CRYSTALLOGRAPHY AND MINERALOGY

UNITS – 1 & 2

6 Yr. Int. **M.Tech.** Geological Technology & Geoinformatics
(Paper Code: MTIGT0306)

Georgius Agricola, 'Father of Mineralogy'
German scientist '**Georg Bauer**' - named by birth
First book on Mineralogy was written by him entitled :
'Bermannus, sive de re metallica dialogus '(1530)
A description of the ore mountain(Ergebrge) – Silver mining district.

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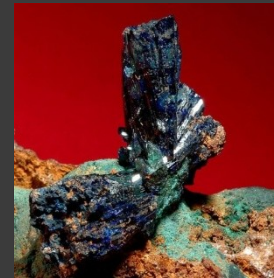
René Just Haüy (1743 –1822)
"Father of Modern Crystallography"
French (Paris) Mineralogist
generally known as **Abbé Haüy**

MTIGT0306: THEORY – CRYSTALLOGRAPHY AND MINERALOGY 4 credits

1. **Elements of Crystallography**: Crystalline and Amorphous forms - Symmetry and Classification of Crystals - System of Crystal Notation - (Weiss and Millerian) - Forms and Habits. Crystal Systems (Isometric, Tetragonal, Hexagonal, Orthorhombic, Monoclinic, Triclinic, Twinning - Crystalline Aggregates – Columnar, Fibrous, Lamellar, Granular - Imitative shapes and Psudomorphism. **12 Hrs.**
2. **Crystal Properties:** Space Symmetry Elements- Translation – Rotation- Reflection - Inversion Screw and Glide-point groups and Crystal classes - Derivation of 32 Crystal classes based on Schoenflies notation - Bravais lattices and their Derivation - An outline of Space Groups. X-ray Crystallography. **12 Hrs.**
3. **Physical Mineralogy**: Physical Properties: (Colour – Structure – Form – Luster - Transparency – Streak – Hardness – Specific Gravity – Tenacity – Feel – Taste – Odour) - Electrical, Magnetic and Thermal properties-Determination of Specific Gravity (Jolly's spring balance, Walker's steel yard, Pycnometer methods) - Empirical and Structural formula of minerals – Isomorphism, Polymorphism and Psudomorphism - Atomic substitution and Solid solution in minerals - Non Crystalline minerals - Fluorescence in minerals - Metamict state. **16 Hrs.**
4. **Optical Mineralogy:** Optical Properties (Colour – Form – Cleavage - Refractive Index - Relief – Alteration – Inclusions – Zoning – Pleochroism – Extinction - Polarization colours – Birefringence) – Twinning - Optic sign (Uniaxial and biaxial)- Interference figures - Primary and Secondary Optic axes - Optic axial angle measurements – Optic Orientation – Dispersion in Crystals - Optic anomalies. **12 Hrs.**
5. **Mineral Groups:** Ortho and Ring Silicates (Olivine group - Garnet group). Alumino silicates (Epidote group - Zircon – Staurolite – Beryl - Cordierite and Tourmaline). Sheet Silicates (Mica group - Chlorite group and Clay minerals) - Chain Silicates (Pyroxene group - Amphibole group and Wollastonite). Frame work Silicates (Quartz -Feldspar - Feldspathoid - Zeolite and Scapolite groups) - Non-silicate (Spinel group, Carbonates and Phosphates). **12 Hrs.**

Crystallography



Azurite

Ice crystals in plane

- is the scientific study of crystals
- **Crystallography** is the experimental science of determining the arrangement of atoms in solids.

Aragonite

Kyanite

Diamond xal

Beryl

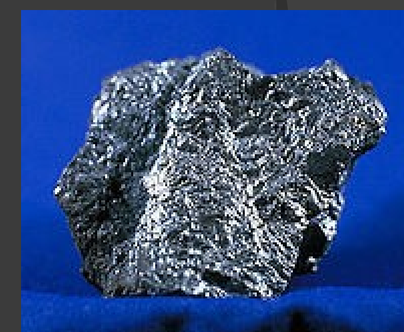
Quartz crystals

An eg. of closely packed lattice system

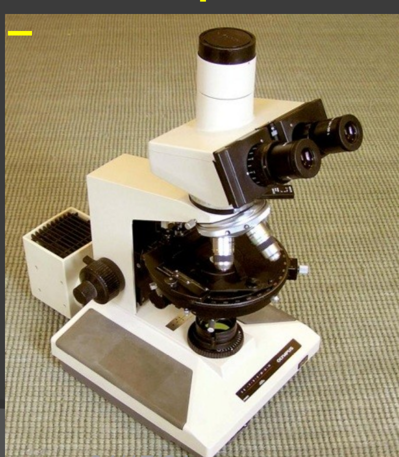
Mineralogy

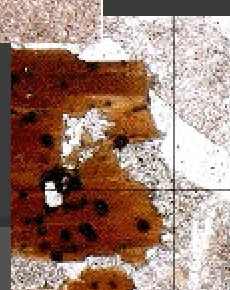
- Mineralogy is the study of chemistry, crystal structure, and physical (including optical) properties of minerals.
- Specific studies within mineralogy include the processes of mineral origin and formation, classification of minerals, their geographical distribution, as well as their utilization.
  - Crystallography
  - Physical Mineralogy
  - Chemical Mineralogy
  - Optical Mineralogy

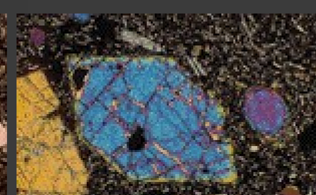
Chalcocite, Copper ore

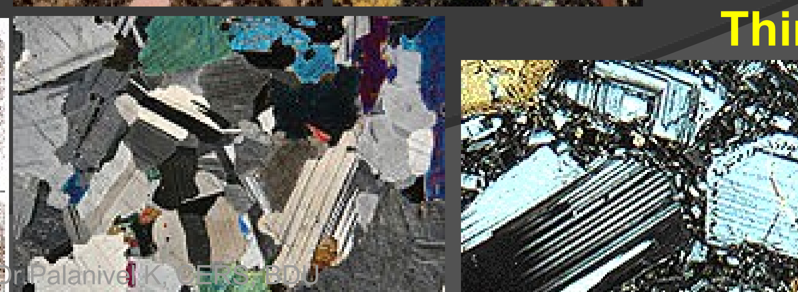


Petrological /Polarizing microscope –

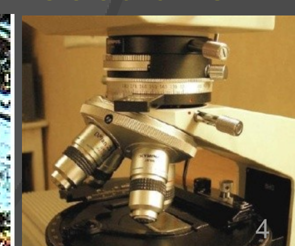








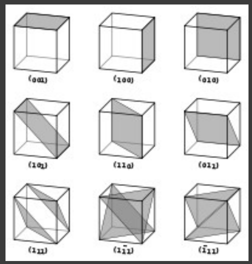
Microscopic view of Mineral Thin sections

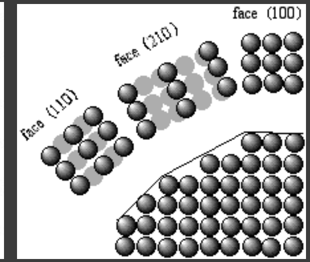


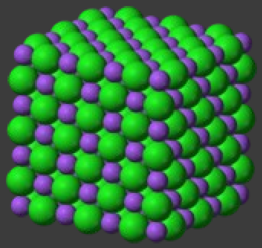
Physical Mineralogy

- Physical mineralogy is the specific focus on physical attributes of minerals. Description of physical attributes is the simplest way to identify, classify, and categorize minerals.

Symmetry & Structures







FYR

Heamatite – Brown streak

Satinspar – Silky Lustre

Garnet – Dodecahderal habit

Smithsonite – Botryoidal habit

Pyrite – Metallic Lustre

What is a crystal? and

How to differentiate it from other solids?

- A **Crystal** (or) **Morphous solid** is an inorganic chemical compound whose constituent atoms, ions, or molecules are arranged in an orderly repeating pattern extending in all three spatial dimensions.

- Definite repeating internal structure of crystal is expressed externally by its smooth surfaces / facets and symmetrical form and

- Defined shapes - e.g. Cube, Hexagonal Prism, Rhombohedral / Diamond shaped, Bipyramidal Triangles, etc.

- An **"Amorphous solid"** is a solid in which there is no long-range order of the positions of the atoms.
- Hence, due to the absence of orderly arrangement of atoms, the amorphous solids show no external crystalline form.

How does the crystals formed?

Igneous

Evaporites

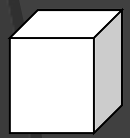
Sublimates / Fumeroles

- **Crystals** are formed from magma, solution or vapour (@ higher Temperature / Pressure than normal) saturated with a chemical compound at slow decreasing of **temperature** and **pressure** conditions.
- **Crystalline** solids are crystals that could have developed with their distinct faces as a result, they form an incomplete crystalline solids.
- **Crystalline rock** masses have consolidated from aqueous solution or from molten magma.
- The vast majority of igneous rocks belong to this group and the degree of crystallization depends primarily on the conditions under which they solidified.

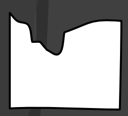
Crystallinity of a crystal:

The 3 different states in which a crystalline substance may appear are:

- **Euhedral** - When a crystal developed uniformly in all directions with its proper plane surfaces (or crystal faces) visible with our naked eyes, then it is named as *'Euhedral crystal'*.



- **Subhedral** - If the crystal formed with a portion of faces only, then it can be called as *'Subhedral crystal'.*



- **Anhedral** - If the solid material has no crystal faces appear on its surface, but when it is studied under electron microscope, the systematic alignment is seen, then it is named as *'Anhedral crystal'*.

Common forms of Crystals

- Most metals encountered in everyday life are **Polycrystals**.
- Crystals are often symmetrically intergrown to form **Crystal twins**.

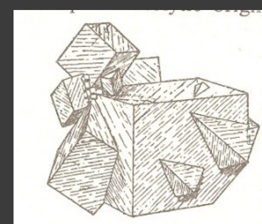


FIG. 119. Fluorspar

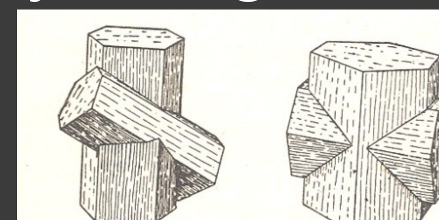
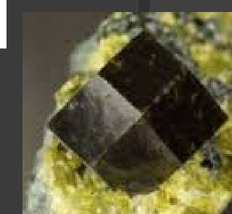


FIG. 134. Staurolite Twins

- **Distorted Crystals** / **Crystal Distortions** – The shape of the crystals are normally disturbed during their growth due to the instability of the Earth – Rotation, Gravity, Plate Tectonic motions, Convection cells within the magma chamber, etc.



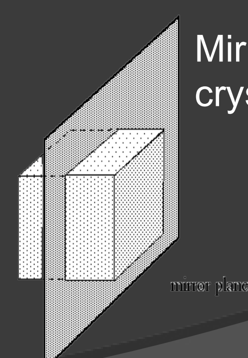
Symmetrical elements of crystals

- A structure that allows the crystal to be divided into parts of an equal shape and size.

- In crystallography, **symmetry** is the property of regularity of position of like-faces, edges, corners, etc.

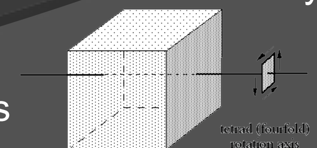
- Thus, the symmetry is defined with reference to three criteria:

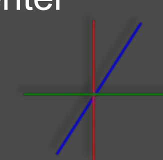
  - 1. Plane of symmetry
  - 2. Axis of symmetry
  - 3. Center of symmetry



Mirror planes, that divides the crystals into two equal halves

Axes penetrates the center point of faces and crystal center

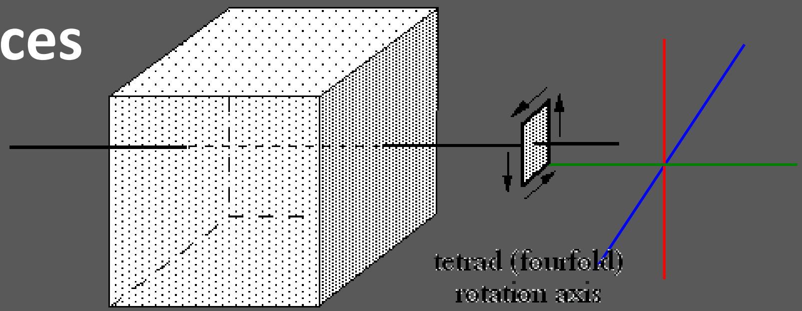




Center of Symmetry is Present, if the features (corners, edges, faces seen on the top half of the crystals are seen on the bottom half also.

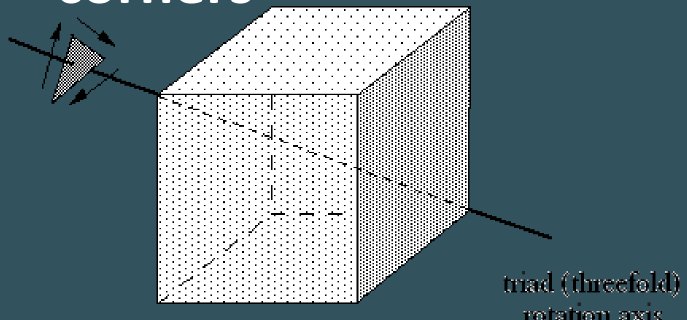
Axes of symmetry

Axes connecting opposite **faces**

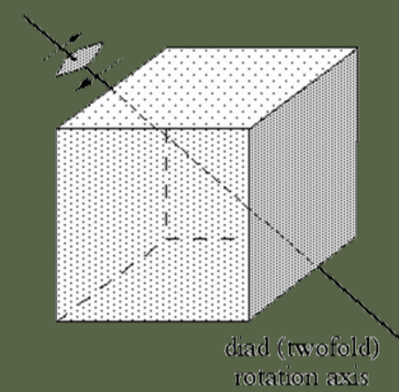


3 Principal Axes of 4 fold symmetry

Diagonal Axes connecting opposite **corners**



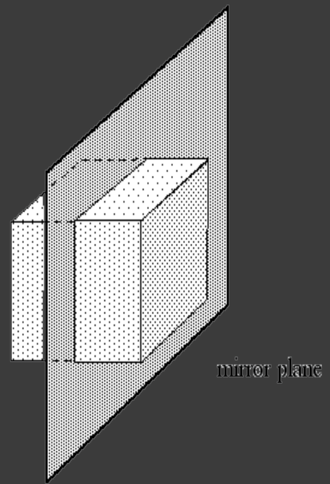
4 Diagonal Axes of 3 fold symmetry

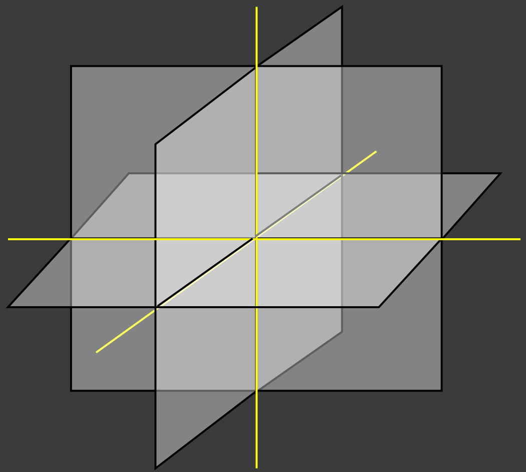


Diagonal Axes connecting opposite **edges**

6 Diagonal Axes of 2 fold symmetry

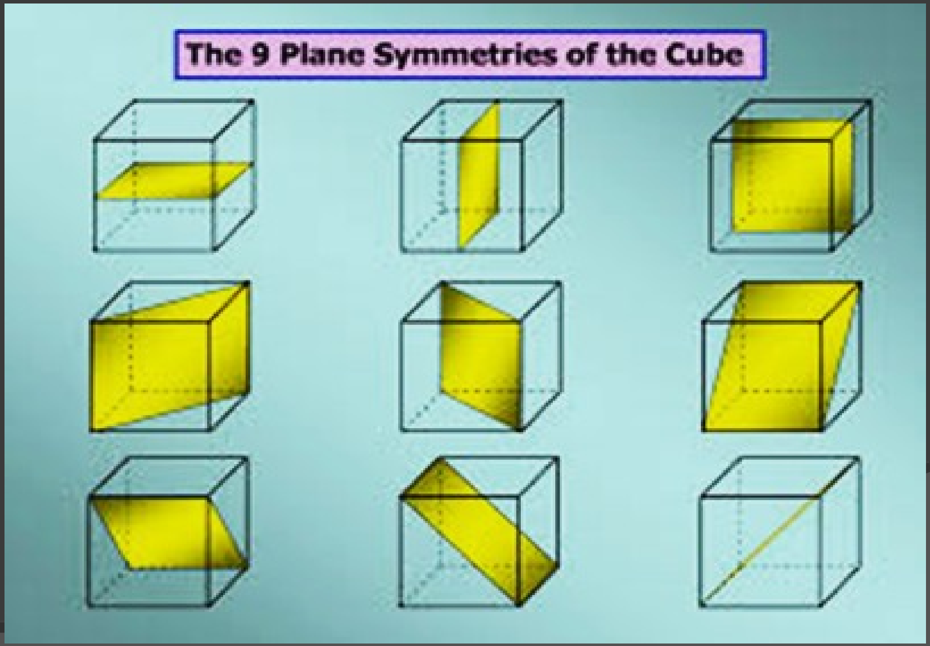
Planes of symmetry





3 principal planes of symmetry

6 diagonal planes of symmetry

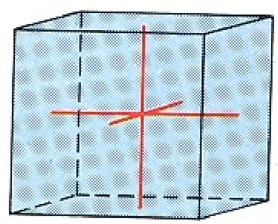
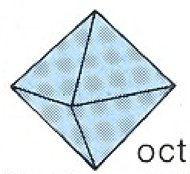
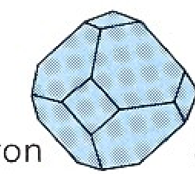
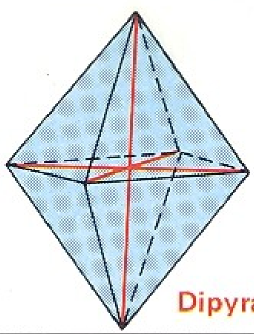
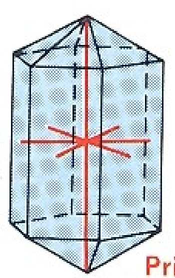


Center of Symmetry

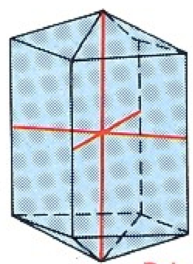
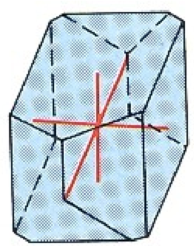
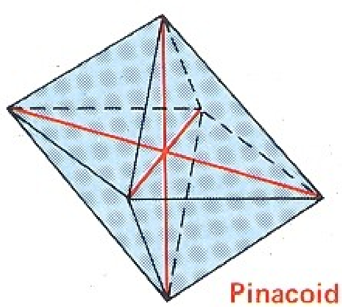
- Like faces, edges, etc., are arranged in pairs in corresponding positions on opposite sides of a central point – Center of symmetry. It is noted as ‘Present or Absent’.

- **The very importance of Symmetrical Elements :** A **crystal's structure** and **symmetry** play a role in determining many of its properties, such as cleavage, hardness, electronic bond structure, and optical properties.

CRYSTAL SYSTEMS AND FORMS

Crystal System	Common Crystal Form and Description	Mineral Examples
Isometric	 **Cube** cubic prism  octahedron  cube-octahedron combination Equidimensional crystals with three axes of equal length and at 90° to one another	halite diamond garnet
Tetragonal	 **Dipyramid** Crystals with three axes at right angles to one another, two of which are of equal length, and the third longer or shorter	zircon (zirconium silicate) cassiterite (tin oxide) rutile (titanium oxide)
Hexagonal	 **Prism-dipyramid combination** Crystals with three equal axes in the same plane intersecting at 60°, and a fourth axis perpendicular to the plane of the other three	quartz calcite dolomite

CRYSTAL SYSTEMS AND FORMS...CONTD...

Orthorhombic	 Prism-dipyramid combination	Crystals with three axes at right angles, each of a different length	olivine anhydrite gypsum topaz
Monoclinic	 Pinacoid-prism combination	Crystals with three unequal axes, two of which are inclined to one another and the third at right angles to these	hornblende augite orthoclase
Triclinic	 Pinacoid	Crystals with three unequal axes all of which are inclined to one another	turquoise plagioclase

LENGTH AND ANGULAR RELATIONS IN CRYSTAL SYSTEMS

Crystal System	#	Cell Parameters
Cubic	1	a1 = a2 = a3; $\alpha = \beta = \gamma = 90°$
Tetragonal	2	a1 = a2 ≠ c; $\alpha = \beta = \gamma = 90°$
Hexagonal: Trigonal	2	a1 = a2 = a3 ≠ c; $\alpha = \beta = 90°$, $\gamma = 120°$
Hexagonal: Rhombohedral	2	a = b = c; $\alpha = \beta = \gamma \neq 90°$
Orthorhombic	3	a ≠ b ≠ c; $\alpha = \beta = \gamma = 90°$
Triclinic	6	a ≠ b ≠ c; $\alpha \neq \beta \neq \gamma$
Monoclinic	4	a ≠ b ≠ c; $\alpha = \gamma = 90°$, $\beta \geq 90°$

Ratios of the Intercepts & Axis ratio

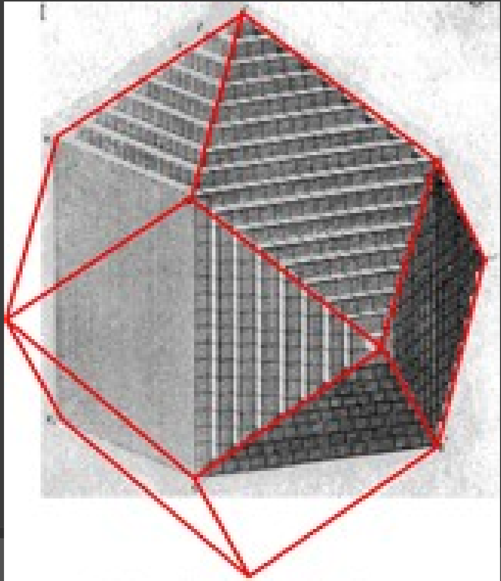
- The ratios of the distances from the origin at which the face cuts the crystallographic axes are the "**ratios of the Intercepts**".
- The expression of length & angle measurement and calculation as multiples of one of their number is known as "**axis ratio**".

Crystallographic notation

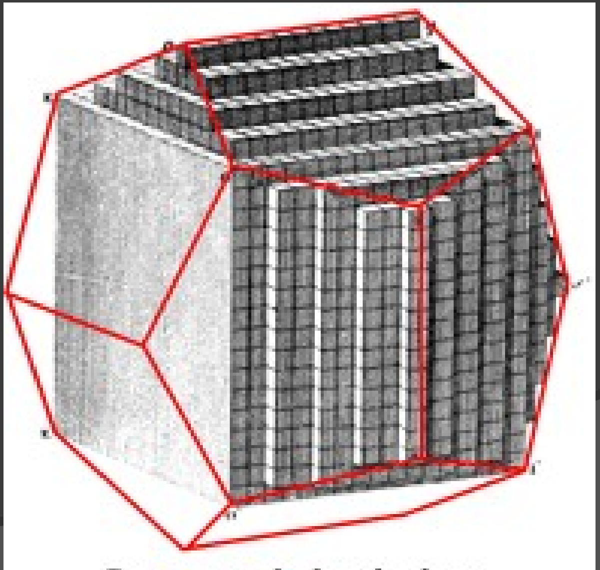
- **Crystallographic notation** is a concise method of writing the relation of any crystal face to the crystallographic axes.
- The most widely used systems depend upon either parameters or indices.
- **Parameters:** Length, Angle, Length ratio…
- The reciprocals of the parameters which form the basis of crystallographic notation are called ‘**indices**’.

Law of Rational Indices

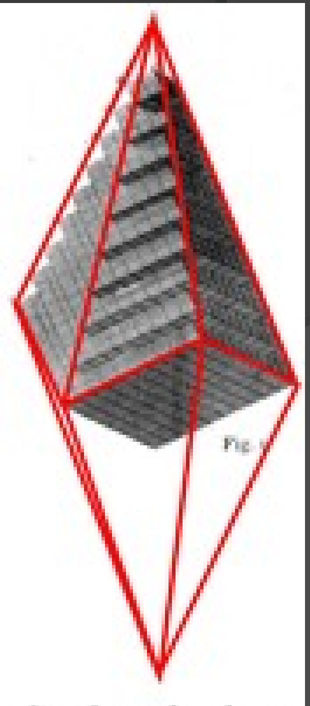
- Through the early studies of Steno and others (17th century), **René-Just Haüy** was able to postulate that if crystals of calcite and cubic garnets were built from **many small regularly-repeating blocks**, then these blocks could easily be used to **describe the faces of these crystals** in terms of **rational indices**. This **law of rational indices** forms the basis of optical crystallography.



Rhomb-dodecahedron



Pentagon-dodecahedron



Scalenohedron

Methods of Crystallographic notation

The chief systems of notations are two:

- The Parameter System of **Weiss** and
- The Index System of **Miller** (modified by Bravais).

Parameter System of Weiss:

Axes are taken in this way:

- *a, a, a* – for three equal axes (a1, a2, a3),
- *a, a, c* – for two axes equal (a1, a2, c), and
- *a, b, c* – for three unequal axes.

The intercept, that the crystal face under discussion makes on the *a*-axis is then written before *a*, the intercept on the *b*-axis before *b*, and the intercept on the *c*-axis before *c*.

Parameter System of Weiss…contd…

- The most general expression for a crystal face in the Weiss notation is:

na, mb, pc,

where, *n, m, p* are the lengths cutoff by the face on the *a, b, c* axes as compared with the corresponding lengths cutoff by the unit form.

- It is usual to reduce either *n* or *m* to unity.

- If a crystal face is parallel to an axis, it can be imagined as cutting that axis at infinite distance (∞).

Parameter System of Weiss…contd…

- Thus a face cutting the a-axis at a distance of 1unit and cutting the b-axis at a distance of 2units or twice the distance cutoff by the unit form along the b-axis and running parallel to the c-axis has the Weiss symbol,

  ***a*, 2*b*, ∞*c*.**

- A face cutting the a-axis, parallel to the b-axis and c-axis obviously has the symbol,

  a, ∞b, ∞c.

Index System of Miller:

- In this system of notation, the indices or reciprocals of the parameters are used. They are written in the axial order a, b, c and are always given in their most simple form by clearing fractions. For e.g., consider the crystal face dealt with in the previous paragraph which has the Weiss symbol

  a, 2b, ∞c.

- The reciprocals of the parameters are

  1, ½, 0

- Clearing of fractions and omitting the axial letters the Miller symbol is obtained

  210

  which is read as : ***Two, One, Naught***.

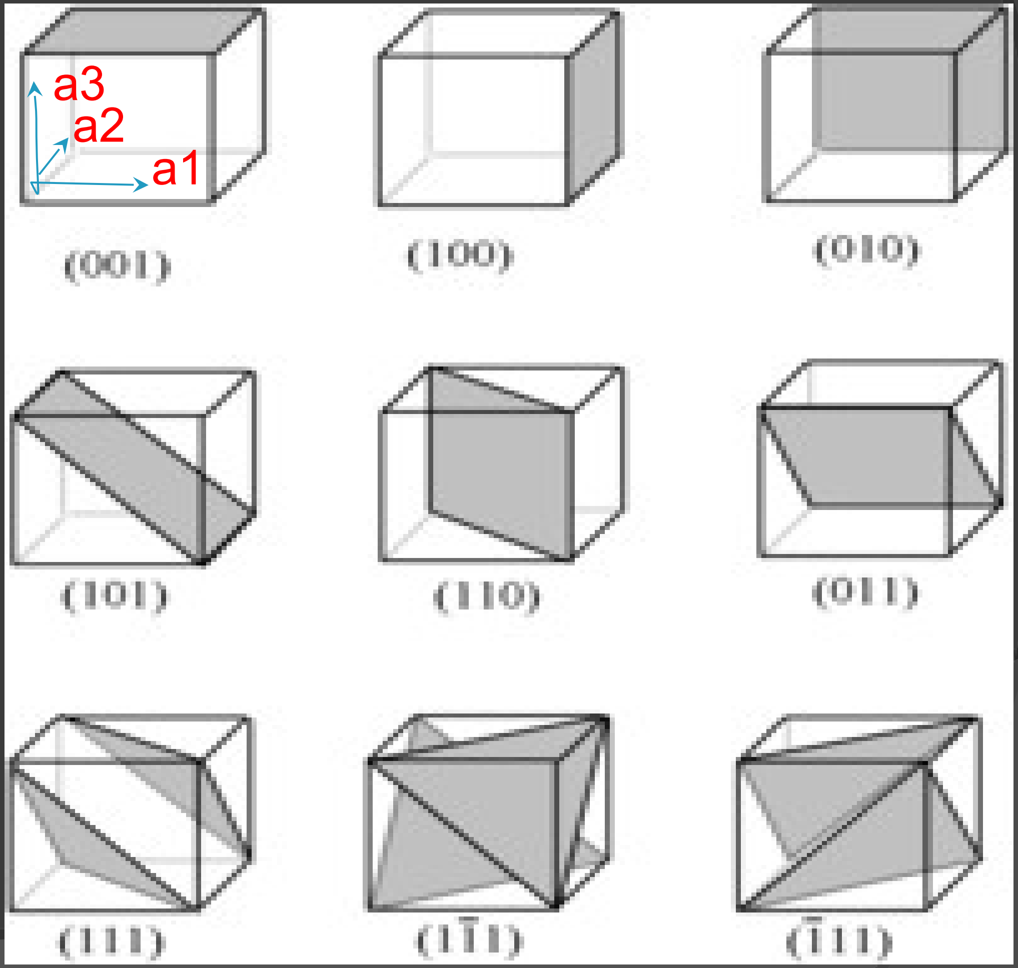
Planes with different Miller indices in Isometric system of crystals

(Location of Planes are shown with reference to cube)

Cube

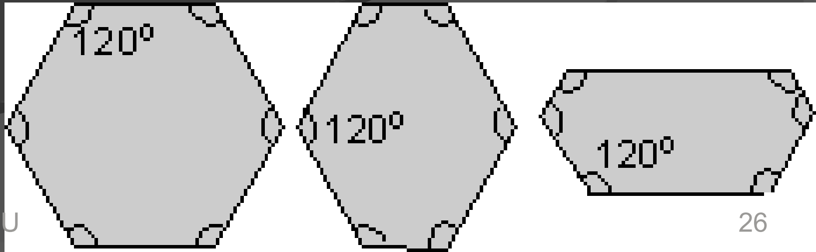
Dodecahedron

Octahedron



Law of constancy of interfacial angles

- Although the crystals may have different sizes, all crystals of a particular system have the same shape or *habit*.
- In particular, the angles between certain pairs of faces of the different crystals will be the same. This crystal habit was first observed by Nicholas Steno in 1669.
- This observation became known as the **law of constancy of <u>interfacial angles</u>.**



Crystal Classes in Crystallographic systems

- Several forms documented / available in every crystallographic systems are grouped into multiple classes.
- The major forms which are also commonly seen in crystals are grouped under “Normal Class”.
- The remaining forms which are all rarer, grouped into separate classes.

Crystal Classes in CUBIC System

- A. Normal Class – Galena type
- B. Pyritohedral Class – Pyrite type
- C. Tetrahedral Class – Tetrahedrite type
- D. Plagiohedral Class – Cuprite type
- E. Tetartohedral Class – Ullmannite type

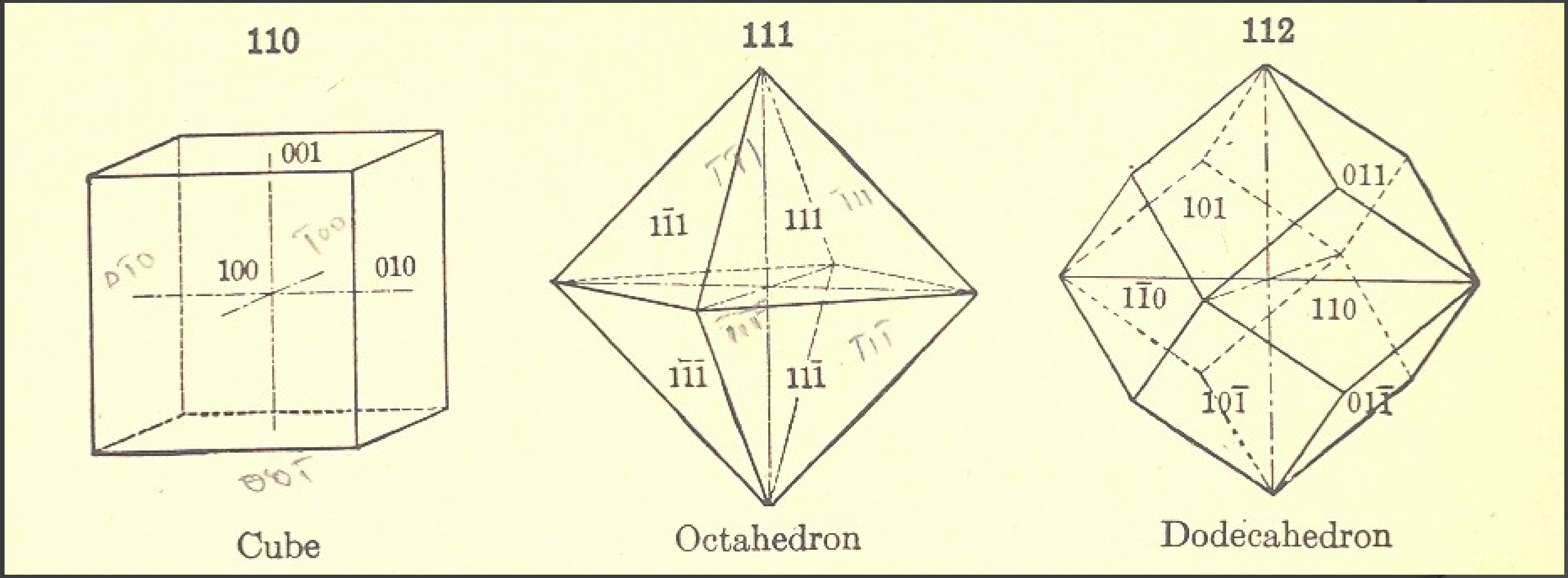
A. Normal Class (Galena Type)

- As far as Cubic System is concerned, the A. Normal Class (Galena Type) contains the forms such as,
- **1) Cube, 2) Octahedron,**
- **3) Dodecahedron,**
- **4) Tetrahexahedron, 5) Trisoctahedron**
- **6) Trapezohedron, 7) Hexoctahedron**
- Symmetry elements: 3 xl. Ax.-4, 4 diag. Ax.-3,

  6 diag. Ax.-2 fold;

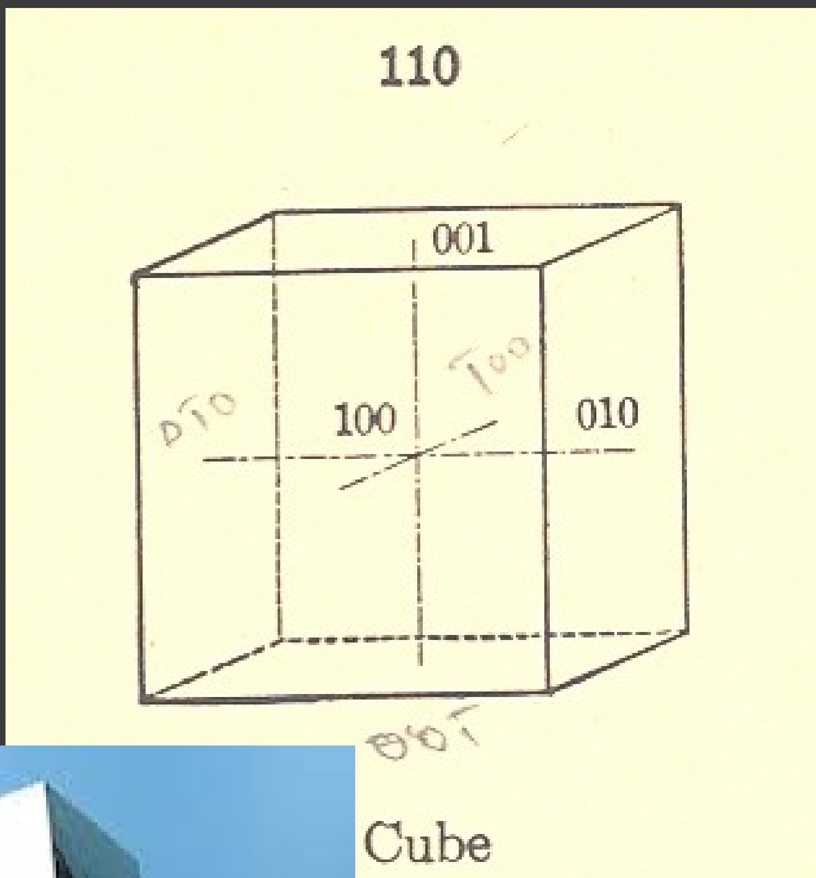
  3 xl. P., 6 diag. P, C.

FORMS in (A) NORMAL CLASS of ISOMETRIC SYSTEM



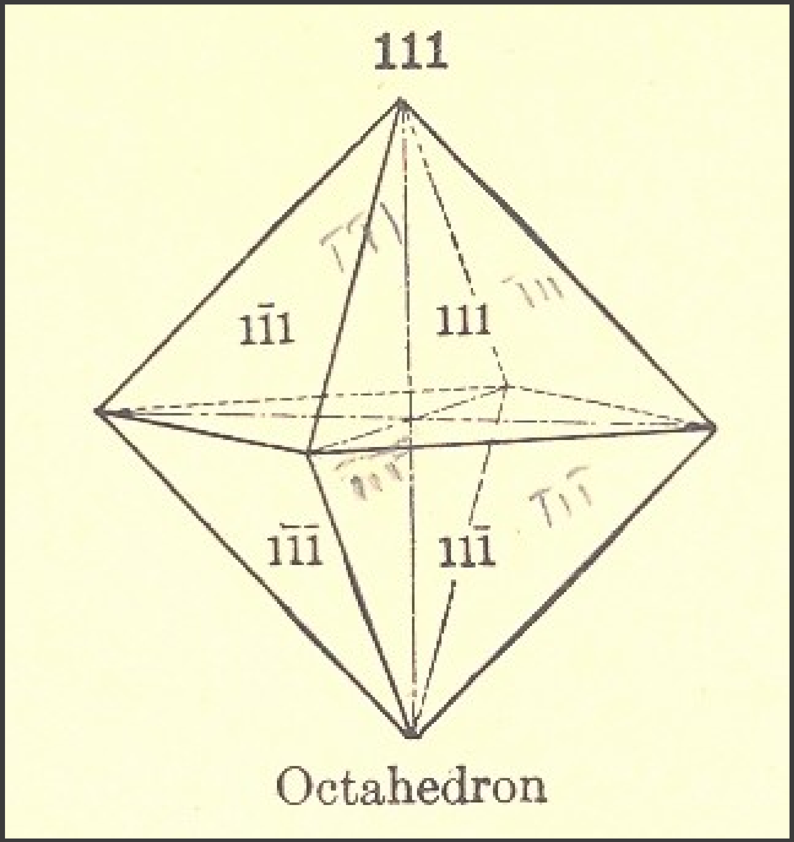
1) Cube, 2) Octahedron, 3) Dodecahedron

1. CUBE



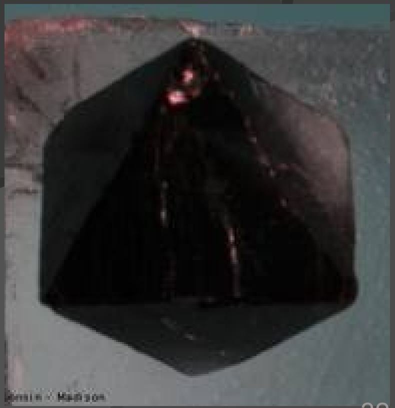
- Also called as 'Hexahedron' (having 6 faces)
- 6 lllr faces, each llel to 2 of the axes
- Interfacial angle (IFA) is 90 deg.
- 100 – Miller Index
- Galena, Pyrite, Halite, etc., are crystallized in this form.

2. OCTAHEDRON

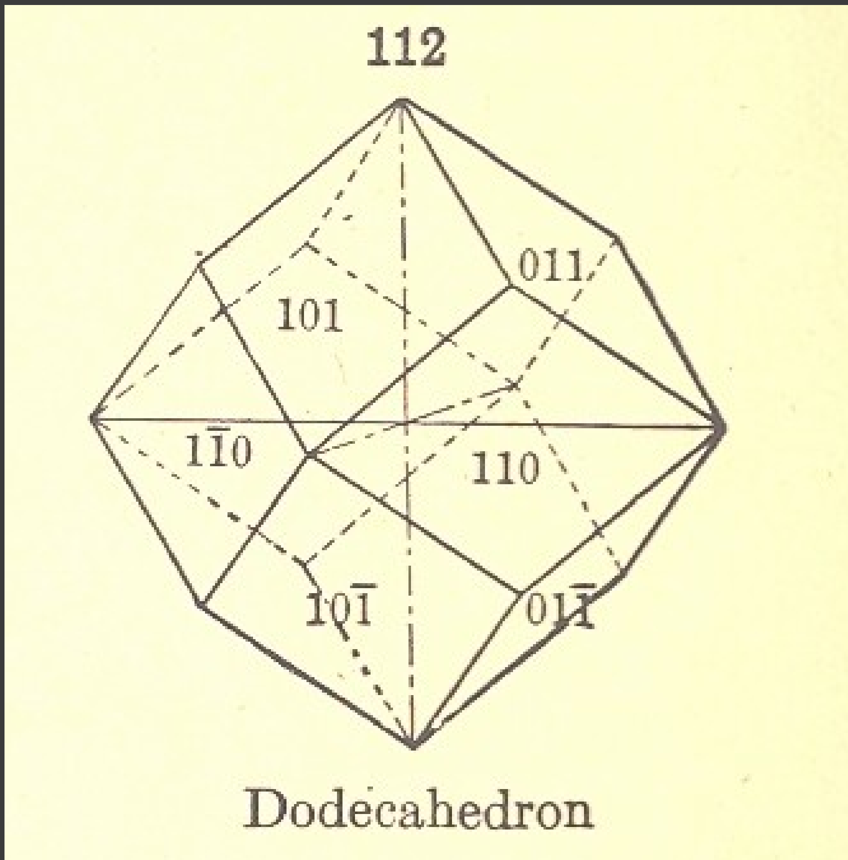


Octahedron

- All 8 IIIr faces are Equilateral triangles
- IFA = 70^o 31’ 44”
- 111 – Miller Index
- Fluorite

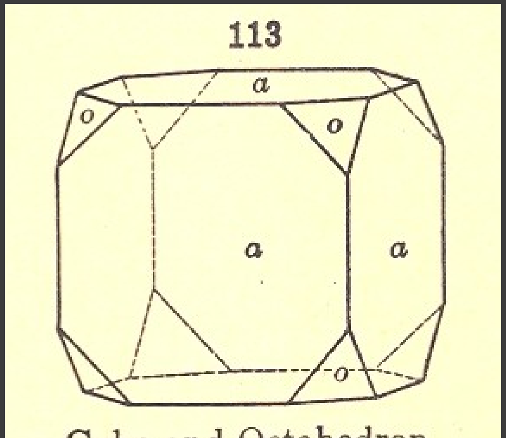



3. DODECAHEDRON

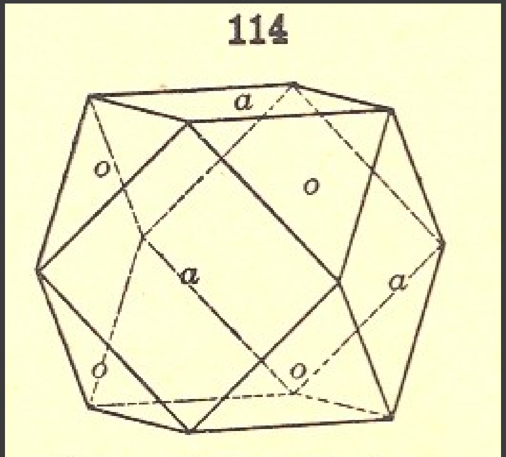


- Rhombic dodecahedron
- Do = 2, + Deca=10,
- Total 12 faces
- Each face is llel to one axis and meets at equal distances with two other axes
- IFA = 60 deg.
- 110 – Miller Index
- Garnet

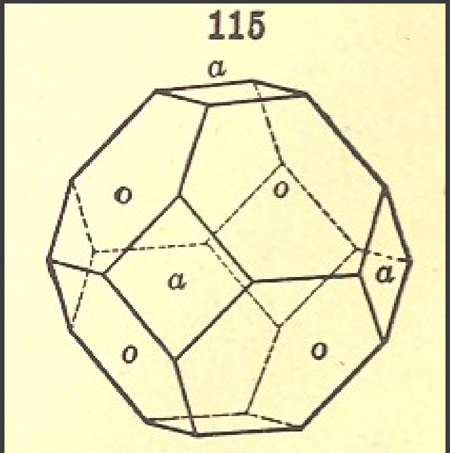
COMBINATION OF FORMS



Cube and Octahedron



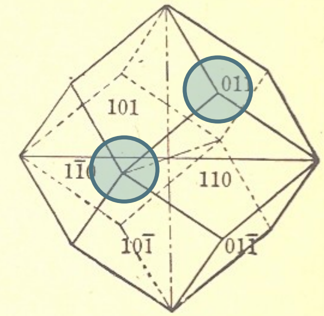
Cube and Octahedron



Octahedron and Cube

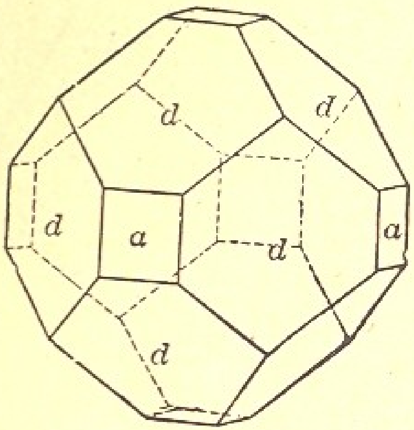
- Cube modified by Octahedron – 113
- Both (C & O) are in equilibrium - 114
- Octahedron faces are replaced by square cubic faces – 115
- By counting the no. of faces – it is easy to identify the combinations

