CRYSTALLOGRAPHY AND MINERALOGY

UNITS – 4 & 5

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.

Prepared by

Dr. K.Palanivel
Associate Professor
Centre for Remote Sensing
Bharathidasan University
Tiruchirappalli – 620 023
Email : kkpvlcers@bdu.ac.in
H. Ph.: 94433 78145

René Just Haüy (1743 –1822)

"Father of Modern Crystallography"

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

Syllabus

- 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 - Chl...ite group ... mi...als) - Cha... ates ... up - ... e gr... Wolla... Frame... Silic... - F... ar - Fe... - Z... pol...) - ... (S... C... a... tes).

Metamict state

- **Metamictization** (sometimes called **metamiction**) is a natural process resulting in the gradual and ultimately complete destruction of a mineral's crystal structure, leaving the mineral amorphous. Affected material is therefore described as **metamict.**

- Certain minerals occasionally contain **interstitial impurities of radioactive compounds** and it is the alpha radiation emitted from these compounds that is responsible for degrading a mineral's crystal structure through internal bombardment.

- Effects of metamictization are extensive: other than negating any birefringence previously present, the process also lowers a mineral's refractive index, hardness, and specific gravity. The mineral's colour is also affected: metamict specimens are usually green or brown. Further, metamictization diffuses the bands of a mineral's absorption spectrum. Curiously and inexplicably, the one attribute which metamictization does not alter is **dispersion**. All metamict materials are themselves radioactive, some dangerously so.
- An example of a metamict mineral is **Zircon**. The presence of uranium and thorium atoms substituting for zirconium in the crystal structure is responsible for the radiation damage in this case. Unaffected specimens are termed as **high zircon** while metamict specimens are termed as **low zircon**. Specimens falling between the two extremes are termed **intermediate**.

- Other minerals known to undergo metamictization include **Allanite, Ekanite** and **Titanite**. Ekanite is almost invariably found completely metamict as thorium and uranium are part of its essential chemical composition.
- Metamict minerals can have their crystallinity and properties restored through **prolonged annealing**.
- A related phenomenon is the formation of **pleochroic halos** surrounding minute Zircon inclusions within a crystal of Biotite or other mineral. The spherical halos are produced by alpha particle radiation from the included uranium or thorium bearing species.

Unit - 4 OPTICAL MINERALOGY

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- 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.**

OPTICAL PROPERTIES OF MINERALS

- STUDY OF MINERAL THIN SECTIONS USING POLARISING MICROSCOPE:

- How Polarizers / Analyzers / Nicol Prisms are made?

- What is a mineral thin section and how it is prepared? (thickness of the mineral film affixed in Thin Section is 0.03mm or 0.001 – 0.003 inch)

Optical Properties of Minerals

Examination of mineral sections under microscope in Four conditions:

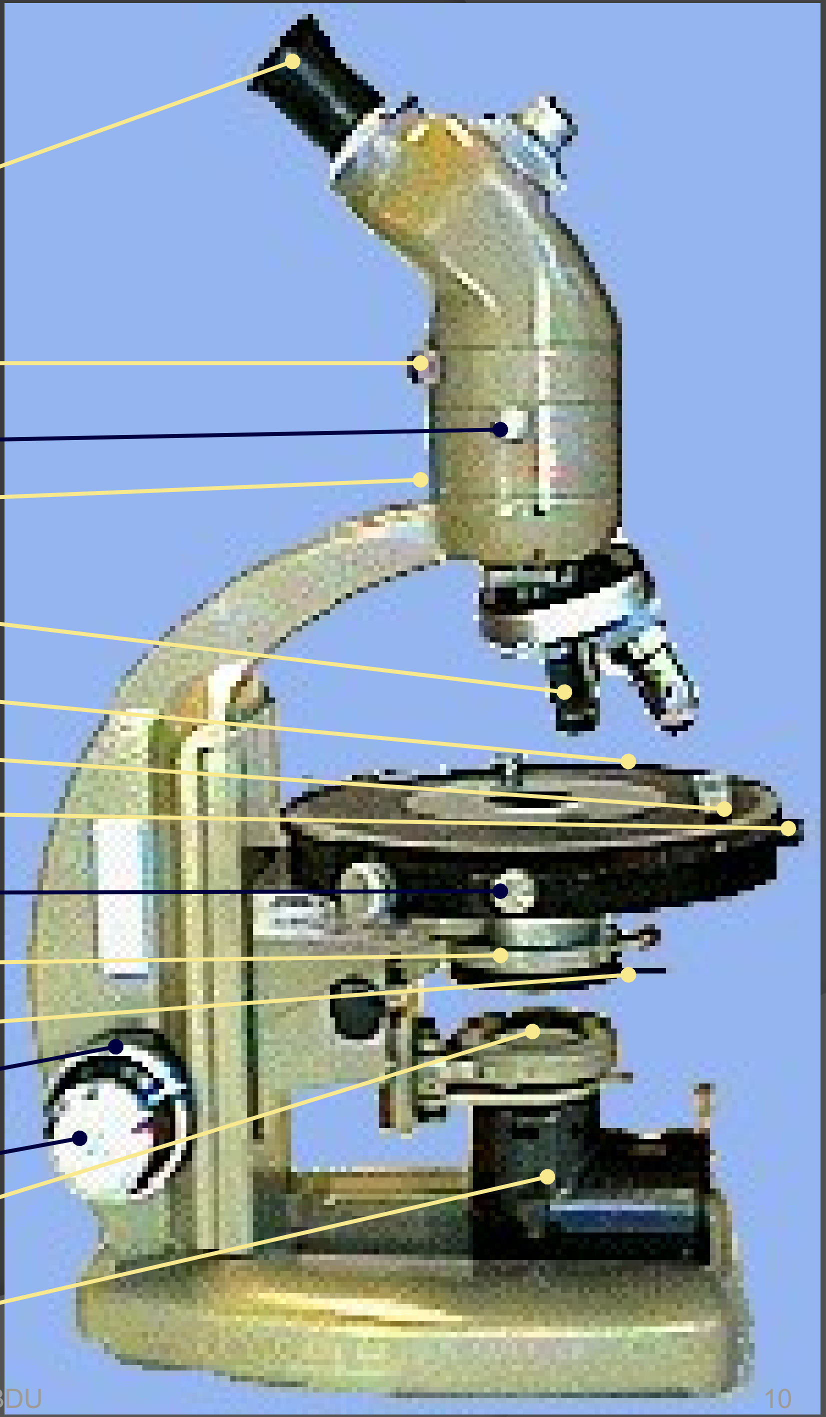
A. UNDER ORDINARY LIGHT (OL)

B. UNDER PLANE POLARIZED LIGHT (PPL)

**C. UNDER CROSSED NICOLS (or)
CROSSED POLARIZERS (CN / CP) &**

D. USING CONVERGENT LIGHT (CL)

POLARIZING / PETROLOGICAL MICROSCOPE



Eye Piece-1

Analyser-2

Bertrand Lense-3

Objective Tube-4

Objective Lenses-5

Rotating Stage -6

Section holding clip-7

Stage adjustment knob-8

Stage Clamp-9

Polarizer-10

Diaphragm-11

Coarse Focus-12

Fine Adjustment-13

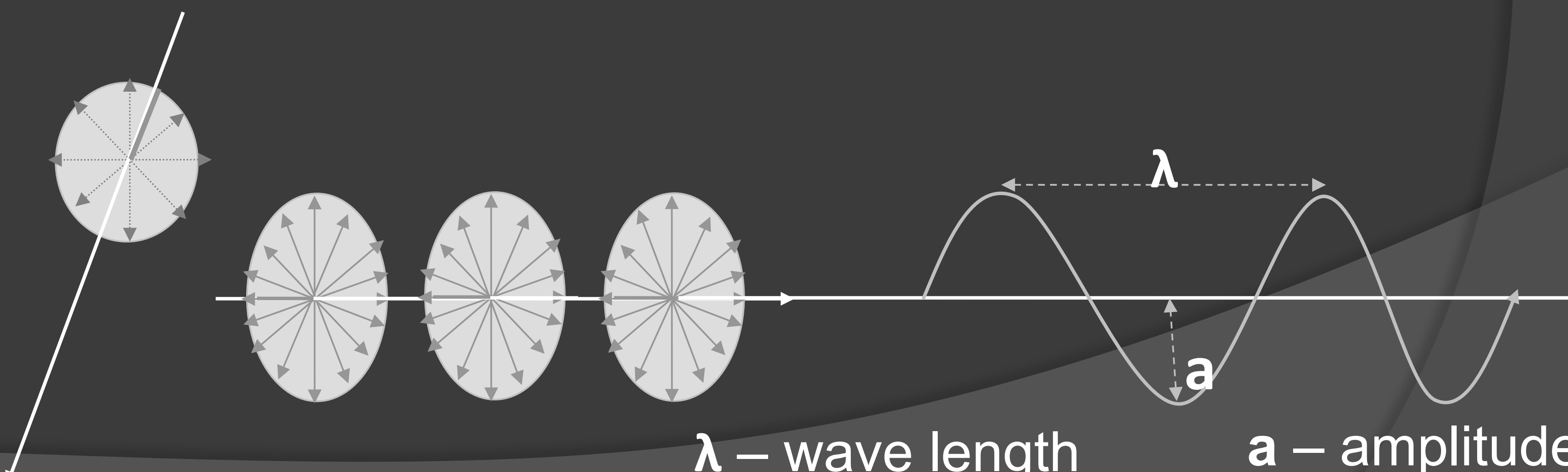
Mirror (Plain /Concave)-14

Light Source (Electric Bulb)-15

Nature of light:

1. UNDER ORDINARY LIGHT

- Light consists of electro-magnetic radiations / vibrations, which
- Vibrates perpendicularly in all directions or at all right angles to
- the transmitting path of the ray, i.e.
- the direction of propagation.



- Wave-length: The distance between two subsequent crests or trough (λ).
- Periodic Time: The time required to travel one wave-length (t), then
- Velocity of light, $v = \lambda / t$
- Colour: Depends upon the wave-length.
- Visible:

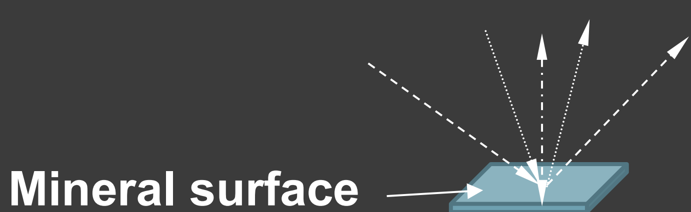
VIBGYOR

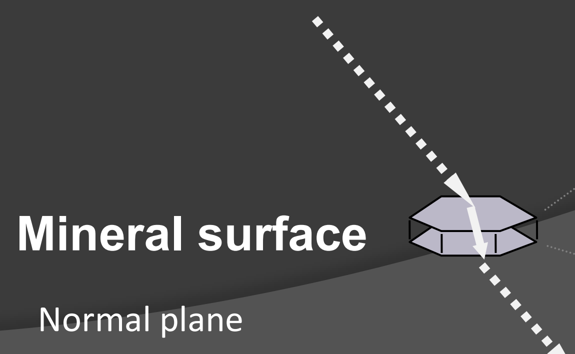
0.00039 mm to 0.00076 mm

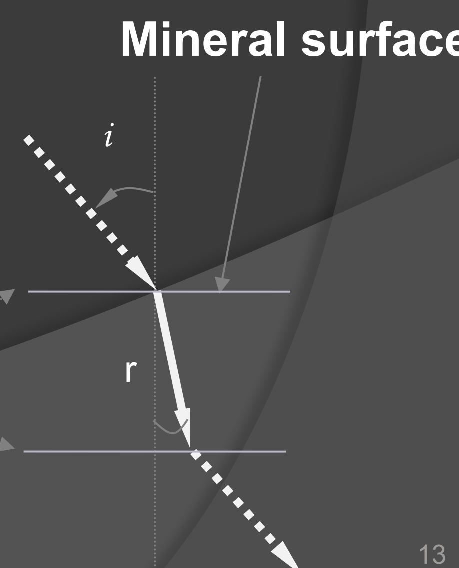
- White light: Consisting of all visible rays.
- Monochromatic light: one wave-length only.

Two types of Minerals / media / substances:

- Isotropic (same velocity in all directions) /
- Anisotropic (different velocity in different directions)
- Reflection: Angle of Incidence = Angle of Reflection
- Refraction: sin i / sin r







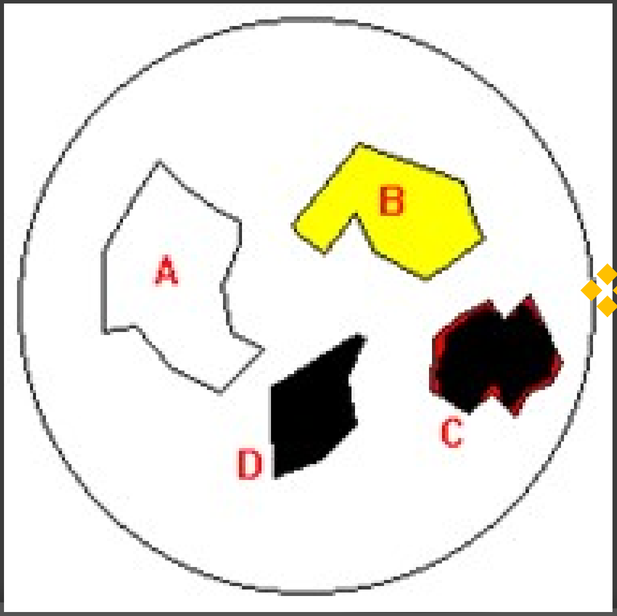
- Refractive Index: A constant value - ratio between sin i and sin r
- For air = 1, Water = 1.33, Flourspar = 1.4, Canada balsam = 1.54, Crown glass = 1.53, Garnet = 1.77, Diamond = 2.42.
- R.I.s of two media is inversely proportional to the ‘v’- velocities of light in them.
- Breaking up of white light into an array of VIBGYOR is known as dispersion.
- i.e., When the white light enters in to the second medium it is refracted and dispersed in it producing an array of colours.

A. EXAMINATION OF MINERAL THIN SECTIONS UNDER ORDINARY LIGHT / PLANE POLARIZED LIGHT

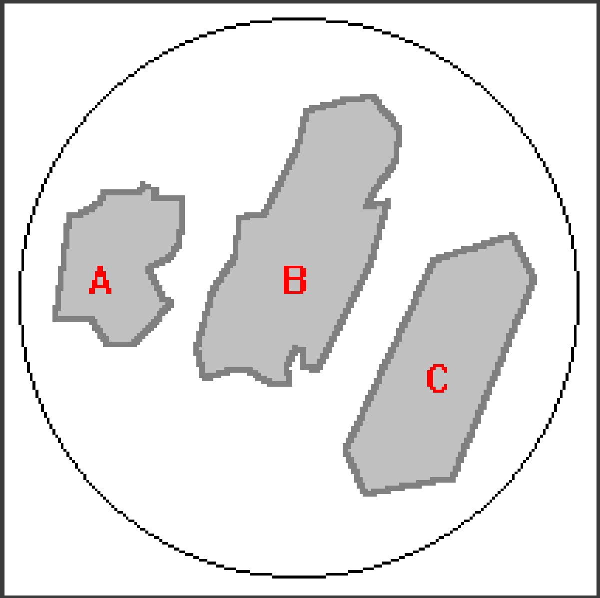
1. Colour
2. Crystallinity / Form
3. Cleavage
4. Transparency
5. Relief
6. Inclusions and Alterations &
7. Refractive Index

1. Colour

- Colour in thin section tends to be more consistent than in hand specimen.
- Most major rock forming minerals are colourless (A). Some have distinctive colours (B).
- Some minerals like Hematite (C) which appear opaque in hand specimen are transparent on thin edges in thin section with dark brown colour.
- The most common truly opaque minerals (D) are metallic oxides (Magnetite, Ilmenite) and sulfides (Pyrite). They look like black in thin section.

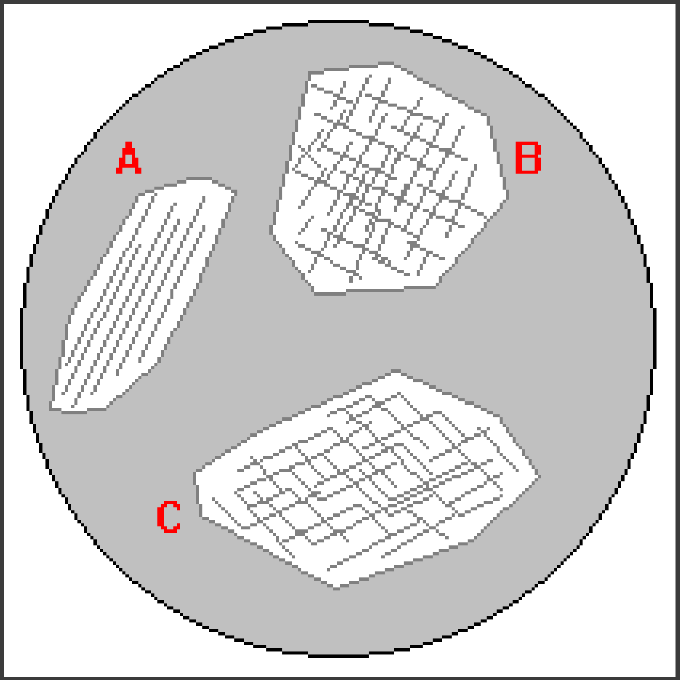


2. Crystal Form



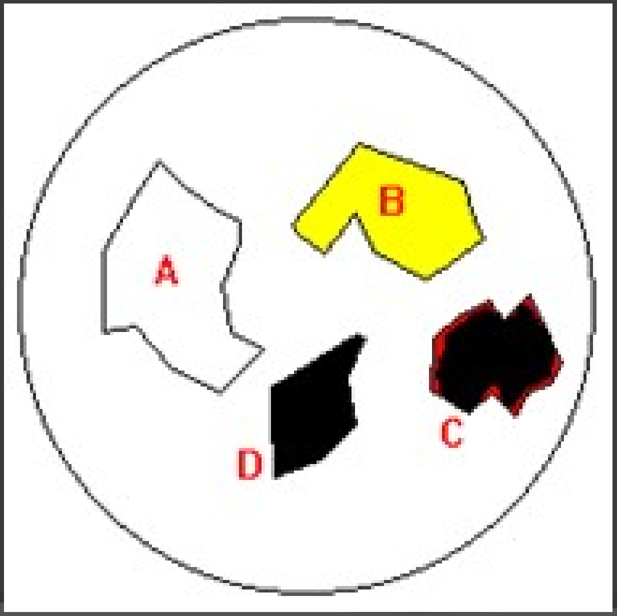
- Grains that show no recognizable crystal form are said to be **Anhedral** (A).
- Grains that show imperfect but recognizable crystal form are said to be **Subhedral** (B).
- Grains that show sharp and clear crystal form are said to be **Euhedral** (C).

