IRREGULARITIES OF CRYSTALS

254. The laws of crystallization, when unmodified by extrinsic causes, should produce forms of exact geometrical symmetry, the angles being not only equal, but also the homologous faces of crystals and the dimensions in the directions of like axes. This symmetry is, however, so uncommon that it can hardly be considered other than an ideal perfection. The various possible kinds of symmetry, and the relation of this ideal geometrical symmetry to the actual crystallographic symmetry, have been discussed in Arts. **14** and **18** *et seq.* Crystals are very generally distorted, and often the fundamental forms are so completely disguised that an intimate familiarity with the possible irregularities is required in order to unravel their complexities. Even the angles may occasionally vary rather widely.

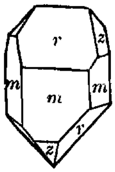
The irregularities of crystals may be treated under several heads: 1, *Variations of form and dimensions;* 2, *Imperfections of surface;* 3, *Variations of angles;* 4, *Internal imperfections and impurities.*

1. VARIATIONS IN THE FORMS AND DIMENSIONS OF CRYSTALS

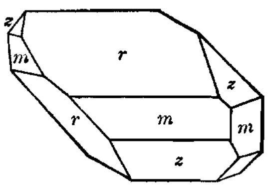
255. Distortion in General. — The variations in the forms of crystals, or, in other words, their *distortion,* may be *irregular* in character, certain faces being larger and others smaller than in the ideal geometrical solid. On the other hand, it may be *symmetrical,* giving to the distorted form the symmetry of a group or system different from that to which it actually belongs. The former case is the common rule, but the latter is the more interesting.

256. Irregular Distortion. — As stated above and on p. 13, all crystals show to a greater or less extent an irregular or accidental variation from the ideal geometrical form. This distortion, if not accompanied by change in the interfacial angles, has no particular significance, and does not involve any deviation from the laws of crystallographic symmetry. Figs. 463, 464 show distorted crystals of quartz; they may be compared with the ideal form, Fig. 284, p. 113. Fig. 465 is an ideal and Fig. 466 an actual crystal of lazulite.

463

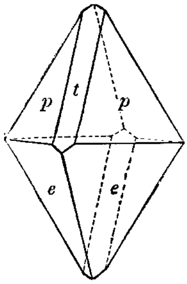


464

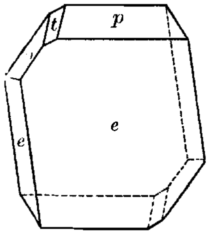


Quartz

465



466



Lazulite

The correct identification of the forms on a crystal is rendered much more difficult because of this prevailing distortion, especially when it results in the entire *obliteration* of certain faces by the enlargement of others. In deciphering the distorted crystalline forms it must be remembered that while the appearance of the crystals may be entirely altered, the interfacial angles remain the same; moreover, like faces are physically alike — that is, alike in degree of luster, in striations, and so on. Thus the prismatic faces of quartz show almost always characteristic horizontal striations.

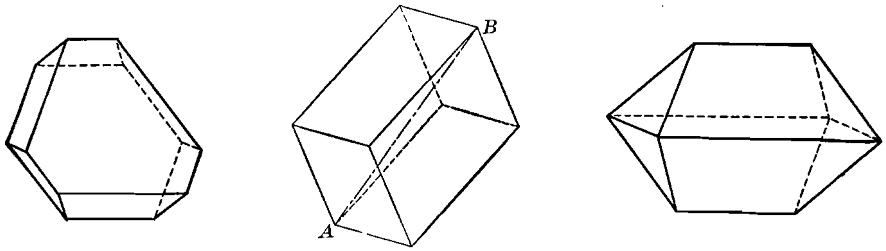
In addition to the variations in form which have just been described, still greater irregularities are due to the fact that, in many cases, crystals in nature are attached either to other crystals or to some rock surface, and in consequence of this are only partially developed. Thus quartz crystals are generally attached by one extremity of the prism, and hence have only one set of pyramidal faces; perfectly formed crystals, having the double pyramid complete, are rare.