112



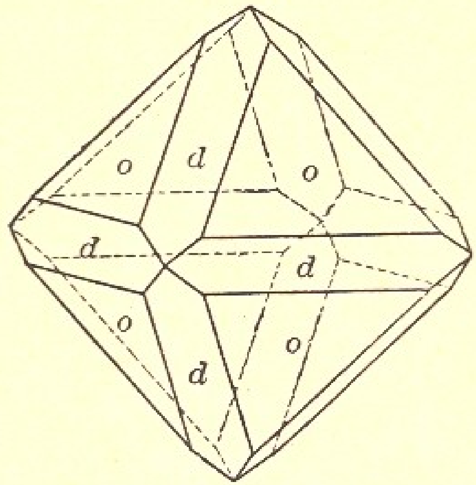
Dodecahedron

116



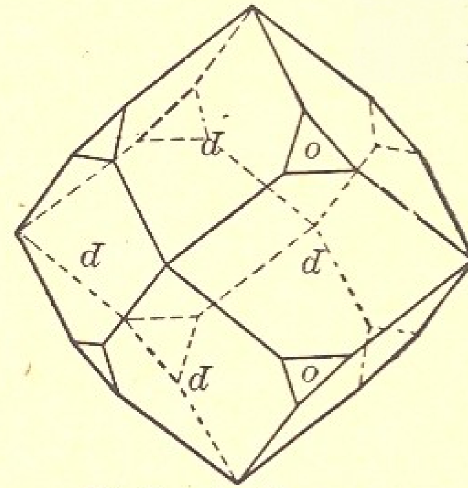
Dodecahedron and Cube

117



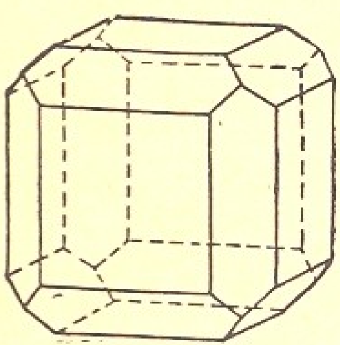
Octahedron and Dodecahedron

118



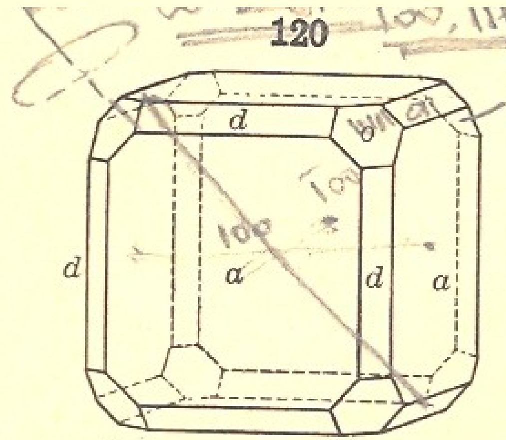
Dodecahedron and Octahedron

119



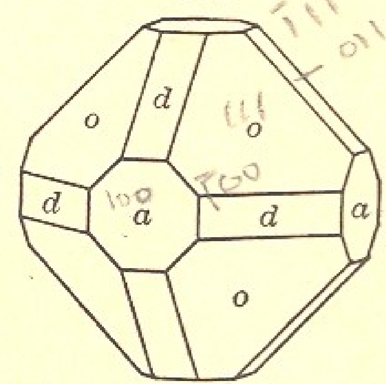
Cube and Dodecahedron

120

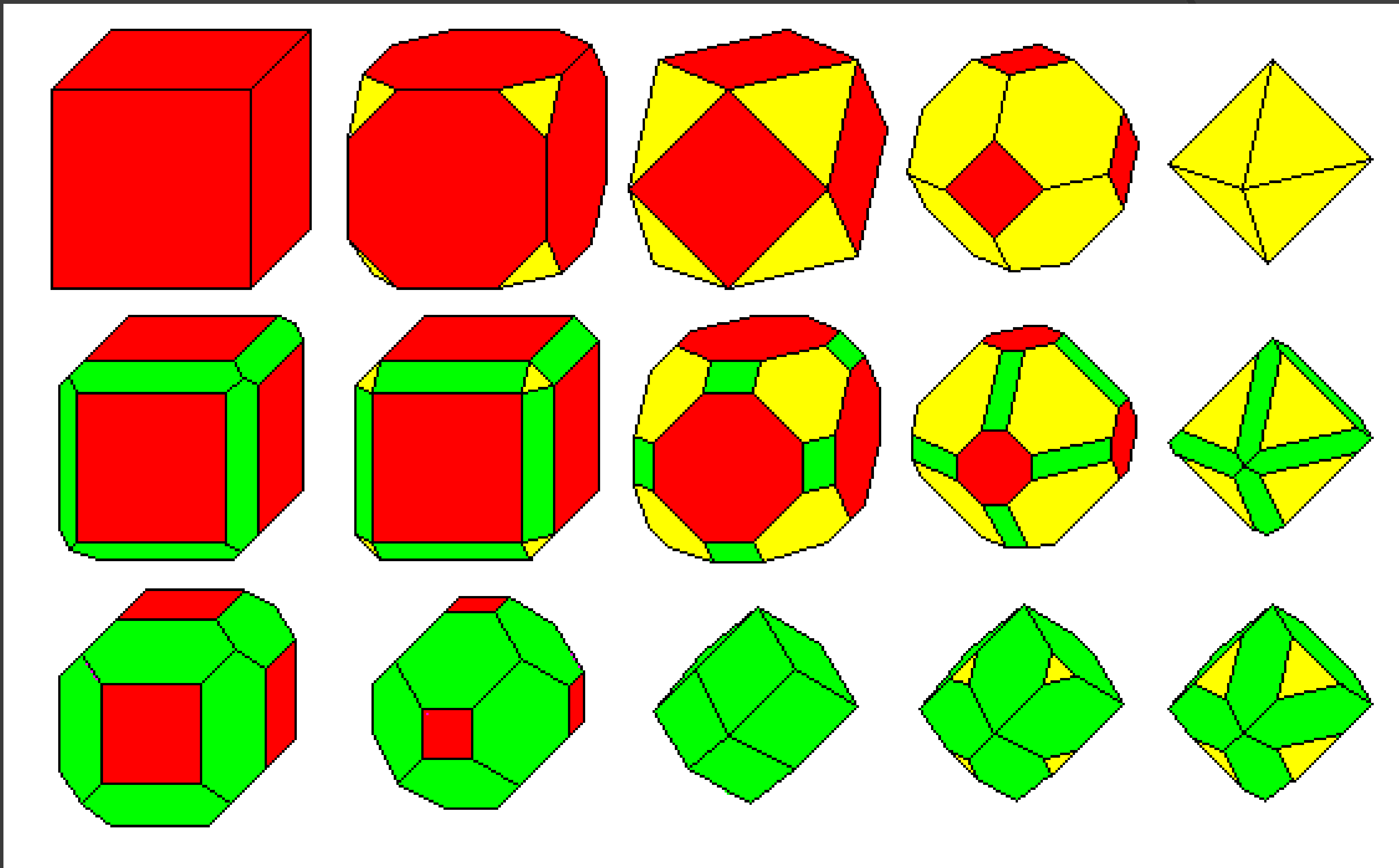


Cube, Octahedron and Dodecahedron

121

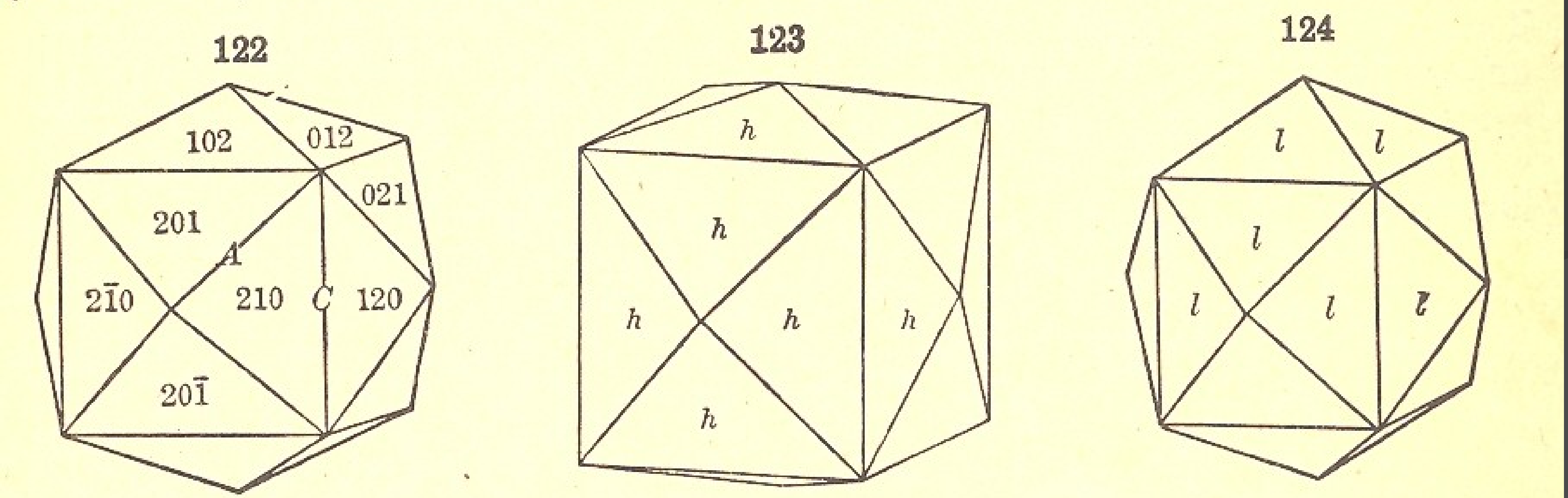


Octahedron, Cube and Dodecahedron



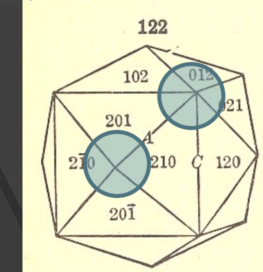
4. TETRAHEXAHEDRON

- Tetra – 4 x hexa – 6, = 24 faces
- All are isosceles triangles
- 210, 410, 530 forms are shown below



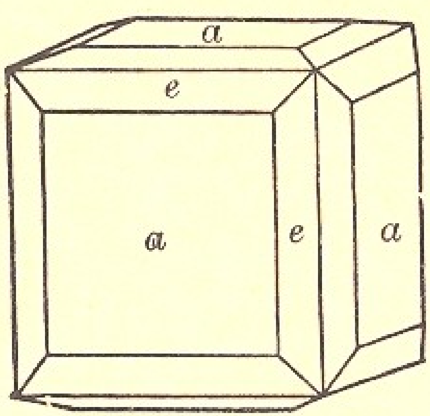
Tetrahexahedrons

COMBINATION OF FORMS



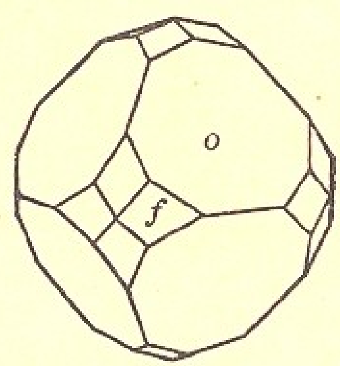
- Quick way to identify the Combinations with Tetrahexahedron – will have either '∗' STAR symbol (with six rays) at the corners of cube (as seen in Tetrahexahedron), or 'X' CROSS symbol at the corners of octahedron / dodecahedron, and
- there are 24 such faces totally.

125



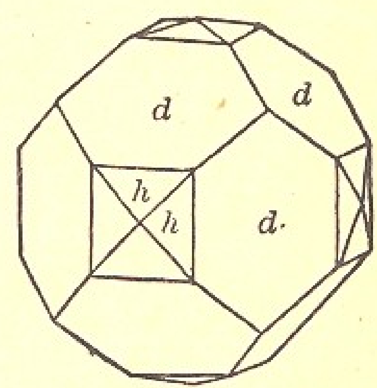
Cube and Tetrahexa-hedron

126



Octahedron and Tetrahexahedron

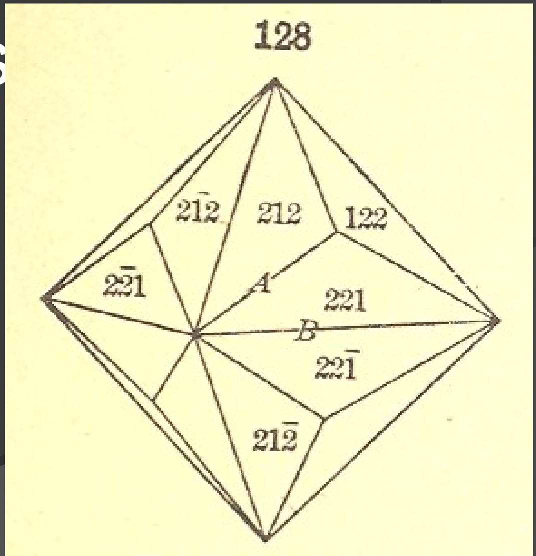
127



Dodecahedron and Tetrahexahedron

5. TRISOCTAHEDRON

- OVERALL OCTAHEDRON IN SHAPE
- IN EACH OCTAHEDRAL FACE, THERE ARE 3 ISOSCLES TRIANGLES SEEN
- Hence, in total, 8 x 3 = 24 faces
- 221 – Miller Index



Trisoctahedron

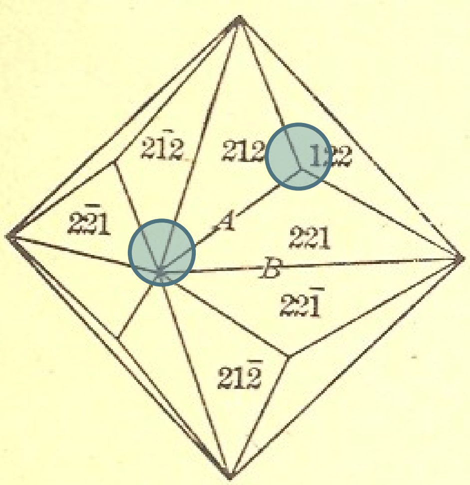
COMBINATION OF FORMS

- Clue-1 : Inverted 'Y' shapes are seen at the triple junction corners of cube (where diagonal axes meet at 8 such corners)
- 24 such (isoscles triangle) faces in different shape but having inverted Y shape, along with other forms.

Or

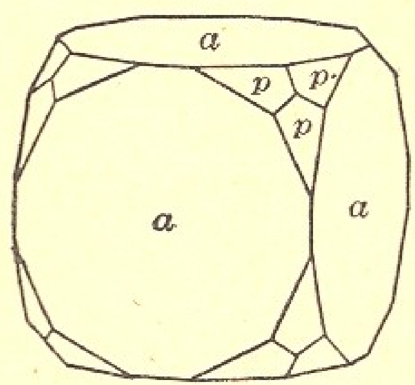
- Clue-2 : Having star symbol (with 8 rays) at the major corners (at Ppl. Axes) of octahedron

128



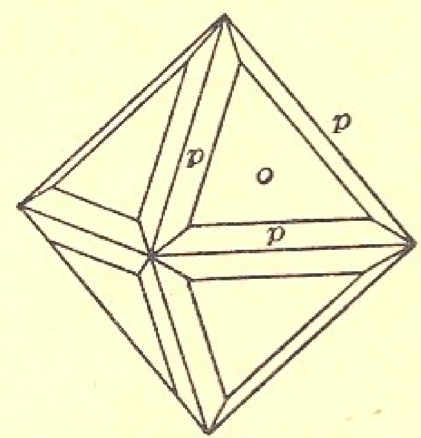
Trisoctahedron

129



Cube and Trisoctahedron

130

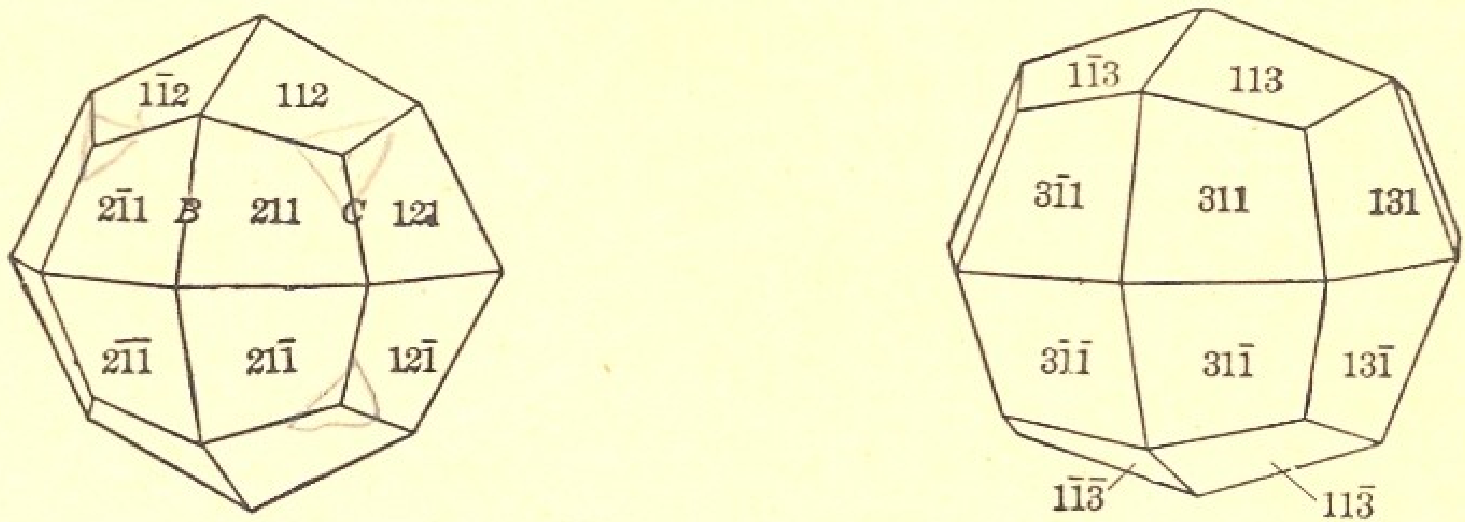


Octahedron and Trisoctahedron

6. TRAPAZOHEDRON

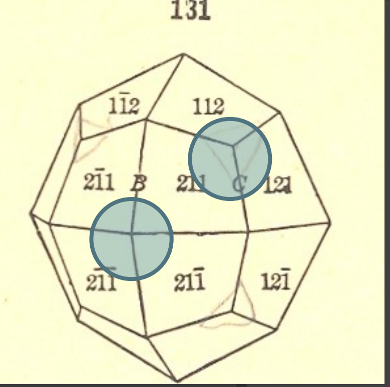
- 24 TRAPAZEUM FACES
- 211, 311 – Miller Index
-

131 132

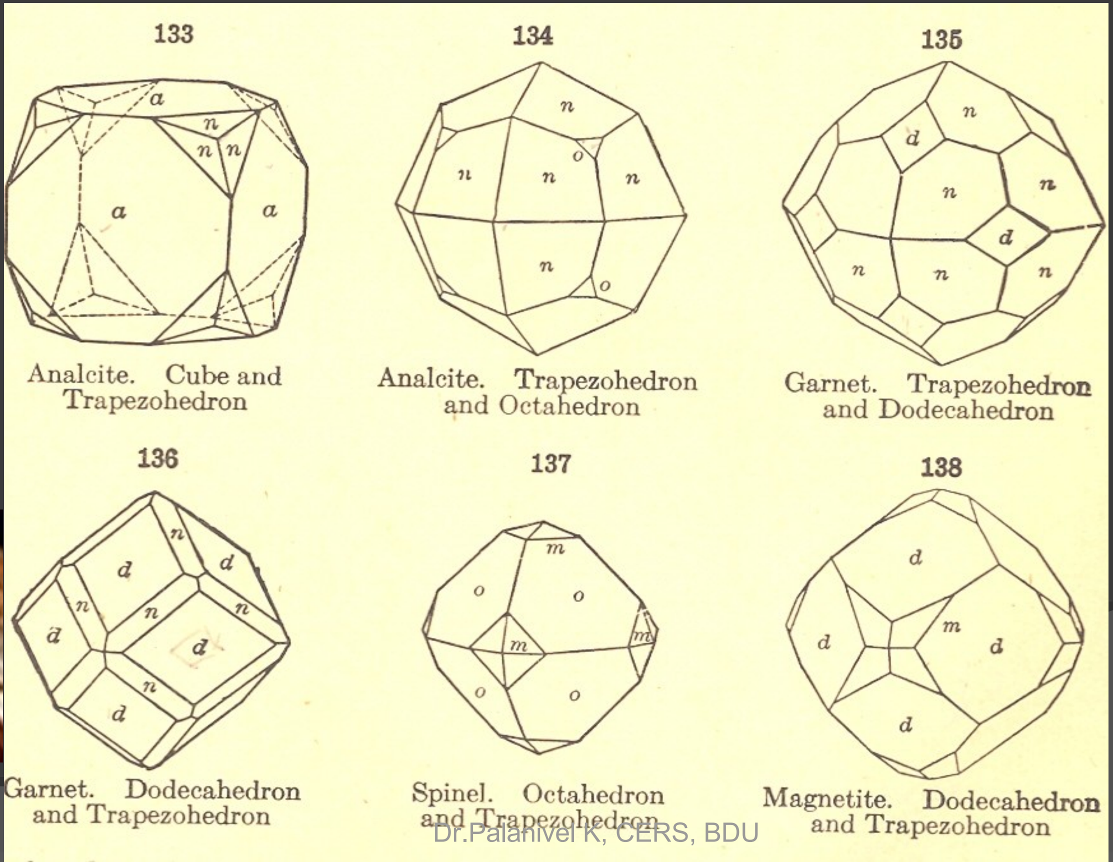


Trapezohedrons

Combinations



- ‘Y’ in up right position in the corners of cube
- ‘+’ symbol at the corners, where Ppl. axes meet
- Total no. of such faces are 24



133 Analcite. Cube and Trapezohedron

134 Analcite. Trapezohedron and Octahedron

135 Garnet. Trapezohedron and Dodecahedron

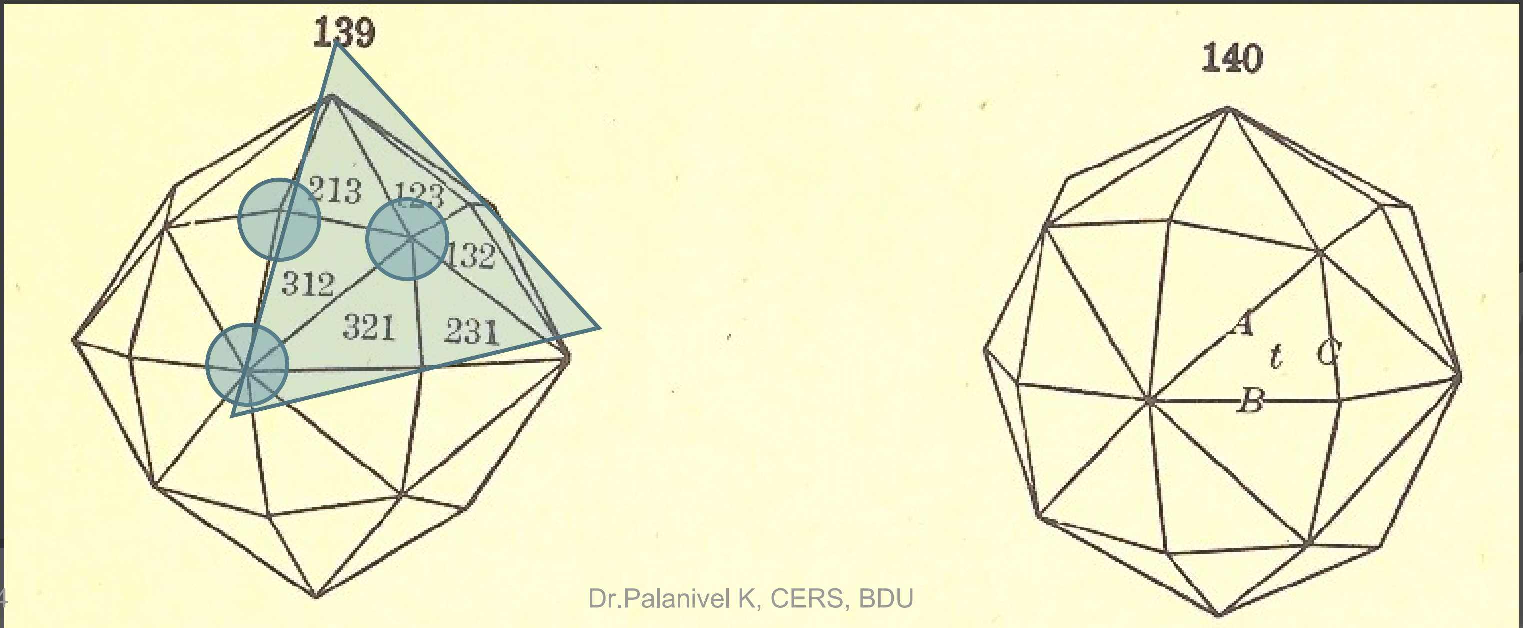
136 Garnet. Dodecahedron and Trapezohedron

137 Spinel. Octahedron and Trapezohedron

138 Magnetite. Dodecahedron and Trapezohedron

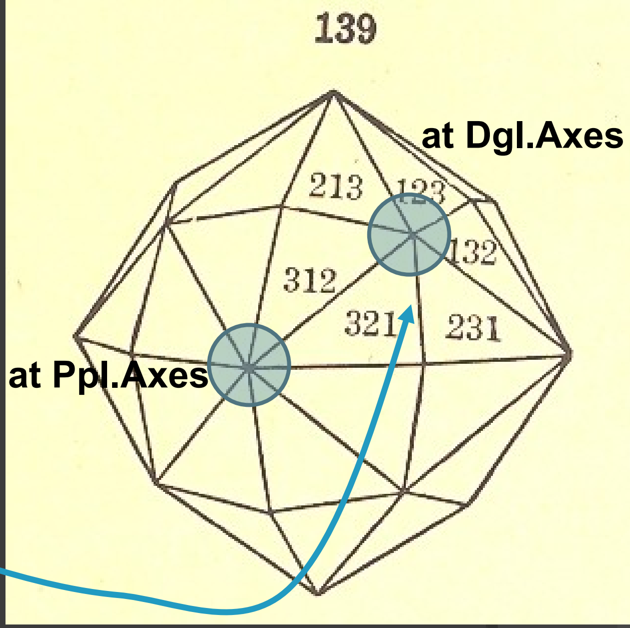
7. Hexoctahedron

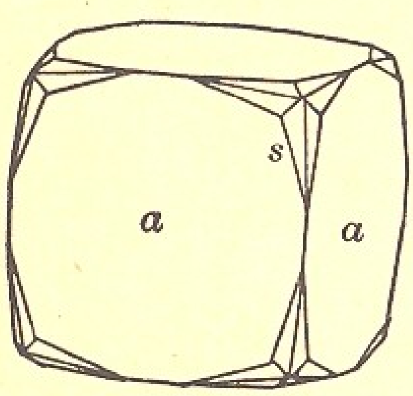
- In every Octahedral face, there are 6 nos. of triangular faces
- Hence in total, there are 8 x 6 = 48 faces
- 312 – Miller Index



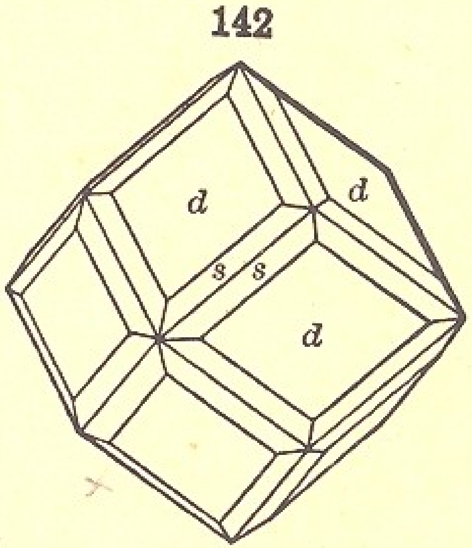
Combinations

- In every corners, 2 types of STAR symbols are seen
- 48 no. of faces are available





Fluorite. Cube and Hexoctahedron

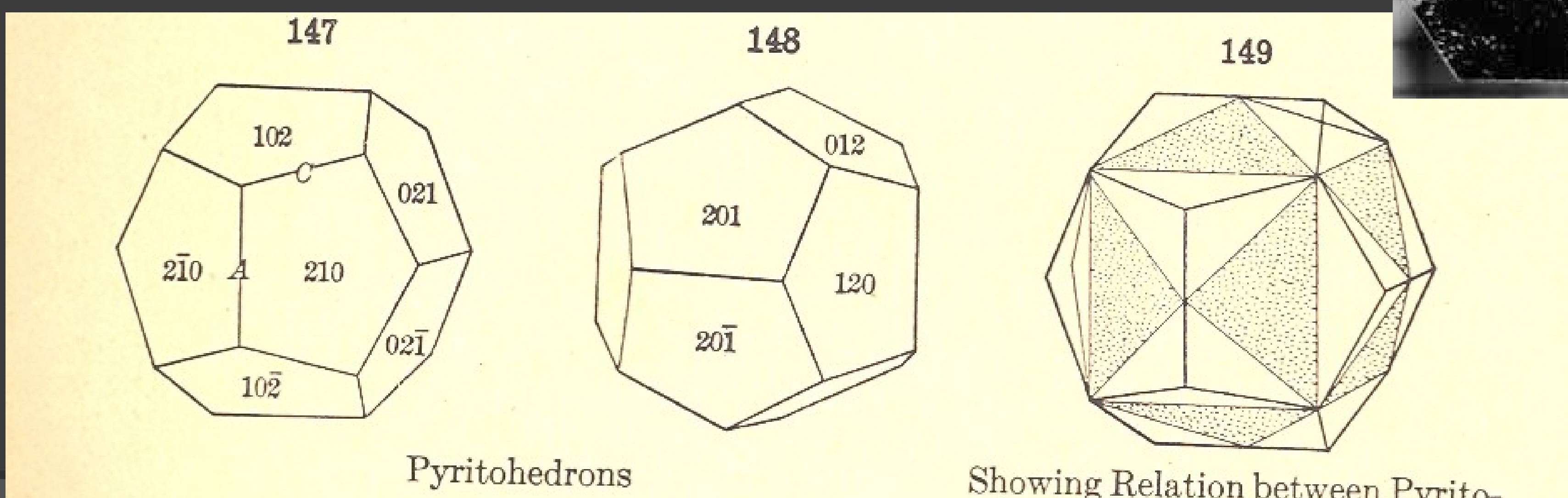


Garnet. Dodecahedron and Hexoctahedron

B. Pyritohedral Class – Pyrite type

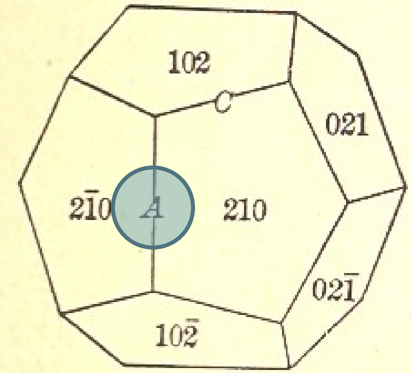
Forms: 1. Pyritohedron

- 12 equilateral pentagons – It is also known as Pentagonal Dodecahedron
- Paired pentagons are located similar to cube faces-6 pairs in each cubic face
- Miller Index is 210
- Symmetry: 3 xl. Ax.-2, 4 diag. Ax.-3, 3 xl. P., C.



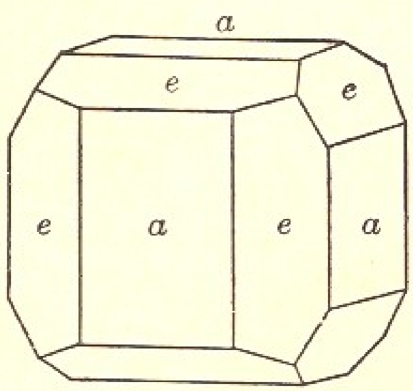
Combinations

147



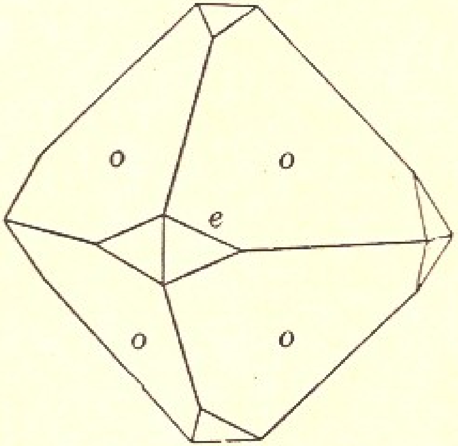
- Vertical / horizontal straight line in corners
- Paired faces sitting in juxtaposition
- Totally 12 paired faces

150



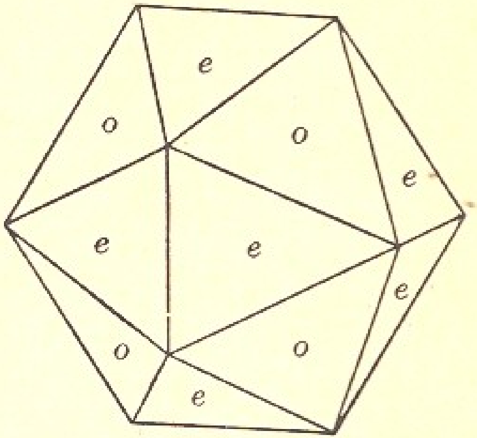
Cube and Pyritohedron

151



Octahedron and Pyritohedron

152

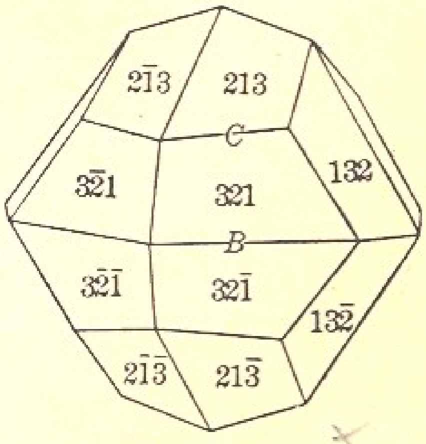


Octahedron and Pyritohedron

2. Diploid

- Double / Paired tetragonal faces
- Totally 24 such faces
- 321 - Miller index

153

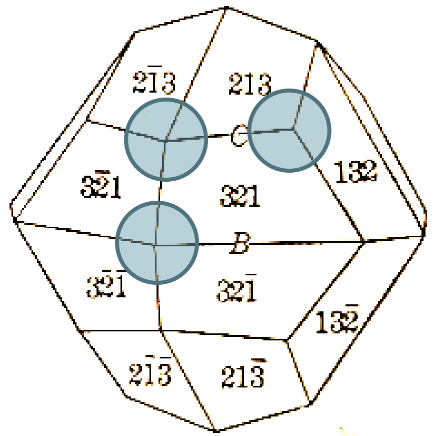


Diploid

Combinations

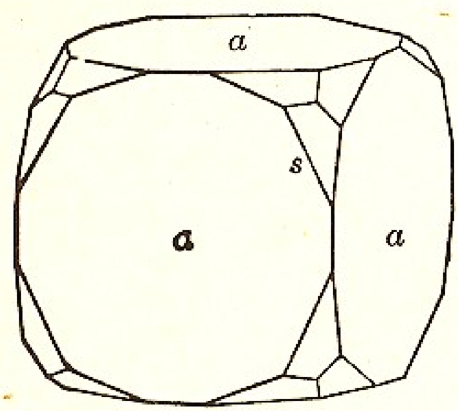
- Tilted ‘Y’ in corners (where diagonal axes meet)
- ‘+’ marks in other corners

153



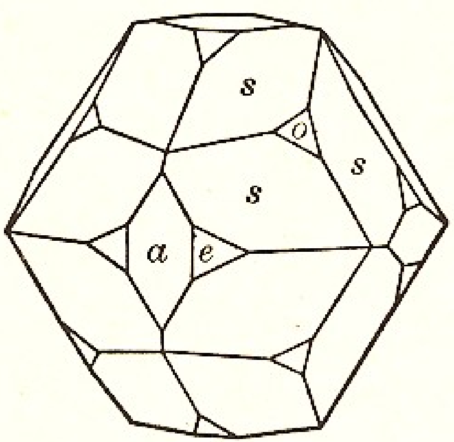
Diploid

154



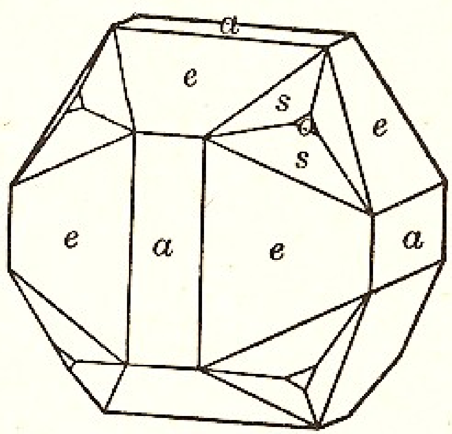
Cube and Diploid

155



Cube, Octahedron and Diploid

156



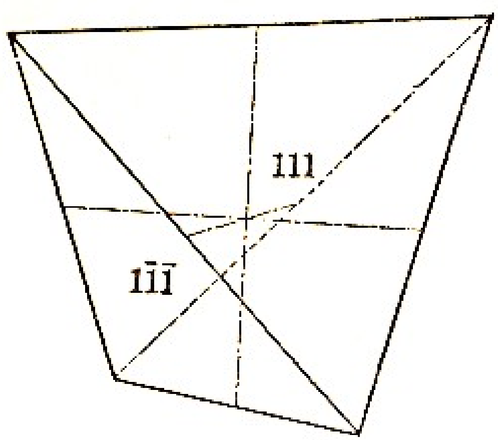
Cube, Diploid and Pyritohedron

C. Tetrahedral Class –Tetrahedrite type

Forms:1. Tetrahedron

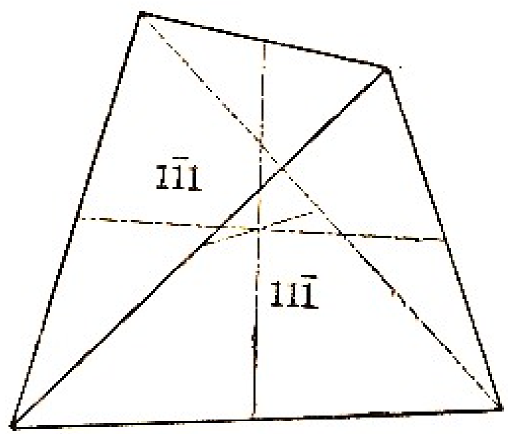
- 4 Equilateral triangles
- 111 – similar to Octahedron – Miller Index
- Symmetry: 3 xl. Ax.-2, 4 diag. Ax.-3, 6 diag. P.

159



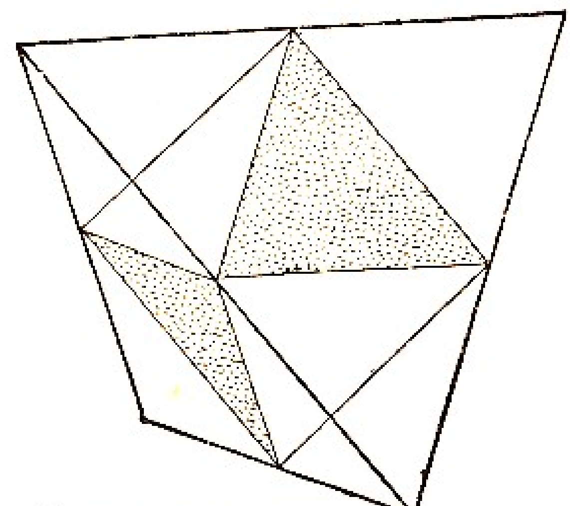
Positive Tetrahedron

160



Negative Tetrahedron

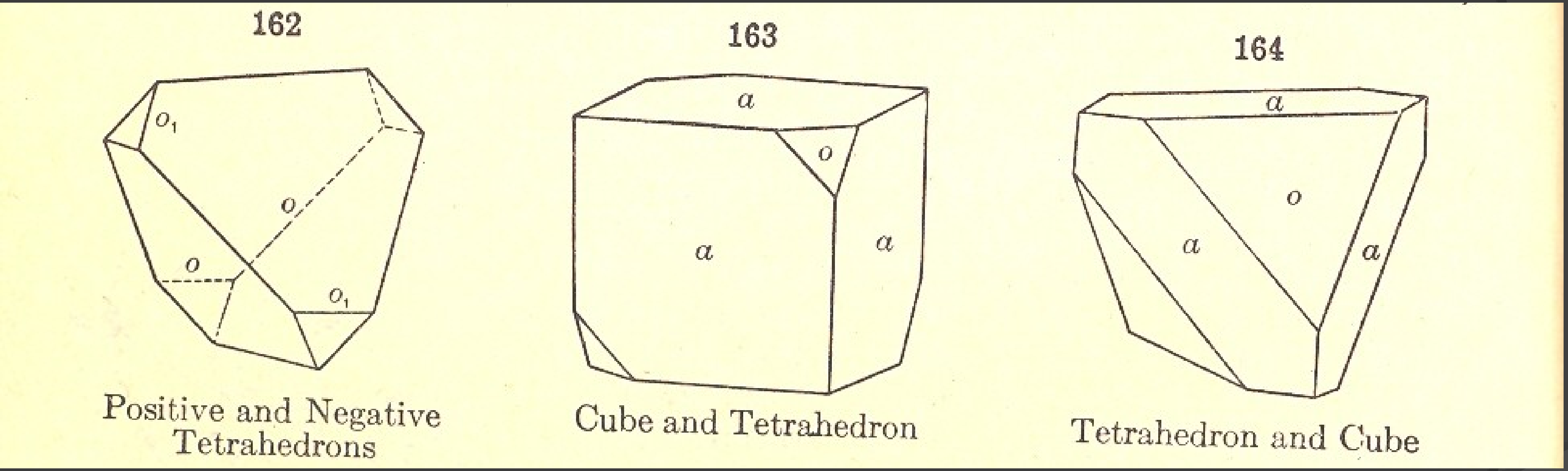
161

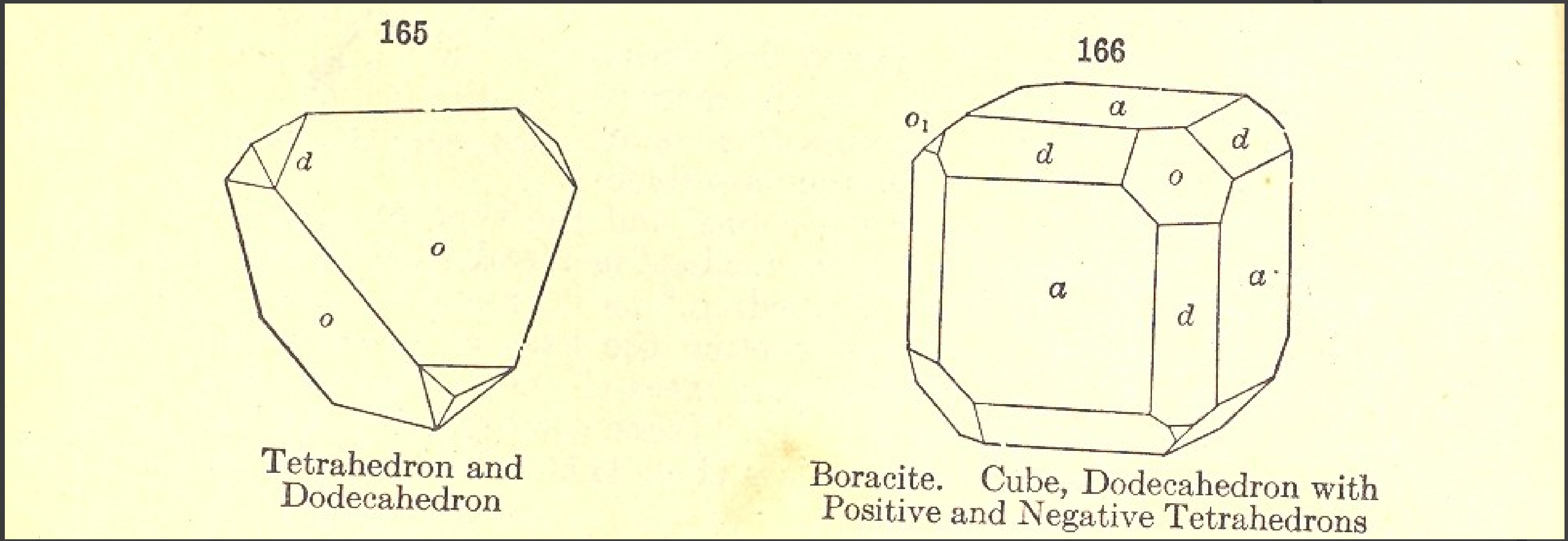


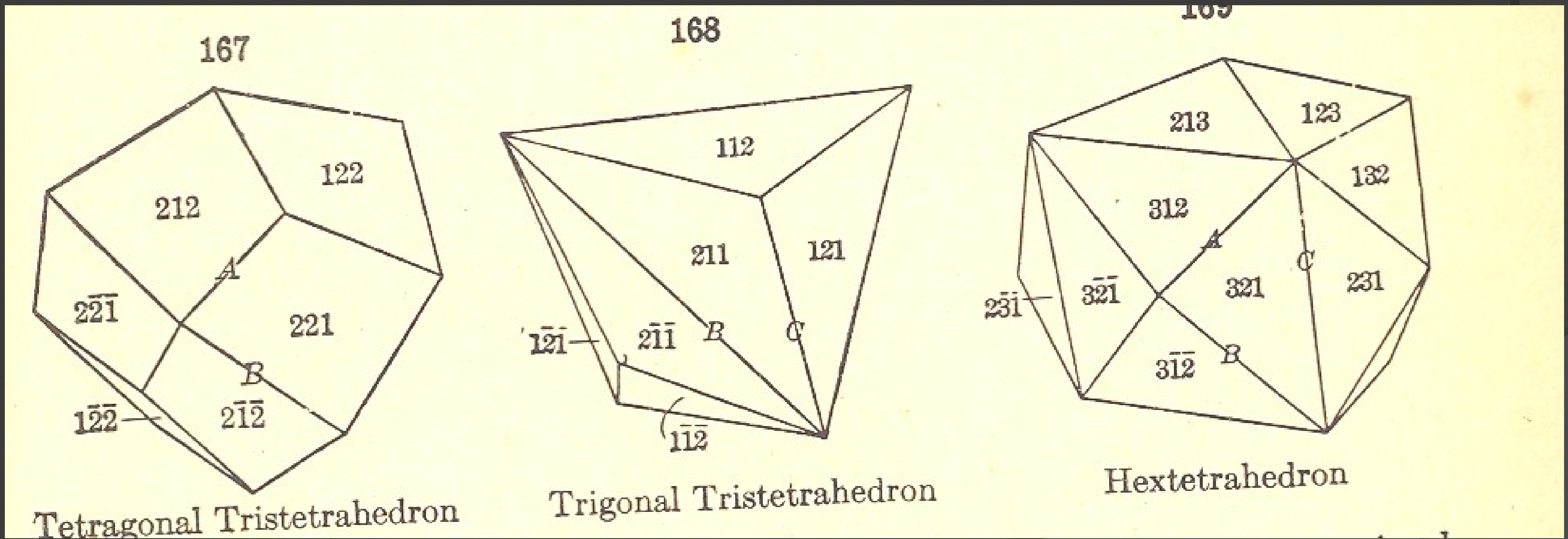
Showing Relation between Octahedron and Tetrahedron

Combinations

- 4 such faces – located in opposite corners only

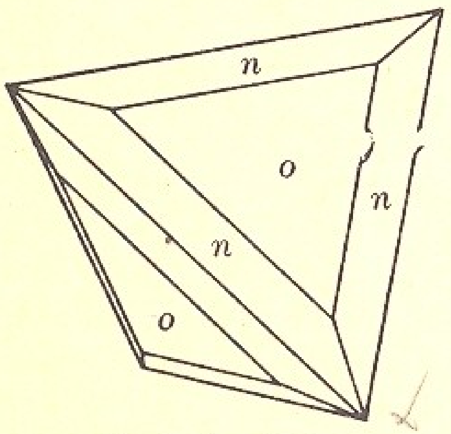






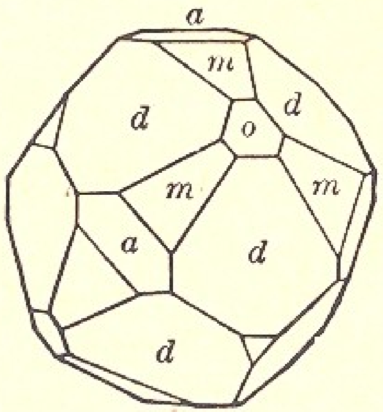
2. Tetragonal Tristetrahedron, 3. Trigonal Tristetrahedron, 4. Hextetgrahedron`

170



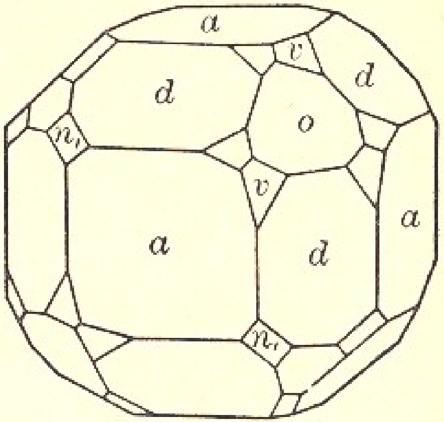
Tetrahedrite

171



Sphalerite

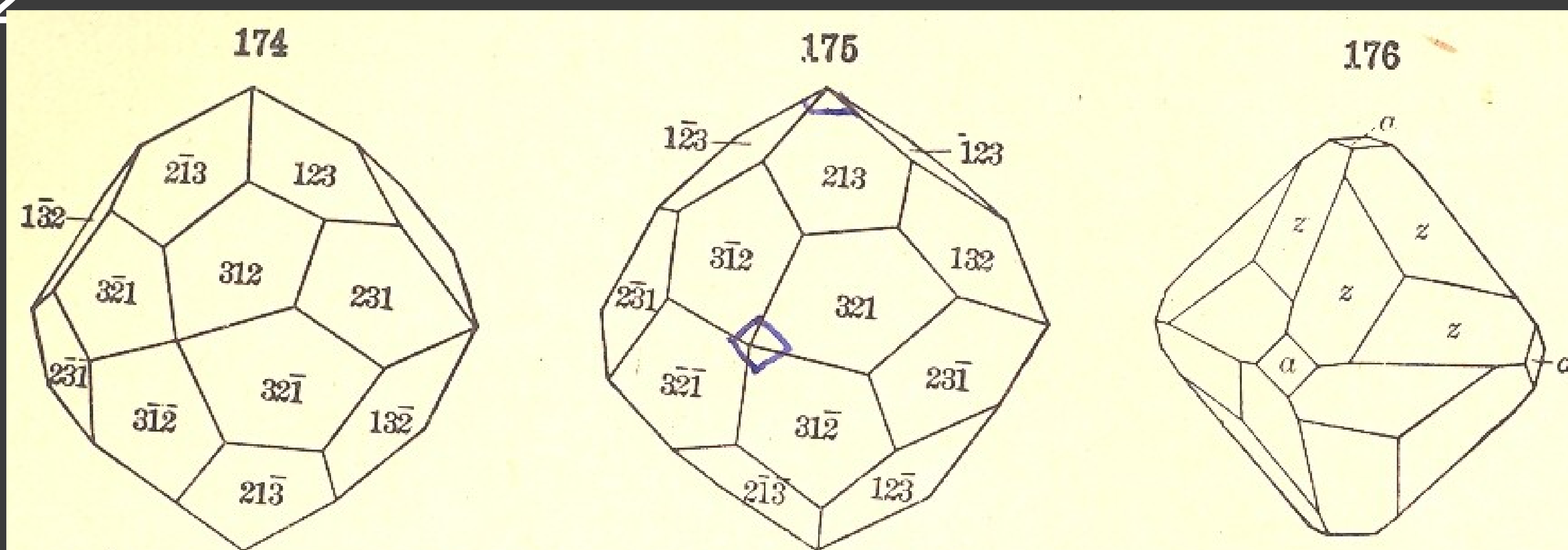
172



Boracite

D. PLAGIOHEDRAL CLASS – CUPRITE TYPE

- Forms : 1. Pentagonal Icositetrahedron - +ve and –ve forms.
- Symmetry: 3 xl. Ax.-4, 4 diag. Ax.-3, 6 diag. Ax.- 2



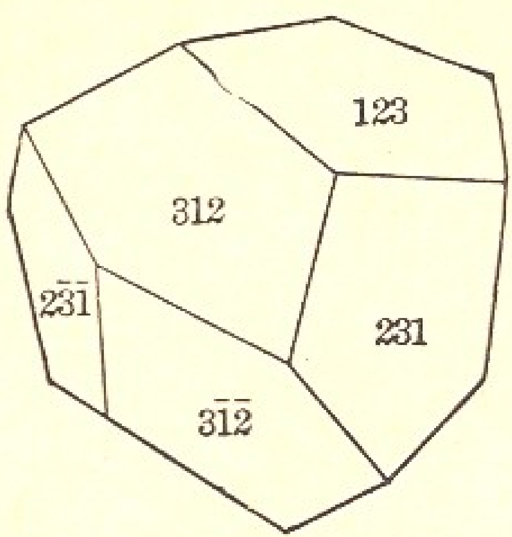
Right- and Left-handed Pentagonal Icositetrahedrons

Cuprite

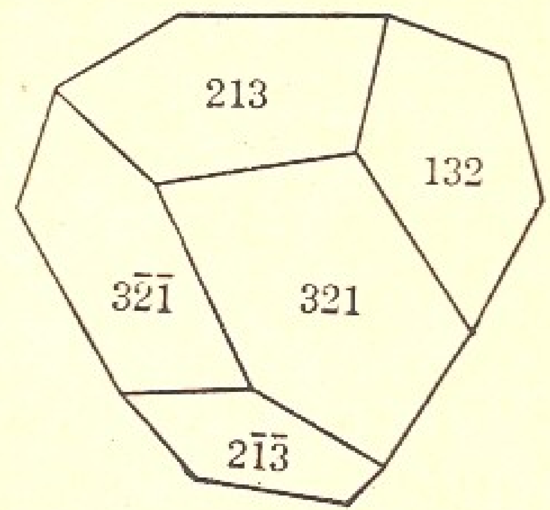
E. Tetartohedral Class- Ullmannite type

- Forms: 1. Tetrahedral-pentagonal-dodecahedron
- Symmetry : 3 xl. Ax.-2, 4 diag. Ax.-3.

