Parallel growth: aggregate of identical xtals with their xtalographic axes and faces parallel.

They may appear several crystals but still a single crystal hence their whole internal structure remain unchanged in orientation

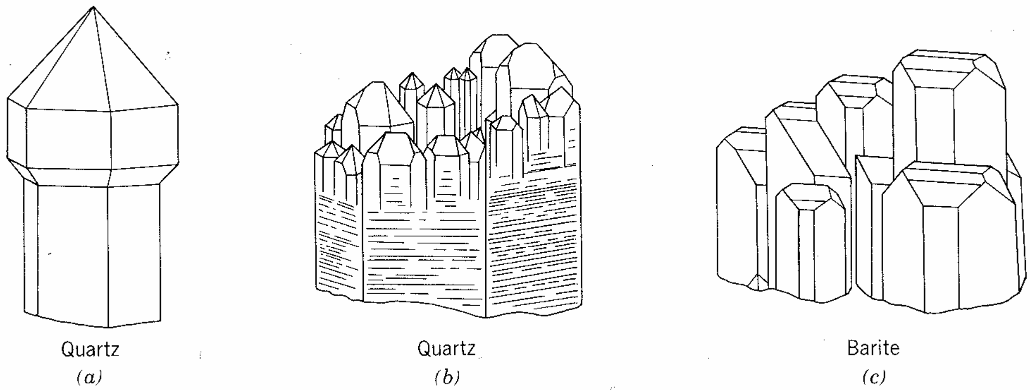
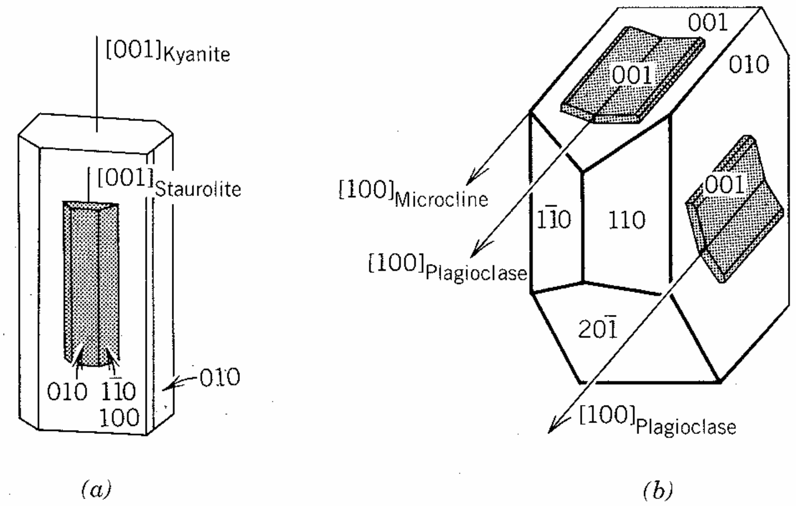


FIG. 2.110. Examples of parallel growth. *(a)* Overgrowth of a larger crystal of quartz on a smaller one, forming the shape of a scepter. *(b)* The termination of a large quartz cyrstal in a collection of smaller crystals, all in parallel orientation. *(c)* Parallel intergrowth of barite crystals.

Epitaxis: two compositionally different crystalline substances exhibit a non-random overgrowth

FIG. 2.111. Examples of epitaxis. *(a)* Parallel growth of staurolite ($Fe_2Al_9O_6(SiO_4)_4(O,OH)_2$) and kyanite ($Al_2SiO_5$). *(b)* Oligoclase ($NaAlSi_3O_8$ with about 13% substitution by $CaAl_2Si_2O_8$) overgrowths on microcline ($KAlSi_3O_8$). (This figure from Kern, R. and Gindt, R., 1958, *Bulletin Societé Française Min. Cryst.*, vol. 81, p. 264.)



Twin: Crystallographic controlled intergrowth (symmetrical intergrowth) and a twin, therefore, composed of two (or more) crystals.

The lattice direction of one xtal in twin exhibits a definite xtallographic relation to the lattice direction of the other xtal.

