CRYSTALLOGRAPHY

UNIT III

Unit -III: SYLLABUS

Hexagonal system: Symmetry elements and forms. A. Hexagonal division: normal,hemimorphic, tripyramidal, and trapezohedral classes with type minerals. B. Rhombohedraldivision: rhombohedral, rhombohedral-hemimorphic, trirhombohedral, and trapezohedral classes. Orthorhombic system: study of the symmetry element and forms of the normal, hemimorphic, and sphenoidal classes with type minerals. -Monoclinic system: study of the symmetry elementsand forms of the normal class. Triclinic system: Study of the symmetry elements and forms of the normal class. Twin crystals: Definition evidence of twinning-laws of twinning-compositional plane, twinning plane and twin axis-twins: simple, repeated (polysynthetic twin), contact, and penetration twin.

Hexagonal system

Definition:

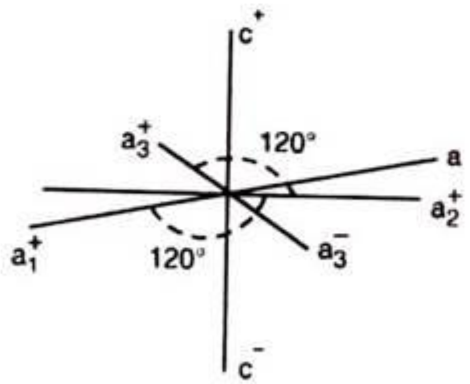
All those crystals which can be referred to four crystallographic axes of which:

(i) Three axes are horizontal, equal, interchangeable and intersecting each other at 120° between the positive ends.

(ii) The fourth axis is vertical and at right angles to the three horizontal axes, is grouped under Hexagonal System.

Axial Diagram:

The horizontal axes, all being equal, are designated by the letter a (a1, a2, a3), and the vertical axis by the letter ‘c’ as usual. (Fig. 10.23)



Axial Diagram

Fig. 10.23.

Divisions:

The Hexagonal System consists of two distinct divisions, namely the hexagonal division and the rhombohedral (trigonal) division. The first includes 7 crystal classes and the second 5 crystal classes.

The two divisions will be described individually:

A. The Hexagonal Division:

Symmetry of Normal Class

(a) Axis of Symmetry:

7 in all. 1 axis, vertical, of six fold symmetry; 6 axes, horizontal, of two fold symmetry;

(b) Planes of Symmetry:

7 in all, 1 plane, horizontal, containing 6 axes of symmetry. 6 planes, vertical and vertical diagonal. And a Centre of Symmetry.

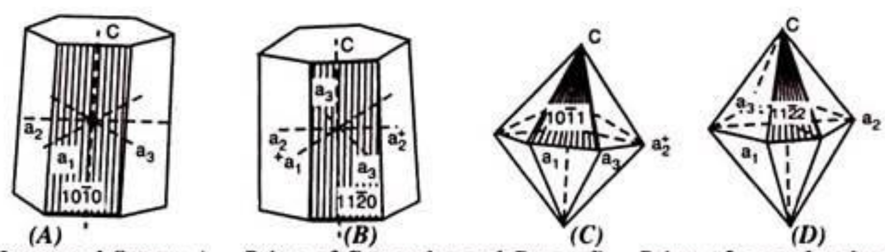
Forms:

Forms of hexagonal system differ in character from forms of all the other systems in that their parameters, indices and symbols are determined with respect to four crystallographic axes (and not three as in other systems). Thus, the relation of any hexagonal form is expressed by the general term, (hkil).

It may further be pointed out here that $h + k + i = 0$ is a typical relation true for all the forms belonging to the hexagonal system.

1. Base (0001):

An open form of two faces in which each face meets the vertical axis only. (Fig. 10.24.)



Forms in Hexagonal System A – Prism of first order and Base, B – Prism of second order and Base C – Pyramid of first and second order

Fig. 10.24.

2. Prisms:

A prism is an open form in which each face is essentially parallel to the vertical axis.

Following three types of prisms are met with in the Hexagonal system:

(a) Prism of First Order $(10\bar{1}0)$:

An open form of six faces in which each face is parallel to one of the three horizontal axes besides the vertical axis. It cuts the two horizontal axes at unit length. (Fig. 10.24)

(b) Prism of Second Order $(11\bar{2}0)$:

An open form of six faces like prism of 1st Order but in this case each face cuts all the three horizontal axes, two axes at equal length and to the third at greater length. It is, of course, parallel to the vertical axis.

