# Bharathidasan University
## Tiruchirappalli – 620 023, Tamil Nadu

6 Yr. Int. **M.Tech. Geological Technology & Geoinformatics** programme

**Course Code: MTIGT0306**

# CRYSTALLOGRAPHY AND MINERALOGY

## UNIT – 1 ELEMENTS OF CRYSTALLOGRAPHY

**Georgius Agricola, 'Father of Mineralogy'**

German scientist '**Georg Bauer**' - named by birth;
his *First book on Mineralogy was published during* 1530
*entitled :* ***'Bermannus, sive de re metallica dialogus'***
(A description of the ore mountain-Ergebrge, Silver mining district)

**René Just Haüy** (1743 –1822)

"**Father of Modern Crystallography**"

French (Paris) Mineralogist generally known as **Abbé Haüy**

*Prepared by*
**Dr. K.Palanivel**
**Professor, Department of Remote Sensing**

# 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.**

6. **Current Contours: (Not for Exam, only for Discussion):** Preparation of Field Kit for testing and identifying minerals during field survey; preparation of mineral and crystal samples for making thin sections, x-ray crystallographic studies. Learn how minerals together form different types of rocks.

## Text Books:


1. Dana, E.S, A Text Book of Mineralogy, Wiley Eastern, 1955.
2. Flint, Y, Basic Crystallography, Mid Publishers, 1970.
3. Phillips, F.C. Longman, An Introduction to Crystallography, 1956.
4. Bloss.F.B., Crystallography and crystal New york 1971
5. Read, H.H, Rutley’s Elements of Mineralogy, CBS Publishers & Distributors, Delhi,1984.

**Reference Books:**


1. Berry Mason, L.G,Mineralogy, W.H. Freeman & co - 1961.
2. D. Perkins, (2002), Mineralogy, 2nd Edition, Pearson Education (Singapore) Pte. Ltd, Delhi, 483pp, ISBN 81-7808-831-2
3. W. D. Nesse, (2000), Introduction to Mineralogy, Oxford University Press, ISBN 0-19- 510691-1
4. Naidu, P.R.J,. Optical Crystallography.
5. Wahlstrom, E.F, Optical Crystallography, John wiley, 1960.
6. Azaroff, L.V,Elements of X-ray Crystallography, 1968.
7. Deer, W.A, Howie, R.A and J.Zussman, LongmansAn Introduction to the Rock Forming Minerals, 1966.
8. Alexander N.Winchell,Elements of Optical Mineralogy, Part I and II,Wiley Eastern (p) Ltd, 1968
9. Ernest, E.Walhstrom, Optical Crystallography, John Wiley & Sons.1960.
10. Kerr B.F,Optical Mineralogy. Mc Graw Hill, 5 th Edition, New York-1995.
11. Mitra, S,Fundamentals of Optical Spectroscopic and X-ray Mineralogy.

# Course outcomes:

**After the successful completion of this course, the students are able to:**

- **Gain knowledge about the source minerals as raw materials for anything on the Earth and for the survival of life**
- **Independently able to classify the crystals based on symmertical elements and face indices**
- **Understand various physical, chemical and optical properties of minerals so as to discriminate them**
- **Provide ideas about the major existence of rock forming silicates at the surface of the Earth**
- **Understand the various properties of mineral groups**
- **Know the crystal and mineral forms and their habits**

# Crystallography

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




Azurite


Ice crystals in plane


Aragonite


Kyanite

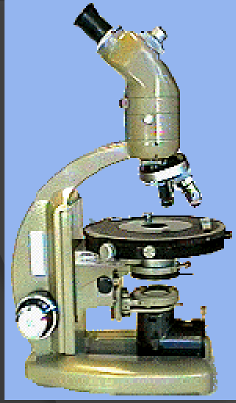

Diamond xal


Beryl

Quartz crystals

An eg. of closely packed lattice system

# Mineralogy

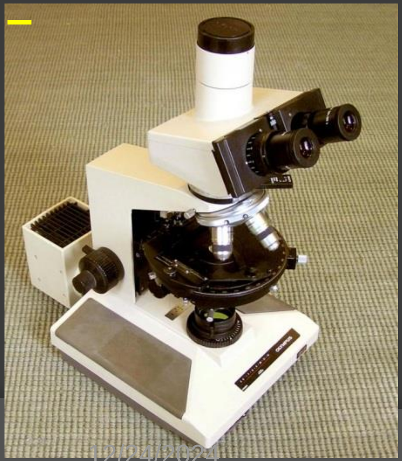


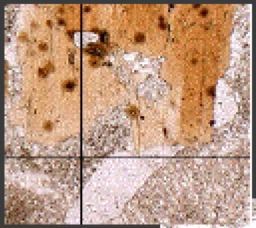
- **Mineralogy is the study of chemistry, crystal structure, and physical (including optical) properties of minerals.**
- **Specific studies within mineralogy include the processes of mineral origin and formation, classification of minerals, their geographical distribution, as well as their utilization.**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

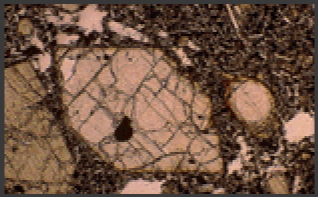
FYR

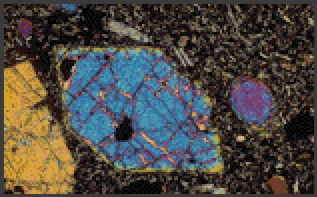
**Chalcocite, Copper ore**

**Petrological / Polarizing microscope –**

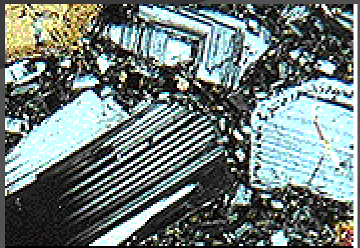








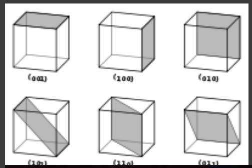
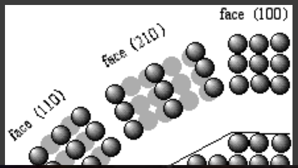
**Microscopic view of Mineral Thin sections**

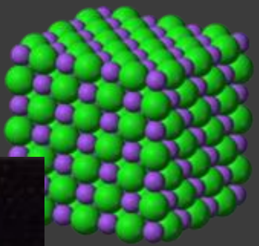


# Physical Mineralogy

- 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.

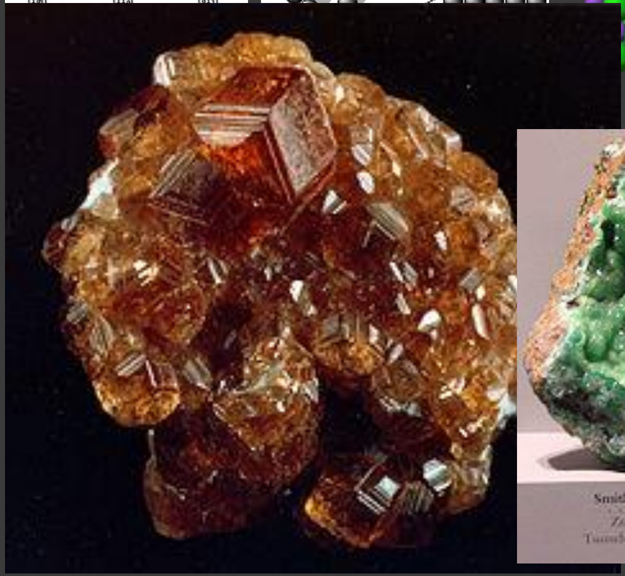
**Symmetry & Structures**



F Y R

**Heamatite – Brown streak**



**Satinspar – Silky Lustre**

**Pyrite – Metallic Lustre**

**Garnet – Dodecahderal habit**

**Smithsonite – Botryoidal habit**

# 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 neither orderly repeating arrangement nor long-range order of the positions of the atoms, i.e., hapazardous.
- Hence, due to the absence of orderly arrangement of atoms, the amorphous solids show no external crystalline form.

# How does the crystals formed?

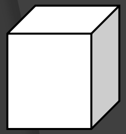
Igneous    Evaporites    Sublimates / Fumeroles

- **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 been developed with their distinct faces as a result, but at many times they form an incomplete crystalline solids due to lack of space for their growth in the chamber / non-availability of saturated liquid / broken due to disturbances caused during their growth, sudden changes in temperature & pressure, etc.
- **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 above said conditions under which they solidified.

# Crystallinity of a crystal:

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

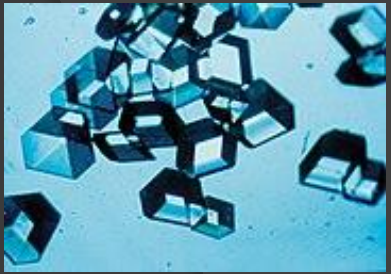
- **Euhedral** - When a crystal developed uniformly in all directions with its proper plane surfaces (or crystal faces) visible with our naked eyes, then it is named as *'Euhedral crystal'*.



- **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**.

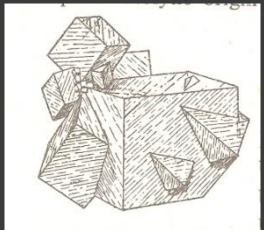


FIG. 119. Fluorspar

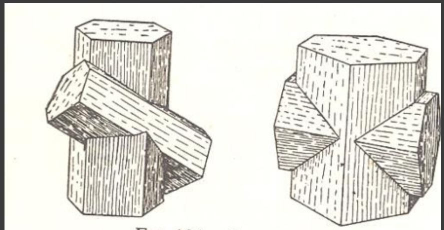
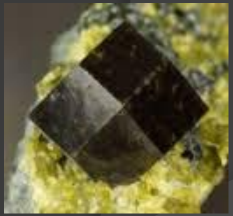


FIG. 134. Staurolite Twins

- **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.

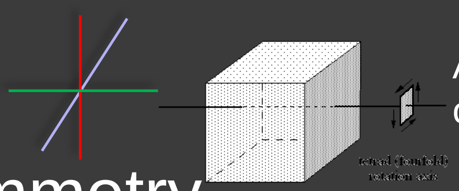


# Symmetrical elements of crystals

- 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, like-edges, like-corners, etc.

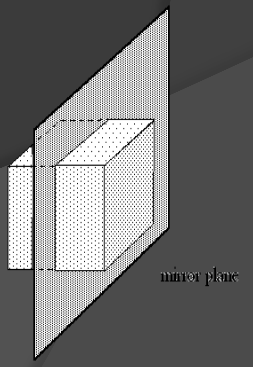
- Thus, the symmetry is defined with reference to **three** criteria:




Axes penetrates the center point of faces and crystal center

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

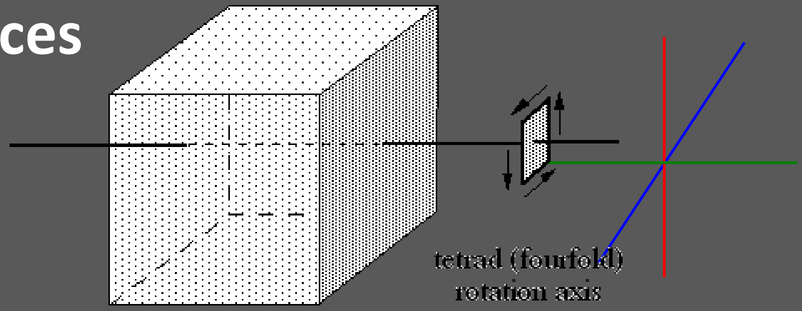
Mirror planes, that divides the crystals into two equal halves




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. It is **Absent**, if such like-features in the top-halft are not present at the bottom-half of that crystal (Hemi-morphic).

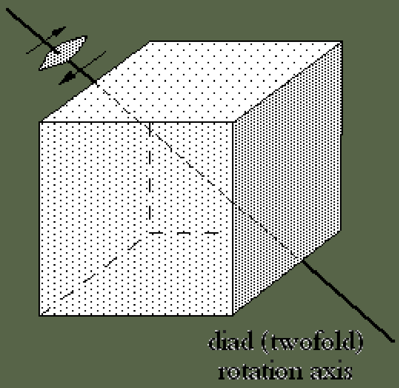
# Axes of symmetry

**Principal Axes** connecting opposite **faces**



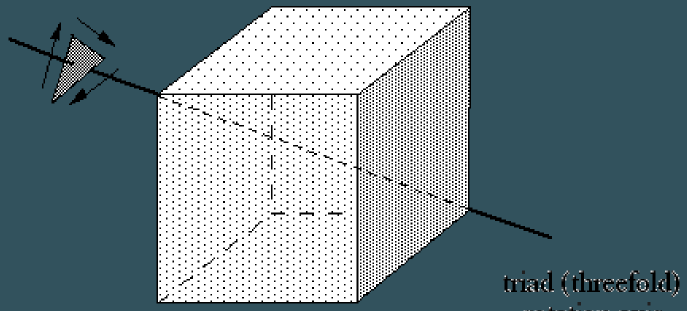

**3 Principal Axes of 4 fold symmetry**

**Diagonal Axes** connecting opposite **edge centers**



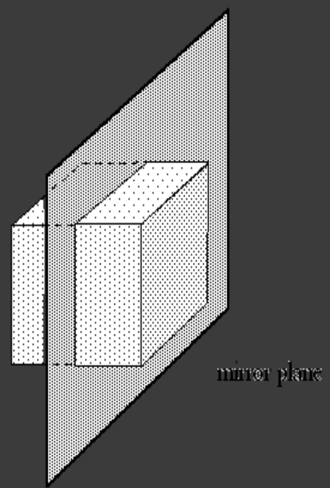

**6 Diagonal Axes of 2 fold symmetry**

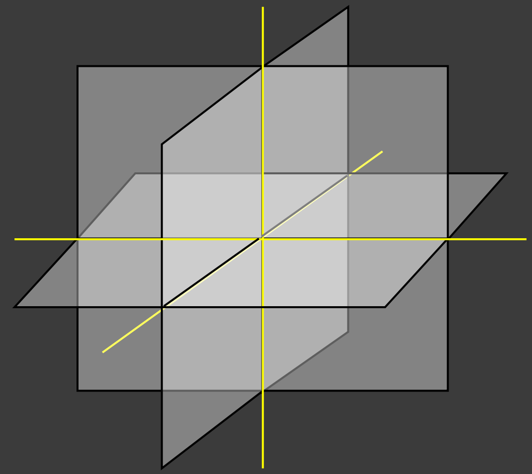
**Diagonal Axes** connecting opposite **corners**




**4 Diagonal Axes of 3 fold symmetry**

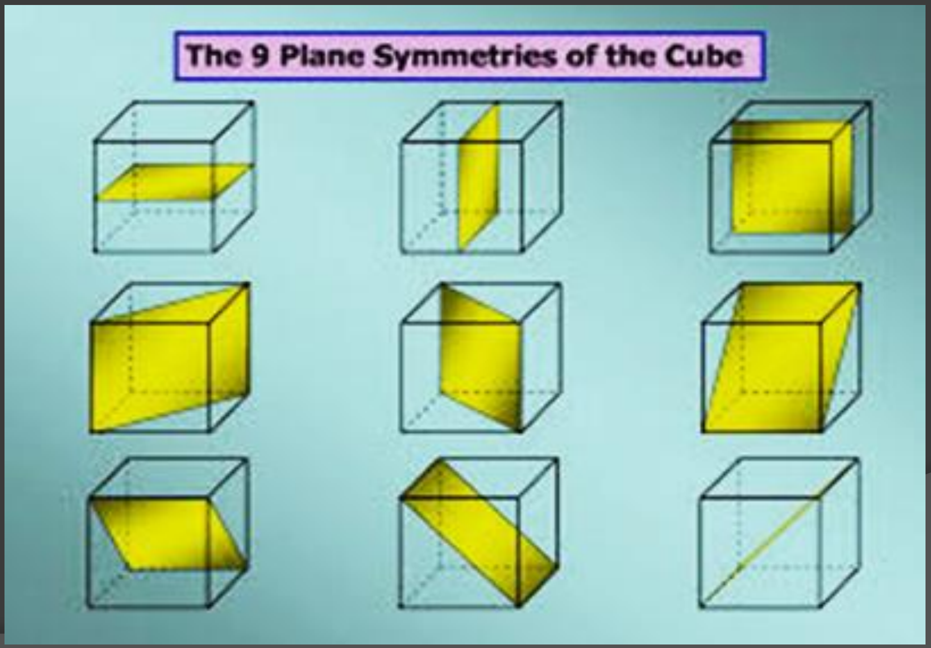
# Planes of Symmetry



3 principal planes of symmetry

6 diagonal planes of symmetry

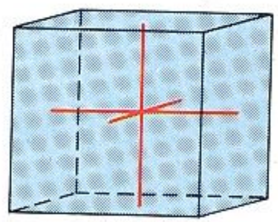
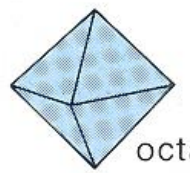
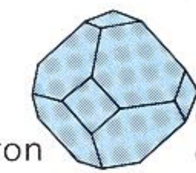
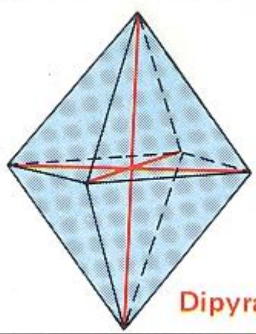
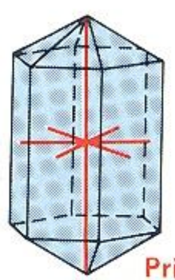


# Center of Symmetry

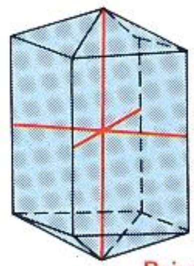
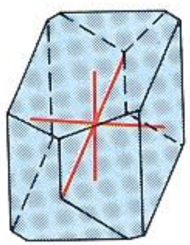
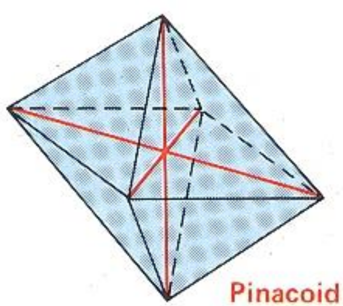
- Like faces, edges, etc., are arranged in pairs in corresponding positions on opposite sides of a central point – Center of symmetry. It is noted as ‘Present or Absent’.