Twin operations* ➔ *Twin elements

Reflection by a mirror ➔ Twin plane
Rotation about an axis ➔ Twin axis
Inversion about a point ➔ Twin centre

Twin operation is also called twin law and twin elements are parallel to lattice elements (namely net or row)

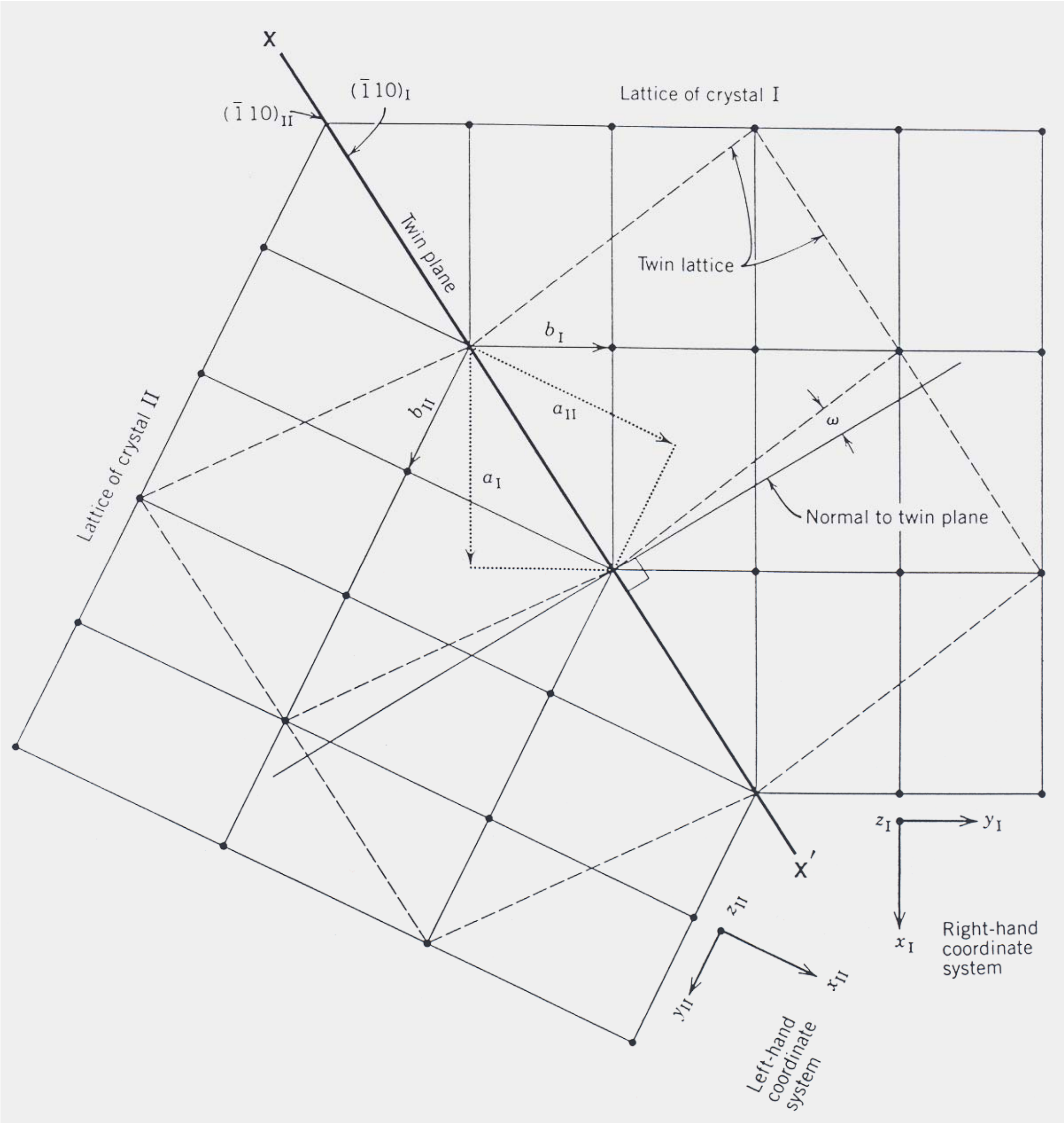
Twin lattice

Twin obliquity: angle between the normal to twin and the lattice row, where the maximum angle is about 6°

Twin index: $\frac{\text{volume per node in twin lattice}}{\text{volume per node in xtal lattice}}$