(c) Prism of Third Order $(hk\bar{i}o)$:

It is also called a dihexagonal prism as it has double the number of faces (twelve), compared to the six faces of prism of 1st order. In this form each face cuts all three horizontal axes at unequal lengths.

Pyramids:

A pyramid is a form that essentially intercepts the vertical axis.

Like prisms, three types of pyramids occur in hexagonal system:

(i) Pyramid of First order $(10\bar{1}1)$:

It is a closed form of twelve faces, six above and six below the horizontal plane, each face essentially cutting the vertical axis and two of the three horizontal axes. It is parallel to the third horizontal axis. (Fig. 10.24)

(ii) Pyramid of Second Order $(hh2\bar{h}l)$:

It is also a closed form of twelve faces but in this each face cuts all the three horizontal axes, two of them at unit length and the third at double the length. It also cuts the vertical axis.

(iii) Pyramid of Third Order $(hk\bar{i}l)$:

It is also called dihexagonal pyramid, as it has double the number of faces (24) of an ordinary hexagonal pyramid. Each face in dihexagonal pyramid cuts all the four crystallographic axes at unequal lengths.

B. Rhombohedral Division:

Symmetry:

The Normal Class of Rhombohedral Division has the following symmetry:

(i) Axis of Symmetry:

4 in all. 1 vertical axis of three fold symmetry. 3 horizontal axes of two fold symmetry.

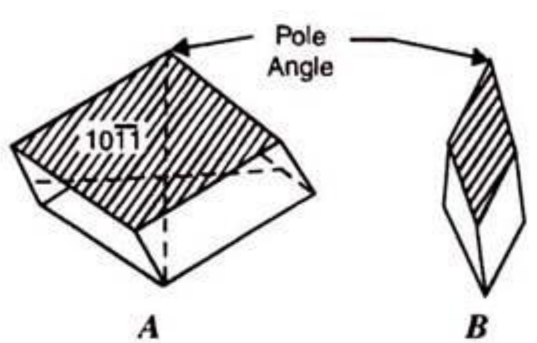
(ii) Planes of Symmetry:

3 in all. All the planes are vertical diagonal in position. A center of Symmetry.

Forms:

a. Rhombohedron:

The most common form of this group is a rhombohedron, a solid bounded by six similar faces, each like a rhomb and meeting the vertical axis. Of the three horizontal crystallographic axes, each face of rhombohedron meets the two axes and is parallel to the third. (Fig. 10.25). The rhombohedron has a symbol of $(10\bar{1}1)$.



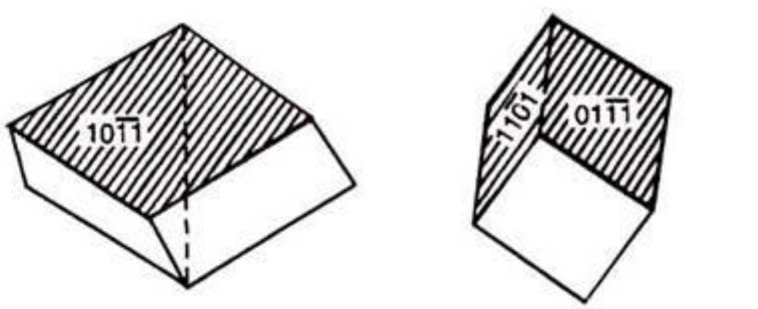
Rhombohedrons A–Obtuse, B–Acute.

Fig. 10.25.

The usual method to hold rhombohedron in a study position is along its vertical axis (c-axis) which joins the two trihedral angles, also called the pole angles. (Fig. 10.25). In such a position, the three horizontal axes join the middle points of the other sides.

The rhombohedron is further distinguished into an obtuse type or an acute type, depending upon the value of the pole angle which in turn depends on the axial ratio a: c.

As a general rule, greater the length of the ‘c’ axis with respect to the a-axis, more acute is the rhombohedron.



A *B*

A–Positive and Negative, B–Rhombohedron.

Fig. 10.26.

