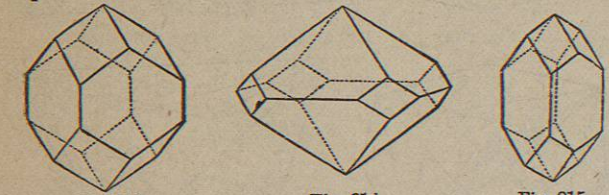


crystal or needle, as happens in red copper and pyrites. Crystals of acicular pyrites occur at the Newton-Stewart lead-mine.

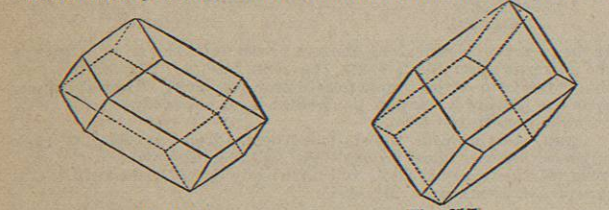
An octahedron flattened parallel to two of its faces is reduced to a tabular crystal (fig. 210). If lengthened in the same direction, it takes the form in fig. 211; or if it is still further lengthened, to the obliteration of two opposite octahedral faces, it becomes an acute rhombohedron (same figure).

When an octahedron is extended in the direction of a line between two opposite edges, it has the general form of a rectangular octahedron; and still further extended, as in fig. 212, it is changed to a rhombic prism with dihedral summits.

The figure represents this prism lying on its acute edge (spinel, fluor, magnetite). The dodecahedron when lengthened in the direction of the upright axis becomes a square prism with pyramidal summits (fig. 213); and when shortened along the same axis it is reduced to a square octahedron with truncated basal angles (fig. 214). Both



these forms are modifications of the square prism; the first mode of distortion is common in garnet, rendering it liable to be considered zircon; the second is seen in apatite, when it might be taken

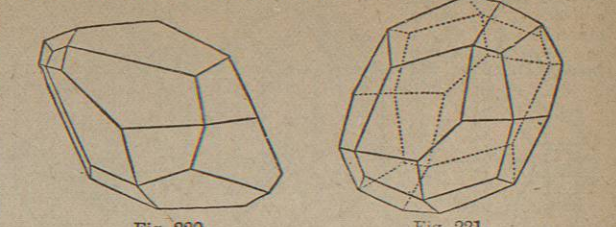


for stannite. When the first of these forms is flattened, as in fig. 215 it resembles a form of stilbite.

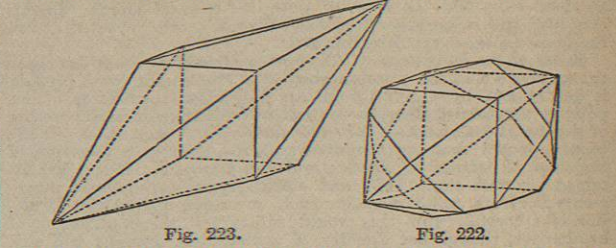
When a dodecahedron again is lengthened along a diagonal between the obtuse solid angles, it becomes a six-sided prism with trihedral summits, as in fig. 216; and when shortened in the same direction, it becomes a rhombohedron which has its six acute angles truncated (fig. 217). In the first case, a crystal of green garnet or uwarowite would resemble diopside; in the latter, colourless garnet would resemble calcite.

The trapezohedron is exceedingly subject to distortions which frequently disguise it much. When elongated in the direction of the upright axis it becomes a double eight-sided pyramid with four-sided summits (fig. 218); a further elongation along the same axis would

result in the obliteration of these summit faces, and in the production of a perfect double octagonal pyramid (fig. 219). The first of these distortions is exceedingly common in analcime and not



uncommon in garnet; the latter rarely occurs in analcime. Lengthened along an octahedral axis it becomes fig. 220; shortened along the same it becomes fig. 221. Both are seen in analcime.



When the tetrakis-hexahedron is lengthened along a single octahedral axis it assumes the form of fig. 222; still further elongated, with obliteration of one half of its planes, it becomes a scalene dodecahedron, resembling the "dog tooth" form of calcite (fig. 223). Fig. 224 is a hemihedron of this form, produced by shortening along an octahedral axis, with obliteration of all the planes which do not touch the poles of that axis.

In the case of modified crystals of this system the distortions are more complex. Fig. 225 represents a crystal of cinnamom-stone from Aberdeen-shire; it is a combination of the dodecahedron and the trapezohedron. Only four dodecahedral faces remain (d), and those of the trapezohedron (n) are of unequal size. It may be best understood by regarding it as fig. 218 with the four vertical faces of fig. 213, so that it combines the distortions of both of these figures.

Crystals of diamond are very frequently distorted, though generally through curvatures of their faces.

Imperfections in the Surfaces of Crystals.

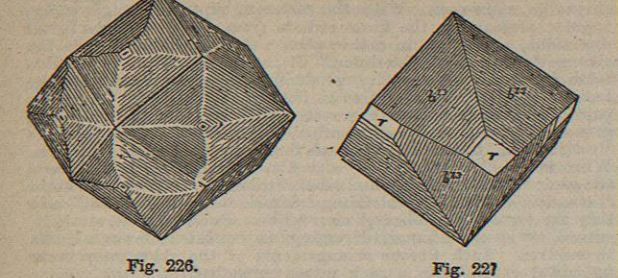
Of these the most important are striae, caverns, and curvatures.