178



179



CLASSES in Tetragonal System

1. NORMAL CLASS
2. HEMIMORPHIC CLASS
3. TRIPYRAMIDAL CLASS
4. PYRAMIDAL-HEMIMORPHIC CLASS
5. SPHENOIDAL CLASS
6. TRAPEZOHEDRAL CLASS
7. TETRAHEDRAL CLASS

TETRAGONAL SYSTEM

NORMAL CLASS - FORMS

i. Base or Basal Pinacoid .... (001)
ii. Prism of the 1st order ....(110)
iii. Prism of the 2nd order ....(100)
iv. Ditetragonal Prism ....(hkl) as 310, 210, 320, ...
v. Pyramid of the 1st Order ... (hhl) as 223, 111, 221, ...
vi. Pyramid of the 2nd Order ...(h0l) as 203, 101, 201, ...
vii. Ditetragonal Pyramid ....(hkl) as 421, 321, 122, ...

Tetragonal System

Normal Class / Zircon Type

Symmetry

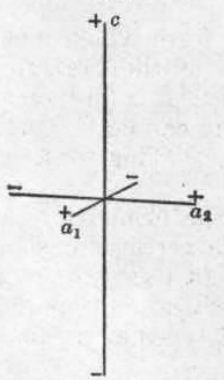
1 Vertical axis of 4 fold

4 horizontal axes of Two fold

1 horizontal Plane

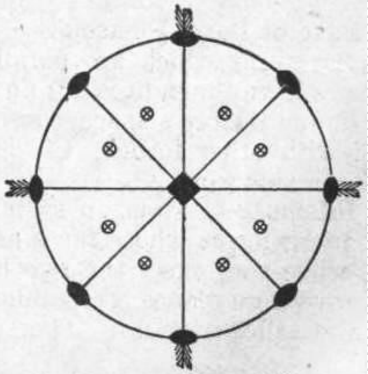
4 Vertical Planes

184



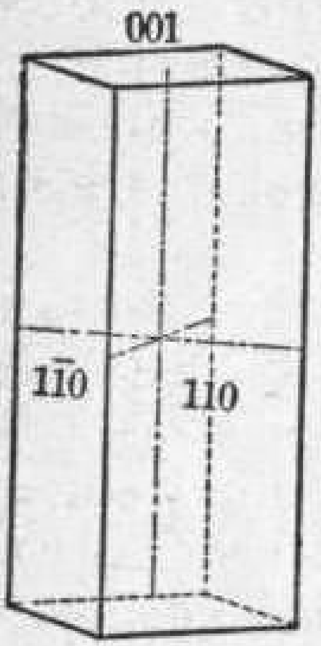
Axes of Tetragonal Mineral, Octahedrite $a : c = 1 : 1.78$

185



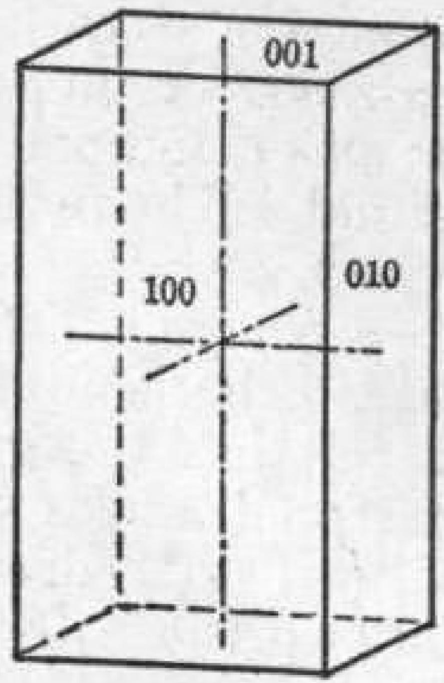
Symmetry of Normal Class Tetragonal System

188



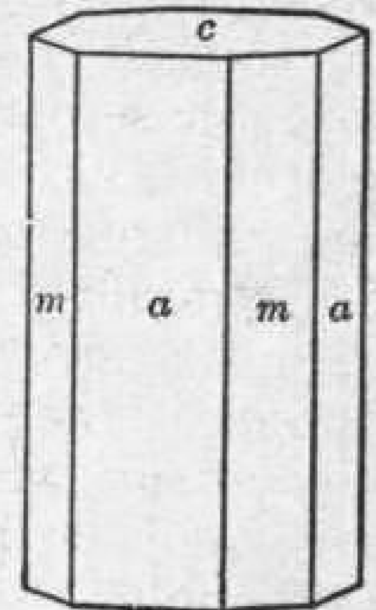
First Order Prism

189

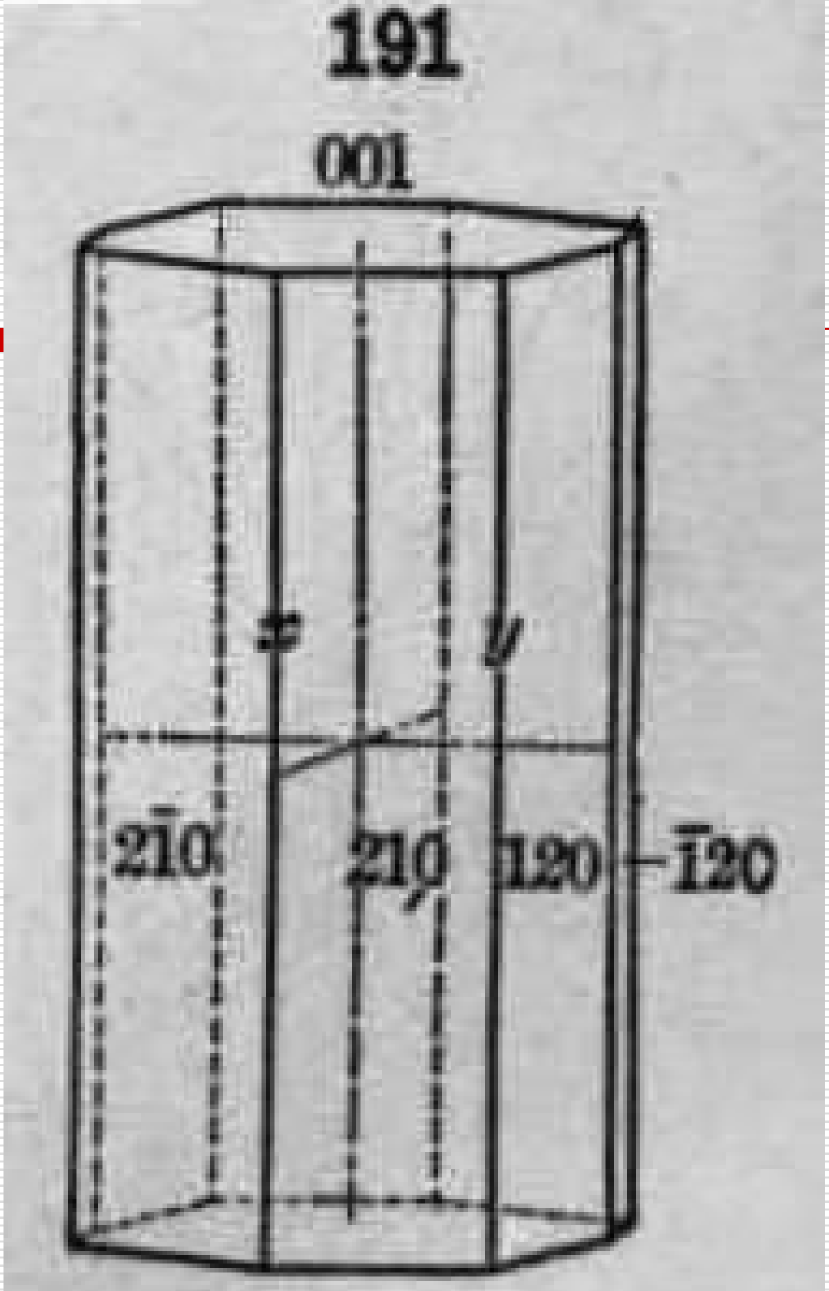


Second Order Prism

190

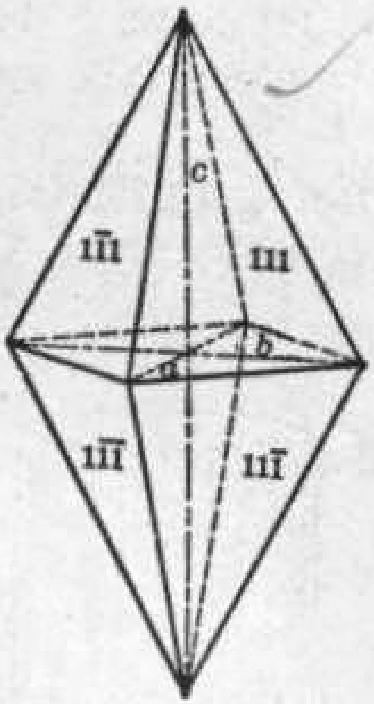


First and Second Order Prisms



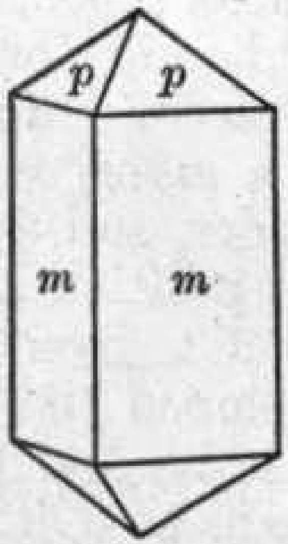
Ditetragonal Prism

192



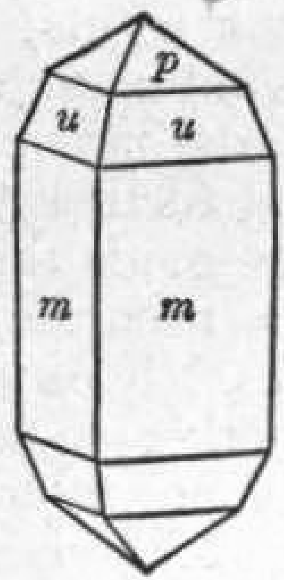
First Order Pyramid

193



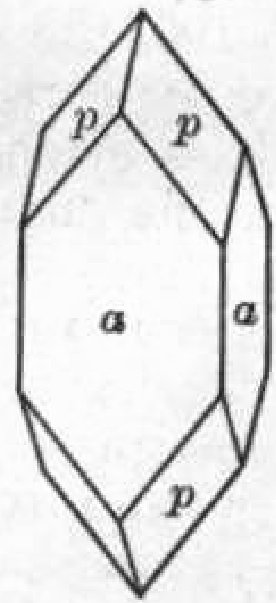
Zircon, First Order Prism and Pyramid

194



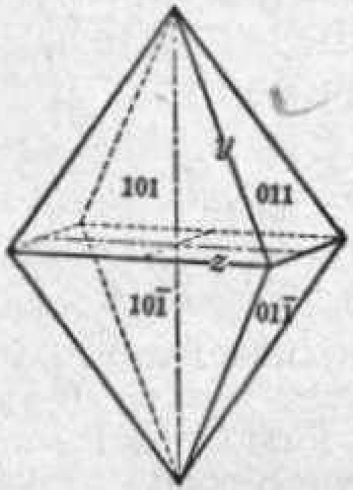
Zircon, First Order Prism and Pyramids

195



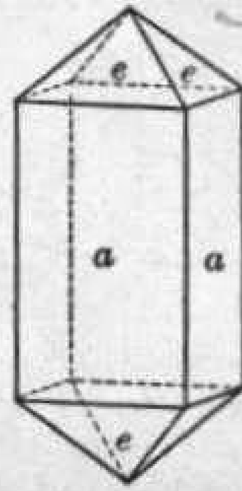
Apophyllite, Second Order Prism and First Order Pyramid

196



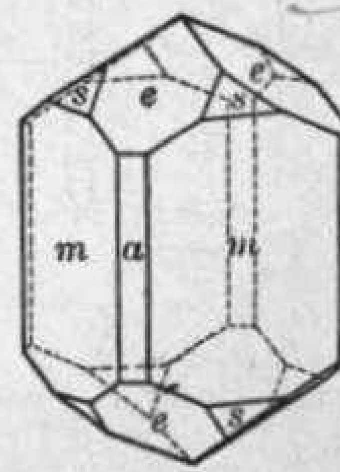
Second Order Pyramid

197



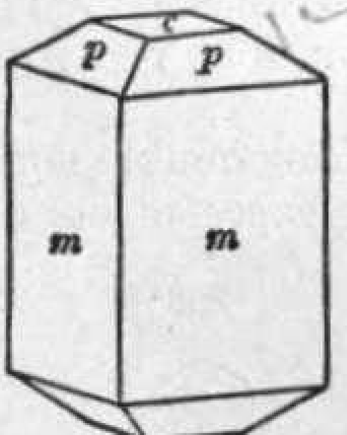
Second Order Prism and Pyramid

198



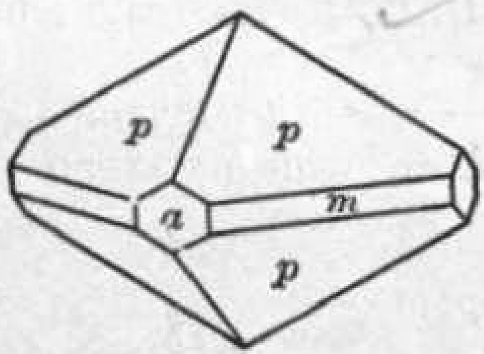
Rutile, First and Second Order Prisms and Pyramids

199



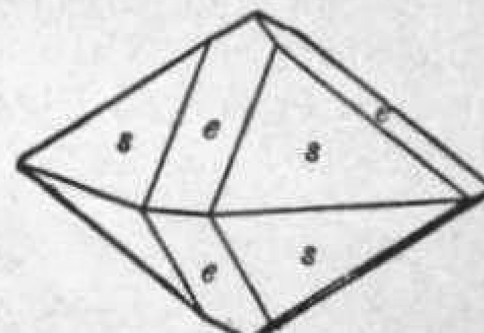
Vesuvianite First Order Prism, Pyramid and Base

200



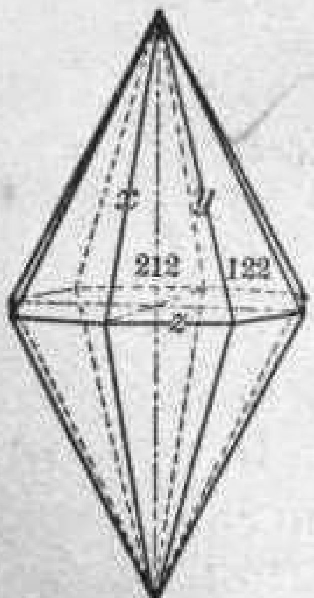
Vesuvianite First Order Pyramid and First and Second Order Prisms

201



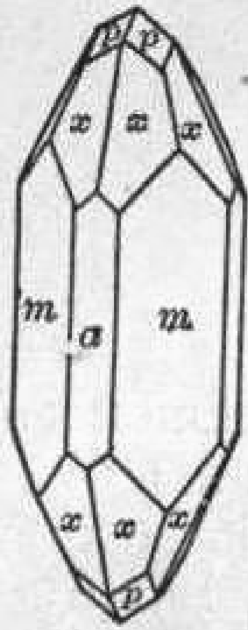
Cassiterite First and Second Order Pyramids

205



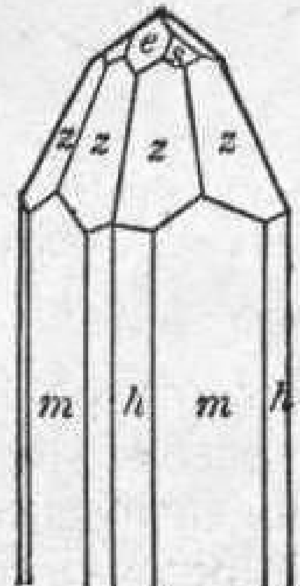
Ditetragonal Pyramid

206



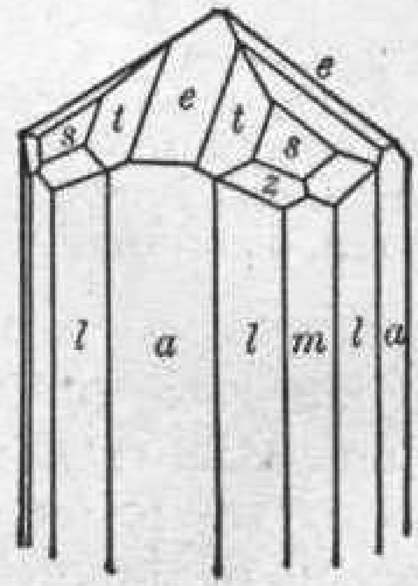
Zircon
First and Second Order Prisms, First Order Pyramid, Ditetragonal Pyramid

207



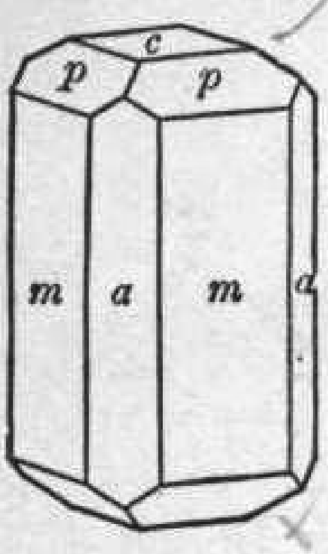
Cassiterite

208



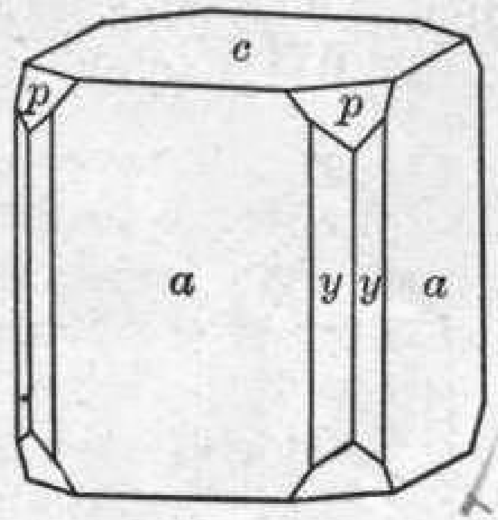
Rutile

202



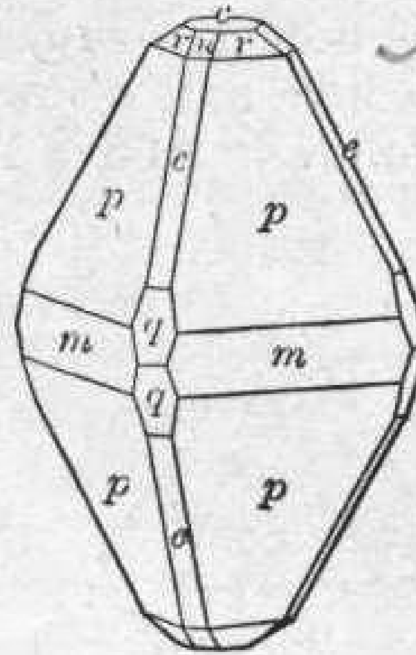
Vesuvianite
First and Second Order Prisms, First Order Pyramid and Base

203



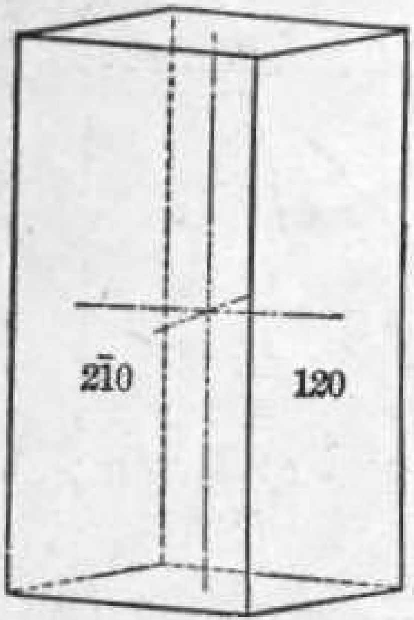
Apophyllite
Second Order Prism, Ditetragonal Prism, First Order Pyramid and Base

204



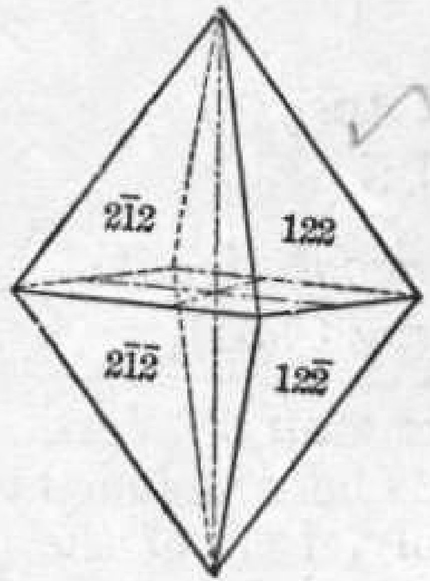
Octahedrite
Two First Order Pyramids, First Order Prism, Three Second Order Pyramids and Base

214



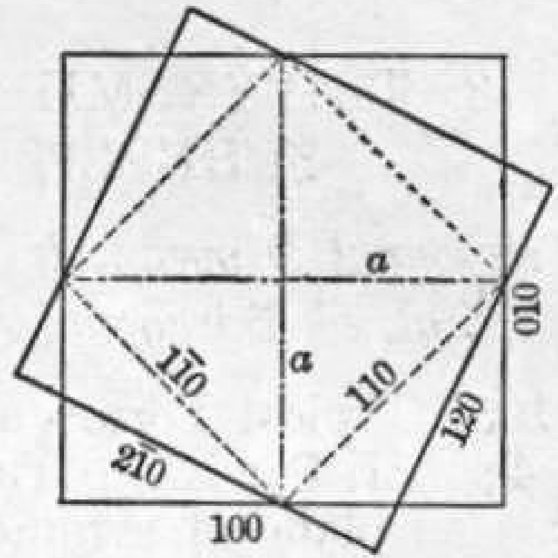
Third Order Prism

215

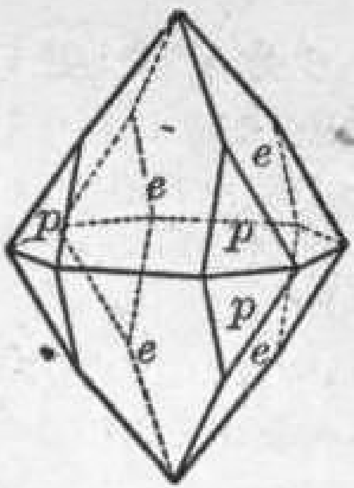


Third Order Pyramid

216

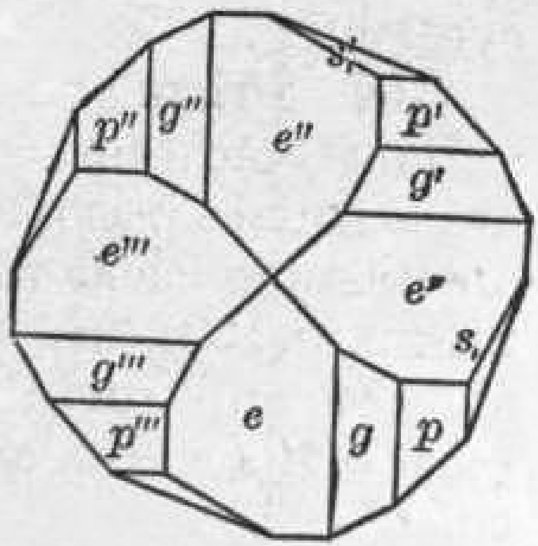


217



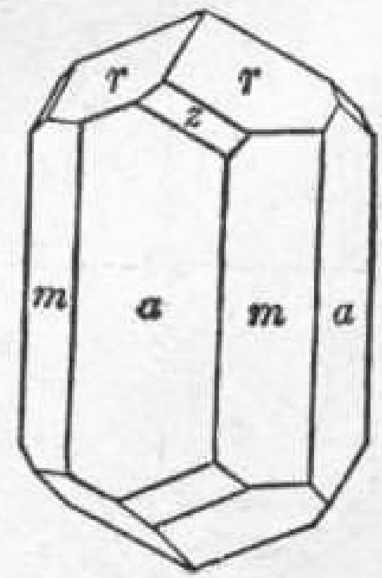
Scheelite

218



Scheelite

219



Meionite

Tetragonal System

Hemimorphic Class / Iodosuccinimide Type

Symmetry

1 Vertical axis of 4 fold

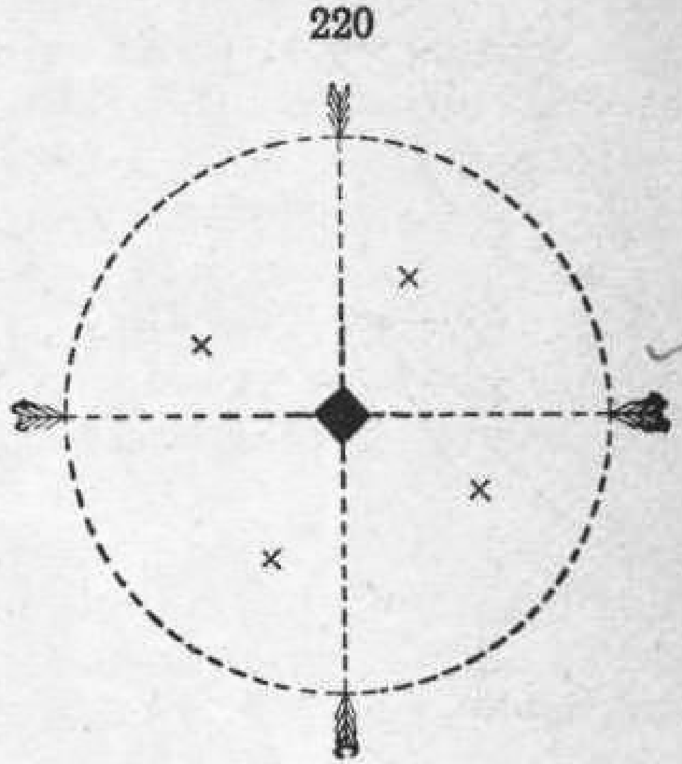
4 Vertical Planes

No H. Axes/Planes – Hemimorphic

Centre of symmetry - Absent

Pyramidal-Hemimorphic Class / Wulfenite Type

Tetragonal System



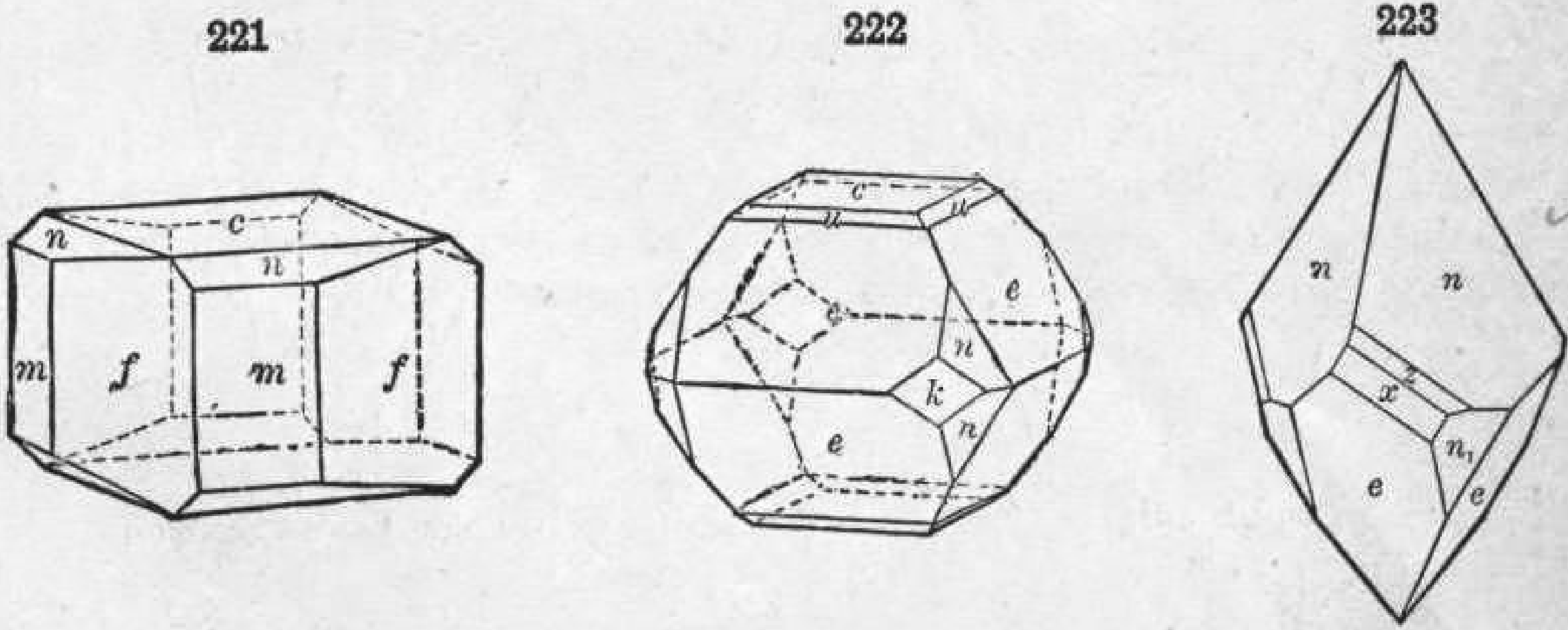
Symmetry of Pyramidal-Hemimorphic Class

Symmetry

1 Vertical axis of 4 fold

No Horizontal Planes

Centre of symmetry - Absent

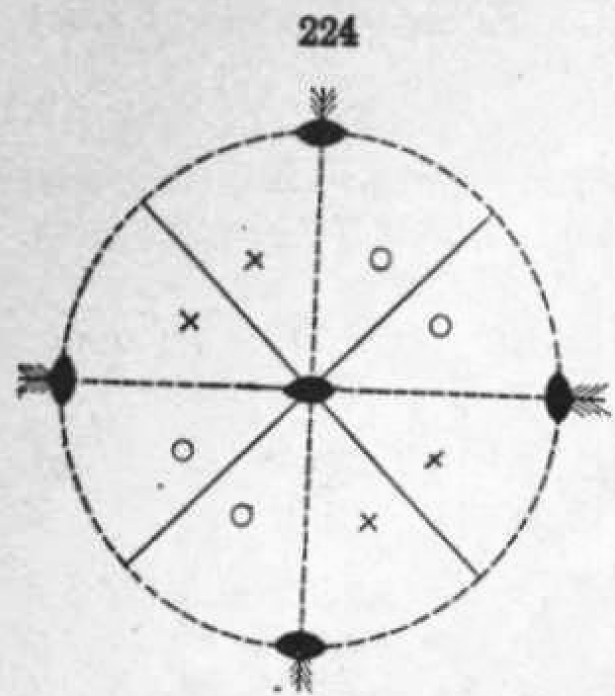


Wulfenite

i. Ditetragonal Prism ....(hkl) as f(230), k(210)
ii. Pyramid of the 1st Order … (hhl) as n(111)
iii. Pyramid of the 2nd Order …(h0l) as e(101), u(102)
iv. Ditetragonal Pyramid ....(hkl) as z(432), x(311)

Sphenoidal Class / Chalcopyrite Type

Tetragonal System



Symmetry of Spnenoida. Class

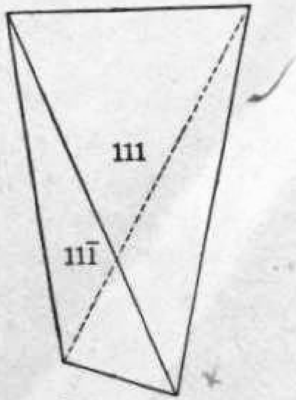
Symmetry

3 Crystallographic axes of 2 fold

2 Vertical diagonal Planes

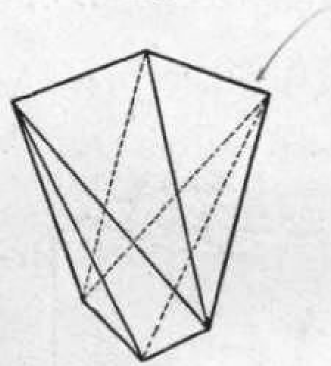
Centre of symmetry - Absent

225



Sphenoid

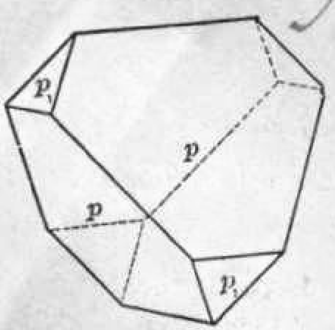
226



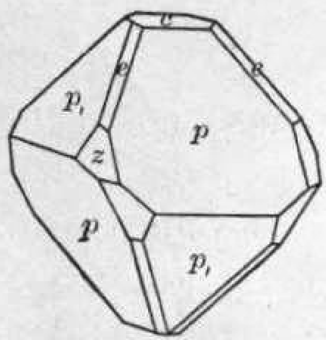
Tetragonal Scalenohedron

8 Scalene triangles (hkl)

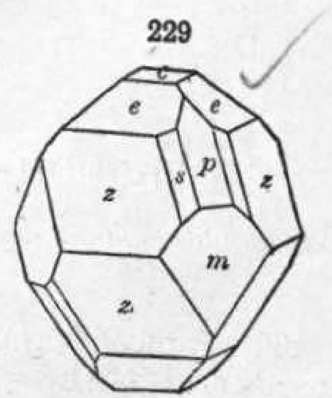
227



228



229



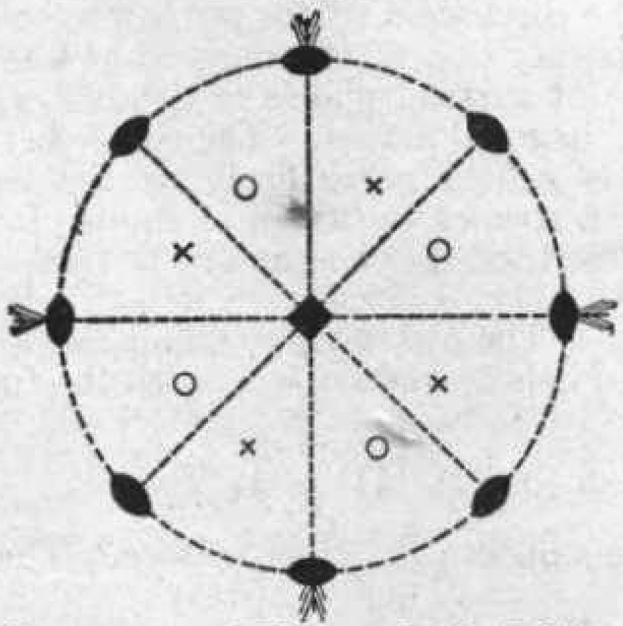
Chalcopyrite

- **i. Tetragonal Scalenohedron ………….(hkl) (111)**
- **ii. +ve, -ve sphenoids**
- **iii. 2nd Order Pyramids …(h0l) as e(101), z(201)**
- **iv. Base ….. c(001)**
- **v. 1st Order Prism … (hhl) as n(111)**
- **vi. 2nd Order Prism…(h0l) as e(101), m(110)**
- **vii. +ve, -ve Ditetragonal Pyramid (hkl) as z(432)**

Trapezohedral Class / Nickel sulphate Type

Tetragonal System

230



Symmetry of Trapezohedral Class

Symmetry

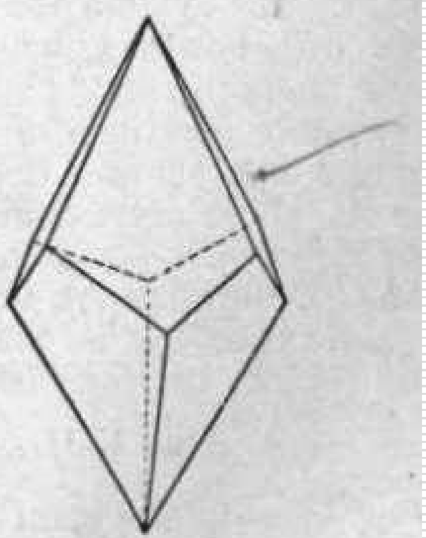
1 Vertical axis of 4 fold

4 Horizontal axes of 2 fold

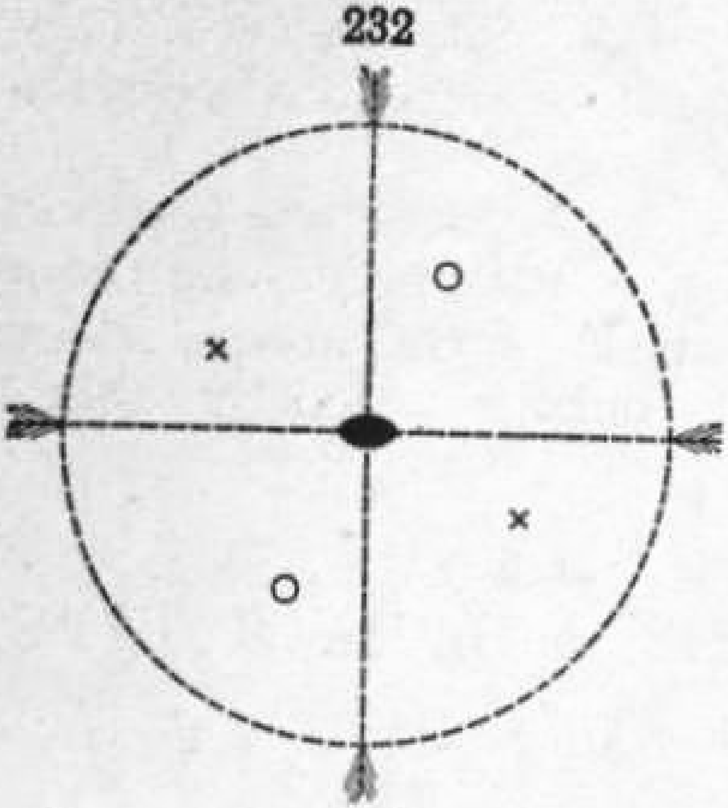
No Planes, &

No Center of symmetry

231



Tetragonal Trapezohedron



Symmetry of Tetartohedral Class

CLASSES in HEXAGONAL SYSTEM

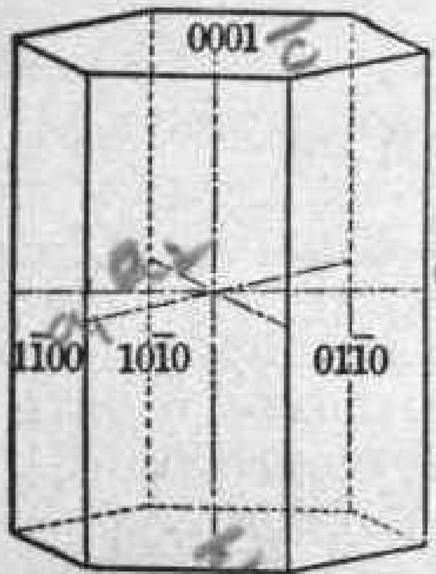
1. NORMAL CLASS
2. HEMIMORPHIC CLASS
3. TRIPYRAMIDAL CLASS
4. PYRAMIDAL-HEMIMORPHIC CLASS
5. TRAPEZOHEDRAL CLASS
6. TRIGONAL CLASS

HEXAGONAL SYSTEM

NORMAL CLASS - FORMS

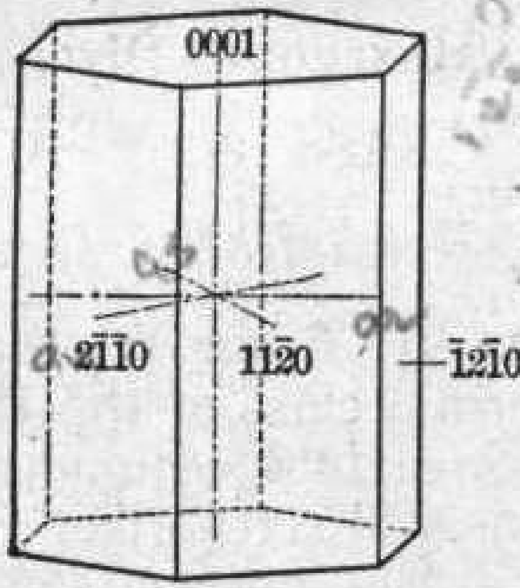
i. **Base .... (0001)**
ii. **Prism of the first order ....$(10\bar{1}0)$**
iii. **Prism of the second order ....$(10\bar{2}0)$**
iv. **Dihexagonal prism....(*hk-l0*) as 10-11)**
v. **Pyramid of the first order........ (h0-hl)**
vi. **Pyramid of the second order... (hh-2hl)**
vii. **Dihexagonal pyramid ....(hk-ll)**