Rhombohedrons are also distinguished into positive and negative types. When in a study position (as described above) the rhombohedron presents a full face to the observer, it is taken to be a positive type; when, however, an edge is in front of the observer in the study position, it is designated as a negative rhombohedron.

Examples of Minerals:

i. Quartz

ii. Corundum

iii. Tourmaline

iv. Calcite

v. Beryl

vi. Hematite

vii. Brucite

viii. Cancrinite

ix. Willemite

x. Chabazite

4. Orthorhombic System:

Definition:

This system includes all those crystals which can be referred to three crystallographic axes, all of which are:

(i) Essentially unequal in length

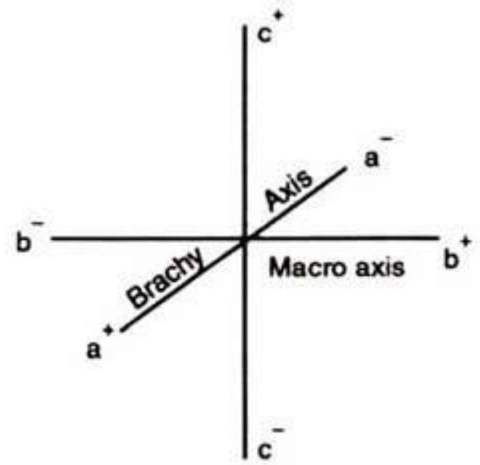
(ii) Essentially at right angles to each other.

Axial Diagram:

The three crystallographic axes are arbitrarily designated as a, b and c, in such a way that the c axes is vertical and the b axis runs from right to left and the a axis extends from front to back in the crystal when held in a proper study position.

The b axis is always longer of the two horizontal axes and is also designated as macro axis.

The a axis being shorter, is designated as brachy axis. (Fig. 10.29.)



Axial Diagram

Fig. 10.29.

In the determination of the Axial Ratio in the crystals of the Orthorhombic System, it is customary to take the length of 'b' axis as unity and express the lengths of the other axes in terms of this unit.

Symmetry of Normal Class:

The system includes three classes. The symmetry of Normal Class (Baryte Type) is given below:

(a) Axis of Symmetry:

3 in all, of two fold symmetry.

(b) Planes of Symmetry:

3 in all, axial in position. A Centre of Symmetry.

Forms:

Common forms developed in the normal class of the Orthorhombic Systems are:

A. Pinacoids:

A Pinacoid is an open form of two faces in which each face meets any one of the three axes and is parallel to the other two axes. A typical symbol is (100). Three types of pinacoids are known in the Orthorhombic System.

(i) a-Pinacoid or Macropinacoid (100):

An open form of two faces, each face cutting the a- axis and being parallel to the other two faces.

(ii) b-Pinacoid or Brachy pinacoid (010):

An open form of two faces, each face cutting the b-axis and being parallel to the other two axes.

(iii) c-Pinacoid or Base (001):

An open form of two faces, each face cutting the c-axis and being parallel to the two horizontal axes.

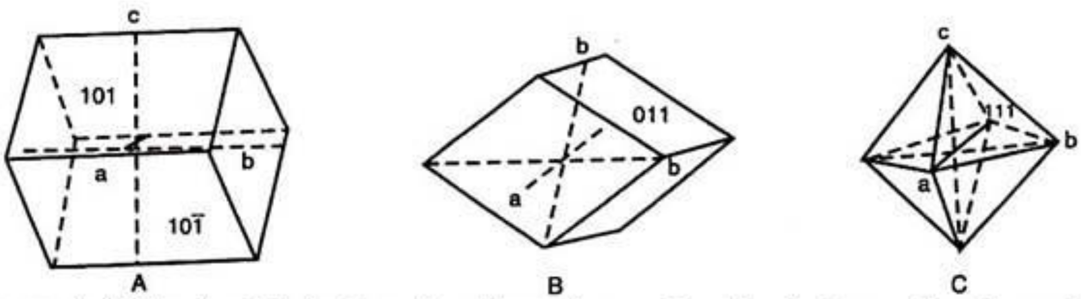
B. Prisms:

A prism is a form which is essentially parallel to the vertical axis.

Three types of prisms are recognized in the Orthorhombic System:

(i) Unit Prism (110):

An open form of four faces in which each face makes intercepts on the horizontal axes corresponding to the assumed axial ratio for the species. (Fig. 10.30).