257. Symmetrical Distortion. — The most interesting examples of the symmetrical distortion of crystalline forms are found among crystals of the isometric system. An elongation in the direction of one cubic axis may give the appearance of tetragonal symmetry, or that in the direction of two cubic axes of orthorhombic symmetry; while in the direction of an octahedral axis a lengthening or shortening gives rise to forms of apparent rhombohedral symmetry. Such cases are common with native gold, silver, and copper.

A *cube* lengthened or shortened along one axis becomes a right square prism, and if varied in the direction of two axes is changed to a rectangular prism. Cubes of pyrite, galena, fluorite, etc., are often thus distorted. It is very unusual to find a cubic crystal that is a true symmetrical cube. In some species the cube or octahedron (or other isometric form) is lengthened into a capillary crystal or needle, as happens in cuprite and pyrite.

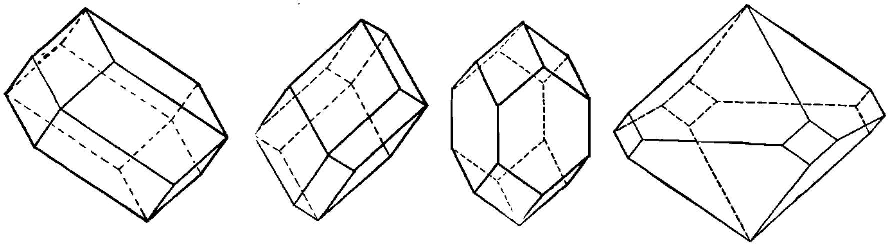
An octahedron *flattened* parallel to a face — that is, in the direction of a trigonal symmetry axis is reduced to a tabular crystal resembling a rhombohedral crystal with basal plane (Fig. 467). If *lengthened* in the same direction (*i.e.* along line A–B, Fig. 468), to the obliteration of the terminal octahedral faces, it becomes an acute rhombohedron.

When an octahedron is extended in the direction of a line between two opposite edges, or that of a binary symmetry axis, it has the general form of a rectangular octahedron; and still farther extended, as in Fig. 469, it resembles a combination of two orthorhombic domes (spinel, fluorite, magnetite).



467 **468** **469**

Distorted Octahedrons



470 **471** **472** **473**

Distorted Dodecahedrons

The *dodecahedron* lengthened in the direction of a trigonal symmetry axis becomes a six-sided prism with three-sided summits, as in Fig. 470. If shortened in the same direction, it becomes a *short* prism of the same kind (Fig. 471). Both resemble rhombohedral forms and are common in garnet. When lengthened in the direction of one of the cubic axes, the dodecahedron becomes a square prism with pyramidal summits (Fig. 472), and shortened along the same axis it is reduced to a square octahedron, with truncated angles (Fig. 473).

The trapezohedron elongated in the direction of an octahedral (trigonal) axis assumes rhombohedral (trigonal) symmetry.

If the elongation of the trapezohedron takes place along a cubic axis, it becomes a double eight-sided pyramid with four-sided summits; or if these summit planes are obliterated by a farther extension, it becomes a complete eight-sided double pyramid.

Similarly the trisoctahedron, tetrahexahedron and hexoctahedron may show distortion of the same kind. Further examples are to be found in the other systems.

2. IMPERFECTIONS OF THE SURFACES OF CRYSTALS

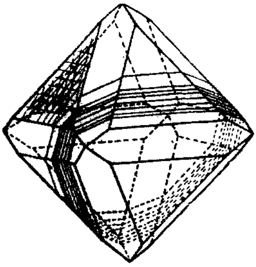
258. Striations Due to Oscillatory Combinations. — The parallel lines or furrows on the surfaces of crystals are called *striæ* or *striations*, and such surfaces are said to be *striated.*

Each little ridge on a striated surface is inclosed by two narrow planes more or less regular. These planes often correspond in position to different faces of the crystal, and these ridges have been formed by a continued oscillation in the operation of the causes that give rise, when acting uninterruptedly, to enlarged faces. By this means, the surfaces of a crystal are marked in parallel lines, with a succession of narrow planes meeting at an angle and constituting the ridges referred to.