- **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

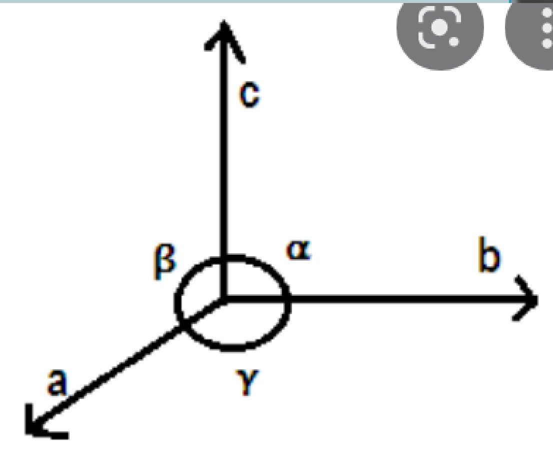
| Crystal System | Common Crystal Form and Description | Mineral Examples |
|---|---|---|
| Isometric |  Cube cubic prism  octahedron  cube-octahedron combination<br>Equidimensional crystals with three axes of equal length and at 90° to one another | **Halite**<br>**Diamond**<br>**Garnet** |
| Tetragonal |  Dipyramid<br>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)**<br>**Cassiterite (Tin oxide)**<br>**Rutile (Titanium oxide)** |
| Hexagonal |  Prism-dipyramid combination<br>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**<br>**Calcite**<br>**Dolomite** |

# CRYSTAL SYSTEMS AND FORMS…CONTD…

| | | | |
|---|---|---|---|
| Orthorhombic |  Prism-dipyramid combination | Crystals with three axes at right angles, each of a different length | **Olivine**<br>**Anhydrite, Gypsum**<br>**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**<br>**Augite**<br>**Orthoclase** |
| Triclinic |  Pinacoid | Crystals with three unequal axes all of which are inclined to one another | **Turquoise**<br>**Plagioclase Feldspar** |

# LENGTH AND ANGULAR RELATIONS IN CRYSTAL SYSTEMS

| Crystal System | # | Cell Parameters |
|---|---|---|
| **Cubic** | 1 | a1 = a2 = a3; α = β = γ = 90° |
| **Tetragonal** | 2 | a1 = a2 ≠ c; α = β = γ = 90° |
| **Hexagonal:** Trigonal & Rhombohedral | 2 | a1 = a2 = a3 ≠ c; α = β = 90°, γ = 120° |
| **Orthorhombic** | 3 | a ≠ b ≠ c; α = β = γ = 90° |
| **Monoclinic** | 4 | a ≠ b ≠ c; α = γ = 90°, β > 90° |
| **Triclinic** | 6 | a ≠ b ≠ c; α ≠ β ≠ γ |



# Ratios of the Intercepts & Axis ratio

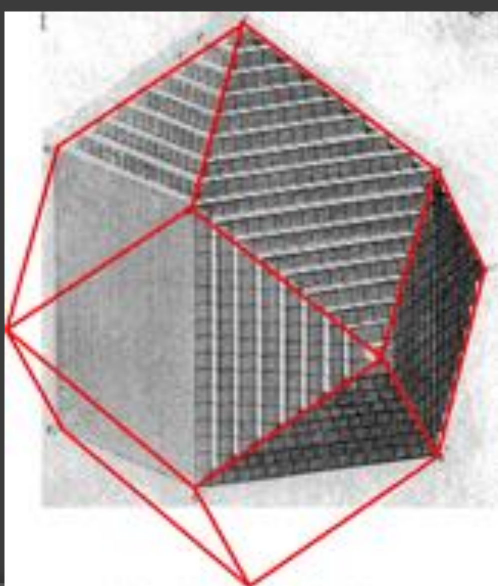
- The ratios of the distances from the origin at which the face cuts the crystallographic axes are the **"ratios of the Intercepts"**.
- The expression of length & angle measurement and calculation as multiples of one of their number is known as **"axis ratio"**.

# Crystallographic notation

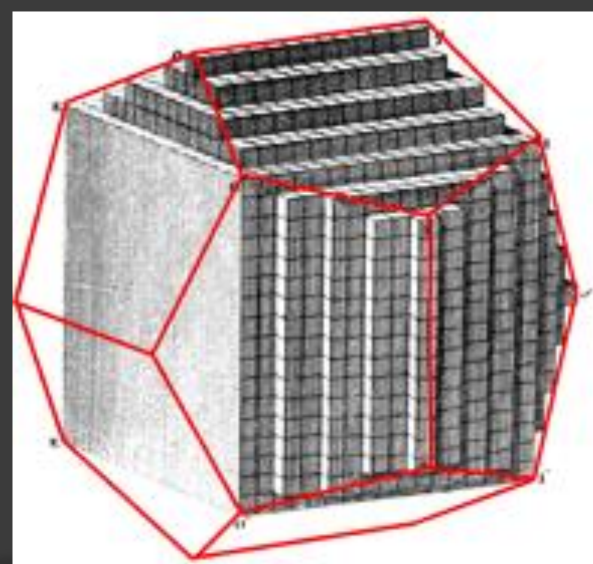
- **Crystallographic notation** is a concise method of writing the relation of any crystal face to the crystallographic axes.
- The most widely used systems depend upon either parameters or indices.
- **Parameters:** Length, Angle, Length ratio…
- The reciprocals of the parameters which form the basis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

# Law of Rational Indices

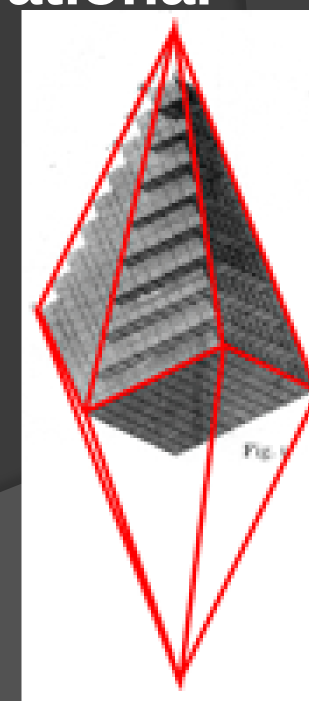
- Through the early studies of Steno and others (17th century), **René-Just Haüy** was able to postulate that if crystals of calcite and cubic garnets were built from **many small regularly-repeating blocks**, then these blocks could easily be used to **describe the faces of these crystals** in terms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

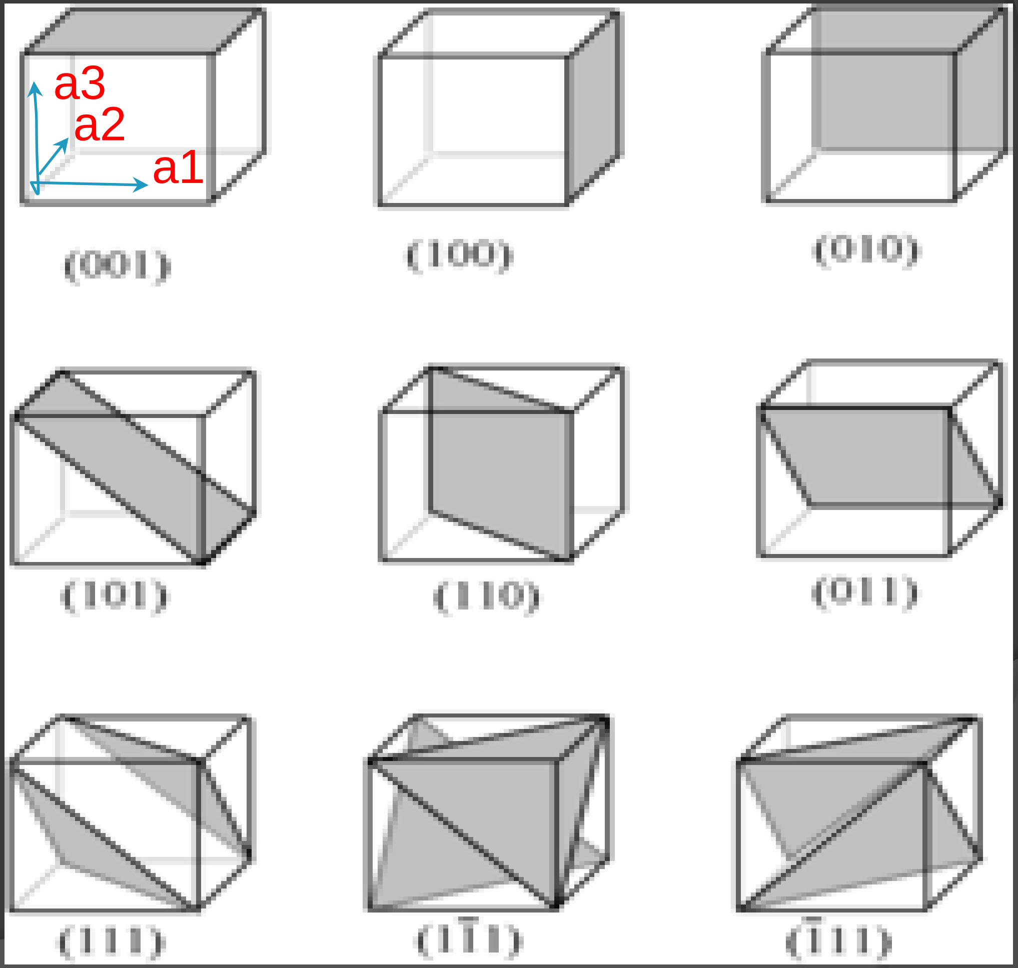
# Planes with different Miller indices in Isometric system of crystals

(Location of Planes are shown with reference to cube)

Cube

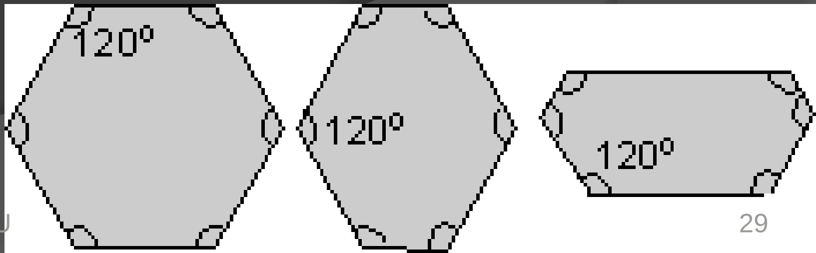
Dodecahedron

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 interfacial angles.**



# 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 ISOMETRIC /CUBIC System

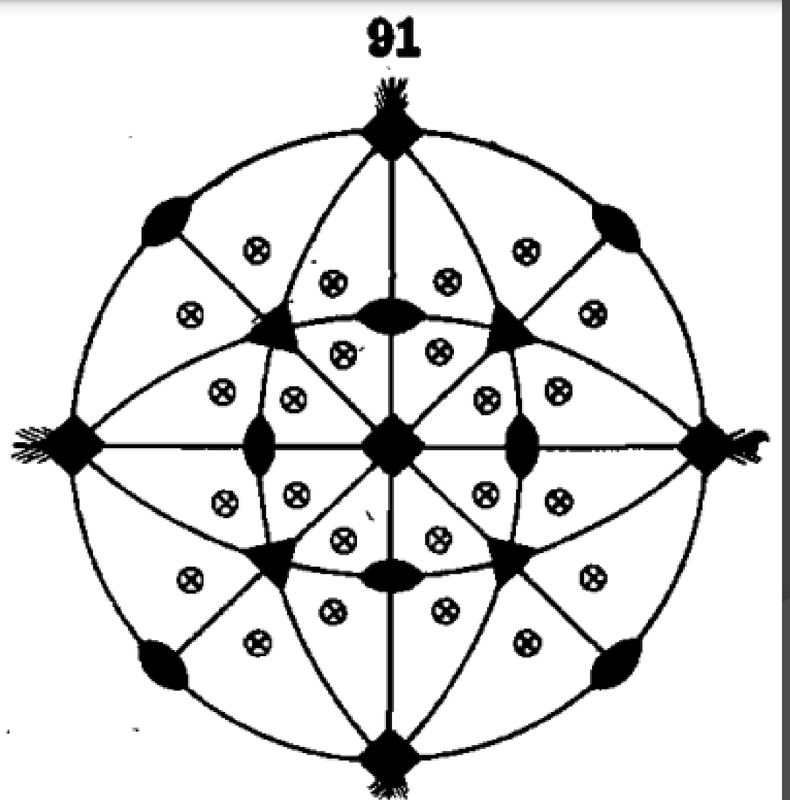
- A. Normal Class – Galena type
- B. Pyritohedral Class – Pyrite type
- C. Tetrahedral Class – Tetrahedrite type
- D. Plagiohedral Class – Cuprite type &
- E. Tetartohedral Class – Ullmannite type.

# A. Normal Class (Galena Type)

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

**Symmetry elements:**

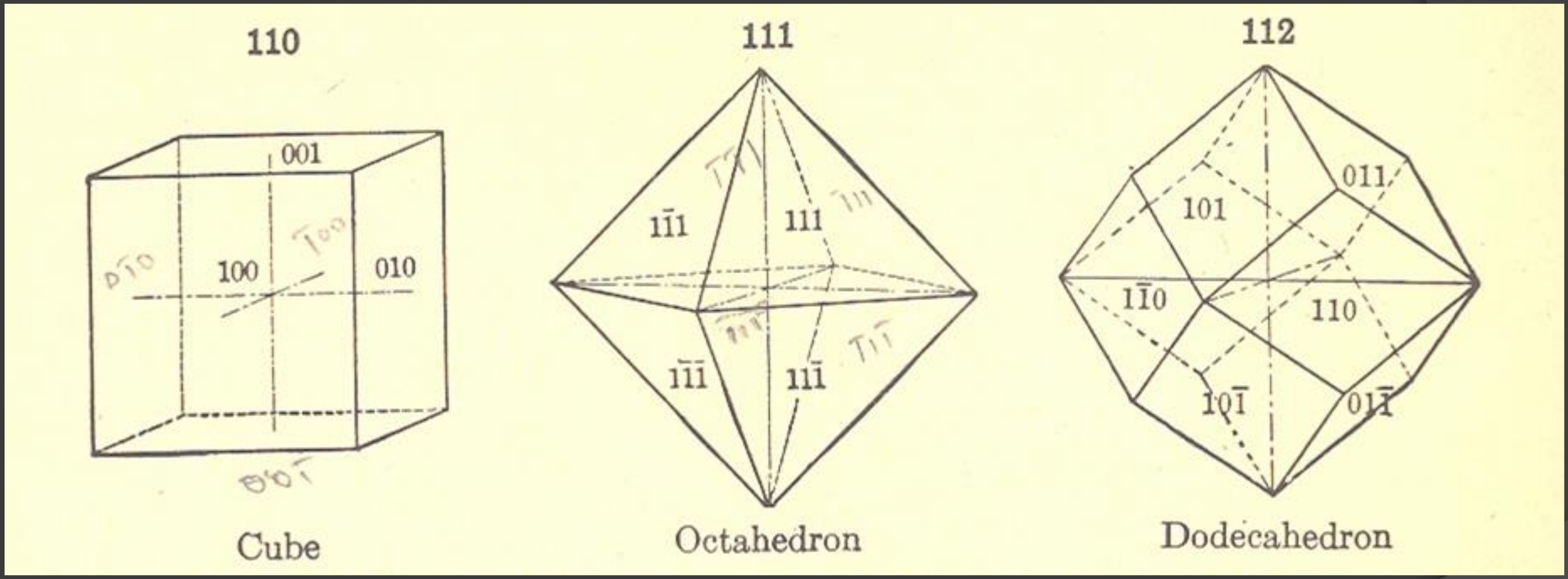
- 3 xl. Ax.-4, 4 diag. Ax.-3,
- 6 diag. Ax.-2 fold;
- 3 xl. P, 6 diag. P & C.