238



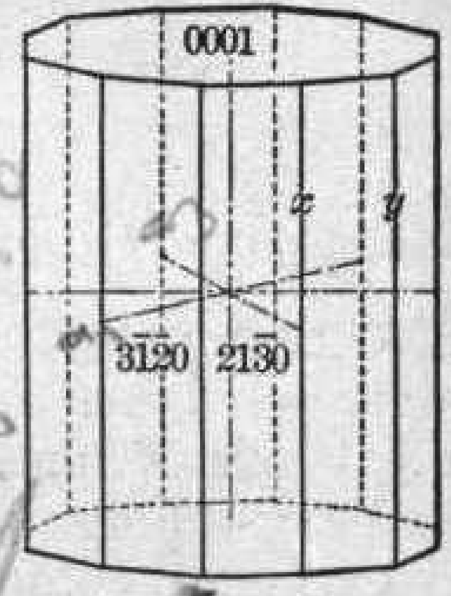
First Order Prism

239



Second Order Prism

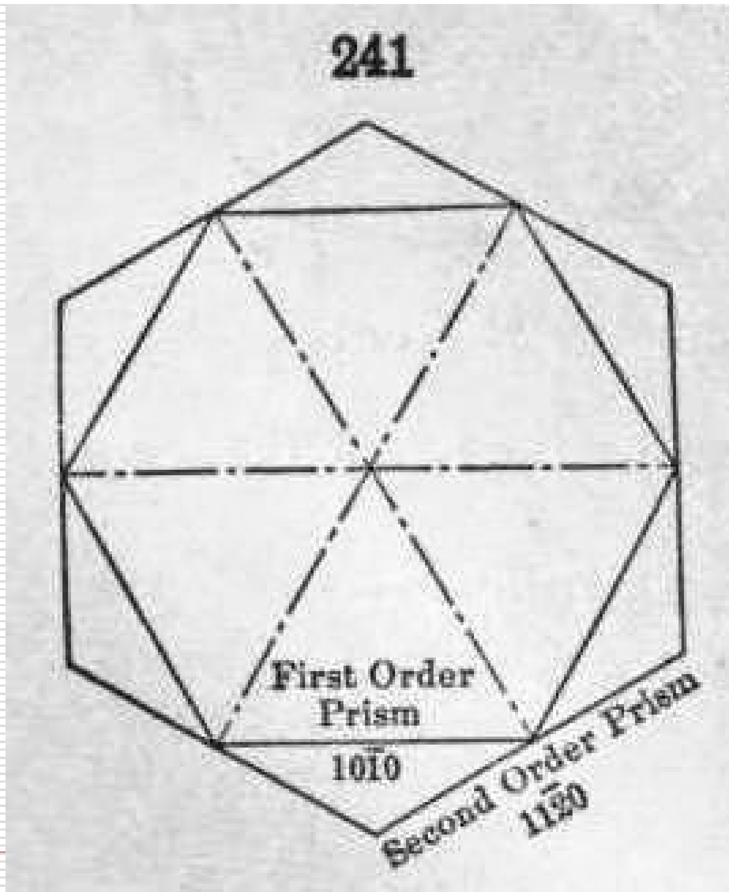
240



Dihexagonal Prism

Normal Class / Beryl Type

Hexagonal System



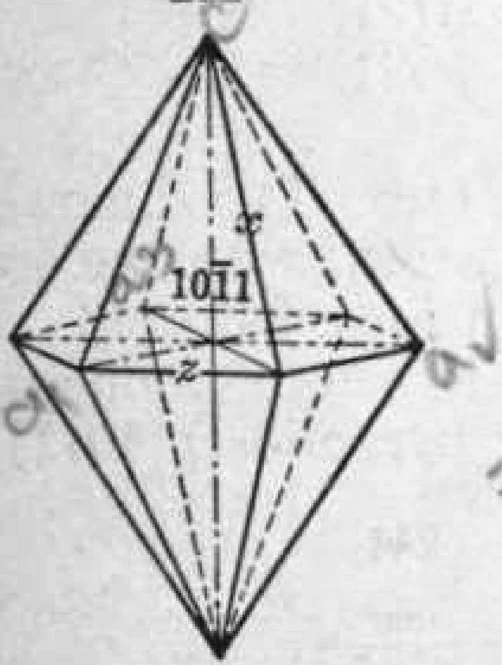
Symmetry

1 Vertical axis of 6 fold

6 Vertical Planes

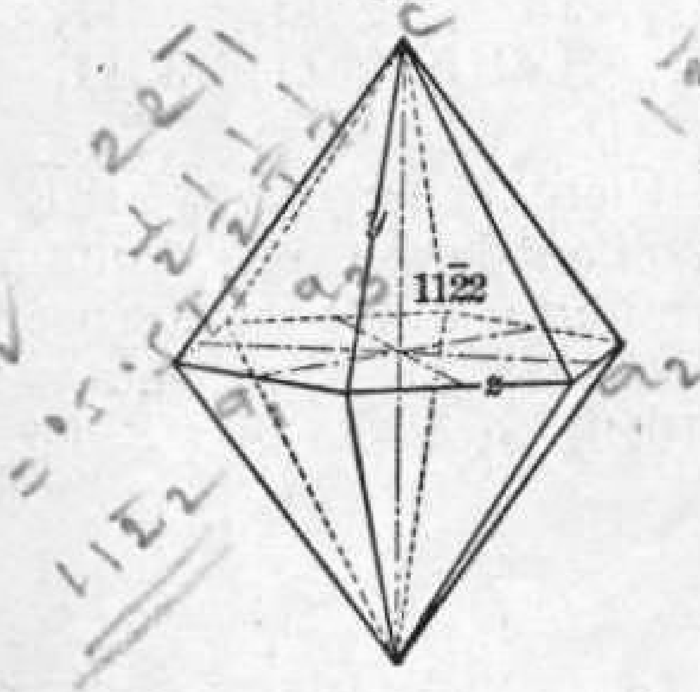
Center of symmetry - Present

242



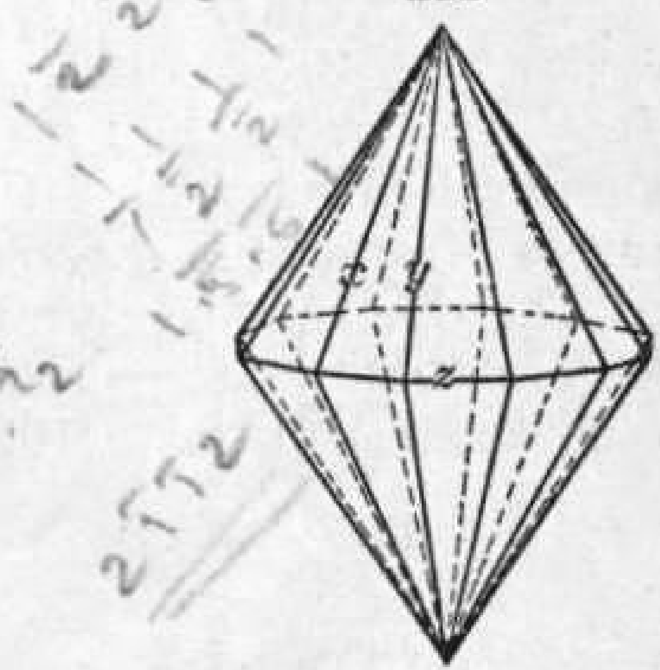
First Order Pyramid

243



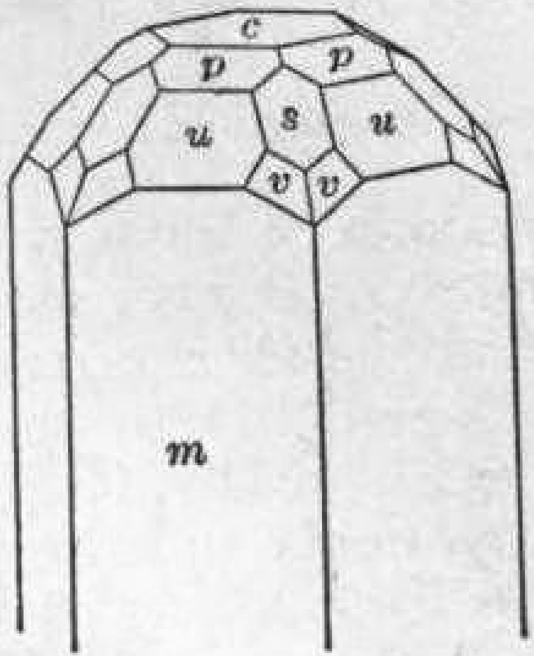
Second Order Pyramid

244



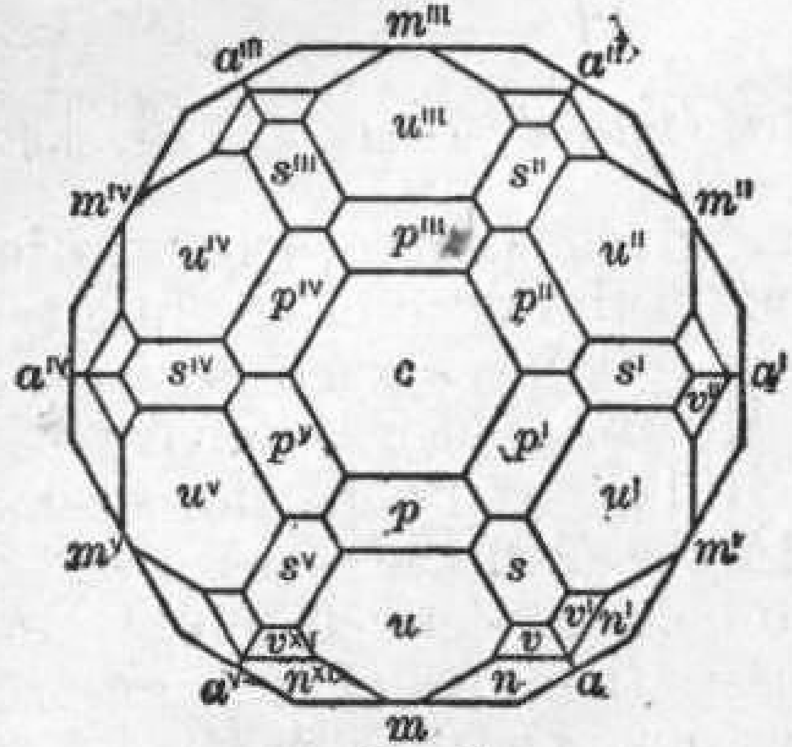
Dihexagonal Pyramid

245



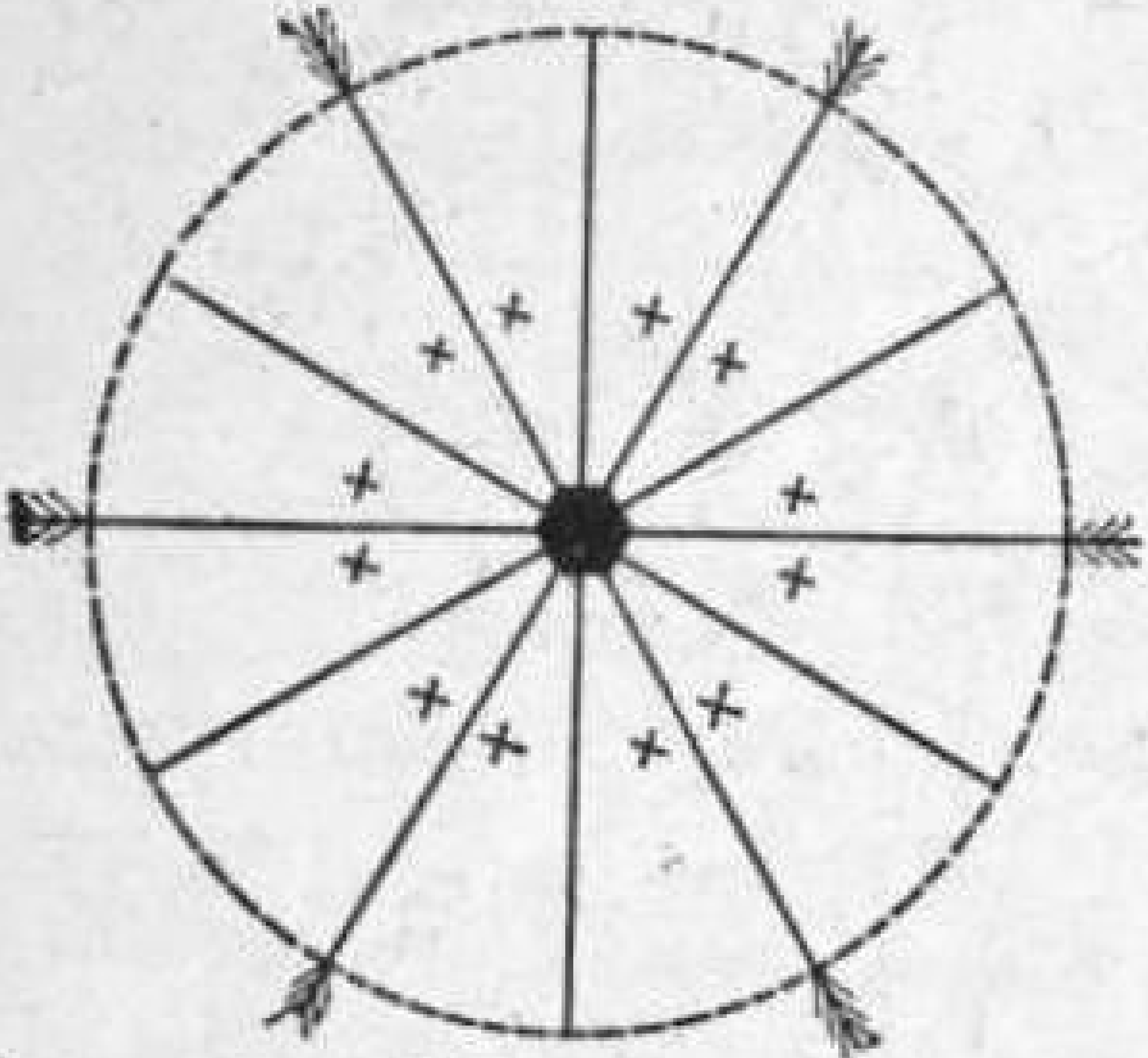
Beryl

246



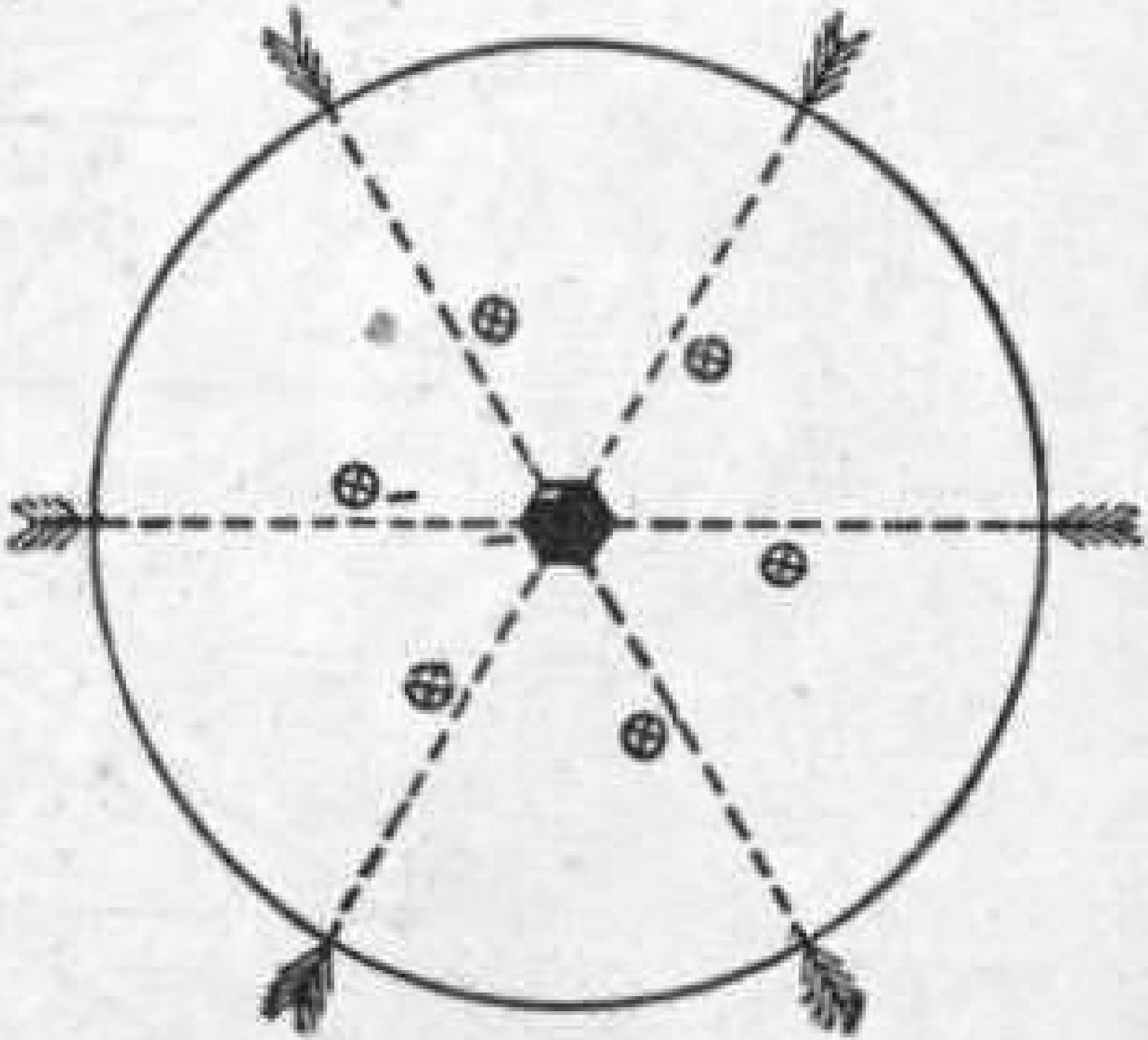
Beryl

249



Symmetry of Hemimorphic Class

250

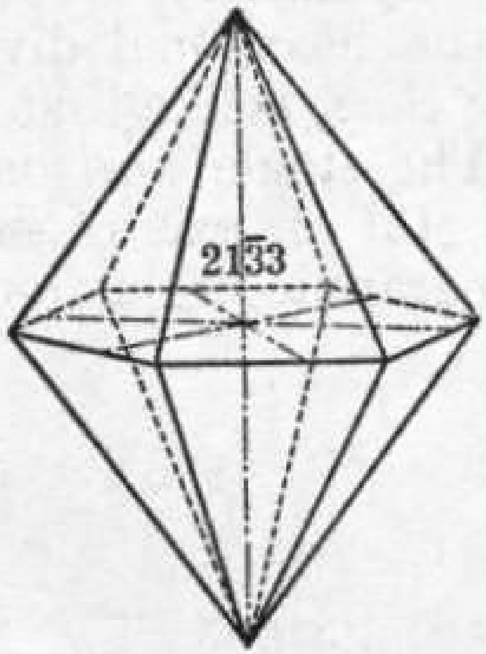


Symmetry of Tripyramidal Class

251

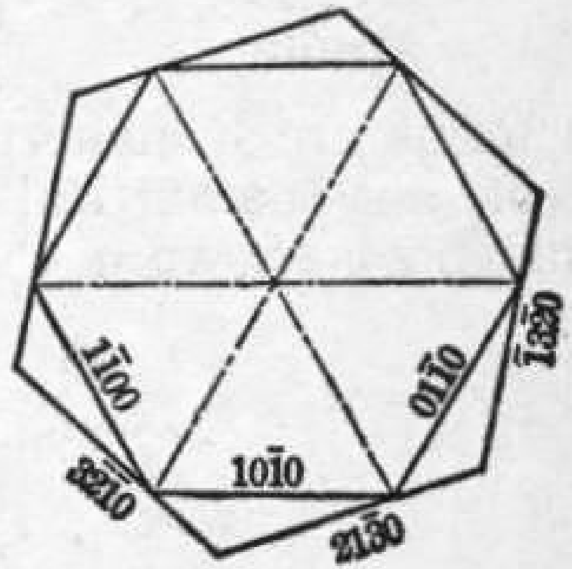
Third Order Prism

252

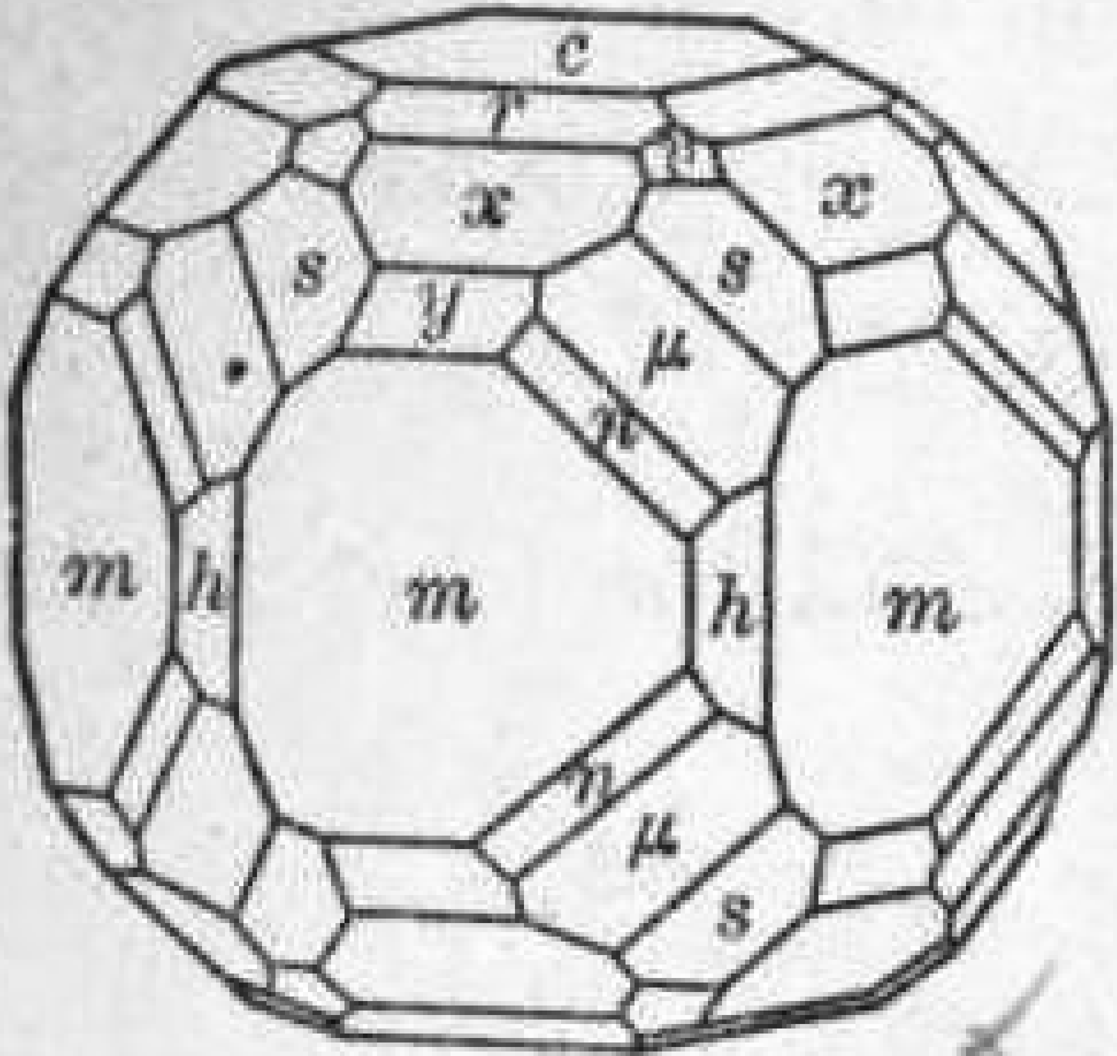


Third Order Pyramid

253

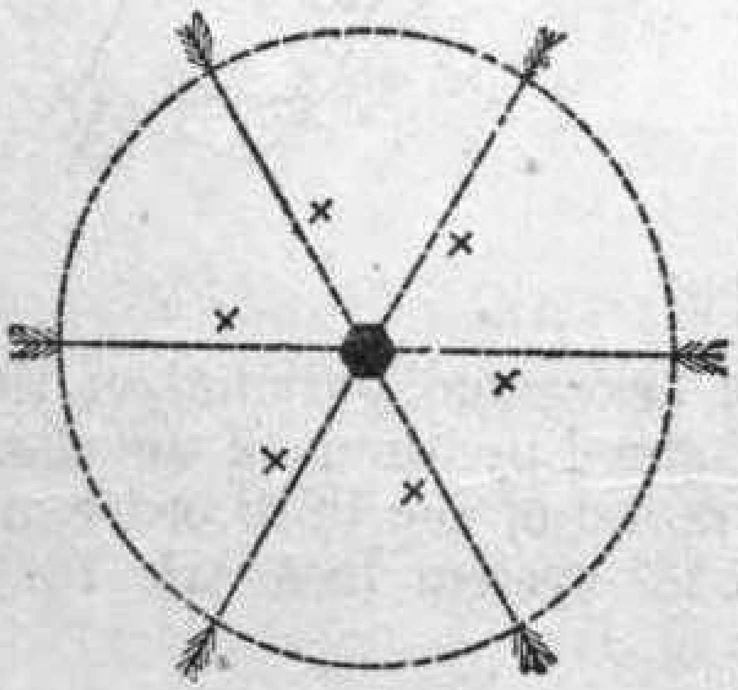


254



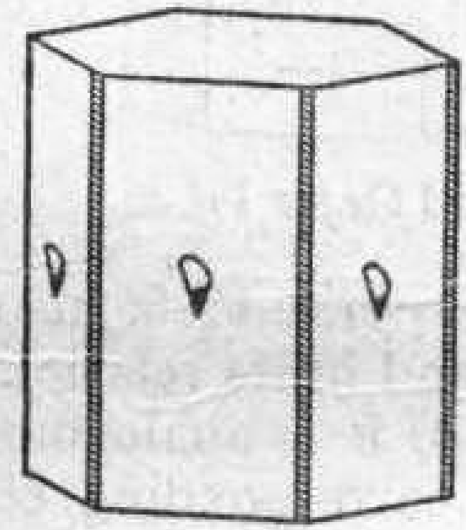
Apatite

255



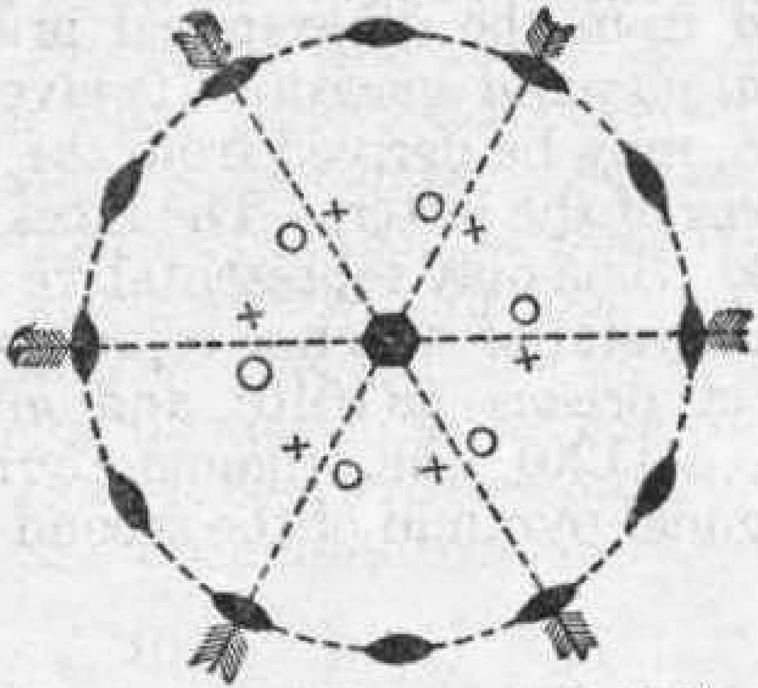
Symmetry of Pyramidal-Hemimorphic Class

256



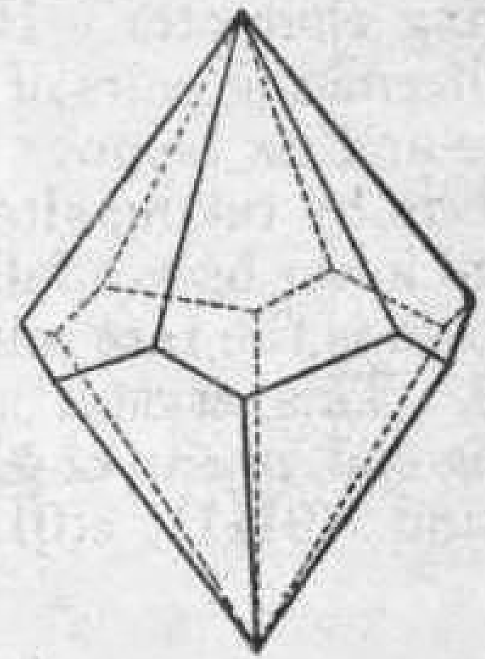
Nephelite

257



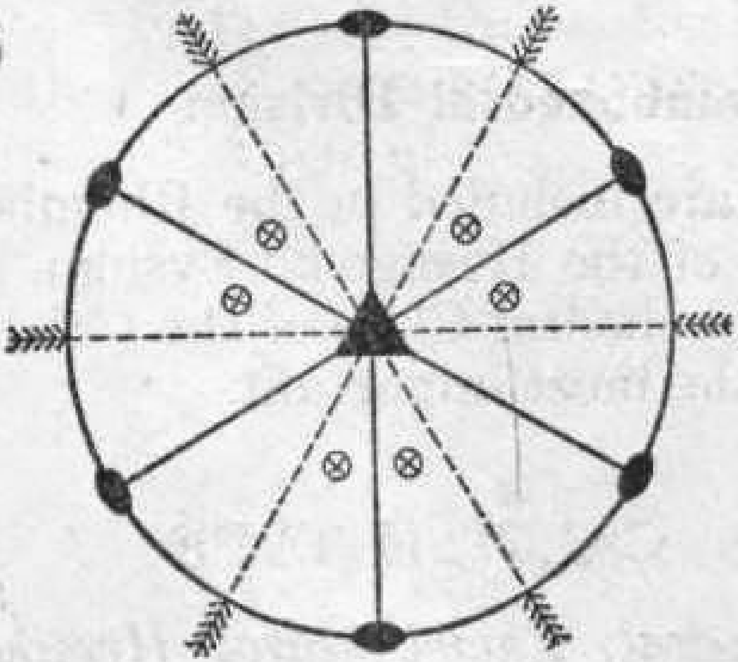
Symmetry of Trapezohedral Class

258



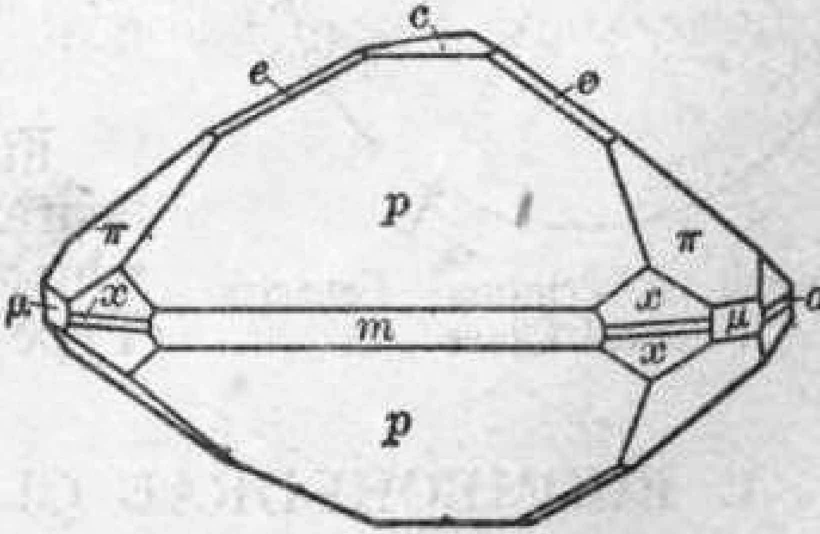
Hexagonal Trapezohedron

259



Symmetry of Trigonal Class

260



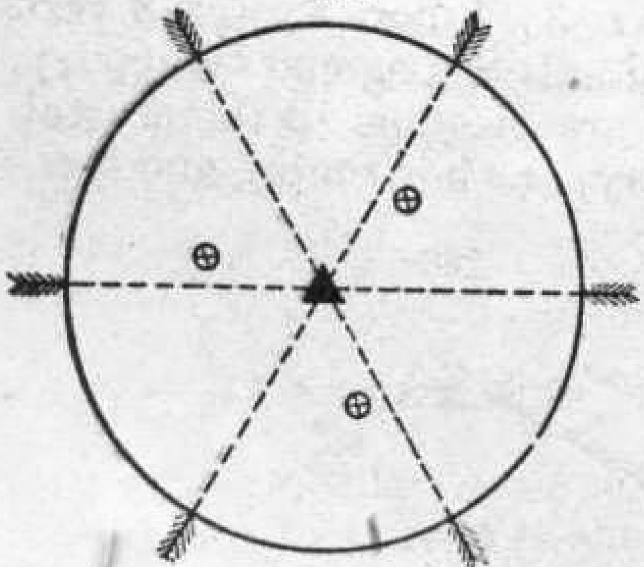
Benitoite (Palache)

TRIGONAL TETARTOHEDRAL

1. RHOMBOHEDRAL CLASS / CALCITE TYPE
2. RHOMBOHEDRAL-HEMIMORPHIC CLASS – TOURMALINE TYPE
3. TRI RHOMBOHEDRAL CLASS – PHENACITE TYPE
4. TRAPEZOHEDRAL CLASS – α-QUARTZ TYPE
5. TRIGONAL TETARTOHEDRAL HEMIMORPHIC CLASS – SODIUM PERIODATE TYPE

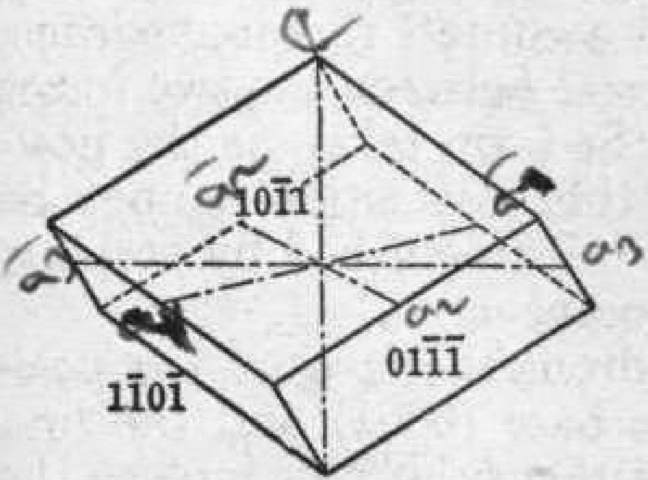
145. Vert. Ax.-3; hor. P.

261



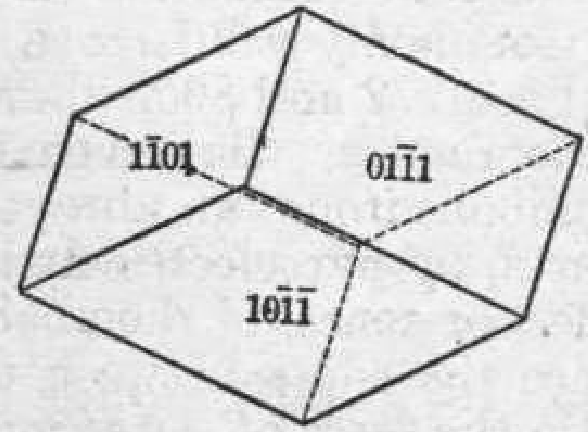
Symmetry of Trigonal Tetarto-hedral Class

263



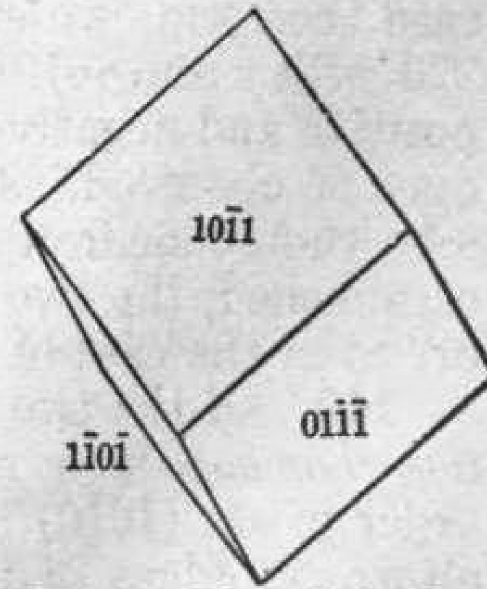
Positive Rhombohedron
Calcite

264



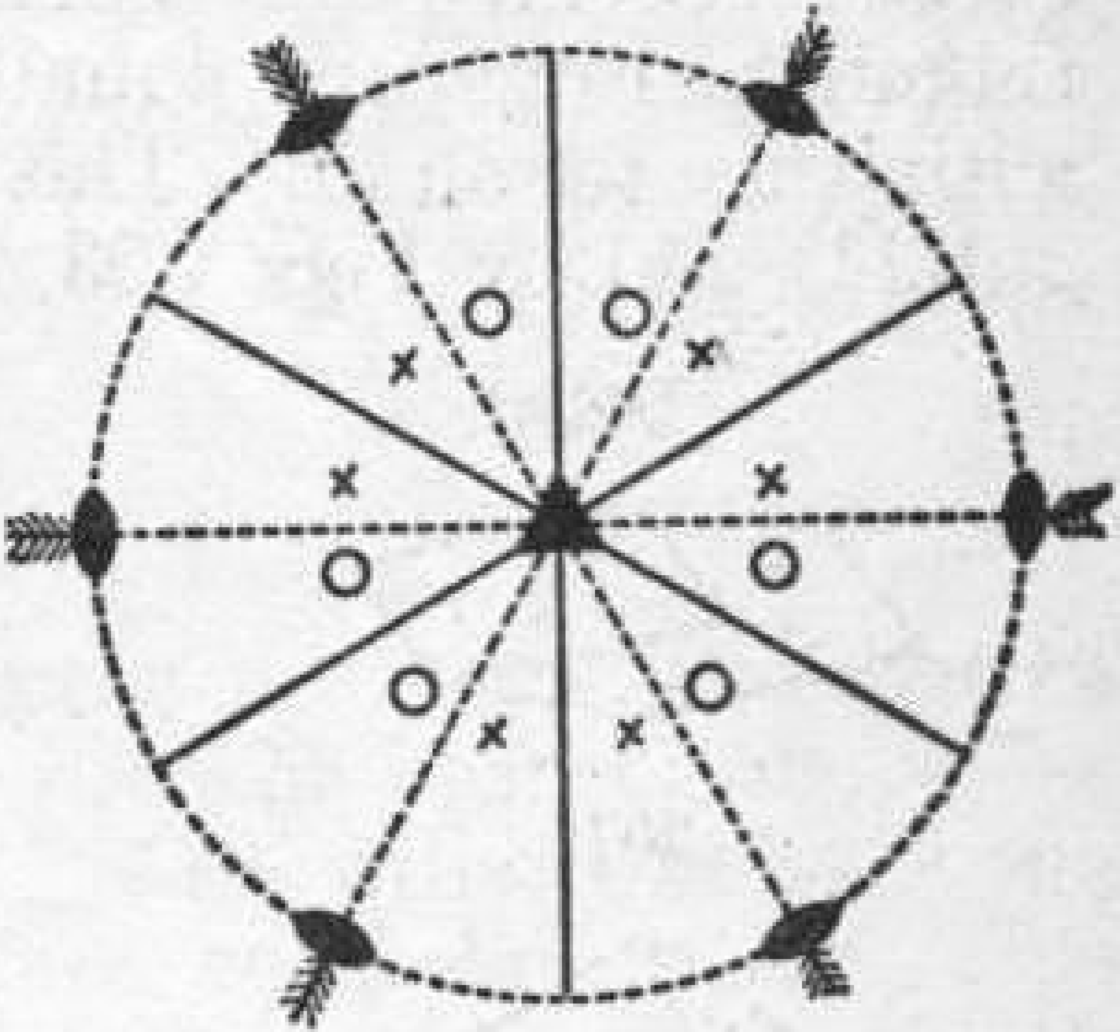
Negative Rhombohedron

265



Positive Rhombohedron
Hematite

262

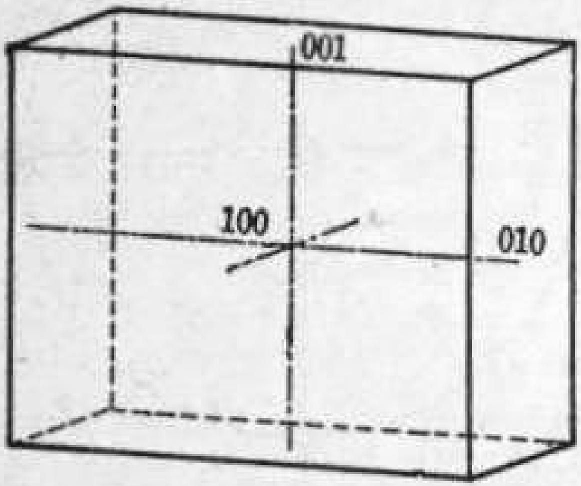


Symmetry of Rhombohedral Class

ORTHORHOMBIC SYSTEM NORMAL CLASS - FORMS

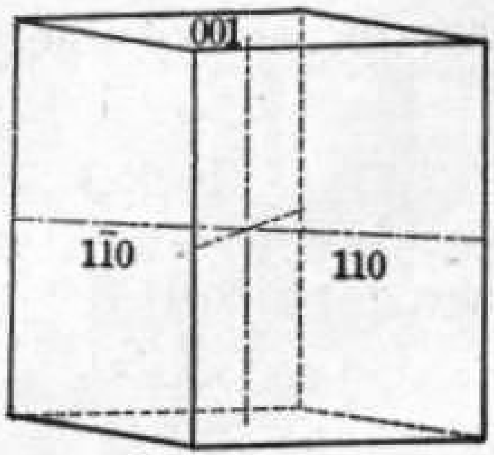
i. Macropinacoid or a-pinacoid (100)
ii. Brachypinacoid or b-pinacoid (010)
iii. Base or c-pinacoid (001)
iv. Prisms (hk0)
v. Macrodomes (h0l)
vi. Brachydomes (0kl)
vii. Pyramids (hkl).

316



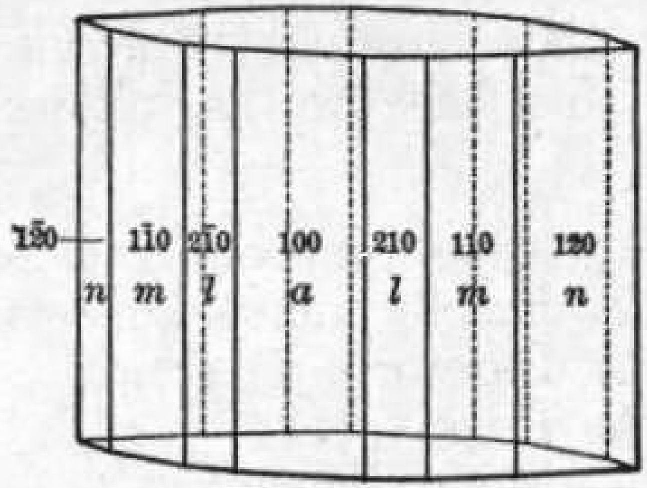
Macro-, Brachy- and Basal Pinacoids

317

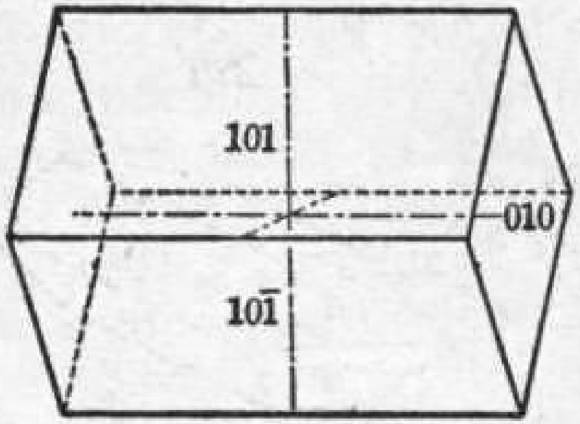


Prism and Basal Pinacoid

318

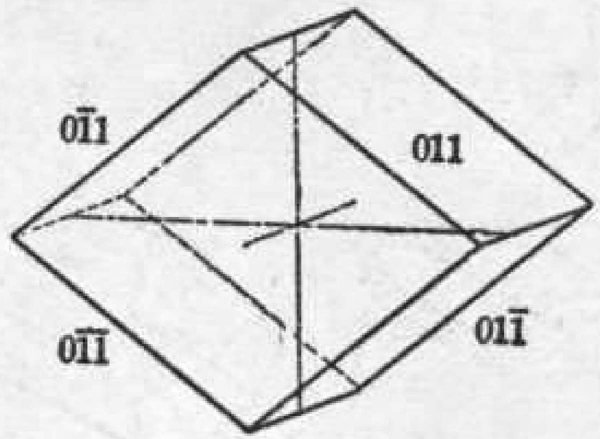


319



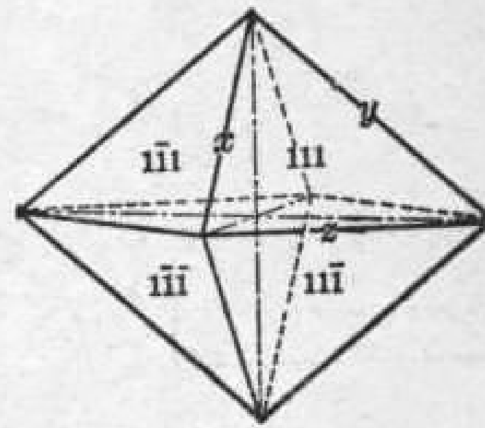
Macrodome and Brachypinacoid

320



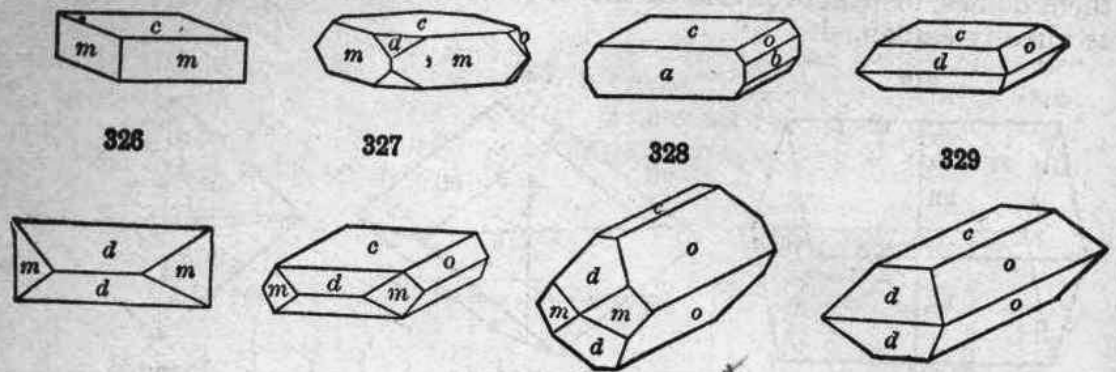
Brachydome and Macropinacoid

321



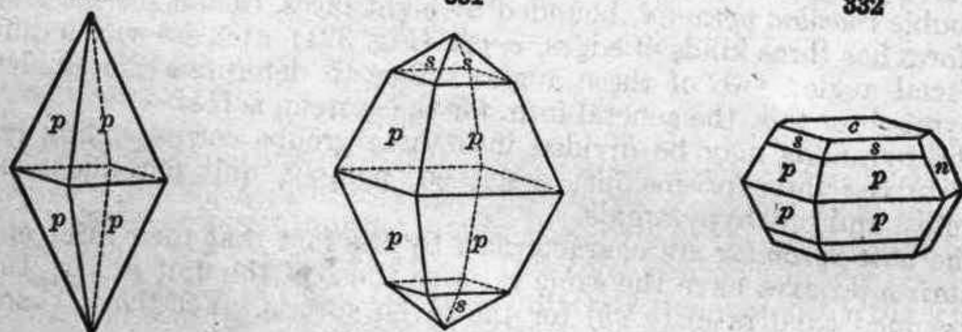
Pyramid

322 323 324 325
326 327 328 329



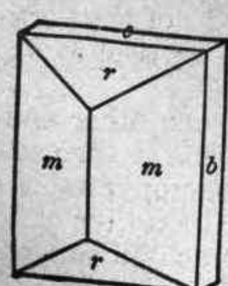
Barite Crystals

330 331 332



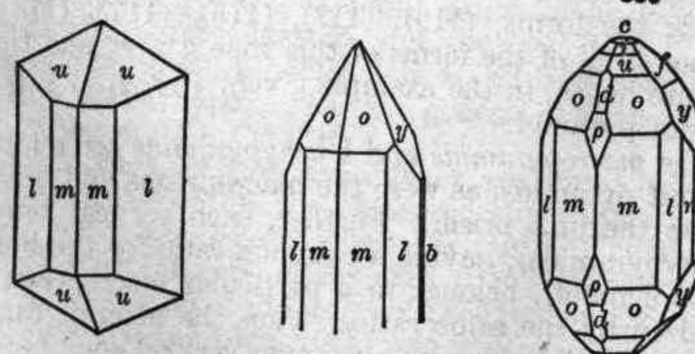
Sulphur Crystals

333



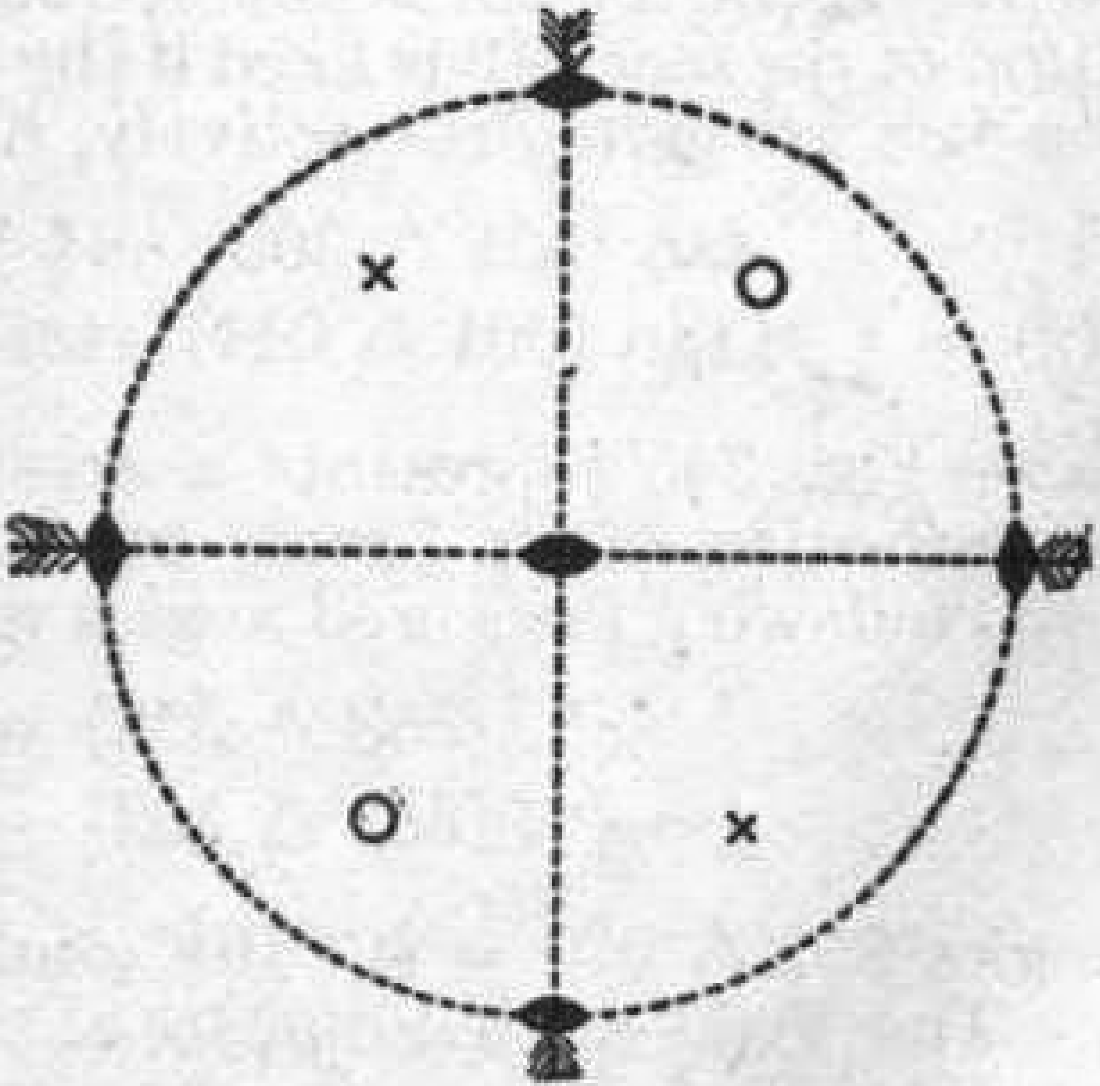
Staurolite

334 335 336



Figs. 334–336, Topaz

343

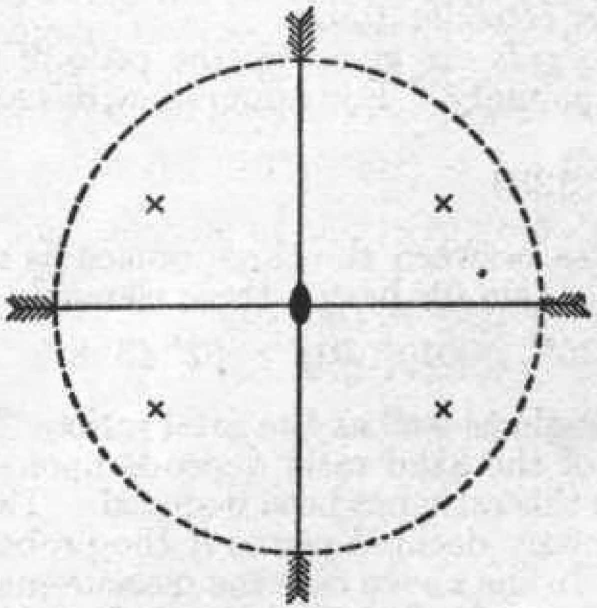


Symmetry of Sphenoidal Class

344

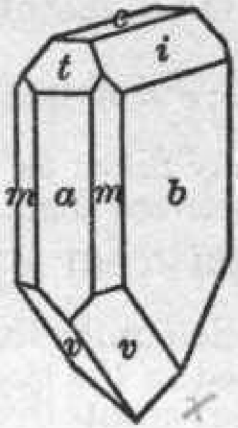
Epsomite

340



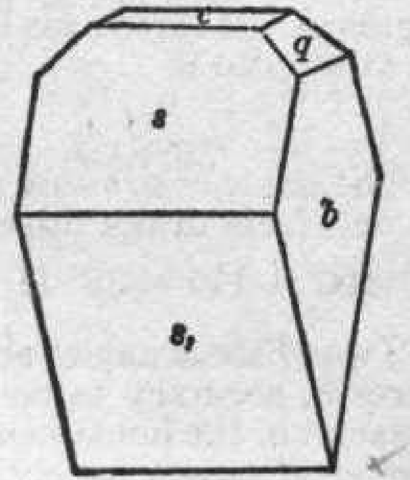
Symmetry of Hemimorphic Class

341



Calamine

342



Struvite

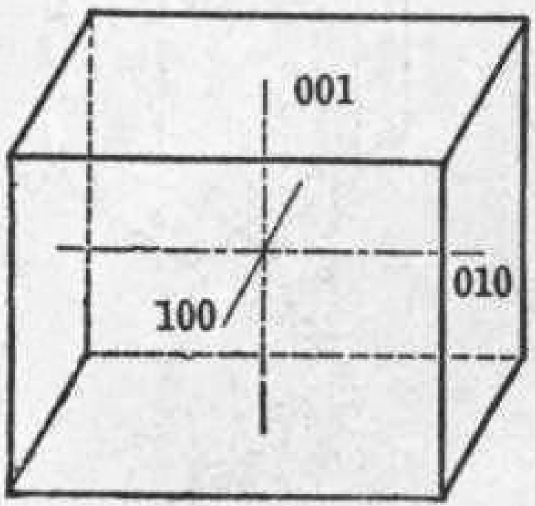
The general symmetry of the class is shown in the stereographic projection, Fig. 340. Further, Figs. 341, of calamine, and 342, of struvite, represent typical crystals of this class. In Fig. 341 the forms present are $t(301)$, $i(031)$, $v(12\bar{1})$; in Fig. 342 they are $s(101)$, $s_1(10\bar{1})$, $q(011)$.