1. *Striated Surfaces.*—The parallel furrows on the surfaces of crystals are called striae, and such surfaces are said to be striated. Each ridge on a striated surface is enclosed by two narrow planes. These planes often correspond in position to a secondary or to the primary planes of the crystal, and we may suppose these ridges to have been formed by repeated oscillation in the operation of those causes which give rise, when acting uninterruptedly, to larger planes. By this means the surfaces of a crystal are marked in parallel lines with a succession of narrow planes, meeting at angles alternately re-entering and salient, and constituting the ridges referred to. This combination of different planes in the formation of a surface has been termed an oscillation of faces.

Cubes of pyrites are generally striated in such a way that the striae on adjacent faces are at right angles to one another. These lines are parallel to the intersections of the primary faces with the planes of the pentagonal dodecahedron, which is the most common form of pyrites; and they have evidently resulted from an oscillation between the primary and this secondary form. The rhombic dodecahedron is often striated parallel either with the

edges, or with the longer or the shorter diagonal of its faces. In the first case, seen in garnet (fig. 226), there is a passage into the six-faced octahedron; the second results from an oscillatory combination of the dodecahedron with the regular octahedron, as in magnetite; and the last with the cube, as in apatite.

Rhombohedral crystals are often striated parallel to the



terminal edges (fig. 227), indicating an oscillatory combination between the primary faces and a secondary plane which bevels these edges.

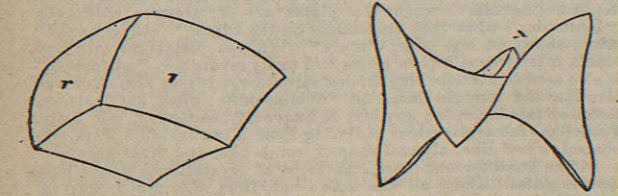
Striation of faces is more frequent in the rhombohedral system than in any of the others. Horizontal striae are of almost invariable occurrence in the prismatic faces of quartz, whatever be the form of the crystal. The oscillation here has taken place between the pyramidal and the prismatic faces (figs. 228, 229, 230). During its growth there seems to have been a continued effort to complete the crystal by the assumption of the terminal planes,—which effort was intermittently overcome by a preponderating one to continue the deposition of matter along its main axis. Quartz crystals, from these alternate efforts, often taper to a point, without having any regular pyramidal face.

The lateral planes of prisms of tourmaline are very frequently convex, owing to oscillation between several lateral faces. In all such cases the interfacial angles cannot be determined, as they are lost in the rounding.

The striations on the lateral faces of foliated minerals are merely the edges of laminae. Examples: mica and gypsum.

2. *Cavernous Crystals.*—Crystals not unfrequently occur with a deep pyramidal depression occupying the place of each plane, as is often observed in common salt, galena (fig. 21), and sulphur. In the solution of crystals through atmospheric exposure, an approach to the same form is sometimes obtained, owing to the fact that the centres of the faces yield sooner than the edges and angles. Crystals of red rutile are often thus cavernous. Sometimes octahedrons occur with a triangular cavity, in place of each face (fig. 22). The same is met with in other forms.

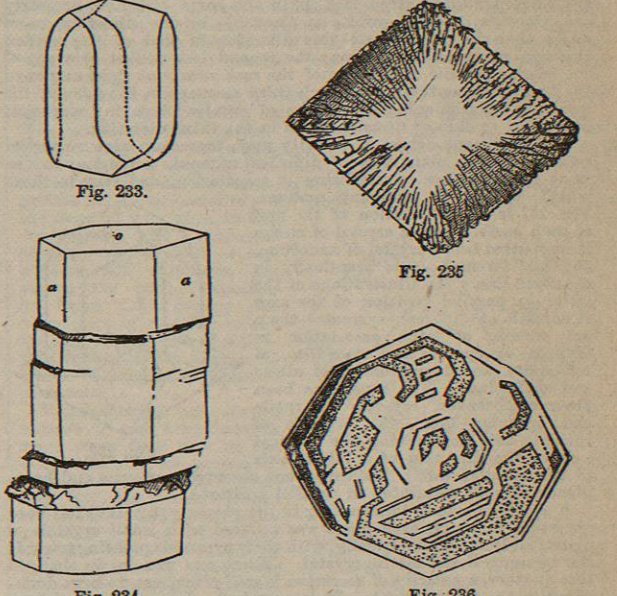
3. *Curved Surfaces.*—Curved surfaces sometimes result from the oscillatory combination already noticed. Others result from a curvature in the laminae constituting the crystal. Crystals of diamond have convex faces, and are sometimes almost spheres. This mode of curvature, in which all the faces are equally convex, is less common than that in which a convex surface is opposite and parallel to a corresponding concave surface. Rhombohedrons of spathic iron and pearl spar are usually thus curved, as is shown in fig. 231. The saddle-shaped crystals of the same mineral (fig.



232) are remarkable instances of several reversed curvatures in the same face. A singular curvature is shown in fig. 233, of calcite. The conical crystals of brown zinc blende, and the lenticular and conical crystals of gypsum, are other examples. Crystals of quartz are sometimes curved and twisted. When this takes place

in the left-handed and right-handed crystals, the twist is to the right or left according as the crystal is right- or left-handed.