Forms in Orthorhombic System A – Macrodome, B – Brachydome, C – Pyramids.

Fig. 10.30.

(ii) Macroprism (hko, h>k):

An open form of four faces in such a way that each face cuts the brachy axis at a greater length. It is parallel to the vertical axes. Example (210). Faces lie between those of macropinacoids and unit prism.

(iii) Brachyprism (hko; h<k):

An open form of four faces in such a way that each face cuts the brachy axis at a smaller length than the macroaxis. Faces of this form lie between the brachypinacoid and the unit prism.

C. Domes:

A dome is defined as forms whose faces essentially meet the vertical axis and are parallel to one of the two horizontal axes.

Two types of domes are distinguished:

(i) Macrodome (hol):

An open form of two faces in which each face meets the vertical axis and the a-axis, and is parallel to the macroaxis.

(ii) Brachydome (Ohl):

An open form of two faces, each face is parallel to the brachy axis and meets the other two axes. (Fig. 10.30 A and B)

D. Pyramids:

In these forms of four faces, each face essentially meets the vertical axis.

Three types of pyramids are recognized:

(i) Unit Pyramid (hhl):

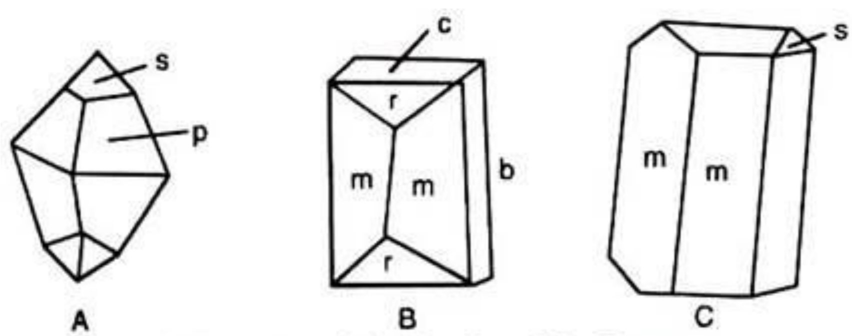
Where the parameters correspond to the assumed axial ratio for the species.

(ii) Macro Pyramid (hkl, h>k):

A closed form of four faces, each face intercepting all the three axes at unequal lengths in such a way that intercepts at a-axis is greater than those at b-axis; e.g. (214).

(iii) Brachy Pyramid (hkl; h<k):

A closed form of four faces in which intercepts at b-axis are greater than those made at a-axis, e.g. (241). (Fig. 10.30)



Minerals of Orthorhombic System

Fig. 10.31.

Examples of Orthorhombic Minerals:

i. Sulphur

ii. Staurolite

iii. Andalusite

iv. Topaz

v. Barytes

vi. Aragonite

vii. Enstatite

viii. Anthophyllite

ix. Stibnite

x. Calamine.

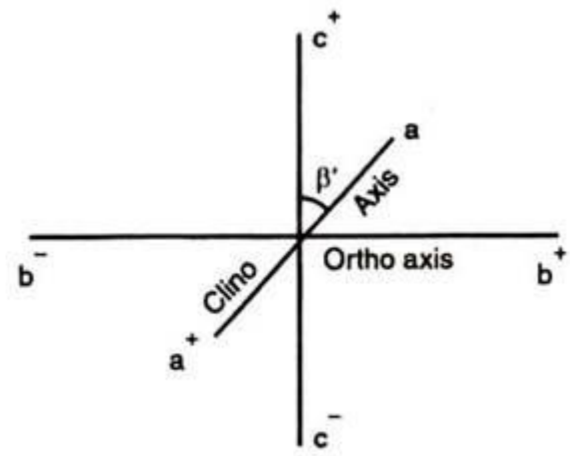
5. Monoclinic System:

Definition:

The Monoclinic System includes all those forms that can be referred to three crystallographic axes which are essentially unequal in length and further that one of these is always inclined. (Mono = single, clino = inclined).

Axial Diagram:

Since all the three axes are unequal, they are designated by the letters a, b and c. The c-axis is always vertical. The inclined axis is a-axis. It is inclined towards the observer and is also referred as clino axis. The longer horizontal axis is as usual designated as b-axis and runs from right to left. It is also referred as ortho axis. (Fig. 10.32)



Axial Diagram of Monoclinic System

Fig. 10.32.

