Twin-planes and cross-planes.

By JOHN W. EVANS, LL.B., D.Sc., F.G.S.
Imperial Institute and Birkbeck College.

[Read January 21, 1908, and January 26, 1909.]

IN a single homogeneous crystal the physical character of parallel lines are everywhere the same, and it may be justifiably assumed that the orientation of the crystal-structure is constant throughout. Compound crystals, however, occur in which the orientation of the crystal-structure is different in different parts although they consist of the same substance.[1]

This difference of orientation may either be original or result from the action of mechanical forces on the crystal-structure.. I shall in the first place assume that the former is the case.

In many occurrences there does not appear to be any significant relation between the orientation of the structure in adjoining portions, and we may conclude that their relative orientation was determined before the progress of crystallization brought them into contact. In other cases there is a simple geometrical relation between the two component structures, and it is reasonable to suppose that the crystallization of one or both started from the surface where they are in contact and that the orientation of the structure of one was influenced by that of the other.

The surface of contact or composition is then usually a plane, the plane of composition, which is in the greater number of cases a possible crystal-face.

The nature of the relation between the two structures that may be expected to exist in the plane of composition is indicated by the results of Mr. T. V. Barker's[2] studies of similar combinations of crystals of two different substances. He has shown that such substances unite with regular relative orientation only where there are certain lines[3] in the plane of composition in which the molecular distances in the two crystals

[1] Enantiomorphic substances are considered to be the same for the purpose of this communication.

[2] T. V. Barker, Mineralogical Magazine, 1907, vol. xiv, pp. 235–257.

[3] The word 'line' is here used in a general sense including all parallel lines, viz. as possessing orientation but not position.

are approximately equal, or those of one are approximately multiples of those of the other.

A similar relation should hold in the plane of composition in combinations of two portions of the same substance with different but related orientation.

The simplest, and therefore probably the most frequent, case will be that in which the molecular distances are exactly equal in the two component structures along one or more lines in the plane of composition. Such a line will obviously represent the coincidence of equivalent lines in the two structures, of which they will be possible crystal-edges, for they both represent rows of molecules.

A line in which equivalent lines, whether possible edges or not, of the two component structures of a compound crystal coincide, may be conveniently referred to as a *common line*.

If the equivalent directions in the two lines coincide, the common line may be said to be *co-directional*. If, on the other hand, the equivalent directions of uniterminal lines are opposed, the common line is *contra-directional*.

We may expect by analogy with the combinations of unlike substances that there will usually be at least two common lines in the plane of composition, each made up of equivalent lines which are possible crystal-edges of the component structures.

If this be the case, the plane of composition must represent two equivalent planes in the component structures, of which they will be possible faces.

A plane in which two equivalent planes, whether possible faces or not, coincide, may be termed a *common plane*.

In some cases all the lines in a common plane are common lines, that is to say, not only are the two equivalent planes co-planar, but all lines in the one are co-linear with equivalent lines in the other.[1]

The common plane then constitutes what is known as a *twin-plane*: provided, of course, that the two structures are not parallel in all respects.

If all the common lines of a twin-plane are co-directional, the twin-plane may be described as co-directional. If, on the other hand, those which represent the coincidence of uniterminal lines are contra-directional, the twin-plane may be said to be contra-directional.

If, on the other hand, a common plane contain only a limited number of common lines,[2] it can be shown that there may be two, four, or six, but

[1] Cf. Max Schuster, Zeits. Kryst. Min., 1886, vol. xii, p. 141.

[2] Cf. Max Schuster, loc. cit.

no other number of common lines, and that these occur in pairs such that the members of a pair are at right angles to each other.

The common plane may then be appropriately described as a *cross-plane.*

In common planes which are neither twin-planes nor cross-planes there are no common lines.

So far, the terms common plane, twin-plane, and cross-plane have been applied only to a plane of composition, and the term common line only to a line in that plane. The same terms may, however, be conveniently extended to all planes and lines[1] in which there are similar relations between equivalent parallel planes and lines in the two component structures.

The common planes, twin-planes, or cross-planes which are planes of composition, may be termed *contact common planes,* contact twin-planes, or contact cross-planes; and those that are not planes of composition may be termed *abstract common planes,* abstract twin-planes, or abstract cross-planes. In the same way, a common line in the plane of composition may be termed a contact common line, and one which does not lie in a plane of composition an abstract common line.

The normal to every common plane is a common line, and vice versa every plane at right angles to a common line is a common plane. A common line at right angles to a twin-plane is called a twin-axis.

It can be shown that every plane at right angles to a twin-plane is either a twin-plane or a cross-plane, and that there is at least one twin-plane at right angles to every cross-plane.

Every compound crystal which possesses a twin-plane may be described as a twin-crystal.

Where the plane of composition is not a possible crystal-face it appears to be always a cross-plane and to contain only one common line, which is a possible crystal-edge of the component structures and in which the molecular intervals coincide. The other common line at right angles to the first is parallel to the intersection of the plane of composition with a possible face in each component, such faces being equivalent to one another.