The smaller obliquity & index, the more frequent the twin

Twin lattice

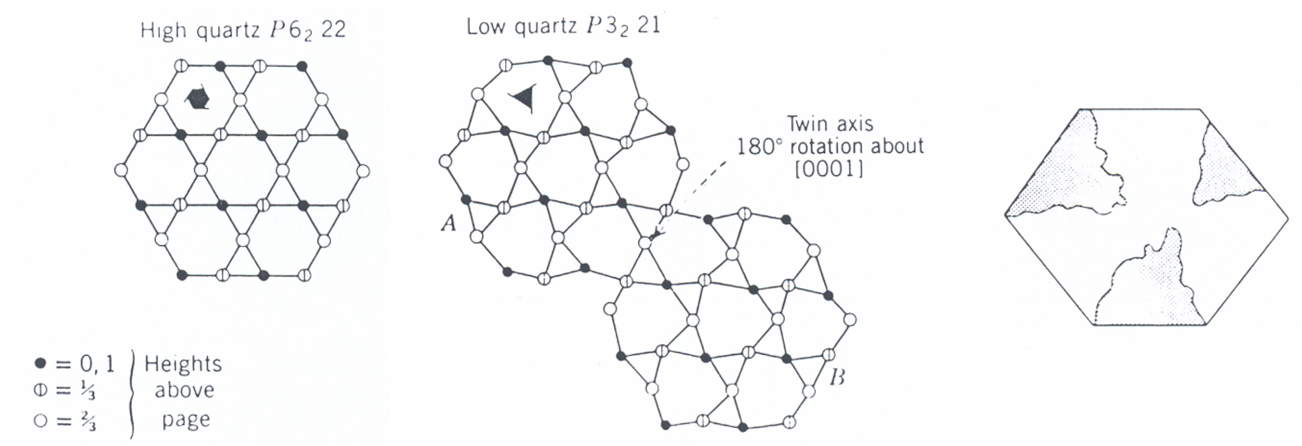


Origin of twinning

<u>Growth twin</u> is considered as primary twinning caused by nucleation errors or accidents during free growth.

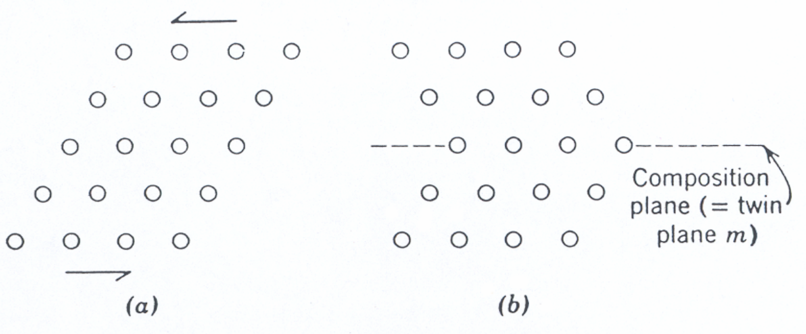
The emplacement of atoms or ions on surface of growing xtal causes interruption of regular arrangement of original xtal structure.

Transformation twin is a secondary twinning. They occur when a crystal formed at high-T is cooled and rearranges its structure to one whose symmetry is different from that of high-T form e.g. high quartz vs low quartz, high-T sanidine & lower-T orthoclase & lowest-T microcline



Gliding (deformation) twin is a secondary twinning occurs when a xtal is deformed by mechanical stress. It is commonly observed in metals and in metamorphosed limestones ➔ polysynthetical twinned calcite

Deformation twinning in an oblique lattice due to the application of mechanical stress as indicated by the arrows. Note that the amount of movement of the first layer above and parallel with the twin plane in *(b)* is less than that of the successive layers further removed from the twin plane.



Composition surface: surface that the two xtals are united. If surface is a plane called composition plane. Composition plane is commonly twin plane, but not always. If twin laws can be defined only by a twin plane, therefore, twin plane is always parallel to a xtal face but NEVER parallel to a plane of symmetry.

Twin axis: is a zone axis or a direction perpendicular to rational lattice plane. It is usually rotation through 180°. However, 90° rotation about previous 2-fold axis does exist e.g. [111] in fluorite, [001] in pyrite.