3. Cleavage



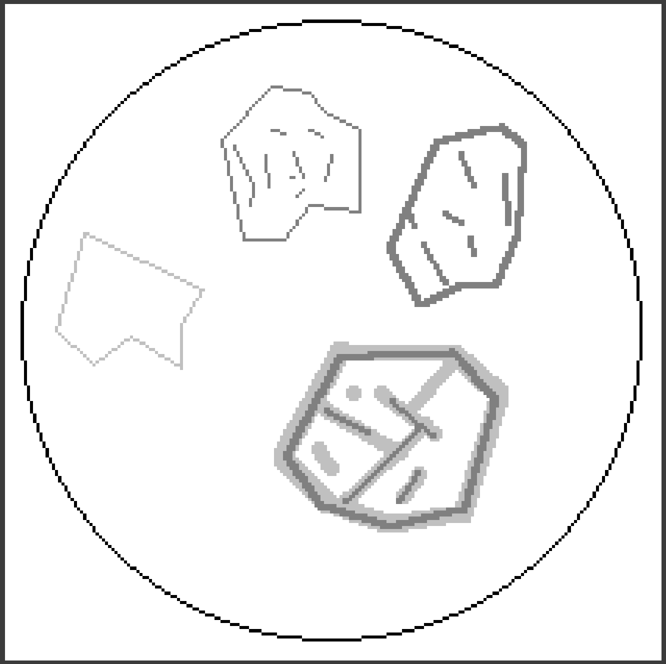
Cleavage is much easier to see in thin section than in hand specimen.
Cleavage along the length of the grain is exhibited by many minerals (A). Pyroxenes viewed end on (B) usually show the characteristic 87-degree cleavage, while cross-sections of amphibole show the characteristic 56-degree cleavage (C).
What you see will depend on the orientation of the grain. A true cross-section of an amphibole will show 56-degree cleavages but an oblique section will show other angles and a longitudinal section will show longitudinal cleavage as in (A).

4. Transparency



- The minerals character of penetrating the light is noted here.
- Mineral A in the figure seems to be **transparent**.
- The Mineral B is **semi-transparent** and having colour.
- Some minerals like Hematite (C) which appear opaque in hand specimen are **translucent** on thin edges in thin section.
- The most common truly **opaque** minerals (D) are metallic oxides (Magnetite, Ilmenite) and sulfides (Pyrite).

5. Relief

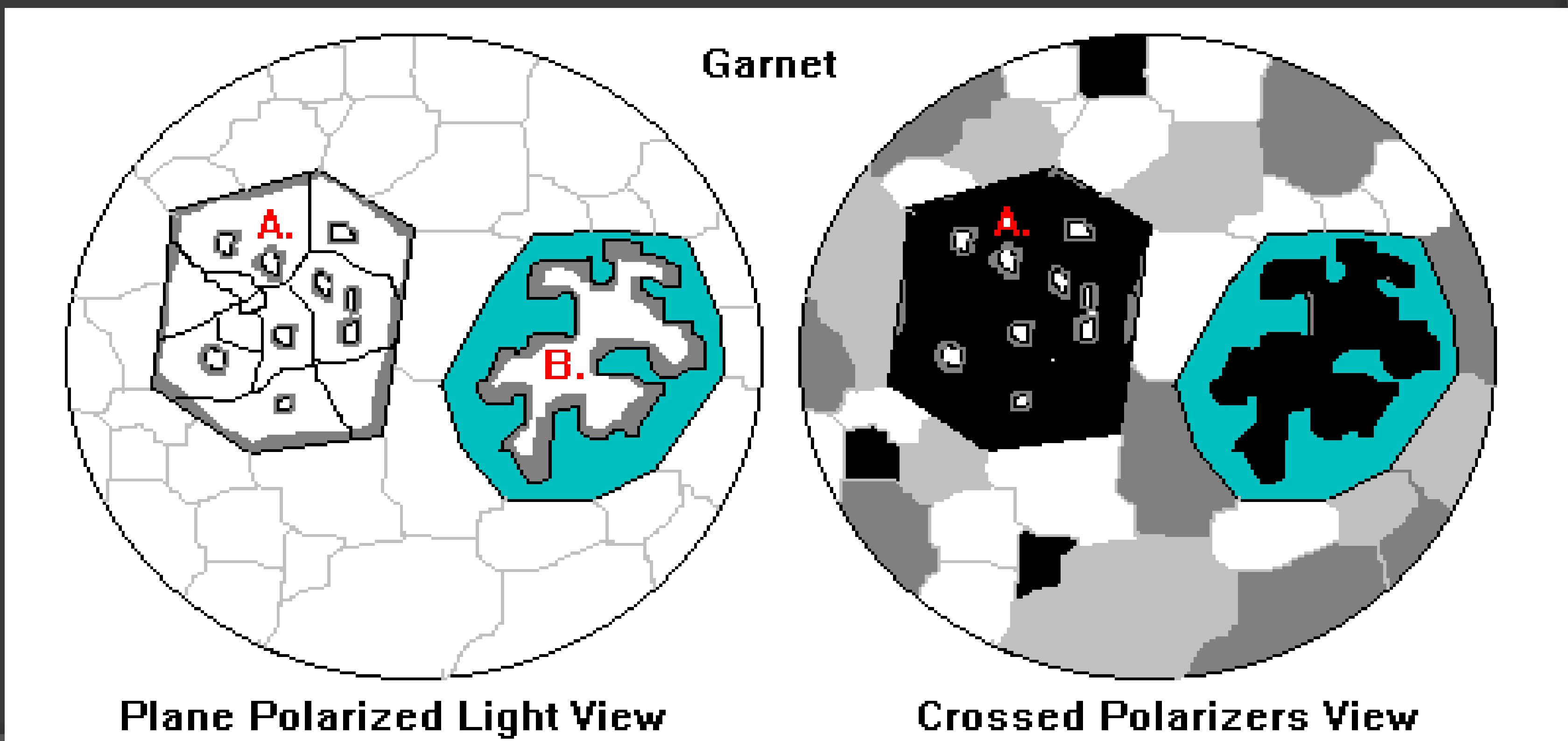


- Relief is the contrast between a mineral and its surroundings due to difference in refractive index.
- The four grains shown here show increasing relief clockwise from left.
- Relief is positive when the grain has higher refractive index than its surroundings, negative if lower.
- Negative relief compared to Quartz, Feldspar and normal slide mounting media is relatively rare.
- A few silicates show small negative relief, but strong negative relief is limited mostly to non-silicates like Fluorite.

6. Inclusions & Alterations

Some of the minerals show alteration and inclusion of new minerals within the parent mineral. These inclusion and alteration products will have different optical properties than the parent mineral that host them.

Garnet Crystals commonly contain inclusions



7. Refractive Index

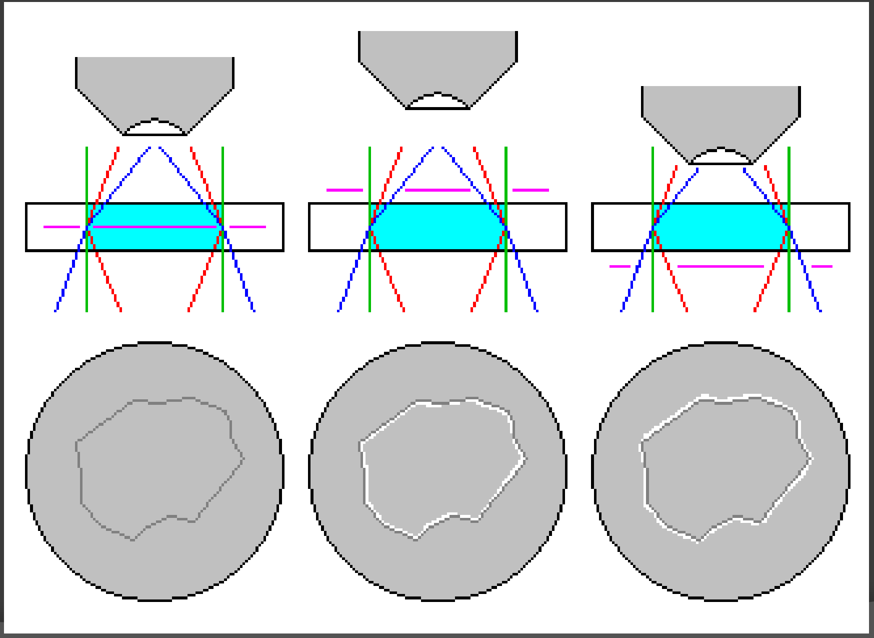
- Since the blue has the less R.I., it occurs nearest the normal and the red has the greatest R.I., it occurs farthest away from the normal.
- **Becke effect:** Becke Line Test – using high power objective and diaphragm (to cut off some of the light) in microscope, if the
- When the Objective tube is raised, the light band travels into the mineral section – that indicates, the mineral under thin section has **Higher Refractive Index.**
- If the light bands travels away from the center of the mineral in thin section – **Low R. I.**
- Isotropic substances have the same R.I. for all directions.

Becke Line Test – Refractive Index

If a grain is not perfectly in focus, it will often appear to be bordered by a bright line called the *Becke Line*. The Becke Line is useful for determining which of two neighboring grains has the highest refractive index.

A grain that has **greater refractive index** than its surroundings will refract and relect light inward like a crude lens.

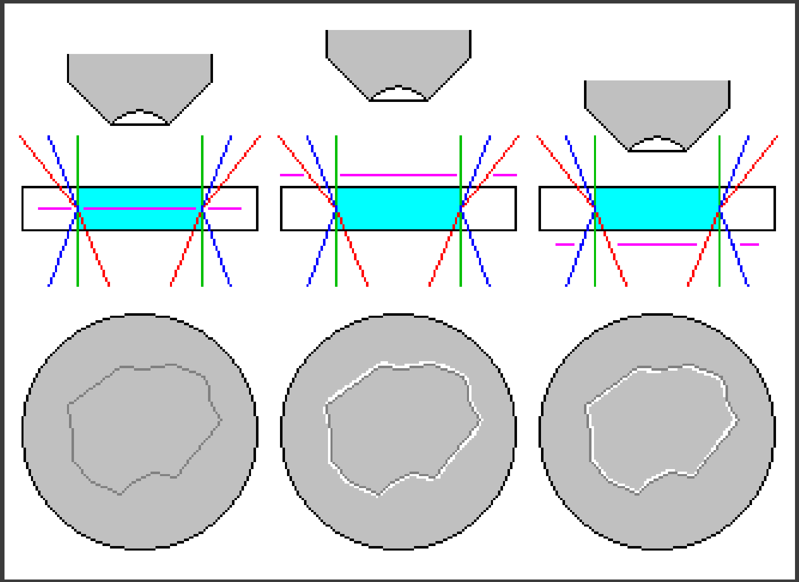
Higher refractive index



- If the focal plane of the microscope is centered within the thin section (purple line) the grain boundary is in sharp focus (left).
- If the focal plane is too high, rays that would normally appear at the grain boundary now appear inside it and a bright border appears inside the grain (center).
- If the focal plane is too low, rays that would normally appear at the grain boundary now appear outside it and a bright border appears outside the grain (right).

Lower refractive index

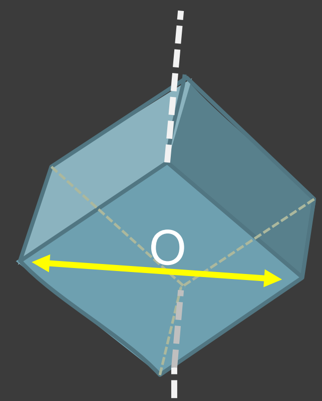
A grain that has **lower refractive index** than its surroundings will refract and reflect light outward like a crude diverging lens.

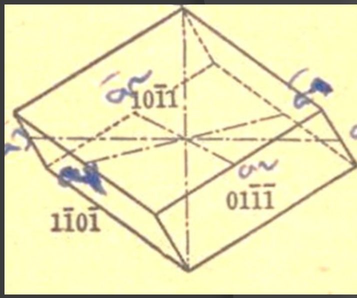


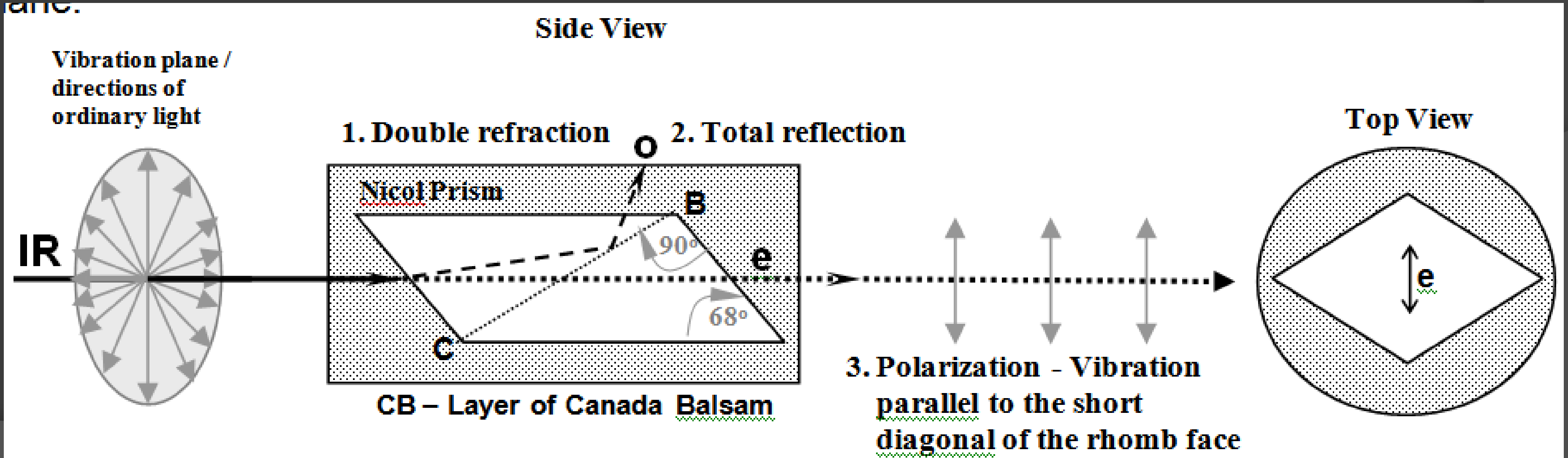
- If the focal plane of the microscope is centered within the thin section (purple line) the grain boundary is in sharp focus (left).
- If the focal plane is too high, rays that would normally appear at the grain boundary now appear outside it and a bright border appears outside the grain (center).
- If the focal plane is too low, rays that would normally appear at the grain boundary now appear inside it and a bright border appears inside the grain (right).

B. UNDER PLANE POLARIZED LIGHT

- Plane polarized / Polarized – If the light ray vibrates in one direction in perpendicular plane.







- **Double Refraction**: The phenomenon of light ray forming two refracted rays, i.e., Ordinary and extraordinary rays while passing from one medium to an another medium is known as double refraction.
- Ordinary image, i.e., Stationary image has been formed by ordinary ray and the extraordinary image moving around the stationary image formed by the extraordinary ray.
- **Ordinary ray** consists of light vibrating parallel to the long diagonal of the rhomb face and
- The **extraordinary ray** consists of light vibrating parallel to the short diagonal.
- Thus, it (e) has got little shorter wavelength when comparing the ordinary ray and hence, little higher energy, it is named as “Extraordinary ray”.

- **Optically uniaxial minerals**: A direction in which the ordinary and extraordinary rays have the same velocities and no double refraction occurs is known as "optic axis" and such crystals showing this phenomenon of only one optic axis in such direction, they are said to be "Uniaxial crystals".

Wave front of ordinary ray is spherical and a section of this is a circle. The **velocity** of extraordinary ray varies with its direction. Along the optic axis (C), it has the same velocity as the ordinary ray, but at right angles to the optic axis it has a maximum velocity. The minerals having the velocity of **extraordinary ray greater than** that of the **ordinary ray** are said to be **"negative"** and the opposite condition, i.e. **lesser** are **"positive".**

1) Isotropic Minerals: Minerals of **Cubic system**.

2) **Anisotropic** Mnls.: (a) **Uniaxial Mnls**. : **Tetragonal** & **Hexagonal**
(b) **Biaxial Mnls.** : Other mnls. Crystallized under **Orthorhombic**, **Monoclinic** & **Triclinic** systems.

B. UNDER PLANE POLARIZED LIGHT… contd…

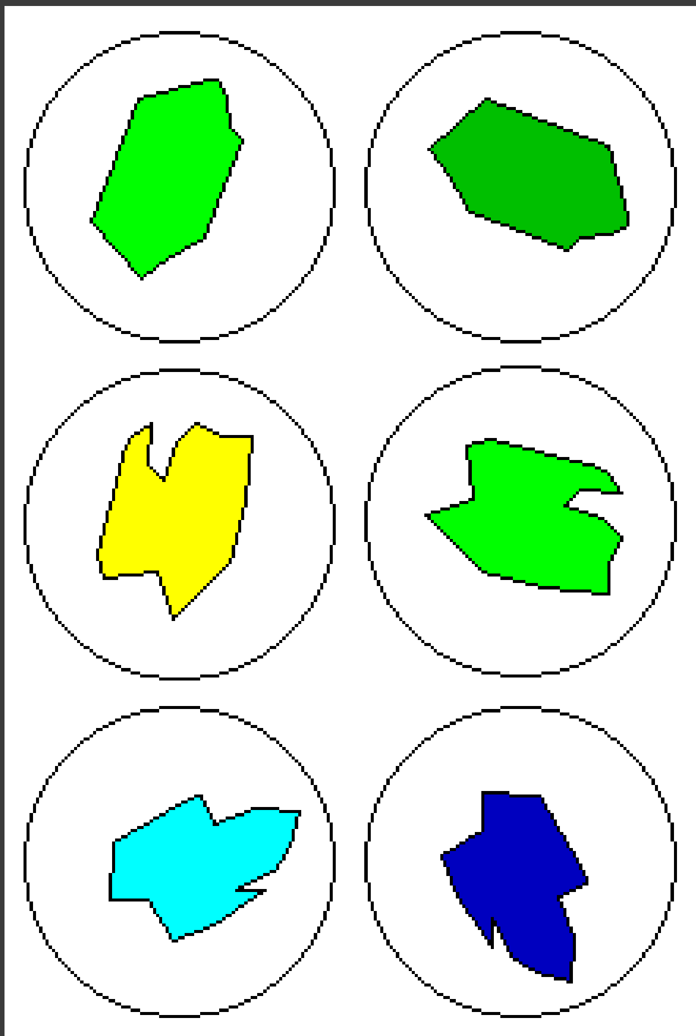
8. Pleochroism

9. Pleochroic Halos and

10. Twinkling.

- The properties discussed so far to be examined under ordinary light will be similar under PPL conditions.
- But, the above three properties of minerals in thin sections can be examined only under PPL.
- Thus, the polarizing microscopes were made with fixed Polarizers at the bottom of the stage.