MONOCLINIC SYSTEM

NORMAL CLASS - FORMS

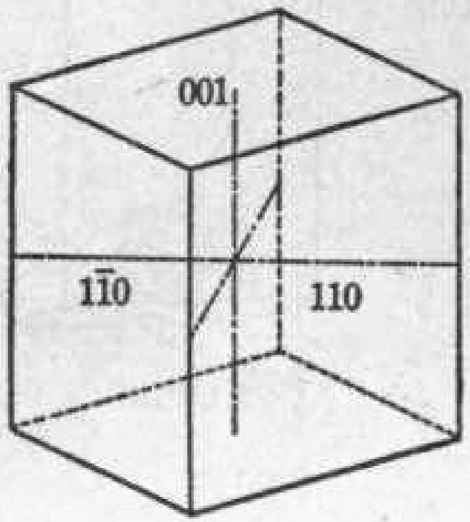
i. **Orthopinacoid or a-pinacoid... (100)**
ii. **Clinopinacoid or b-pinacoid.... (010)**
iii. **Base or c-pinacoid ....(001)**
iv. **Prisms ....(hk0)**
v. **Orthodomes ....(h0l), (-h0l)**
vi. **Clinodomes ....(0kl)**
vii. **Pyramids ....(hkl), (-hkl).**

353



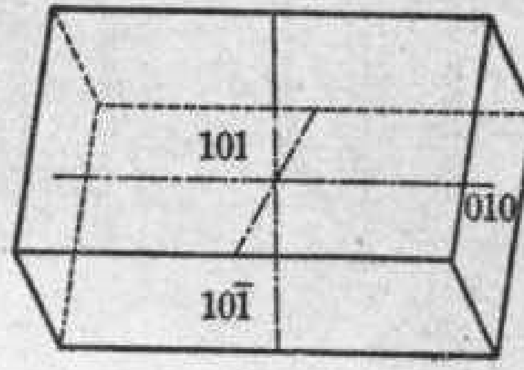
Ortho-, Clino-
and Basal Pinacoids

354



Prism and
Basal Pinacoid

355



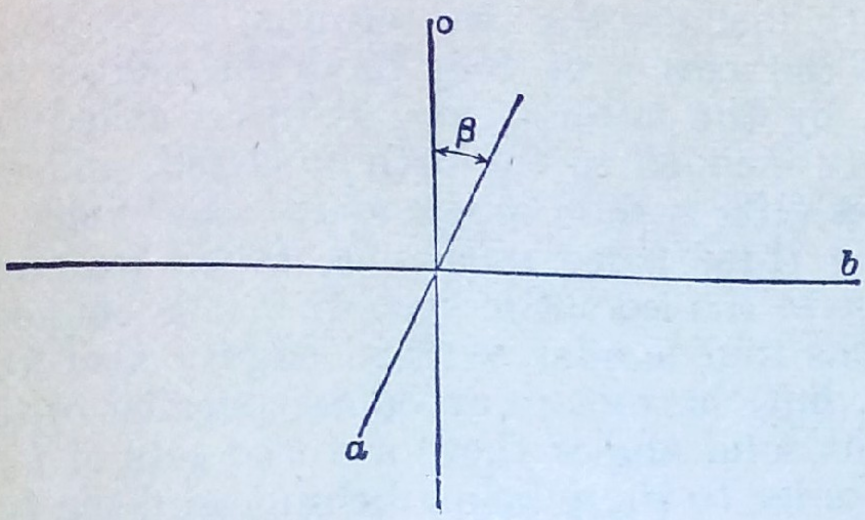
Orthodomes
and Clinopinacoid

Symmetry Elements of

Monoclinic System:

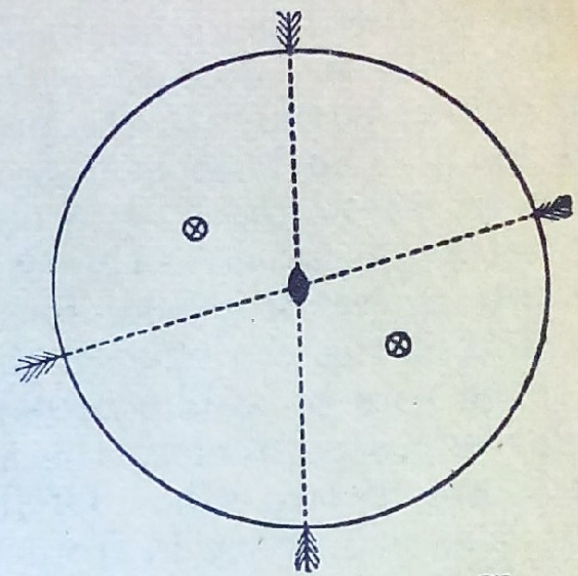
B xl. Ax. 2; a-c xl. P. ; C.

351



Crystal Axes of Orthoclase
$a:b:c = 0{\cdot}66:1:0{\cdot}55.\ \beta = 64°$

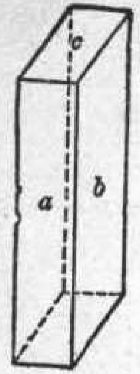
352



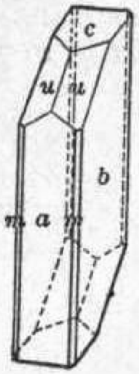
Symmetry of Normal Class

1. NORMAL CLASS (28). GYPSUM TYPE

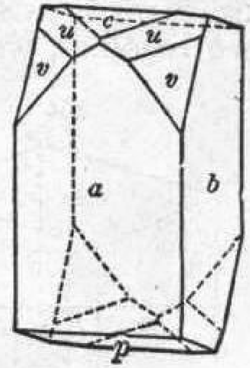
356



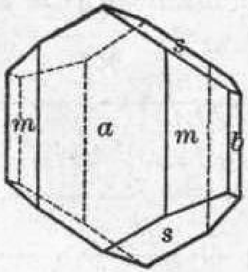
357



358

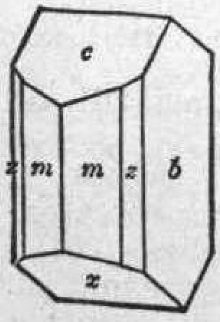


359

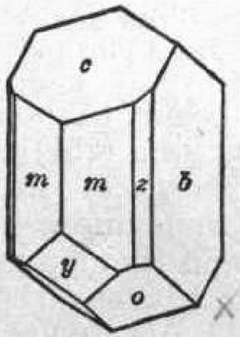


Pyroxene

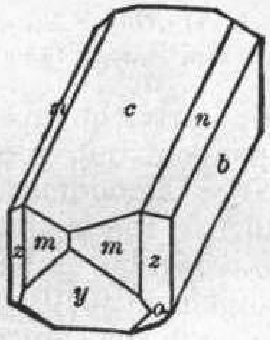
360



361

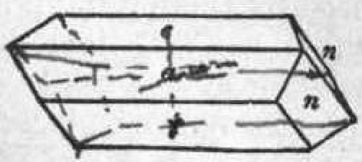


362



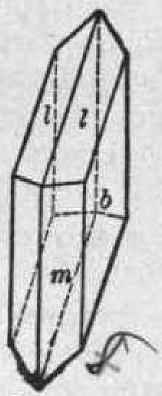
Orthoclase

363



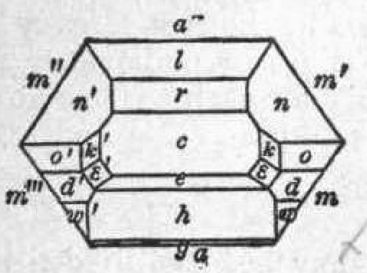
Epidote

364

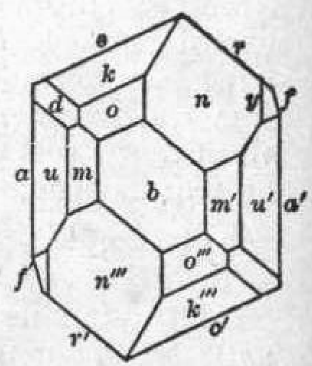


Gypsum

365

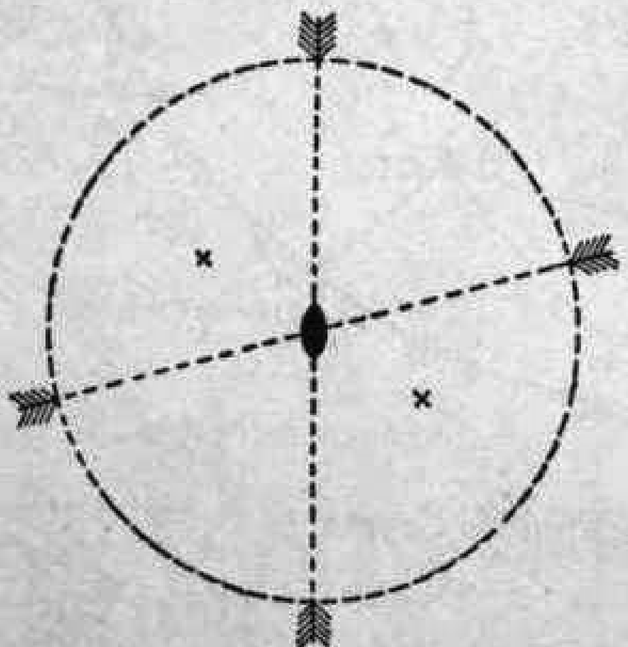


366



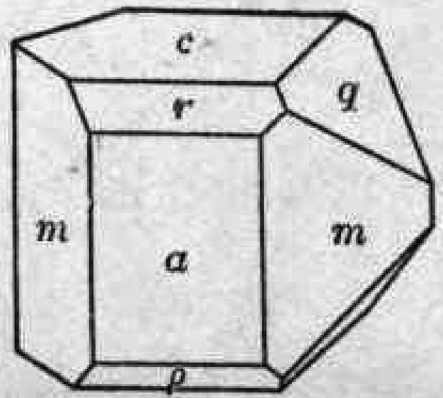
Epidote

369



Symmetry of Hemimorphic Class

370



Tartaric Acid

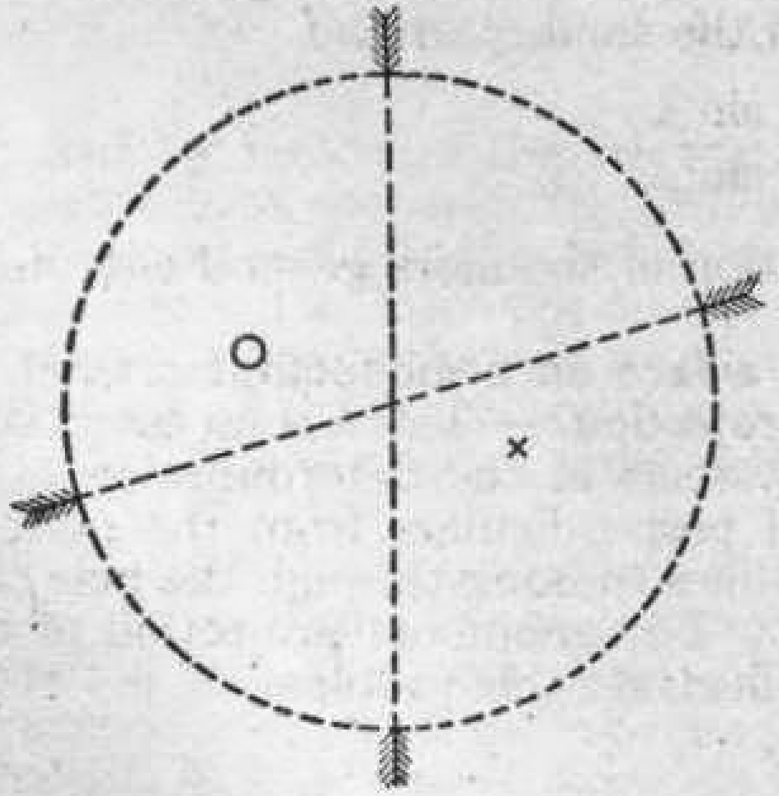
TRICLINIC SYSTEM

NORMAL CLASS - FORMS

i. Macropinacoid or a-pinacoid..... (100)
ii. Brachypinacoid or b-pinacoid.... (010)
iii. Base or c-pinacoid ....(001)
iv. Prisms ....(hk0), (h-k0)
v. Macrodomes ....(h0l), (-h0l)
vi. Brachydomes ....(0kl), (0-kl)
vii. Pyramids.(hkl), (-hkl), (-h-kl), (h-kl).

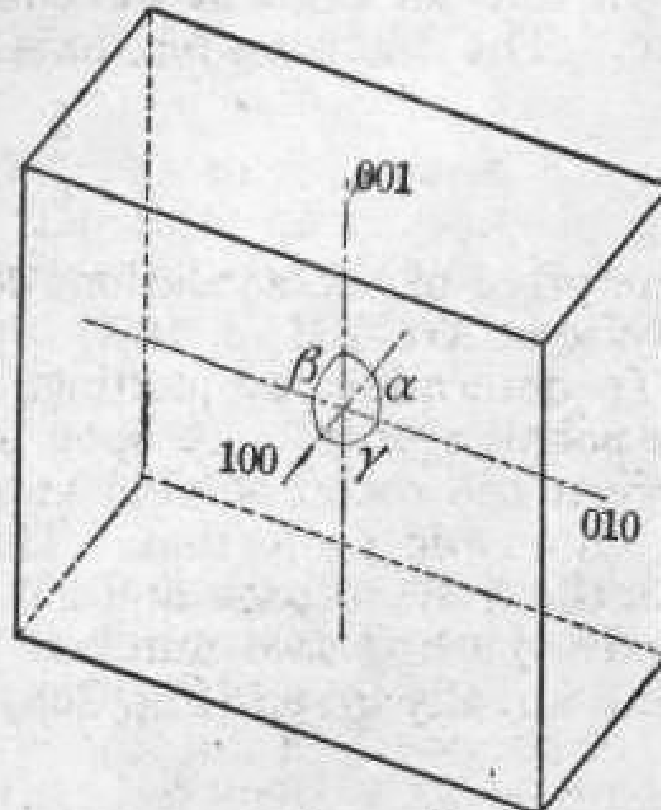
The crystals of Triclinic system has Center of Symmetry only.

378



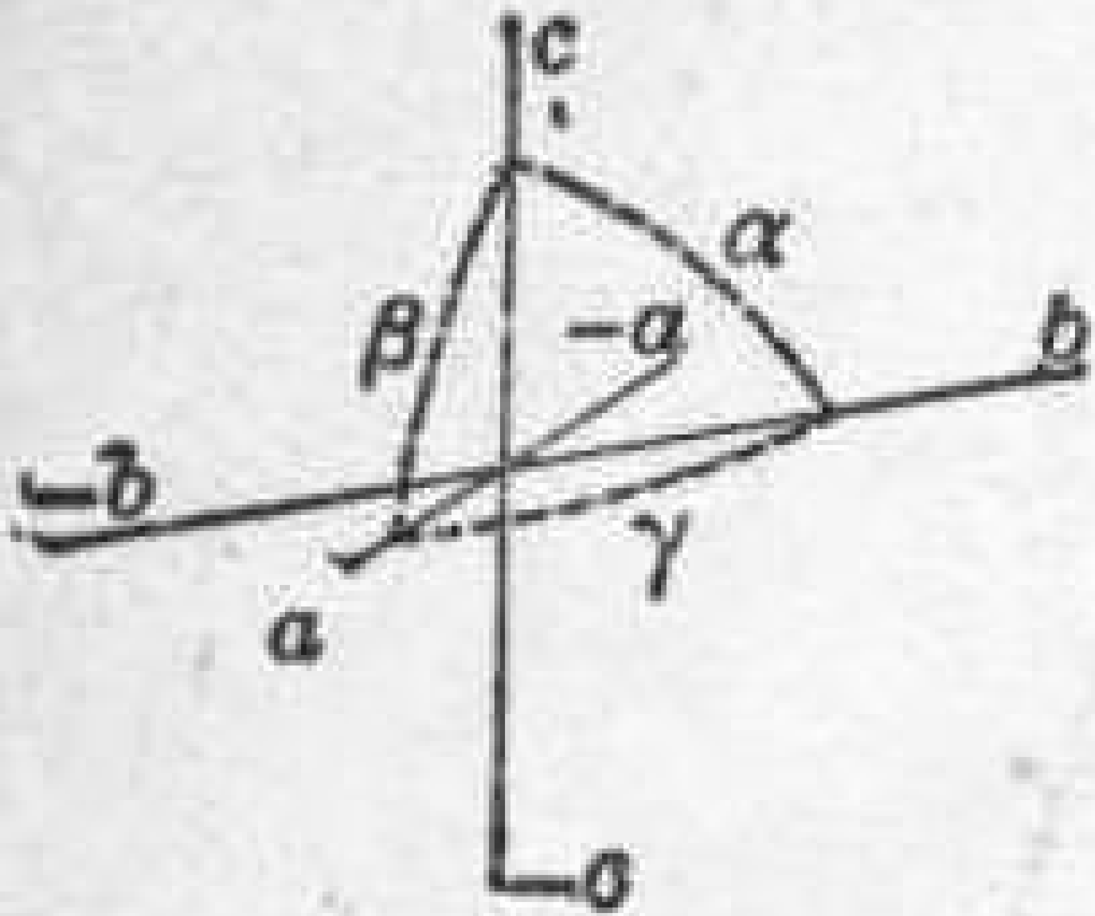
Symmetry of Normal Class

379



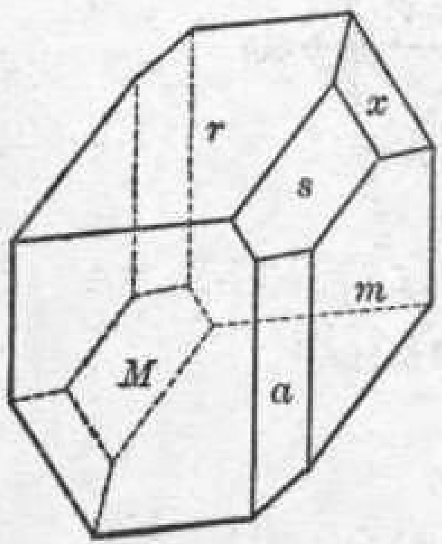
Triclinic Pinacoids

377



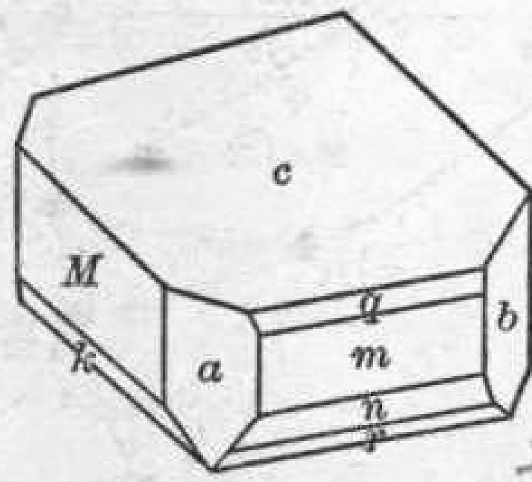
Triclinic Axes

380

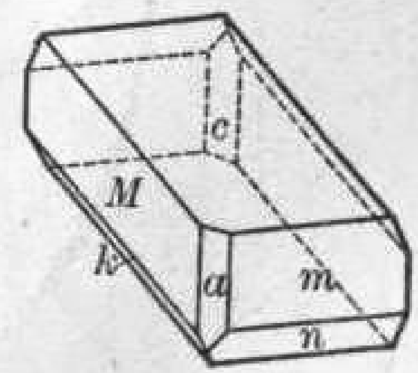


Axinite

381

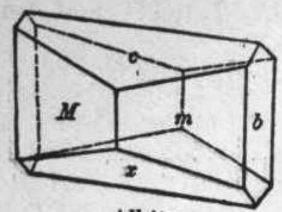


382



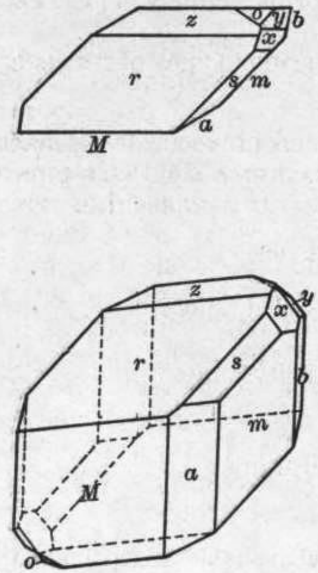
Rhodonite

383

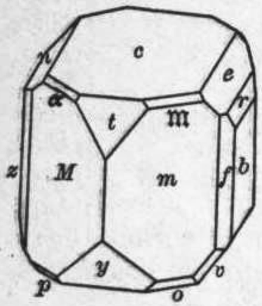


Albite

385



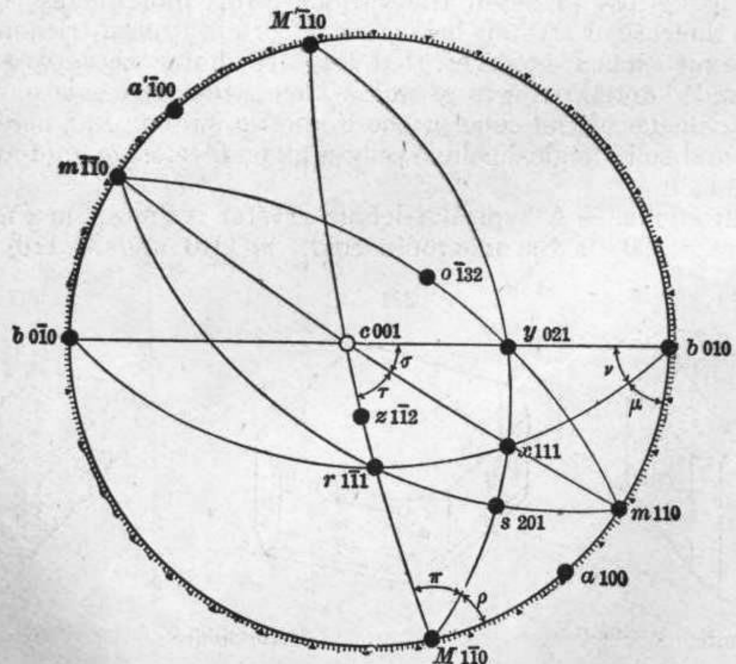
384



Anorthite

Axinite

386



Stereographic Projection of an Axinite Crystal

Crystal Classes in TETRAGONAL 2 System

A. Normal Class

B. . Hemimorphic Class or Iodosuccinimide type

C. Tripyramidal Class or Scheelite type

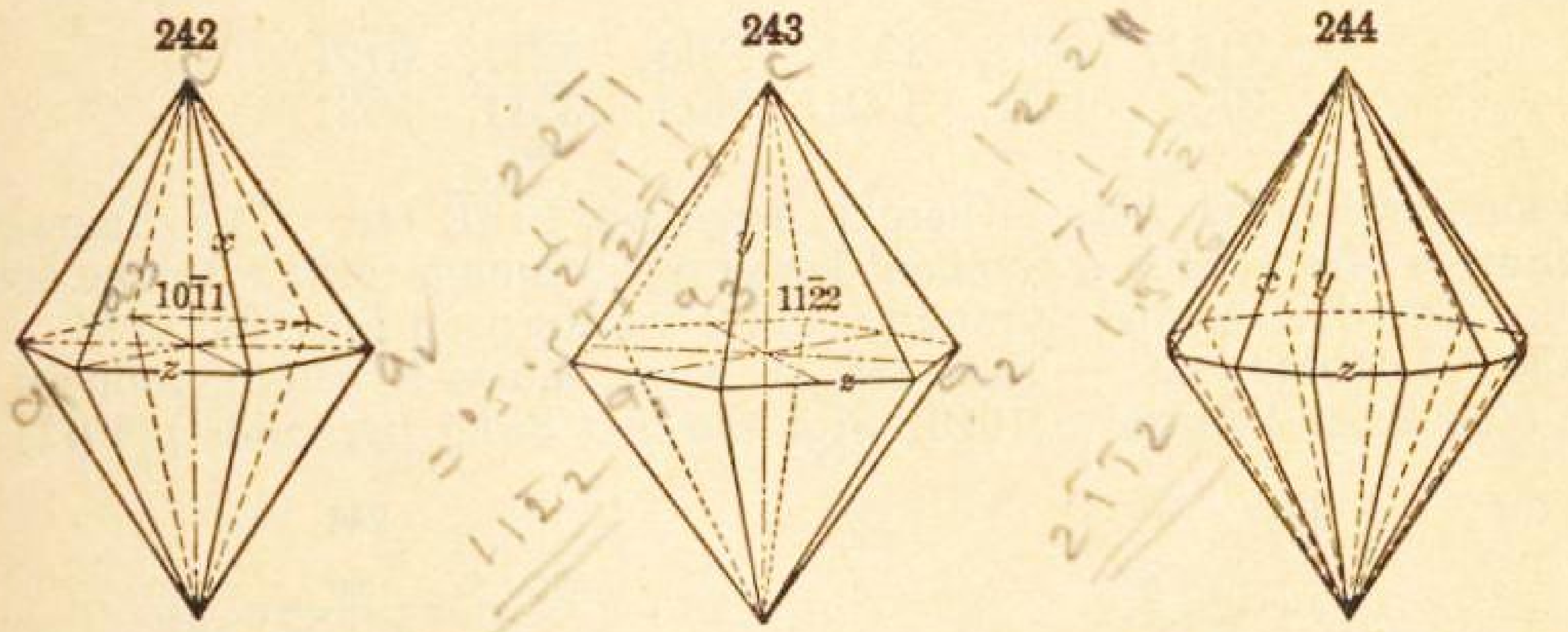
D. Plagiohedral Class – Cuprite type

E. Tetartohedral Class – Ullmannite type

TETRAGONAL SYSTEM

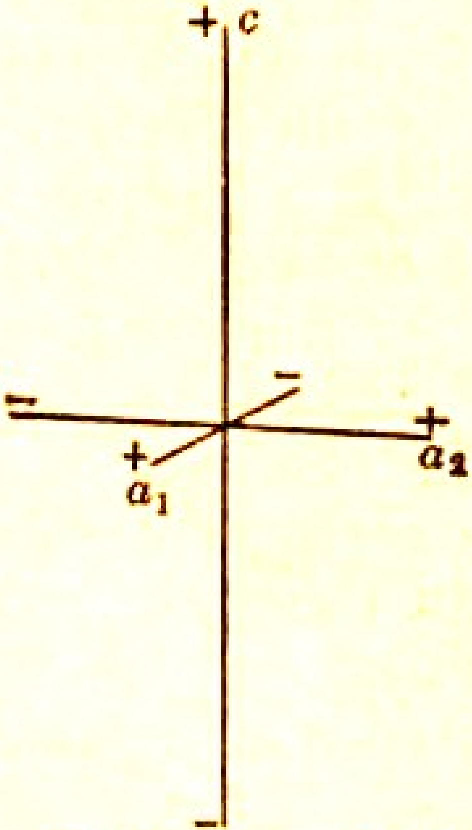
1. Normal class
   i. Base or Basal Pinacoid (001)
   ii. Prism of the 1st order (110)
   iii. Prism of the 2nd order (100)
   iv. Ditetragonal Prism (hkl) as 310, 210, 320, …
   v. Pyramid of the 1st Order (hhl) as 223, 111, 221, …
   vi. Pyramid of the 2nd Order (h0l) as 203, 101, 201, …
   vii. Ditetragonal Pyramid (hkl) as 421, 321, 122, …

Symmetry: Vert. Ax.-4; 4 Hor.Ax.-2; Hor. P.; 4 Vert. P.; C.



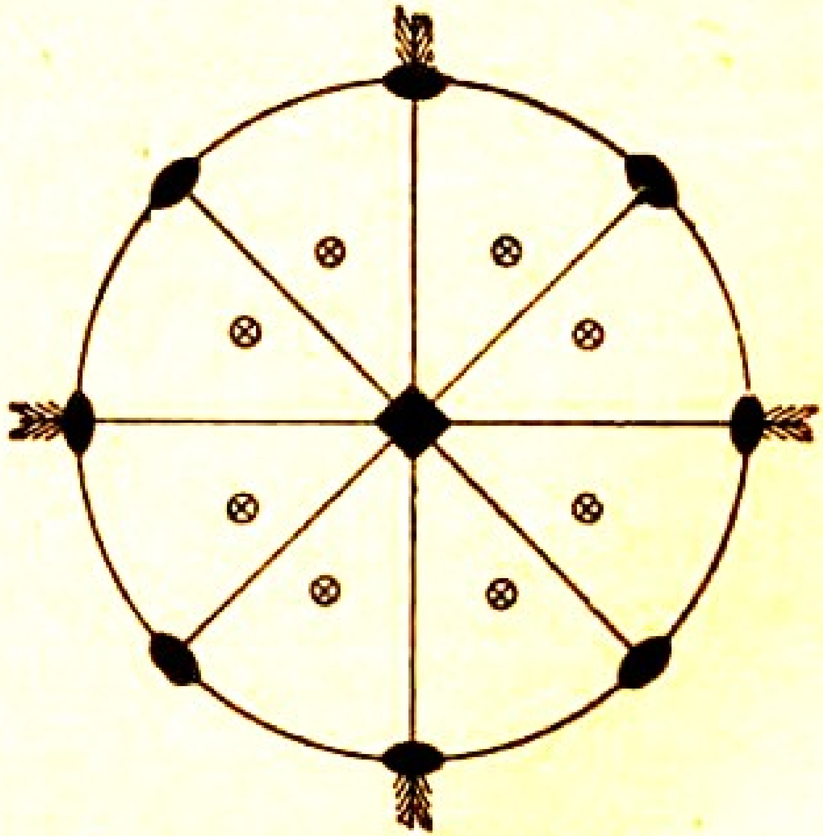
First Order Pyramid | Second Order Pyramid | Dihexagonal Pyramid

184



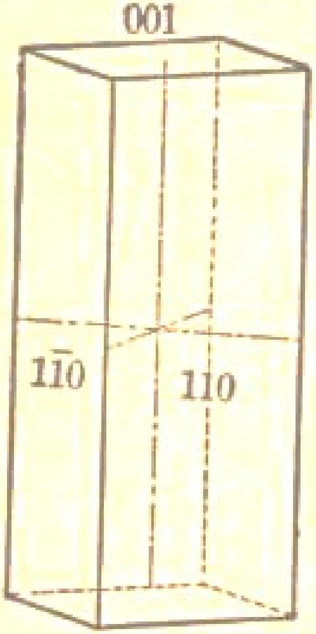
Axes of Tetragonal Mineral,
Octahedrite $a : c = 1 : 1.78$

185



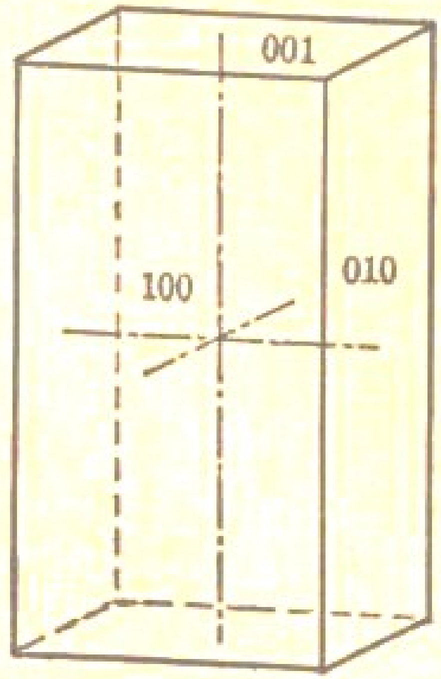
Symmetry of Normal Class
Tetragonal System

188



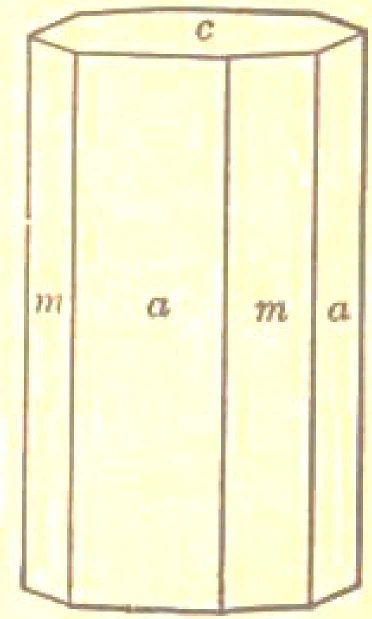
First Order Prism

189

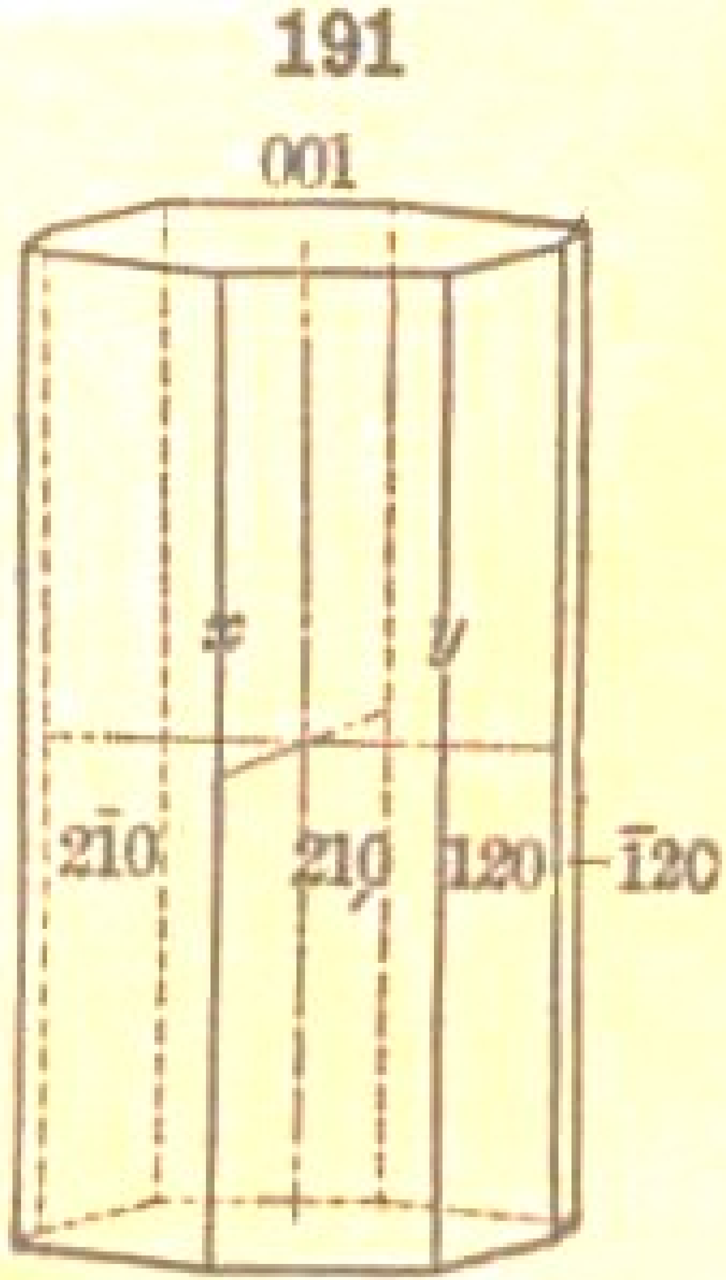


Second Order Prism

190

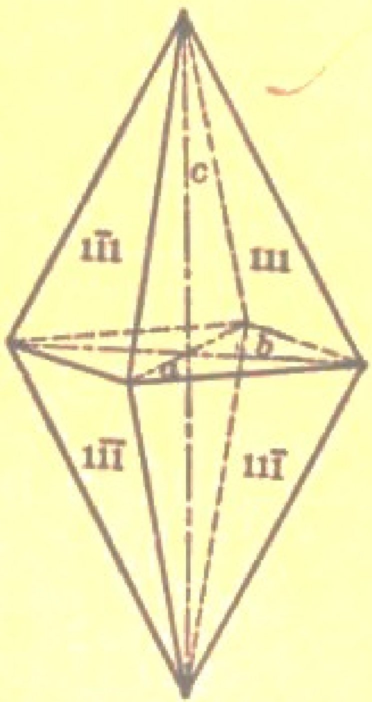


First and Second Order Prisms



Ditetragonal Prism

192

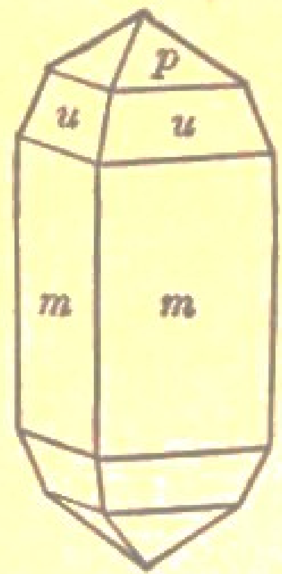


First Order Pyramid

193

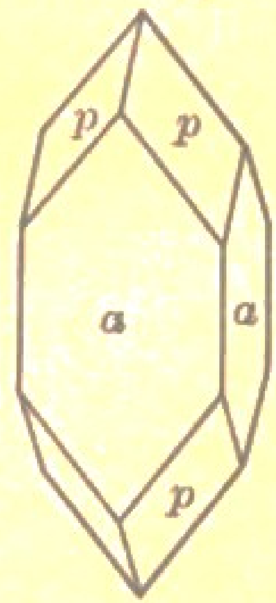
Zircon, First Order Prism and Pyramid

194



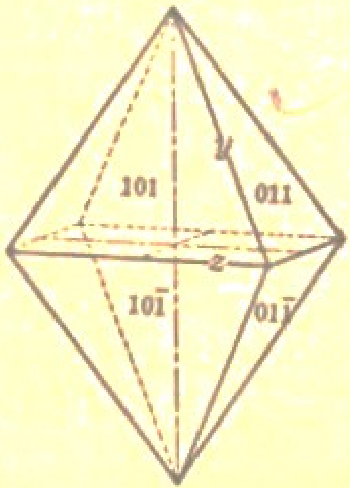
Zircon, First Order Prism and Pyramids

195



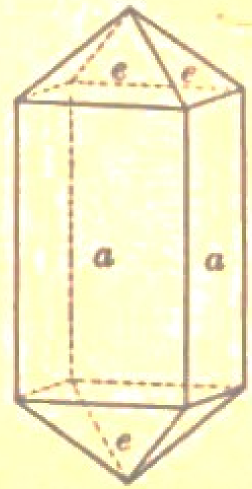
Apophyllite, Second Order Prism and First Order Pyramid

196



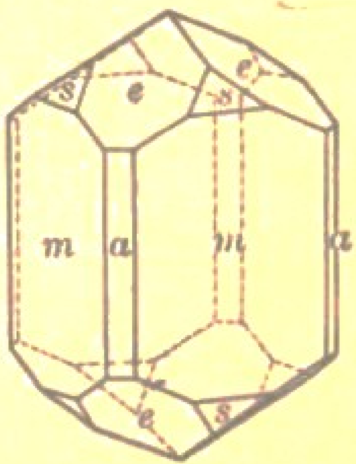
Second Order Pyramid

197



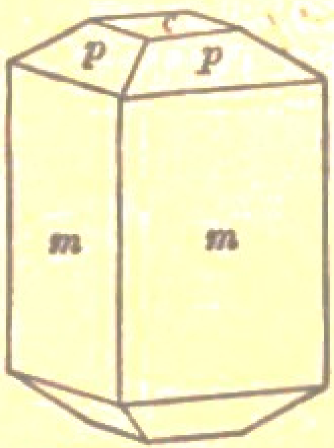
Second Order Prism and Pyramid

198



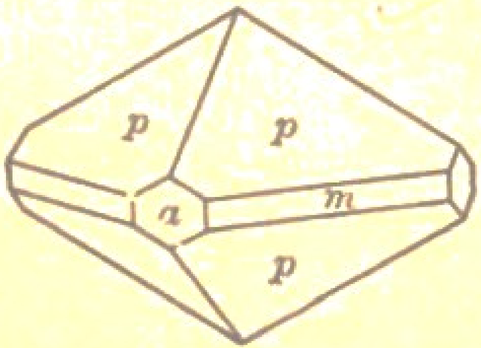
Rutile, First and Second Order Prisms and Pyramids

199



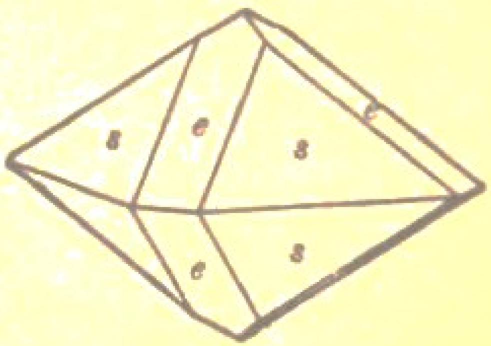
Vesuvianite First Order Prism, Pyramid and Base

200



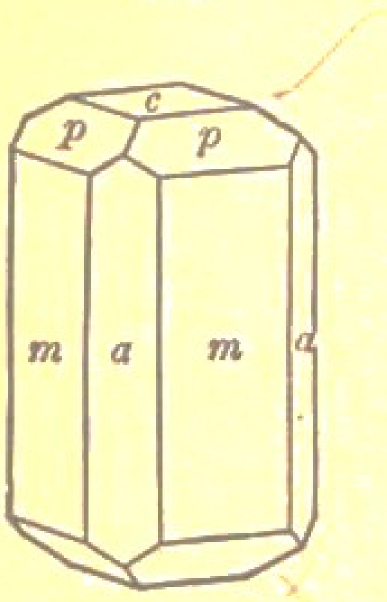
Vesuvianite First Order Pyramid and First and Second Order Prisms

201



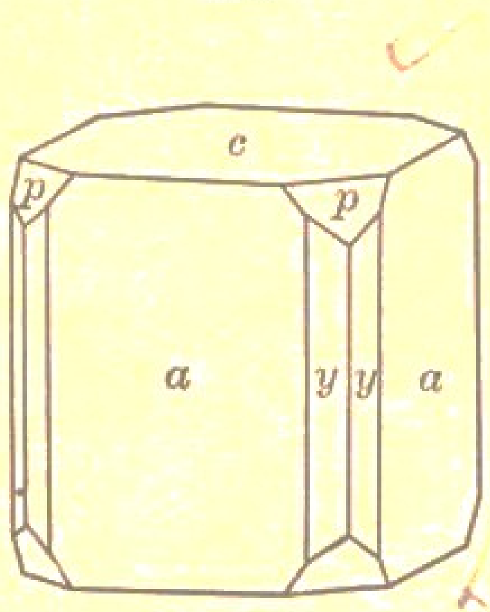
Cassiterite First and Second Order Pyramids

202



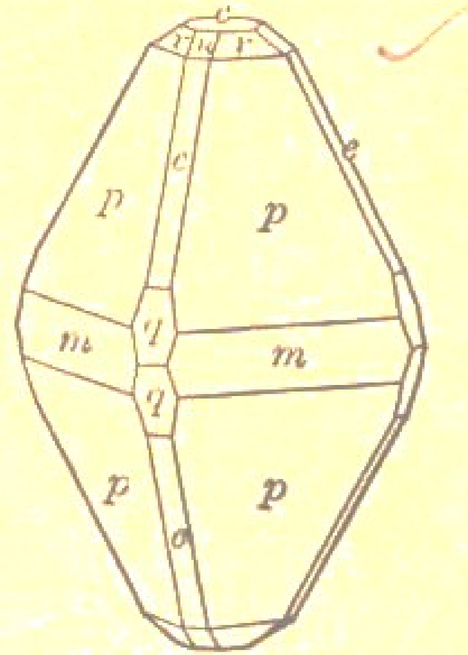
Vesuvianite
First and Second Order Prisms, First Order Pyramid and Base

203



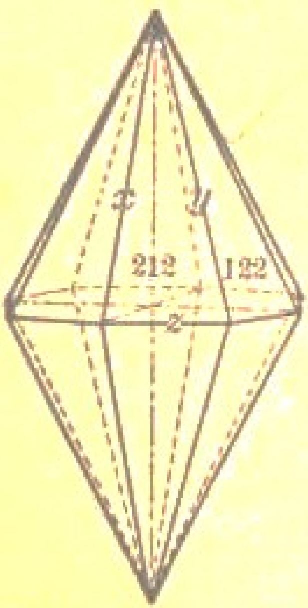
Apophyllite
Second Order Prism, Ditetragonal Prism, First Order Pyramid and Base

204



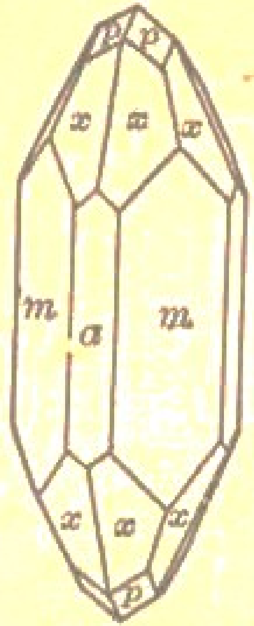
Octahedrite
Two First Order Pyramids, First Order Prism, Three Second Order Pyramids and Base

205



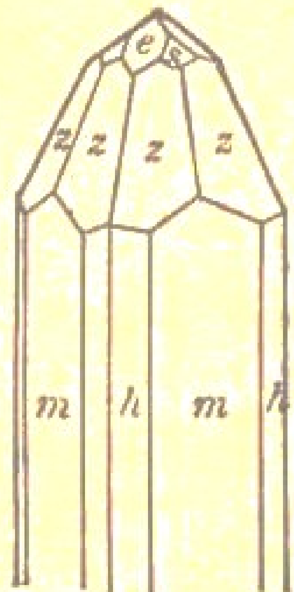
Ditetragonal Pyramid

206



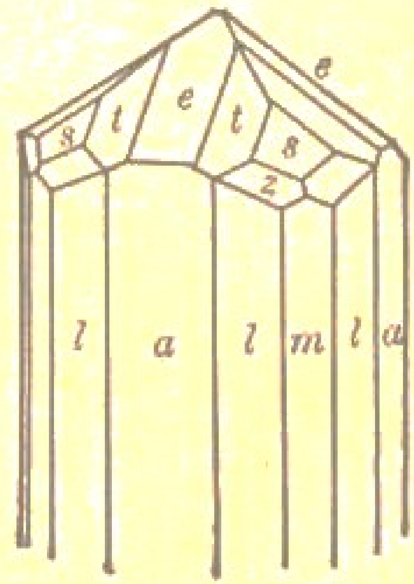
Zircon
First and Second Order Prisms, First Order Pyramid, Ditetragonal Pyramid

207



Cassiterite

208



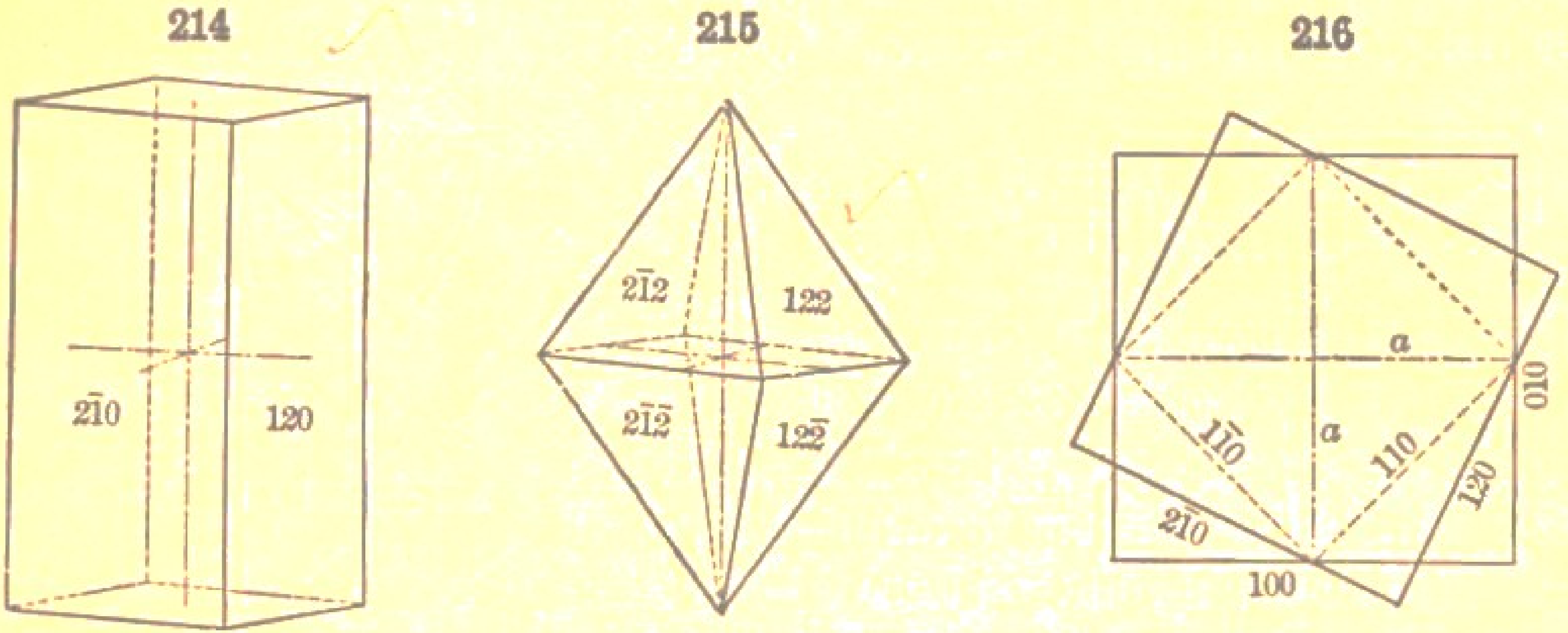
Rutile

2. Hemimorphic Class or Iodosuccinimide type

Symmetry: Vert. Ax.-4; 4 Vert. P.
Forms : Six distinct pyramidal forms, corresponding to the upper and lower halves of the 1st and 2nd order pyramids and the ditetragonal pyramid.