Classification of twinning

- ➔ Contatct VS Penetration twins
- ➔ Simple VS Multiple twins
  - polysynthetic twin
  - cyclic twin

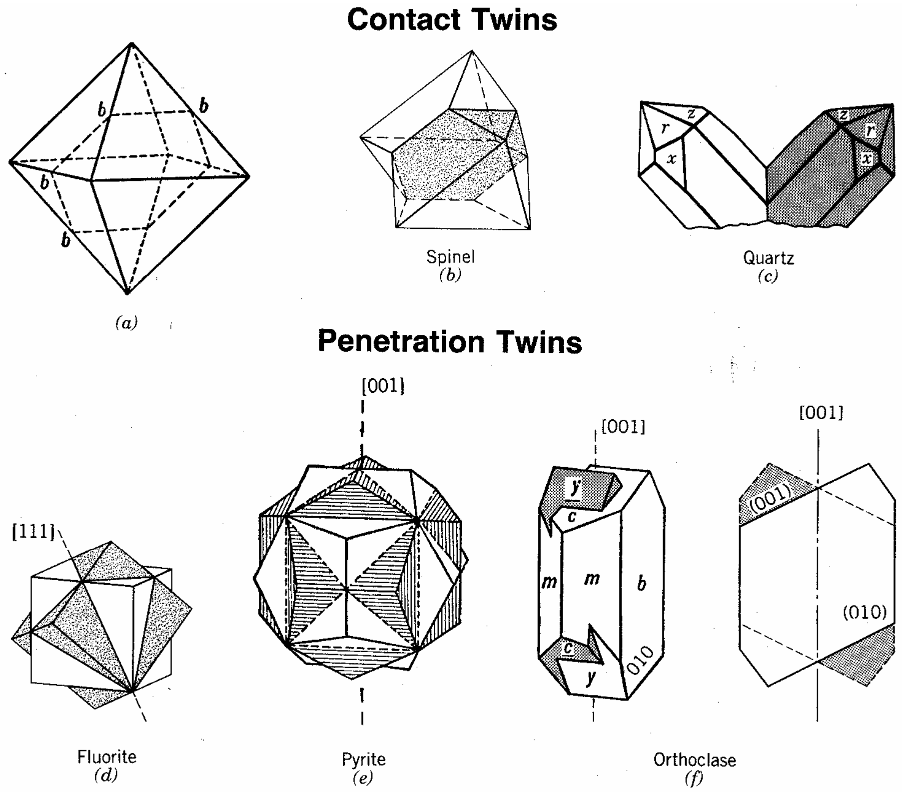


FIG. 2.112. *(a)* Octahedron with possible twin plane *b-b*($\bar{1}\bar{1}1$). This is one of four octahedral directions in the form {111}. *(b)* Octahedral twinning {111} as shown by spinel. *(c)* Right- and left-handed quartz crystals twinned along (11$\bar{2}$2), the *Japan twin* law. *(d)* Two interpenetrating cubes of fluorite twinned on [111] as the twin axis. *(e)* Two pyritohedral crystals (of pyrite) forming an *Iron Cross*, with twin axis [001]. *(f)* Orthoclase exhibiting the *Carlsbad twin* law in which two interpenetrating crystals are twinned by 180° rotation about the *c* axis, [001] direction. The schematic cross section, parallel to (010), reveals the presence of the 2-fold twin axis along [001].

Common twin laws:

Triclinic system:

albite twin {010}

pericline twin {001}

albite-pericline twin

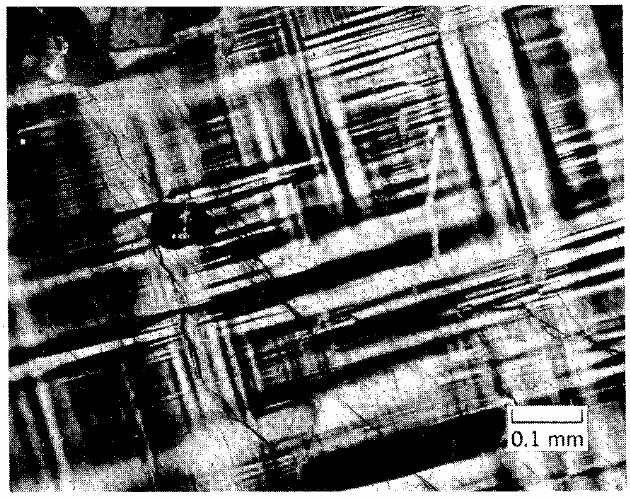


FIG. 2.114. Photomicrograph of transformation twinning (see p. 156) in microcline. The specimen is viewed under a microscope with crossed polarizers. The section of the photograph is approximately parallel to (001). The twin laws represented are albite with twin and composition plane (010), and pericline with twin axis direction [010].

