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TWIN LAWS VERSUS ELECTRICAL AND OPTICAL CHARACTERS IN LOW QUARTZ

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Abstract

The terms "electrical" (E) and "optical" (O) cannot be construed as definitions of twin laws: they refer to characters (reversal of electrical polarity and reversal of optical activity) that help detect twinning. These characters belong as follows to the three types of penetration twins in low quartz: the $6'22'$ (Dauphiné) twin is E but not O; the $\bar{6}'2m'$ (Combined) twin is O but not E; the $\bar{3}'2/m'$ (Brazil) twin is both O and E. Conversely the two observations yield no more than the following information. E but not O: two crystals of the same hand (Dauphiné twin); O but not E: two crystals of different hands (Combined twin); both O and E: either two crystals of different hands (Brazil twin) or three (or four) crystals, two of one hand and one (or two) of the other (all three twin laws).

Introduction

It is well-known that low quartz (symmetry 32) shows three types of twinning by merohedry (or twinning by twin-lattice symmetry with index 1). Their twin symmetries are written $6'22'$, $\bar{3}'2/m'$, and $\bar{6}'2m'$ in the black-white symbolism, which Curien & Le Corre (1958) have used to describe the symmetry of a dual twin (twin made up of two crystals). These twin symmetries are correlated with the corresponding twin laws as follows: $6'22'$ with Dauphiné twinning, $\bar{3}'2/m'$ with Brazil twinning, and $\bar{6}'2m'$ with the Combined twinning. In each case the unprimed elements are crystal-symmetry elements, that is, cyclic groups of operations that carry each of the two crystals in the twin to self-coincidence, while the twin operations (or twin-symmetry operations), which bring crystal I to coincide with crystal II, are contained in the primed elements. Note that, in each type, the 3-fold axis is a subgroup of index 2 of the black-white axis along *c*, as shown by the direct products: $6' = 3 \times 2'$, $\bar{3}' = 3 \times \bar{1}'$, $\bar{6}' = 3 \times (1/m')$.

If the twin operations are proper rotations, as in $6'2\,2'$, crystals I and II are both right-handed or both left-handed. If the twin operations are improper rotations, as in $\bar{3}'2/m'$ and $\bar{6}'2\,m'$, one of the crystals is right-handed, the other left-handed. Likewise the polarity of the secondary 2-fold axes is preserved or reversed by the twin operation, depending on the nature of the black-white element: it is preserved by a 60° rotary-inversion ($\bar{6}'$ axis); it is reversed by a 60° rotation ($6'$ axis) or a 120° rotary-inversion ($\bar{3}'$ axis).

A twin in which the hand of the crystal is reversed can be detected by optical means; one in which the polarity of the 2-fold axes is reversed can be recognized by electrical tests; a twin in which both properties are reversed can be seen both optically and electrically (Table 1).

Nomenclatures in Conflict

A survey of the literature reveals that the mineralogical names of the twin laws are properly matched with the twin symmetries in all the papers examined, with one exception — in Curien & Donnay (1958) the Brazil twin and the Combined twin have their symmetry symbols interchanged, an erratum that has been noted by Donnay & Donnay (1974). The term "electrical twinning" has been used, not only to signify reversal of electrical polarity, but also as a synonym of "Dauphiné twinning", as stated in the *Glossary of Terms* (Anonymous 1945).[1] The use of expressions containing the words "optical twinning" has been found inconsistent. Although some authors, notably Frondel (1945, p. 448), recognize that all quartz twins other than the Dauphiné twin are "optical" twins, other writers

[1]This Glossary was appended to a symposium on quartz oscillator-plates, to which Drs. C. Frondel and W. Parrish contributed most of the papers. Despite its anonymity, it is authoritative in the field. The synonymy "Dauphiné=electrical" and "Brazil=optical" is also recorded in Frondel (1962).

TABLE 1. THE THREE TYPES OF TWINNING BY TETARTOHEDRY IN LOW QUARTZ

Type number:	1	2	3
Twin law:	Dauphiné	Brazil	Combined
Twin symmetry:	6'22'	$\bar{3}'2/m'$	$\bar{6}'2m'$
Optical activity along 3-fold axis:	preserved	*reversed*	*reversed*
Electrical polarity of the 2-fold axes:	*reversed*	*reversed*	preserved
Character of twinning:	electrical	optical and electrical	optical

have restricted "optical twinning" to the Brazil twin, with the result that this expression has been used as an alternate way of stating the Brazil twin law. (The anonymous *Glossary* faithfully records both usages.) As a sequel the expression "combined electrical-optical twin" was construed to be synonymous with "combined Dauphiné-Brazil twin" (Cady 1946, p. 422), which it obviously is not (see Table 1). Therein lies the core of the confusion.

The following quotation from a paper on the terminology of penetration twins in low quartz (Thomas 1945) illustrates our statement.

"While it has been customary to term *the second type* an optical twin and *the third type* a combined electrical and optical twin (compound optical twin), this nomenclature is sometimes; *and it is thought incorrectly,* reversed." [Emphasis added.] Thus Thomas states the customary incorrect usage, and he agrees with it! His quarrel is with the would-be reformers. The remedy he prescribed turned out to be worse than the ailment. Here is the terminology actually proposed by Thomas (1945), to which we must take exception:

Type 1: "electrical" twinning;
Type 2: "optical" or "simple optical" twinning;
Type 3: "compound optical" twinning.