Symmetry of Normal Class, Isometric System

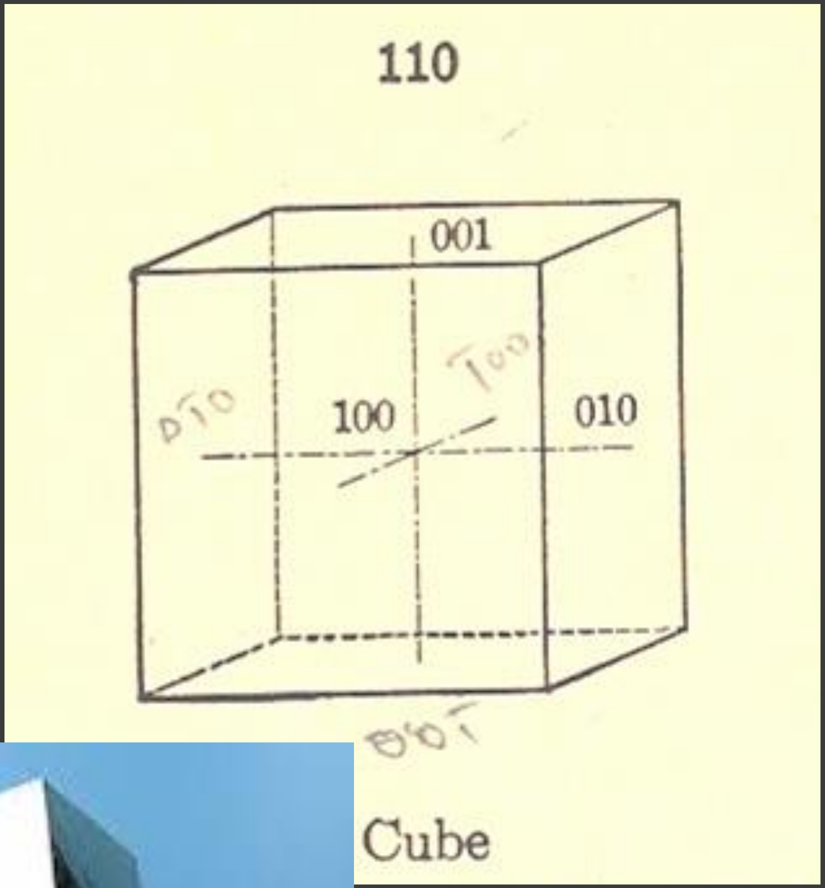
Back…2..CS

# FORMS in (A) NORMAL CLASS of ISOMETRIC SYSTEM



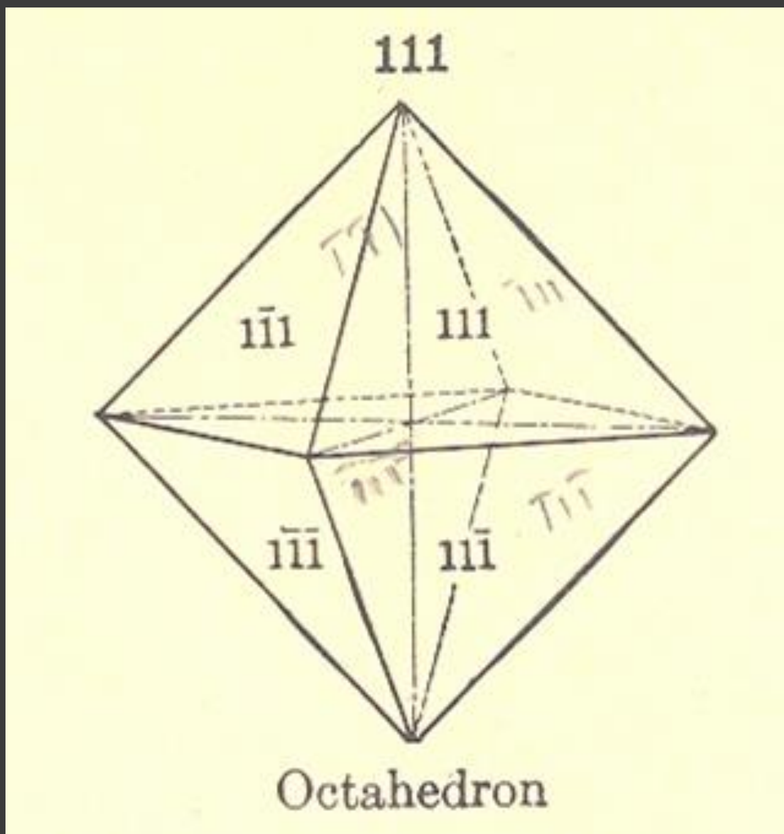

**1) Cube, 2) Octahedron, 3) Dodecahedron**

# 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.

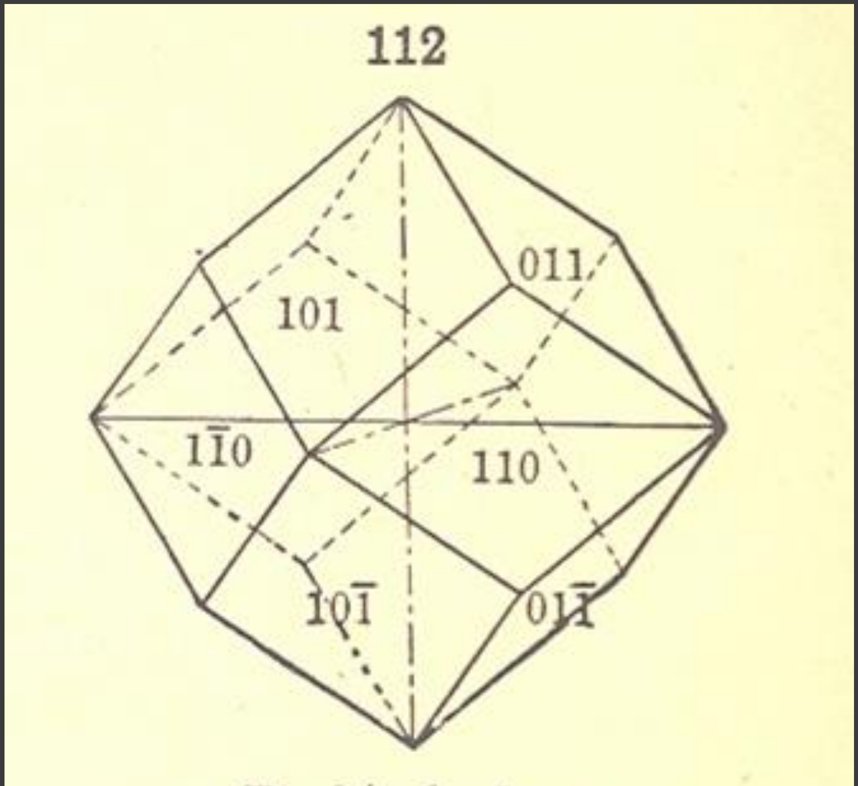
# 2. OCTAHEDRON




Octahedron

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

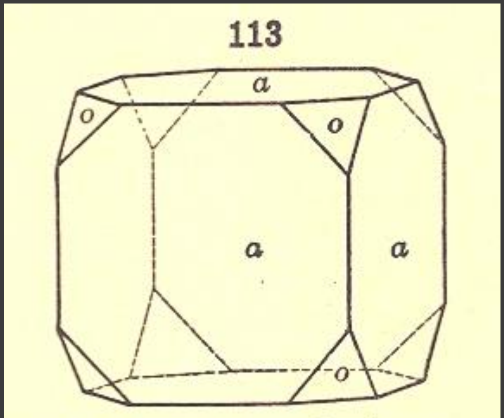
# 3. DODECAHEDRON



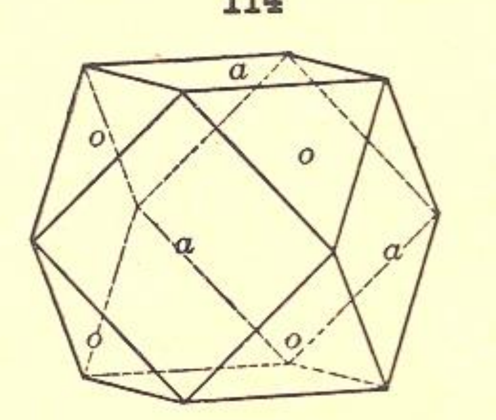
Dodecahedron

- 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

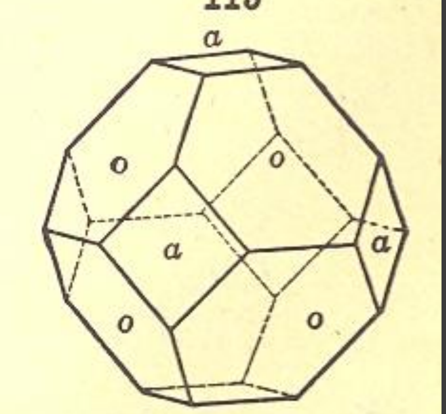
# COMBINATION OF FORMS



Cube and Octahedron



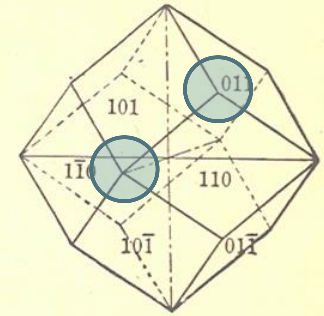
Cube and Octahedron



Octahedron and Cube

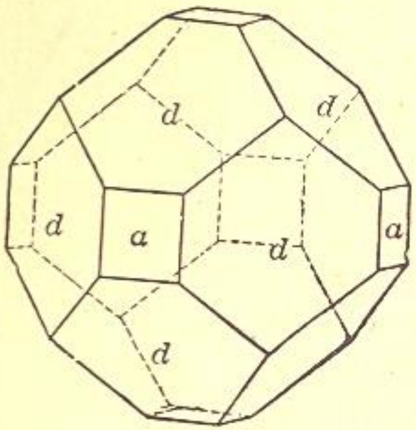
- Cube modified by Octahedron – 113
- Both (C & O) are in equilibrium - 114
- Octahedron faces are replaced by square cubic faces – 115
- By counting the no. of faces – it is easy to identify the combinations

112



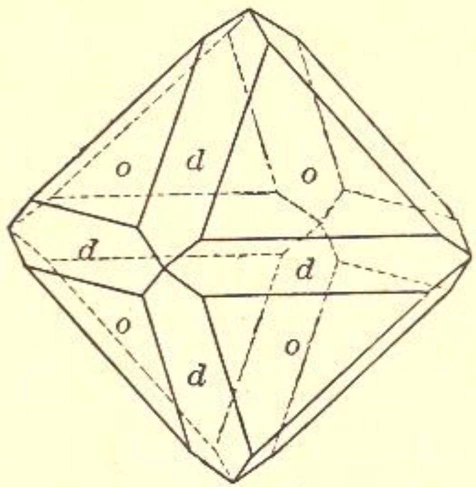

Dodecahedron

116



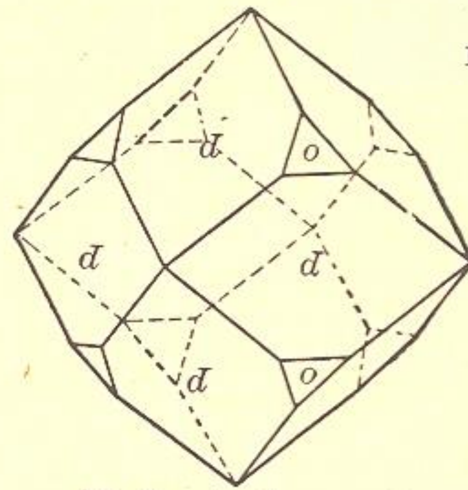

Dodecahedron and Cube

117



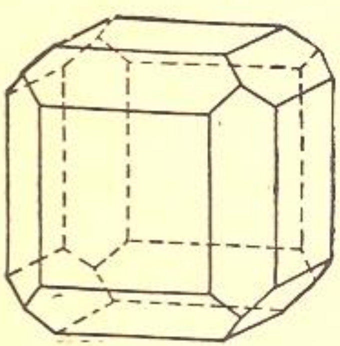

Octahedron and Dodecahedron

118



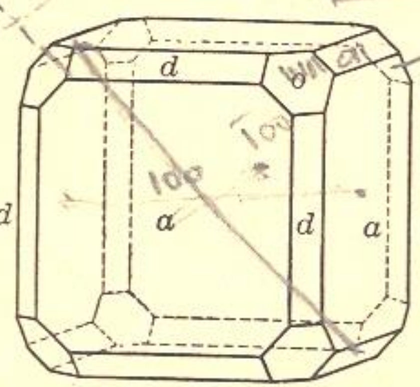

Dodecahedron and Octahedron

119



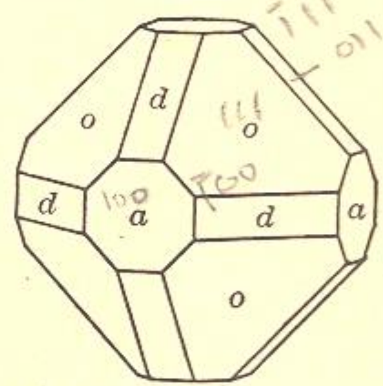
Cube and Dodecahedron

120

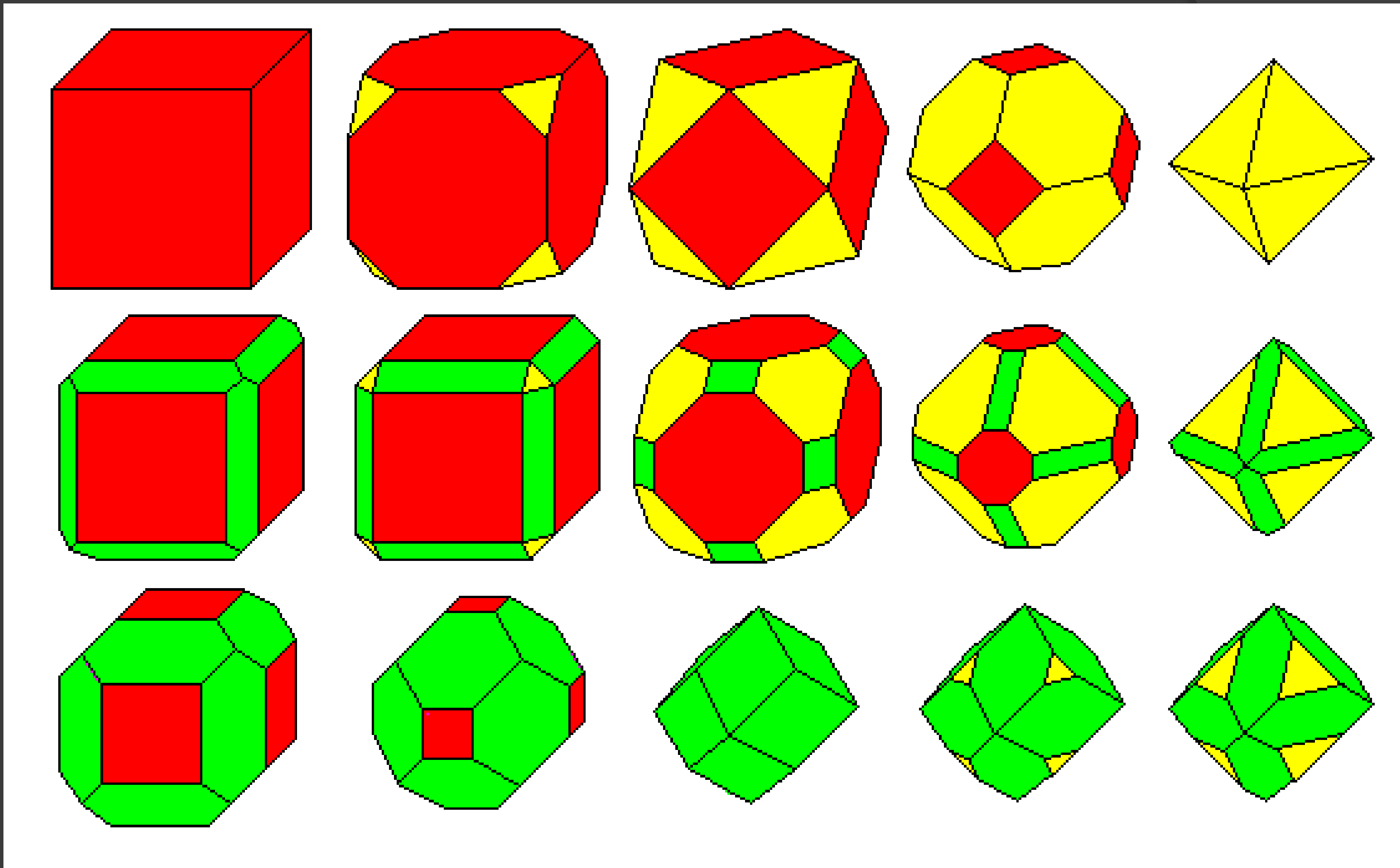



Cube, Octahedron and Dodecahedron

121

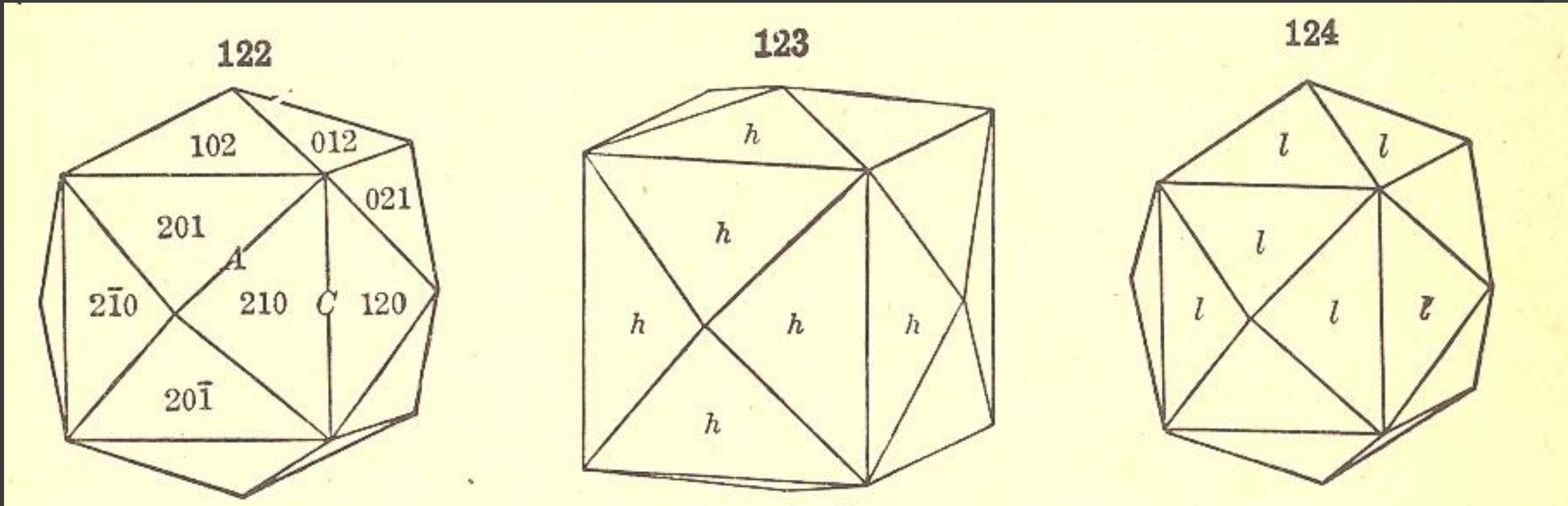



Octahedron, Cube and Dodecahedron



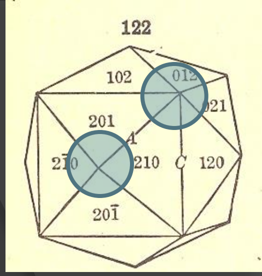
# 4. TETRAHEXAHEDRON

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



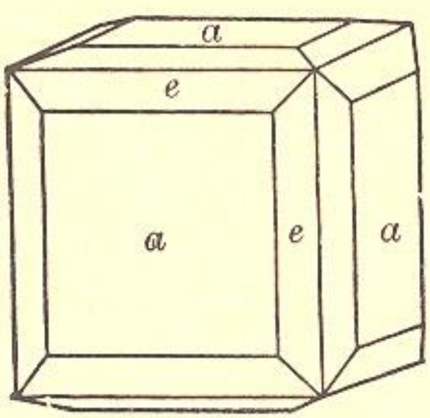

Tetrahexahedrons

# COMBINATION OF FORMS



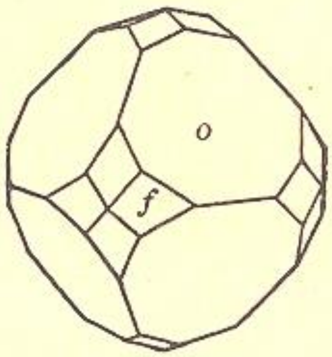

- Quick way to identify the Combinations with Tetrahexahedron – will have either '∗' STAR symbol (with six rays) at the corners of cube (as seen in Tetrahexahedron), or 'X' CROSS symbol at the corners of octahedron / dodecahedron, and
- there are 24 such faces totally.

125



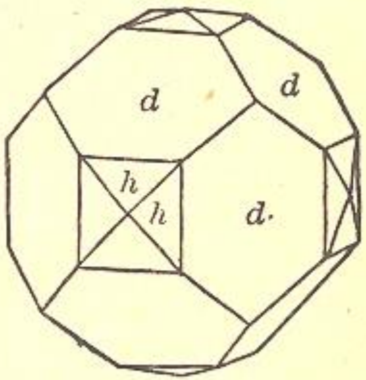

Cube and Tetrahexa-hedron

126




Octahedron and Tetrahexahedron

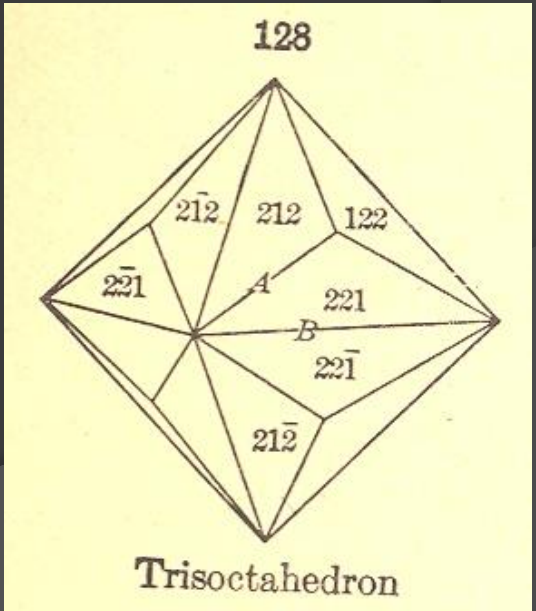
127




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

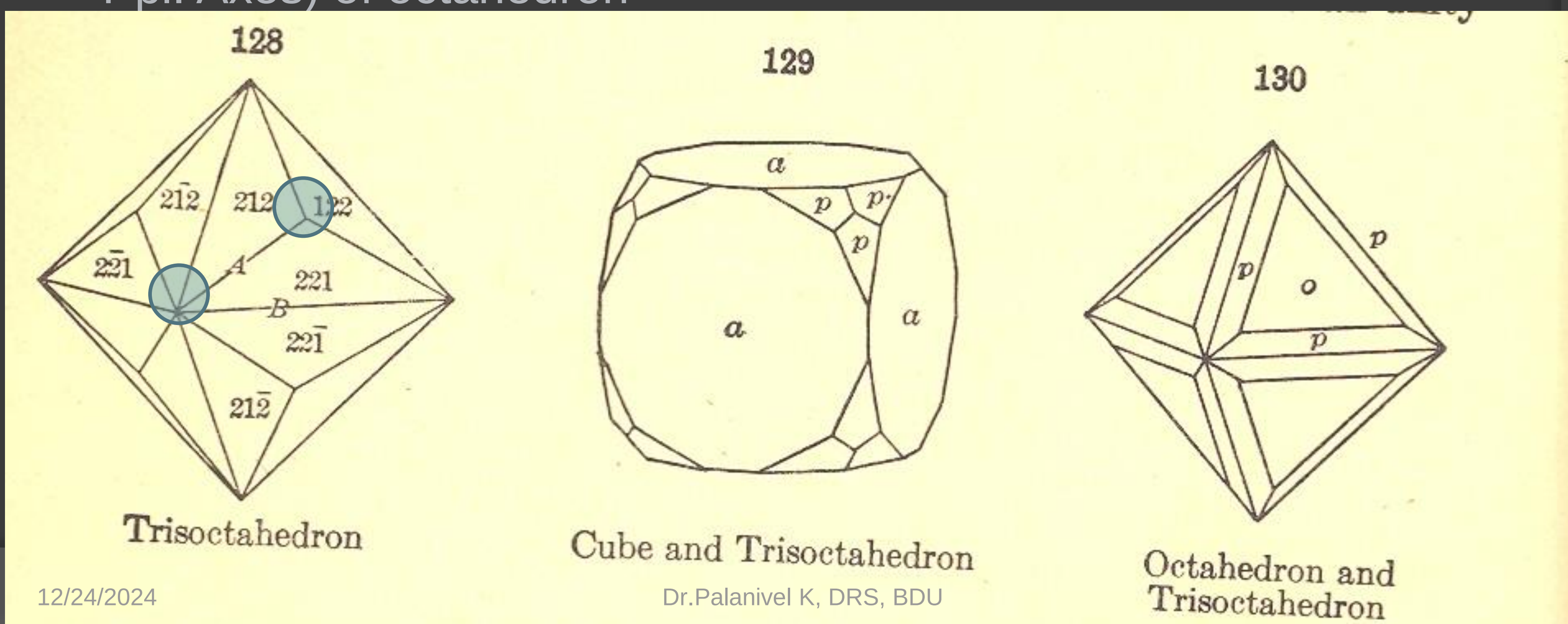


# COMBINATION OF FORMS

- 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** edges, along with other forms.