The surfaces of crystals are frequently far from flat, on account of fracture, with dislocation of the several fragments, occasioned by motion in the enclosing rock, the material of which is forced, or it may be transfused, into the rents. The tourmalines and beryls (fig. 234) which occur in granitic dykes are very subject to this, the fragments being often bent as well as displaced. A more or less simultaneous effort in the crystallization of two substances may produce a structure with the external form of one, the interior of which exhibits imbedded crystals of the other, more or less perfect in their development. In pegmatite or graphic granite, rude crystals of felspar contain skeleton forms of quartz, of which generally only one side of the prism and two of the pyramid occur, forming a rude lettering. Similar hollow quartz forms occur imbedded in garnet, radiating from its centre (fig. 235), and roughening its surface from protrusion, without distorting its form. Totally imbedded microscopic crystals, "microliths," are, as in the latter cases, chemi-



cally non-assimilable. These are frequently arranged in layers in the including crystal, as in augite and leucite. When there is a certain amount of chemical resemblance there may occur a definiteness in the arrangement; and if the enclosed substance crystallizes in a system differing from that of the mineral which includes it, the angles of the latter are more or less distorted. This is the case in "microcline," where the intrusion of a plagioclase felspar causes some departure from the rectangularity of orthoclase. Foreign amorphous matter caught up or attaching itself to the surfaces of a crystal, during the process of its growth, causes lines of feeble cohesion,—as in the case of capped crystals of quartz. Here an occasional selectiveness in the sets of faces to which the foreign matter adheres seems to indicate that it has been to some extent under the influence of a polarity in its adhesion. Something of the same kind seems to have influenced the arrangement of the quartz grains caught up during the formation of the crystal of garnet shown in fig. 236. The perfect modelling of rock crystals is, however, but little interfered with by the almost numberless substances which they contain.

Aggregation of Crystals.

Crystalline aggregates which pass into amorphous masses may, in their more marked or perfect form, be assigned to an imperfect twinning.

Crystals are often grouped in linear series, as in native copper and silver, and thus constitute long threads or reticulations. In clustered crystals those adjoining each other are generally parallel in position, and are united by a plane parallel to one of the principal sections, or to planes of common occurrence. Senarmont mentions a union in galena,

parallel to the octahedral faces, as common: and he also describes an instance where the union was parallel to the plane 3 $\frac{1}{2}$.

The positions of crystals on the supporting rock seem at first to be without any regularity. But by closer inspection we detect even here the same law of harmony that governs the formation of the simple and compound crystal. The various positions assumed correspond generally with the more common kinds of composition in twin crystals. This regularity is not always manifest on account of the unevenness of the surface on which they rest. In general, however, on glancing over a surface covered with crystals, a reflexion from one face will be accompanied with reflexions from the corresponding face in each of the other crystals, showing that the crystals are similarly positioned throughout.

This tendency to parallelism in the positions of associated crystals is apparent even in crystalline aggregates. In granite, for example, which is composed of felspar, quartz, and mica, the felspar crystallizations have usually a common position; that is, the corresponding extremities lie in the same direction, or nearly so. On this account granite is cleavable in one direction more easily than in others, and this direction is that of the perfect cleavage plane of the felspar; the second less perfect cleavage of the felspar permits of fracture of the rock nearly at right angles to the first; but, as there is no such third cleavage in the felspar, the workman, in fashioning the blocks of granite for paving stones, is compelled to chip or dress them off in the third direction.

Parallelism in crystal growth.

The dominant action of polarity may, moreover, give a parallel position to the main axes of different minerals belonging to the same system, when crystallizing in association, and even to those which belong to different systems. Fig. 237 is an illustration of the first of such cases, where a crystal of zircon is implanted into a crystal of xenotime, and has its main axis identically in the same line. As illustrations of the latter—a parallel position of the axes of crystals of different systems—there are records of such association in crystals of cyanite and staurolite, of muscovite and haughtonite, of albite and orthoclase. The same has been observed between crystals of rutile and specular iron,—the crystals of rutile in this case having the vertical axis in the direction of a lateral axis of the specular iron. Haidinger has observed pyroxene and hornblende crystals associated in parallel positions.

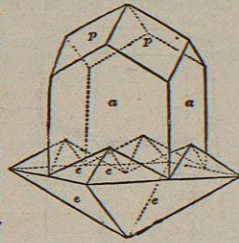


Fig. 237.

Irregular aggregation of crystals.

A prism of calcite terminating in the planes *g* (fig. 106) has been observed, in which each plane was covered with small crystals of quartz all lying symmetrically, with their pyramids pointing towards the summit of the calcite crystal. When one mineral is changed into another, a polarity of accretion is still often seen to have dominated in the arrangement. In a crystal of calcite which had been changed into a number of minute crystals of aragonite, the main axes of the latter all lay in the direction of the main axis of the original crystal of calcite.

Irregular Aggregation of Crystals.—Besides the regular unions now described, crystals are often aggregated in peculiar ways, to which no fixed laws can be assigned.

Thus some crystals, apparently simple, are composed of concentric crusts or shells, which may be removed one after the other, always leaving a smaller crystal like a kernel, with smooth distinct faces. Some specimens of quartz from Beeralston in Devonshire consist apparently of hollow hexagonal pyramids placed one within another. Other minerals, as fluor-spar, apatite, idocrase, heavy spar, and calc-spar, disclose a similar structure by bands of different colours. A growth rendered intermittent through the deposition of a thin layer of foreign matter is thus developed.

Many large crystals, again, appear like an aggregate of numerous small crystals, partly of the same partly of different forms. Thus some octahedrons of fluor-spar from Schlaggenwald are made up of small dark violet-blue cubes, whose projecting angles give a drusy character to the faces of the larger form. Such polysynthetic crystals, as they may be called, are very common in calc-spar.

Forms of Crystalline Aggregates.—Crystals have often been produced under conditions preventing the free development of their forms; and, according to the direction of the axis in which the development has been checked, they may be divided into "columnar" and "lamellar" arrangements.