This combination of different planes in the formation of a surface has been termed *oscillatory combination.* The horizontal striations on prismatic crystals of quartz are examples of this combination, in which the oscillation has taken place between the prismatic and rhombohedral faces. Thus crystals of quartz are often tapered to a point, without the usual pyramidal terminations.

Other examples are the striations on the cubic faces of pyrite parallel to the intersections of the cube with the faces of the pyritohedron; also the striations on magnetite due to the oscillation between the octahedron and dodecahedron. Prisms of tourmaline are very commonly bounded vertically by three convex surfaces, owing to an oscillatory combination of the faces in the prismatic zone.

474



Magnetite

259. Striations Due to Repeated Twinning. — The striations of the basal plane of albite and other triclinic feldspars, also of the rhombohedral surfaces of some calcite, have been explained in Art. **241** as due to polysynthetic twinning. This is illustrated by Fig. 474 of magnetite from Port Henry, N. Y. (Kemp.)

260. Markings from Erosion and Other Causes. — The faces of crystals are often uneven, or have the crystalline structure developed as a consequence of etching by some chemical agent. Cubes of galena are frequently thus uneven, and crystals of lead sulphate (anglesite) or lead carbonate (cerussite) are sometimes present as evidence with regard to the cause. Crystals of numerous other species, even of corundum, spinel, quartz, etc., sometimes show the same result of partial change over the surface — often the incipient stage in a process tending to a final removal of the whole crystal. Interesting investigations have been made by various authors on the action of solvents on different minerals, the actual structure of the crystals being developed in this way. This method of etching is fully discussed, with illustrations, in another place (Art. **286**).

The markings on the surfaces of crystals are not, however, always to be ascribed to etching. In most cases such depressions, as well as the minute elevations upon the faces having the form of low pyramids (so-called *vicinal* prominences), are a part of the original molecular growth of the crystal, and often serve to show the successive stages in its history. They may be imperfections arising from an interrupted or disturbed development of the form, the perfectly smooth and even crystalline faces being the result of completed action free from disturbing causes. Examples of the markings referred to occur on the crystals of most minerals, and conspicuously so on the rhombohedral faces of quartz.

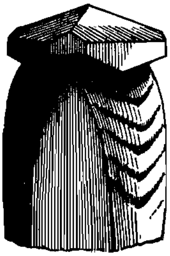
Faces of crystals are often marked with angular elevations more or less distinct, which are due to oscillatory combination. Octahedrons of fluorite are common which have for each face a surface of minute cubes, proceeding from an oscillation between the cube and octahedron. Sometimes an examination of such a crystal shows that though the form is apparently octahedral, there are no octahedral faces present at all. Other similar cases could be mentioned.

Whatever their cause, these minute markings are often of great importance as revealing the true molecular symmetry of the crystal. For it follows from the symmetry of crystallization that like faces must be physically alike — that is, in regard to their surface character; it thus often happens that on all the crystals of a species from a given locality, or perhaps from all localities, the same planes are etched or roughened alike. There is much uniformity on the faces of quartz crystals in this respect.

261. Curved surfaces may result from (*a*) oscillatory combination; or (*b*) some independent molecular condition producing curvatures in the laminæ of the crystal; or (*c*) from a mechanical cause.

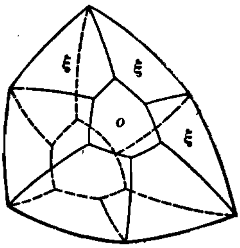
Curved surfaces of the *first* kind have been already mentioned (Art. **258**). A singular curvature of this nature is seen in Fig. 475, of calcite; in the lower part traces of a scalenohedral form are apparent which was in oscillatory combination with the prismatic form.

475



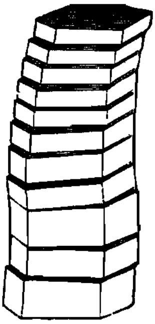
Calcite

476



Diamond

477



Beryl

Curvatures of the *second* kind sometimes have all the faces convex. This is the case in crystals of diamond (Fig. 476), some of which are almost spheres. The 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 dolomite and siderite are usually thus curved. The feathery curves of frost on windows and the flagging-stones of pavements in winter are other examples. The alabaster rosettes from the Mammoth Cave, Kentucky, are similar. Stibnite crystals sometimes show very remarkable curved and twisted forms.