8. Pleochroism



The optical property of the mineral in thin section showing variation in colours or its density of colour seen in varying angles under plane polarized light is known as Pleochroism.

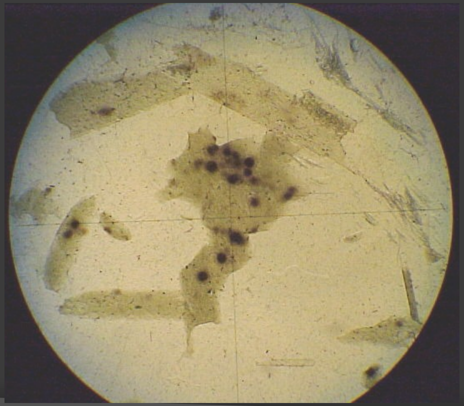
The mineral said to be Pleochroic or not is based on the colour change or colour intensity change while rotating the stage under PPL condition.

Colored minerals often show different colors in thin section depending on how the grain is oriented relative to the polarizer directions.

- Top: Most minerals change from lighter to darker as the stage is rotated.
- Middle: Some minerals change color entirely as the grain is rotated.
- Bottom: In a few cases the color change is so extreme that the mineral is, in effect, a natural polarizer. Thin slices of tourmaline were often used as polarizing filters before good synthetic filters became available.

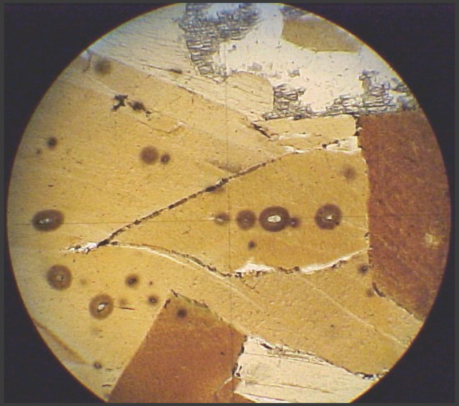
9. Pleochroic Haloes

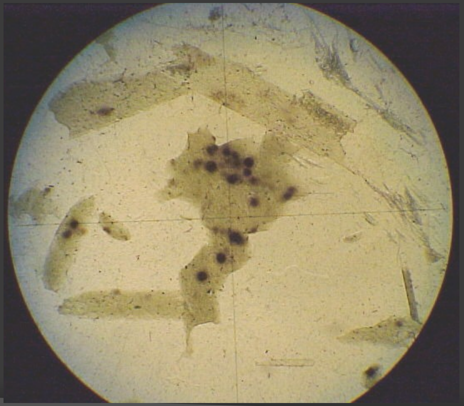
Biotite of different shades dotted with numerous dark haloes around Zircon inclusions



10. Twinkling

The pleochroic minerals said to have this property under PPL conditions due to colour change or colour intensity change.





C. Under Crossed Nicols

The properties of minerals in thin section under CNC are:

11. **Isotropism and Anisotropism**
12. **Extinction & Angle of Extinction**
13. **Polarization / Interference Colours**
14. **Twinning and type of twinning**
15. **Alteration / Zoning and**
16. **Elongation.**

D. Using Convergent Light

17. **Interference Figures and**
18. **Optic Sign of the Mineral in thin**

C. UNDER CROSSED NICOLS (or) CROSSED POLARIZERS

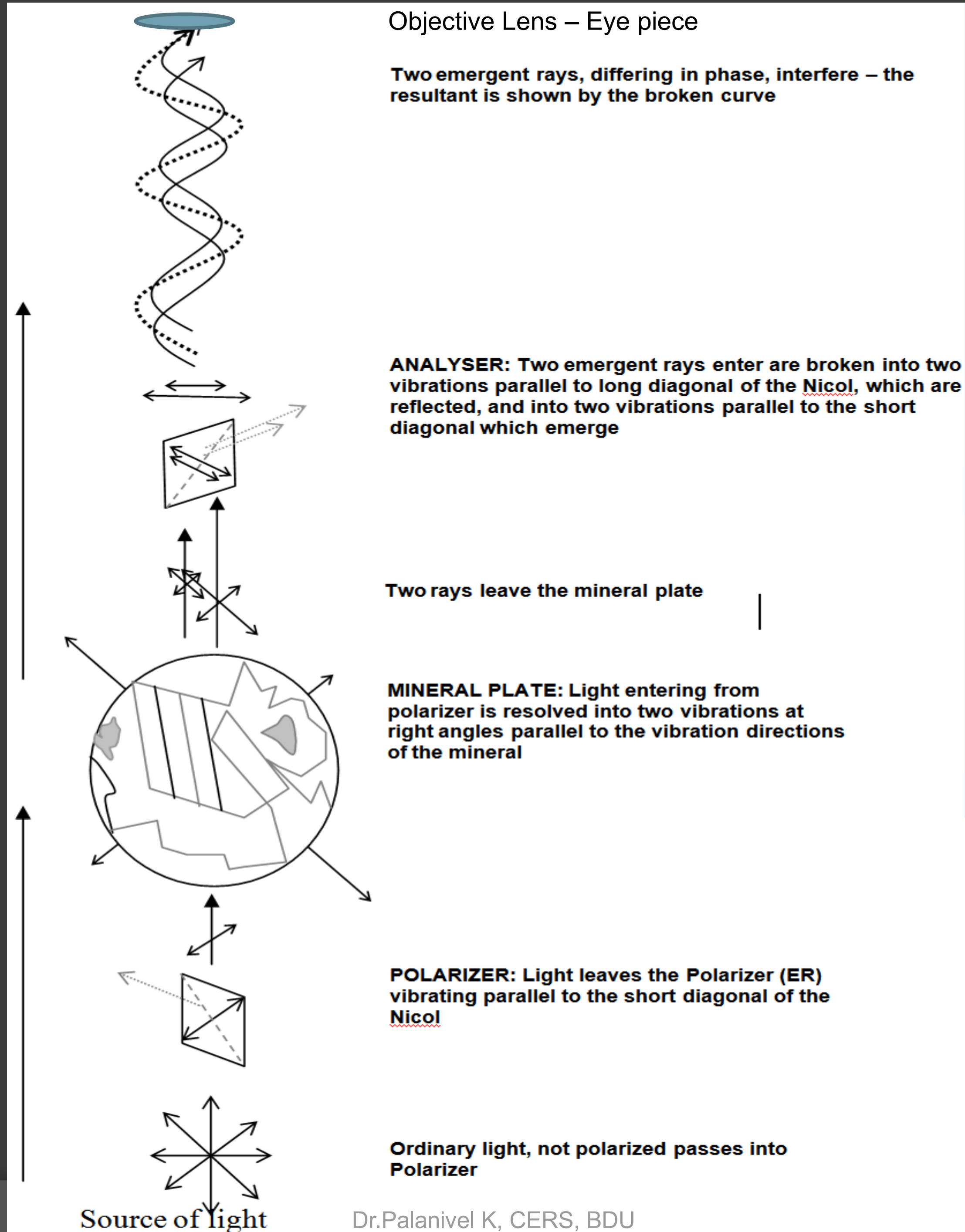
11. Isotropic / Anisotropic:

- The two nicols of the microscope are said to be crossed when the shorter diagonal of the one is at right angles to the shorter diagonal of the other.
- Isotropic minerals between crossed Nicols: The isotropic minerals are single refracting. It gives blackness between crossed nicols at all positions of rotation of the microscopic stage.

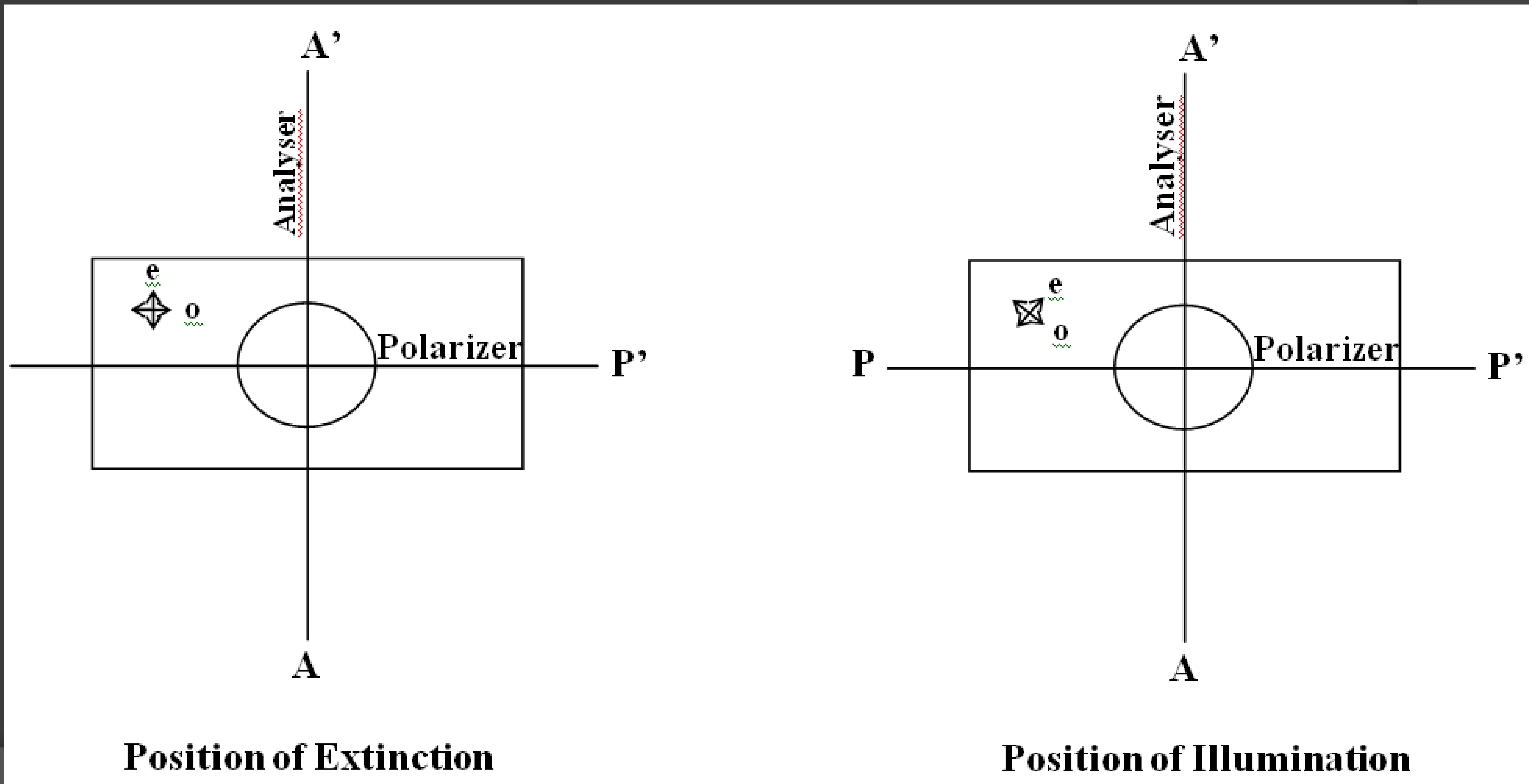
Anisotropic minerals between crossed Nicols:

- The anisotropic mnls. are doubly refracting, so that a ray of light entering a plate is broken up into two rays, vibrating at right angles and traveling with different velocities.
- The directions of vibration of the two rays are called the **Vibration direction** and one ray is the fast ray and the one slow.

Behaviour of Light Travelling inside the Polarizing Microscope

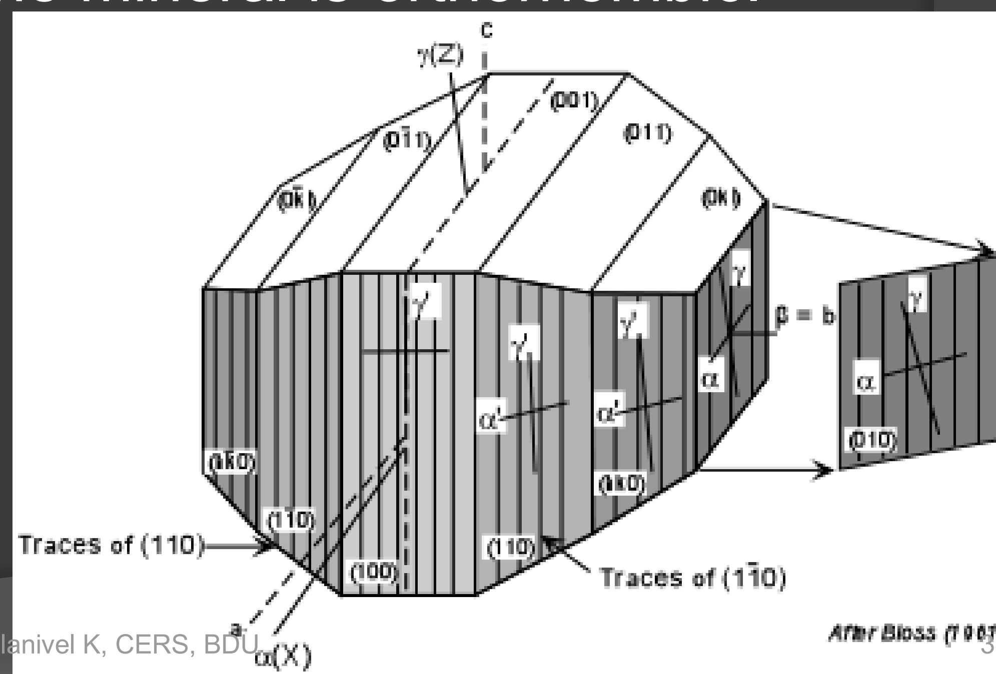


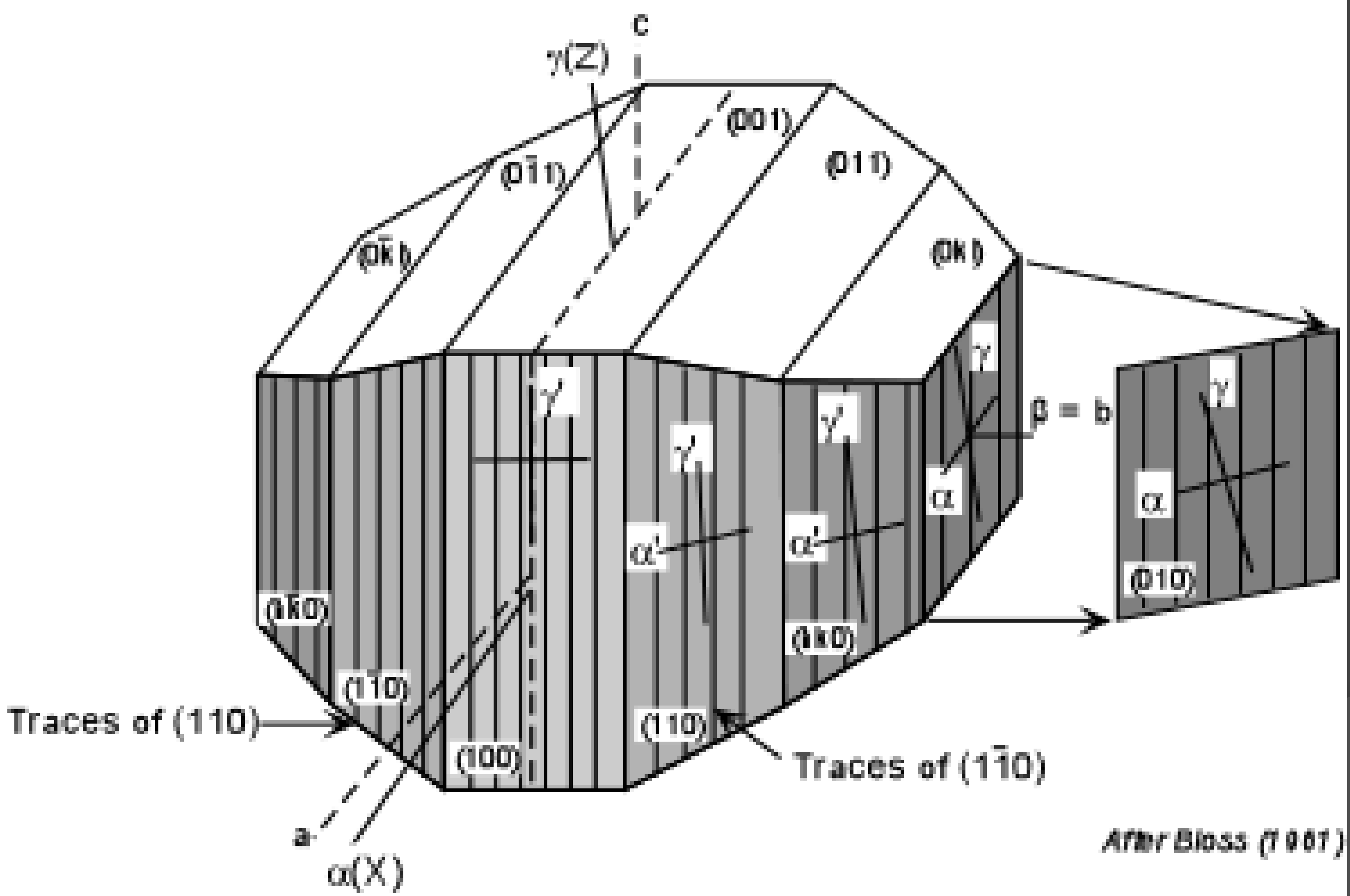
12. Extinction & angle of extinction



Extinction Angle

- Uniaxial minerals that have cleavage parallel to the c axis will have parallel extinction on all faces lying with the c axis parallel to the stage, and have symmetrical extinction on all other faces if the cleavages intersect.
- Biaxial minerals that have cleavage parallel to the c axis will usually have inclined and asymmetrical extinction if the mineral is triclinic or monoclinic, and will have parallel and symmetrical extinction if the mineral is orthorhombic.
- Extinction angles that reported will be the maximum possible acute angle, and thus different orientations of the minerals could produce extinction angles from 0 to 45^o.