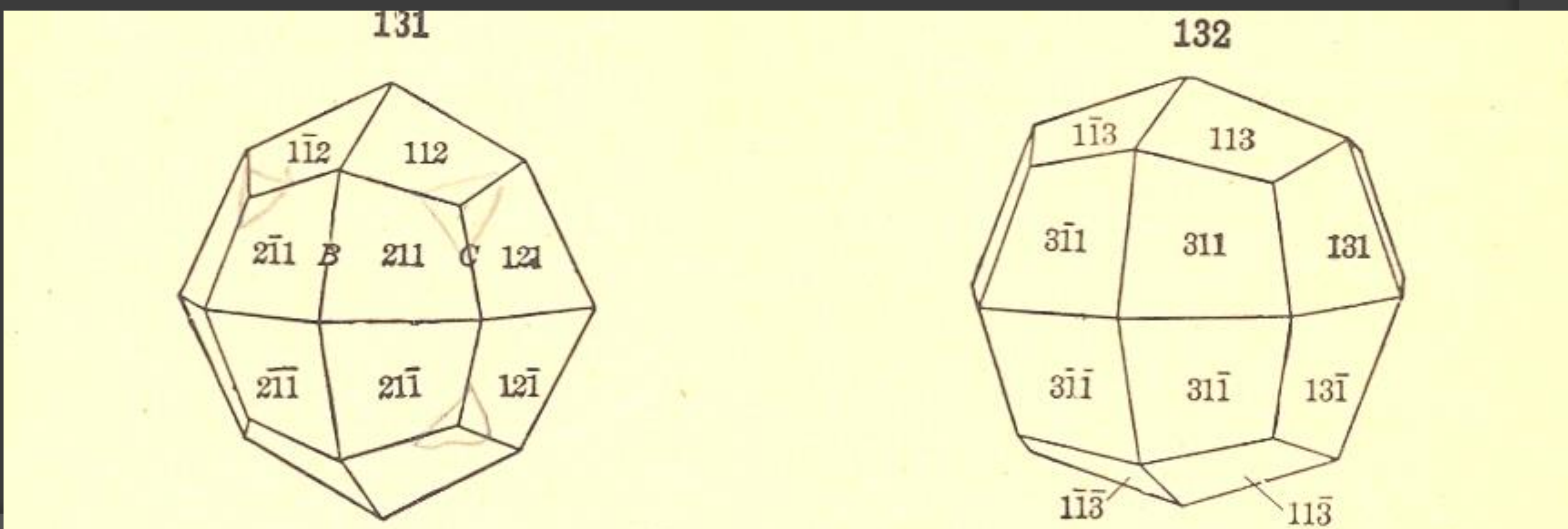
Or

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



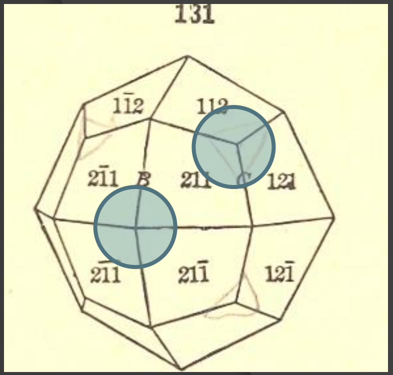
# 6. TRAPAZOHEDRON

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

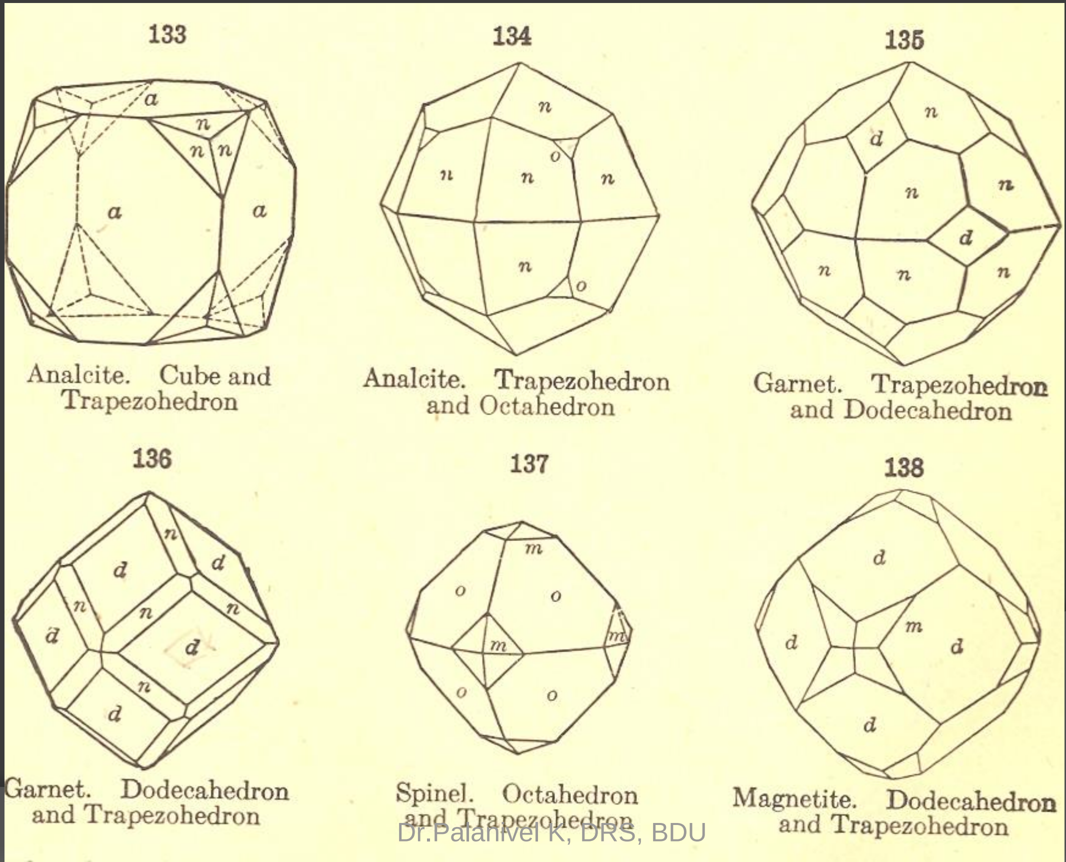



Trapezohedrons

# Combinations

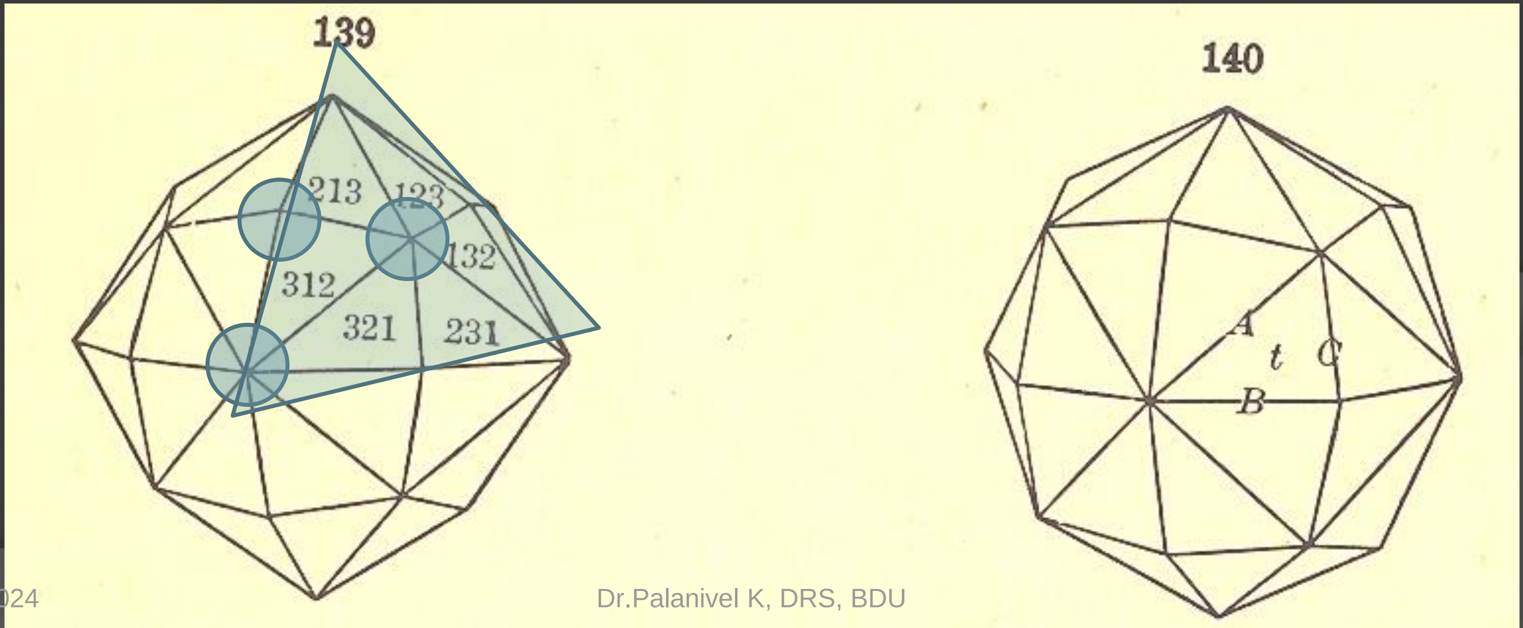



- 'Y' in upright position in the corners of cube
- '+' symbol at the corners, where Ppl. axes meet
- Total no. of such faces are 24



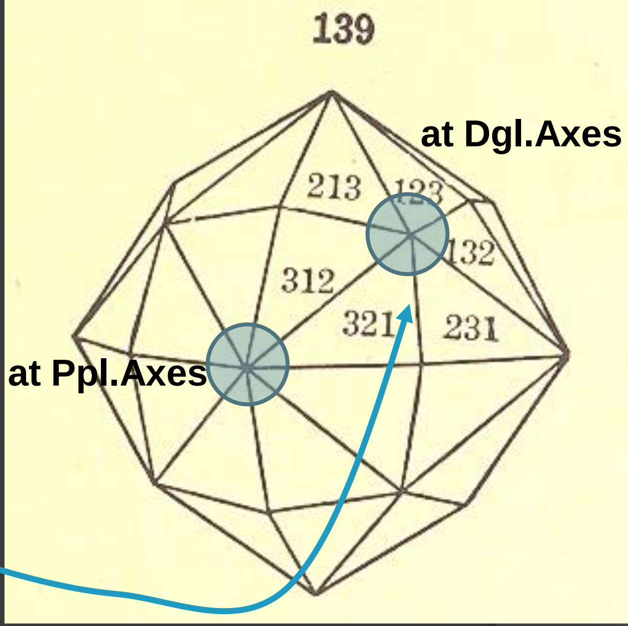

# 7.Hexoctahedron

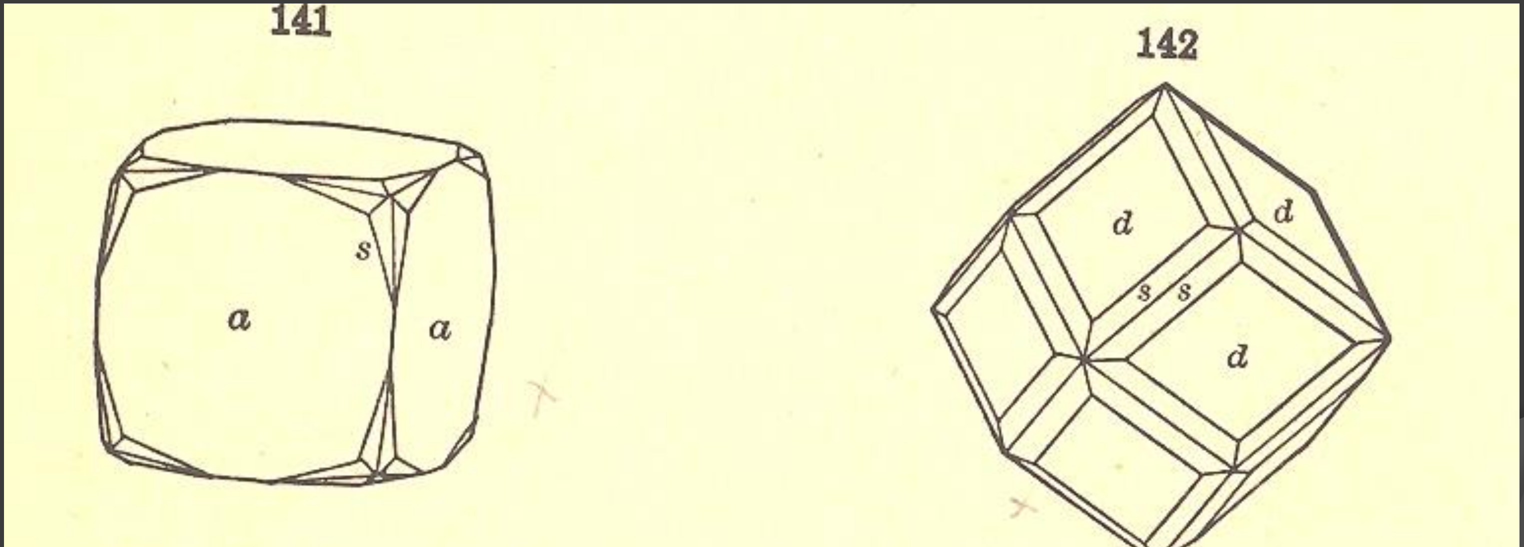
- In every Octahedral face, there are 6 nos. of triangular faces
- Hence in total, there are 8 x 6 = 48 faces
- 312 – Miller Index



# Combinations

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



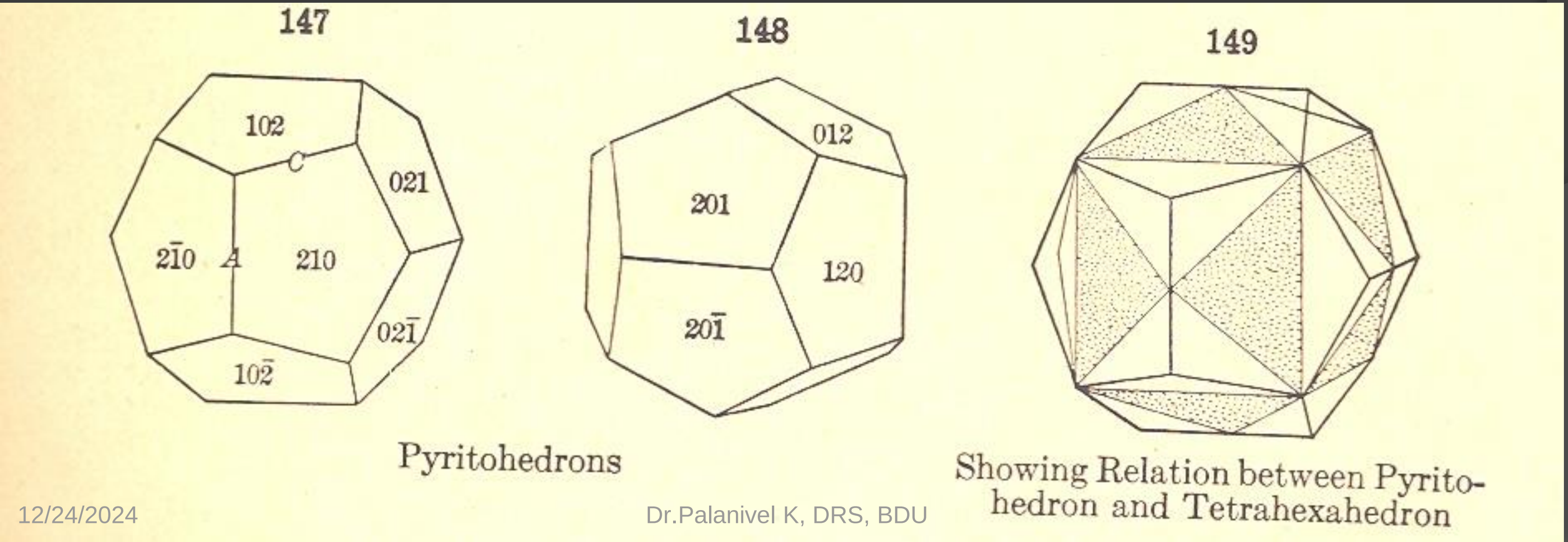

Fluorite. Cube and Hexoctahedron

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




Pyritohedrons

Showing Relation between Pyritohedron and Tetrahexahedron

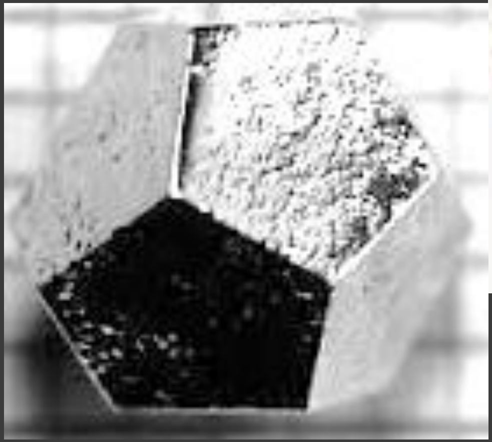
**Symmetry:**

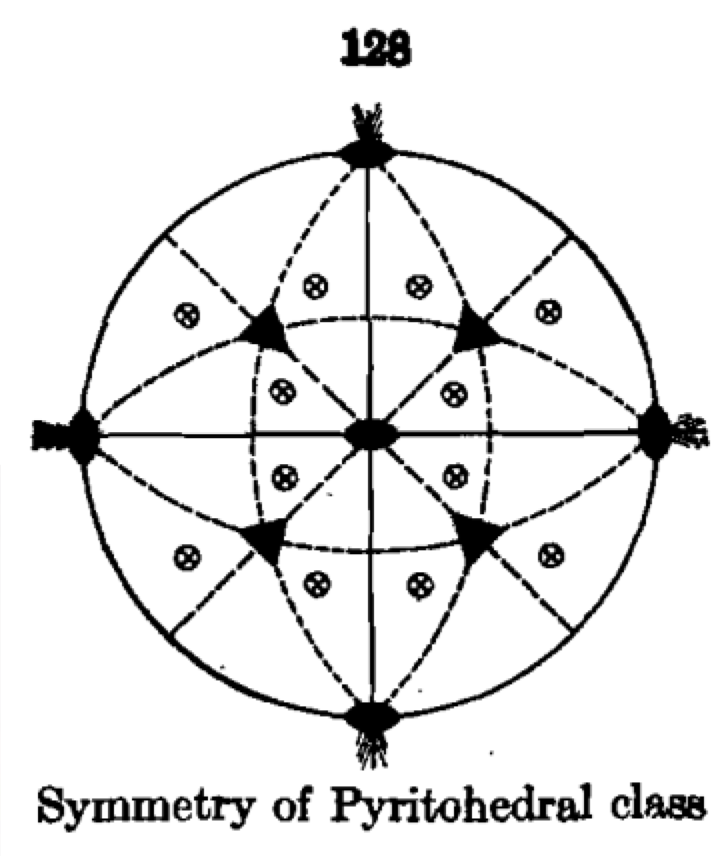
3 xl. Ax.-2,

4 diag. Ax.-3,

3 xl. P. &

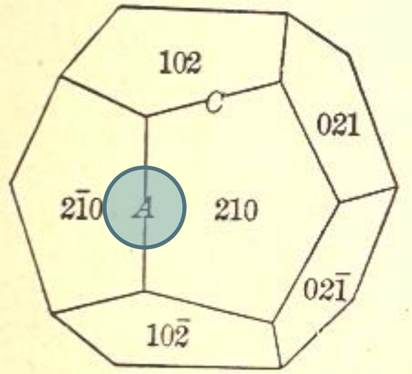
C.





