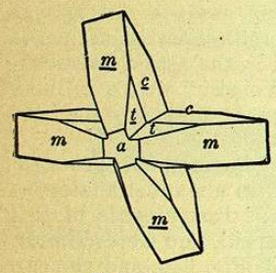
COMPOUND OR TWIN CRYSTALS.

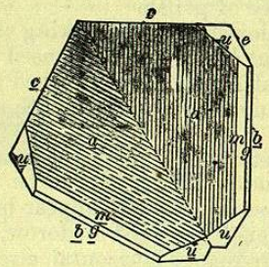
212. Twin Crystals.—Twin crystals are those in which one or more parts regularly arranged are in reverse position with reference to the other part or parts. They often appear externally to consist of two or more crystals symmetrically united, and sometimes have the form of a cross or star. They also exhibit the composition in the reversed arrangement of part of the faces,

346.



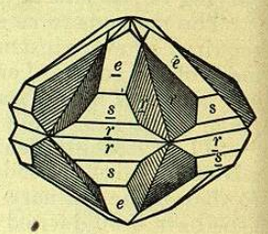
Thenardite.

347.



Columbite.

348.

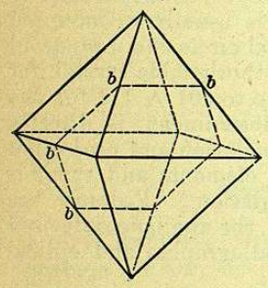


Chabazite.

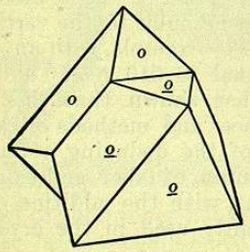
in the striæ of the surface, and in re-entering angles; in certain cases the compound structure can only be surely detected by an examination in polarized light. The above figures (Figs. 346–348) are examples of typical kinds of twin crystals, and many others are given on the pages following.

To illustrate the relation of the parts in a twin crystal, Figs. 349, 350 are given. Fig. 349 shows a regular octahedron divided into two halves by a plane parallel to an octahedal face. If now the lower half be supposed to be revolved 180° about an axis normal to this plane, the twinned octahedron of Fig. 350 results. This is a common type of twin in the isometric system, and the method here employed to describe the position of the parts of the crystal to one another is applicable to nearly all twins.

349.



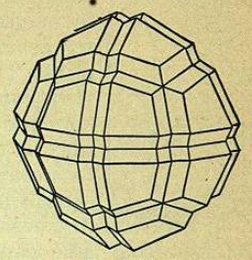
350.



213. It is important to understand that crystals, or parts of crystals, so grouped as to occupy parallel positions with reference to each other—that is, those whose similar faces are parallel—are not called twins; the term is applied only where the crystals or parts of them are united in their reversed position in accordance with some deducible mathematical law. Thus Fig. 351, which represents a cluster of partial crystals of analcite, is said to be a case of *parallel grouping* simply (see Art. **231**); but Fig. 369 illustrates twinning, and this is true of Fig. 378 also. Since though in these cases the axes remain parallel the similar faces (and planes of symmetry) are reversed in position.

214. Twinning-axis.—The relative position of the parts of a twinned crystal can be best described as just explained, by reference to that line or axis called the *twinning-axis*, a revolution of 180° about which would serve to bring the twinned part parallel to the other, or in other words, which would cause one of the parallel parts to take a twinned position relatively to the other.

351.



Analcite.

The twinning-axis is always a possible crystalline line—that is, either a crystallographic axis or the normal to some possible face on the crystal, usually one of the common fundamental forms.

It is not to be supposed that ordinary twins have actually been formed by such a revolution of the parts of crystals, for all twins (except those of secondary origin, see Art. **221**) are the result of regular molecular growth or enlargement, like that of the simple crystal. This reference to a *revolution*, and an *axis of revolution*, is only a convenient means of describing the forms.

In certain rare cases, particularly of certain pseudo-hexagonal species, a revolution of 60° or 120° about a normal to the base has been assumed to explain the complex group observed.

215. Twinning-plane.—The plane normal to the axis of revolution is called the *twinning-plane*. The axis and plane of twinning bear the same relation to both individuals in their reversed position; consequently, in the majority of cases the twinned crystals are symmetrical with reference to the twinning-plane.

The twinning-plane is, with rare exceptions, parallel to a possible occurring face on the given species, and usually one of the more frequent or fundamental forms. The exceptions occur only in the triclinic and monoclinic systems, where the twinning-axis is sometimes one of the oblique crystallographic axes, and then the plane of twinning normal to it is obviously not necessarily a crystallographic plane; this is conspicuously true in albite.