The columnar structure is made up of a more or less fibrous arrangement; and this may be supposed to have accrued from the simultaneous growth of a multitude of crystals from a single or

from closely adjacent centres of support, so that, while the crystals were free to elongate themselves in the direction of their main axis, their increase was restrained laterally, by their impact upon one another. When the surfaces of support are level, or consist of the opposing sides of a vein, the columns or fibres, frequently exceedingly delicate, are parallel, and not unfrequently they then have a silky lustre. In the latter of the above circumstances the fibres are disposed transversely to the vein. Examples: gypsum, chrysotile, satin-spar. When the surface of support is rough, or has angular projections, the fibres radiate from certain of these in all directions, producing, in a thin vein, a starlike form, whence the arrangement is called "stellular." Example: wavellite. When this takes place in an open cavity, producing brush-like forms, they are termed "radiant." Examples: antimonite, needlestone. When the points of divergent growth are so positioned that the radiating groups interlace with one another, the structure is said to be "reticulated," from its resemblance to a net. Example: tremolite. When individual members of such fibrous structure project above the general surface with acuminated extremities, they are said to be "acicular"; when the protruding columns are of uniform thickness they are termed "bacillary," or rod-like. Such terms as straight, curved, twisted-columnar, diverging, or confused-fibrous explain themselves. Such fibrous arrangements as the above may occur imbedded centrally in a rock mass, which had been the magma out of which they were formed; or they may line the inner surface of cavities, filled originally either with water or aqueous vapour. These modes of occurrence have been distinguished by Mohs as crystal groups and druses. The former includes all unions of imbedded crystals round a central nucleus; the latter those of crystals of simultaneous or regularly successive growth on a common support. In the first case, there may be spheroidal, ellipsoidal, cockscomb, or other forms, frequently seen in marcasite, pyrite, and gypsum. In the second, spheroidal forms are less rare, but are seen in the case of several of the fibrous zeolites. In such cases surfaces more or less rough are coated, and diminished in angularity, through the hemispherical forms produced by the radiation of a multitude of fibres. Certain imitative outlines thus result from the successive deposition of layers of these crystals. These forms or uniting masses are termed "globular" when nearly spherical, "botryoidal" when like bunches of grapes, "reniform" or kidney-shaped when the spheres are larger, more confluent, and less distinct, and "mammillated" when the masses are nearer to hemispheres. Mesolite occurs in globular forms; prehnite in botryoidal; hematite and chalcodony in reniform; and siderite and calamine in mammillated. In all the above cases the transverse fracture of such structures discloses the fibrous arrangement of the parts; but, if the growth has been intermittent, lines of deposit, concentric with the central nucleus of each sphere, are evidenced by layers of distinct colours. Fracture or separation frequently takes place, also, along such lines. In such drusy cavities—termed "geodes" when they are circular—after a certain number of such lines of deposit, grouped arrangements which have somewhat more of free crystalline development may assume other imitative forms in which there is a certain dependence on the crystallographic character of the mineral concerned. There are thus produced coralloidal or coral-like groups, fruticose or cauliflower-like groups, capillary or hair-like, and filiform or thread-like or wire-like forms. Often these groups expand in several directions, and produce arborescent, dendritic, plumose, mossy, dentiform, or other forms. Such are common among the native metals; as gold, silver, and copper. Mesolite is very frequently plumose. A "drusy crust" is the term applied to a thin rough layer of crystals, which invests either a large crystal or the surface of some other body lodged in the interior of cavities.

In the lamellar structure a development along the main axis would appear to have been checked, and the crystallographic force to have expended itself laterally; though this is not the invariable habit of a species under all circumstances, as exemplified by baryte. This structure consists of flat crystals, plates, or leaves. It is termed "tabular" when the plates are of uniform thickness, "lenticular" when they are thinner on the edges, "wedge-shaped" when sharp on one edge, "scaly" when the plates are thin and small, "foliaceous" when larger and easily separable; "micaceous" is also used to describe this kind of structure. It may also be curved lamellar and straight lamellar. Wollastonite, when flat lamellar, is called tabular spar; gypsum is frequently lenticular, talc scaly. Lamellar minerals when radiating from a centre often form fan-shaped, wheel-like, almond-shaped, comb-like, and other groups.

In the granular structure, the force of crystallization has been exerting itself along all the axes: but, from the multiplicity of crystallizing centres, there has been such mutual interference that no single individuals have been able to assume perfect or even characteristic forms. The particles in a granular structure differ much in size. When coarse, the mineral is described as coarsely granular; when fine, finely granular; if not distinguishable by the naked eye, the structure is termed impalpable. Examples of the first may be observed in granular carbonate of lime, of the

second in some varieties of specular iron, of the last in chalcedony, opal, and other species.

The above terms are indefinite, but of necessity, as there is every degree of fineness of structure in the mineral species, from perfectly impalpable, through all possible shades, to the coarsest granular. The term phanerocrystalline has been used for varieties in which the grains are distinct, and crypto-crystalline for those in which they are not discernible without the aid of a lens. Granular minerals, when easily crumbled in the fingers, are said to be friable.

The minute or crypto-crystalline minerals form aggregates somewhat similar to the above. When globular or oolitic, the minute crystals often appear to radiate from a centre, or form concentric crusts. These are often globular or nodular; as in dolomite. Somewhat similar are the stalactites and stalagmites, in which the mineral (especially rock-salt, calc-spar, malachite, hematite, limonite) has been deposited from a fluid dripping slowly from some overhanging body, or some rent in the roof of a cave. In this case there is generally found a long pendent cylinder or cone, the principal axis of which, generally hollow, is vertical, whilst the marginal parts are arranged at right angles to it, except where they curve round the termination of the tube, when they become hemispherical.