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Undulatory / Wavy Extinction

Deformation of minerals can result in strain of the crystal structure, which causes different parts of the same mineral to have different crystallographic axes and therefore optical orientations.

When this occurs, the parts of the crystal with different orientations will go extinct at different rotational positions.

This is referred to as undulatory extinction. It is common in Quartz found in metamorphic rocks.

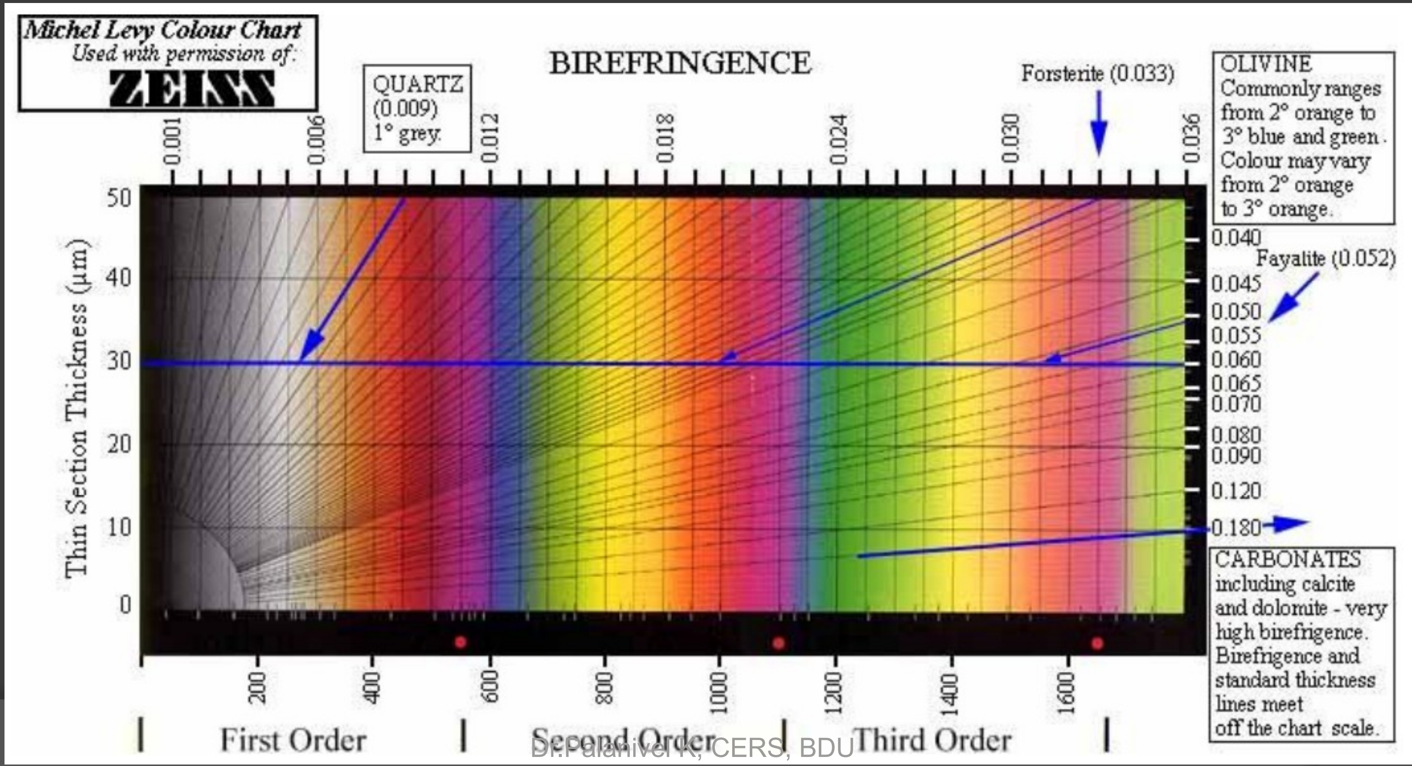
Undulatory Extinction in Quartz

Accessory Plates:

- **Quartz-wedge:** It provides Newton's scale of Interference colours to estimate the birefringence and to determine the optic sign of uniaxial minerals.
- **Gypsum or Selenite plate:** It gives the sensitive tint, the purple at the end of the First order, between crossed nicols. When placed over a mineral, it gives blue when the phase-difference is increased and red or yellow when it is decreased, so that phase-differences are easily told.
- **Mica Plate:** For yellow light it gives a retardation of a quarter of a wave-length.
- The gypsum and mica plates have the character fast or slow of the vibration parallel to their lengths marked on them.
- **Determination of Optical sign**: Uniaxial and Biaxial.

13. INTERFERENCE COLOURS:

- The microscopic property of minerals producing darkness and maximum colour at different positions on inserting Quartz Wedge in between crossed Nicols in white light, due to various components of different wave-lengths for each light in series along the wedge, is known as **Newton's scale of interference colours**.

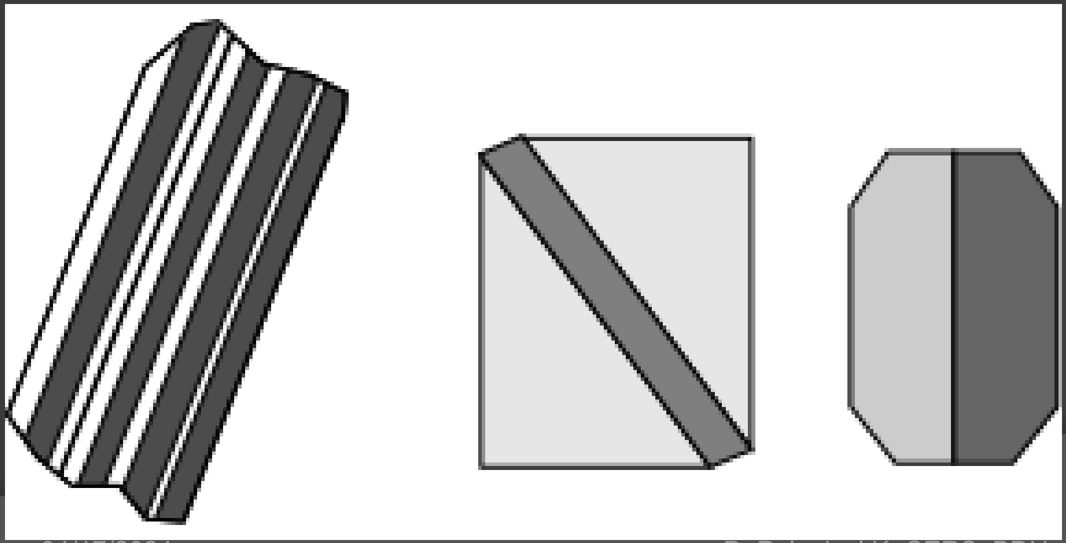


14. Twinning and Type of Twinning

Since twinning is an intergrowth of two or more crystals, optical properties will change at the boundaries between twins.

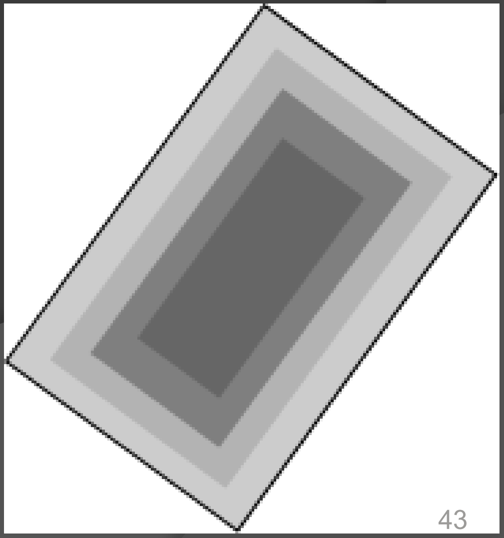
Thus, different parts of the crystal will go extinct at different times as a result of twin planes.

In **Plagioclase,** polysynthetic twinning is seen as dark and light colored stripes running through the crystal under crossed polars (left-hand illustration). Cyclical twins and simple contact twins are shown in the other illustrations.



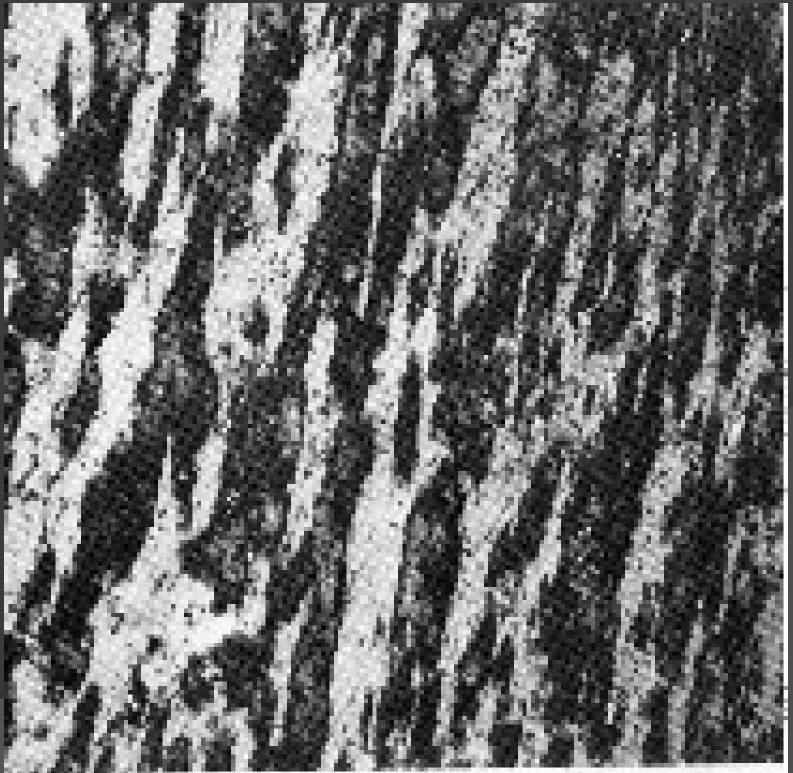
15. Alteration and Zoning

- Zoning occurs as a result of incomplete reaction of **solid solutions** and results in the chemical composition of the mineral changing through the mineral.
- The Optical properties, depend on chemical composition, and thus if the composition changes through a crystal, the optical properties will vary through the crystal as well.
- In particular, the orientation of the principal vibration directions may change, and thus the angle at which the mineral goes extinct may change.
- This can be observed by rotating a zoned crystal and noting that the whole crystal does not go extinct all at once.
- Each part that goes extinct at the same time or has the same interference color at the same time has a chemical composition distinct from other parts of the same crystal.



Exsolution Lamellae

- Some minerals that form solid solutions at high temperature exsolve as they pass through lower temperatures.
- This exsolution often results in domains of one mineral inside of the other, called exsolution lamellae.
- This is very common in the Alkali Feldspars that occur in plutonic igneous rocks, as shown here.
- It also occurs in other minerals, particularly the Pyroxenes. When exsolution lamellae are present, they can be very diagnostic of the mineral.


Exsolution Lamellae in Alkali Feldspar

Abnormal Interference Colors

As discussed under uniaxial minerals, if a mineral has strong absorption of certain wavelengths of light, these same wavelengths will be absorbed by the crystal with the analyzer inserted, and thus the crystal may produce an abnormal or anomalous interference color, one that is not shown in the interference color chart. For example, imagine a crystal that shows strong absorption of all wavelengths of light except green. Thus, all other wavelengths are absorbed in the crystal and the only wavelengths present that can reach the analyzer are green. The crystal will thus show a green interference color that is not affected by the other wavelengths of light, and thus this green color will not appear in the interference color chart. When a mineral exhibits abnormal interference colors, it will usually be listed as one of the diagnostic properties.

Associations

- Some minerals commonly occur with other minerals in the same rock due to the chemical composition of the rock. Likewise, some minerals do not occur in association with other minerals.
- Mineral associations can be very useful diagnostic properties.
- For example, Nepheline and Quartz do not usually occur with one another, nor does Mg-rich Olivine and Quartz. Thus, if Quartz is seen in a rock, then, the Mg-rich Olivine or Nepheline will not likely find in that rock.
- The Aluminous Schists, result from metamorphism of Shales, which contain an abundance of Al-rich clay minerals, can have Al-rich minerals, like Garnet, Muscovite, Alkali Feldspar, Biotite, and an Al_2SiO_5 mineral like Kyanite, Andalusite, or Sillimanite.
- Mineral associations often make mineral identification much easier, because it becomes easy to know what minerals to expect. The Petrologists
- Deer, Howie and Zussman, have referred the mineral associations with ***Paragenesis.***

BIREFERINGENCE

- The wide separation of the two refracted rays by Calcite, which makes the phenomenon so striking, is a consequence of the large difference in the values of its Indices of Refraction. It is due to the strength of its double refraction or its birefringence.

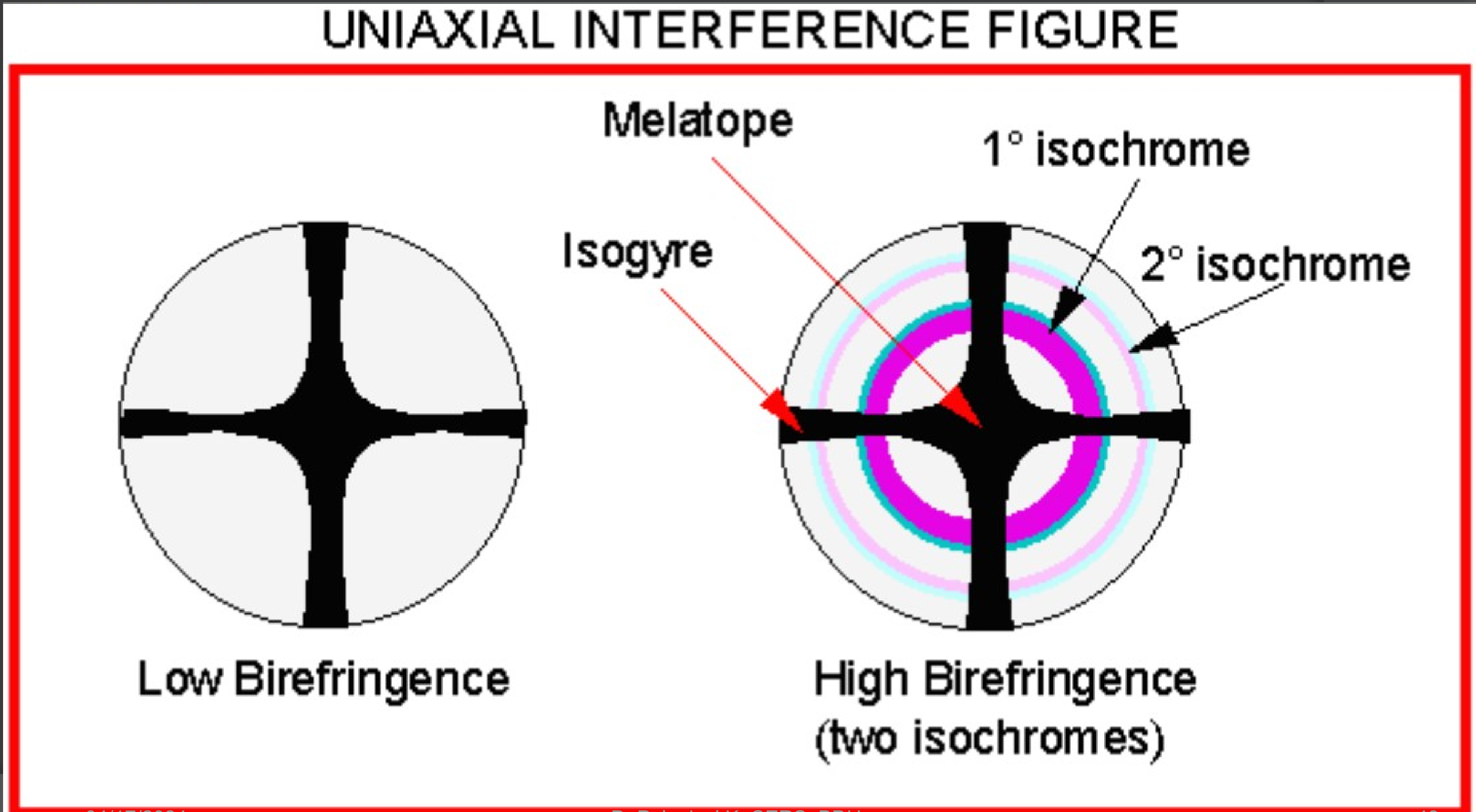
- **Birefringence is defined that the strength of double refraction property of that particular mineral**.

- This strength of double refraction is varying between different minerals.
- This can be measured for mineral thin sections having a thickness between 0.03 to 0.04mm.

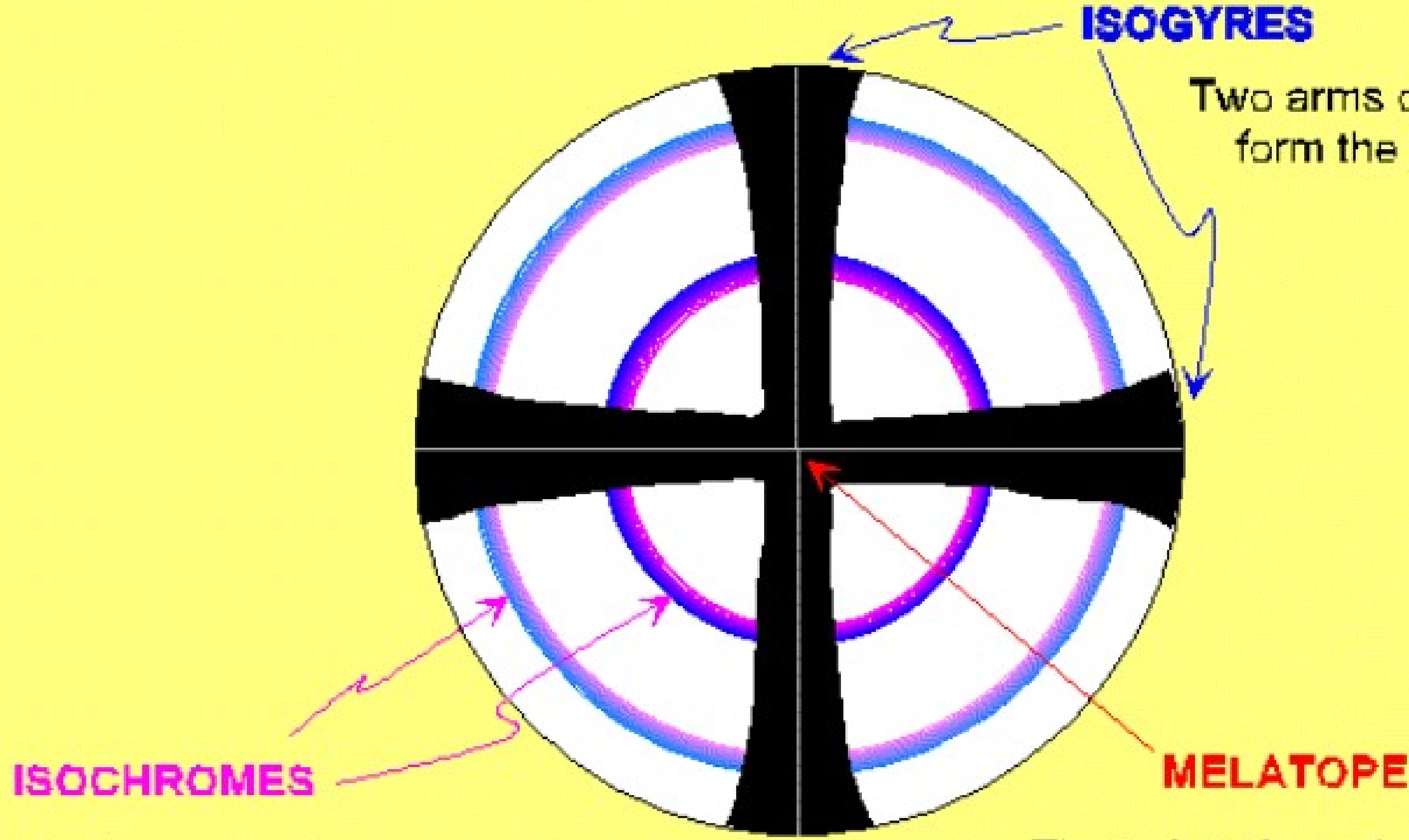
- But, the order of interference colour of a section, varies with the
  - thickness of the mineral,
  - its crystallographic orientation and
  - strength of its birefringence.