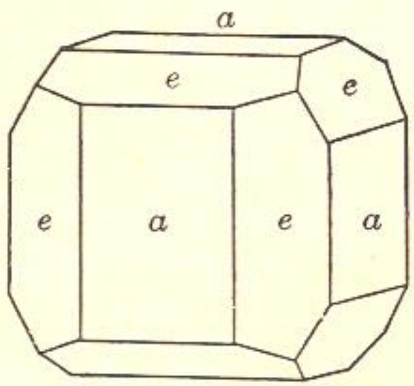
# Combinations

147



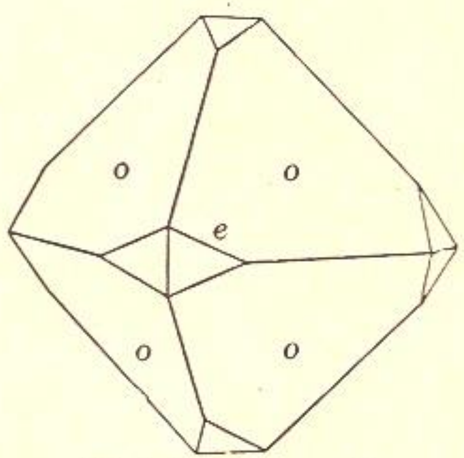

- Vertical / horizontal straight line in corners
- Paired faces sitting in juxtaposition
- Totally 12 paired faces

150



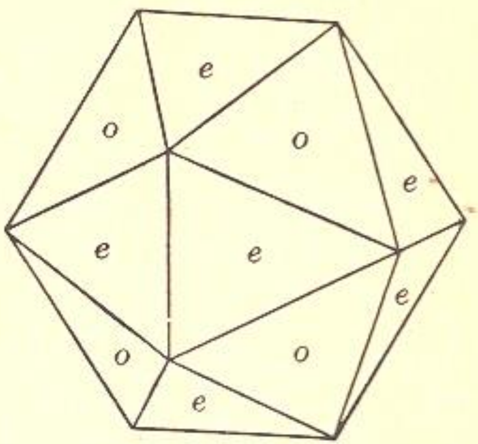

Cube and Pyritohedron

151




Octahedron and Pyritohedron

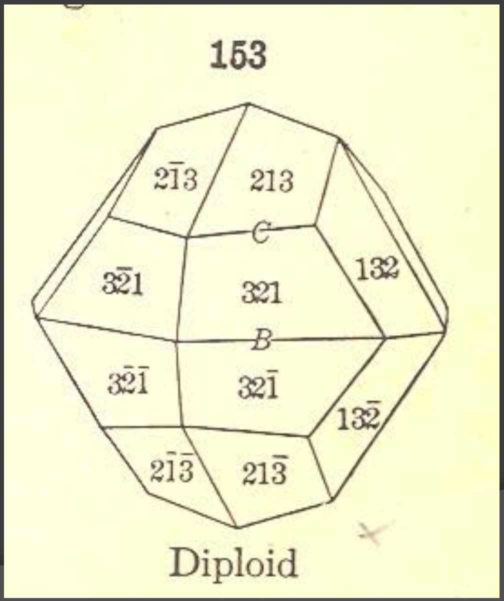
152




Octahedron and Pyritohedron

# 2. Diploid

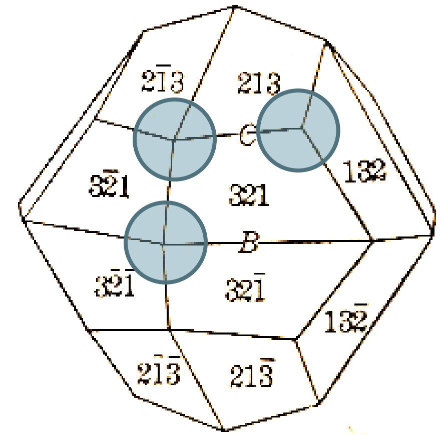
- Double / Paired tetragonal faces
- Totally 24 such faces
- 321 - Miller index



# Combinations

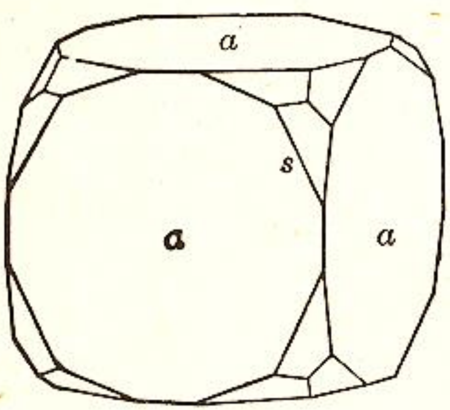
- Tilted ‘Y’ in corners (where diagonal axes meet)
- ‘+’ marks in other corners

153



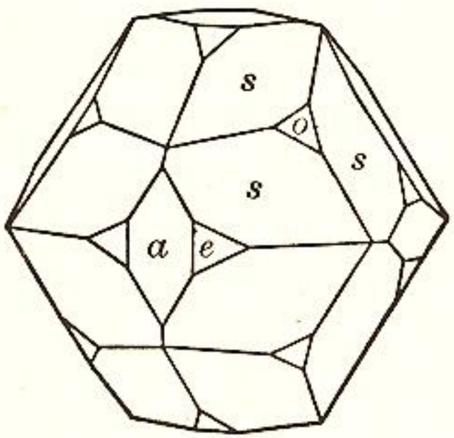

Diploid

154



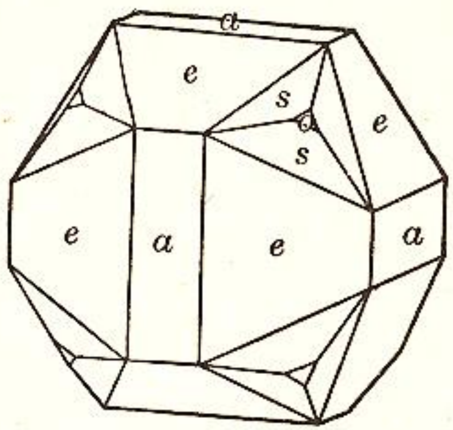

Cube and Diploid

155




Cube, Octahedron and Diploid

156




Cube, Diploid and Pyritohedron



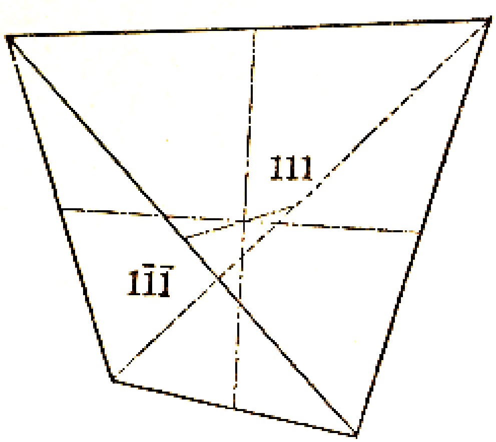
Back…2..CS

# C. Tetrahedral Class – Tetrahedrite type

## Forms:1. Tetrahedron

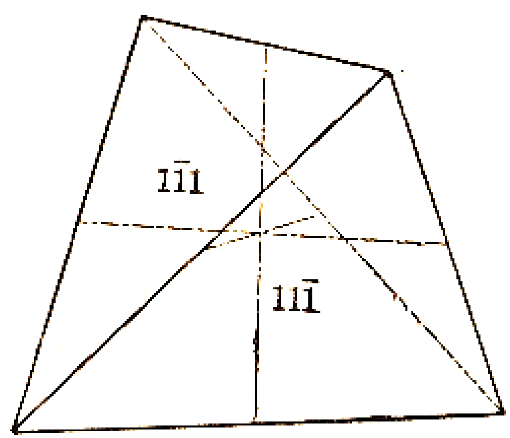
- 4 Equilateral triangles
- 111 – similar to Octahedron – Miller Index

159



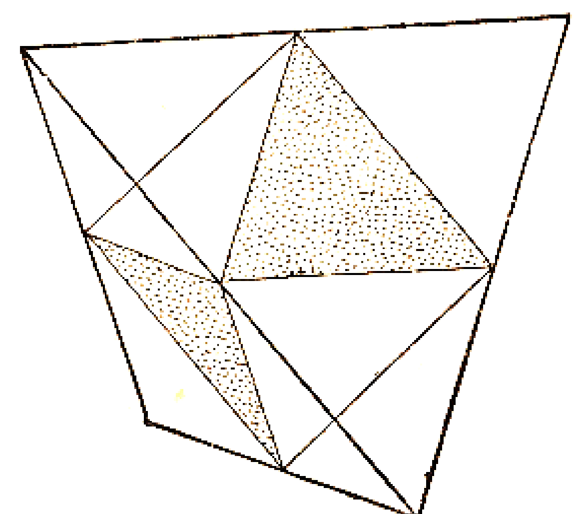

Positive Tetrahedron

160



Negative Tetrahedron

161



Showing Relation between Octahedron and Tetrahedron

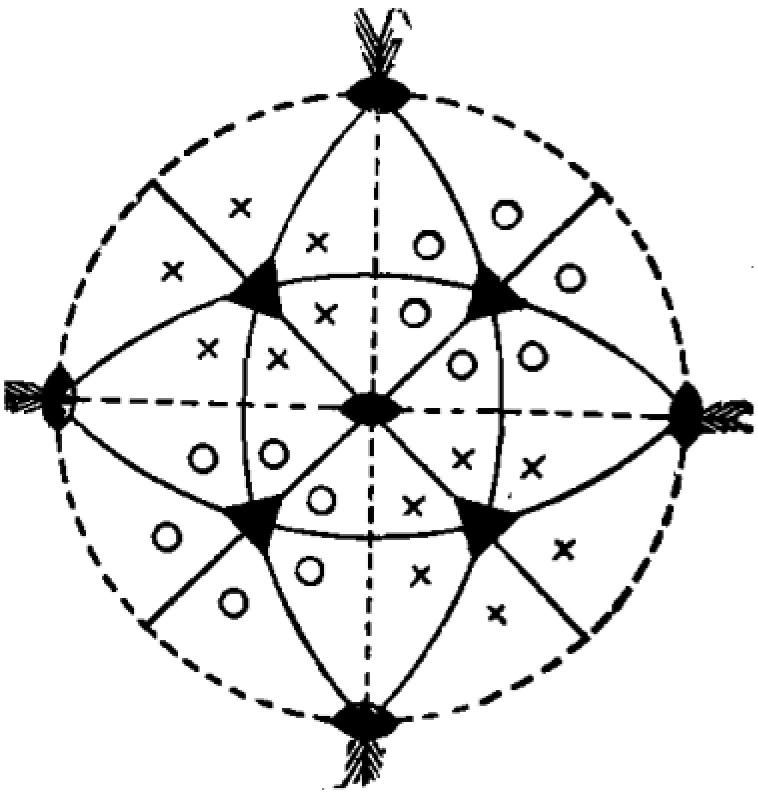
**Symmetry:**

3 xl. Ax.-2,

4 diag. Ax.-3 &

6 diag. P.

140

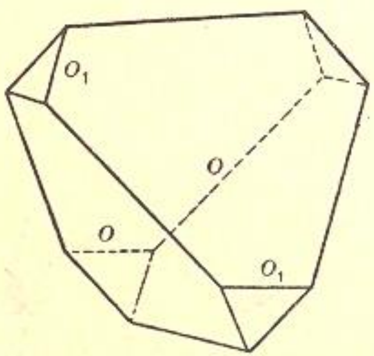


Symmetry of Tetrahedral Class

# Combinations

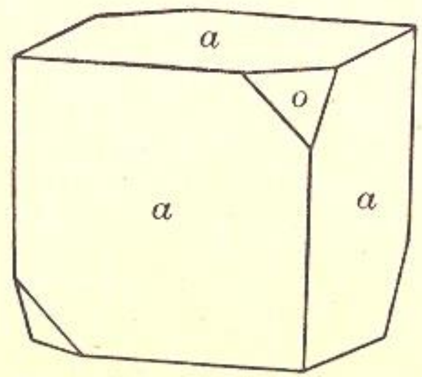
- 4 such faces – located in opposite corners only