3. Tripyramidal Class or Scheelite type

Symmetry: Vert. Ax.-4; Hor. P.; C.

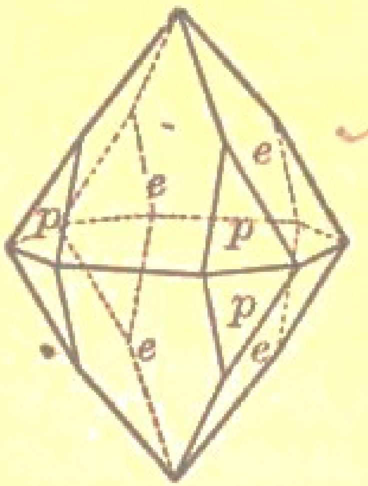


Third Order Prism

Third Order Pyramid

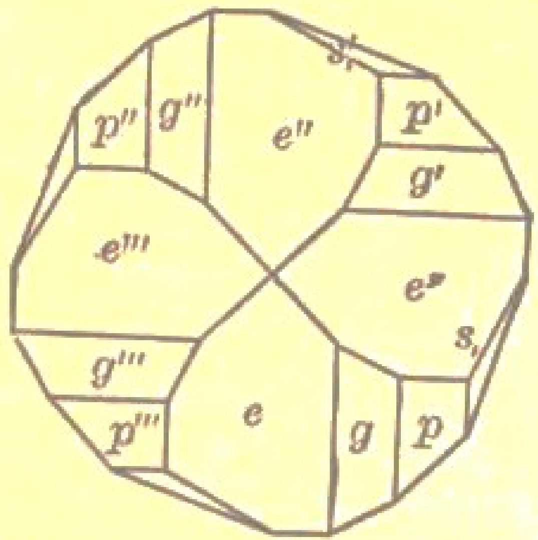
Forms: Prism of the 3rd order; Base (001); square prisms a(100); m(110) and square pyramids h0l & hhl.

217



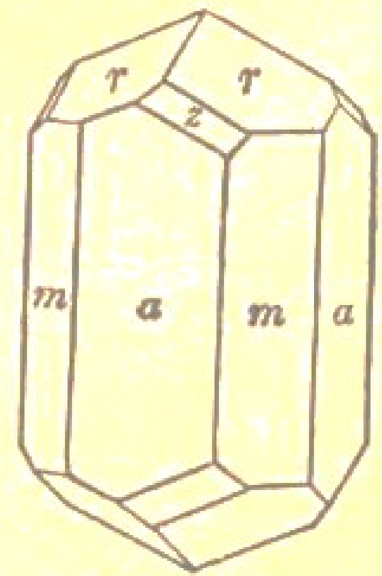
Scheelite

218

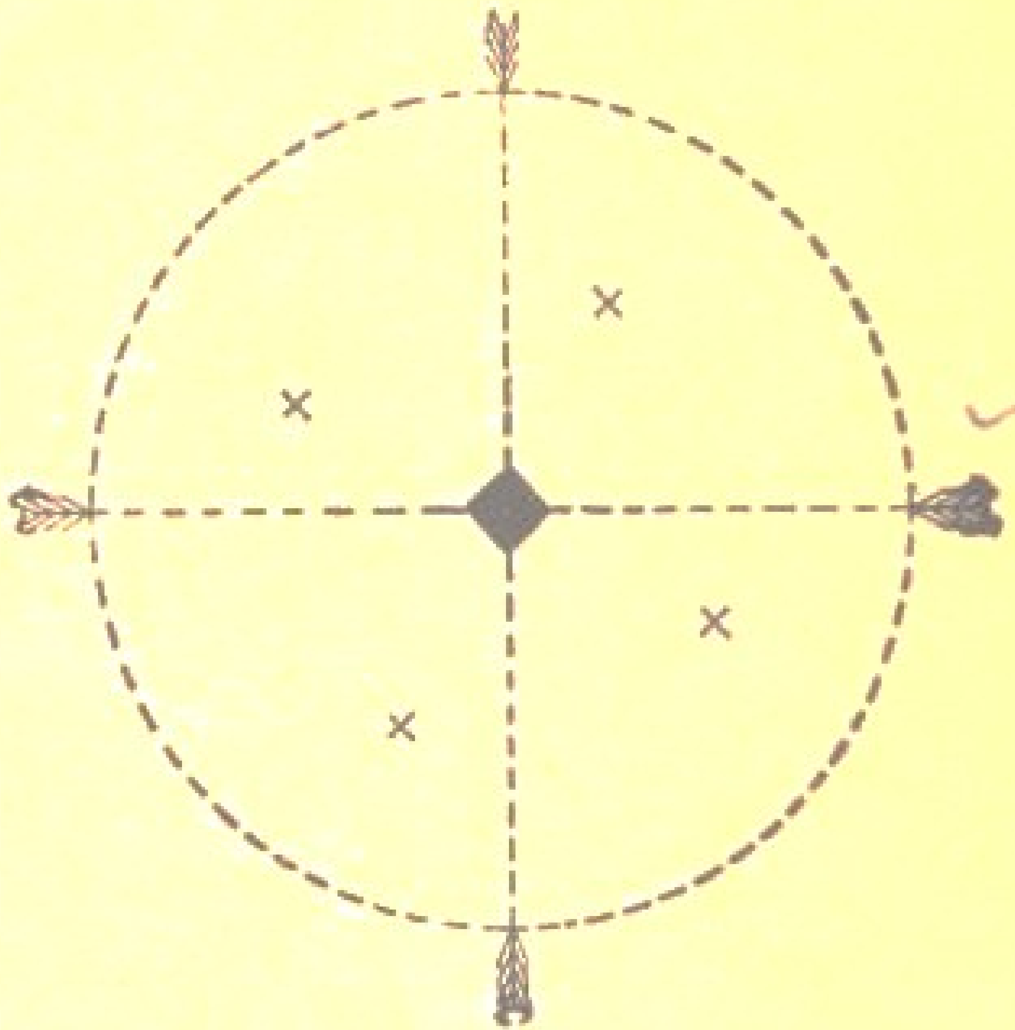


Scheelite

219

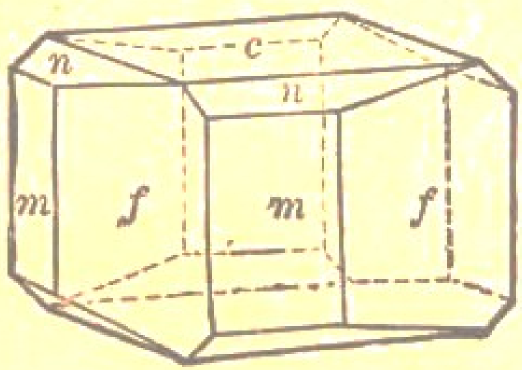


Meionite

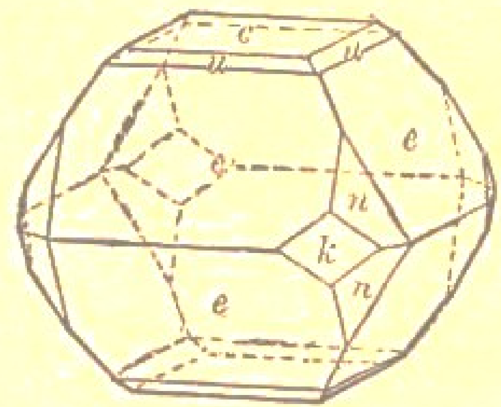


Symmetry of Pyramidal-Hemimorphic Class

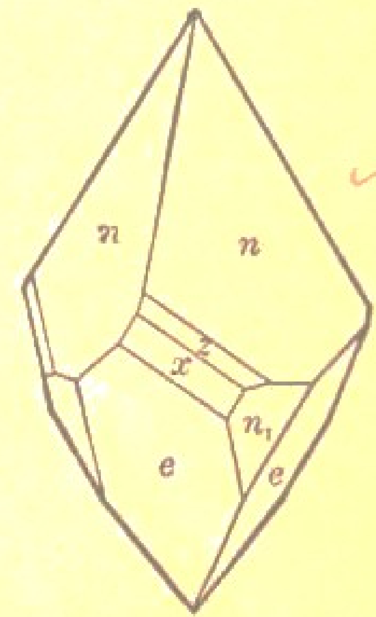
221



222



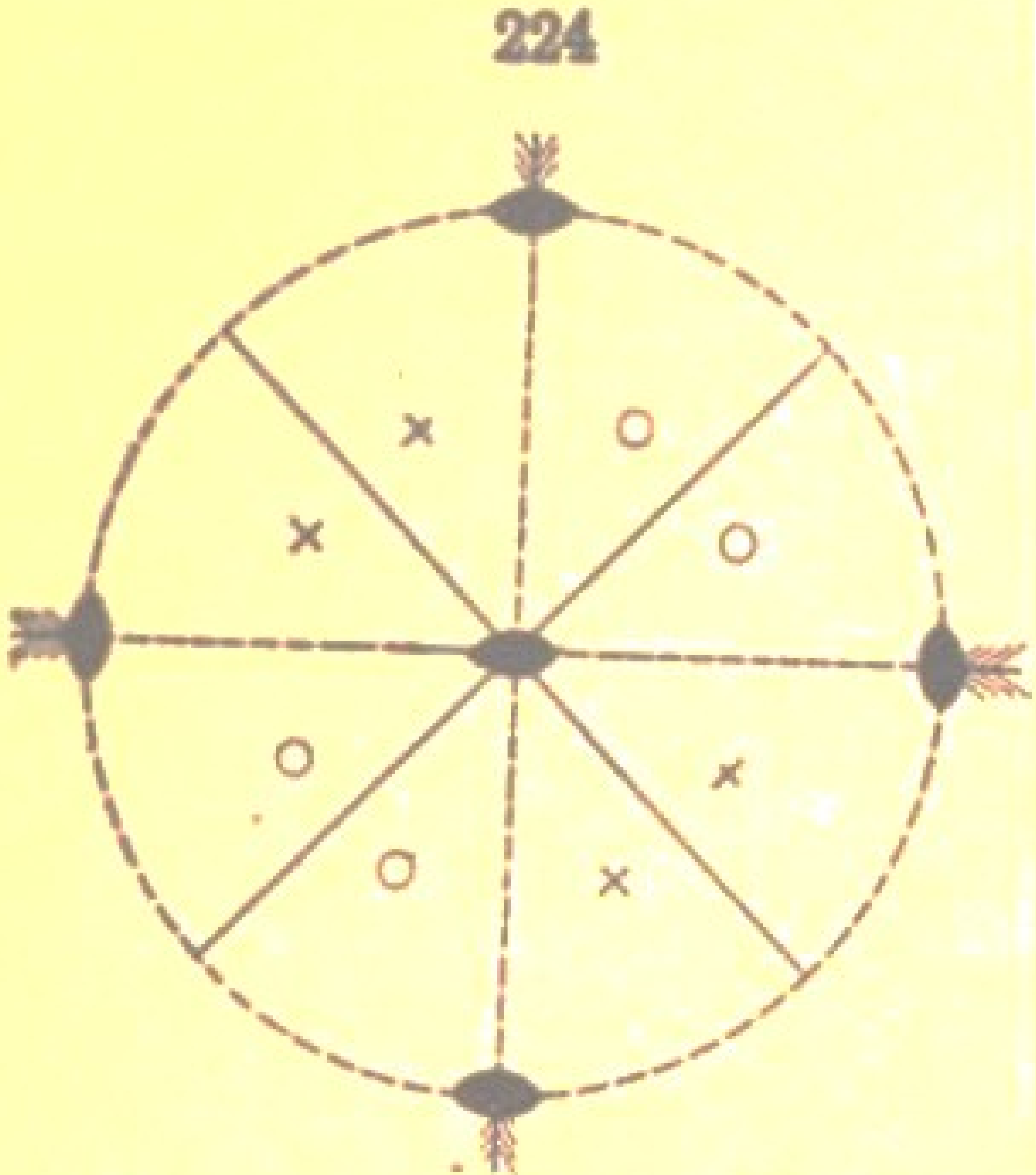
223



Wulfenite

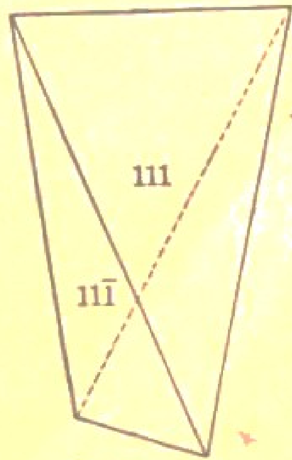
5. SPHENOIDAL CLASS (10). CHALCOPYRITE TYPE

(Tetragonal Sphenoidal, Sphenoidal Hemihedral, Didigonal Scalenohedral, or Ditetragonal Alternating Class)



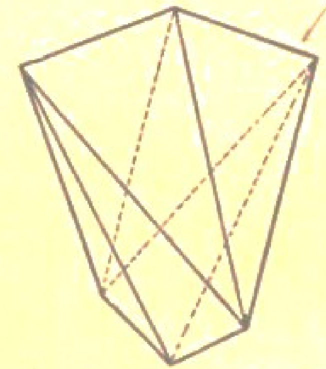
Symmetry of Spnenoida. Class

225



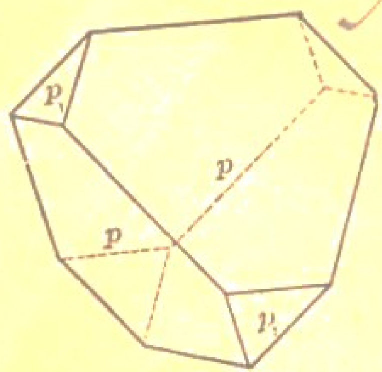
Sphenoid

226

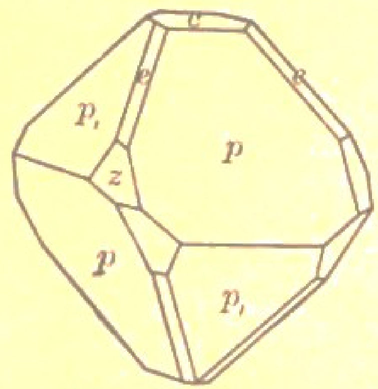


Tetragonal Scalenohedron

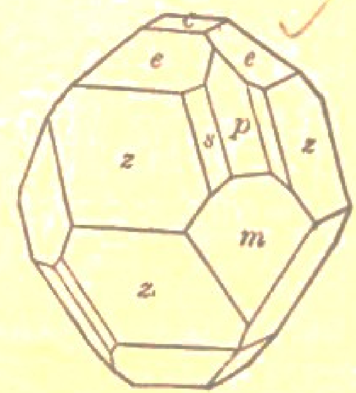
227



228



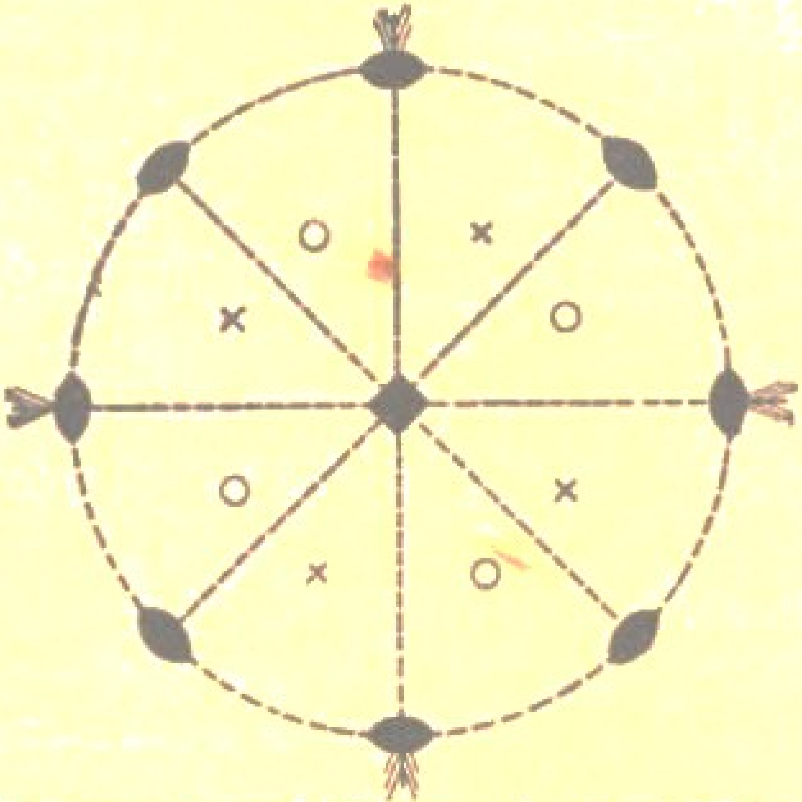
229



Chalcopyrite

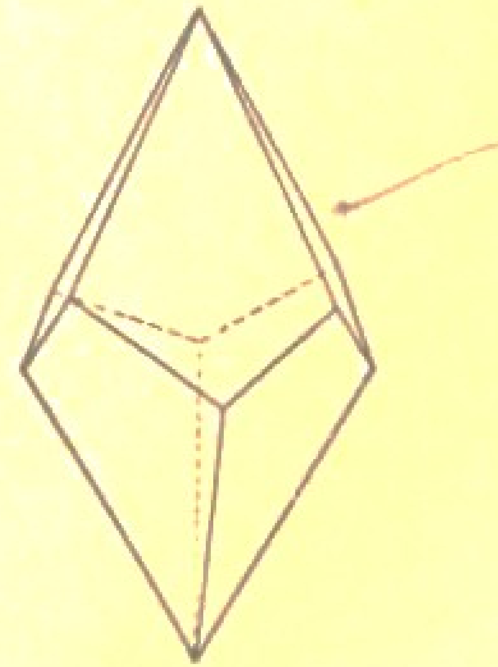
In the species chalcopyrite, which belongs to this class, the deviation in angle and in axial ratio from the isometric system is very small, and hence the unit sphenoid cannot by the eye be distinguished from a tetrahedron (compare Fig. 227 with Fig. 162, p. 84). For this species $c = 0{\cdot}985$ (instead of 1, as in the isometric system), and the normal sphenoidal angle is $108° 40'$, instead of $109° 28'$, the angle of the tetrahedron. Hence a crystal of chal-

230

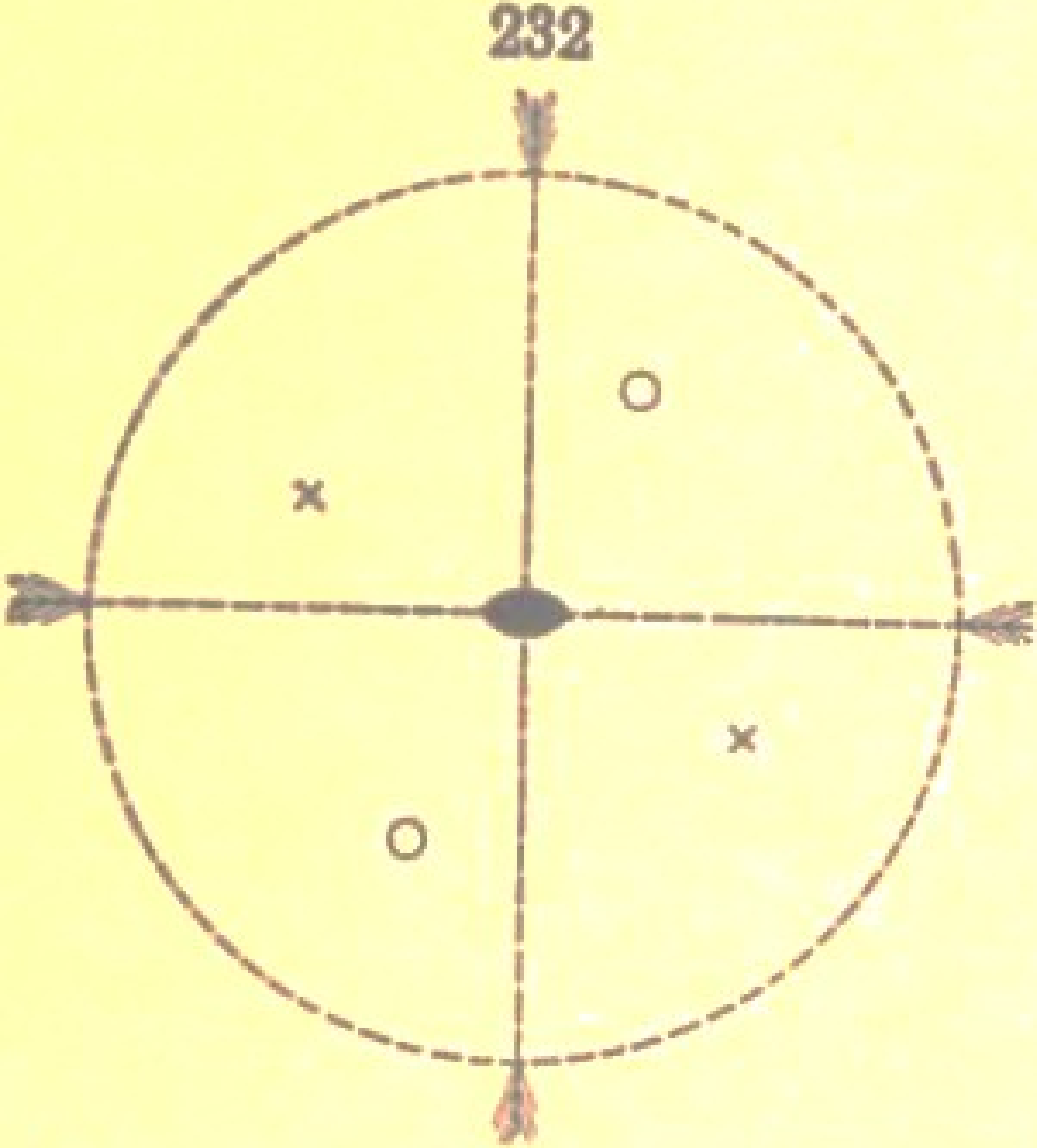


Symmetry of Trapezohedral Class

231



Tetragonal Trapezohedron



Symmetry of Tetartohedral Class

HEXAGONAL SYSTEM

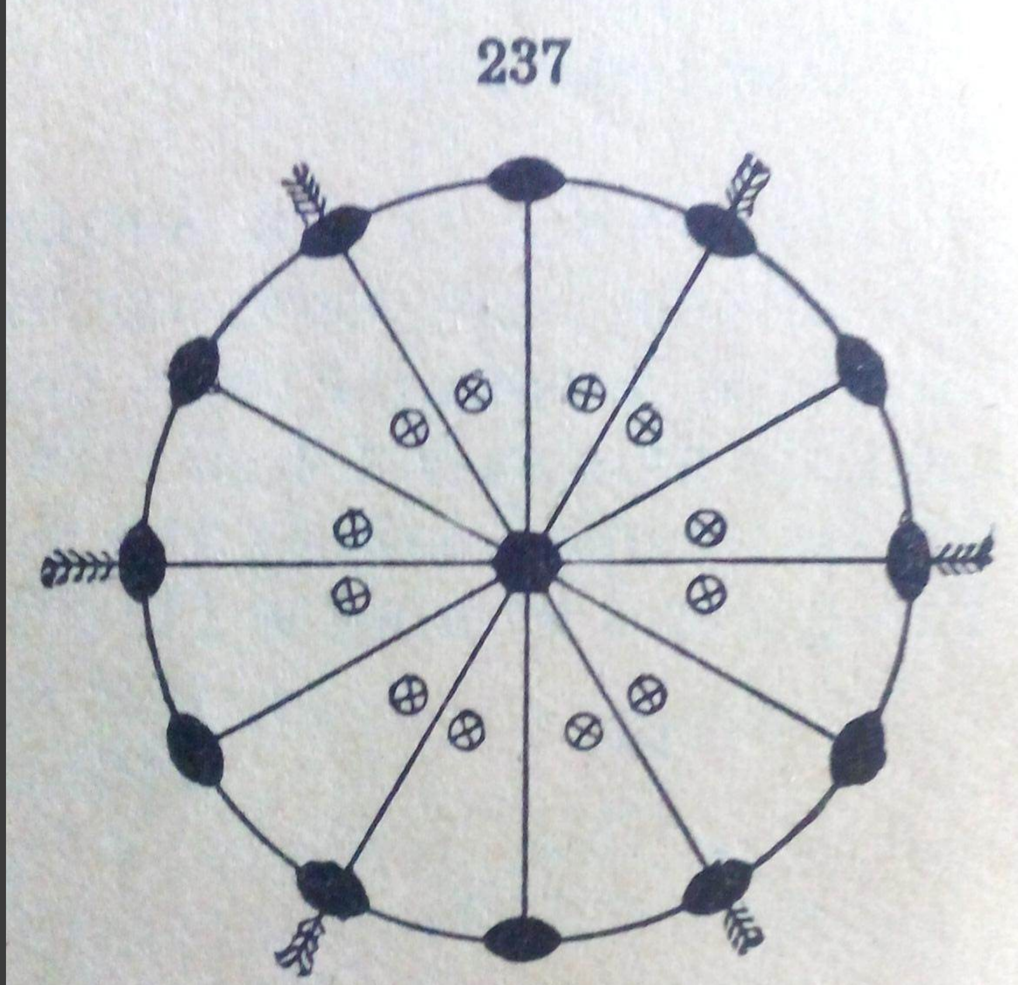
Crystal Classes & Forms in Hexagonal system

1. **Normal class / Beryl type**
   1. Base (0001)
   2. Prism of the 1st order $(10\bar{1}0)$
   3. Prism of the 2nd order $(10\bar{2}0)$
   4. Dihexagonal Prism $(hk\bar{i}0)$ as $21\bar{3}0$ …
   5. Pyramid of the 1st Order $(h0\bar{h}l)$ as 223, 111, 221, …
   6. Pyramid of the 2nd t Order $(hh2\bar{h}l)$ as $11\bar{2}2$, …
   7. Dihexagonal Pyramid $(hk\bar{i}l)$ as $21\bar{3}1$, …

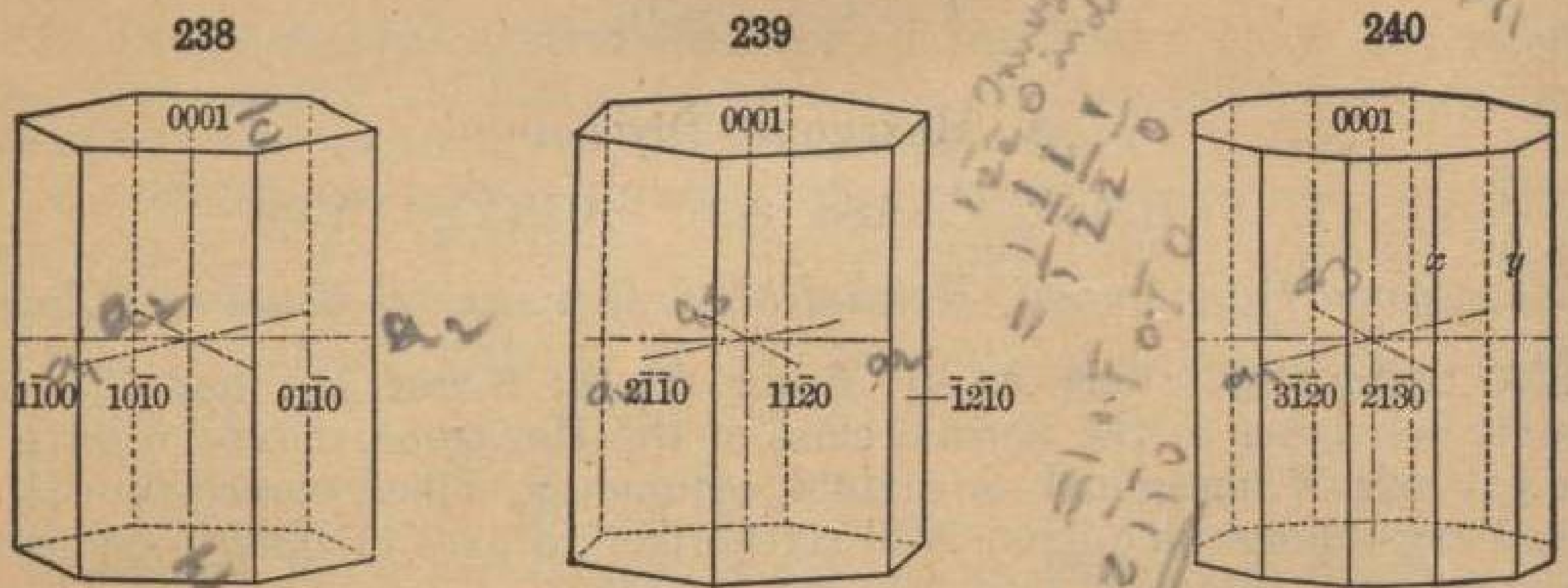
   In the above h>k, and h+k = -*i*.

Symmetry Elements of Hexagonal System:

Vert. Ax.-6;
6 Hor. Ax.-2;
6 Vert. P.;
Hor. P.;
C.



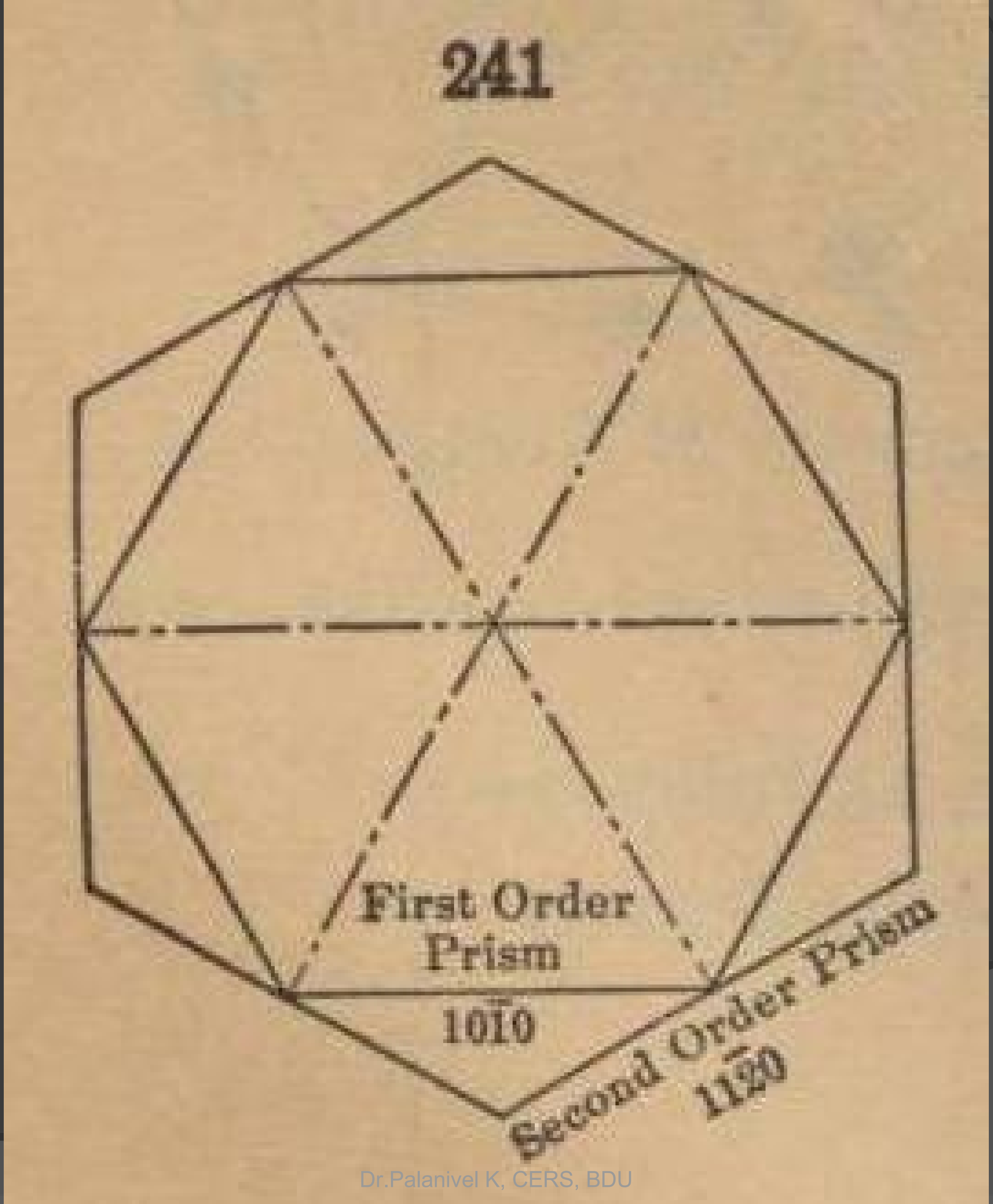
Symmetry of Normal Class



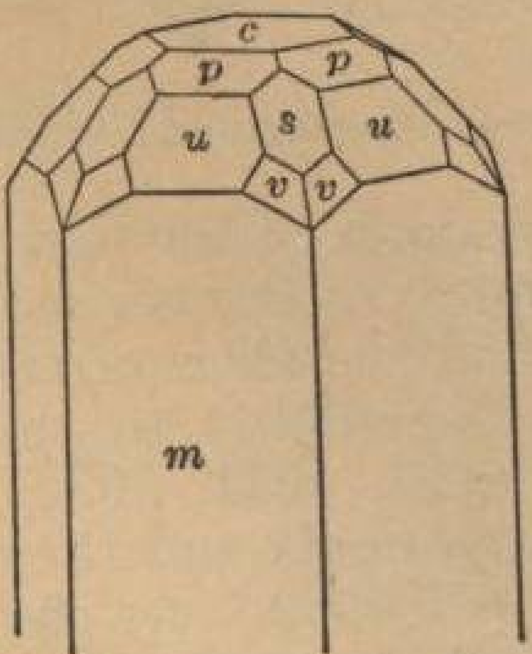
First Order Prism

Second Order Prism

Dihexagonal Prism

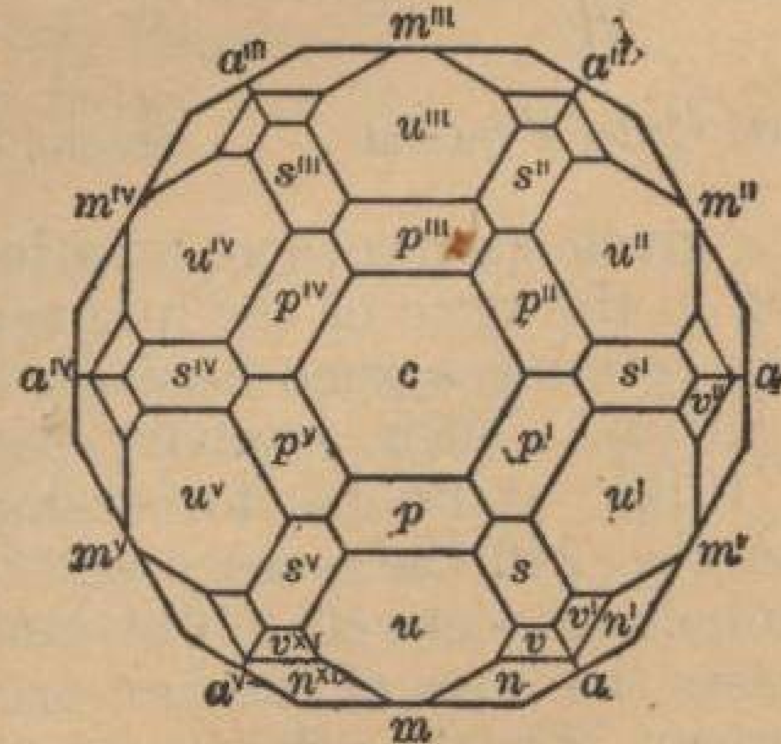

241
First Order
Prism
10$\bar{1}$0
Second Order Prism
11$\bar{2}$0

245



Beryl

246

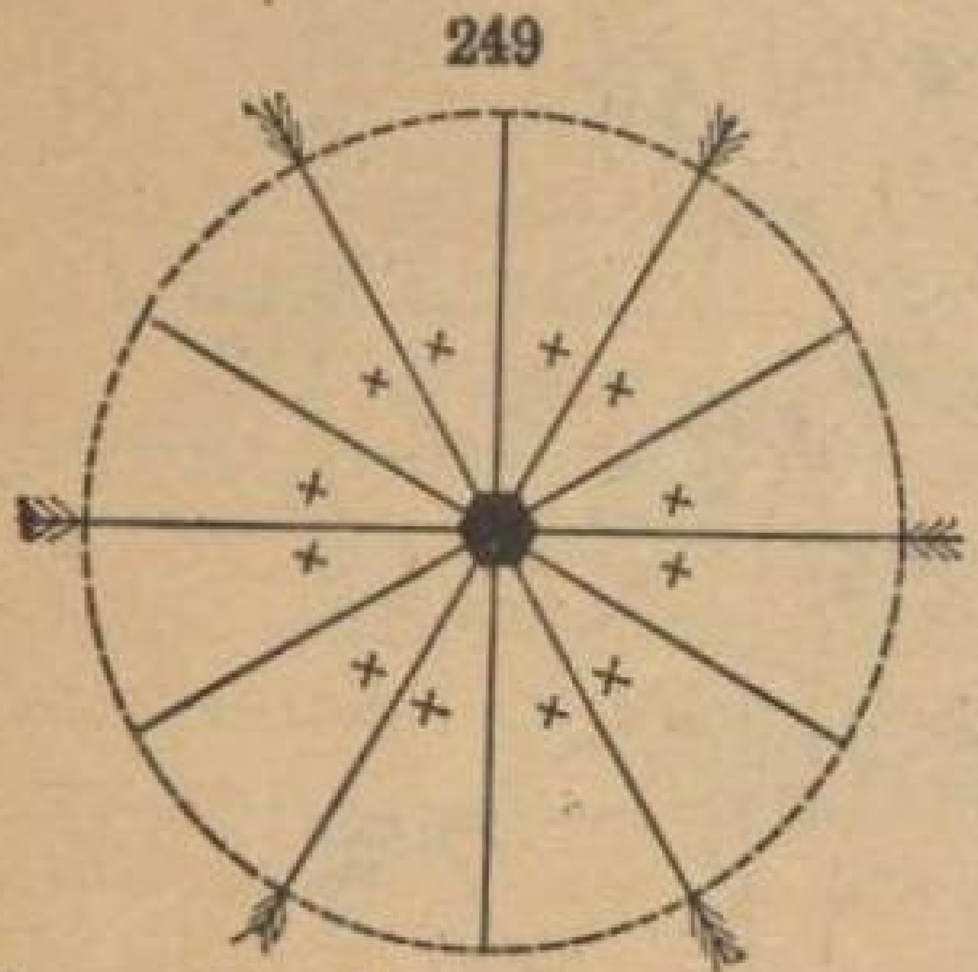


Beryl

2. Hemimorphic class / Zincite type

Symmetry Elements of Hemimorphic Class :

Vert. Ax. 6;
6 Vert. P.

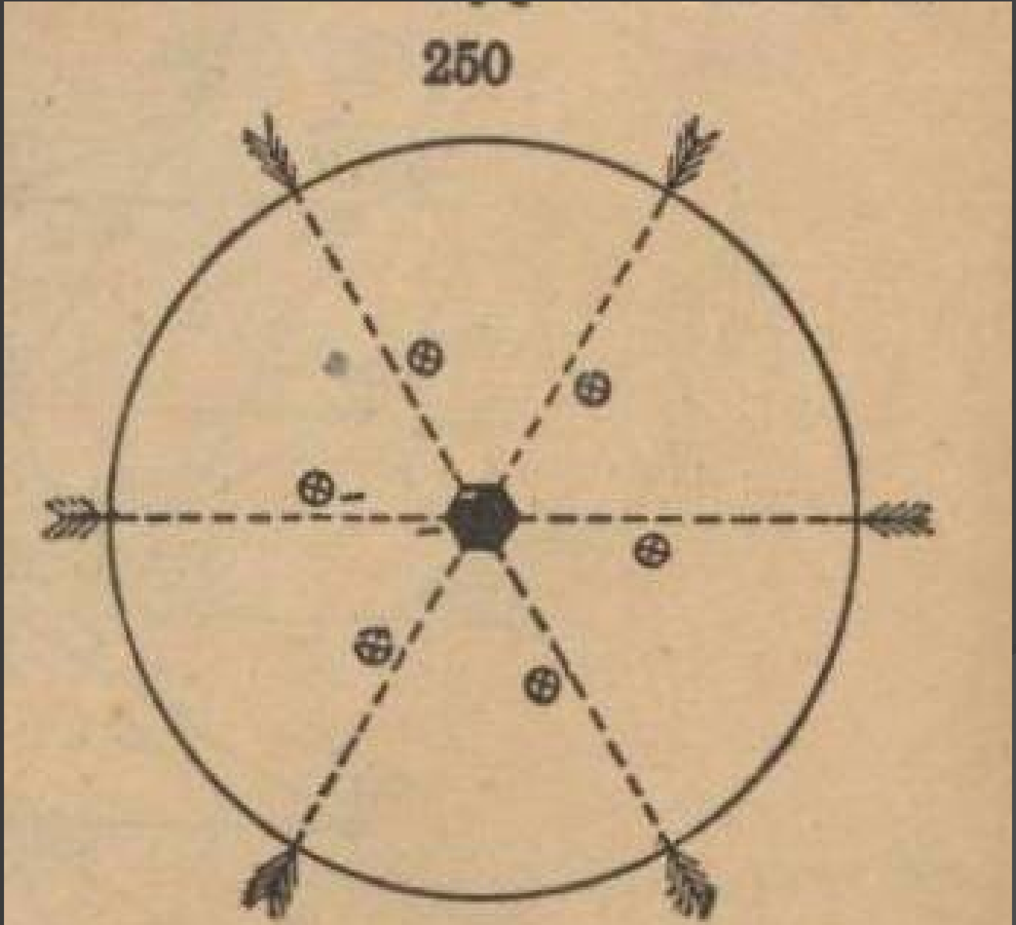


Symmetry of Hemimorphic Class

3. Tripyramidal class / Apatite type

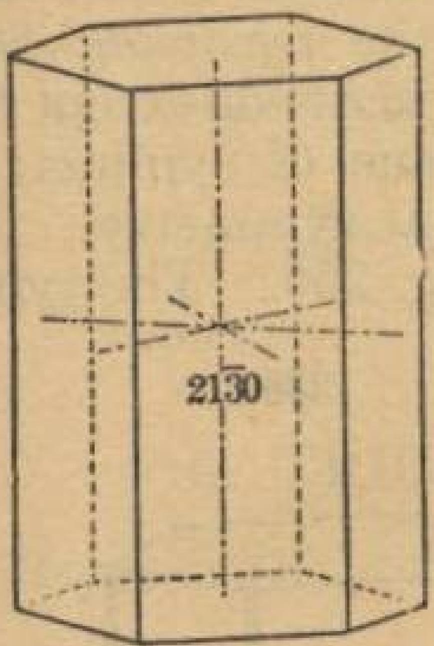
Symmetry Elements of Tripyramidal Class:

Vert. Ax. 6;
Hor. P
C.