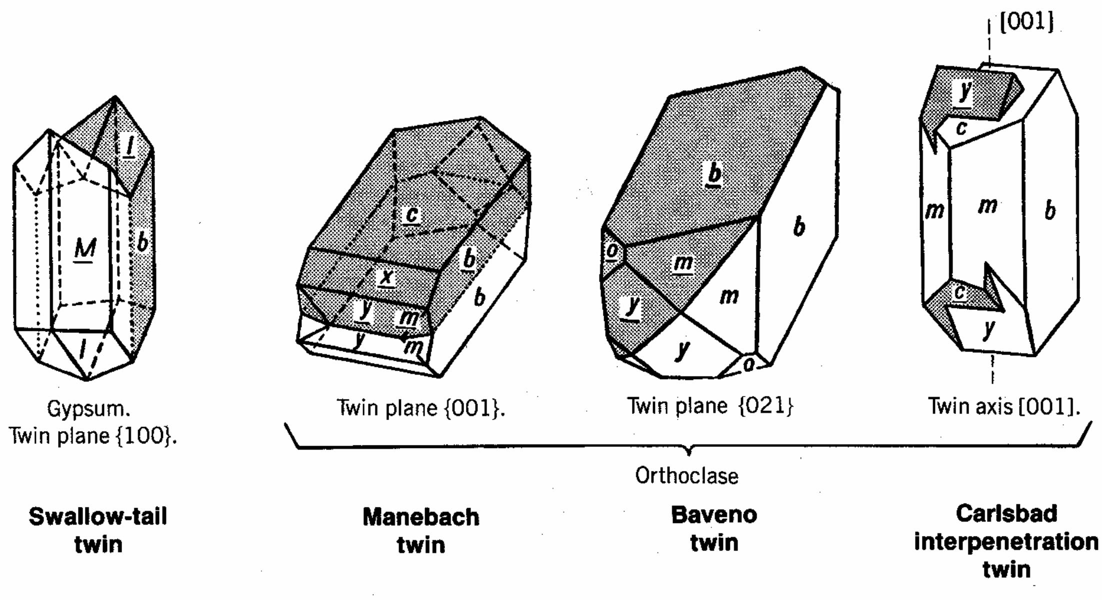
Monoclinic system: Swallow-tail twin {100}

Manebach twin {001}

Baveno twin {021}

Carlsbad interpenetration twin [001]

Monoclinic Twins



Orthorhombic system: Contact and cyclic twin

{110} => aragonite, cerussite (pseudo-hexagonal)

{031}, {231}=> staurolite (pseudo-orthorhombic)