- If, the first two factors are known, the birefringence of the mineral can be estimated by noting the order of interference colour seen in thin section by the method of compensation through observing and inserting Quartz Wedge inside the objective tube of microscope, slowly.

Interference figures



UNIAXIAL INTERFERENCE FIGURE



Two arms of the cross form the Isogyres

Interference colours, identical to those on the colour chart. Increase in order from the Melatope outwards.

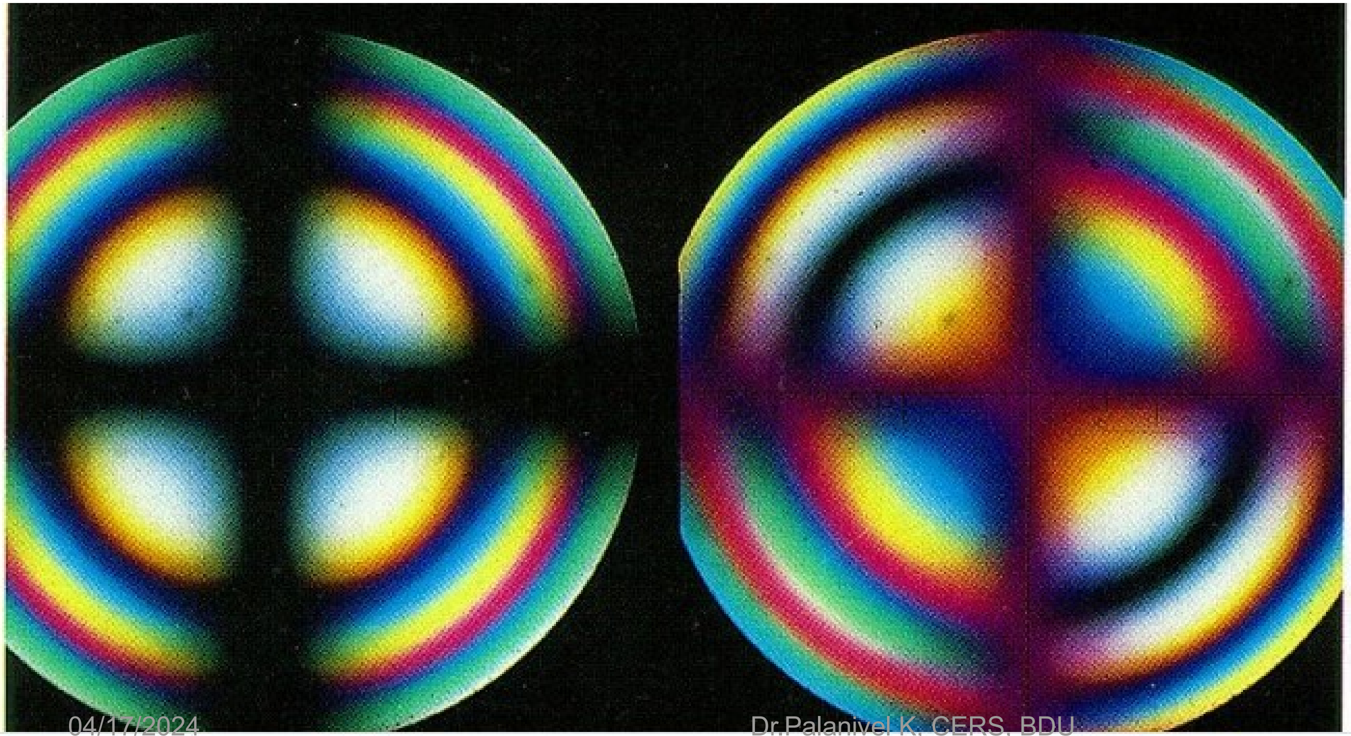
The point where the Isogyres cross is the where the Optic Axis emerges in the interference figure

How to obtain Interference Figure?

To obtain and observe an interference figure using the microscope.

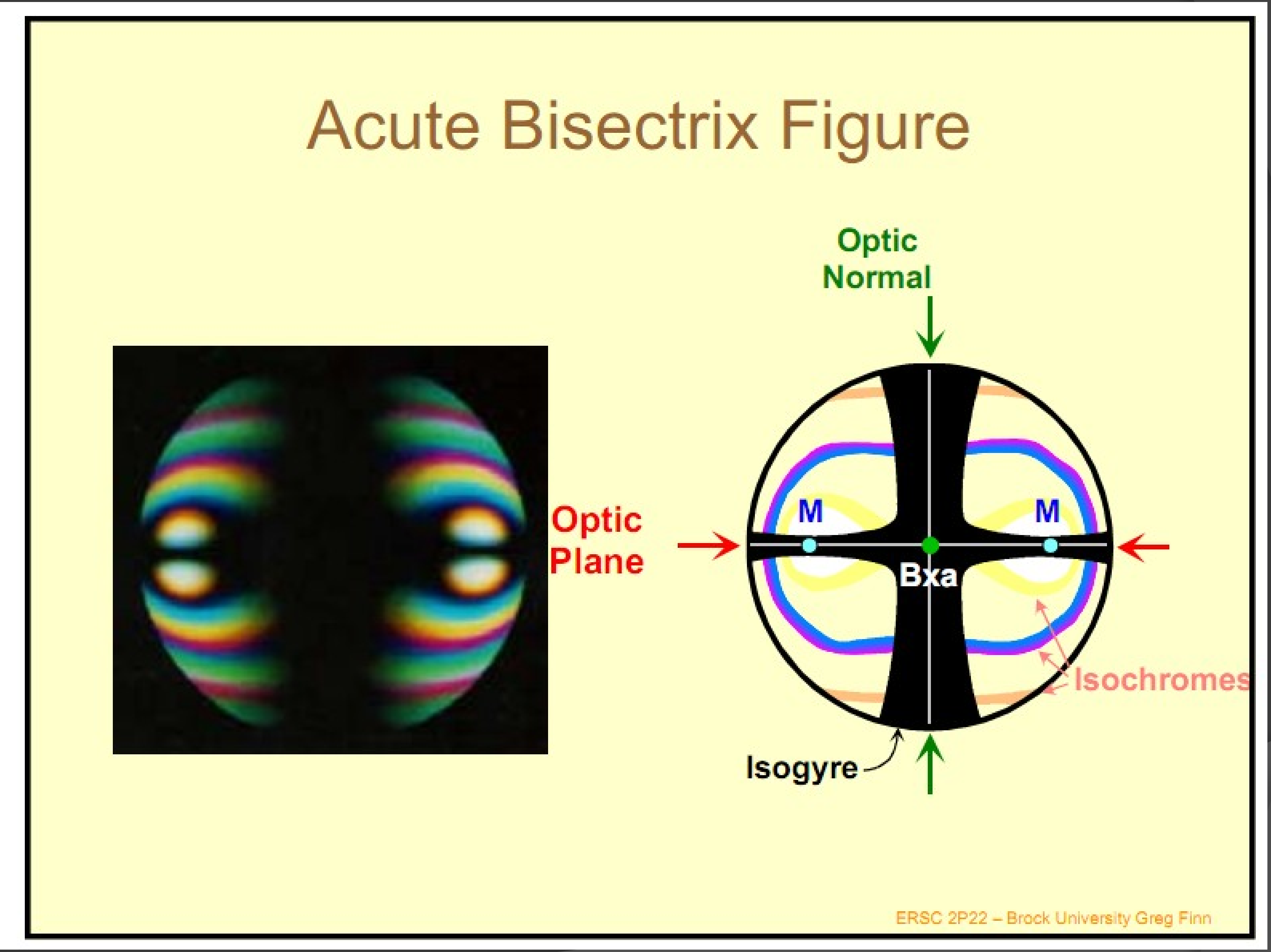
1. With high power, focus on a mineral grain free of cracks and inclusions
2. Flip in the auxiliary condensor and refocus open aperture diaphragm up to its maximum.
3. Cross the polars
4. Insert the Bertrand lens or remove the ocular and look down the microscope tube.

Will not see the grain, but the interference figure, which appears on the top surface of the objective lense.

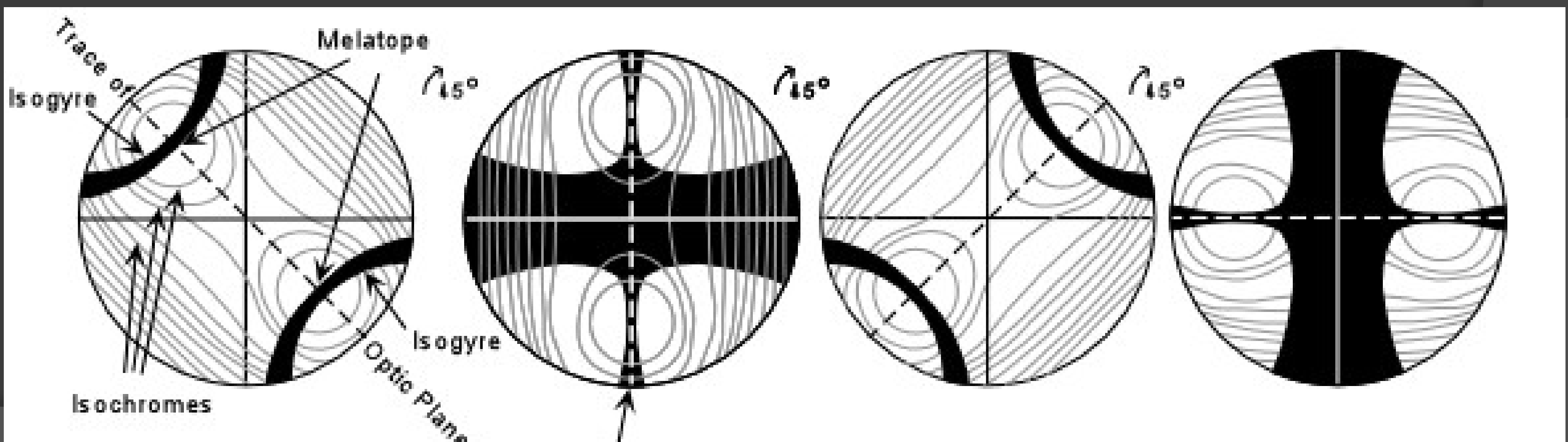


The interference figure consists of a pattern of interference colours and a black band which may form a cross. Nature and pattern for the figure is dependent on the orientation of the grain.

Biaxial Interference Figure



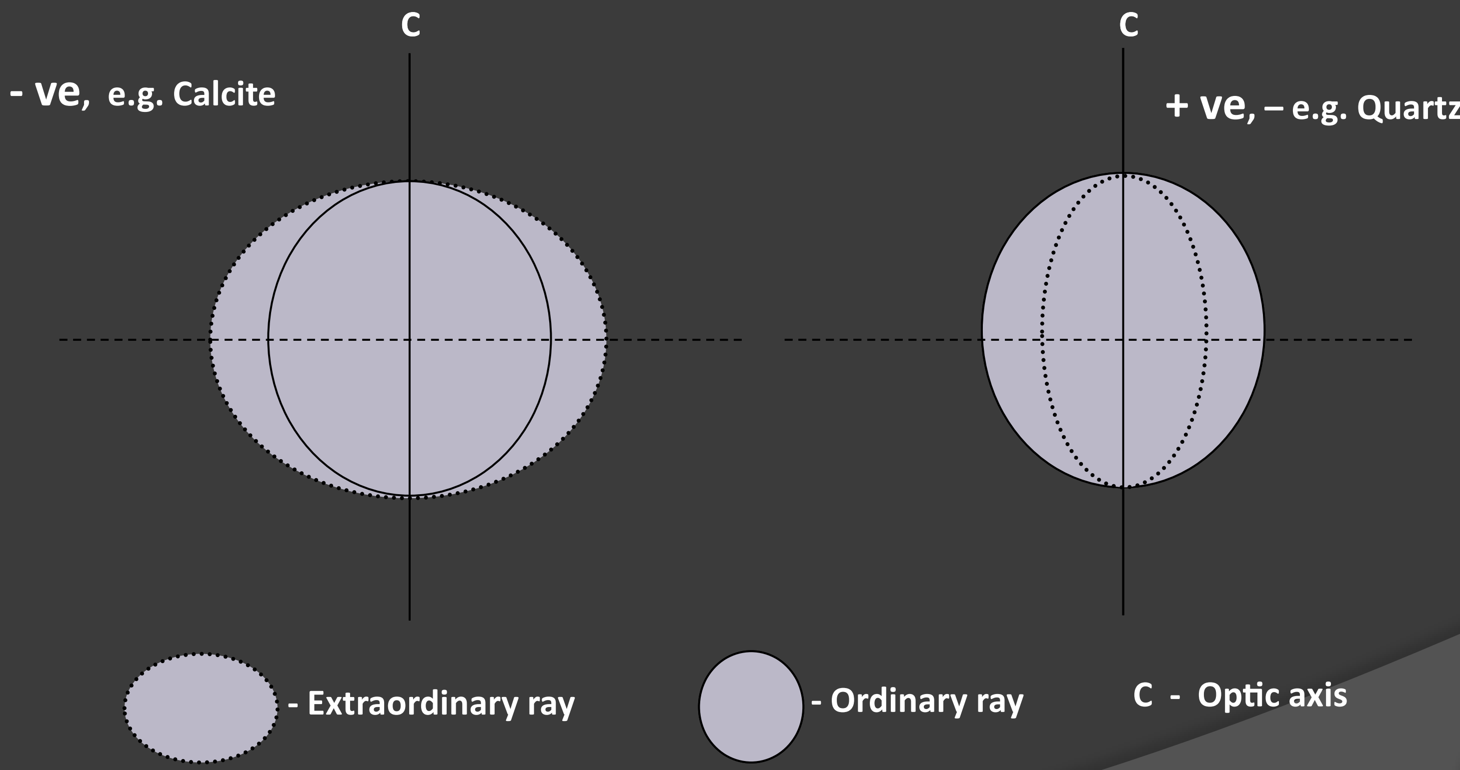
- The dark isogyres mark the positions where light vibrating parallel to the polarizer has passed through the crystal.
- At the points of maximum curvature of the isogyres are the two melatopes that mark the positions where rays that traveled along the optic axis emerge from the field of view.
- Note that the distance between the two melatopes is proportional to the angle 2V between the optic axes.
- Also seen are isochromes, which show increasing interference colors in all directions away from the melatopes. The number of isochromes and maximum order of the interference colors seen will increase with increasing thickness and absolute birefringence of the crystal.
- Shown in the figure is the trace of the optic axial plane which includes the two optic axes.



Optic sign (Uniaxial and biaxial)

- Wave front of ordinary ray is spherical and a section of this is a circle.
- The **velocity** of extraordinary ray varies with its direction.
- Along the optic axis (C), it has the same velocity as the ordinary ray, but at right angles to the optic axis it has a maximum velocity.
- The minerals having the velocity of **extraordinary ray greater than** that of the **ordinary ray** are said to be **“negative”** and the opposite condition, i.e. **lesser** are **“positive”.**

Wave fronts in Uniaxial Crystals



Biaxial interference figures consists of two black curves known as the **isogyres** and non circular rings of interference colours known as the isochromes.

Within the isogyres at the centre of the rings of colour are two points known as the **melatopes**.

These marks the projection of the two optic axes of the mineral. The line connecting the melatopes is the optic axial plane.

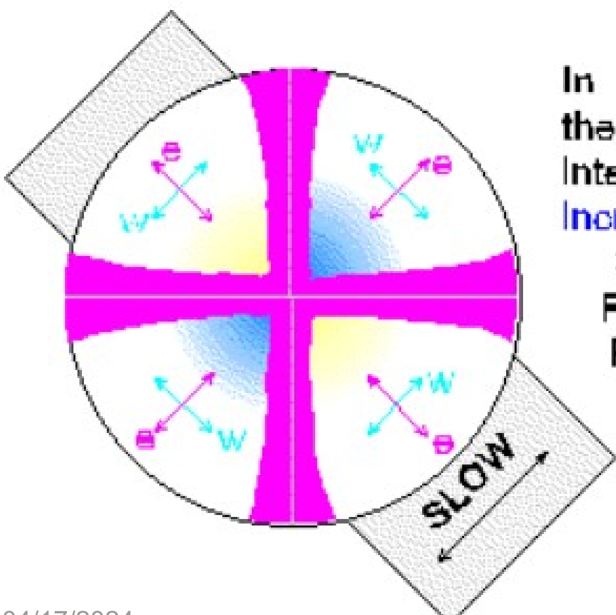
How to determine option sign?

1. Obtain an optic axis interference figure.
   one that is centred in field of view
2. Insert accessory plate into the light path.
3. Observe the interference colours:
   - in two quadrants the colours increase, move to the right,
   - in other two quadrants the colours decrease, move to the left.
4. Look at the NE quadrant of the interference figure.

