nearly all cases, when the methods of trial are sufficiently delicate. Huygens observed long ago that the cleavage face of a crystal of calc-spar differed in hardness from the other faces; and even in a monometric crystal it has been found that the faces of the cube and octahedron are not exactly alike in this respect.

2. *Tenacity*.—Solid minerals are said to be brittle, sectile, malleable, flexible, or elastic:—

1. *Brittle*, when parts of a mineral separate in powder or grains on attempting to cut it; as baryte, calc-spar.
2. *Sectile*, when pieces may be cut off with a knife without falling to powder, but still the mineral pulverizes under a hammer; as brucite, gypsum.
3. *Malleable*, when slices may be cut off, and these slices flatten out under a hammer; as native gold, native copper.
4. *Flexible*, when the mineral will bend and remain bent after the bending force is removed; as gypsum, graphite, talc.

5. *Elastic*, when after being bent it will spring back to its original position; as mica.

A liquid is said to be *viscous* when, on pouring it, the drops lengthen and appear ropy; as petroleum.

3. *Elasticity*.—Investigations on this property have not to any extent been entered upon. The unequal elasticity of unlike faces of crystals has been shown by Savart in his acoustic investigations, and he was able to distinguish the rhombohedral from the other faces in the pyramid of quartz crystals; he also showed that the figures formed upon vibrating plates of crystals were directly connected with their optic axes. Milne, by measuring the amount of recoil of a sphere of calcite when struck at different points by another of rock-crystal, found that the elasticity, as thus measured, was greatest along the line of the optic axis, and least in directions at right angles to it. He also found that points which lay intermediate between the main and the transverse axes were most indented by the blows. This goes to show that, although there may be fewest molecules arranged along the lines of the transverse axes, yet cohesion operates with greater intensity along these than in intermediate directions.

When the tenacity of a mineral is overcome by an overwhelming amount of traction, or its elasticity by a sudden shock, its parts are separated, either in flat and continuous surfaces, or in surfaces which are irregular in the extreme. The first of these modes is termed cleavage, the second fracture. In those substances in which cleavage exists it is found that the planes or directions along which it takes place lie in certain strictly definite positions to one another and to the axes of the crystal. They show not the smallest tendency to a transition or gradual passage into the other directions of greater coherence.

4. *Cleavage*.—The number of these parallel cleavage-planes is altogether indefinite, so that the only limit that can be assigned to the divisibility of some minerals, as gypsum and mica, arises from the coarseness of our instruments. These minima of coherence, or cleavage-planes, are always parallel to some face of the crystal; and similar equal minima occur parallel to every other face of the same form. Hence they are always equal in number to the faces of the form, and the figures produced by cleavage agree in every point with true crystals, except that they are artificial. They are thus most simply and conveniently described by the same terms and signs as the faces of crystals.

Some minerals cleave in several directions parallel to the faces of different forms, but the cleavage is generally more easily obtained and more perfect in one direction than in the others. This complex cleavage is well seen in calc-spar and fluor-spar, and very remarkably in zinc blende, where it takes place in no less than six directions. As in each of these the division may be indefinitely continued, it is clear that no lamellar structure in any proper sense can be assigned to the mineral. All that can be affirmed is that contiguous atoms have less coherence along a direction normal to these planes than in other directions. When cleavage takes place in three directions, it of course produces a perfect crystal form, from which the system of crystallization and angular dimensions of the species may be determined; it is thus often of very great importance.

The common cleavage in the different systems is as follows, those of most frequent occurrence being in italics:—(1) In the cubic system, *Octahedral*, O, along the faces of the octahedron; *Hexahedral*, $\infty O\infty$, along those of the cube; and *Dodecahedral*, ∞O . (2) In the tetragonal system, *Pyramidal*, P, or $2P\infty$; *Prismatic*, ∞P , or $\infty P\infty$; or *Basal*, OP . (3) In the hexagonal system with holohedral forms, *Pyramidal*, P, or $P2$; *Prismatic*, ∞P , or $\infty P\infty$; or *Basal*, OP ; with rhombohedral forms, *Rhombohedral*, R; *Prismatic*, ∞R ; or *Basal*, OR . (4) In the right prismatic system, *Pyramidal*, P; *Prismatic*, ∞P ; *Macrodomatic* or *Brachydomatic*, $P\infty$ or $P\infty$; *Basal*, OP ; *Macrodomatic*, $\infty P\infty$; or *Brachydomatic*, $\infty P\infty$. (5) In the oblique prismatic system, *Hemipyramidal*, P, or $-P$; *Prismatic*, ∞P ; *Clinodomatic*, $P\infty$; *Hemidomatic*, $P\infty$ or $-P\infty$; *Basal*, OP ; *Orthodomatic*, $\infty P\infty$; or *Clinodomatic*, $\infty P\infty$. (6) In the