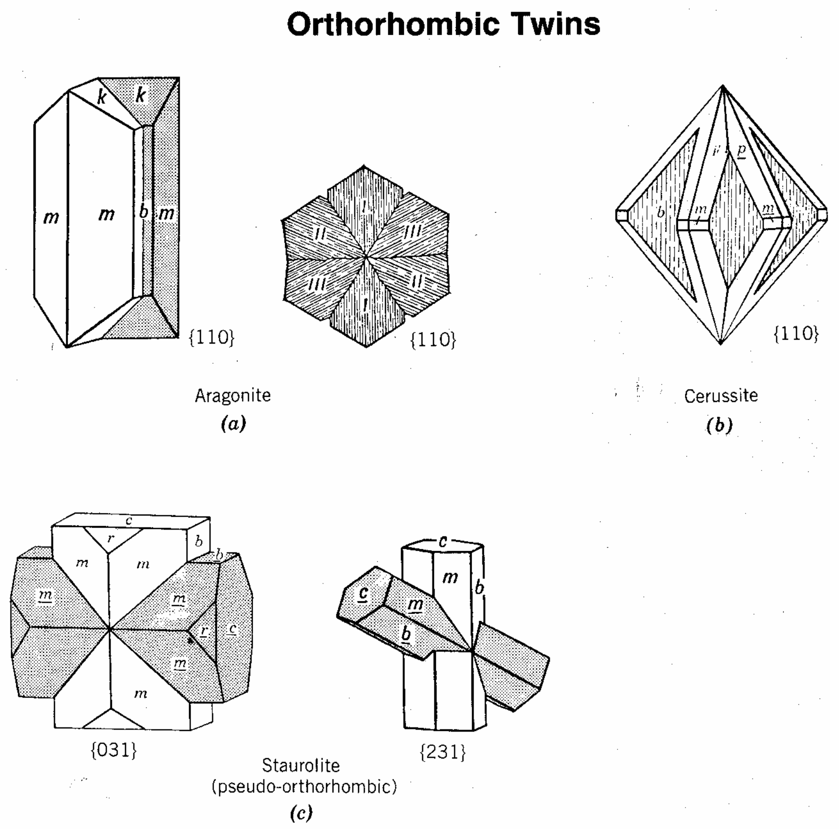
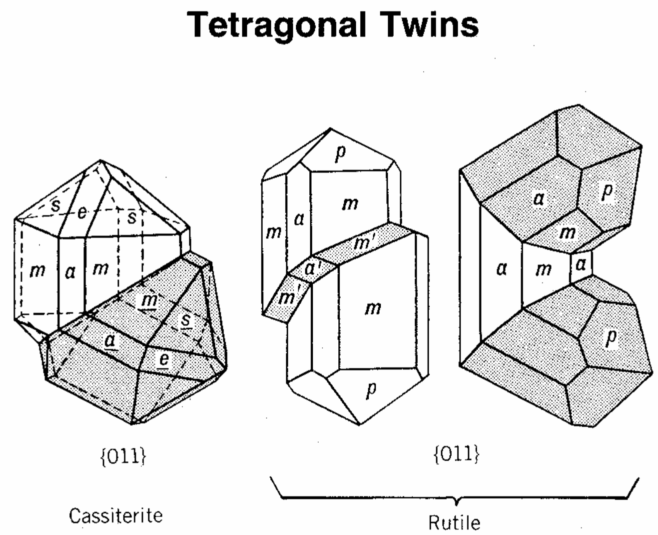


FIG. 2.116. Examples of common twins in orthorhombic crystals. *(a)* Contact and cyclic twinning on {110} in aragonite. *(b)* A cyclic twin on {110} in cerussite. *(c)* Staurolite twinned on {031} and {231}. The staurolite structure is actually monoclinic with β = 90°; it therefore appears pseudo-orthorhombic. It is illustrated here because of its orthorhombic-looking morphology.

Tetragonal system: {011} => cassiterite, rutile

FIG. 2.117. Examples of common twin laws in tetragonal crystals.