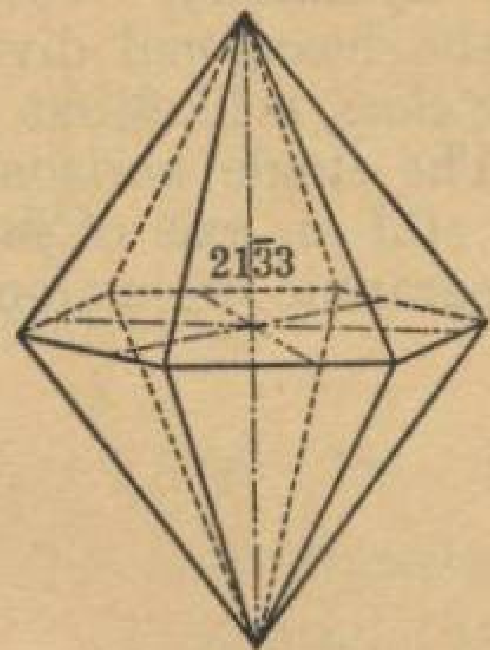
Symmetry of Tripyramidal Class

251



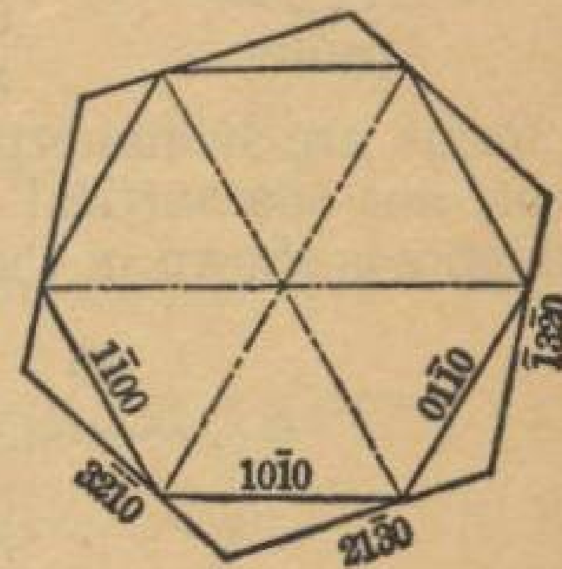
Third Order Prism

252



Third Order Pyramid

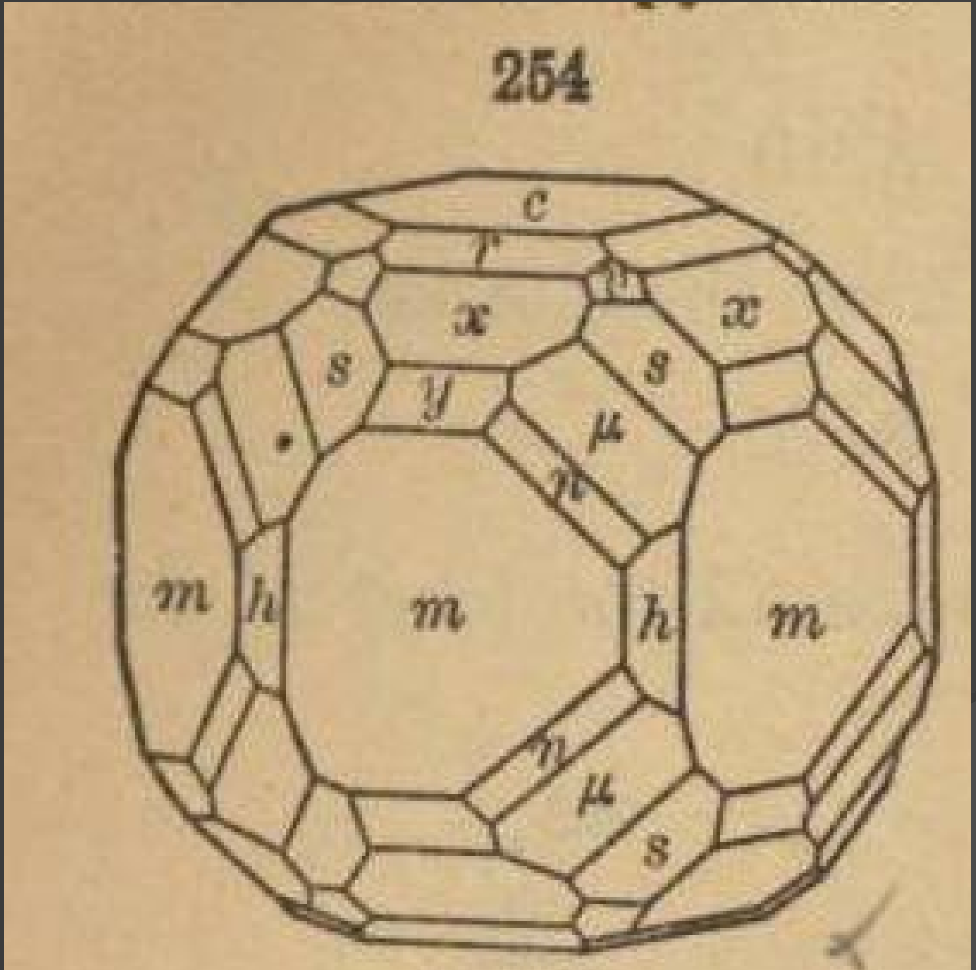
253



4. Pyramidal –Hemimorphic class / Nephelite type

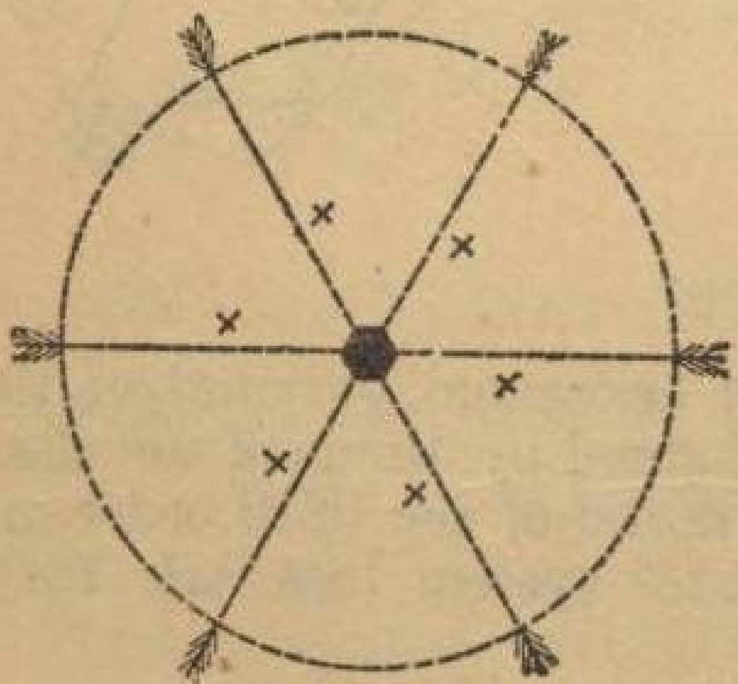
Symmetry Elements of Tripyramidal Class:

Vert. Ax. 6;



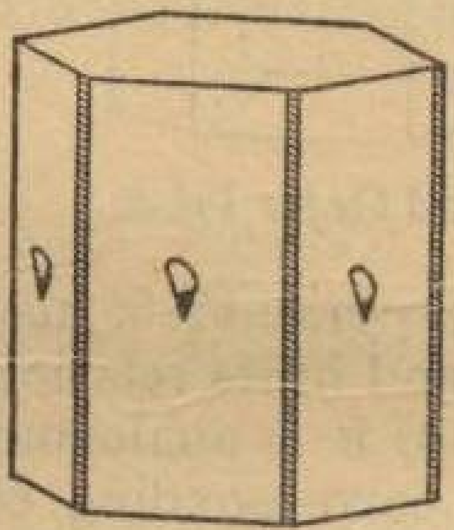
Apatite

255



Symmetry of Pyramidal-Hemimorphic Class

256



Nephelite

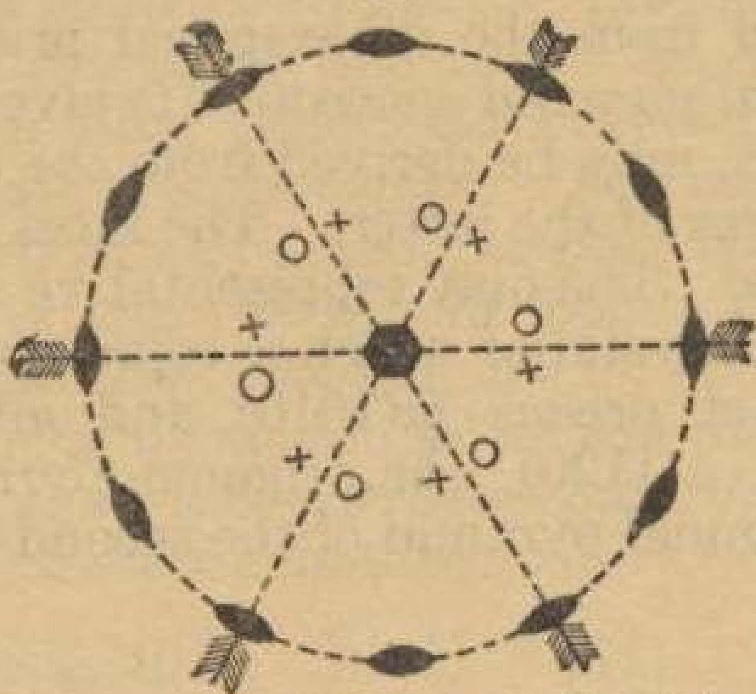
Etch Figure, in Nephelite

5. Trapezohedral class / β-Quartz type

Symmetry Elements of Trapezohedral Class:

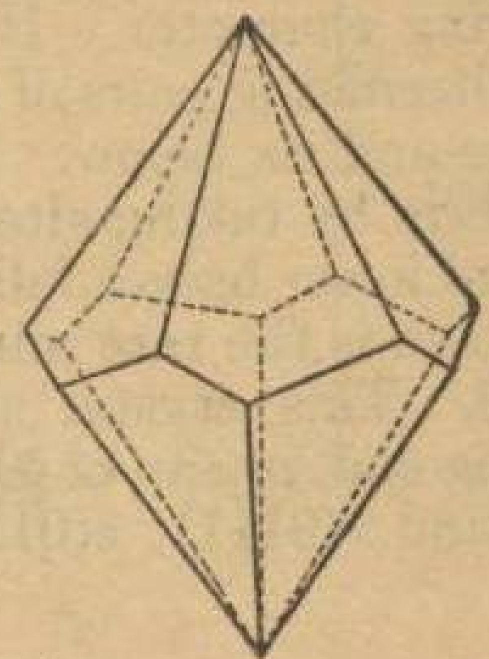
Vert. Ax. 6;
6 Hor. Ax. -2.

257



Symmetry of Trapezohedral Class

258



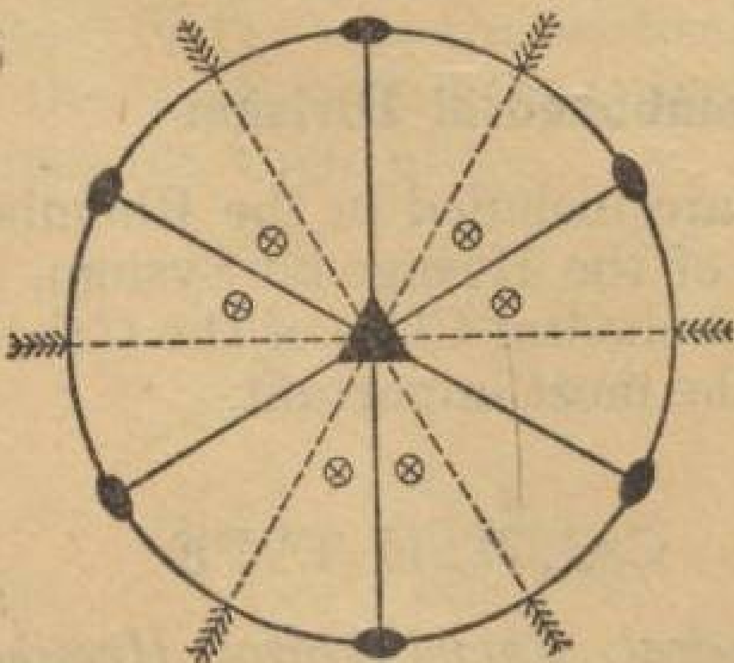
Hexagonal Trapezohedron

6. Trigonal class / Benitonite type

Symmetry Elements of Trigonal Class:

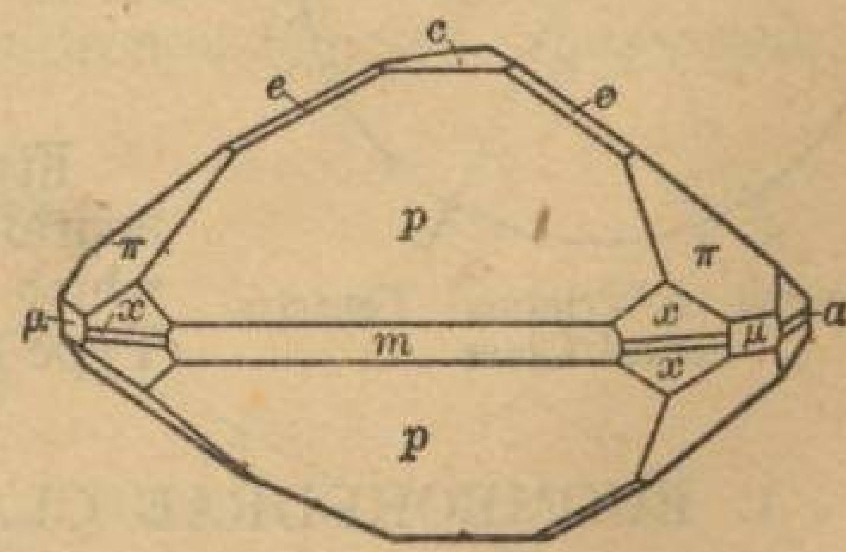
Vert. Ax. 3; 3 Hor. Ax. 2; 3 vert. P; Hor. P.

259



Symmetry of Trigonal Class

260

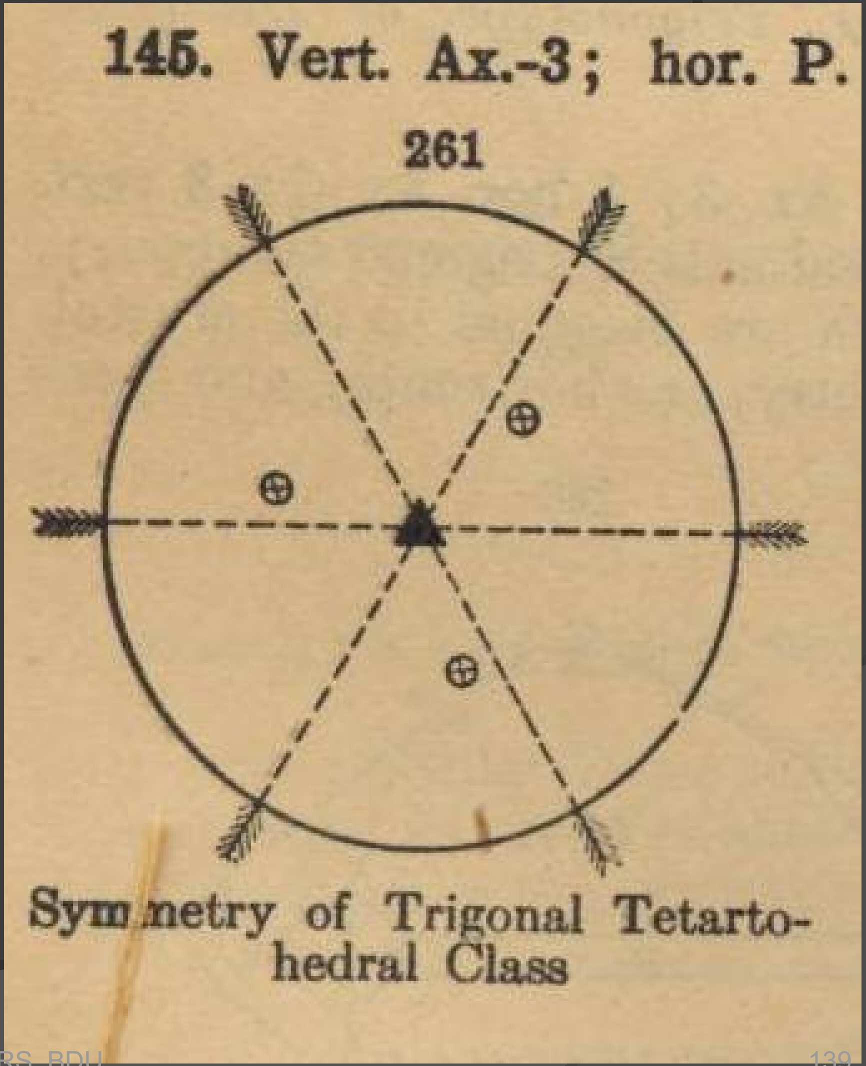


Benitoite (Palache)

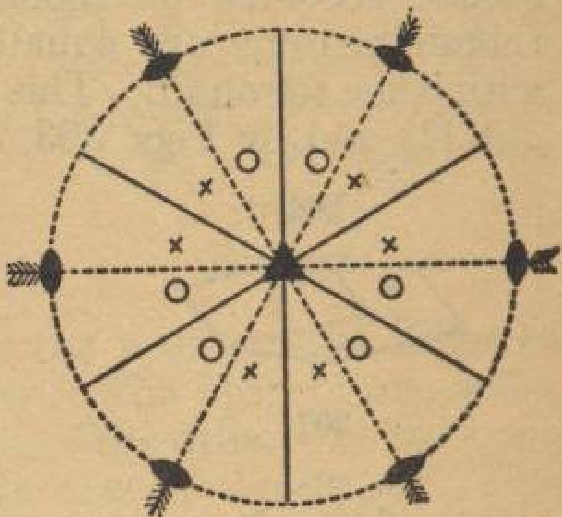
7. Trigonal Tetartohedral class / Disilverortho-phosphate type

Symmetry Elements of
Trigonal Tetartohedral Class:

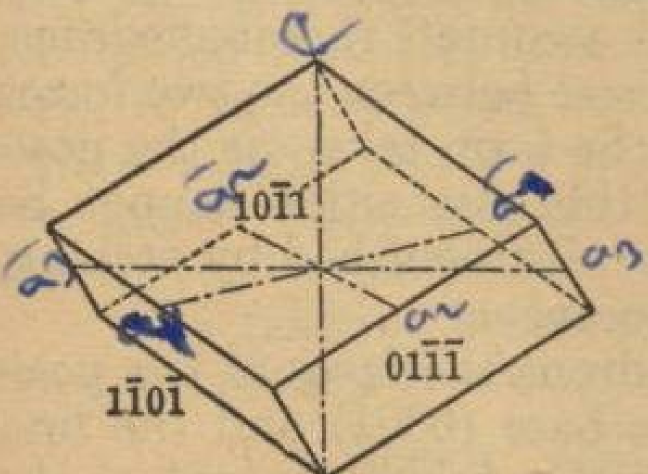
Vert. Ax. 3;
Hor. P.



262

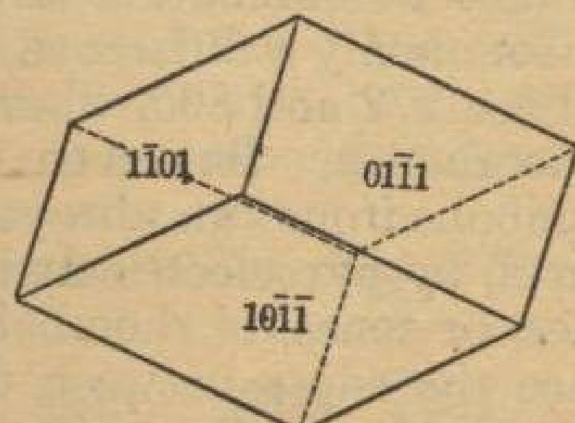


Symmetry of Rhombohedral Class



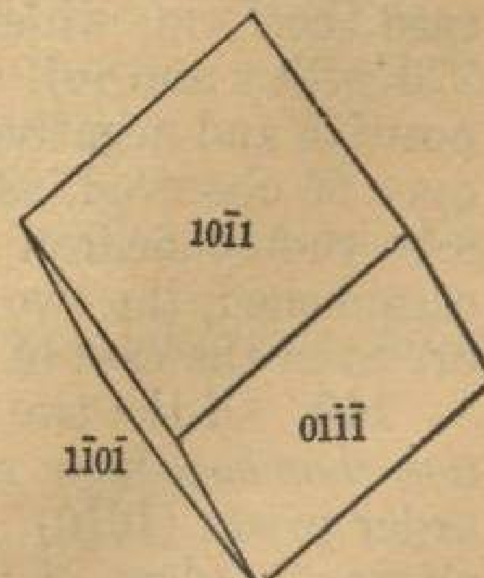
Positive Rhombohedron
Calcite

264



Negative Rhombohedron

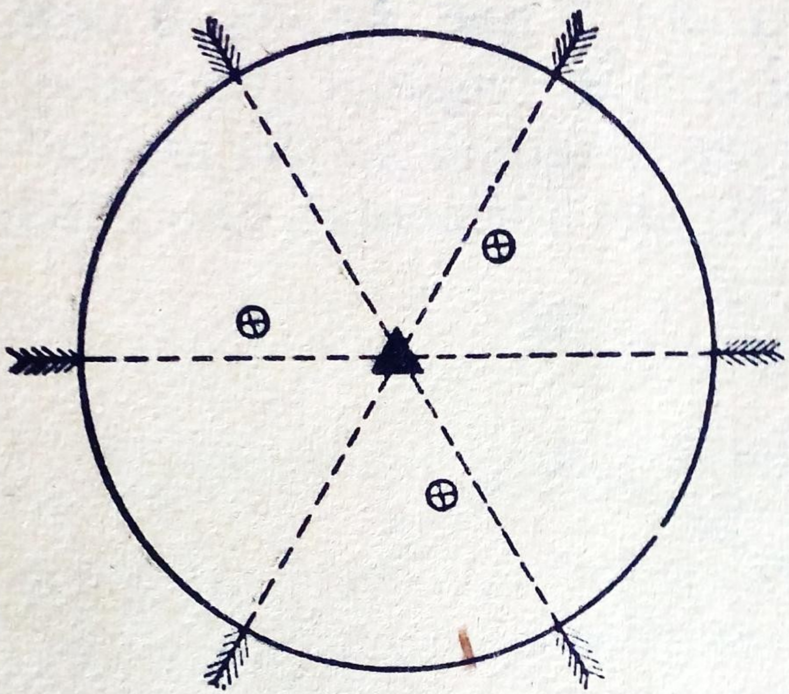
265



Positive Rhombohedron
Hematite

145. Vert. Ax.-3; hor. P.

261



Symmetry of Trigonal Tetarto-hedral Class

ORTHORHOMBIC SYSTEM

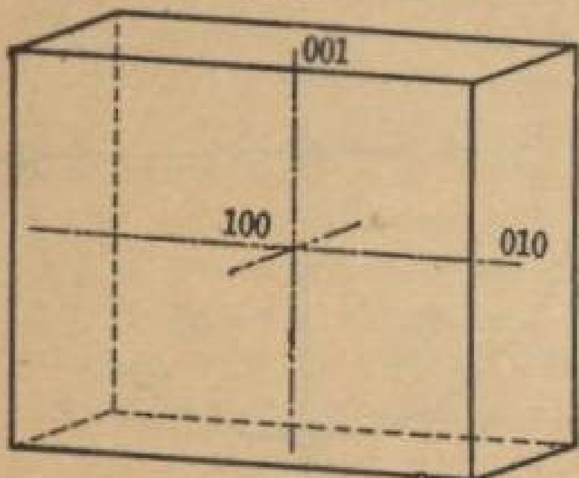
Crystal Classes & Forms in **Orthorhombic system**

1. **Normal class / Barite type**
   i. Macropinacoid or a-pinacoid (100)
   ii. Brachypinacoid or b-pinacoid (010)
   iii. Base or c-pinacoid (001)
   iv. Prisms (hk0)
   v. Macrodomes (h0l)
   vi. Brachydomes (0kl)
   vii. Pyramids (hkl).

Symmetry Elements of Orthorhombic System:

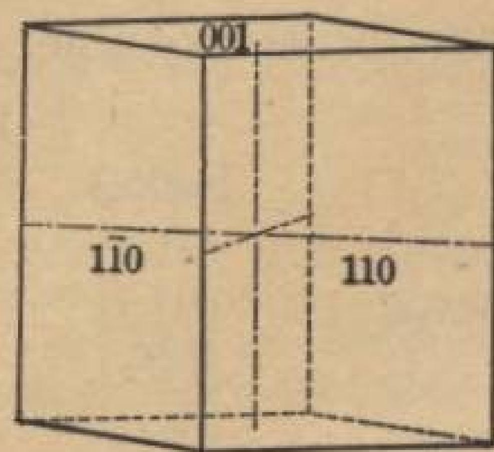
3 Xl. Ax.-2;
3 Xl. P;
C.

316



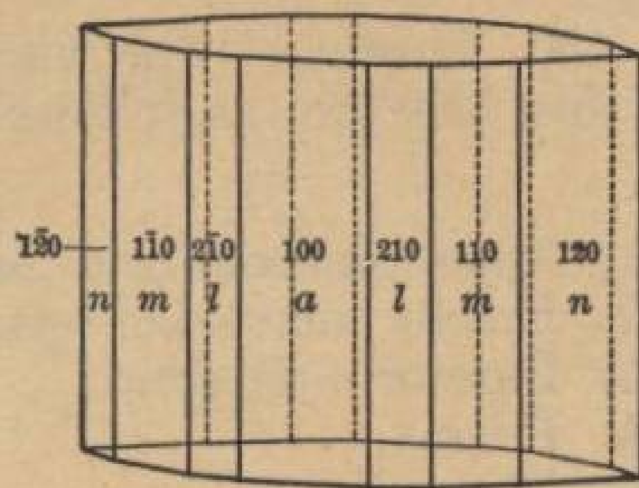
Macro-, Brachy- and
Basal Pinacoids

317

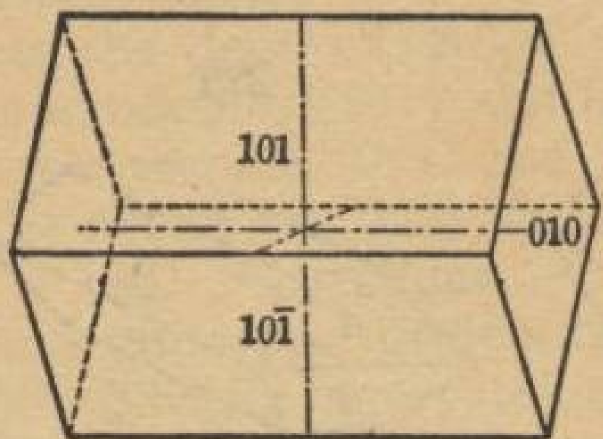


Prism and Basal
Pinacoid

318

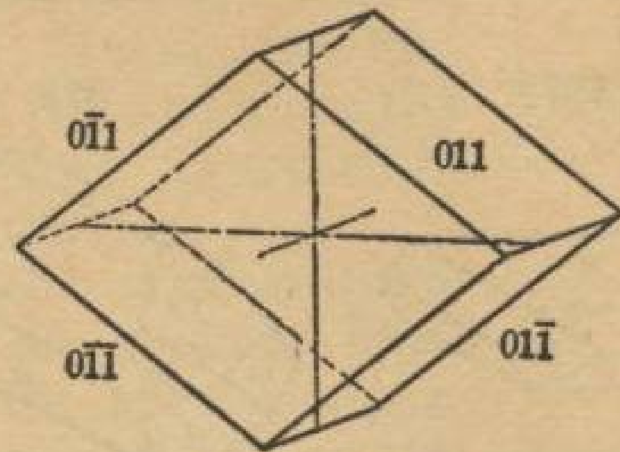


319



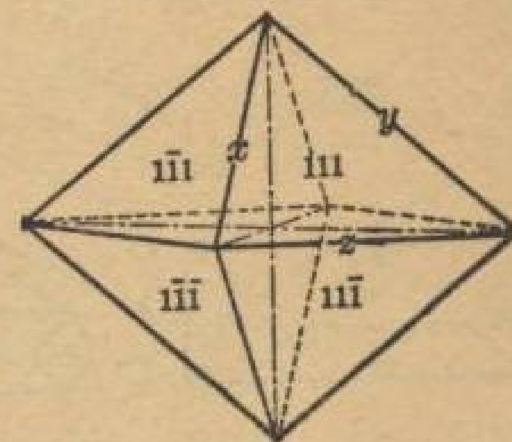
Macrodome and
Brachypinacoid

320



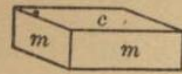
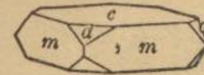
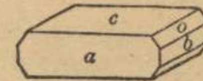
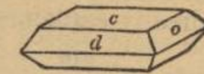
Brachydome
and Macropinacoid

321

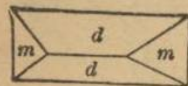
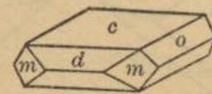
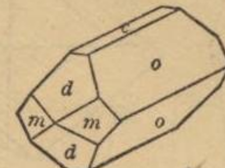
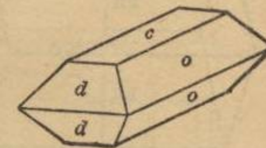


Pyramid

322 323 324 325

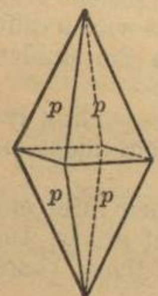
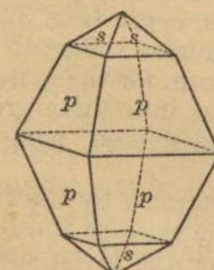
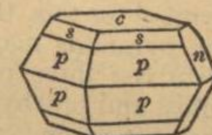
   

326 327 328 329

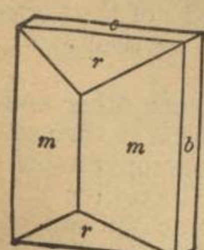
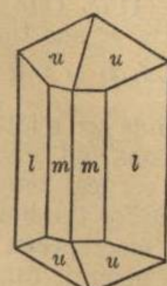
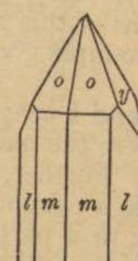
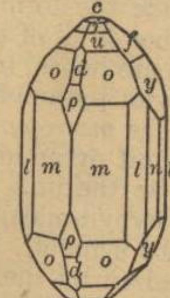
Barite Crystals

330 331 332

Sulphur Crystals

333 334 335 336

Staurolite

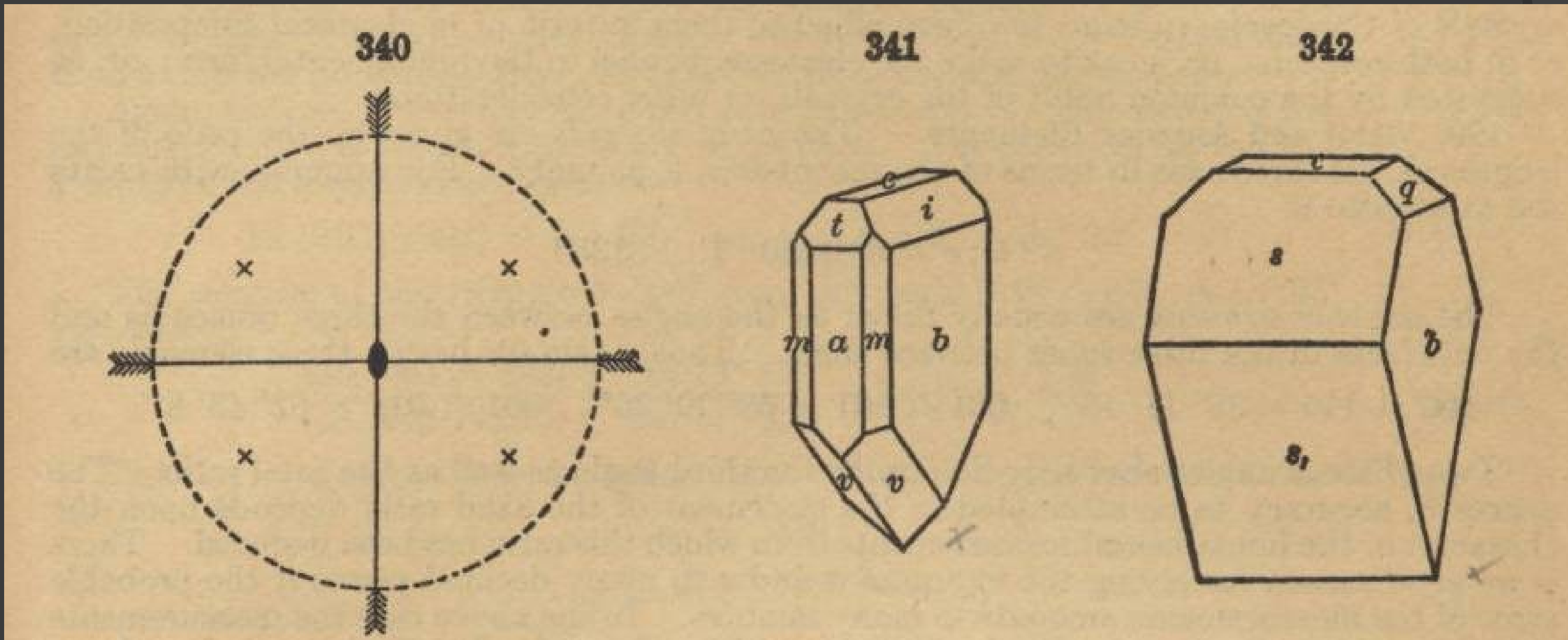
Figs. 334–336, Topaz

Figs. 330–332 of native sulphur show a series of crystals of pyramidal habit with the dome $n(011)$, and the pyramids $p(111)$, $s(113)$. Note n truncates the terminal edges of the fundamental pyramid p. In general it should

2. Hemimorphic class / Calamine type

Symmetry elements of Hemimorphic class:

Vert. Ax. -2; 2 Vert. Xl. P.



Symmetry of Hemimorphic Class

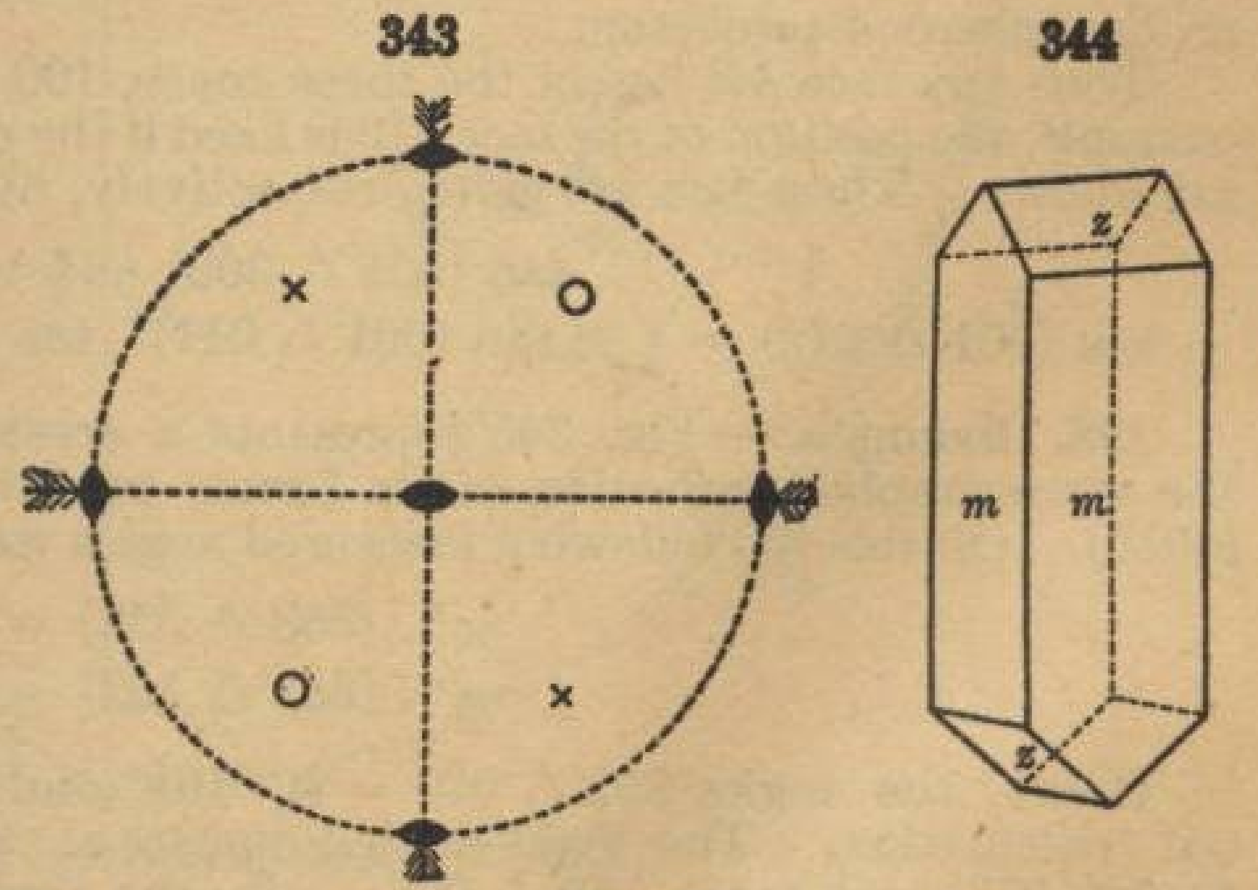
Calamine

Struvite

3. Sphenoidal Class / Epsomite type

Symmetry Elements :

3 Xl. Ax.-2.



Symmetry of Sphenoidal Class

Epsomite

MONOCLINIC SYSTEM

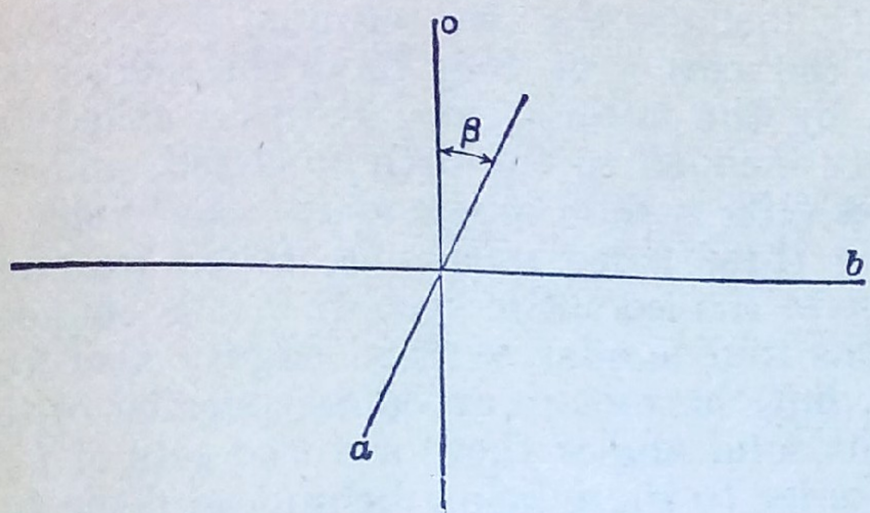
Crystal Classes & Forms in **Monoclinic system**

1. **Normal class / Gypsum type**
   i. Orthopinacoid or a-pinacoid (100)
   ii. Clinopinacoid or b-pinacoid (010)
   iii. Base or c-pinacoid (001)
   iv. Prisms (hk0)
   v. Orthodomes (h0l), ($\bar{h}$0l)
   vi. Clinodomes (0kl)
   vii. Pyramids (hkl); ($\bar{h}$kl).

Symmetry Elements of Monoclinic System:

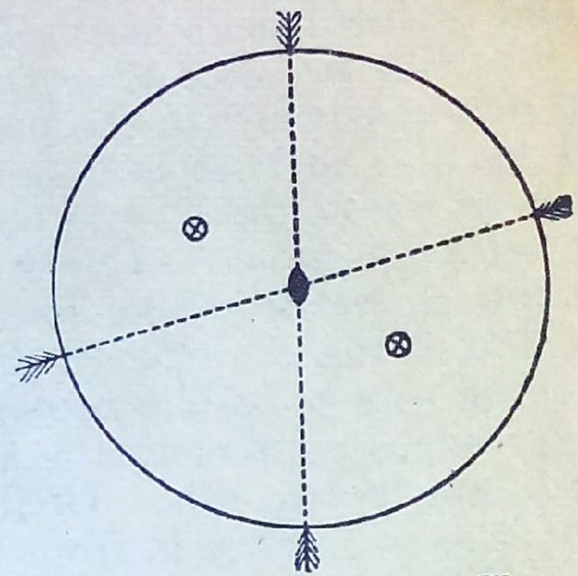
B xl. Ax.-2; a-c xl. P. ; C.

351



Crystal Axes of Orthoclase
$a:b:c = 0{\cdot}66:1:0{\cdot}55.\ \beta = 64°$

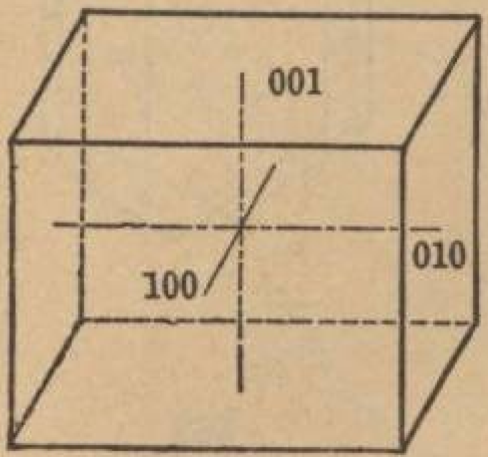
352



Symmetry of Normal Class

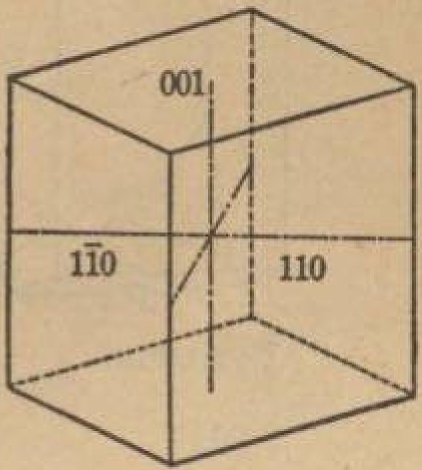
1. NORMAL CLASS (28). GYPSUM TYPE

353



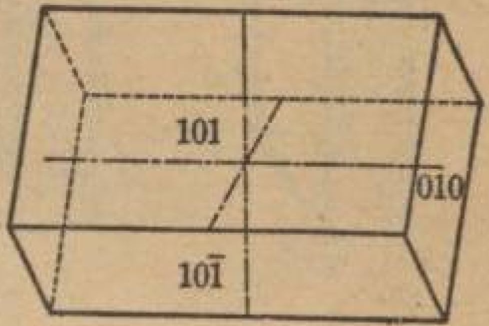
Ortho-, Clino- and Basal Pinacoids

354

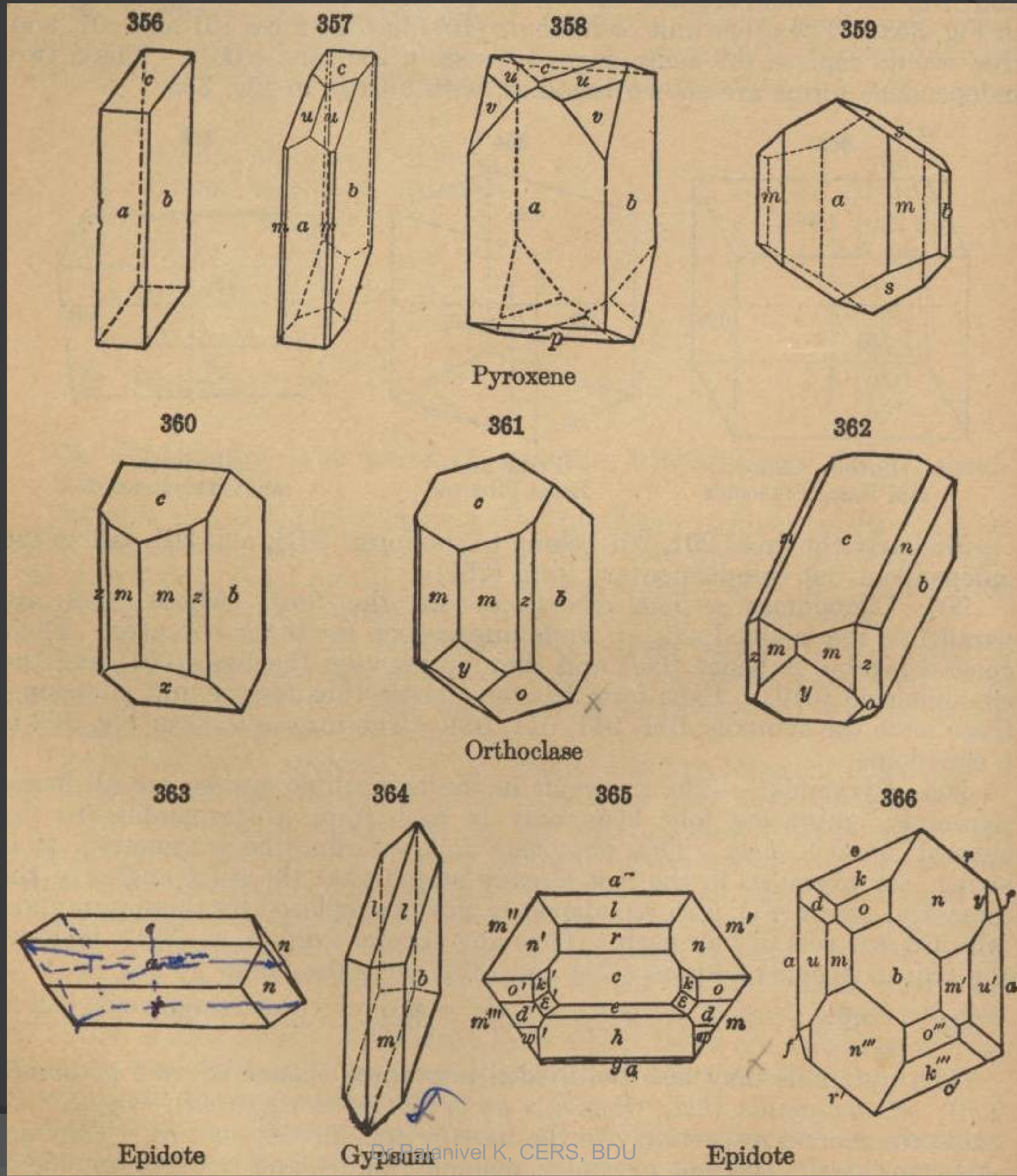


Prism and Basal Pinacoid

355

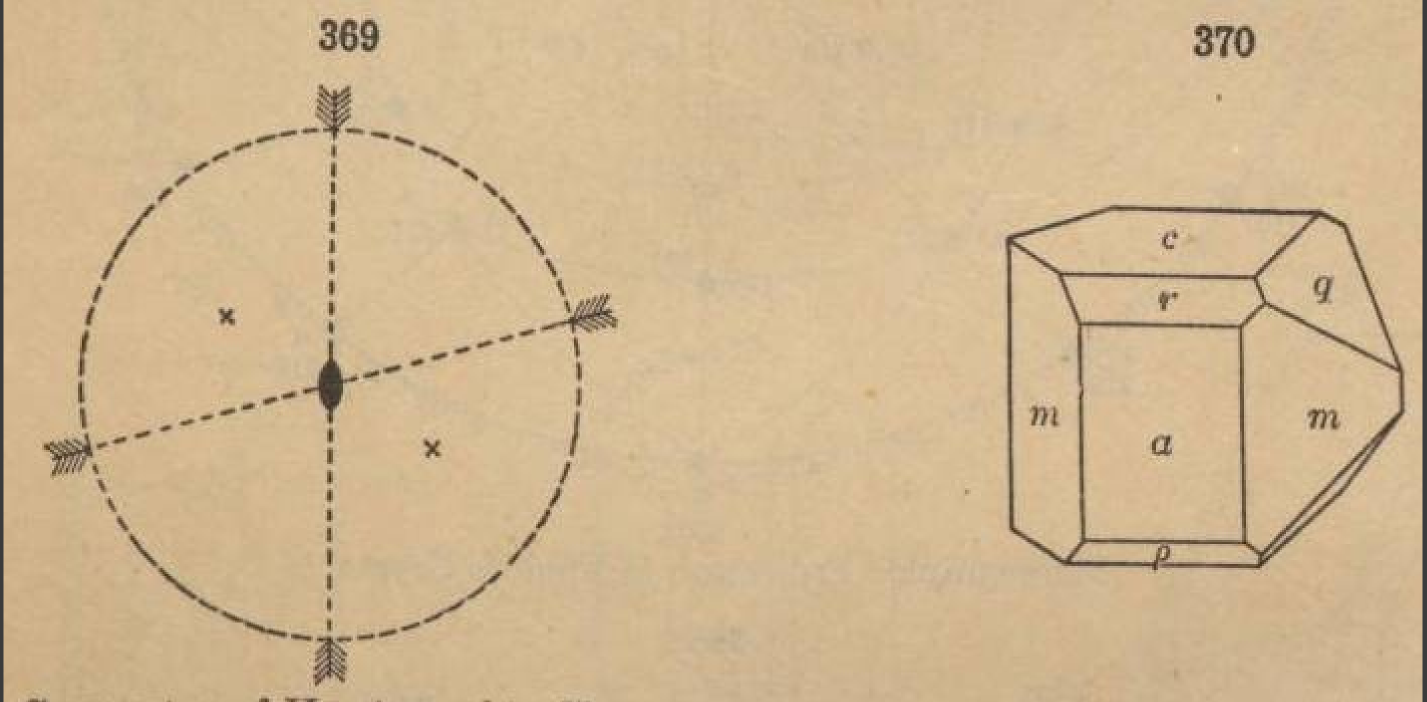


Orthodomes and Clinopinacoid


356
357
358
359
Pyroxene
360
361
362
Orthoclase
363
364
365
366
Epidote
Gypsum
Epidote

2. Hemimorphic Class / Tartaric Acid Type

Sym.: b Xl. Ax. 2.