By far the largest masses of the mineral kingdom have, however, been produced under conditions in which a free development of their forms was excluded, and are termed amorphous. This has been the case with the greater portion of the minerals composing rocks or filling veins and dykes. The structure of these masses on the large scale belongs to geology, but some varieties of the textures, visible in hand specimens, may be noticed. The individual grains or masses have seldom any regular form, but appear round, long, or flat, according to circumstances, and as each has been more or less checked in the process of formation. Even then, however, a certain regularity in the position of the parts is often observable, as in graphic granite, where the axes of the skeleton crystals of quartz are parallel. The rock is termed massive when the grains which form it are small, or granular when they are longer and more distinct. Sometimes the rock becomes slaty, dividing into thin plates; or concretionary, forming roundish masses; at other times the interposition of some foreign substance (gas or vapour) has rendered it porous, cellular, or vesicular, giving rise to drusy cavities. These cavities are often empty, but have occasionally been more or less filled by products of change in the rock. It is named amygdaloidal when the cavities so filled have the form of an almond.

Changes of Crystalline Structure.

"Pseudomorphs" are minerals which appear under a form of crystallization which does not belong to the species. They may be recognized either by their having no cleavage, which is most usual, or by their cleavage being altogether different in direction from that of the mineral imitated. Generally they have rounded angles, rough and dull surfaces, and when broken show a granular structure. The faces of the crystal, moreover, are often covered with minute crystals of a form different from that of the mineral imitated, but which is that belonging to the substance now present. Occasionally the resemblance to real crystals is so perfect, from the perfect polish of the faces, that they are distinguished with difficulty. They may be frequently found still undergoing change.

Pseudomorphs have been classed under four heads:—

1. **Pseudomorphs by Alteration.**—Formed by a gradual change of composition in a species. Of these there are two varieties: they may be pseudomorphous by loss of an ingredient, or by addition of an ingredient; change of augite to steatite is an example of the first, and of galena into anglesite is one of the second.

2. **Pseudomorphs by Substitution.**—Those formed by the replacement of a mineral which has been removed, or is gradually undergoing removal; e.g., galena takes the form of pyromorphite.

3. **Pseudomorphs by Incrustation.**—Those formed through the incrustation of a crystal, which may be subsequently dissolved away. Often the cavity is afterwards filled by infiltration: e.g., change of fluor to quartz.

4. **Pseudomorphs by Paramorphism.**—Those formed when a mineral passes from one dimorphous state to another: e.g., change of aragonite to calcite.

These different kinds of change are not always distinguishable. In some cases a change may take place through alteration of the surface, and then, this process ceasing, the interior may be dissolved out, leaving a pseudomorph like one of incrustation, or a pseudomorph that appears to be a result of mere chemical alteration may be wholly due to substitution simply.

Again, changes of scapolite to a felspar, and of augite to uraltite (hornblende), have been considered by Scheerer examples of paramorphism,—scapolite being considered dimorphous with some felspars, and augite with hornblende. But while such paramorphic changes undoubtedly take place with aragonite, their occurrence in these silicates—which are common associates in the same rock, and must have been formed under like circumstances—is hardly probable.

Where mineral bodies have taken the form of organisms, it is more a case of molecular replacement than of true pseudomorphism.

Pseudomorphism should be understood, however, to consist, not simply in alteration of crystals, but in many instances of change in beds of rock. Thus all serpentine, whether in mountain masses or in simple crystals, has been formed through a process of pseudomorphism—or, in more general language, of metamorphism—of olivine and augite. The same is true of other magnesian rocks, a steatitic, talcose, and chloritic slates. The crystalline rocks offer other examples of a change similar in nature. The graphite of these rocks is probably but a metamorph of some vegetable organism. Thus the subject of metamorphism, as it bears on all crystalline rocks, and that of pseudomorphism, are but branches of one system of phenomena; the chemistry of both is the same, and a knowledge of such changes is indispensable to a study of the older rock strata of the earth.

The common change of pyrites, forming the main ingredient of the upper part of metallic lodes, to earthy red or brown iron ore, thus producing the "gossan" of miners, is one of many examples of these processes now in progress. Often the gossan contains disseminated silver or gold, derived from the decomposed ores. This is a case of pseudomorphism, as truly as when a simple crystal of pyrites becomes limonite; the mode of change and its laws are the same. Again, phosphates, vanadates, and arseniates of lead, &c., as well as carbonates and sulphates, are among the surface species, or those that occupy the upper part of metallic lodes; they are the results of alteration within those depths to which atmospheric agencies penetrate.

Pseudomorphs are always records of past existences, in some cases they may be the only evidence we possess of such prior existence. Figs. 238, 239 are pseudomorphs of quartz or hornstone after datholite; the measured angles of these crystals show that the imitated crystal was datholite; but that mineral does not now occur in crystals of either of these forms.

The process of petrification of organic bodies is in reality a species of pseudomorphic formation, and has been produced in all the above modes.

External and internal casts of organic bodies are not uncommon. In other cases the original substance has been replaced by some mineral which has preserved, not merely the external form, but even the minutest detail of internal structure,—so that the different kinds of wood have been distinguished in their silicified trunks. The most common petrifying substances are silica and carbonate of lime. In encrinetes, echinites, belemnites, and other fossils, the crystals of calc-spar often occur in very regular positions. In some varieties of petrified wood both the ligneous structure and the cleavage of the calc-spar are observable.

Different from the above are mineralized bodies, in which the original structure is still retained, but their chemical nature partially changed. In these a complete series may be often traced, as from wood or peat, through the varieties of brown coal, common coal, anthracite, and graphite.