INTERPRETATION

GYPSUM PLATE

+ve



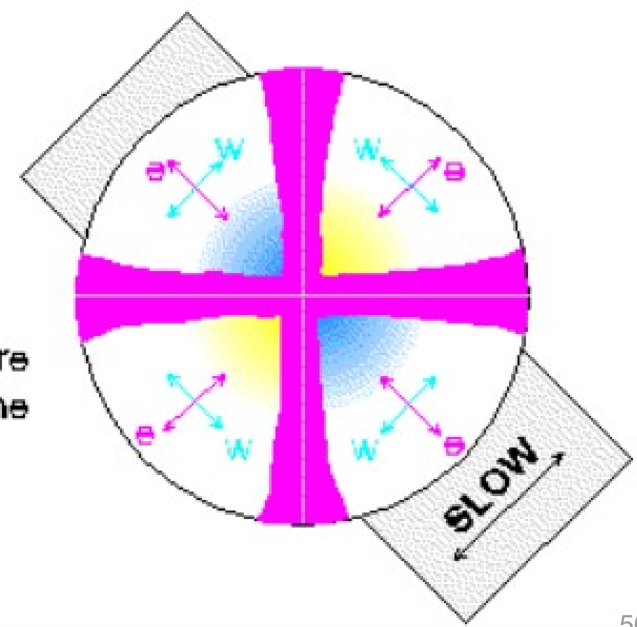
In opposite quadrants of the interference figure the interference colours either increase or decrease.

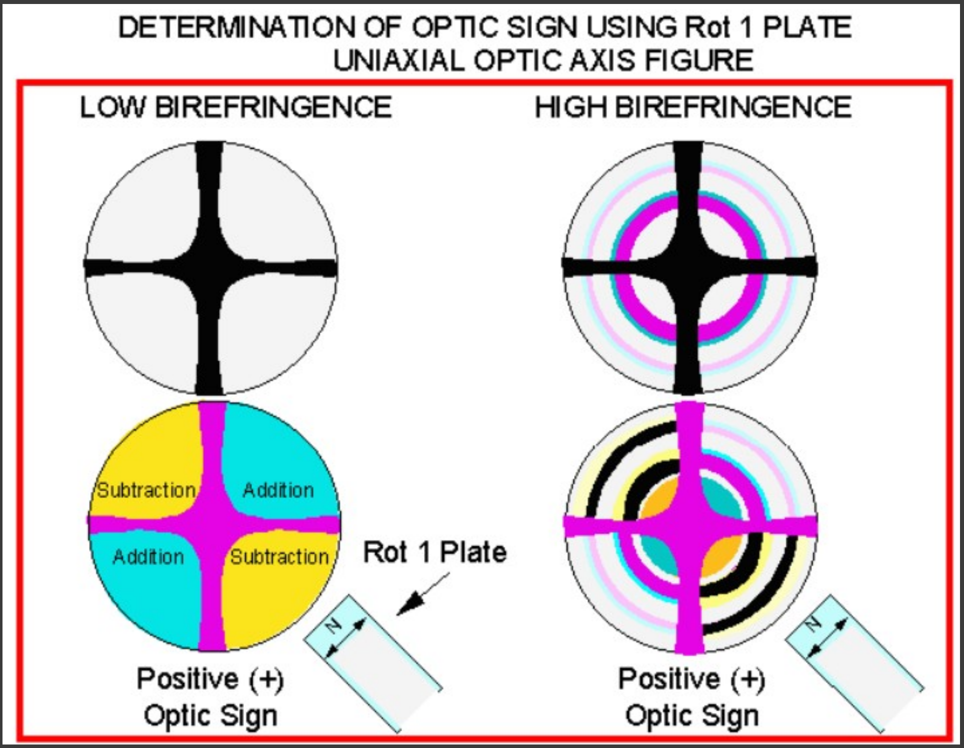
$Slow_{min}$ + $Slow_{acc}$ = Increase

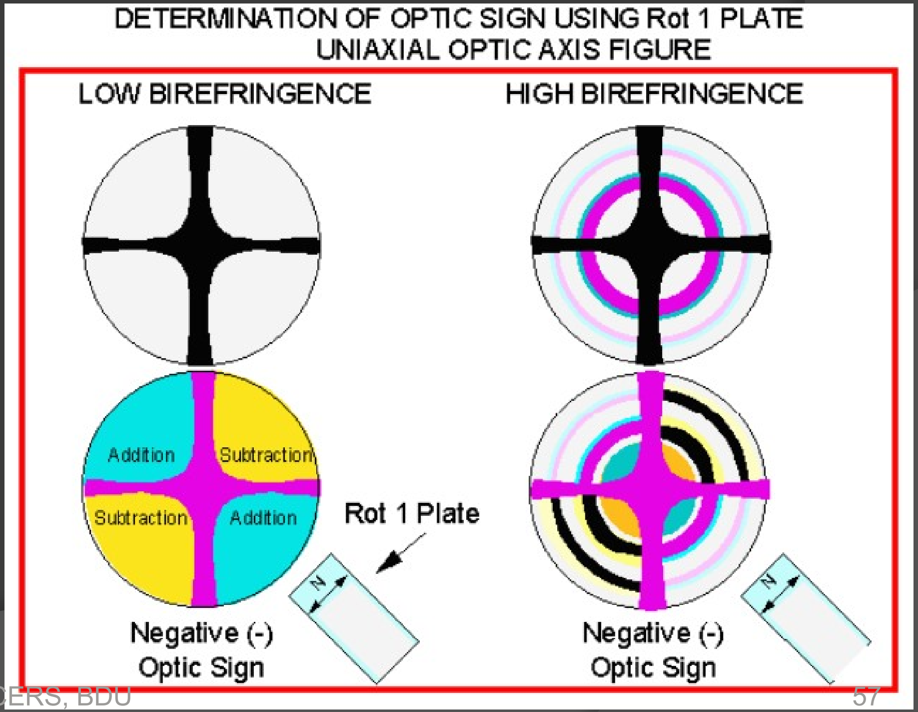
$Fast_{min}$ + $Slow_{acc}$ = Decrease.

Remember you are determining whether e is the fast or slow ray.

-ve

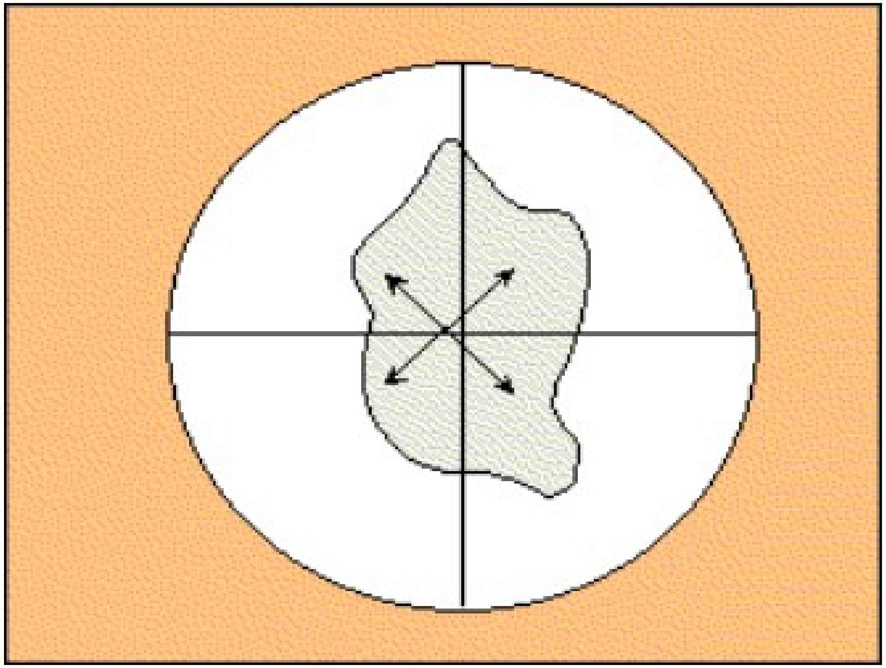



DETERMINATION OF OPTIC SIGN USING Rot 1 PLATE
UNIAXIAL OPTIC AXIS FIGURE
LOW BIREFRINGENCE
HIGH BIREFRINGENCE
Subtraction
Addition
Addition
Subtraction
Rot 1 Plate
N
Positive (+)
Optic Sign
N
Positive (+)
Optic Sign


DETERMINATION OF OPTIC SIGN USING Rot 1 PLATE
UNIAXIAL OPTIC AXIS FIGURE
LOW BIREFRINGENCE
HIGH BIREFRINGENCE
Addition
Subtraction
Subtraction
Addition
Rot 1 Plate
N
Negative (-)
Optic Sign
N
Negative (-)
Optic Sign

OPTIC SIGN USING THE GYPSUM PLATE

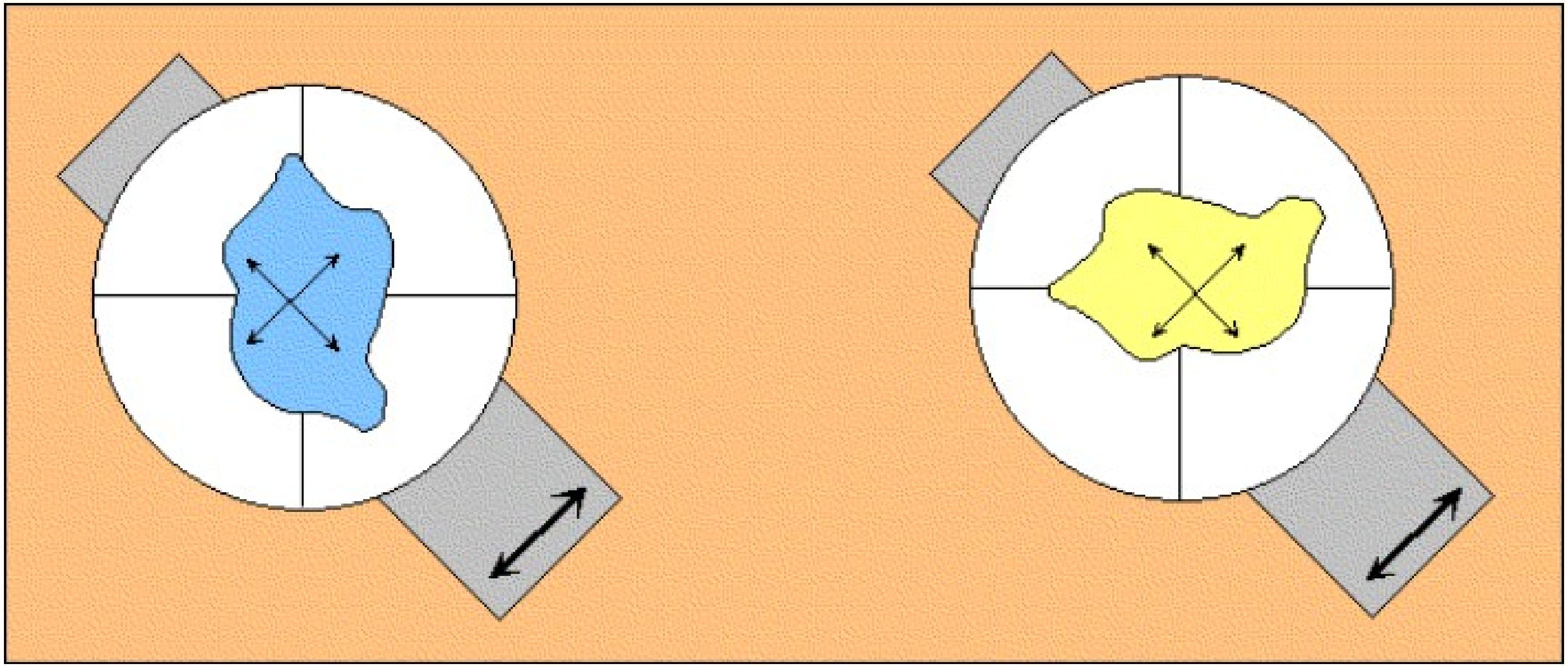
Under crossed polars, without the gypsum plate, a first order grey interference colo
retardation of approximately 200 nm.



This first order grey colour, on inserting the gypsum plate, will either;

1. Increase to second order blue-green, the colour shown on the left below,
   (200 + 550 =750 nm)
   giving a total retardation = 750 nm
   or

2. Decrease to first order yellow, the colour shown on the right below,
(200-550 |-350| nm)
giving a total retardation = 350 nm.



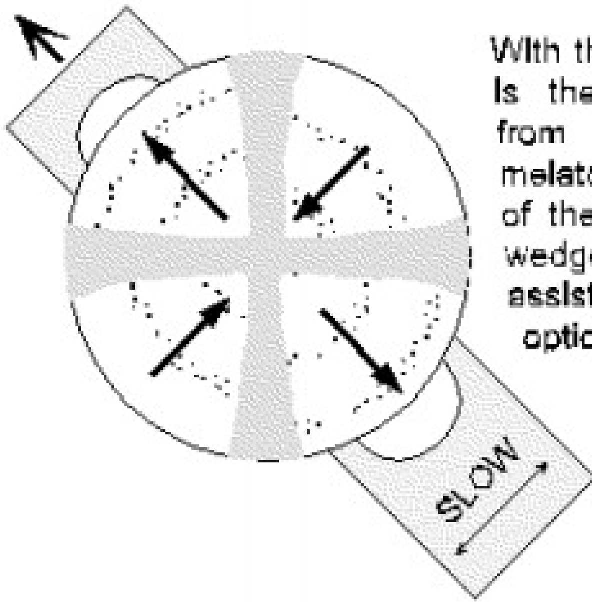
The blue or green colour results from the addition of the slow vibration direction of plate to the slow vibration direction of mineral.

The yellow colour results from the subtraction of the slow vibration direction of plate from the fast vibration direction of mineral.

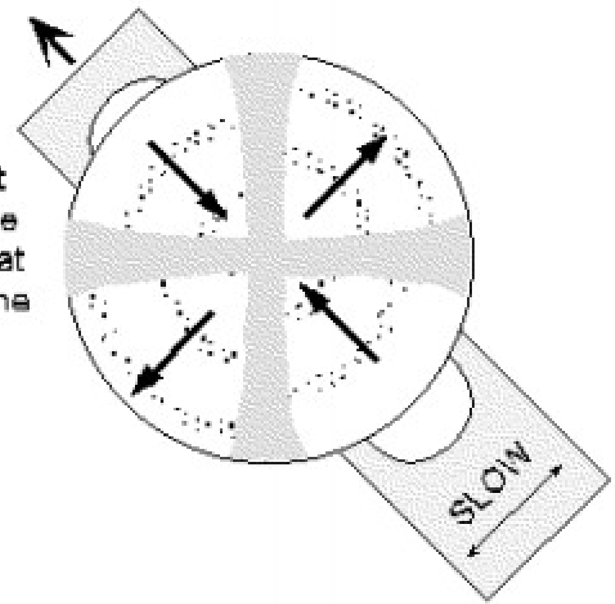
OPTIC SIGN USING THE QUARTZ WEDGE

If the interference figure displays numerous isochromes colour changes produced with gypsum plate become difficult to detect. In this case the quartz wedge is used.

QUARTZ WEDGE



With the quartz wedge it is the direction, away from or towards the melatope, of movement of the isochromes as the wedge is inserted that assists in determining the optic sign.



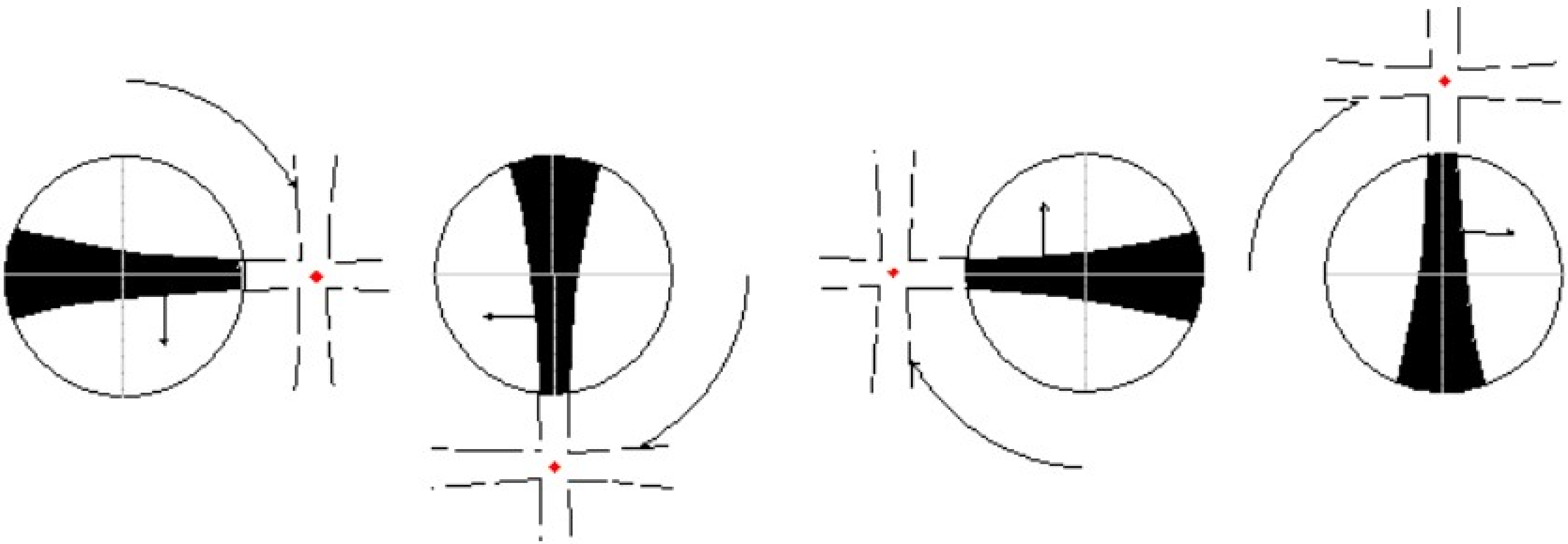
In the NE and SW quadrants of the figure the isochromes move in.
In the NW and SE quadrants of the figure the isochromes move out.

In the NE and SW quadrants of the figure the isochromes move out.
In the NW and SE quadrants of the figure the isochromes move in.