The facts pertaining to the three types of twinning are well-recorded by Thomas in three sketches, which agree perfectly with our Table 1. (They are reproduced in Frondel, 1962, as Fig. 46.) The misunderstanding begins in the analysis of type 2 (Brazil twinning), about which Thomas writes: "It should be noted that the cause of this reversed polarity is unrelated to electrical twinning as described above." Note that he uses "electrical twinning" as a synonym of type 1 or Dauphiné twinning. He goes on, "This type of twin [type 2] should be regarded as a purely optical twin, but confusion arises because of the accompanying electrical inhomogeneity. If the crystal [*sic*] is described as a combined electrical and optical twin, it might be thought that the reference was to a combined Dauphiné and Brazilian twin, which is incorrect."

The Symmetry Argument

In rebuttal we submit that the geometrical figure that expresses the property under consideration, *viz.* electrical polarity, is a *planar figure* — essentially a circle with six radii 60° apart, the ends of which carry alternating *plus* and *minus* signs. The interchange of the signs by the twin operation results in an electrical twin by definition. While it is true that the twin operation is a 180° rotation (equivalent to a 60° rotation) about the twin axis in type 1 and an inversion through the twin center in type 2, these two operations reduce to a single one, namely a 180° rotation about a *twin digyre,* when only the planar figure is concerned. A digyre is a symmetry element of order 2 for planar figures; here it is the point in which the *c* axis intersects the plane of the circle. We thus see that the cause of the reversed polarity in type 2, far from being unrelated to what it is in type 1, is indeed identically the same.

A Brazil twin is not only optical; it is also electrical, and this fact should not be swept under the rug! There is no reason why anyone, after glancing at Table 1, should want to equate "combined optical and electrical" with "combined Dauphiné-Brazil". And if one of the three twins deserves to be called "simple optical", it certainly is type 3, not type 2.

The geometrical figure that expresses optical activity, in contrast to that used above for electrical polarity, is *a three-dimensional figure* — a cylindrical screw. A left screw goes into a right one by inversion or by reflection. Types 2 and 3 both have an inversion as part of the twin

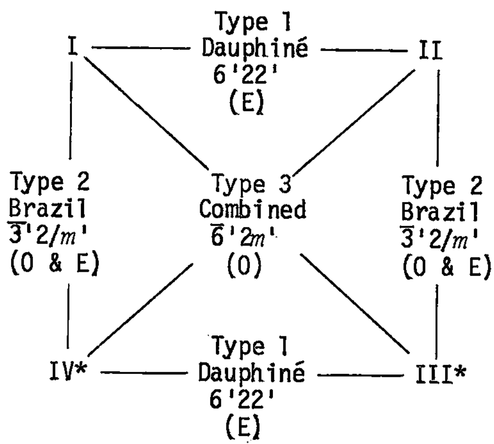

FIG. 1. Schematic representation of the complete twin. The asterisk indicates change of hand of the crystal. The four crystals in the twin are shown by Roman numerals.

operation, considered as a rotatory-inversion; the other part, being a rotation, does not alter the character of the screw. In both types the twin operation may also be taken as a reflection, either in a secondary twin mirror (*.m'.*) in type 2 or in a tertiary twin mirror (*. .m'*) in type 3. Both twin types are optical, even though the cause of the reversed optical activity, that is, the twin operation, differs from type to type.

Type 3 twinning ("Combined" twin) occurs very rarely alone, that is, in a dual twin. In the complete twin with its four crystals, or even in a twin with three crystals, the existence of type 3 twinning is trivial, for there it is a logical necessity (Fig. 1). Designating the crystals in the twin by Roman numerals, let I-II be a Dauphiné twin and II-III* a Brazil twin, then I-III* *must* be a Combined twin. Likewise let III*-IV* be a Dauphiné twin, then IV*-I must be a Brazil twin, since III*-I is a Combined twin. More generally, any one of the three twin laws can be expressed as the product of the other two[2]. (The asterisk attached to a Roman numeral indicates a change of hand brought about by the twin law.)

It is of interest to derive, from Figure 1, the inferences that can be drawn from the observation of a reversal in electrical polarity (E), optical activity (O), or both these characters.: The results can be summarized as follows, with respect to number of crystals in the twin, their chirality (left or right). and twin laws present.

First case, E but not O: two crystals, I-II or III*-IV*, both left or both right. Dauphiné twin.

Second case, O but not E: two crystals I-III*, one left, the other right. Combined twin. (Labelling the crystals II-IV* brings no new results.)

Third case, both O and E: three possibilities.

(1) Two crystals, I-IV*, one left, the other right. Brazil twin. (The labelling II-III* is equivalent.)
(2) Three crystals, represented by any three corners of the square in Figure 1, say, I-II-III*, two left, one right or two right, one left. All three twin laws are present.
(3) Four crystals, I-II-III*-IV*, two left and two right. This is the complete twin. All three twin laws are there, and each one is acting twice, accounting for six dual twins (Fig. 1).

The above synopsis shows that the two observations can identify the Dauphiné twinning, when it occurs alone, and the rare Combined law, also when alone. If both reversals are observed, however, it is impossible to infer the number of crystals, chirality, or twin law(s) without additional observations, such as etch figures.

[2]Only because Dauphiné and Brazil twins occur much more frequently than the Combined twin, has the latter been taken as *the* combined twin. The term was introduced by Frondel (1945).

A Final Plea

In conclusion "electrical twinning" should not be used to mean "twinning by a 60° rotation around the *c* axis", not any more than "optical twinning" should be taken as a synonym of "twinning by inversion in a twin center". The adjectives "electrical" and "optical" properly describe characters of twins.

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