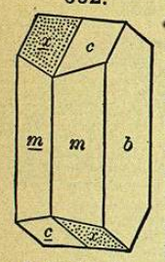
216. Composition-plane.—The plane by which the reversed crystals are united is the *composition-plane*. This and the twinning-plane very commonly coincide; this is true of the simple example given above (Fig. 350), where the plane about which the revolution may be conceived to take place (normal to the twinning-axis) and the plane by which the semi-individuals are united are identical. When not coinciding, the two planes are generally at right angles to each other—that is, the composition-plane is parallel to the axis of revolution. Examples of this are given beyond. Still again, where the crystals are not regularly developed, and where they interpenetrate, the contact surface may be interrupted, or may be exceedingly irregular. In such cases the axis and plane of twinning have, as always, a definite position, but the composition-plane loses its significance.

Thus in quartz twins the interpenetrating parts have often no rectilinear boundary, but mingle in the most irregular manner throughout the mass, showing this composite irregularity by abrupt variations in the character of the surfaces. This irregular internal structure, found in many quartz crystals, even the common kinds, is well brought out by means of polarized light; also by etching with hydrofluoric acid.

The composition-plane has sometimes a more definite signification than the twinning-plane. This is due to the fact that in many cases, whereas the former

is fixed, the twinning-axis (and twinning-plane) may be exchanged for another line (and plane) at right angles to each, respectively; since a revolution about the second axis will also satisfy the conditions of producing the required form. An example of this is furnished by Fig. 352, of orthoclase; the composition-plane is here fixed—namely, parallel to the crystal face, *b* (010). But the axis of revolution may be either (1) parallel to this face and normal to *a* (100), which is then consequently the twinning-plane, though the axis does not coincide with the crystallographic axis; or (2) the twinning-axis may be taken as coinciding with the vertical axis, and then the twinning-plane normal to it is not a crystallographic face. In other simpler cases, also, the same principle holds good, generally in consequence of the possible mutual interchange of the planes of twinning and composition. In most cases the true twinning-plane is evident, since it is parallel to some face on the crystal of simple mathematical ratio.

352.



217. An interesting example of the possible choice between two twinning-axes at right angles to each other is furnished by the species staurolite. Fig. 409 shows a prismatic twin from Fannin Co., Ga. The measured angle for *bb* was 70° 30′. The twinning-axis deduced from this may be normal to the face (230), which would then be the twinning-plane. Or, instead of this axis, its complementary axis at right angles to it may be taken, which would equally well produce the observed form. Now in this species it happens that the faces, 130 and 230 (over 100), are almost exactly at right angles with each other, and, according to the latter supposition, 130 becomes the twinning-plane, and the axis of revolution is normal to it. Hence, either 230 or 130 may be the twinning-plane, either supposition agreeing closely with the measured angle (which could not be obtained with great accuracy). The former method of twinning (tw. pl. 230) conforms to the other twins observed on the species, and hence it may be accepted. What is true in this case, however, is not always true, for it will seldom happen that of the two complementary axes each is so nearly normal to a face of the crystal. In most cases one of the two axes conforms to the law in being a normal to a possible face, and the other does not, and hence there is no doubt as to which is the true twinning-axis.

Another interesting case is that furnished by columbite. The common twins of the species are similar to Fig. 347, p. 118, and have *e* (021) as the twinning-plane; but twins also occur like Fig. 404, p. 128, where the twinning-plane is *q* (023). The two faces, 021 and 023, are nearly at right angles to each other, but the measured angles are in this case sufficiently exact to prove that the two kinds cannot be referred to one and the same law.

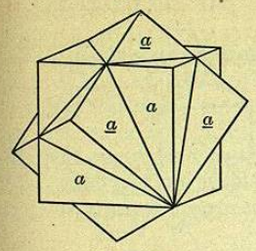
218. Contact- and Penetration-twins.—In *contact-twins*, when normally formed, the two halves are simply connate, being united to each other by the composition-plane; they are illustrated by Figs. 347, 350, etc. In actually occurring crystals the two parts are seldom symmetrical, as demanded by theory, but one may preponderate to a greater or less extent over the other; in some cases only a small portion of the second individual in the reversed position may exist. Very great irregularities are observed in nature in this respect. Moreover, the re-entering angles are often obliterated by the abnormal developments of one or other of the parts, and often only an indistinct line on some of the faces marks the division between the two individuals.

Penetration-twins are those in which two or more complete crystals interpenetrate, as it were crossing through each other. Normally, the crystals have a common center, which is the center of the axial system for both; practically, however, as in contact-twins, great irregularities occur.