Causes of Change.—The causes of change are the simplest and most universal operations about us:—(1) the process of gradual alteration to which some substances are liable on account of the presence of oxygen and carbonic acid in the atmosphere, and the reaction of substances thus formed on adjacent ingredients, aided or promoted by electrical currents or by heat; (2) the solvent power of ordinary waters, cold or hot, or of steam; (3) reactions, in accordance with chemical principles, of the ingredients

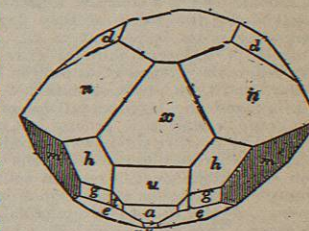


Fig. 238.

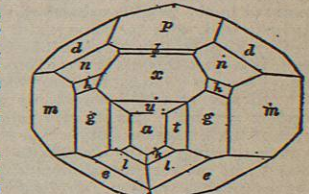


Fig. 239.

dissolved in these waters, or in mineral or sea waters, heated or at the ordinary temperature; (4) the action of gases exhaling from the earth; (5) changes referable to volcanic action.

Ordinary waters hold in solution, as is well known, more or less of mineral matter. When water containing carbonic acid is passed through a large number of ordinarily occurring minerals, it gives evidence of the presence of an alkali, or lime, or magnesia; and some of these minerals give the tests even with the first drops. Pure water gives with many of them a similar result, but more slowly. Limestone in forty-eight hours yields soluble ingredients to the extent of 0.4 to 1 per cent. of the whole mass. The lime, magnesia, and alkalies appear in the condition of carbonates; and the iron passes from the state of carbonate to that of peroxide during evaporation. The silicates of magnesia, lime, and manganese are especially ready in yielding to this action. Silica, however, is more soluble in ordinary than in carbonated water.

These facts illustrate two important points:—(1) that ordinary waters lying upon and filtering through the earth's crust are constantly active in dissolving and decomposing minerals and rocks, and that even species reputed indestructible are thus acted upon; and (2) that the waters are thus furnishing themselves with agents capable of effecting other chemical changes. These waters penetrate all rocks, as well as percolate through soils. Hence the action is a universal one, everywhere going on; and the results are universal. Bones, shells, corals, and animal remains generally are also sources of carbonate of lime, phosphates, and fluorides; and plants may contribute also potash and soda, and sometimes silica.

Carbonic acid is a constant ingredient of the atmosphere, and is dissolved by the rains as they descend; hence this active decomposing agent is present in all ordinary waters; but it is also a result of different mineral changes. Sulphate of iron along with vegetable matters gives oxygen to the carbon of the vegetable matter, and thus produces carbonic acid and pyrites or sulphuret of iron; and the large quantities of pyrites in coal-beds show on how grand a scale this process has taken place. Sulphate of zinc in a similar manner produces carbonic acid and blende or sulphuret of zinc. Bischof observes that the carbonic acid which has thus been eliminated must have been sufficient in quantity to make an atmosphere of carbonic acid equal in height to our present atmosphere. Again, decomposition of sulphurets produces sulphuretted hydrogen; this by the oxidating action of the atmosphere forms sulphuric acid, and the sulphuric acid acting on limestone produces gypsum, and liberates carbonic acid. Sulphurous acid is also generated in the neighbourhood of volcanoes, and rapidly becomes sulphuric acid, with the same result. Moreover, silica in waters, if aided by heat, will decompose limestone and liberate carbonic acid. Hence it is that this gas is exceedingly common in exhalations from mineral springs; indeed it occurs more or less in all waters.

The dissolving and decomposing action of carbonated waters is therefore general. The sea also partakes of this character, and, in virtue of the numerous salts which it holds dissolved, is a powerful agent in carrying on the changes to which the process leads. Such changes and the various pseudomorphs to which they give rise have to be regarded as types and evidences of vast metamorphic transformations,—processes either of decay or of reformation which have modified widespread rock-masses, and which are at the present time altering the structure of the crust of the earth. It is through a study of pseudomorphs, and of the processes which have gone to form them, that mineralogy is to become the germ from which alone the petrological department of geology can have its true development, and become a living instead of a merely speculative science.

PHYSICAL PROPERTIES OF MINERALS.

Characters Depending on Light.

There are few more interesting departments of science than the relations of mineral bodies to light, and the modifications which it undergoes either when passing through them or when reflected from their surface. In this place, however, we only notice these phenomena so far as they point out distinctions in the internal constitution of minerals, or furnish characters for distinguishing one species from another.

Lustre.—Though the varieties of lustre admit of no precise or mathematical determination, they are of considerable value in mineralogy. One highly important distinction founded on them is that between minerals of metallic and non-metallic aspect or character. Transparency and opacity nearly coincide with this division,—the metallic minerals

being almost constantly opaque, the non-metallic more or less transparent. Minerals which are perfectly opaque, and show the peculiar brilliancy and opacity of surface of polished metals, are named metallic; those which possess these properties in an inferior degree are semi-metallic; and those without these properties are non-metallic.

Lustre has reference to either the intensity or the quality of the reflected light, considered as distinct from colour. Several degrees in intensity have been named:—(1) splendid, when a mineral reflects light so perfectly as to be visible at a great distance, and lively and well-defined images are formed in its faces, as galena, specular iron, or cassiterite; (2) shining, when the reflected light is weak, and only forms indistinct and cloudy images, as heavy spar or calcite; (3) glistening, when the reflected light is so feeble as not to be observable at a greater distance than arm's length, and no longer forms an image, as talc; (4) glimmering, when the mineral held near the eye in full clear daylight presents only a number of small shining points, as red hæmatite and granular limestone. When, as in chalk or kaolin, the lustre is so feeble as to be indiscernible, the mineral is said to be dull.