The angle between the a-axis and the c-axis is designated as β and is always an acute angle. For the determination of the axial ratio, the length of b-axis is taken as unity.

Normal Class Symmetry:

There are three symmetry classes placed in Monoclinic System.

The symmetry of the normal class (gypsum type) is as given below:

(a) Axis of Symmetry:

1 axis of two fold Symmetry only.

(b) Planes of Symmetry:

1 plane of symmetry only. And a Centre of symmetry. The plane of symmetry is that plane which contains the crystallographic axes ‘a’ and ‘c’.

Forms:

The common forms of this system are:

a. Pinacoids:

A pinacoid is an open form of two faces, each face being parallel to the two axes and cutting the third at a unit length.

Three pinacoids are distinguished in the Monoclinic System:

(i) a-Pinacoid (100):

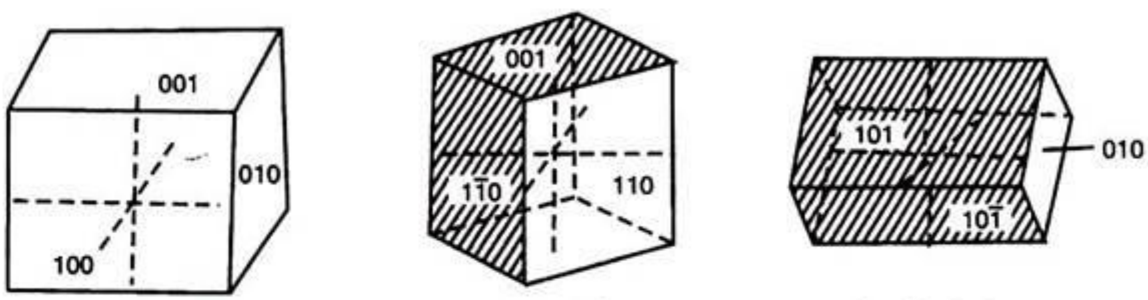
It is also called orthopinacoid; as the symbol indicates, each face cuts the a-axis and is parallel to the other two axes (Fig. 10.33A).

(ii) b-Pinacoid (010):

It is also called clinopinacoid; in this each face cuts the b-axis at unit length and is parallel to the other two axes.

(iii) c-Pinacoid (001):

It is also called base. The form has two faces, each cutting the vertical axis at unit length.



A – Pinacoids. B – Prism. C – Orthodome.

Forms in Monoclinic System

Fig. 10.33.

b. Domes:

A dome is also a form of two faces, each face meeting the vertical axis and one of the other two axes. It is parallel to the third axis (Fig. 10.33).

Two types of domes are recognized depending on to which of the other two axis it is parallel:

(i) Orthodome (hol):

An open form of two faces, each face is parallel to the ortho axis and cuts the other two axis.

(ii) Clinodome (ohl):

An open form of two faces, each face is parallel to the clino axis and cuts the other two axis.

c. Prism:

These are open forms of four faces each, in which each face is essentially parallel to the vertical axis.

There are three types of prisms recognized in the monoclinic system:

(i) Unit Prism (110):

It is an open form of four faces in which each face is cutting the a and b axis at the assumed axial ratio of the species.

(ii) Orthoprism (hko, h>k):

It is an open form of four faces in which each face is parallel to the vertical axis and meets the clino-axis (a-axis) at a greater distance.

(iii) Clinoprism (hko, h<k):

It is an open form of four faces in which each face is parallel to the vertical axis and cuts the ortho axis with a smaller intercept.

d. Pyramids:

These are closed forms and in these each face meets all the three axes. Three types of pyramids are distinguished.

(i) Unit Pyramid (hhl):

Each face cuts all the three axes at the assumed axial ratio of the species.

(ii) Orthopyramid (hkl, h>k):

A type of pyramid in which each face makes a smaller intercept on the orthoaxis. e.g. 321 etc.