162



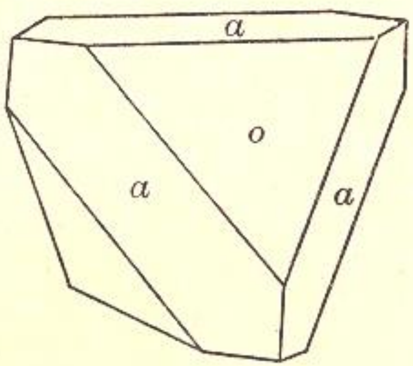

Positive and Negative Tetrahedrons

163

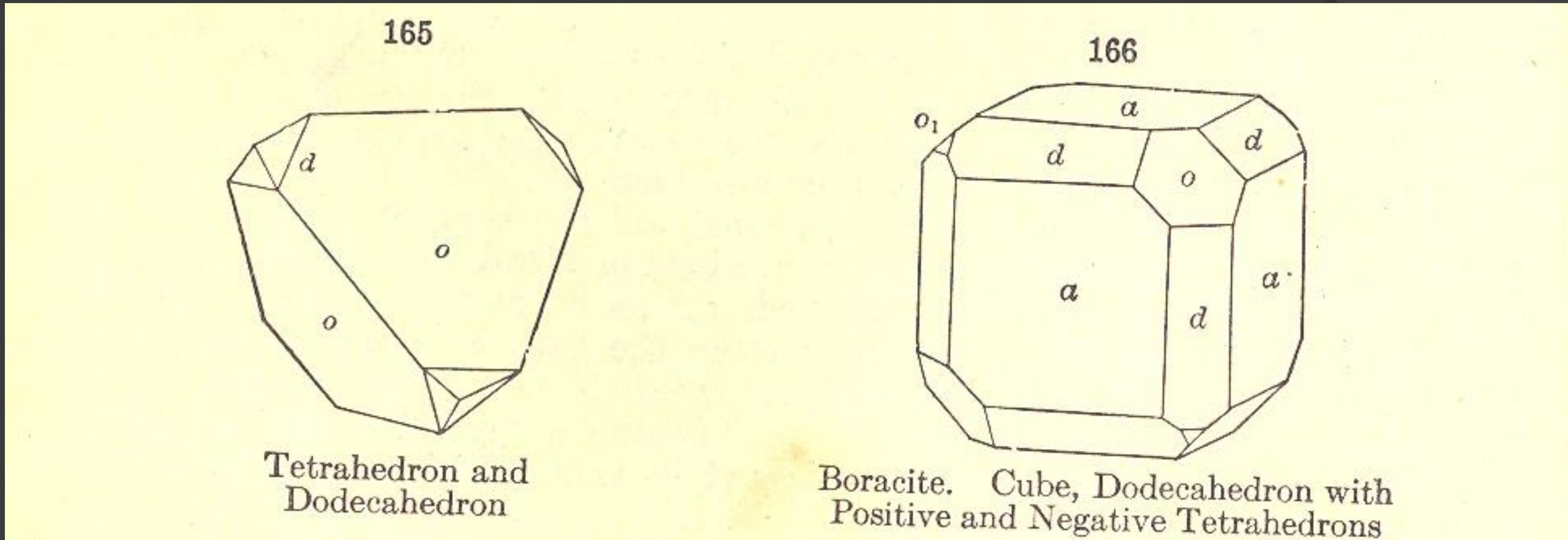


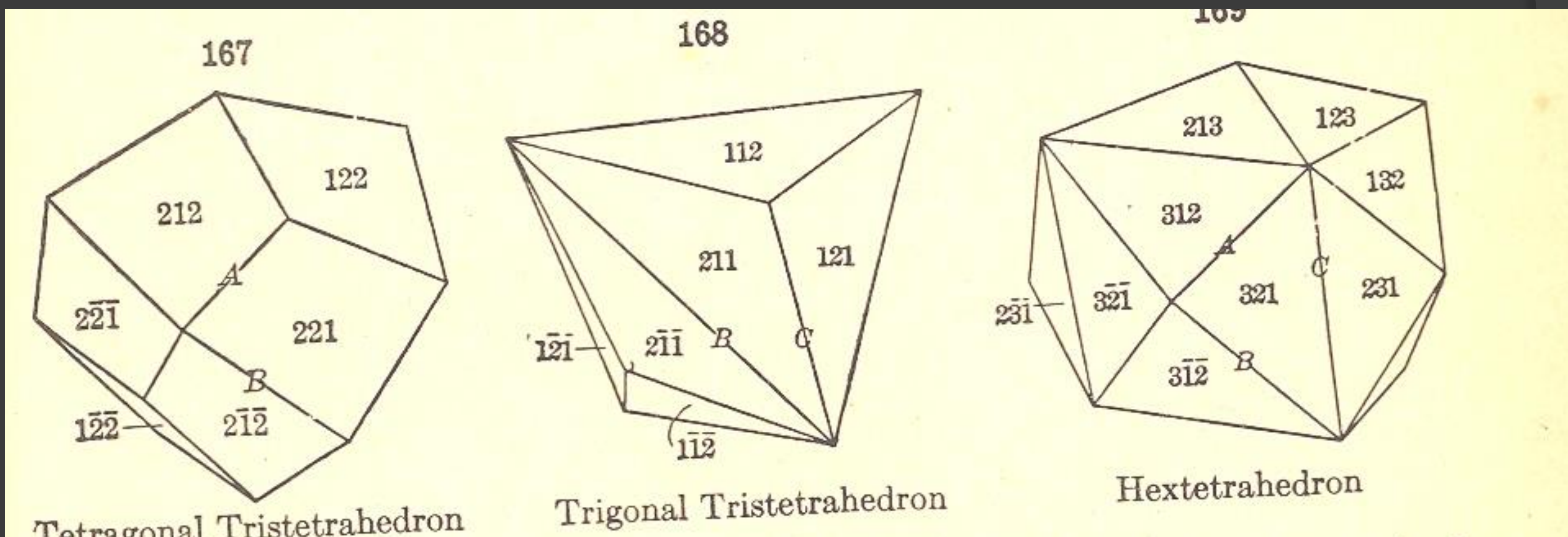

Cube and Tetrahedron

164

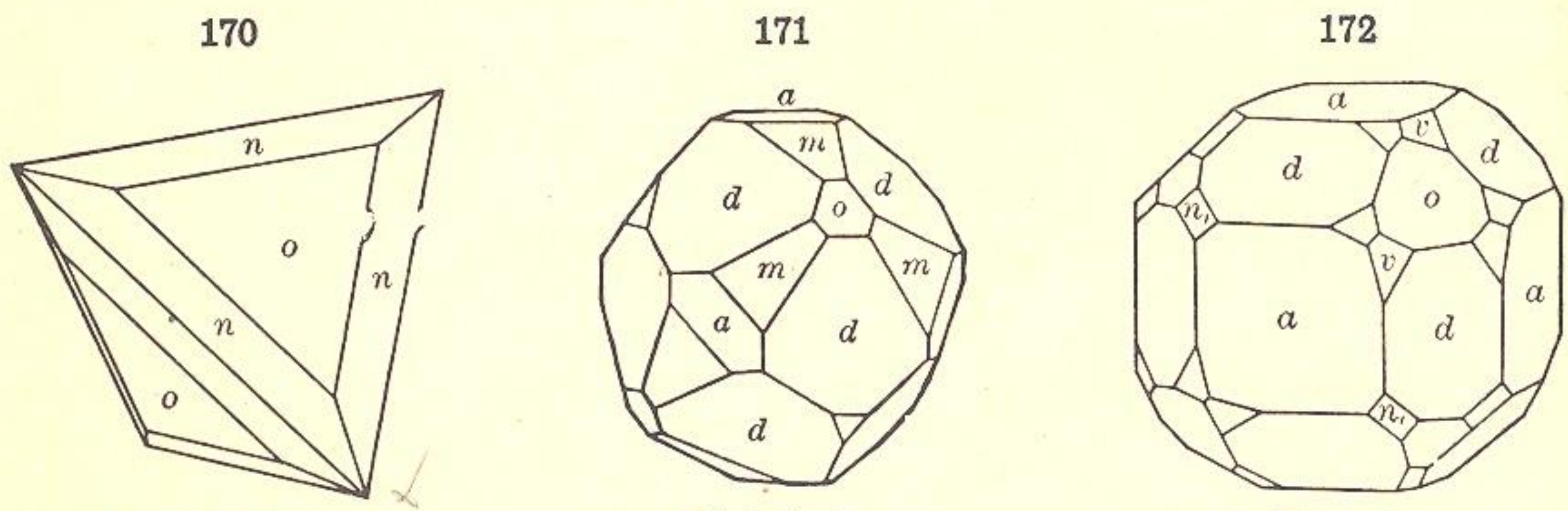



Tetrahedron and Cube




**2. Tetragonal Tristetrahedron, 3. Trigonal Tristetrahedron, 4. Hextetrahedron`**



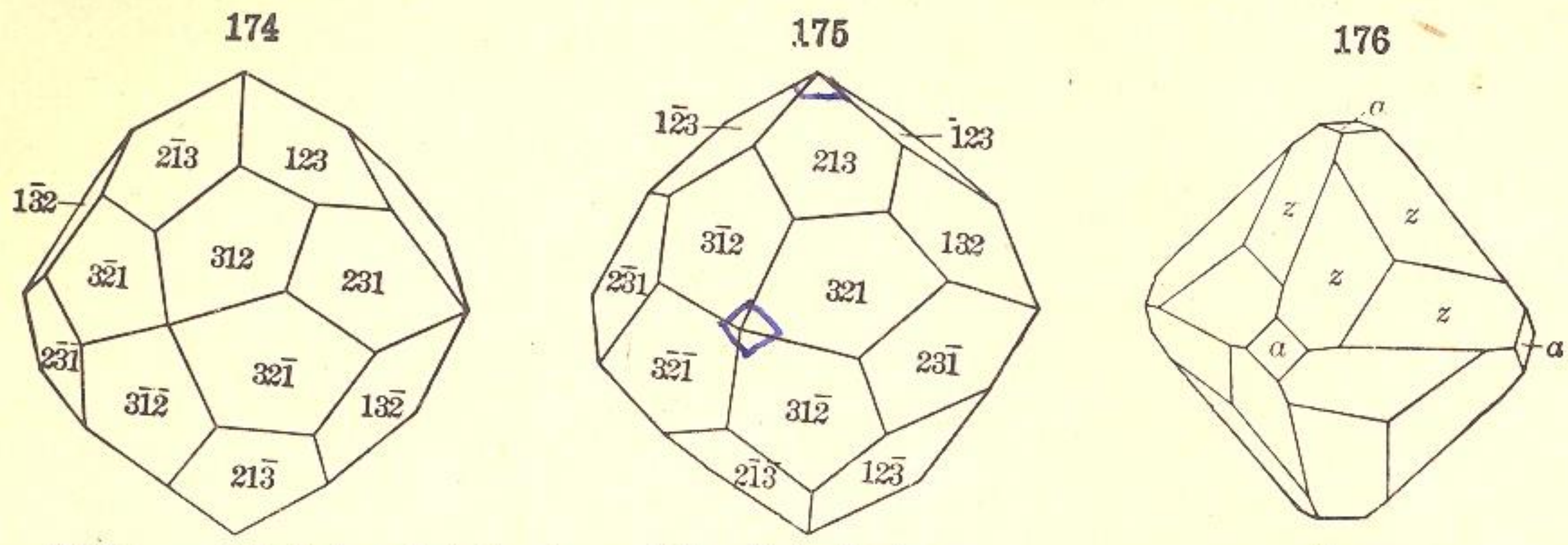

Tetrahedrite Sphalerite Boracite

o - +ve Tetrahedron
n, m – Trigonal tristetrahedron
d – Dodecahedron
a – Cube
n, - -ve Tetrahedron
v - +ve Hextetrahedron

Back…2..CS

# D. PLAGIOHEDRAL CLASS – CUPRITE TYPE

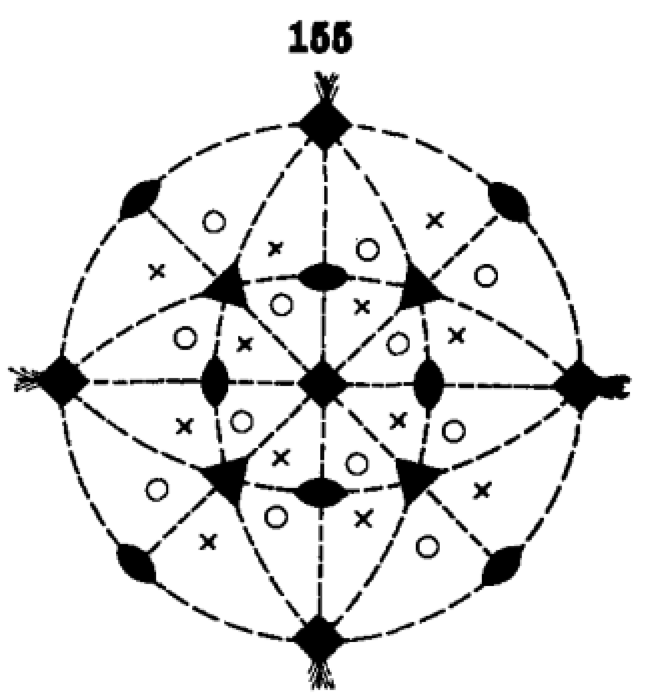
- Forms : 1. Pentagonal Icositetrahedron
  - +ve and –ve forms.




Right- and Left-handed Pentagonal Icositetrahedrons

Cuprite

**Symmetry:**
3 xl. Ax.-4,
4 diag. Ax.-3 &
6 diag. Ax.-2.




Symmetry of Plagiohedral Class

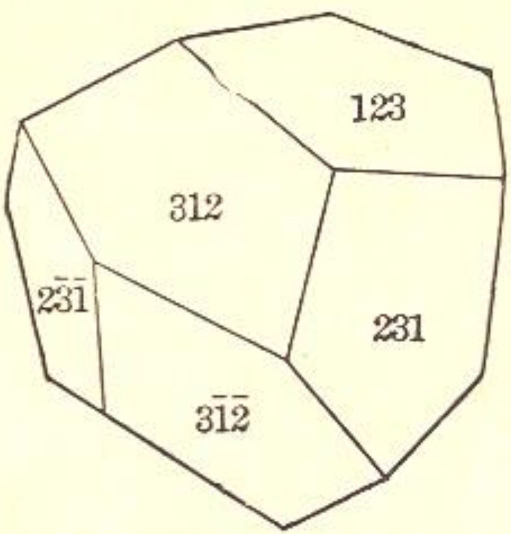
CUPRITE

Back…2..CS

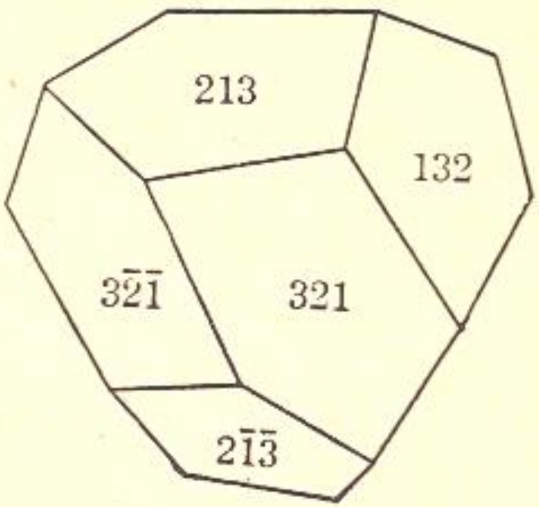
# E. Tetartohedral Class- Ullmannite type

- Form:
- 1. Tetrahedral-pentagonal-dodecahedron
  - Left handed and Right handed forms

178

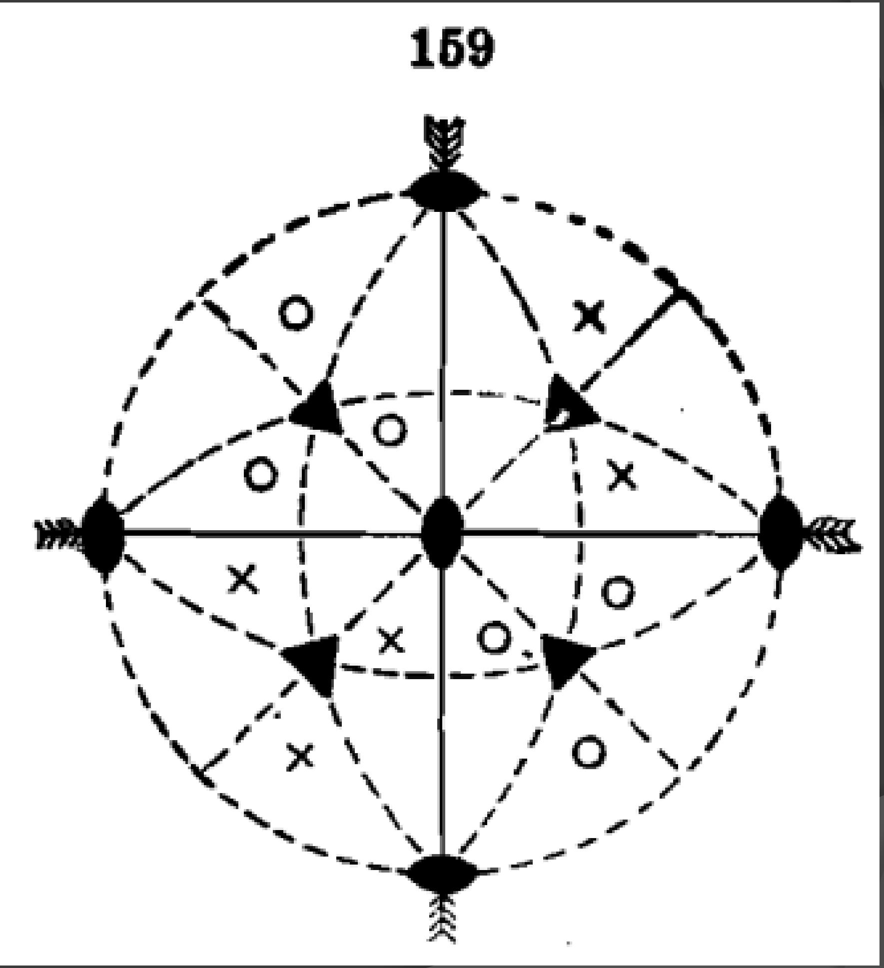



179



# Symmetry :

3 xl. Ax.-2 &
4 diag. Ax.-3.




Back…2..CS

# CLASSES in Tetragonal System

1. <u>NORMAL CLASS</u> - Zircon Type (Ditetragonal Bipyramidal, or Holohedral class)
2. <u>HEMIMORPHIC CLASS</u> - Iodosuccinimide type (Ditetragonal Pyramidal, or Holohedral Hemimorphic class)
3. <u>TRIPYRAMIDAL CLASS</u> – Scheelite Type (Tetragonal Bipyramidal or Pyramidal Hemihedral class)
4. <u>PYRAMIDAL-HEMIMORPHIC CLASS</u> - Wulfenite Type (Tetragonal Pyramidal / Hemihedral Hemimorphic or Tetragonal Polar class
5. <u>SPHENOIDAL CLASS</u> – Chalcopyrite Type (Tetragonal Sphenoidal, Sphenoidal Hemihedral, Didigonal Scalenohedral or Ditetragonal Alternating class)
6. <u>TRAPEZOHEDRAL CLASS</u> – Nickel Sulphate type (Tetragonal Trapezohedral / Trapezohedral Hemihedral / Tetragonal Holoaxial class)
7. <u>TETARTOHEDRAL CLASS</u> (Tetragonal Bisphenoidal / Sphenoidal Tetartohedral, Tetragonal Alternating class)

# TETRAGONAL SYSTEM

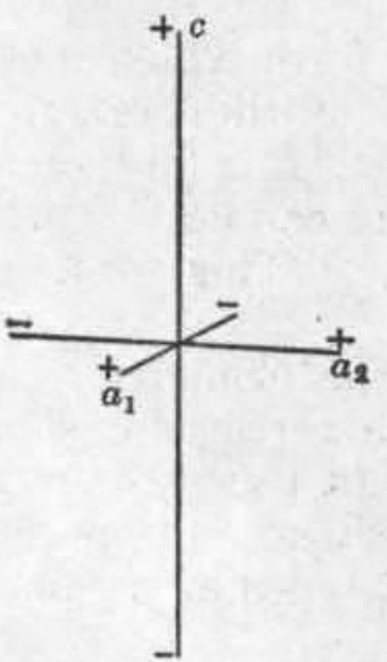
# 1. NORMAL CLASS - FORMS

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, ...**

# 1. Normal Class / Zircon Type

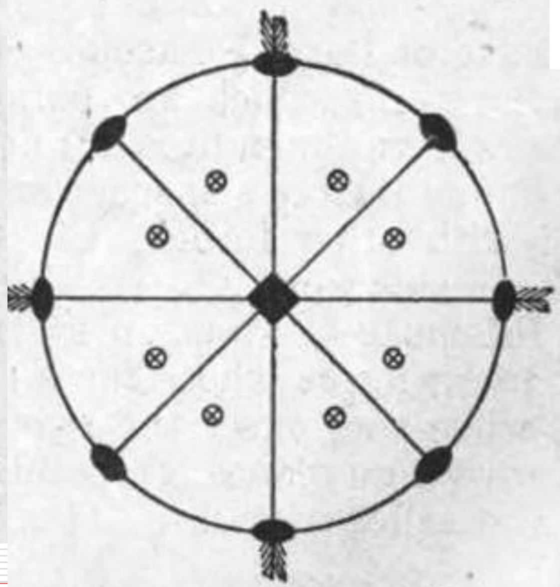
## Tetragonal System

184




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

185



Symmetry of Normal Class Tetragonal System

**Symmetry elements**

1 Vertical axis of 4 fold

4 horizontal axes of Two fold

1 horizontal Plane

4 Vertical Planes &

Centre of Symmetry is present

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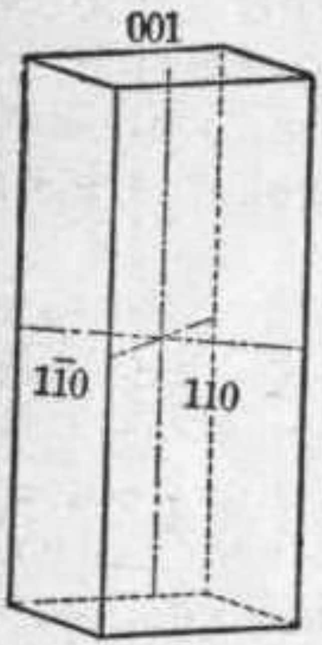
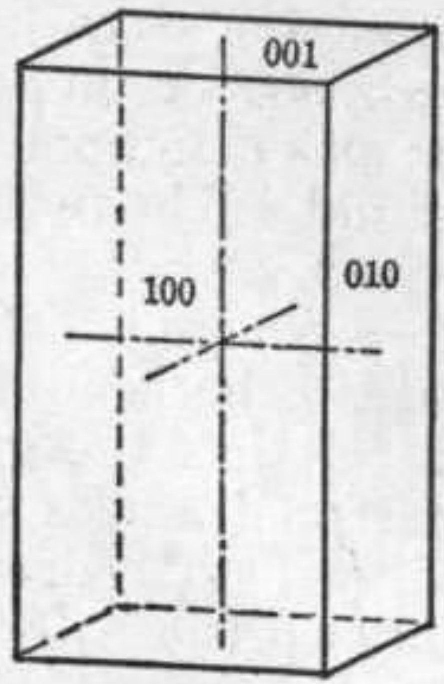