In regard to the kind or quality of the lustre, the following varieties are distinguished:—(1) the metallic, seen in much perfection in native metals and their compounds with sulphur, and imperfectly in glance coal; (2) adamantine, found in beautiful perfection in the diamond, and in some varieties of blende and cerussite; a modification is metallic adamantine, as seen in wolfram and black cerussite; (3) vitreous or glassy, seen in rock crystal, or common glass, or, inclining to adamantine, in flint glass; sub-vitreous is seen in broken calcite; (4) resinous, when the body appears as if smeared with oil, as in pitchstone, blende, and garnet; (5) waxy, like beeswax, as seen in wax-opal and ozocerite; (6) pearly, like mother-of-pearl, seen in gyrolite, talc, heulandite; (7) silky, the glimmering lustre seen on fine fibrous aggregates like amianthus, tremolite, chrysotile, kroidolite.

These degrees and kinds of lustre are generally exhibited differently by unlike faces of the same crystal, but always similarly by like faces. The lateral faces of a right square prism may thus differ in lustre from that of a terminal face. Thus the lustre of the lateral faces of apophyllite is vitreous, while that of the terminal, at right angles thereto, is pearly; chrysotile is silky when split along the fibres, dull when at right angles to them.

The surface of a cleavage plane, in foliated minerals, generally differs in lustre from the sides; and here again in some cases the latter are vitreous, while the former is pearly, as in heulandite.

As shown by Haidinger, only the vitreous, adamantine, and metallic lustres belong to faces perfectly smooth and pure. In the first, the index of refraction of the mineral is 1.3 to 1.8; in the second, 1.9 to 2.5; in the third, above 2.5. The pearly lustre is a result of reflexion from numberless lamellæ, or cleavage planes, within a translucent mineral; and in hydrated minerals, as in the zeolites, it is the result of incipient change,—namely, a loss of water which ensues upon exposure to the atmosphere.

Colour.—This is a property which is of very inferior value. Minerals are so seldom, if ever, absolutely pure that very minute quantities of an intensely coloured impurity may impart colour to a substance inherently colourless, or overpower a feebler colour which may be its own.

Some few minerals have colour so strong, or have a constitution so little susceptible of intermixture, that they retain almost unpaired the colour special to them. Such a substance is pyrite; its brass-yellow colour may be heightened to gold-yellow by intermixture with copper sulphide, or it may be slightly bleached by arsenic; but the nature of its composition does not admit of the intrusion of ordinary colouring ingredients. The yellow of native gold, again, may be paled by impoverishment with the white of silver, down to the dull tint of electrum; but no foreign colouring matter can intrude itself into a metallic mass. Such substances as these,—native metals, sulphides, and oxides,—have colours essential to them, dependent on their constitution, and to a great extent characteristic of the species.

A second class of minerals are colourless of themselves, and thus very subject to the influence of minute quantities of foreign tinctorial impurity. These are absolutely transparent and devoid of colour when in crystals, but white and opaque when reduced to powder; as ice and snow, calcite and chalk, rock-crystal and sand. But such substances are generally coloured; "muddied" it would be called in the first case, though it is equally so with the others. Such false colour may be imparted in several ways. It may be (1) from their holding dissolved some colouring matter; (2) from mechanical mixture of colouring substances such as metallic oxides, or minute crystals ("endomorphs") of another mineral; or

(3) from chemical replacement,—the substitution of a smaller or larger quantity of a coloured isomorphous ingredient.

As illustration of the first, silica, colourless in rock-crystal, has been found of almost every tint, due frequently to volatile hydrocarbons which are dissipated by heat. Fluorite also, found of almost every shade of every colour, may possibly be to a certain extent referred here.

Quartz, felspar, and calcite are often coloured accidentally by imbedded layers of foreign "inclusions," or by "spangling endomorphs." These are mechanically mixed, so far as regards their presence in a structure of different and non-assimilable chemical composition, but crystallographically arranged. They either mark the lines of interrupted or intermittent growth; or, in the case of endomorphs, the axial positions of the minute intruding foreign crystals lie in one plane, or in the same sets of planes.

As an instance of colours introduced through definite chemical replacement, calcite may be cited. Carbonate of lime is colourless; if a portion of this be replaced by carbonate of magnesia there is a certain amount of pearly opacity; if by carbonate of manganese, of a pink tinge; if by carbonate of iron, of yellow, which may be increased through oxygen absorption and "weathering" to an ochre tint, and ultimately to a dark brown.

Sulphuret of zinc, chemically white, and mineralogically transparent, may, through metallic substitution, be found of almost all tints of yellow, orange, brown, and black. Again, hornblende, augite, and garnet,—silicates, which in their purest states of tremolite, malacolite, and water garnet are colourless,—acquire green, brown, red, and black tints from the assimilation of other metallic silicates.

Hence it would appear that a very advanced practical knowledge of the subject is necessary to enable us to avail ourselves of the information which is to be derived from this external feature.

The accidental coloured minerals sometimes present two or more colours or tints, even in a single crystal,—very remarkable examples occurring in fluor-spar, apatite, sapphire, amethyst, tourmaline, and cyanite. This is still more common in compound minerals, on which the colours are variously arranged in points, streaks, clouds, veins, stripes, bands, or in brecciated and ruin-like forms. Some minerals again change their colour from exposure to light, the air, or damp. Then either the surface alone is affected or "tarnished," and appears covered as with a thin film, producing in some minerals, as silver and arsenic, only one colour; in others, as chalcopryite, hæmatite, bismuth, stibine, and anthracite, various or iridescent hues, when they are said to have a pavonine lustre. Or occasionally the change pervades the whole mineral, the colour either becoming paler, or disappearing, as in chrysoptase and rose-quartz, or becoming darker, as in brown spar, siderite, and rhodonite. In a few minerals a complete change of colour takes place, as in heterosite, and in the chlorophane of the Western Isles of Scotland, which, on exposure for a few hours, passes from a transparent yellow-green to black. These mutations are generally connected with some chemical or physical change. The tarnished colours sometimes only appear on certain faces of a crystal belonging to a peculiar form. Thus a crystal of copper pyrites (like fig. 89) has one face P free from tarnish; the faces *b* and *c*, close to P, dark blue; the remainder of *c*, first violet, and then, close to P, gold-yellow.