(iii) Clino Pyramid (hkl, h<k):

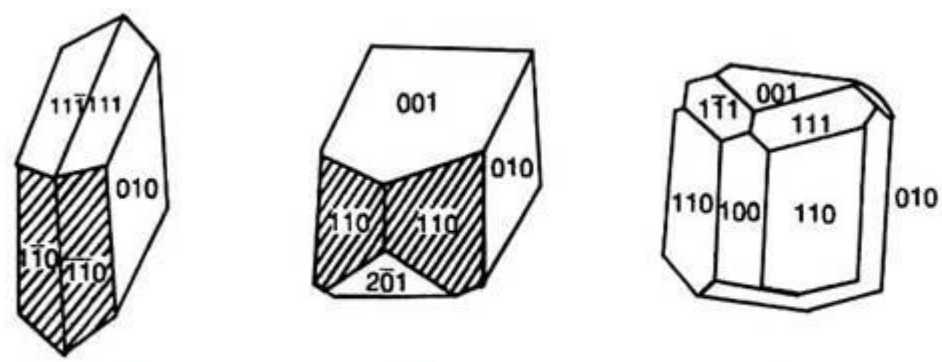
That type of pyramid in which each face makes a smaller intercept on the clinoaxis. e.g. 231 etc.

Examples of Monoclinic Minerals:

(1) Gypsum

(2) Orthoclase

(3) Pyroxene



A. Gypsum B. Orthoclase C. Pyroxene

Some Minerals of Monoclinic System

Fig. 10.34.

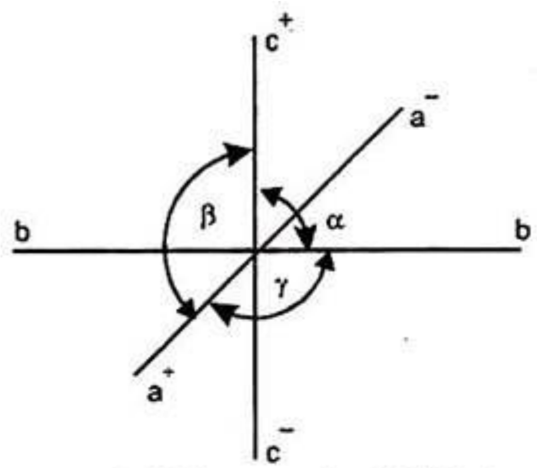
<u>6. Triclinic System:</u>

Definition:

Those crystals which can be referred to three crystallographic axes, all of which are essentially unequal in length and inclined at various angles to each other, are grouped under triclinic system.

Axial Diagram:

The proper orientation of a crystal of this system would be in which any one of the crystallographic axes is given a vertical position and is designated as c axis. Of the remaining two crystallographic axes, the one which is shorter and sloping towards the observer may be designated as a-axis (brachy axis). The third axis then running approximately right to left and is designated as b-axis (macro-axis). (Fig. 10.35)



Axial Diagram in Triclinic System

Fig. 10.35.

Following is the scheme of nomenclature for the angles between the three axes:

α = angle between b axis and c axis;

β = angle between a axis and c axis;

γ = angle between a axis and b axis.

Normal Class:

There are only two symmetry classes falling in the Triclinic System. The normal class is named axinite type after the mineral.

(i) Axes of Symmetry-none.

(ii) Planes of Symmetry-none.

The class is characterized by only a centre of symmetry which is the point of intersection of the three crystallographic axes.

Forms:

All the forms of monoclinic system are found in the crystals of this system also. The main feature of the forms of the triclinic system is that each form has only two faces symmetrical with respect to the centre of symmetry of the crystal. These are, therefore, hemiforms.

a. Pinacoids:

These are open forms, each of two faces, meeting only one axis and being parallel to the other two.

Three types of pinacoids are found in the Triclinic System also as in the Monoclinic and Orthorhombic systems:

(i) a-pinacoid (100) – also called macropinacoid

(ii) b-pinacoid (010) – also called brachypinacoid has two faces each meeting the b-axis at unit length.

(iii) c-pinacoid (001) – also called base has two faces, each intersecting the c-axis.

b. Prisms:

These are open forms of two faces only in the Triclinic System; hence they are also called hemi-prisms. Their general symbol is hko. In all, four prismatic faces with the above symbol are possible, but since there are no planes of symmetry, these four faces will occur in two groups, each being symmetrical to a centre of symmetry only.

c. Domes:

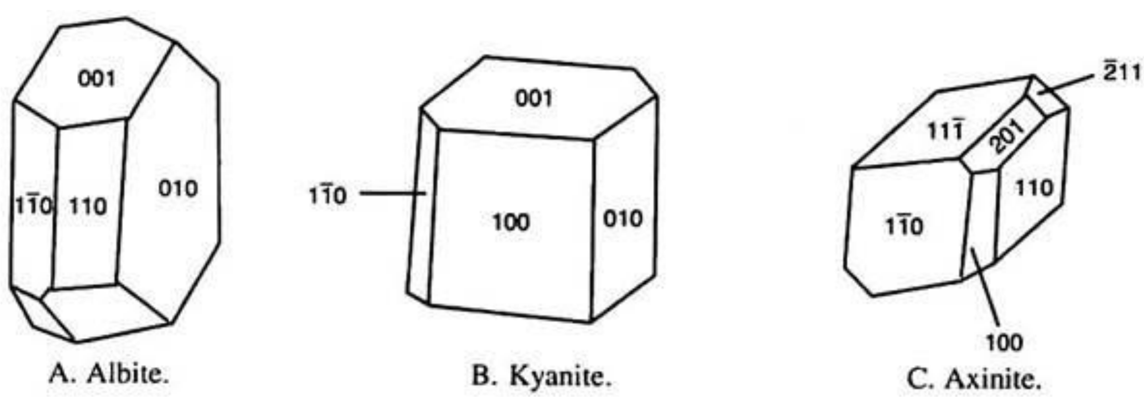
In the Triclinic System, domes are also hemiforms, that is, these contain only one half of the usual number of faces.

The macrodome has two faces, with a symbol of (hol).

The brachydome has two faces with a symbol of (ohl).

d. Pyramids:

Four types of pyramids each with two faces only and each face cutting the vertical axis exist in the Triclinic System. These are called Tetrato-bipyramids (4 bifaced pyramids) represented by the symbol (hkl); Fig. 10.36; 211



Some Minerals of Triclinic System

Fig. 10.36.

Examples of Triclinic Minerals:

i. Albite

ii. Kyanite

iii. Axinite

iv. Microcline

v. Anorthite

vi. Rhodonite

vii. Turquoise

Twin crystal

Generally crystals grow from the melts as individual specimens, each having its own shape, form and crystallographic characteristic. Sometimes, however, two crystals of the same compound may be formed from the same melt in such a way that both are essentially united, each bearing a definite crystallographic relation to the other.

A group of two crystals mutually united and intimately related are called twins and the phenomenon of their formation is called Twinning.

Twinning is an interesting field of study in mineralogy because quite a good number of minerals have the habit of occurring in twinned forms. Such mineral twins form valuable pieces of collection in a geological museum.

Similarly, Gypsum, a hydrated calcium sulphate ($CaSO_4 \cdot 2H_2O$), commonly occurs in simply flattened or prismatic crystals. Occasionally, two crystals of gypsum may be naturally united as twins popularly known as swallow-tail twins (Fig. 10.39).Similarly, Gypsum, a hydrated calcium sulphate ($CaSO_4 \cdot 2H_2O$), commonly occurs in simply flattened or prismatic crystals. Occasionally, two crystals of gypsum may be naturally united as twins popularly known as swallow-tail twins (Fig. 10.39).

A. Simple crystal of gypsum B. Twins of gypsum called swallow tail twins

Twinning Explained

Fig. 10.39.

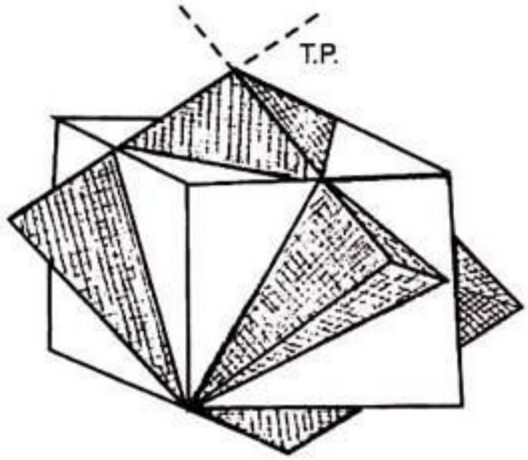
Following is a brief outline of the most commonly observed twin laws in different crystallographic systems:

1. Isometric System:

Spinel Law:

It is so named because of its presence in minerals of spinel group. In this law, octahedral face (111) is the twining plane, which is also in most cases, the composition plane. Further, the octahedral-axis is the twining axis.