Parallel to these faces are a succession of plane-nets of molecules which outcrop (if the expression may be used) in the plane of composition in

[1] See note, ante, p. 390. The use of the term 'common edge' or 'common face' in the case of parallel equivalent edges or faces in two structures is already recognized; see, for instance, Max Schuster, loc. cit.

parallel lines at equal intervals in the two structures, and it is the coincidence of these edges which determines the plane of composition.

For instance, in the pericline-twins of the plagioclase-felspars the plane of composition (the rhombic section) is a cross-plane containing only two common lines—the macro-axis and the line at right angles to it. The former is a possible crystal-edge and along it the molecular intervals exactly coincide in the two component structures. The common line at right angles to it is not a possible edge, nor is the cross-plane that forms the plane of composition a possible face. Its position is determined so that the second common line may lie in the brachypinacoidal cleavage, an important structural plane. The intergrowth accordingly takes place in such a manner that the edges of the plane-nets of molecules giving rise to the brachypinacoidal cleavage, which outcrop from the two component structures in the plane of composition, exactly coincide. Not only are these edges parallel, but the intervals between them are the same in the two component structures.

The outcropping edges of the plane-nets of molecules parallel to any hemi-prism (e.g. *l*) also coincide with those of the other corresponding hemi-prism (e.g. *T*); but these coinciding edges are not equivalent lines like the outcropping edges of the brachypinacoidal cleavage, and do not therefore form a common line. However, though not equivalent, they must be closely similar in physical characters, and it can be easily shown that the intervals between them are identical in both structures.

In these twins the twin-plane is at right angles to the plane of composition; and their line of intersection and the twin-axis are each one of the common lines in the plane of composition. The twin-plane in such a case possesses no structural importance.

It can be shown that every twin-crystal as thus defined can be obtained from two parallel structures by the application to one structure of one of the three following 'twinning operations':—(1) A reflection about a plane, or, as I prefer to describe it, a reversal relatively to a plane. This may be termed *plane-twinning*. The two structures are now symmetrical to the plane, which becomes a twin-plane. (2) A rotation through a half circle round a line, or, what comes to the same thing, a reversal relatively to a line. This is *line-twinning*, and the two structures may be said to be symmetrical to a line, which becomes a twin-axis. (3) Inversion or reversal relatively to a point. In this, which may be termed *point-twinning*, the two structures are symmetrical to a point; every plane is a twin-plane and every line a twin-axis.[1]

[1] Point-twinning is referred to by G. Linck ('Grundriss der Krystallographie,' 1896, p. 24) and H. A. Miers ('Mineralogy,' 1902, pp. 91 and 371), who term it alternating twinning. Curiously enough, the former states that no example is known. As a matter of fact, it is found in quartz, pyrargyrite, nepheline, hemimorphite, sodium chlorate, chalcopyrite, and other crystals belonging to the same classes.

There can be obviously no plane-twinning about a plane which is a plane of symmetry in the untwinned crystal, no line-twinning about a line which is a line of symmetry,[1] and no point-twinning where there is a centre of symmetry.

In most cases the same twin-crystal may be referred to two of the three categories or modes of twinning above mentioned. For instance, if a twin-crystal show point-twinning, there will be plane-twinning about every plane at right angles to a line of symmetry[2] and line-twinning about every normal to a plane of symmetry. Again, if there be a centre of symmetry, the same twin-axis and twin-plane may be referred to both plane- and line-twinning.

Where a twin-crystal possesses more than one twin-plane and axis the question arises as to which shall be selected for descriptive purposes. If there be a plane of composition which is a twin-plane, it is convenient to select it as the principal twin-plane and its normal as the principal twin-axis. If there is no plane of composition which satisfies this condition, it is best to select as twin-axis the line which has the highest symmetry in the untwinned crystal.

A similar question arises where a twin-crystal may be explained by more than one mode of twinning. Where point-twinning exists it is more important than the plane- or line-twinning, if any, that accompanies it, for it is independent of the line selected as twin-axis and corresponds to a simple fundamental relation—the reversal of every direction in one component crystal compared with the other. Where there is a centre of symmetry, and every twin-axis is an axis of both plane-twinning and line-twinning, the former is the more convenient conception for purposes of exposition. Reversal relatively to, or reflection about, a twin-plane is more easily recognized than reversal relatively to (or rotation through a half turn round) a twin-axis. The former, as pointed out by V. Goldschmidt,[3] has a genetic significance,[4] while the latter is open to misconception by the elementary student.

In the same way, where the choice lies between an axis of plane-twinning and one of line-twinning, the former should be chosen, unless

[1] If complete self-coincidence can be obtained by a reversal relatively to a line or rotation through a half circle round it, the line may be termed a line of symmetry.

[2] As for instance in the α laevodextrogyral or 'Brazilian' twins of quartz.

[3] V. Goldschmidt, Zeits. Kryst. Min., 1898, vol. xxx, p. 254.