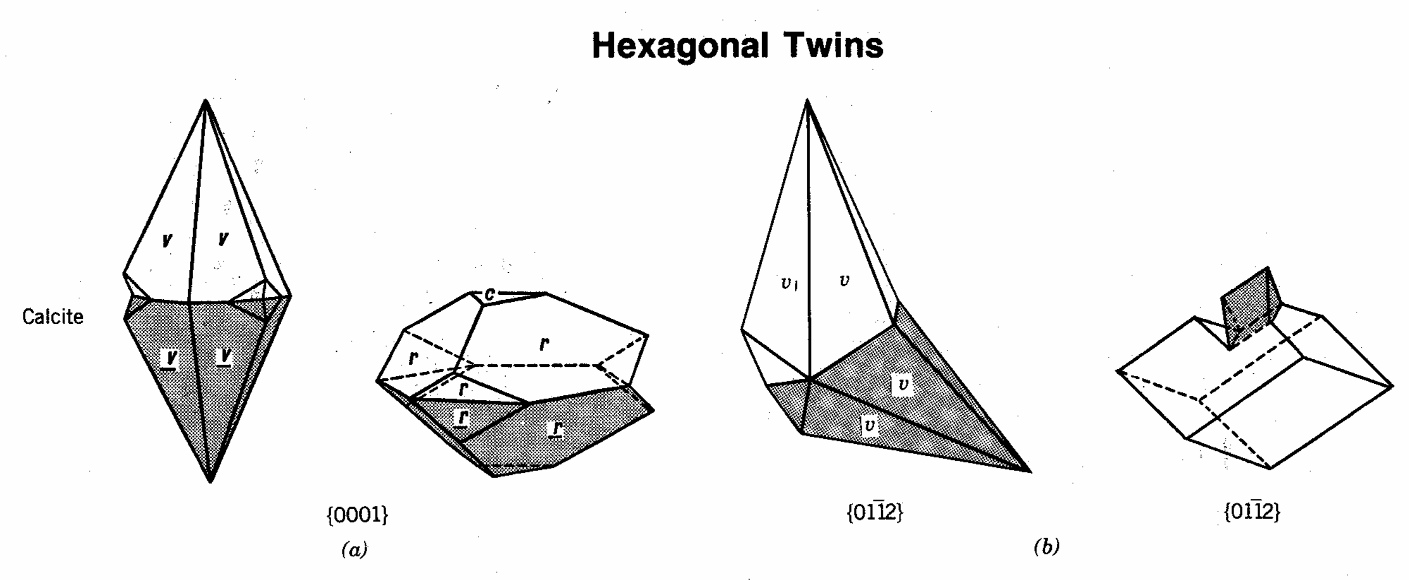


***Hexagonal system*:** $\{0001\}$, $\{10\bar{1}1\}$ and $\{10\bar{1}2\}$

Brazil twin $\{10\bar{2}0\}$

Dauphiné twin [0001]

Japan twin $\{10\bar{2}2\}$



Various twins in calcite

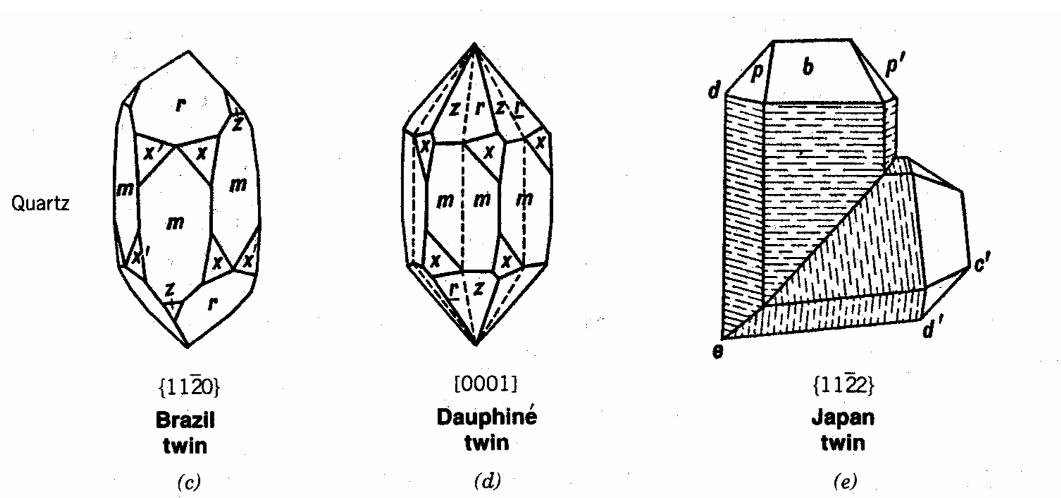
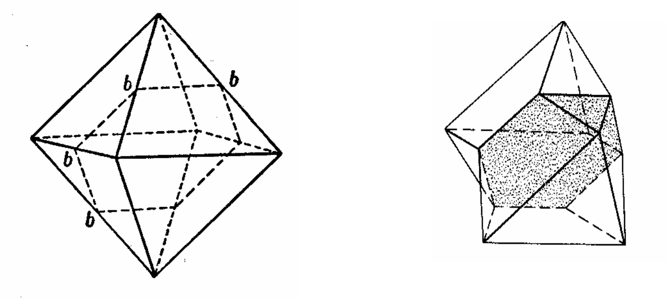
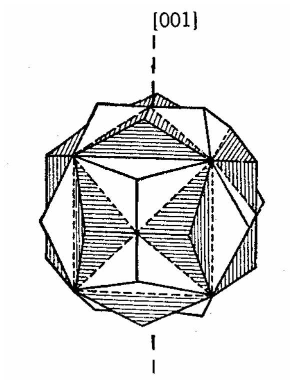


FIG. 2.118. Examples of twins in the hexagonal system. *(a)* and *(b)* Various twins in calcite. The calcite twin on the right is artificial and can be produced by pressure with a knife edge. *(c)* A *Brazil twin* in quartz. *(d)* A *Dauphiné twin* in quartz formed by rotation of 180° about the *c*-axis is, [0001]; see also Fig. 3.55. *(e)* A *Japan twin* in quartz.

Isometric system: Spinel twin {111}



Iron cross [001] => pyrite



Fluorite twin [111]