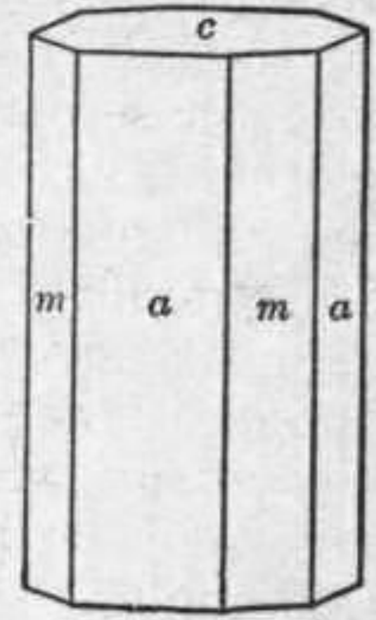

First Order Prism

189



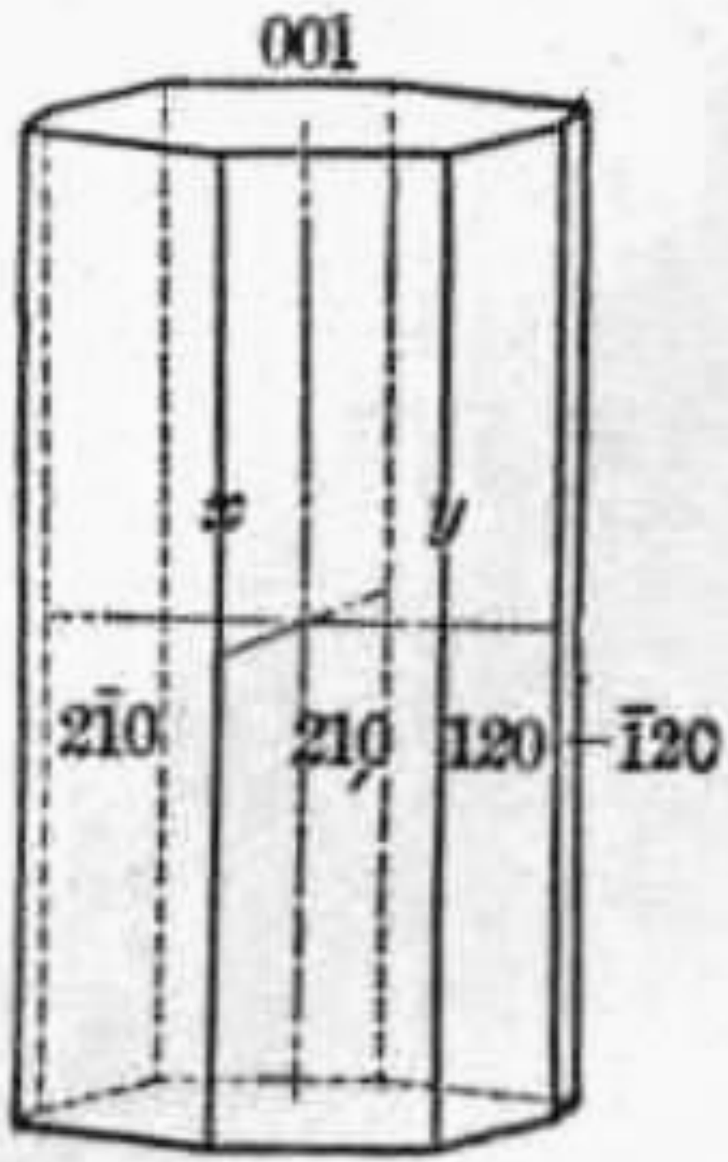

Second Order Prism

190



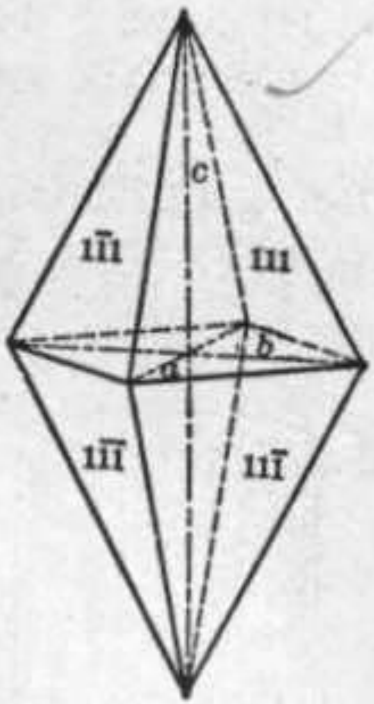

First and Second Order Prisms

191




Ditetragonal Prism

192

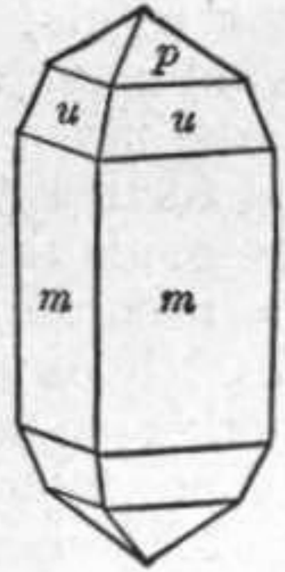



First Order Pyramid

193

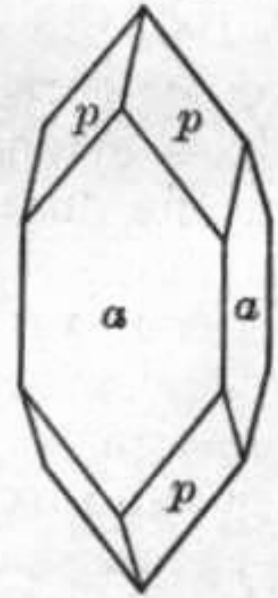

Zircon, First Order Prism and Pyramid

194



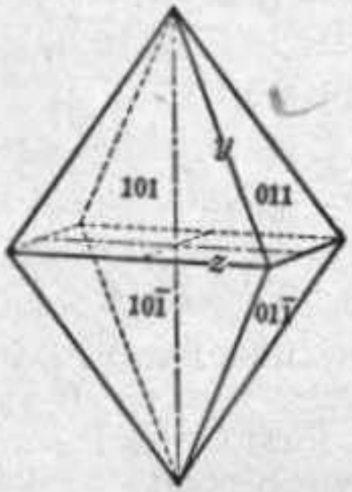

Zircon, First Order Prism and Pyramids

195




Apophyllite, Second Order Prism and First Order Pyramid

196

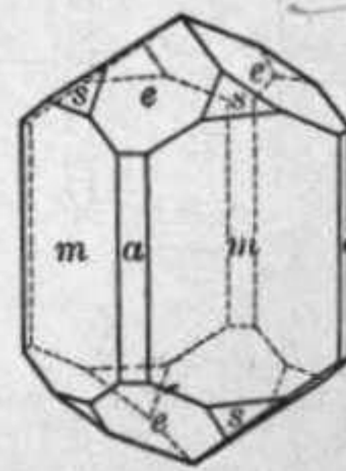



Second Order Pyramid

197

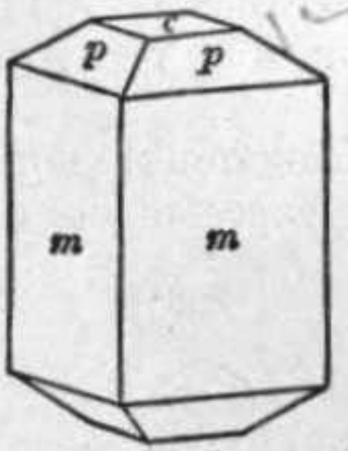

Second Order Prism and Pyramid

198



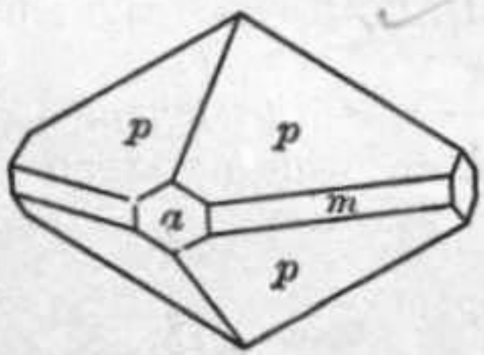

Rutile, First and Second Order Prisms and Pyramids

199



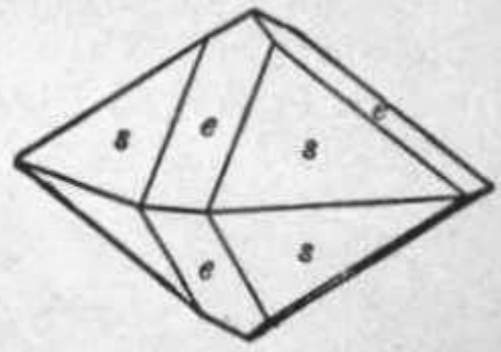

Vesuvianite
First Order Prism, Pyramid and Base

200



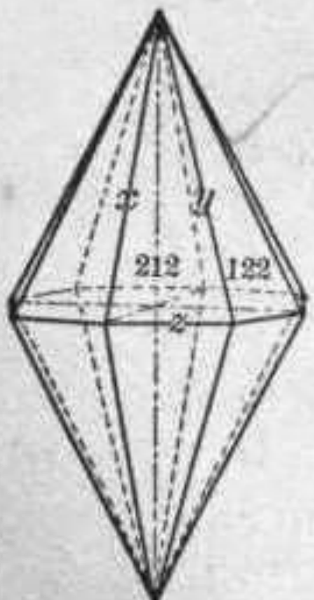

Vesuvianite
First Order Pyramid and First and Second Order Prisms

201



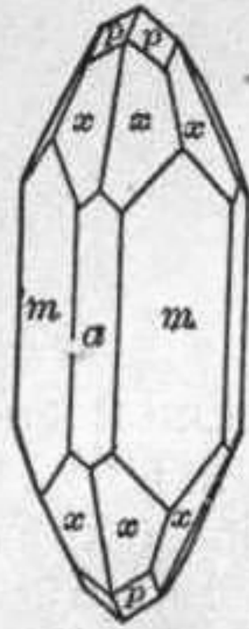

Cassiterite
First and Second Order Pyramids

205



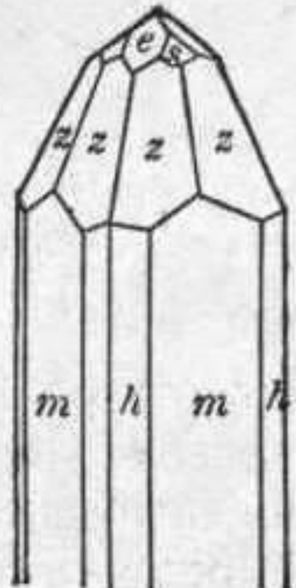
Ditetragonal
Pyramid

206



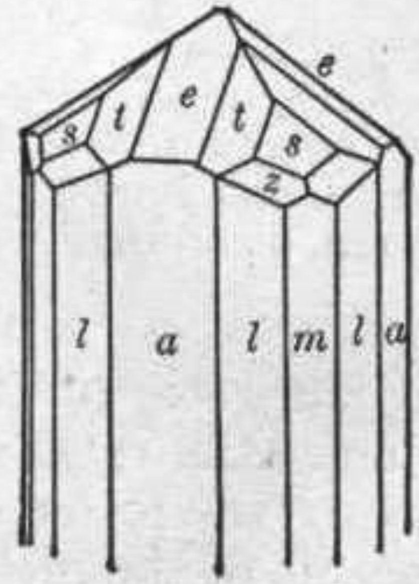
Zircon
First and Second Order
Prisms, First Order
Pyramid, Ditetrag-
onal Pyramid

207



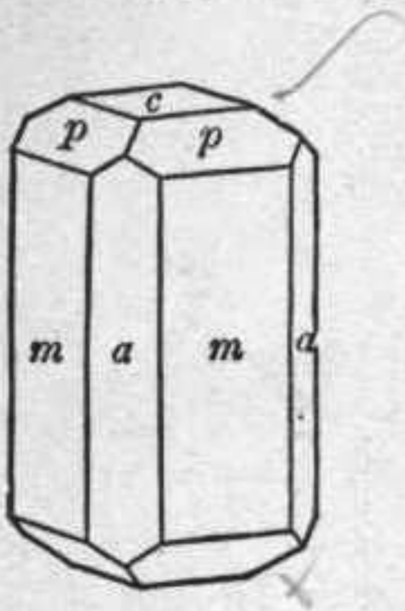
Cassiterite

208



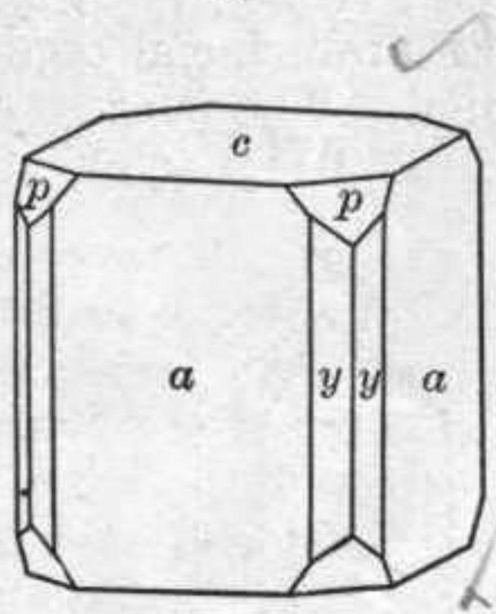
Rutile

202



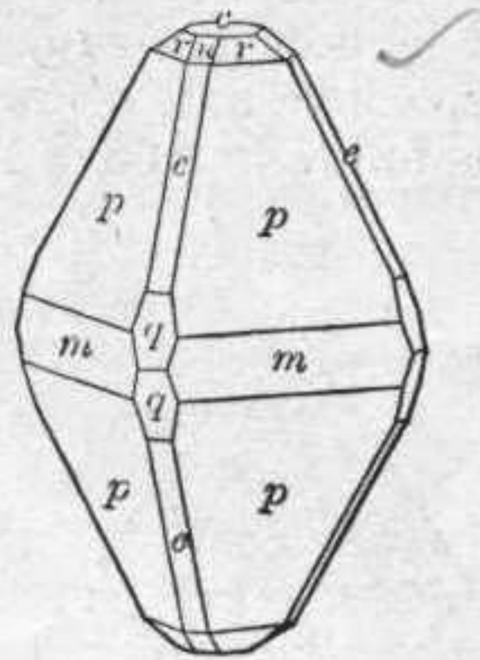

Vesuvianite
First and Second Order Prisms, First Order Pyramid and Base

203




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

204

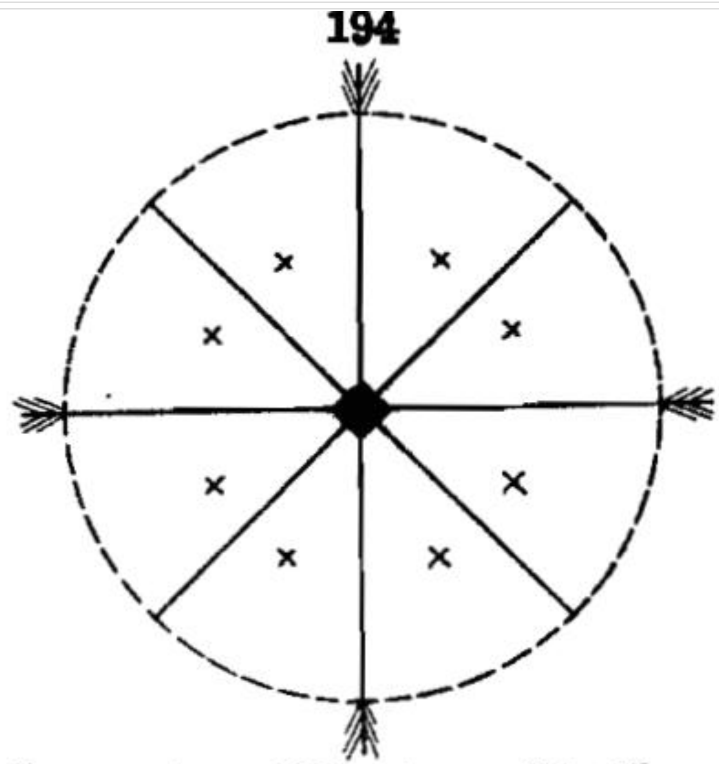



Octahedrite
Two First Order Pyramids, First Order Prism, Three Second Order Pyramids and Base

Back…2..TS

# 2. Hemimorphic Class / Iodosuccinimide Type

## Tetragonal System




Symmetry of Hemimorphic Class

**Symmetry**

1 Vertical axis of 4 fold

4 Vertical Planes

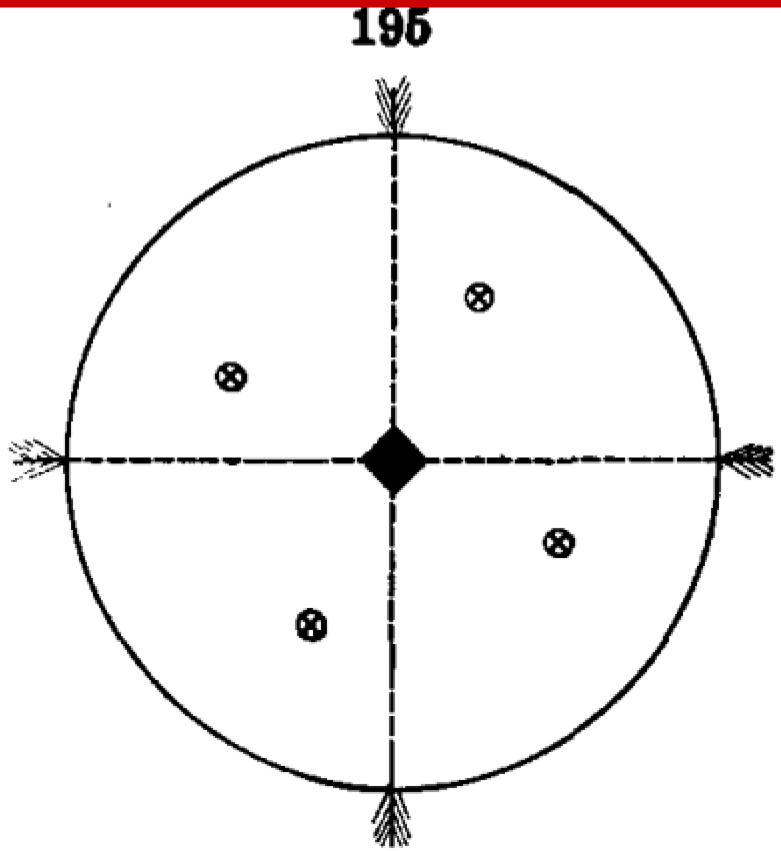
No H. Axes/Planes – Hemimorphic

Centre of symmetry - Absent

Back…2..TS

# 3. Tripyramidal Class / Scheelite Type

## Tetragonal System




Symmetry of Tri-Pyramidal Class

**Symmetry**

**1 Vertical axis of 4 fold**

**1 Horizontal Plane**

**& Centre of symmetry - Present**

Back…2..TS

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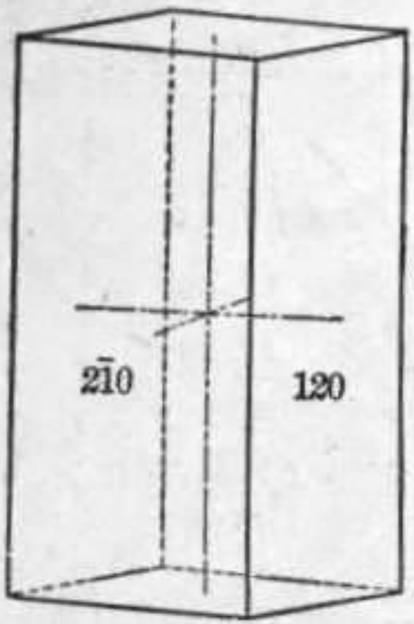
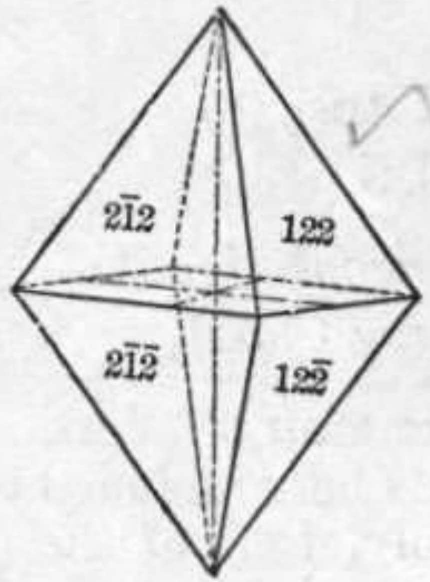


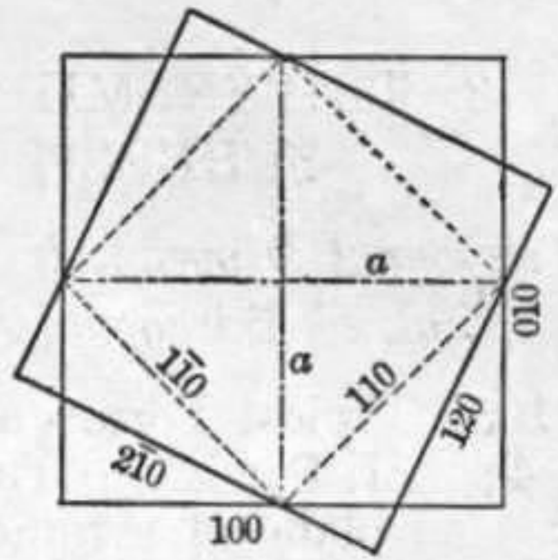

Third Order Prism

215




Third Order Pyramid

216

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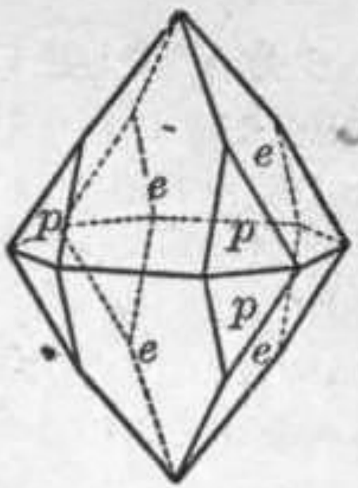
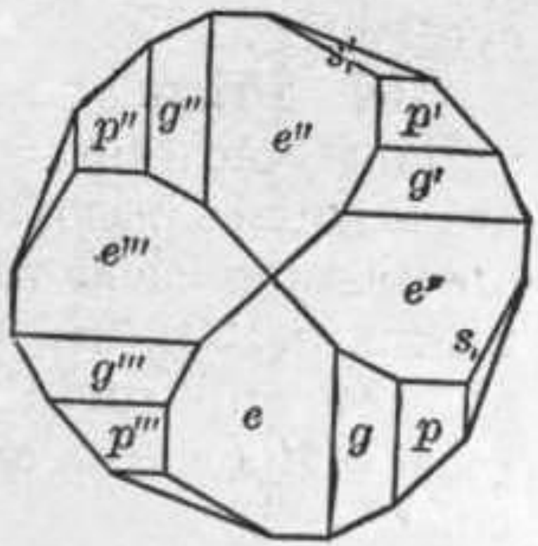
217