Interference figure from Off-Centered optic axis

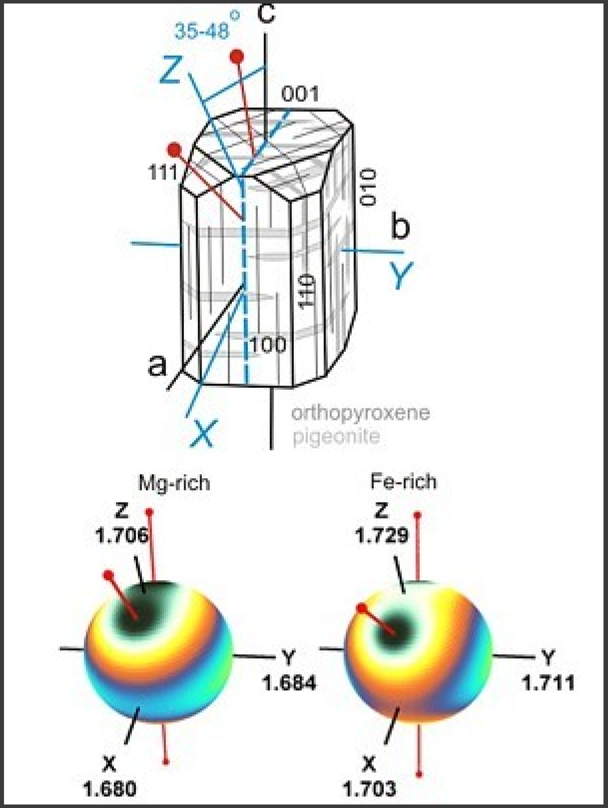
If the melatope is just in the field of view the optic sign can easily be determined, using the technique outlined above.

If the melatope is well outside the field of view the isogyres sweep across the field of view in sequence as the stage is rotated - with the isogyres always remaining parallel to the crosshairs.



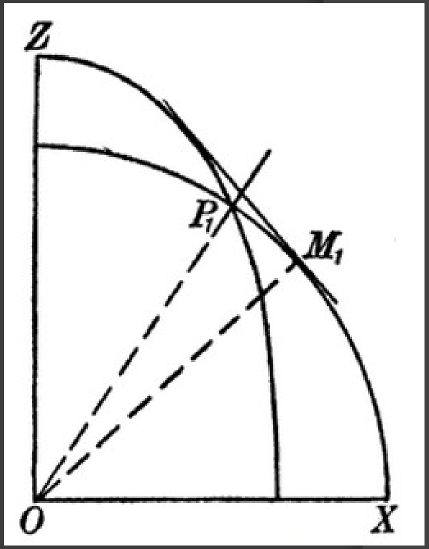
By noting the direction and sequence of how the isogyres pass through the field of view, as the stage is rotated, it is possible to identify which quadrant is being viewed and therefore the optic sign may be determined, knowing the vibration directions of omega & epsilon, in the NE quadrant of the interference figure.

Primary and Secondary Optic axes



Primary optic axis:
One of two optic axes in a crystal that are perpendicular to the circular sections of the indicatrix and along which all light rays travel with equal velocity.

Secondary optic axis: One of two optic axes in a crystal along which all light rays travel with equal velocity. Secondary optic axes are close to but do not necessarily coincide with primary optic axes.



A crystal orientation diagram for Augite is shown above. The Z axis of the optic indicatrix is inclined to the c-axis of augite by 35-48 degrees with the two optic axes separated by an angle of 25-75 degrees from each other (the 2V angle). The birefringence spheres show the interference colour of sections of Augite seen at different viewing angles. Along the optic axes crystals are isotropic, along the c-axis crystals show first order grey to white colours and along the Y axis they show maximum birefringence.

Optic axial angle measurements

- The **optic axis of a crystal** is the direction in which a ray of transmitted light suffers no birefringence (double refraction).
- Due to the internal structure of the crystal (the specific structure of the crystal lattice, the form of atoms or molecules of its components), light behaves differently when propagating along the optic axis than in other directions.
- Light propagating along the optic axis of a uniaxial crystal (e.g. calcite, quartz), has no unusual results. Light propagates along that axis with a speed independent of its polarization.
- If the light beam is not parallel to the optic axis, then the beam is split into two rays (the ordinary and extraordinary) when passing through the crystal. These rays will be mutually orthogonally polarized.

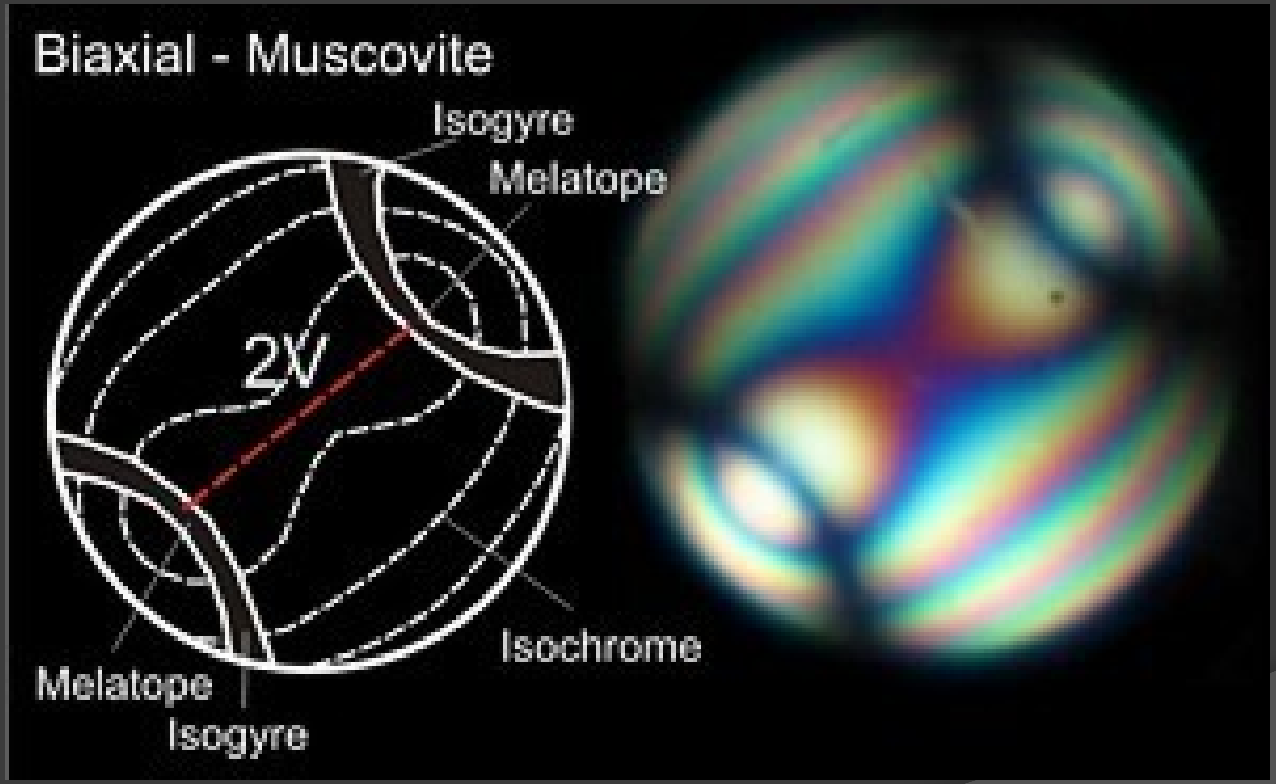
Optic Orientation

- The relation between the principal vibration directions of a crystal and the crystallographic axes is known as optic orientation.
- The orientation of the principal vibration axes of a crystal's optical indicatrix and its crystallographic axes constitutes the crystal's **optical orientation**.

2V

2V = angle between optic axes

The value of 2V is often a useful property in identifying minerals and further more can provide an approximate composition for some minerals.

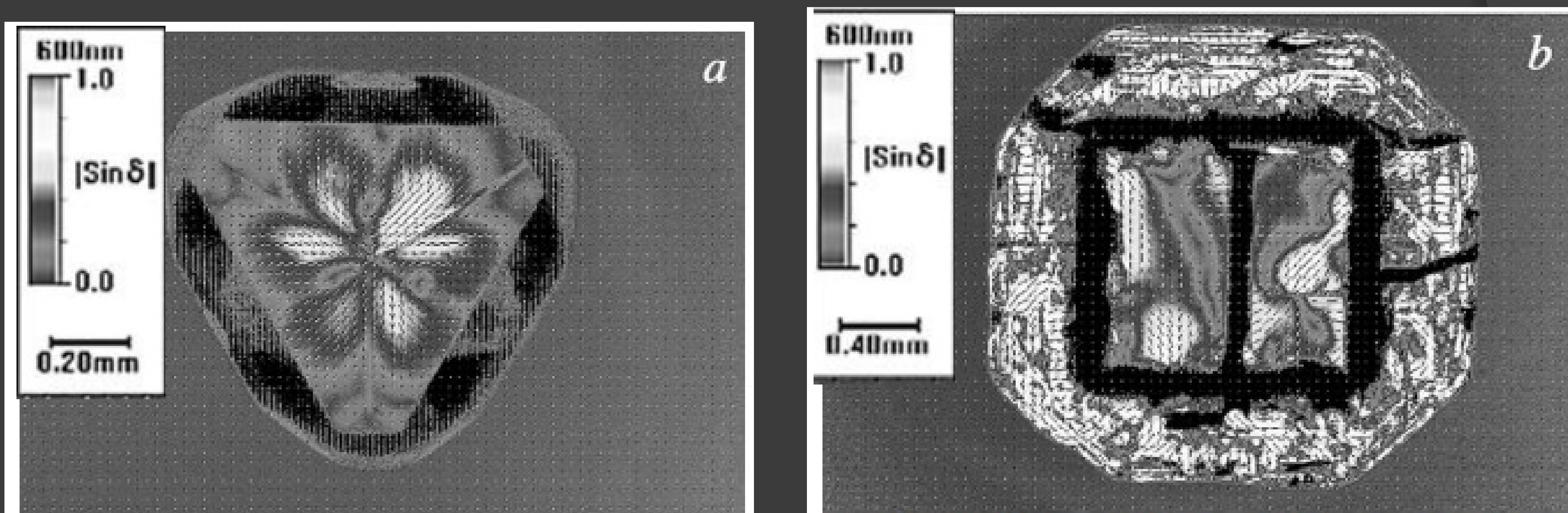


In a centered Bxa figure, the closer the melatopes and the stronger curvature of the isogyres, the lower the 2V angle.

Optic anomalies

Optic anomaly is an apparent lack of harmony between the crystal form of a mineral and its optical properties.

For example, anomalous Birefringence of a Diamond is shown here:



Optically anomalous Birefringence Images of a Diamond. (a) Section cut Perpendicular to the three fold axis. (b) Another Section cut perpendicular to the four fold axis. The False color scale plotted as (sinδ), where $\delta = 2\pi\Delta nL/\lambda$, $\Delta n = n_\perp - n_\parallel$, L is the sample thickness, and λ is the wavelength of light. Hash marks indicate the extinction directions, the orientation of the most refracting directions.

Source: Figure courtesy of Dr.M.Geday.

Dispersion in Crystals

Whenever the white light is incident on a crystal, then it is getting refracted and the refracted ray dispersed into its primary colours, known as Dispersion in Crystals.

There are three possible optical orientation through which dispersion takes place in Monoclinic minerals.

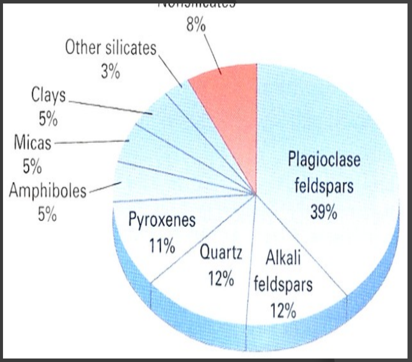
1) Inclined Dispersion: It is observed in the case where the direction Y coincides with the axis b.
2) Horizontal dispersion: The crystallographic axis b coincides with the obtuse bisectrix which may be either the X or Z direction depending upon the optical character of the crystal.
3) Crossed Dispersion: The crystallographic axis b coincides with the acute bisectrix, which may be either the X or Z direction depending upon the optical character of the crystal.

UNIT – 5 MINERAL GROUPS

- 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).

ROCK FORMING MINERALS

1. Silicates



<u>Structures of Silicates</u>

- Independent tetrahedron
- Single Chain tetrahedron
- Double Chain
- Sheet structure
- Framework silicates

Table 2–1 Abundances of chemical elements in the earth's crust*

Element and symbol	Percentage by weight	Percentage by number of atoms	Percentage by volume
Oxygen (O)	46.6	62.6	93.8*
Silicon (Si)	27.7	21.2	0.9
Aluminum (Al)	8.1	6.5	0.5
Iron (Fe)	5.0	1.9	0.4
Calcium (Ca)	3.6	1.9	1.0
Sodium (Na)	2.8	2.6	1.3
Potassium (K)	2.6	1.4	1.8
Magnesium (Mg)	2.1	1.9	0.3
All other elements	1.5		
	100.0	100.0†	100.0†

*Note the high percentage of oxygen in the earth's crust.
†Includes only the first eight elements.
(Based on B. Mason, *Principles of Geochemistry*, New York, John Wiley & Sons, Inc., 1966.)

2. Non-silicates

a. Metallic, b. Non-metallic

- **- Oxides**
- **- Sulphides**
- **- Sulphates**
- **- Chlorides**
- **- Carbonates**
- **- Phosphates and**
- **- Halides**

Rock-Forming Minerals

MINERAL	COMPOSITION	PRIMARY OCCURRENCE
Ferromagnesian silicates		
Olivine	$(Mg,Fe)_2SiO_4$	Igneous, metamorphic rocks
Pyroxene group		
Augite most common	Ca, Mg, Fe, Al silicate	Igneous, metamorphic rocks
Amphibole group		
Hornblende most common	Hydrous* Na, Ca, Mg, Fe, Al silicate	Igneous, metamorphic rocks
Biotite	Hydrous K, Mg, Fe silicate	All rock types
Nonferromagnesian silicates		
Quartz	SiO_2	All rock types
Potassium feldspar group		
Orthoclase, microcline	$KAlSi_3O_8$	All rock types
Plagioclase feldspar group	Varies from $CaAl_2Si_2O_8$ to $NaAlSi_3O_3$	All rock types
Muscovite	Hydrous K, Al silicate	All rock types
Clay mineral group	Varies	Soils and sedimentary rocks
Carbonates		
Calcite	$CaCO_3$	Sedimentary rocks
Dolomite	$CaMg(CO_3)_2$	Sedimentary rocks
Sulfates		
Anhydrite	$CaSO_4$	Sedimentary rocks
Gypsum	$CaSO_4 \cdot 2H_2O$	Sedimentary rocks
Halides		
Halite	NaCl	Sedimentary rocks

*Contains elements of water in some kind of union.

Table 2–5 Common rock-forming silicate minerals

Silicate mineral	Composition	Physical properties
Quartz	Silicon dioxide (silica, SiO_2)	Hardness of 7 (on scale of 1 to 10); will not cleave (fractures unevenly); specific gravity: 2.65
Potassium feldspar group	Aluminosilicates of potassium	Hardness of 6.0–6.5; cleaves well in two directions; pink or white; specific gravity: 2.5–2.6
Plagioclase feldspar group	Aluminosilicates of sodium and calcium	Hardness of 6.0–6.5; cleaves well in two directions; white or gray; may show striations on cleavage planes; specific gravity: 2.6–2.7
Muscovite mica	Aluminosilicates of potassium with water	Hardness of 2–3; cleaves perfectly in one direction, yielding flexible thin plates; colorless; transparent in thin sheets; specific gravity: 2.8–3.0
Biotite mica	Aluminosilicates of magnesium, iron, potassium, with water	Hardness of 2.5–3.0; cleaves perfectly in one direction, yielding flexible thin plates; black to dark brown; specific gravity: 2.7–3.2
Pyroxene group	Silicates of aluminum, calcium, magnesium, and iron	Hardness of 5–6; cleaves in two directions at 90°; black to dark green; specific gravity: 3.1–3.5
Amphibole group	Silicates of aluminum, calcium, magnesium, and iron	Hardness of 5–6; cleaves in two directions at 56° and 124°; black to dark green; specific gravity: 3.0 3.3
Olivine	Silicate of magnesium and iron	Hardness of 6.5–7.0; light green; transparent to translucent; specific gravity: 3.2–3.6
Garnet group	Aluminosilicates of iron, calcium, magnesium, and manganese	Hardness of 6.5–7.5; uneven fracture, red, brown, or yellow; specific gravity: 3.5–4.3

TABLE 2.3 Important Mineral Groups

Group	Member	Formula	Economic Use
Oxides	Hematite	Fe_2O_3	Ore of iron
	Magnetite	Fe_3O_4	Ore of iron
	Corundum	Al_2O_3	Gemstone, abrasive
	Ice	H_2O	Solid form of water
	Chromite	$FeCr_2O_4$	Ore of chromium
Sulfides	Galena	PbS	Ore of lead
	Sphalerite	Zns	Ore of zinc
	Pyrite	FeS_2	Fool's gold
	Chalcopyrite	$CuFeS_2$	Ore of Copper
	Bornite	Cu_5FeS_4	Ore of copper
	Cinnabar	HgS	Ore of mercury
Sulfates	Gypsum	$CaSO_4 \cdot 2H_2O$	Plaster
	Anhydrite	$CaSO_4$	Plaster
	Barite	$BaSO_4$	Drilling mud
Native elements	Gold	Au	Electronics, jewelry
	Copper	Cu	Electronics
	Diamond	C	Gemstone, abrasive
	Sulfur	S	Sulfa drugs, chemicals
	Graphite	C	Pencil lead, dry lubricant
	Silver	Ag	Jewelry, photography
	Platinum	Pt	Catalyst
Halides	Halite	$NaCl$	Common salt
	Fluorite	CaF_2	Used in steel making
	Sylvite	KCl	Fertilizer
Carbonates	Calcite	$CaCO_3$	Portland cement
	Dolomite	$CaMg(CO_3)_2$	Portland cement
	Aragonite	$CaCO_3$	Portland cement
Hydroxides	Limonite	$FeO(OH) \cdot nH_2O$	Ore of iron, pigments
	Bauxite	$Al(OH)_3 \cdot nH_2O$	Ore of aluminum
Phosphates	Apatite	$Ca_5(F,Cl,OH)(PO_4)_3$	Fertilizer
	Turquoise	$CuAl_6(PO_4)_4(OH)_8 \cdot 4H_2O$	Gemstone
Silicates	(Silicate minerals make up 92 percent of the Earth's crust. Figure 2.13 summarizes the rock-forming minerals.)		

The Silicate Class

- The silicates are the largest, the most interesting and the most complicated class of minerals by far.
- Approximately 30% of all minerals are silicates and
- some geologists estimate that 90% of the Earth's crust is made up of silicates.
- With oxygen and silicon are the two most abundant elements in the earth's crust – thus silicates are in abundance.