A *third* kind of curvature is of *mechanical origin.* Sometimes crystals appear as if they had been broken transversely into many pieces, a slight displacement of which has given a curved form to the prism. This is common in tourmaline and beryl. The beryls of Monroe, Conn., often present these interrupted curvatures, as represented in Fig. 477.

Crystals not infrequently occur with a deep pyramidal depression occupying the place of each plane, as is often observed in common salt, alum, and sulphur. This is due in part to their rapid growth.

3. VARIATIONS IN THE ANGLES OF CRYSTALS

262. The greater part of the distortions described in Arts **256, 257** occasion no change in the interfacial angles of crystals. But those imperfections that produce convex, curved, or striated faces necessarily cause such variations. Furthermore, circumstances of heat or pressure under which the crystals were formed may sometimes have resulted not only in distortion of form, but also some variation in angle. The presence of impurities at the time of crystallization may also have a like effect.

Still more important is the change in the angles of completed crystals which is caused by subsequent pressure on the matrix in which they were formed, as, for example, the change which may take place during the more or less complete metamorphism of the inclosing rock.

The change of composition resulting in pseudomorphous crystals (see Art. **273**) is generally accompanied by an irregular change of angle, so that the pseudomorphs of a species vary much in angle.

In general it is safe to affirm that, with the exception of the irregularities arising from imperfections in the process of crystallization, or from the subsequent changes alluded to, variations in angles are rare, and the constancy of angle alluded to in Art. **11** is the universal law.

In cases where a greater or less variation in angle is observed in the crystals of the same species from different localities, the cause for this can usually be found in a difference of chemical composition. In the case of isomorphous compounds it is well known that an exchange of corresponding chemically equivalent elements may take place without a change of form, though usually accompanied with a slight variation in the fundamental angles.

The effect of heat upon the form of crystals is alluded to in Art. **433.**

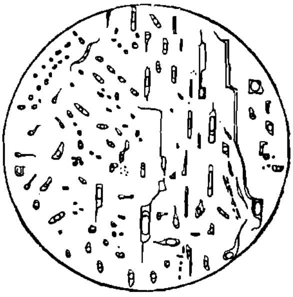
4. INTERNAL IMPERFECTIONS AND INCLUSIONS

263. The transparency of crystals is often destroyed by disturbed crystallization; by impurities taken up from the solution during the process of crystallization; or, again, by the presence of foreign matter resulting from partial chemical alteration. The general name, *inclusion,* is given to any foreign body inclosed within the crystal, whatever its origin. These inclusions are extremely common; they may be gaseous, liquid, or solid; visible to the unaided eye or requiring the use of the microscope.

Rapid crystallization is a common explanation of inclusions. This is illustrated by quartz crystals containing large cavities full or nearly full of water (in the latter case, these showing a movable bubble); or, they may contain sand or iron oxide in large amount. In the case of calcite, crystallization from a liquid largely charged with a foreign material, as quartz sand, may result in the formation of crystals in which the impurity makes up as much as two-thirds of the whole mass; this is seen in the famous Fontainebleau limestone, and similarly in that from other localities.

264. Liquid and Gas Inclusions. — Attention was early called by Brewster to the presence of fluids in cavities in certain minerals, as quartz, topaz, beryl, chrysolite, etc. In later years this subject has been thoroughly studied by Sorby, Zirkel, Vogelsang, Fischer, Rosenbusch, and others. The nature of the liquid can often be determined, by its refractive power, or by special physical test (*e.g.*, determination of the critical point in the case of CO_2), or by chemical examination. In the majority of cases the observed liquid is simply water; but it may be the salt solution in which the crystal was formed, and not infrequently, especially in the case of quartz, liquid carbon dioxide (CO_2), as first proved by Vogelsang. These liquid inclusions are marked as such, in many cases, by the presence in the cavity of a movable bubble of gas. Occasionally cavities contain two liquids, as water and liquid carbon dioxide, the latter then inclosing a bubble of the same substance as gas (cf. Fig. 478). Interesting experiments can be made with sections showing such inclusions (cf. literature, p. 181). The mixture of gases yielded by smoky quartz, meteoric iron, and other substances, on the application of heat, has been analyzed by Wright.