Twins of different types such as simple, contact, multiple contact and penetration twins based on this law have been observed in many minerals of isometric system, such as magnetite, galena, fluorite and pyrite, besides spinel. (Fig. 10.40).



Spinel Law.

A–Face of Octahedron (Possible) is twining plane.

Fig. 10.40.

2. Tetragonal System:

Rutile Law:

In such twins, the face of a pyramid of Second Order (101) is the twinning plane. This is the most common law for the crystals of the tetragonal system. Twins commonly observed in these crystals are of repeated type. Example- rutile, cassiterite, zircon and scheelite.

3. Hexagonal System:

i. The Brazillian Law:

In this law, the prism of Second Order $(11\bar{2}0)$ is a twin plane. Quartz (SiO2) shows development of twins according to this law.

ii. The Dauphine Law:

In this law, c-axis is the twinning axis. Twins are generally intergrown. Some Quartz twins are also based on this law.

iii. The Japanese Law:

Contact twins result on this law in which pyramid $(11\bar{2}2)$ is a twinningplane. Quartz shows twinning according to this law also.

It may be mentioned here that quartz showing twinning on the above laws becomes a useless material for optical purposes.

4. Orthorhombic System:

In this system, crystals show twinning in a variety of ways of which following are more common.

Prism-Face (110) as the twinning-plane.

There are two variations:

(a) When the prism angle is about 60° and the twinning is repeated, a crystal with pseudo symmetry of higher order is produced. This is seen in the minerals of Aragonite group, which on account of repeated twinning on prism face appear hexagonal in outline.

(b) When the prism angle is 70°. Twins of this type are alsocommon.

Staurolite Twinning:

This mineral shows cruciform twins of two types:

(a) Right-angled Cross – These result when face (031) is a twinningplane.

(b) Sea-horse twin in which the face (231) is a twin plane.

In both the cases the twins are of penetration type:

5. Monoclinic System:

This system includes the largest number of minerals and also shows a great variety of laws on which twinning occurs in minerals.

The following five laws are the most common and in no case exclusive:

i. Carlsbad Law:

In this case, the c (or vertical) axis is the twinning-axis. The minerals commonly show inter-penetration or contact type of twinning.

ii. Baveno Law:

In this law, the mineral shows twinning with clino-dome (021) as the twinning plane. Twins may be of simple contact or repeated contact type.

iii. Manbach Law:

Here, the basal pinacoid (001) is a twinning plane.

Felspar orthoclase shows twinning according to one or other of the above mentioned laws.

iv. Gypsum Twins:

The mineral gypsum, a hydrated calcium sulphate ($CaSO_4.2H_2O$) shows twinning of simple contact type in which the a-pinacoid is the twinning plane. When the rotation is complete along this plane, the resulting twins resemble a swallow-tail. Hence, twins are also referred as swallow-tail twins.

V. Pyroxene Twins:

In this group of monoclinic minerals, twinning is generally according to Manbach Law where basal pinacoid (001) is the twinning plane. The twins are, however, generally of repeated polysynthetic type.

In other cases of pyroxenes, Orthodome (101) is the twinning plane.

6. Triclinic System:

The group of silicate minerals called the Plagioclase felspars having Albite ($NaAlSi_3O_8$) and Anorthite ($CaAl_2Si_2O_8$) as the end members show interesting types of twinning.

Following are common examples:

i. Albite Law:

In this case, a plane parallel to fr-pinacoid is the twinning plane. Twinning is most commonly of repeated lamellar type involving very thin lamellae of the mineral.

ii. Pericline Law:

Here, the twinning axis is easily defined as the one parallel to b-axis. The twins may be repeated polysynthetic lamellar type.

The Felspar Plagioclase minerals also show twinning on laws found in Monoclinic Felspars such as Carlsbad, Manbach and Baveno laws. The twinning in these felspars being generally of repeated lamellar type is difficult to recognize in hand specimens and requires preparation of thin sections for study under microscope.

Simple Twins:

When a twin crystal has very well defined two-halves held together according to easily understandable relationships, these may be said as simple twins.

By

m.p.kowsalya

Reference

- https://www.britannica.com>science

- www.:www.geo.umass.edu>
- http://metafysica.nl
- https:// www.tulane.edu>
- https://www.tulane.edu
- https://www.geologyin.com