Examples of twins of this second kind are given in the annexed figures, Fig. 353 of fluorite, Fig. 354 of tetrahedrite, and Fig. 355 of chabazite. Other examples occur in the pages following, as, for instance, of the species staurolite (Figs. 408–411), the crystals of which sometimes occur in nature with almost the perfect symmetry demanded by theory. It is obvious that the distinction

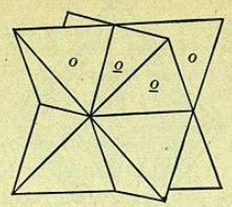
between contact- and penetration-twins is not of great importance, and the line cannot always be clearly drawn between them.

353.



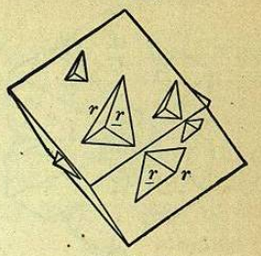
Fluorite.

354.



Tetrahedrite.

355.

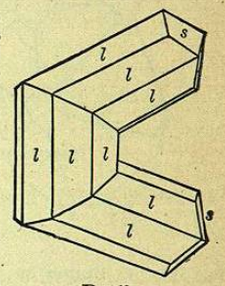


Chabazite.

219. Paragenic and Metagenic Twins.—The distinction of paragenic and metagenic twins belongs rather to crystallogeny than crystallography. Yet the forms are often so obviously distinct that a brief notice of the distinction is important.

In ordinary twins, the compound structure had its beginning in a nucleal compound molecule, or was compound in its very origin; and whatever inequalities in the result, these are only irregularities in the development from such a nucleus. But in others, the crystal was at first simple; and afterwards, through some change in itself or in the condition of the material supplied for its increase, received new layers, or a continuation, in a reversed position. This mode of twinning is *metagenic*, or a result subsequent to the origin of the crystal; while the ordinary mode is *paragenic*. One form of it is illustrated in Fig. 356. The middle portion had attained a length of half an inch or more, and then became geniculated simultaneously at either extremity. These geniculations are often repeated in rutile, and the ends of the crystal are thus bent into one another, and occasionally produce nearly regular prismatic forms.

356.



Rutile.

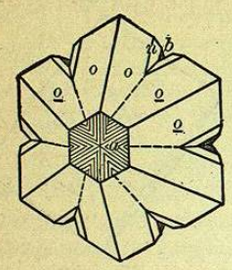
This metagenic twinning is sometimes presented by the successive layers of deposition in a crystal, as in some quartz crystals, especially amethyst, the inseparable layers, exceedingly thin, being of opposite kinds. In a similar manner, crystals of the triclinic feldspars, albite, etc., are often made up of thin plates parallel to *b* (010), by oscillatory composition, and the face *c* (001), accordingly, is finely striated parallel to the edge *c*, *b*.

220. Repeated Twinning, Polysynthetic and Symmetrical.—In the preceding paragraph one case of repeated twinning has been mentioned, that of the feldspars; it is a case of *parallel* repetition or parallel grouping in reversed position of successive crystalline lamellæ. This kind of twinning is often called *polysynthetic twinning*, the lamellæ in many cases being extremely thin, and giving rise to a series of parallel lines (striations) on a crystal face or a surface of cleavage. The triclinic feldspars show in many cases polysynthetic twinning and not infrequently on both *c* (001) and *b* (010), cf. p. 130. It is also observed with magnetite (Fig. 456), pyroxene, barite, etc.

Another kind of repeated twinning is illustrated by Figs. 357–362, where the successively reversed individuals are not parallel. In these cases the axes may, however, lie in a zone, as the prismatic twins of aragonite, or they may be inclined to each other, as in Fig. 359 of staurolite. In all such cases the repetition of the twinning tends to produce circular forms, when the angle between the two axial systems is an aliquot part of 360° (approximately). Thus six-rayed twinned crystals, consisting of three individuals (hence called *trillings*), occur with chrysoberyl (Fig. 357), or cerussite (Fig. 358), or staurolite

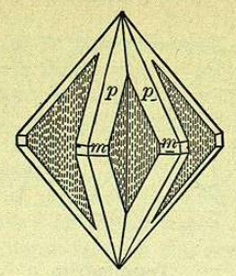
(Fig. 359), since three times the angle of twinning in each case is not far from 360°. Again, five-fold twins, or *fivelings*, occur in the octahedrons of gold and

357.



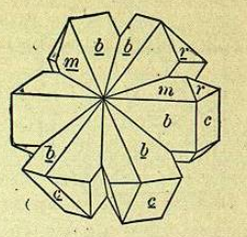
Chrysoberyl.

358.



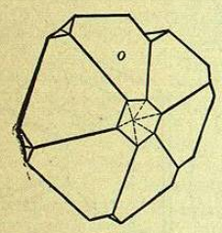
Cerussite.

359.