CHEMICAL PROPERTIES OF MINERALS.

Influence of Chemical Composition on the External Characters of Minerals.—That the characters of a compound must to a certain extent depend on those of its component elements seems, as a general proposition, to admit of no doubt. Hence it might be supposed possible from a knowledge of the composition of a mineral to draw conclusions in reference to its form and its other properties, but practically this has not yet been effected.

The distinction between the mineralizing and mineralizable or the forming and formed elements lies at the foundation of all such inquiries. Certain elements in a compound apparently exert more than an equal share of influence in determining its physical properties. Thus the more important non-metallic elements, as oxygen, sulphur, chlorine, fluorine, are remarkable for the influence they exert on the character of the compound. The sulphurets, for example, have more similarity among themselves than the various compounds of one and the same metal with the non-metallic bodies. Still more generally it would appear that the electro-negative element in the compound is the most influential, or exerts the greatest degree of active forming power. After the non-metallic elements the brittle, easily fusible metals rank next in power; then the ductile ignoble metals; then the noble metals; then the brittle, difficultly fusible; and, last of all, the metals of the earths and alkalis.

Generally each chemical substance crystallizes only in one form or series of forms. Some substances, however, show dimorphism, or crystallize in two forms, and thus may compose two or more minerals. Thus sulphur, which in nature usually crystallizes in the right prismatic system, when melted forms oblique prismatic crystals. Carbon in one form is the diamond, in another graphite; carbonate of lime appears as calc-spar and as aragonite; the bisulphuret of iron as pyrite and as marcasite. An example of trimorphism occurs in titanite acid, forming the three distinct species anatase, rutile, and brookite. It is remarkable that of dimorphic minerals one form is almost always right prismatic; thus:—

	<i>Rhombic Form.</i>
Cyanite, anorthic	Sillimanite, Andalusite.
Calc-spar, hexagonal	Aragonite.
Sassanite, do.	Leadhillite.
Rutile	Brookite.
Anatase } pyramidal	Brookite.
Pyrolusite, right prismatic	Poianite.
Cuprite, cubic	Chalcotrichite (?)
Senarmonite, cubic	Valentinite.
Pyrite, do.	Marcasite.
Rammelsbergite, do.	Chloanthite.
Argentite, do.	Acanthite.
Freieslebenite, oblique prismatic	Diaphorite.
Sulphur, do.	Sulphur.

Even the temperature at which a substance crystallizes influences its forms, and so far its composition, as seen in aragonite, Glauber salt, natron, and borax.

Isomorphism.—Still more important is the doctrine of isomorphism, designating the fact that two or more simple or compound substances crystallize in one and the same form, or often in forms which, though not identical, yet approximate very closely. This similarity of form is generally combined with a similarity in other physical and in chemical properties. Among minerals that crystallize in the tesseral system, isomorphism is of course common and perfect, there being no diversity in the dimensions of the primary form; but for this very reason it is generally of less interest. It is of more importance among crystals of the other systems, the various series of which are separated from each other by differences in the proportions of the primary form. In these perfect identity is seldom observed, but only very great similarity.