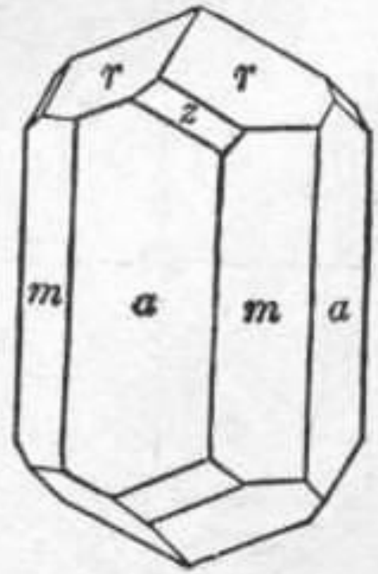

Scheelite

218




Scheelite

219

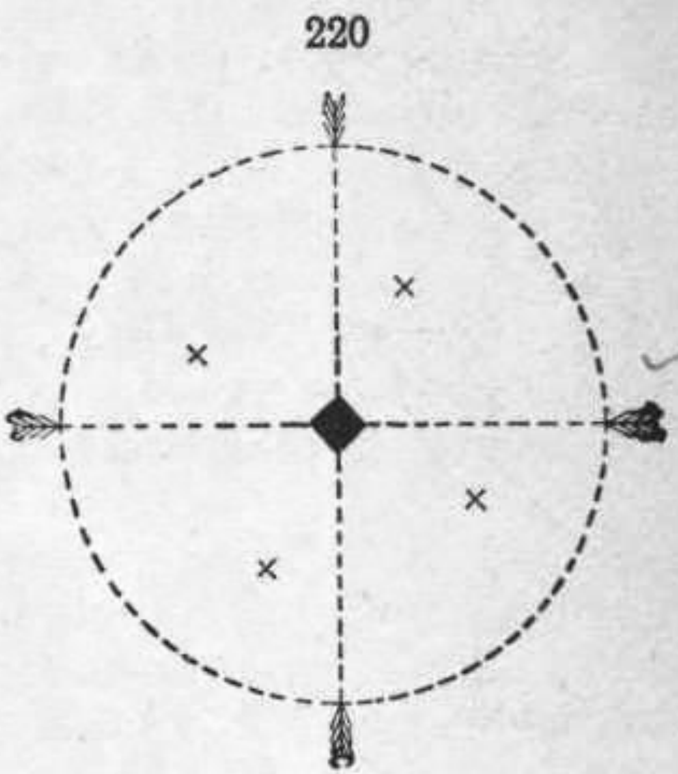



Meionite

Back…2..TS

# 4. Pyramidal-Hemimorphic Class / Wulfenite Type

## Tetragonal System




Symmetry of Pyramidal-Hemimorphic Class

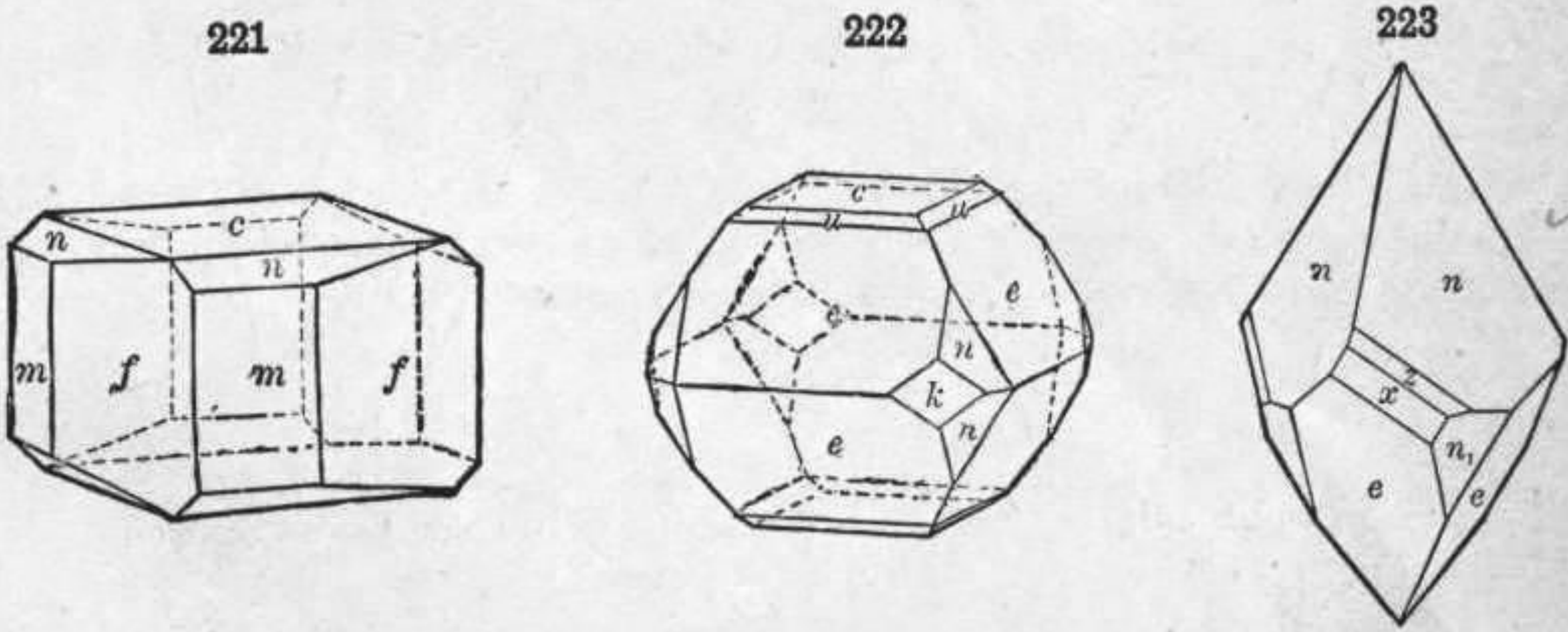
**Symmetry**

1 Vertical axis of 4 fold

No Horizontal Planes

**Centre of symmetry - Absent**

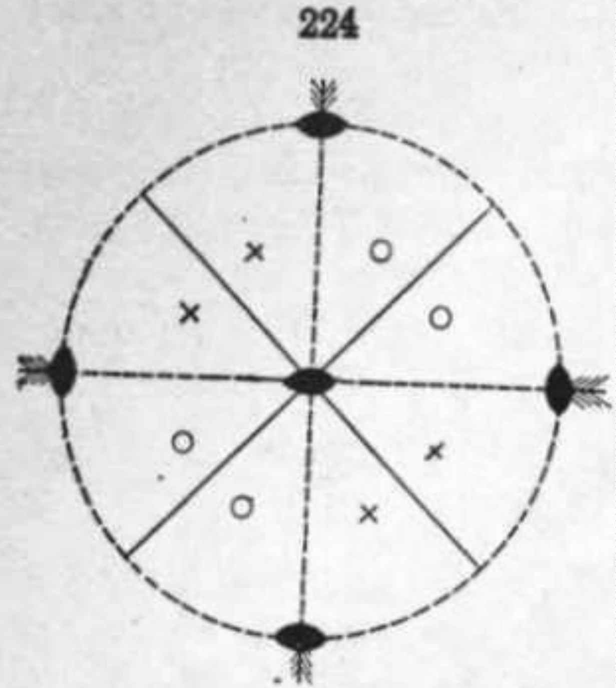
Back…2..TS




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)**

# 5. Sphenoidal Class / Chalcopyrite Type

## Tetragonal System



Symmetry of Spnenoida. Class

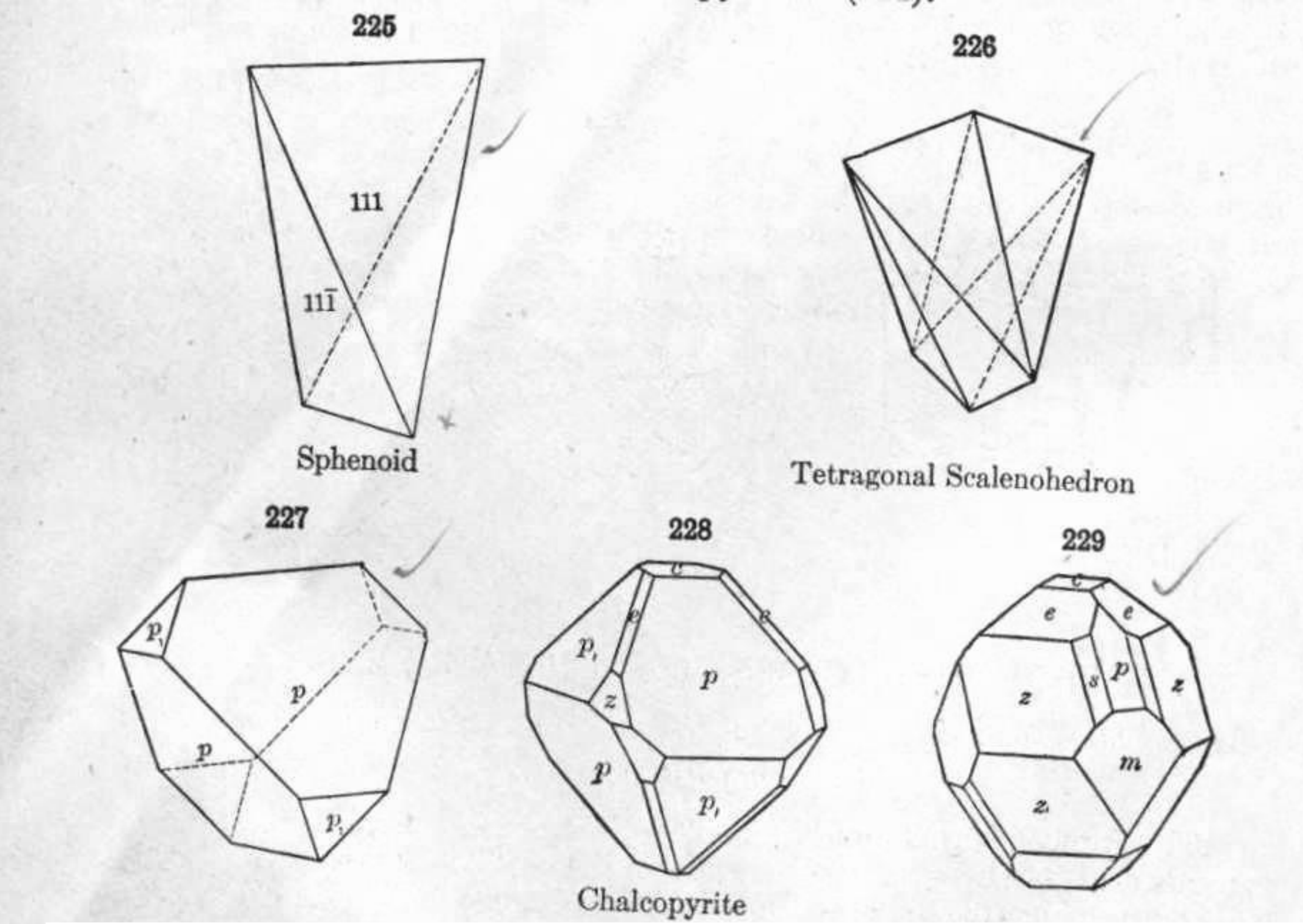
**Symmetry**

3 Crystallographic axes of 2 fold

2 Vertical diagonal Planes

**Centre of symmetry - Absent**

Back…2..TS

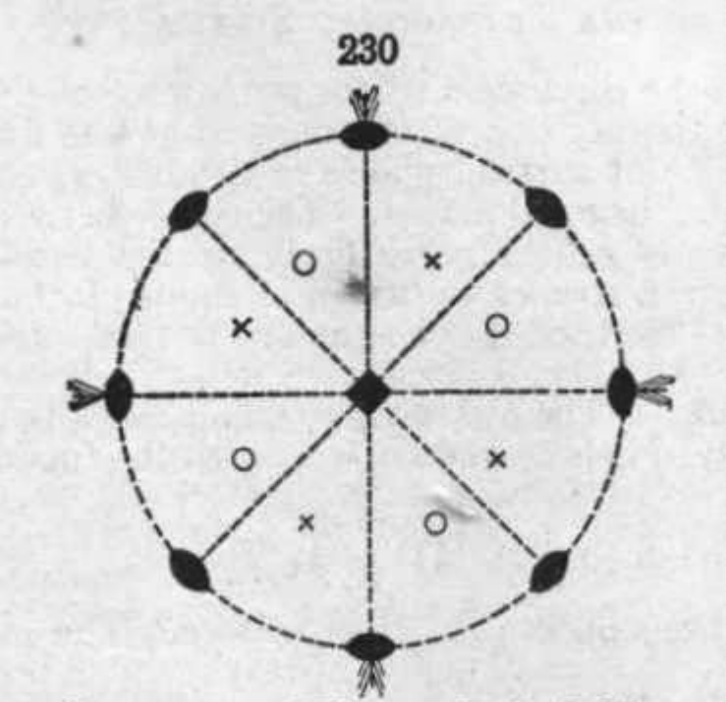



8 Scalene triangles (hkl)

**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)**

# 6. Trapezohedral Class / Nickel sulphate Type

## Tetragonal System



Symmetry of Trapezohedral Class

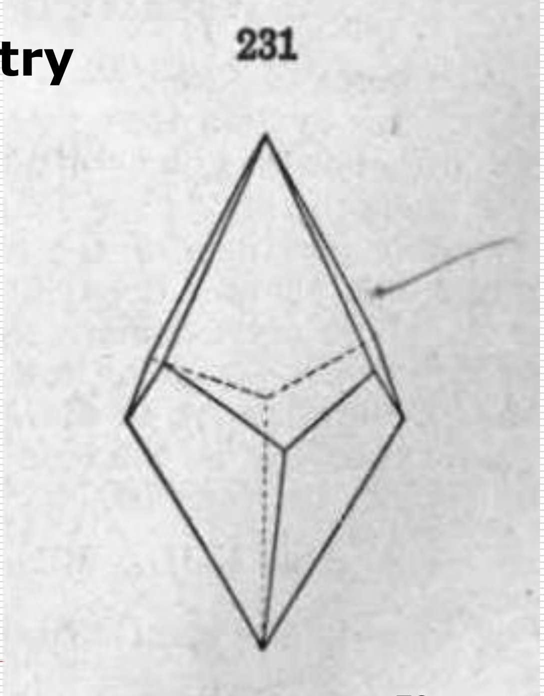
**Symmetry**

1 Vertical axis of 4 fold

4 Horizontal axes of 2 fold

No Planes, &

No Center of symmetry

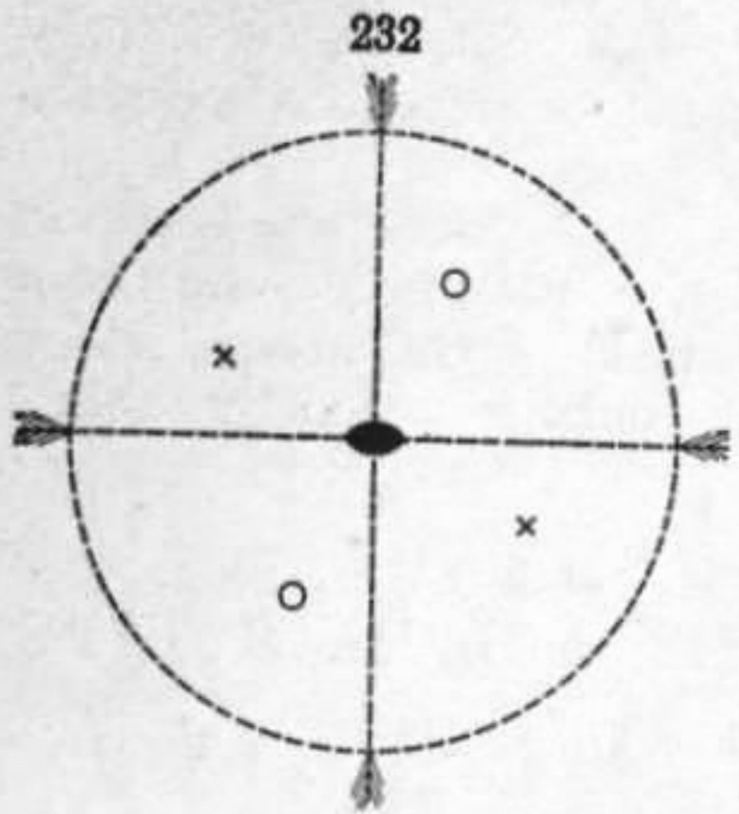


Tetragonal Trapezohedron

Back…2..TS

# Tetragonal System

# 7. Tetartohedral Class / Disphenoidal Tetragonal / Sphenoidal Tetartohedral class

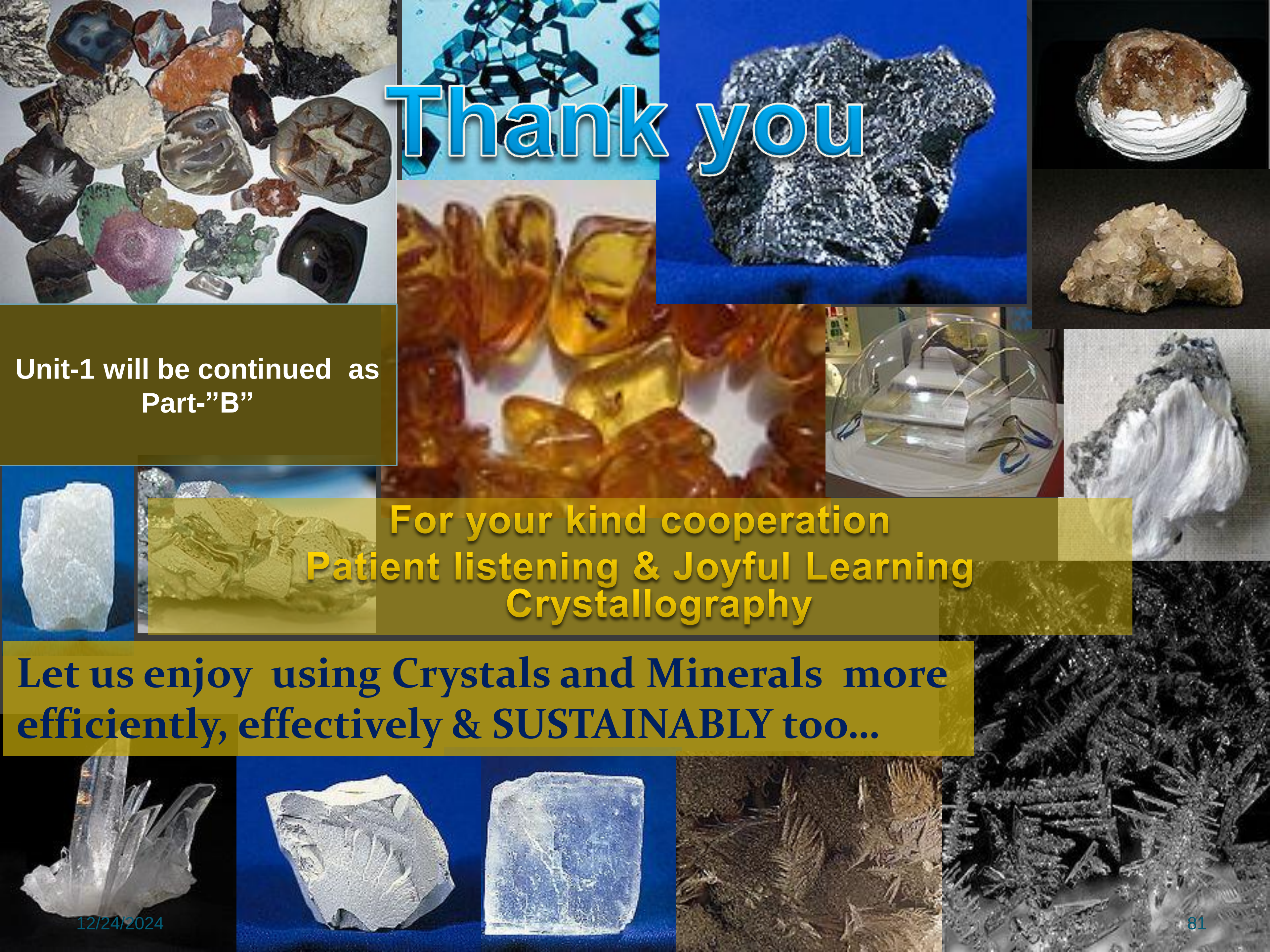


Symmetry of Tetartohedral Class

**Symmetry**

1 Vertical axis of 2 fold

Back…2..TS


Thank you
Unit-1 will be continued as Part-"B"
For your kind cooperation
Patient listening & Joyful Learning
Crystallography
Let us enjoy using Crystals and Minerals more efficiently, effectively & SUSTAINABLY too...