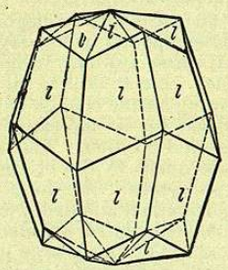
Staurolite.

360.



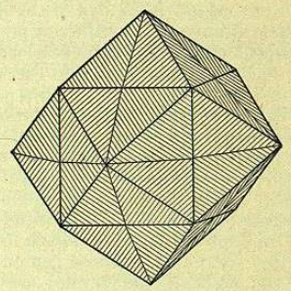
Spinel.

361.



Rutile.

362.



Phillipsite.

spinel (Fig. 360), since $5 \times 70° 32' = 360°$ (approx.). Eight-fold twins, or *eightlings*, of rutile (Figs. 361, 357) occur, since the angle of the axes in twinned position goes approximately eight times in 360°.

Repeated twinning of the symmetrical type often serves to give the compound crystal an apparent symmetry of higher grade than that of the simple individual, and the result is often spoken of as a kind of pseudo-symmetry (Art. **20**), cf. Fig. 397 of aragonite, which represents a *pseudo-hexagonal* crystal. Fig. 362 of phillipsite (cf. Figs. 422–424) is an interesting case, since it shows how a multiple twin of a monoclinic crystal may simulate an isometric crystal (dodecahedron).

Compound crystals in which twinning exists in accordance with two laws at once are not of common occurence; an excellent example is afforded by staurolite, Fig. 411. They have also been observed on albite, orthoclase, and in other cases.

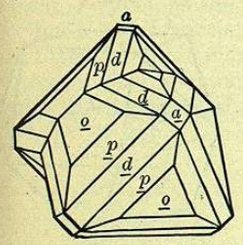
221. Secondary Twinning.—When there is reason to believe that the twinning has been produced subsequently to the original formation of the crystal, or crystalline mass, as, for example, by pressure, it is said to be *secondary*. Thus the calcite grains of a crystalline limestone often show such secondary twinning lamellæ. The same are occasionally observed (‖*c*, 001) in pyroxene crystals. Further, the polysynthetic twinning of the triclinic feldspars is often

secondary in origin. This subject is further discussed on a later page, where it is also explained that in certain cases twinning may be produced artificially in a crystal individual—*e.g.*, in calcite (see Art. **261**).

EXAMPLES OF IMPORTANT METHODS OF TWINNING.

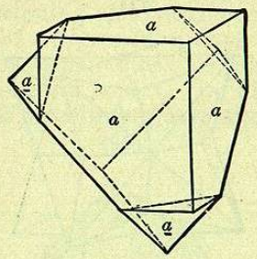
222. Isometric System.—With few exceptions the twins of the normal group of this system are of one kind, the twinning-axis an octahedral axis, and the twinning-plane consequently parallel to an *octahedral face;* in most cases, also, the latter coincides with the composition-plane. Fig. 350, p. 118,* shows this kind as applied to the simple octahedron; it is especially common with the spinel group of minerals, and is hence called in general a *spinel-twin*. Fig. 363 is a similar more complex form; Fig. 364 shows a cube twinned by this

363.



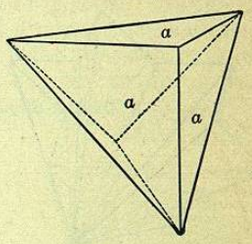
Galena.

364.



Copper.

365.

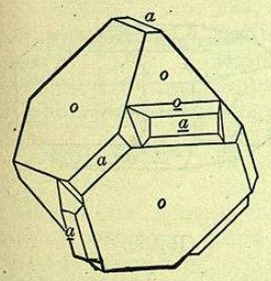


Copper.

method, and Fig. 365 represents the same form but shortened in the direction of the octahedral axis, and hence having the anomalous aspect of a triangular pyramid. All these cases are contact-twins.

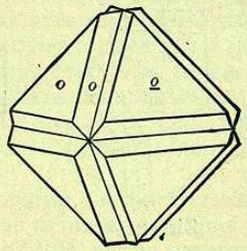
Penetration-twins, following the same law, are also common. A simple case of fluorite is shown in Fig. 353, p. 121; Fig. 366 shows one of galena;

366.



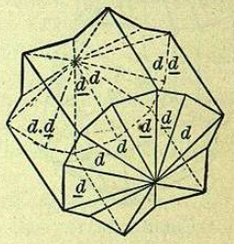
Galena.

367.



Haüynite.

368.



Sodalite.

Fig. 367 is a repeated octahedral twin of haüynite, and Fig. 368 a dodecahedral twin of sodalite.

* It will be noted that here and elsewhere the letters used to designate the faces on the twinned parts of crystals are distinguished by a subscript line.