478



Beryllonite

In some cases the cavities appear to be empty; if they then have a regular form determined by the crystallization of the species, they are often called *negative crystals.* Such cavities are commonly of secondary origin, as remarked on a later page.

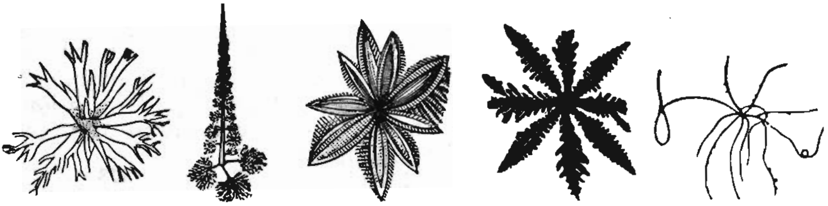
265. Solid Inclusions. — The solid inclusions are almost infinite in their variety. Sometimes they are large and distinct, and can be referred to known mineral species, as the scales of göthite or hematite, to which the peculiar character of aventurine feldspar is due. Magnetite is a very common impurity in many minerals, appearing, for example, in the Pennsbury mica; quartz is also often mechanically mixed, as in staurolite and gmelinite. On the other hand, quartz crystals very commonly inclose foreign material, such as chlorite, tourmaline, rutile, hematite, asbestus, and many other minerals. (Cf. also Arts. **266, 267.**)

The inclusions may consist of a heterogeneous mass of material; as the granitic matter seen in orthoclase crystals in a porphyritic granite; or the feldspar, quartz, etc., sometimes inclosed in large coarse crystals of beryl or spodumene, occurring in granite veins.

266. Microlites, Crystallites. — The microscopic crystals observed as inclusions may sometimes be referred to known species, but more generally their true nature is doubtful. The term *microlites*, proposed by Vogelsang, is often used to designate the minute inclosed crystals; they are generally of needlelike form, sometimes quite irregular, and often very remarkable in their arrangement and groupings; some of them are exhibited in Fig. 484 and Fig. 485, as explained below. Where the minute individuals belong to known species they are called, for example, feldspar microlites, etc.

Crystallites is an analogous term used by Vogelsang to cover those minute forms which have not the regular exterior form of crystals, but may be considered as intermediate between amorphous matter and true crystals. Some of the forms are shown in Figs. 479–483; they are often observed in glassy volcanic rocks, and also in furnace-slags. A series of names has been given to varieties of crystallites, such as globulites, margarites, etc. Trichite and belonite are names introduced by Zirkel; the former name is derived from *θρίξ, hair;* trichites, like that in Fig. 483, are common in obsidian.

479 480 481 482 483

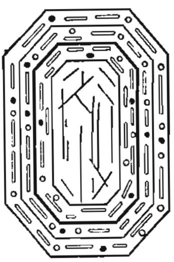


Crystallites

The microscopic inclusions may also be of an irregular glassy nature; this kind is often observed in crystals which have formed from a molten mass, as lava or the slag of an iron furnace.

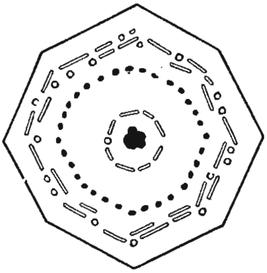
267. Symmetrically Arranged Inclusions. — In general, while the solid inclusions sometimes occur quite irregularly in the crystals, they are more generally arranged with some evident reference to the symmetry of the form, or external faces of the crystals. Examples of this are shown in the following figures. Fig. 484 exhibits a crystal of augite, inclosing magnetite, feldspar and nephelite microlites, etc. Fig. 485 shows a crystal of leucite, a species

484



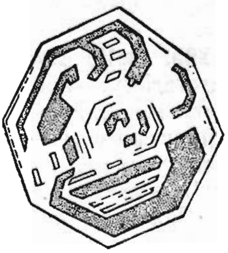
Augite (Zirkel)

485



Leucite (Zirkel)

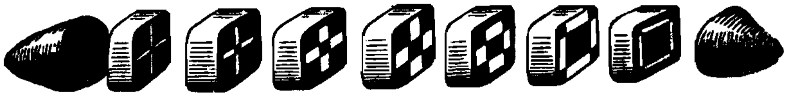
486



Garnet inclosing quartz (Heddle)

whose crystals very commonly inclose foreign matter. Fig. 486 shows a section of a crystal of garnet, containing quartz.