Symmetry of Hemimorphic Class

Tartaric Acid

3. Clinohedral Class / Clinohedrite Type

Sym.: a-c xl. P.

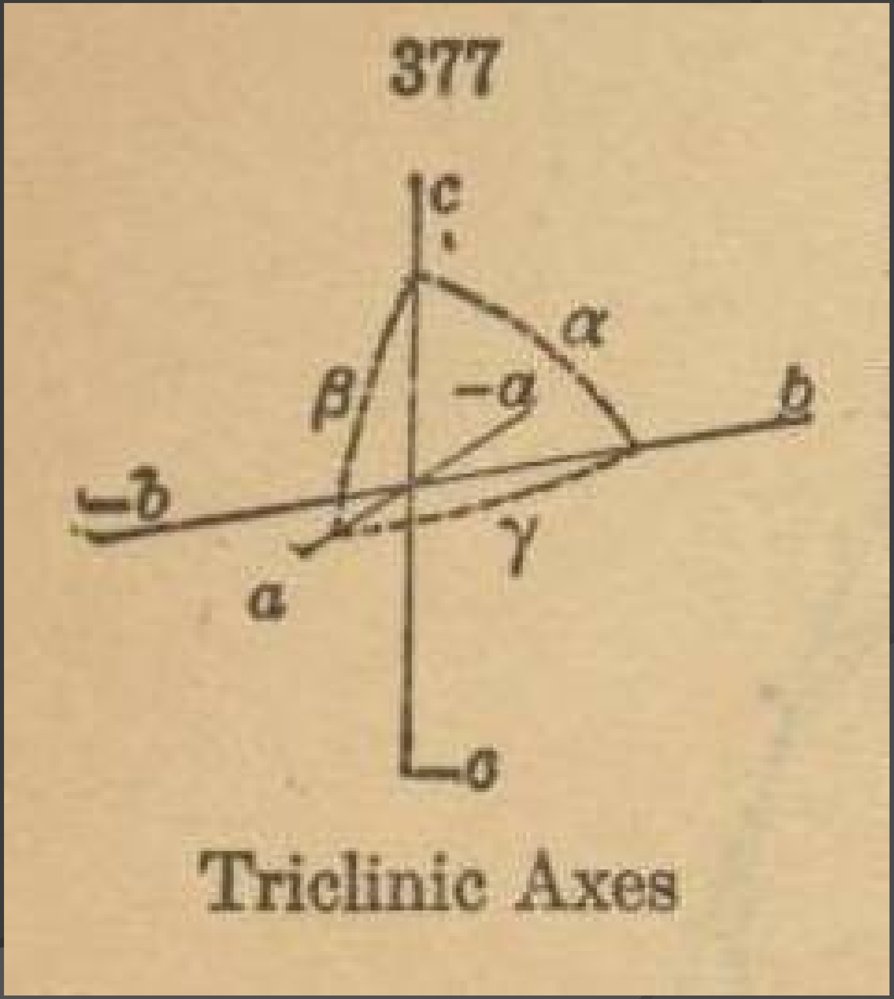
TRICLINIC SYSTEM

Crystal Classes & Forms in **Triclinic system**

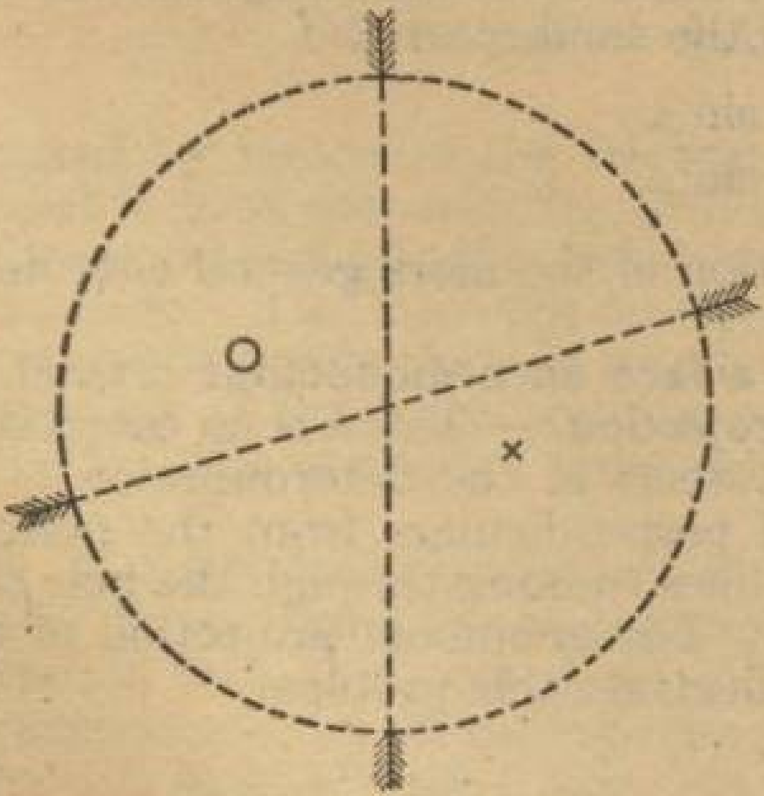
1. **Normal class / Axinite type**
   1. Macropinacoid or a-pinacoid (100)
   2. Brachypinacoid or b-pinacoid (010)
   3. Base or c-pinacoid (001)
   4. Prisms (hk0), $(h\bar{k}0)$
   5. Macrodomes (h0l), $(\bar{h}0l)$
   6. Brachydomes (0kl), $(0\bar{k}l)$
   7. Pyramids (hkl); $(\bar{h}kl)$, $(\bar{h}\bar{k}l)$, $(h\bar{k}l)$.

Symmetry Elements of Triclinic System:

C.

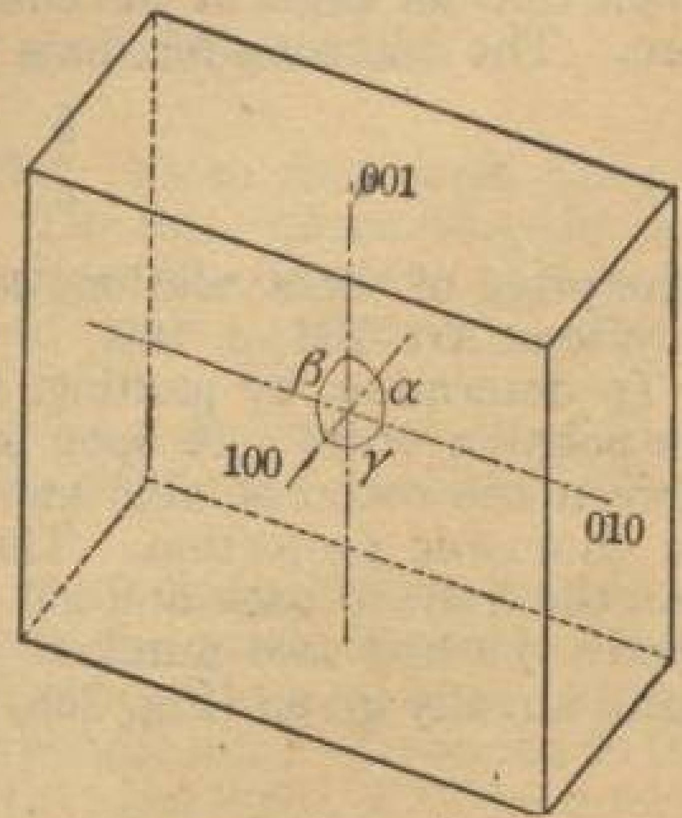


378

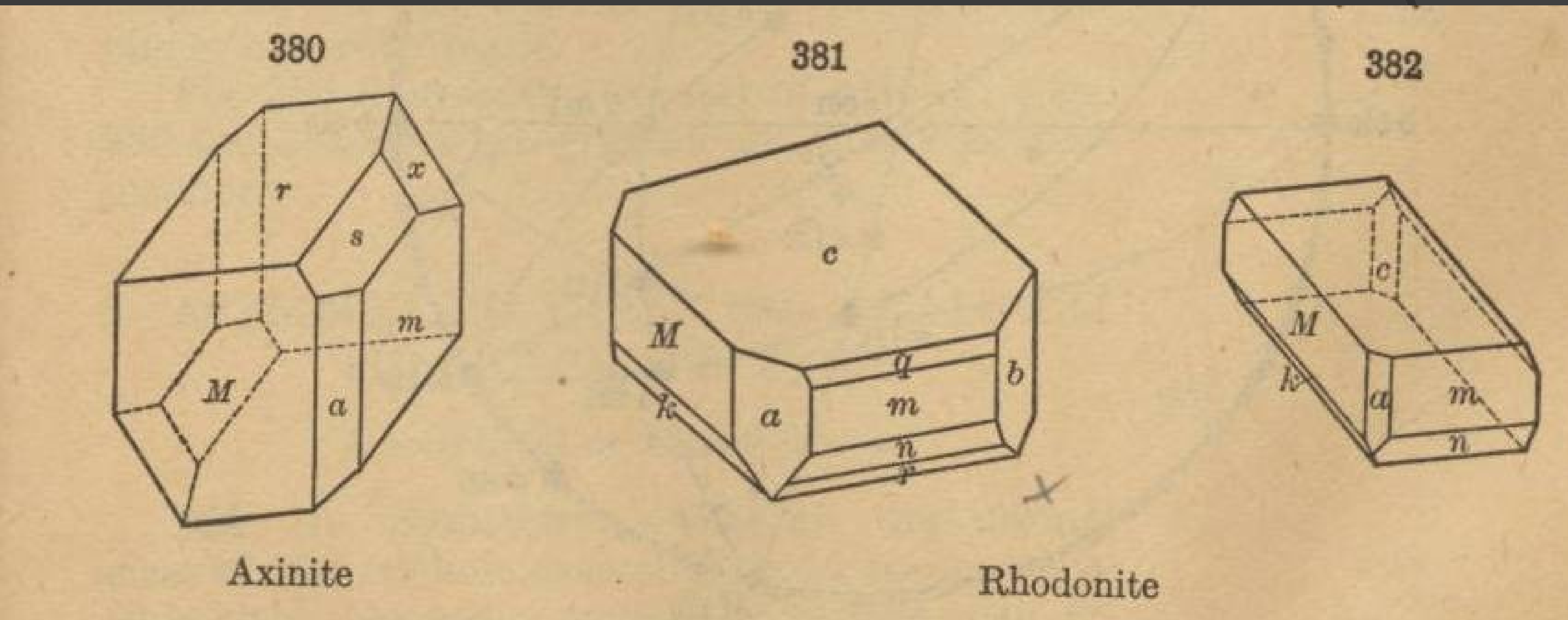


Symmetry of Normal Class

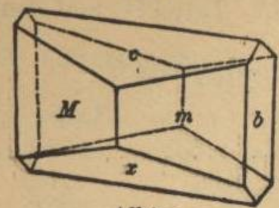
379



Triclinic Pinacoids

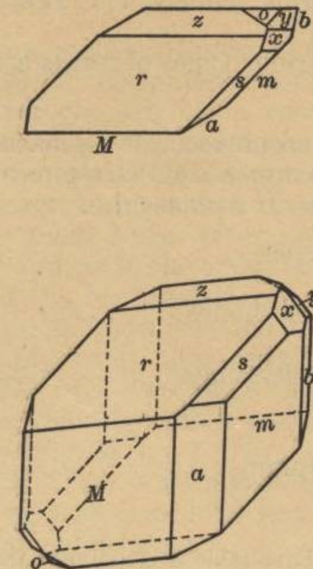

380
381
382
r
x
s
m
M
a
c
M
k
a
q
m
b
n
p
c
M
k
a
m
n
Axinite
Rhodonite

383



Albite

385



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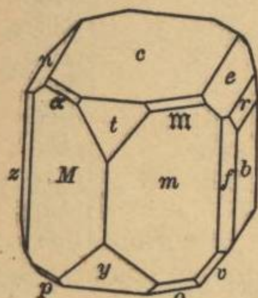
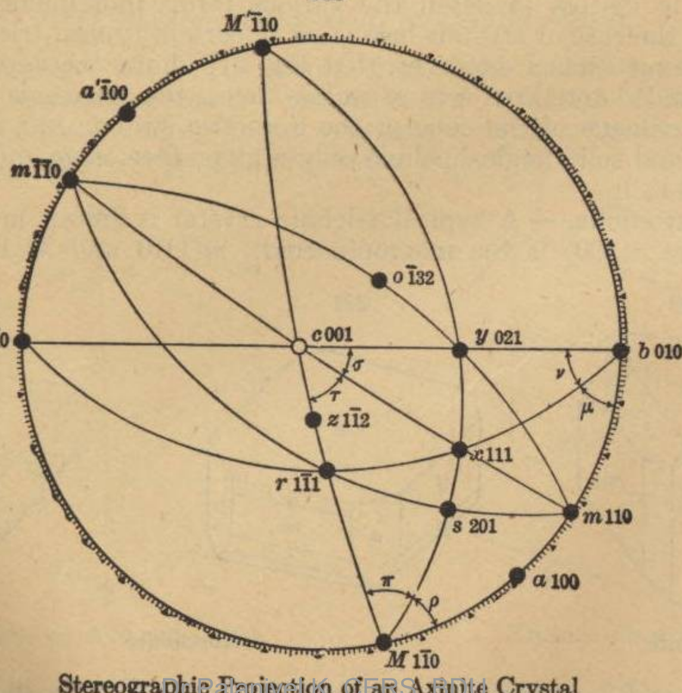


Anorthite

Axinite

386



Stereographic Projection of an Axinite Crystal

2. Assymmetric class / Calcium Thiosulphate type

No symmetry.

One face only.

E.g. $CaS_2O_3.6H_2O$ Calcium Thiosulphate

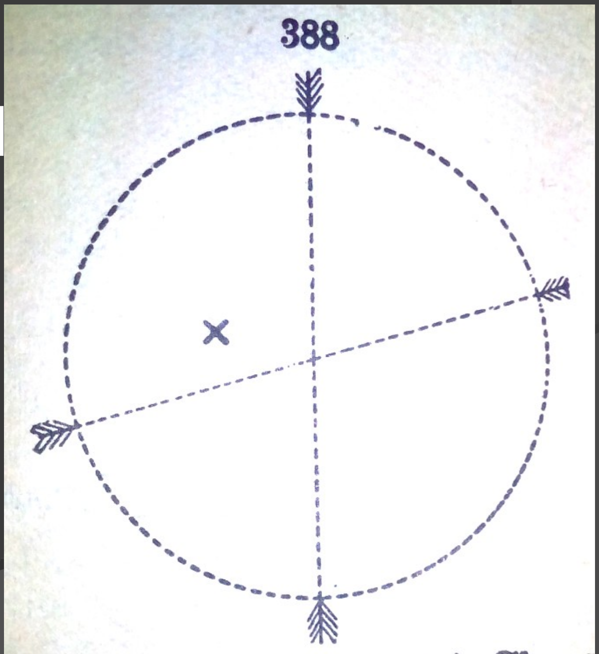
Macropinacoid or a-pinacoid (100)

or

Brachypinacoid or b-pinacoid (01

or

Base or c-pinacoid (001)



Symmetry of Asymmetric Class


Garnets

STATE OF AGGREGATION:

Crystal habits and forms

- The Shape and size of crystals give rise to certain descriptive terms applied to the typical appearance are known as **habit of crystals.**
- Factors influencing a crystal's habit include:
  - Combination of two or more crystal forms;
  - Trace impurities present during growth;
  - Crystal twinning and
  - Growth conditions (i.e., heat, pressure, space).

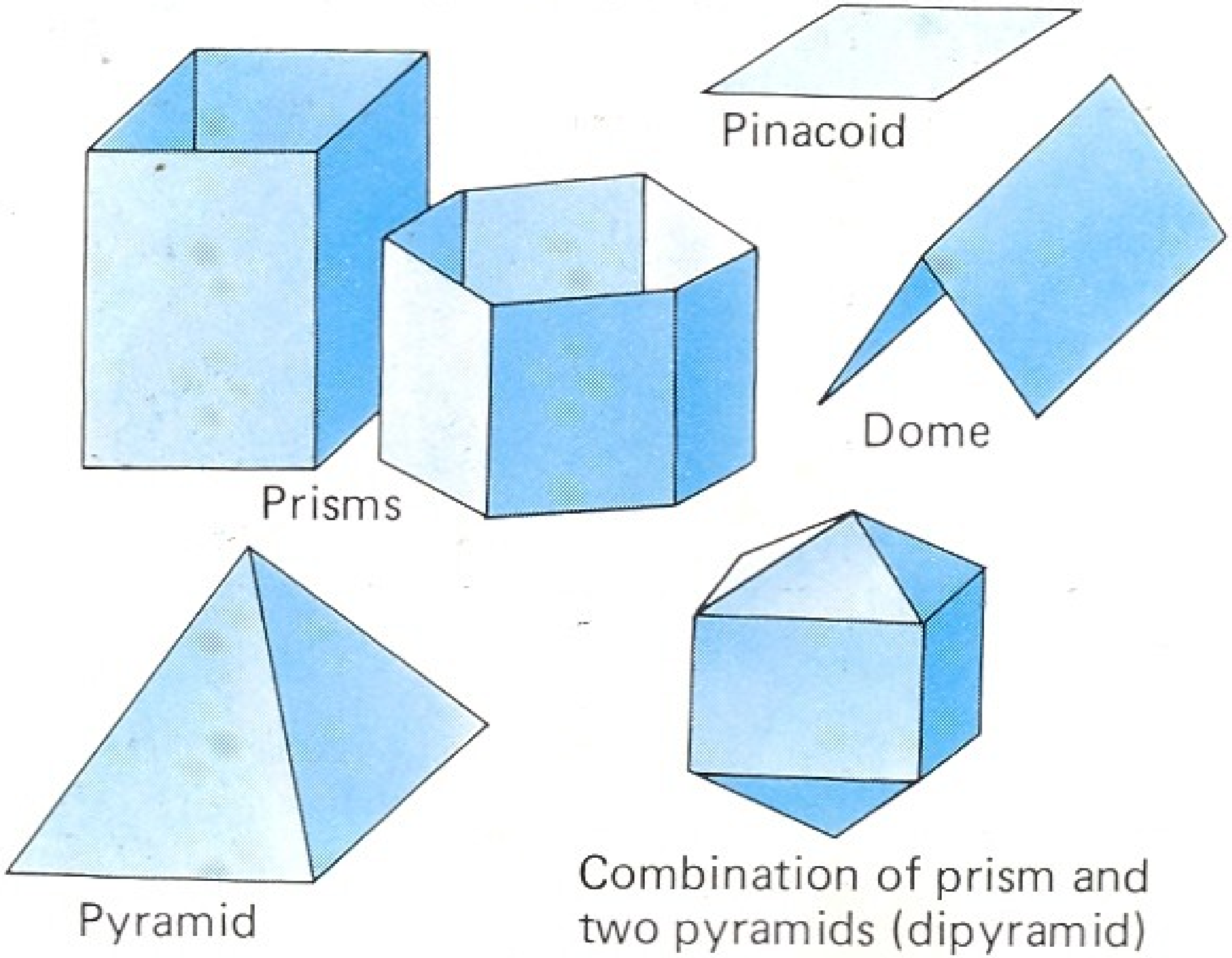


Figure 2–13 Some common crystal forms.

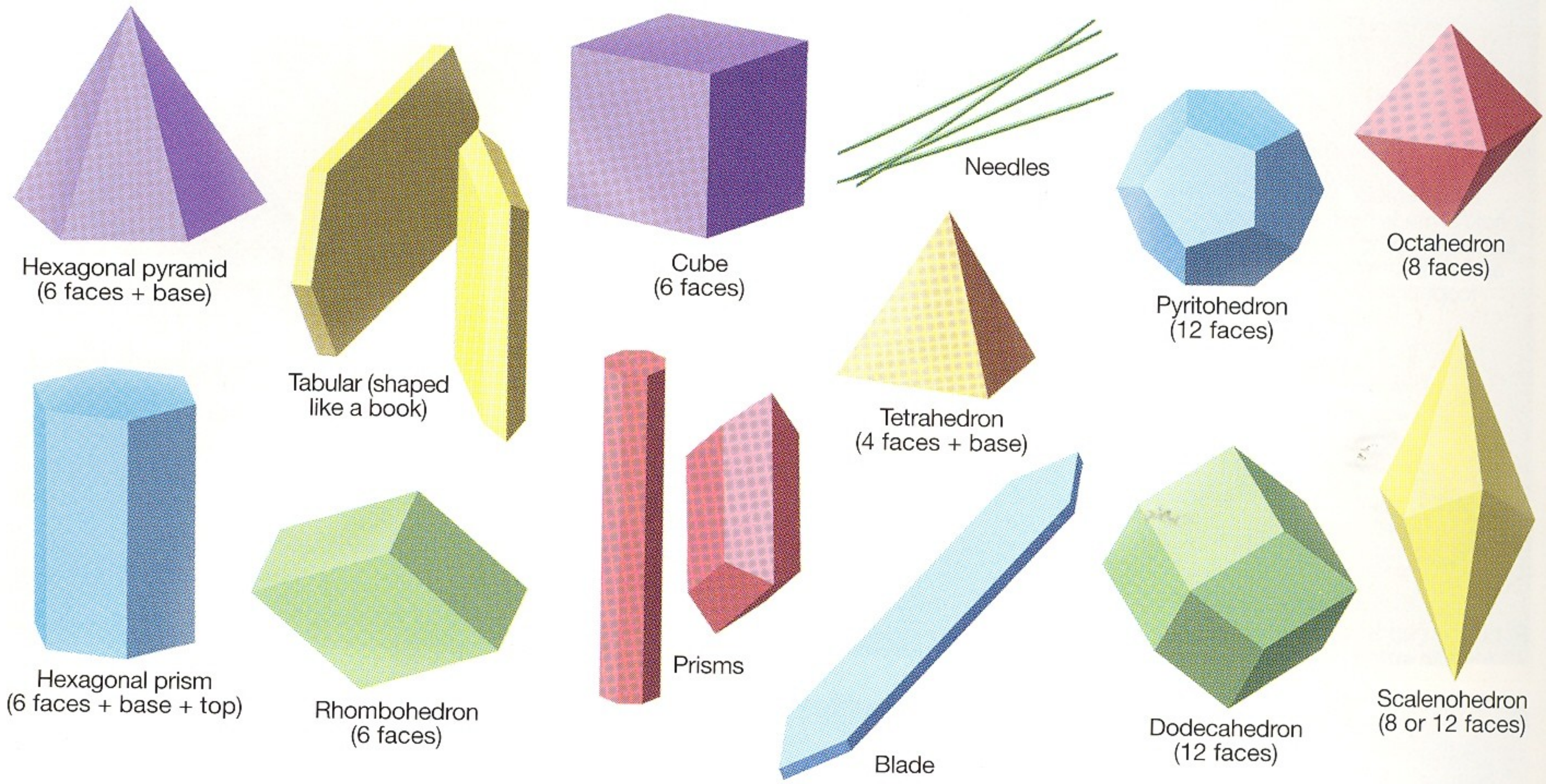


FIGURE 2.3 Some *crystal forms* (geometric shapes). The flat surfaces of these forms are called *crystal faces*.

List of crystal Habits, Forms and Crystalline Aggregates

Habit:	Description:	Example:
Crystallized	having fully developed faces	Quartz, Calcite, etc.
Crystalline	aggregate of imperfectly formed crystals that are interfered with one another during their growth	NaCl crystals
Cryptocrystalline	only very little traces of crystalline structures	Obsidian
Amorphous	complete absence of crystalline structure	Opal
Acicular	Needle-like, slender and/or tapered	Rutile in quartz
Amygdaloidal	Almond-shaped	Heulandite
Anhedral	Poorly formed, external crystal faces not developed	Olivine

Bladed	Blade-like, slender and flattened	Kyanite
Botryoidal or globular	Bunch of Grapes-like, hemispherical masses	Chalcedony, Smithsonite, Hemimorphite, Adamite and Variscite.
Capillary	Fine hair like	Millerite, Nickel sulphide, Hair Pyrites
Columnar	Similar to fibrous: Long, slender prisms often with parallel growth	Calcite
Coxcomb	Aggregated flaky or tabular crystals closely spaced.	Barite
Dendritic or arborescent	Tree-like, moss-like branching in one or more direction from central point	Magnesite in opal, Mn Oxides
Dodecahedral	Dodecahedron, 12-sided	Garnet
Drusy or encrustation	Aggregate of minute crystals coating a surface	Uvarovite

Enantiomorphic	Mirror-image habit and optical characteristics; right- and left-handed crystals	Quartz
Equant, stout, stubby or blocky	Length, width, and breadth roughly equal	Zircon
Euhedral	Well-formed, external crystal faces developed	Spinel
Fibrous	Extremely slender prisms	Tremolite, Satinspar, Asbestos
Filiform or wiry	Thin wires, extremely fine twisted like the strands of a rope	Natrolite, Native silver and copper
Foliated or micaceous	Layered structure, parting into thin sheets	Mica
Granular	Aggregates of anhedral crystals in matrix	Scheelite
Hemimorphic	Doubly terminated crystal with two differently shaped ends.	Hemimorphite

Lamellar		Wollastonite
Lenticular	Flattened balls or pellets as in nodular/concretionary mnls.	
Mamilliated	Breast-like: surface formed by intersecting partial spherical shapes	Malachite
Massive or compact	Shapeless, no distinctive external crystal shape	Serpentine
Nodular, Concretionary or tuberose	Deposit of roughly spherical form with irregular protuberances	Geodes, Nodules of , Chalk and Phosphates
Octahedral	Octahedron, eight-sided (two pyramids base to base)	Diamond
Plumose	Fine, feather-like scales	Mottramite
Prismatic	Elongate, prism-like: crystal faces parallel to c-axis well-developed	Tourmaline
Pseudo-hexagonal	hexagonal appearance due to cyclic twinning	Aragonite
Pseudomorphous	Occurring in the shape of another mineral through pseudomorphous replacement	Tiger's eye

Radiating or divergent	Fibres radiating outward from a central point	Stibnite, Pyrite suns
Reniform or colloform	Similar to mamillary: intersecting kidney-shaped masses	Hematite
Reticulated	Cross-meshes like (net-like) acicular crystals forming intergrowths	Cerussite, Rutile needles in Mica
Rosette	Platy, radiating rose-like aggregate	Gypsum
Scaly	Small plates	Tridymite
Sphenoid	Wedge-shaped	Sphene
Stalactitic	Forming as stalactites or stalagmites; cylindrical or cone-shaped	Rhodochrosite
Stellate	Star-like, radiating	Pyrophyllite
Striated/striations	Surface growth lines parallel or perpendicular to a crystallographic axis	Chrysoberyl
Subhedral	External crystal faces only partially developed	
Tabular or lamellar	Flat, tablet-shaped, prominent pinnacoid	Ruby
Tuberose	Very irregular rounded surfaces-gnarled, root like shapes	Aragonite variety Flos-ferri
Wheat sheaf	Aggregates resembling hand-reaped wheat sheaves	Zeolites

Pseudomorphism & Polymorphism

- Pseudomorphism – the assumption by a mineral of a form other than that which really belongs to it, by incrustation, infiltration, replacement or by alteration.
- Polymorphism – Two minerals of markedly different physical properties, but may have identical chemical compositions.
  - Dimorphism - Calcite – Aragonite, Graphite – Diamond.
  - Trimorphous – Titanium Dioxide-Anatase-Brookite-Rutile.

Twinning or Crystal Intergrowth

- Intergrowth of two or more individual crystals in such a way as to yield parallelism in the case of certain parts of different individuals and at the same time other parts of the different individuals are in reverse positions in respects to each other.
- They often appear externally to consist of two or more crystals symmetrically united.
- There are several types of twinning identified

Types of twinning

- **Simple twin**: The twin of calcite consisting of two halves symmetrical with respect to the twin-plane is simple twin is also known as contact-twin. (Dana 445 – 452)

- **Penetration twin**: The two halves of the twin have grown so mixed together that the twin cannot be divided in to two separate halves is known as penetration twin. Eg.: Iron cross twins of Pyrite, interpenetrated twins of Fluorite and cross-shaped twins of Staurolite. (D433-435, 464-466)

- **Repeated twin**: The repetition of twinning along the twin-plane. If it is composed of three parts it is called as 'trilling', if 4 parts – 'fourling'. If the twin-plane is parallel in all parts and there so many repetitions, is described as 'polysynthetic'. Eg.: Plagioclase feldspars. If the twin-plane does not remain parallel, the resulting twin approaches a curved form called 'cyclic'. Eg.: Aragonite. (D456, 484,

- **Compound or complex twin**: Twining has taken place on two or more laws is called as compound or complex twin.

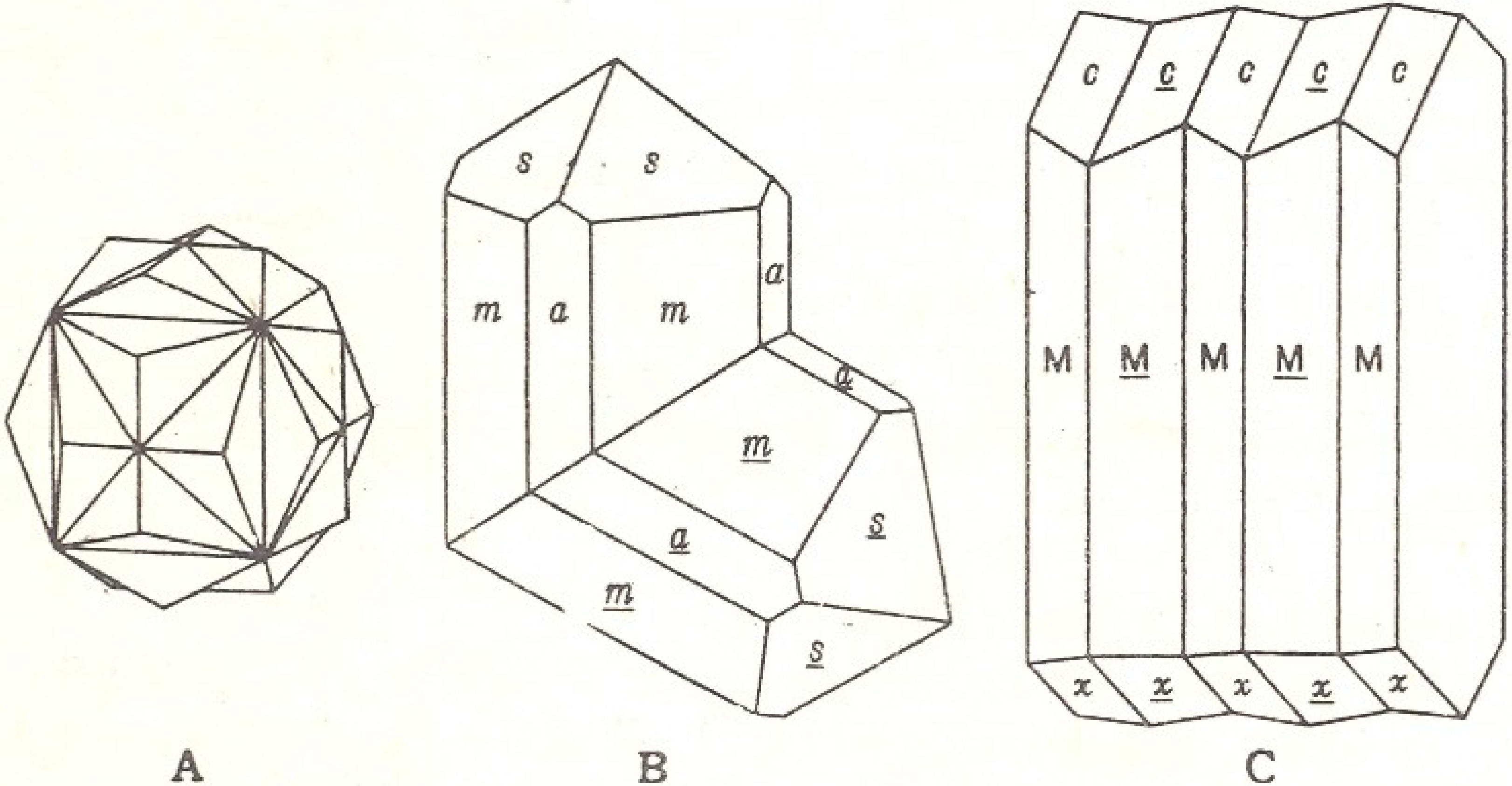


FIG. 87. Examples of Twins. A. Pyrite: Interpenetration Twin. B. Rutile: Geniculate Twin: twin-plane 101. C. Plagioclase: Repeated Twin: twin-plane 010.

Laws of Twinning:

- In Cubic system: ***Spinel law*** is the common twin in Galena type, in which the twin-plane is the octahedral face and the twin-axis is at right angles to this. Interpenetrated twins of Fluorspar in the octahedral face, Iron-cross of pyrite in the rhombo-dodecahedral face of pyritohedrons, normal Galena type are some of the other forms. D409, 410

- In Tetragonal system: ***Rutile law*** is the commenest type of twinning in which the pyramidal face of second order(101) or (301) is the twin-plane and composition-plane. It produced a knee-shaped or geniculate twin with 101 face or a sharper knee twins with 301 face. D420

Laws of Twinning:...contd...

- In <u>Hexagonal system</u>: ***Calcite twins*** (0001-base or the gliding planes such as 011-2, 10-11 & 02-21 rhombohedraons are the twin-planes), ***Quartz twins*** – interpenetration twin, vertical xallographic axis is the twin axis, with right and left handed crystals along 11-20 prism plane as twin-plane.

- In <u>Orthorhombic system</u>: ***Cyclic twins*** of Aragonite (110 prism is the twin-plane). The prism angle is nearly 60o so that twinning repeated five times to produce a pseudo-hexagonal crystal. ***Maltese cross*** (032-dome) and ***skew twin*** (232-bipyramid) in staurolite

Laws of Twinning:...contd...

- In <u>Monoclinic system</u>: ***Swallow-tails twins*** in Gypsum, Hornblende and Augite twins, ***Carlspad twin*** and interpenetration Carlspad twin (vertical crystallographic axis is twin axis and the clinopinacoid (010) is the composition-plane), ***Baveno twin*** (clinodome-021 is the twin-plane and composition-plane), and ***Manebach twin*** (basal pinacoid-001).

- In <u>Triclinic system</u>: ***Albite law*** (010 the side pinacoid is the twin-plane), which is also repeated and polysynthetic twin. This repeated twin produces striations on the basal planes of the crystal and is also excellently seen in thin section of plagioclase.

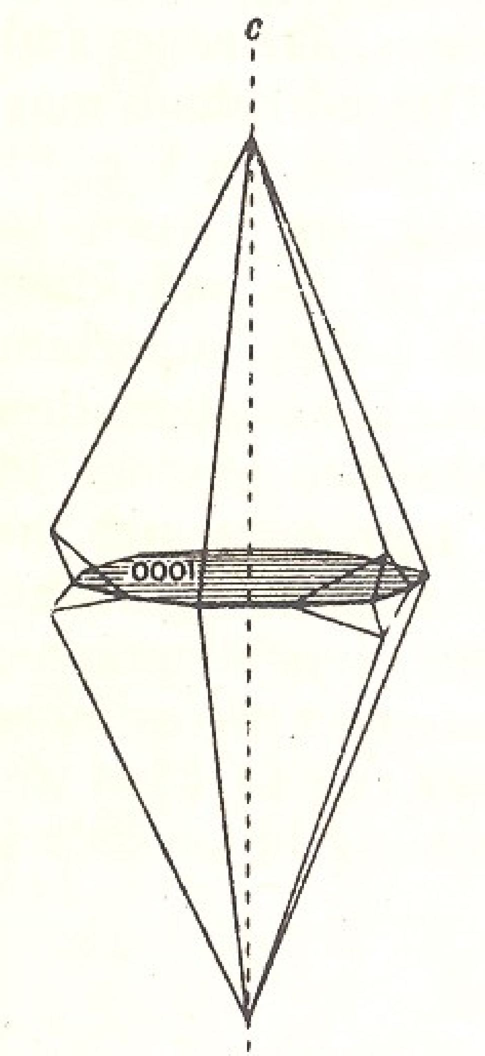
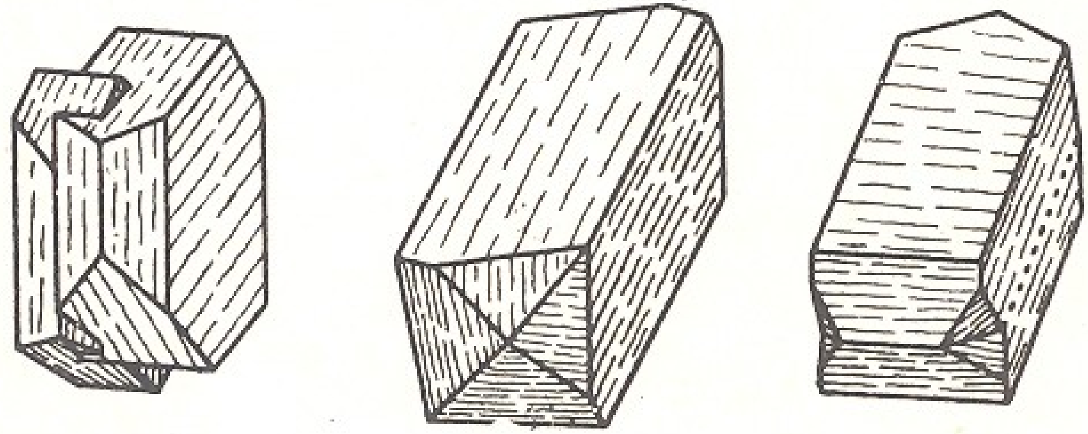


FIG. 86. Calcite Twin: Scalenohedron, twin-plane basal pinacoid 0001, twin-axis c.



Carlsbad Twin.

Baveno Twin.

Manebach Twin.

FIG. 88. Orthoclase Twins.

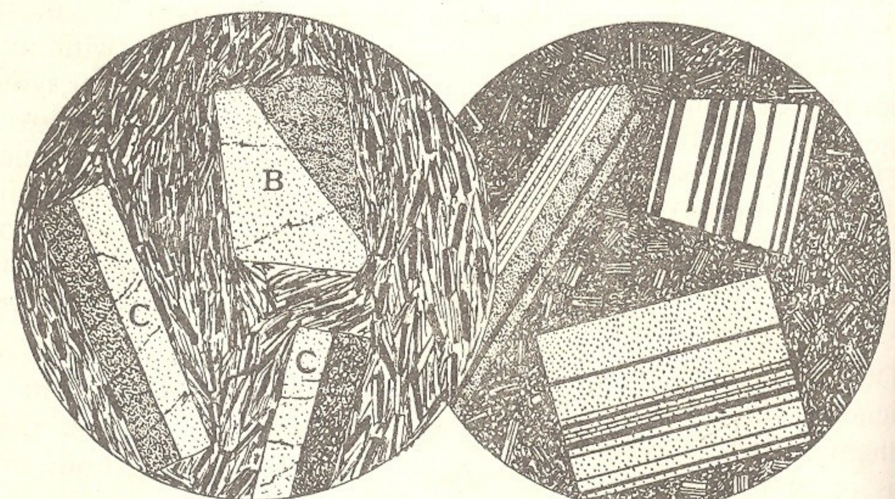


FIG. 144. Feldspars in thin section: Left, *orthoclase* showing Carlsbad twinning (C) and Baveno twinning (B); right, *plagioclase* showing Albite twinning—both figures between crossed nicols.

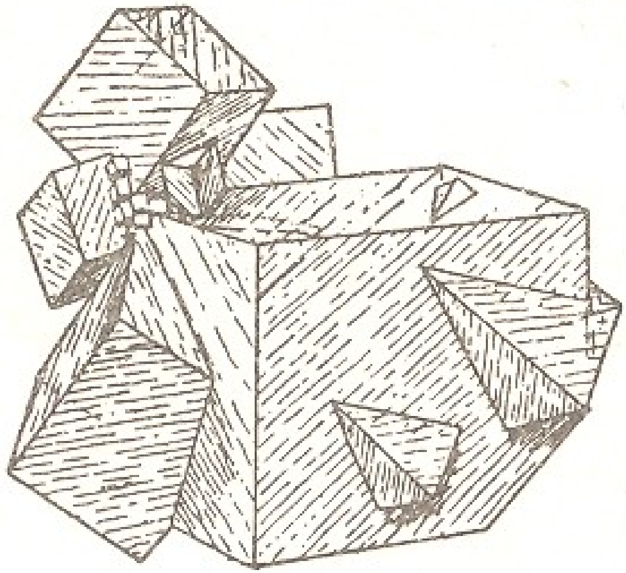


FIG. 119. Fluorspar

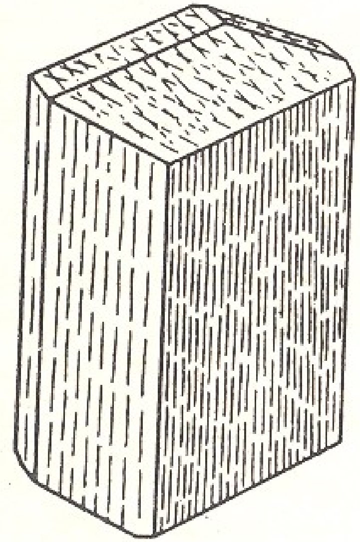


FIG. 139. Horn-
blende

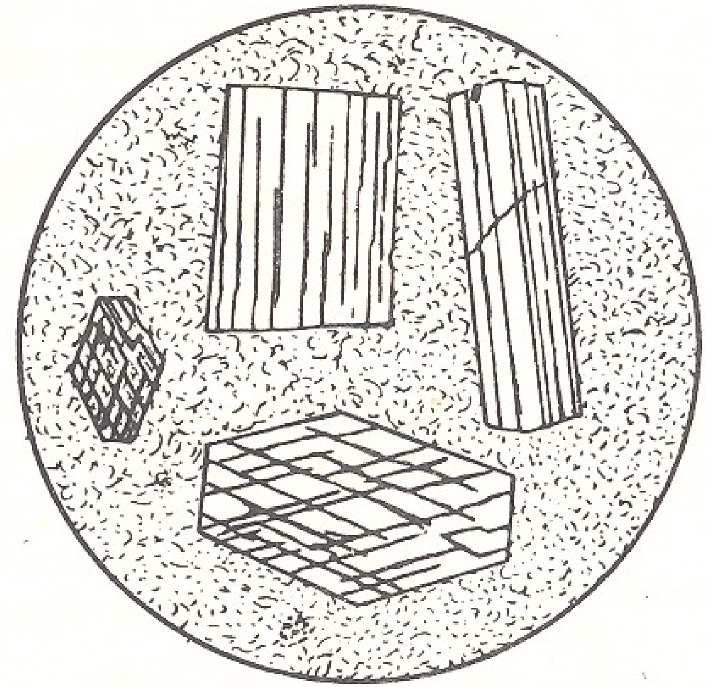


FIG. 140. Sections of hornblende, showing cleavages: above prismatic sections, below transverse section.

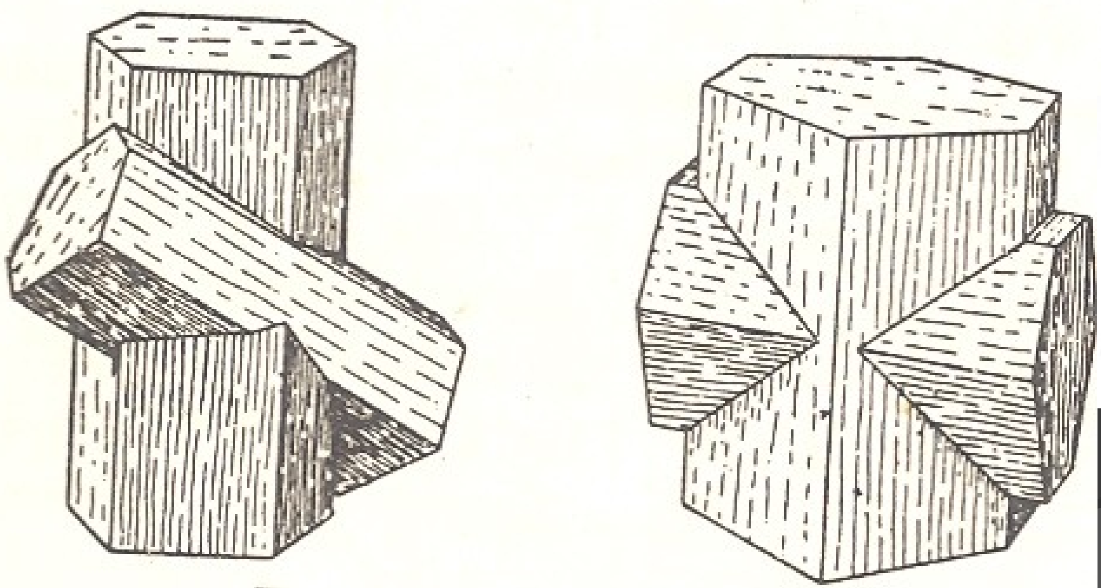
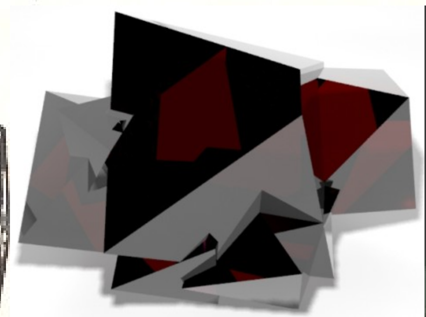


FIG. 134. Staurolite Twins



Imitative Shapes in Crystals

- Accidental imitative shapes – Presuppose an empty space, which has been filled up by the individuals of compound minerals to which is transferred the form of the pre-existing space. E.g. Implanted globular, reniform, botryoidal.
- Regular Accidental imitative shapes are also known as Psudomorphoses or Supposititious.
- Irregular Accidental imitative shapes – Petrifaction, tuberose, …

Thank you

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