Some crystalline minerals exhibit in certain directions a very lively play or change of colours from reflected light. It is well seen in many various hues on the cleavage-planes of labradorite, and seems produced by a multitude of very thin quadrangular pores, interposed in the mineral, like minute parallel laminae. On the cleavage-planes of hypersthene it appears copper-red, and is occasioned by similar pores, or by numerous small brown or black laminae of some foreign substance interposed in a parallel position between the planes of the hypersthene. The chatoyant or changing colours of the sun-stone arise from scales of hæmatite similarly interposed, and that of aventurine from scales of mica. The play of colour in the noble opal seems to be produced very nearly in the same manner as that in the labradorite. A similar opalescence is seen in certain minerals when cut in particular forms. In the sapphire, cut hemispherically over the chief axis, it appears like a star with six rays; in garnet it shows four rays; in certain varieties of chrysoberyl and of adularia it has a bluish tint; and it is also very remarkable in the cat's-eye variety of quartz. Iridescence often arises from very fine fissures, producing semicircular arches of prismatic tints, which, like the colours of thin plates in general, are referred to the interference of light.

Streak.—This name is applied to the appearance and the colour of the line or furrow produced in minerals by drawing the edge of a hard-tempered knife or file along their surface, or to the stain obtained by rubbing a soft mineral on such a substance as paper or porcelain. Taken along with the hardness, which may to a certain extent be

determined by the same operation, it is one of the most valuable tests which we possess.

The furrow may be lustrous or it may be dull. Powder or splinters may lie along its course, or a still adherent ridge may have been merely rolled over. The furrow and the powder may each be possessed of colour, though such may not be distinguishable in the mineral, or may have a colour quite different from that of the mineral. Three illustrations of the usefulness of this test may suffice. Argentiferous gold, chalcopryite, and pyrite, differing immensely in value, may readily be mistaken for each other. The knife, when drawn along the surface of the first, sticks in it, ruts up an adhering ridge, and leaves a shining streak of the same colour as the specimen. When drawn along the second it ruts up a trench covered with a dusty powder, which when rubbed on paper or in the hand is greenish yellow. When drawn along the third it has no effect, as pyrite is harder than the knife. Psilomelane, hæmatite, and limonite all occur in black, glossy, stalactitic forms, and have all been termed "black hæmatite." There is here also great difference in the value. The knife makes little impression on psilomelane, but leaves a blue lustrous line; it makes a blood-red line in hæmatite, and a rich ochre-yellow in limonite. Graphite and molybdenite both crystallize in hexagonal plates, both occur in the same rocks, both have a grey-black colour and a brilliant metallic lustre, both stain the hands or paper; the streak of the first—best seen on paper—is black, tending to blue; that of the last is greenish. Rough porcelain is the best material for determining the streak of soft minerals.

Diaphaneity.—Minerals, and even different specimens of the same species, vary much in this quality. Some transmit so much light that small objects can be clearly seen, or letters read, when placed behind them; such are named transparent. They are semitransparent when the object is seen only dimly, as through a cloud, and translucent when the light that passes through is so broken that the form of the object can be no longer discerned; some minerals are only thus translucent on the thinnest edges. Others transmit no light, and are named opaque.

Refraction.—It has already been mentioned that most crystals—all, in fact, except those of the cubical system—exhibit the phenomena of double refraction. For a general explanation of these phenomena the reader is referred to LIGHT, vol. xv. p. 609 *sq.*

The direction in which there is no double refraction is named the optic axis of the crystal,—sometimes, less happily, the axis of double refraction. Now in certain minerals it is found that there is only one direction with this property, whereas in others there are two such directions; and they have in consequence been divided into uniaxial and biaxial. To the former belong all crystals of the tetragonal and hexagonal systems, to the latter all those of the other three systems. In the former the optic axis coincides with or is parallel to the crystallographic chief axis. In some uniaxial crystals the index of refraction for the extraordinary ray is greater than for the ordinary ray; and in others it is smaller. According as it is greater or less they are said to have positive (attractive) or negative (repulsive) double refraction.

Quartz is an example of the former, the index of refraction, according to Malus, being for O=1.5484, for E=1.5582; calc-spar of the latter, the index of O being =1.6543, that of E 1.4833. The index of E is in both cases taken at its maximum.

It should be observed that the optic axes are not single lines, but directions parallel to a line, passing through every part of the crystal. It is also important to remark that this property divides crystals into three precise groups:—the cubic, with single refraction; the tetragonal and hexagonal, with double refraction, and uniaxial; those of the other three systems, also double, but biaxial. These properties are therefore of the greatest use in determining the system to which a mineral belongs.

Polarization.—Intimately connected with this property is that of the polarization of light, which affords an easier means of determining mineralogical characteristics than the direct study of double refraction. For the elements of this subject see LIGHT, vol. xv. p. 611 *sq.*

While a consideration of the optic axes enabled us merely to arrange the systems of crystallization in three groups, the phenomena of polarization not only bear out a further subdivision of the whole into the above six systems, but disclose, in many cases, phenomena markedly special to individual species. The optical consideration of these phenomena enables us to fix three directions of