The more important isomorphous substances are either simple substances, as (1) fluorine and chlorine; (2) sulphur and selenium; (3) arsenic, antimony; (4) cobalt, iron, nickel; (5) copper, silver, mercury, gold (?); or combinations with oxygen, as (6) lime, magnesia, and the protoxides of iron, manganese, zinc; (7) sesquioxides, as of iron, manganese, chromium, and alumina; (8) phosphoric acid, vanadic acid, arsenic acid; (9) sulphuric, selenic, chromic acids; or combinations with sulphur, as (10) sulphuret of iron and of zinc; (11) sulphuret of antimony and of arsenic; (12) sulphuret of lead, of copper, and of silver. These substances are named vicariously from the singular property that in chemical compounds they can mutually replace each other in definite proportions, and very often without producing any important change in the form or other physical properties. But there are numerous instances among the silicates where the mutual replacement of the isomorphous

anorthic system, Hemiprismatic, ∞P , or ∞P ; Hemidomatic either along the macrodome or the brachydome: *Basal* OP ; *Macrodomatic*, $\infty P\infty$; or *Brachydomatic*, $\infty P\infty$.

In some minerals, as mica and gypsum, the cleavage is readily procured; these may be held in the hand and divided by a knife. Others only cleave with more or less difficulty; these must be placed on a firm support resting on lead, folded paper, or cloth, and a sharp blow struck on a chisel applied in a proper direction. This may often be ascertained by examining the specimen in a strong light. Sometimes it is necessary to subject them to extreme compression in a vice. Some of the hardest substances have not only a perfect but a facile cleavage,—as euclase, topaz, and diamond; many of the softest species have none. The planes produced also vary much in their degree of perfection, being highly perfect in some, as mica and calc-spar, and imperfect in others, as garnet and quartz. In a very few crystalline minerals cleavage-planes can hardly be said to exist. Cleavage must be carefully distinguished from the planes of union in twin crystals, and the division-planes of laminar minerals.

5. *Fracture*.—This is the irregular manner in which substances may be broken. Even minerals possessed of cleavage may be fractured in other directions; but in amorphous bodies fracture alone occurs. The following varieties of fracture occur, and are highly characteristic:—

1. *Conchoidal*, almost typical of amorphous bodies, but occasionally seen in crystals,—rounded cavities, more or less deep. The name is taken from the resemblance to the successive lines of interrupted growth in a bivalve shell. Seen in flint, obsidian, asphalt. In calcite the direction of this fracture is intermediate to the planes of the mineral's cleavage.
2. *Even*, when the surface of fracture is smooth and free from inequalities.
3. *Rough*, when the surface of fracture is rugged, with numerous small elevations and depressions.
4. *Splintery*, when covered with small wedge-shaped splinters.
5. *Hackly*, when the elevations are sharp, slightly bent, or jagged, as broken iron.
6. *Earthy*, when it shows only fine dust.

Taste, Odour, Touch.

Taste belongs only to soluble minerals. The different kinds adopted for reference are as follows:—

1. *Astringent*, the taste of blue vitriol.
2. *Sweetish astringent*, taste of alum.
3. *Saline*, taste of common salt.
4. *Alkaline*, taste of soda.
5. *Cooling*, taste of saltpetre.
6. *Bitter*, taste of epsom salts.
7. *Sour*, taste of sulphuric acid.
8. *Pungent*, taste of sal-ammoniac.
9. *Metallic*, taste of zinc sulphate.

Odour.—Excepting a few gaseous and soluble species, minerals in the dry unchanged state do not give off odour. By friction, moistening with the breath, and the elimination of some volatile ingredient by heat or acids, odours are sometimes obtained which are thus designated:—

1. *Alliaceous*, the odour of garlic. Friction of arsenical iron elicits this odour; it may also be obtained from any of the arsenical ores or salts by means of heat.
2. *Horse-radish odour*, the odour of decaying horse-radish. This odour is strongly perceived when the ores of selenium are heated.
3. *Sulphurous*. Friction will elicit this odour from *ovrites*, and heat from many sulphurets.
4. *Bituminous*, the odour of bitumen.
5. *Fetid*, the odour of sulphuretted hydrogen or rotten eggs. It is elicited by friction from some varieties of quartz and limestone.
6. *Argillaceous*, the odour of moistened clay. It is obtained from serpentine and some allied minerals after moistening them with the breath; others, as pyrrargillite, afford it when heated.
7. *Empyreumatic* or *ozonic*. Quartz, when two portions strike one another.

Touch.—Some minerals are distinguished by a greasy feeling, as talc; others feel smooth, as celestionite; others meagre, like clay; others cold. This last character distinguishes true gems from their imitations in glass. Some, in virtue of their hygroscopic nature, adhere to the tongue.