487



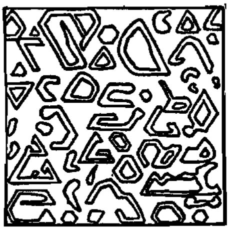
Andalusite

Another striking example is afforded by andalusite (Fig. 487), in which the inclosed carbonaceous impurities are of considerable extent and remarkably arranged, so as to yield symmetrical figures of various forms. Staurolite occasionally shows analogous carbonaceous impurities symmetrically distributed.

The magnetite common as an inclusion in muscovite, alluded to above, is always symmetrically disposed, usually parallel to the directions of the percussion-figure (Fig. 491, p. 189). The asterism of phlogopite is explained by the presence of symmetrically arranged inclusions (cf. Art. **368**).

Fig. 488 shows an interesting case of symmetrically arranged inclusions due to chemical alteration. The original mineral, spodumene, from Branchville, Conn., has been altered to a substance apparently homogeneous to the eye, but found under the microscope to have the structure shown in Fig. 488. Chemical analysis proves the base to be albite and the inclosed hexagonal mineral to be a lithium silicate ($LiAlSO_4$) called eucryptite. It has not yet been identified except in this form.

488



Eucryptite in Albite

LITERATURE

Some of the most important works on the subject of microscopic inclusions are referred to here; for a fuller list of papers reference may be made to the work of Rosenbusch (1904); also that of Zirkel and others mentioned on pp. 3 and 4.

Brewster. Many papers, published mostly in the Philosophical Magazine, and the Edinburgh Phil. Journal, from 1822–1856.

Blum, Leonhard, Seyfert, and **Söchting.** Die Einschlüsse von Mineralien in krystallisirten Mineralien. Haarlem, 1854. (Preisschrift.)

Sorby. On the microscopical structure of crystals, etc. Q. J. G. Soc., **14,** 453, 1858 (and other papers).

Sorby and **Butler.** On the structure of rubies, sapphires, diamonds, and some other minerals. Proc. Roy. Soc., No. 109, 1869.

Reusch. Labradorite. Pogg. Ann., **120,** 95, 1863.

Vogelsang. Labradorite. Arch. Néerland., **3,** 32, 1868.

Fischer. Kritische-microscopische mineralogische Studien. Freiburg in Br., 64 pp., 1869; 1te Fortsetzung; 64 pp., 1871; 2te Forts., 96 pp., 1873.

Kosmann. Hypersthene. Jahrb. Min., 532, 1869; 501, 1871.

Schrauf. Labradorite. Ber. Ak. Wien, **60** (1) 996, 1869.

Vogelsang. Die Krystalliten. 175 pp., Bonn, 1875.

Vogelsang and **Geissler.** Ueber die Natur der Flüssigkeitseinschlüsse in gewissen Mineralien. Pogg. Ann., **137,** 56, 257, 1869.

Hartley. Liquid CO_2 in cavities, etc. J. Chem. Soc., **1,** 137; **2,** 237, 1876; **1,** 241; **2,** 271, 1877; also, Proc. Roy. Soc., **26,** 137, 150, 1877.

Gümbel. Enhydros. Ber. Ak. München, **10,** 241, 1880; **11,** 321, 1881.

Hawes. Smoky quartz (CO_2). Am. J. Sc., **21,** 203, 1881.

A. W. Wright. Gases in smoky quartz. Am. J. Sc., **21,** 209, 1881

Rutley. Notes on Crystallites. Min. Mag., **9,** 261, 1891.

Vater. Das Wesen der Krystalliten, Zs. Kr., **27,** 505, 1896.