[4] Such twins are also explained by a symmetry about a plane by Max Schuster, Zeits. Kryst. Min., 1886, vol. xii, pp. 139 and 147, and by H. A. Miers, 'Mineralogy,' 1902, p. 87.

the latter is at right angles to a plane of composition or possesses higher symmetry.

We may now proceed to consider compound crystals with more or less definite relations between the component structures, but in which there is no twin-plane.

In the first place, they may have a plane of composition which contains one and only one common line and is therefore not a common plane formed by the coincidence of equivalent planes in the two structures. Such compound crystals comprise the combinations which are referred to by V. Goldschmidt[1] as 'einzonige' or 'einkantige Verwachsungen'. Examples are furnished by groups of prismatic crystals with no definite relations except the parallelism of the axes of the prisms.

In another class of cases the plane of composition is a common plane formed by the coincidence of equivalent planes, which contains no common lines and is therefore neither a twin-plane nor a cross-plane. The normal, however, is a common line. These combinations are described by Goldschmidt[2] as 'einflächige Verwachsungen'. Examples are found where small crystals of quartz, flattened parallel to a prism-face, adhere to a prism-face of a larger crystal of the same mineral without any other definite relative orientation.

Both classes of combinations are grouped together by Goldschmidt under the name of 'einachsige Verwachsungen', which may be rendered 'unilinear combinations', for they possess one common line, either in the plane of composition or normal to it. Any other combination in which there is a single common line may be included in the same category.

Such combinations may be conceived geometrically as the result of the rotation of a portion of a simple crystal round any line, or of one of the two component structures of a twin-crystal round a common line, which may either be the twin-axis or a line in the twin-plane; provided such rotation does not result in a twin-crystal or leave the two structures parallel. The axis of rotation will remain a common line. The plane at right angles to it, though it remains a common plane, will not, by hypothesis, be a twin- or cross-plane. Miers[3] has described combinations of bournonite and of pyrargyrite, which are at first sight true twins of those minerals with crystal-faces as twin-planes, but which usually show a small

[1] V. Goldschmidt, Zeits. Kryst. Min., 1907, vol. xliii, p. 585.

[2] V. Goldschmidt, loc. cit.

[3] H. A. Miers, Mineralogical Magazine, 1884, vol. vi, p. 77; 1888, vol. viii, p. 75.

inconstant deviation from the theoretical relation. This deviation corresponds to a rotation through a small angle round either a crystal-edge in the theoretical twin-plane or round the theoretical twin-axis.

It can be shown, however, that, if one portion of a simple crystal be rotated round any line or if one component structure of a twin-crystal be rotated round a common line, the common plane at right angles to the axis of rotation will be a cross-plane, provided that (*a*) the two component planes which coincide in it are each symmetrical to a line in it, or (*b*) the cyclic order of the succession of equivalent lines is opposite in these two planes; unless of course the rotation converts the common plane into a twin-plane or the two structures are brought into a parallel position. The existence of such a cross-plane implies a plane at right angles to it which satisfies the definition of a twin-plane. In many cases, however, the common lines of the cross-plane have no structural significance and the compound crystal will not differ essentially from a unilinear combination. It may then be termed an *accidental twin-crystal*, and the twin-plane an accidental twin-plane.

The subject of the combination of differently orientated structures of the same substance in which there are no common lines, but merely lines with approximately equal molecular distances, does not fall within the scope of the present paper. They have been dealt with to some extent by Goldschmidt under the name of 'hetero-axiale Zwillinge' or 'Heterozwillinge',[1] and by Max Schuster[2] and Baumhauer.[3]

It only remains to consider combinations of differently orientated portions of a crystal substance which were originally parallel. There is no evidence that in any case one portion has moved as a whole relatively to the other (that is to say without change in the internal structure) so as to give rise to a definite geometrical relation between them.

There are, however, many compound crystals in which the structure of one portion has suffered a new arrangement of the molecules which is equivalent to a change of orientation of the structure. This change may be the result of (*a*) external forces, or (*b*) internal stresses due to crystallization or change of crystal-structure under conditions of constraint. In the latter case the rearrangement of the molecules may be but slightly posterior to the formation of the crystal-structure itself.

In the majority of cases the movement of the molecules is in the nature of a translation parallel to the plane of composition of the

[1] V. Goldschmidt, loc. cit.

[2] Max Schuster, Zeits. Kryst. Min., 1886, vol. xii, p. 149.

[3] H. Baumhauer, ibid., 1899, vol. xxxi, pp. 252-275.

resulting compound crystal, the amount of movement being proportional to the distance from it. The plane of composition, or gliding-plane as it is termed, will then satisfy the conditions of a twin-plane.

In other cases the movement appears to comprise a rotation as well as a translation, so that the plane of composition becomes a cross-plane with a twin-plane at right angles to it.

It is probable that all cases of lamellar twinning are essentially secondary, due to the action of mechanical forces on the crystal-structure.