- The basic chemical unit of silicates is the (**SiO4**) tetrahedron shaped anionic group with a negative four charge (-4).

- The central silicon ion has a charge of positive four while each oxygen has a charge of negative two (-2) and

- thus each silicon-oxygen bond is equal to one half (1/2) the total bond energy of oxygen.

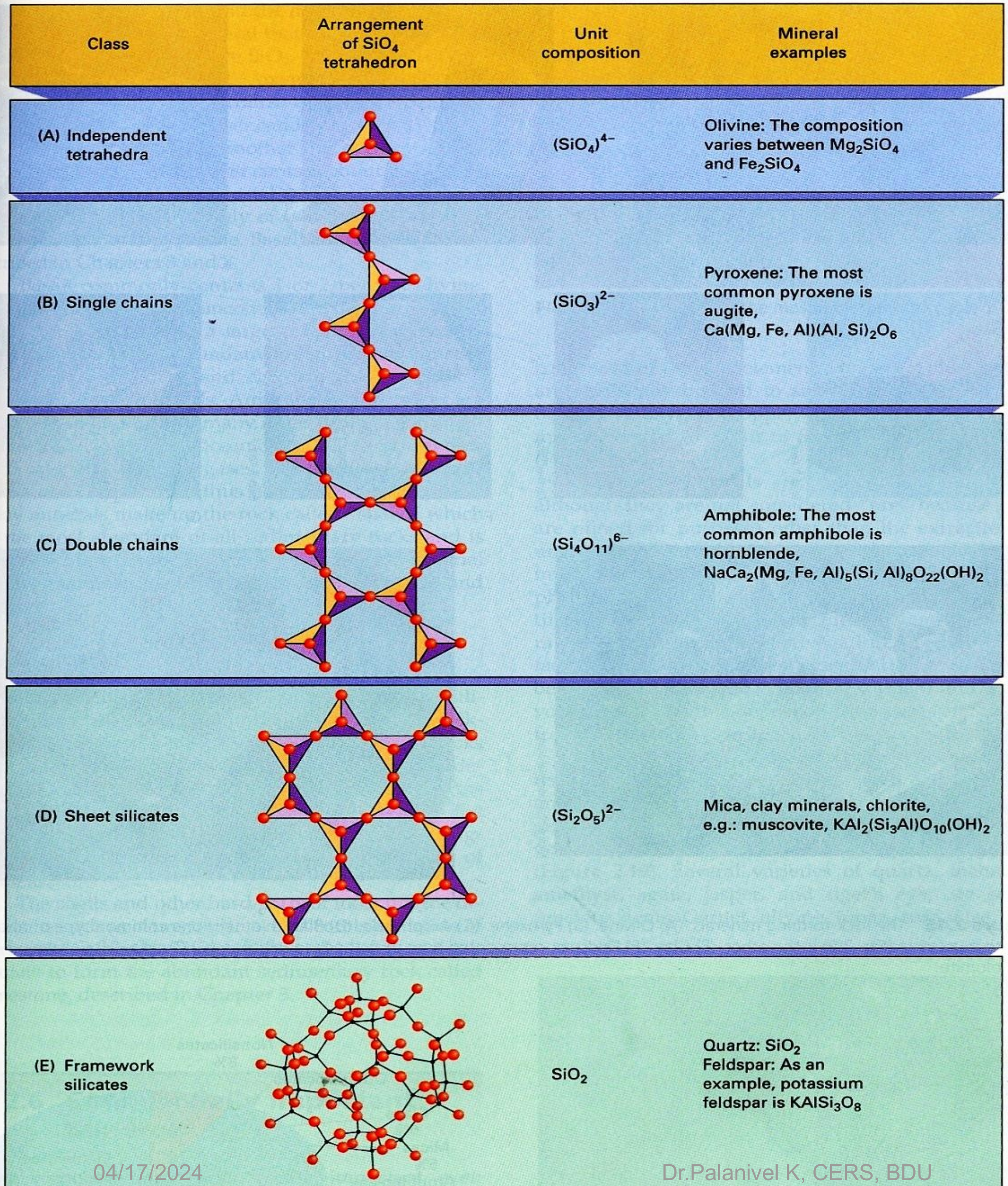
- This condition leaves the oxygens with the option of bonding to another silicon ion and therefore linking one (**SiO4**) tetrahedron to another and another, etc.

- **The structures formed by SiO_4 tetrahedron are, single units, double units, chains, sheets, rings and framework structures.**

- **The different ways that the silicate tetrahedrons combine is what makes the Silicate Class the largest, the most interesting and the most complicated class of minerals.**

The Silicates are divided into the following subclasses, not by their chemistries, but by their *structures*:

- Nesosilicates / Orthosilicates ***(single tetrahedrons)***
- Sorosilicates ***(double tetrahedrons)***
- Inosilicates ***(single and double chains)***
- Cyclosilicates ***(rings)***
- Phyllosilicates ***(sheets)***
- Tectosilicates ***(frameworks)***



Class	Arrangement of SiO_4 tetrahedron	Unit composition	Mineral examples
(A) Independent tetrahedra		$(SiO_4)^{4-}$	Olivine: The composition varies between Mg_2SiO_4 and Fe_2SiO_4
(B) Single chains		$(SiO_3)^{2-}$	Pyroxene: The most common pyroxene is augite, $Ca(Mg, Fe, Al)(Al, Si)_2O_6$
(C) Double chains		$(Si_4O_{11})^{6-}$	Amphibole: The most common amphibole is hornblende, $NaCa_2(Mg, Fe, Al)_5(Si, Al)_8O_{22}(OH)_2$
(D) Sheet silicates		$(Si_2O_5)^{2-}$	Mica, clay minerals, chlorite, e.g.: muscovite, $KAl_2(Si_3Al)O_{10}(OH)_2$
(E) Framework silicates		SiO_2	Quartz: SiO_2 Feldspar: As an example, potassium feldspar is $KAlSi_3O_8$

The five silicate structures are based on sharing of oxygen atoms among silicate tetrahedra.

(A) An **Independent tetrahdra** share no Oxygen atoms.

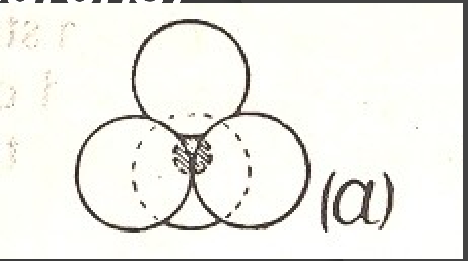
(B) In **single chains**, each tetrahedron shares two Oxygens with adjacent tetrahedra, forming a chain.

(C) A **double chain** is a pair of single chains that are cross-linked by additional Oxygen sharing.

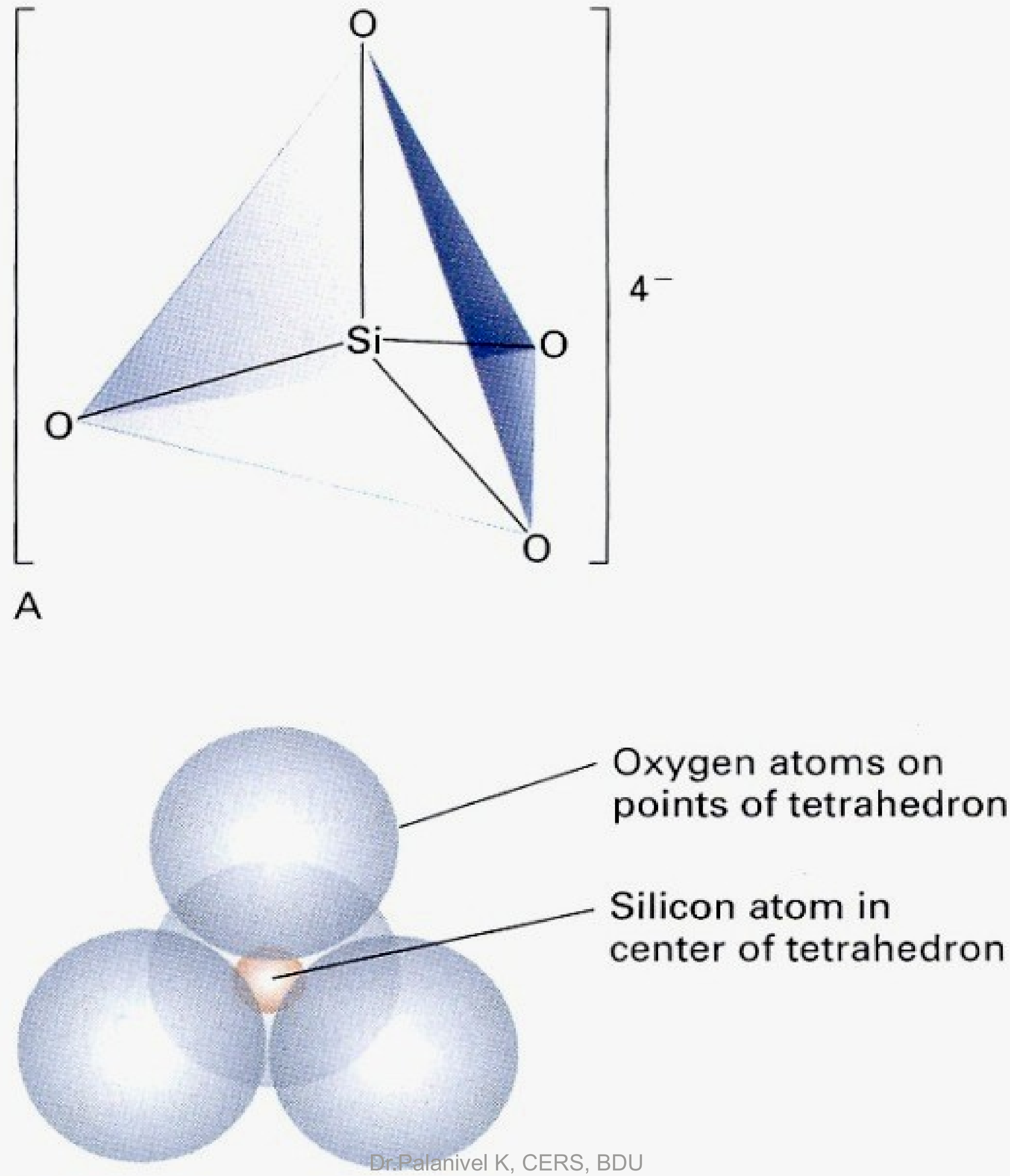
(D) In **sheet silicates** each tetrahedron shares three Oxygens with adjacent tetrahedra.

(E) A **three-dimensional silicate framework** shares all four Oxygens of each tetrahedron.

Nesosilicates / Orthosilicates *(single tetrahedrons)*



- **Simplest form of all**
- (SiO_4) **tetrahedrons are unbonded to other tetrahedrons.**
- **In this way, they are similar to other mineral classes such as the** sulfates **and** phosphates(PO4 & SO4).
- **Nesosilicates, which are sometimes referred to as orthosilicates, have a structure that produces stronger bonds and a closer packing of ions**
- **Therefore a higher density, index of refraction and hardness than chemically similar silicates in other subclasses.**
- **Consequently, there are more** gemstones **in the nesosilicates than in any other silicate subclass.**


O
Si
O
O
O
4^-
A
Oxygen atoms on points of tetrahedron
Silicon atom in center of tetrahedron

More common members of the Nesosilicates

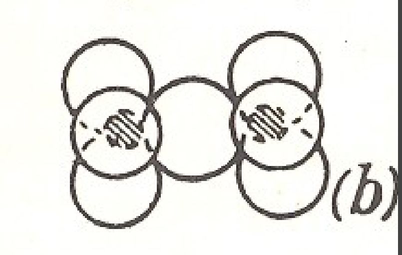
- Andalusite *(Aluminum Silicate)*
- Chloritoid *(Iron Magnesium Manganese Aluminum Silicate Hydroxide)*
- Datolite *(Calcium Boro-Silicate Hydroxide)*
- Euclase *(Beryllium Aluminum Silicate Hydroxide)*
- The Olivine Group *(Magnesium Iron Silicate)*
- Fayalite *(Iron Silicate)*
- Fosterite *(Magnesium Silicate)*
- Gadolinite *(Yttrium Iron Beryllium Silicate)*
- The Garnet Group: **1. PYRALSPITE GROUP**
  - Pyrope *(Magnesium Aluminum Silicate)*
  - Almandine *(Iron Aluminum Silicate)*
  - Spessartine *(Manganese Aluminum Silicate*

  2. UGRANDITE GROUP
  - Uvarovite *(Calcium Chromium Silicate)*
  - Grossular *(Calcium Aluminum Silicate)*
  - Andradite *(Calcium Iron Silicate)*

OTHER NESOSILICATES

Howlite *(Calcium Boro-Silicate Hydroxide)*
Humite *(Magnesium Iron Silicate Fluoride Hydroxide)*
Kyanite *(Aluminum Silicate)*
Phenakite *(Berylium Silicate)*
Sillimanite *(Aluminum Silicate)*
Sphene or Titanite *(Calcium Titanium Silicate)*
Staurolite *(Iron Magnesium Zinc Aluminum Silicate Hydroxide)*
Thorite *(Thorium Uranium Silicate)*
Topaz *(Aluminum Silicate Fluoride Hydroxide)*
Uranophane *(Hydrated Calcium Uranyl Silicate)*
Willemite *(Zinc Silicate)*
Zircon *(Zirconium Silicate)*

Sorosilicates (double tetrahedro



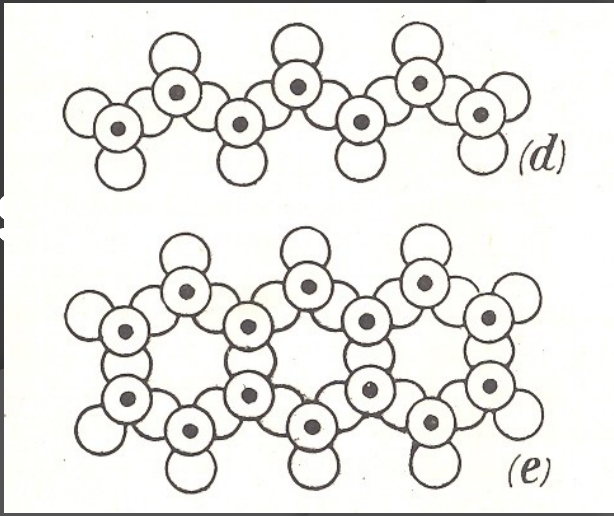
- Sorosilicates have two silicate tetrahedrons that are linked by one oxygen ion and thus the basic chemical unit is the anion group (Si_2O_7) with a negative six charge (-6).
- This structure forms an unusual hourglass-like shape and it may be due to this oddball structure that this subclass is the smallest of the silicate subclasses.
- It includes minerals that may also contain normal silicate tetrahedrons as well as the double tetrahedrons.
- The more complex members of this group, such as Epidote, contain chains of aluminum oxide tetrahedrons being held together by the individual silicate tetrahedrons and double tetrahedrons.
- Most members of this group are rare, but epidote is widespread in many metamorphic environments.

More common members of the sorosilicates

- Bertrandite ***(Beryllium Silicate Hydroxide)***
- Danburite ***(Calcium Boro-Silicate)***
- The Epidote group
  - Allanite (***Yttrium Cerium Calcium Aluminum Iron Silicate Hydroxide)***
  - Clinozoisite ***(Calcium Aluminum Silicate Hydroxide)***
  - Epidote ***(Calcium Iron Aluminum Silicate Hydroxide)***
  - Zoisite ***(Calcium Aluminum Silicate Hydroxide)***
- Hemimorphite ***(Hydrated Zinc Silicate Hydroxide)***
- Ilvaite ***(Calcium Iron Silicate Hydroxide)***
- Idocrase or Vesuvianite ***(Calcium Magnesium Aluminum Silicate Hydroxide)***

Inosilicates

- Inosilicates, or chain silicates, have interlocking chains of silicate tetrahedra with either SiO_3, 1:3 ratio, for single chains or Si_4O_{11}, 4:11 ratio, for double chains.
- **Single chain inosilicates**
- **Double chain inosilicates**



Single chain inosilicates

- Pyroxene group
  - Enstatite - orthoferrosilite series
    - Enstatite - $MgSiO_3$
    - Ferrosilite - $FeSiO_3$
  - Pigeonite - $Ca_{0.25}(Mg,Fe)_{1.75}Si_2O_6$
  - Diopside - hedenbergite series
    - Diopside - $CaMgSi_2O_6$
    - Hedenbergite - $CaFeSi_2O_6$
    - Augite - $(Ca,Na)(Mg,Fe,Al)(Si,Al)_2O_6$
  - Sodium pyroxene series
    - Jadeite - $NaAlSi_2O_6$
    - Aegirine (Acmite) - $NaFe^{3+}Si_2O_6$
  - Spodumene - $LiAlSi_2O_6$

Pyroxenoid group

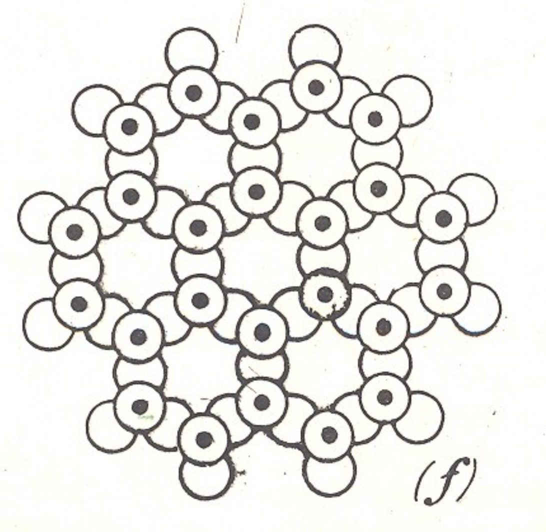
- Wollastonite - $CaSiO_3$
- Rhodonite - $MnSiO_3$
- Pectolite - $NaCa_2(Si_3O_8)(OH)$

Double chain inosilicates

- Amphibole group
  - Anthophyllite - $(Mg,Fe)_7Si_8O_{22}(OH)_2$
  - Cumingtonite series
    - Cummingtonite - $Fe_2Mg_5Si_8O_{22}(OH)_2$
    - Grunerite - $Fe_7Si_8O_{22}(OH)_2$
  - Tremolite series
    - Tremolite - $Ca_2Mg_5Si_8O_{22}(OH)_2$
    - Actinolite - $Ca_2(Mg,Fe)_5Si_8O_{22}(OH)_2$
  - Hornblende - $(Ca,Na)_{2-3}(Mg,Fe,Al)_5Si_6(Al,Si)_2O_{22}(OH)_2$
  - Sodium amphibole group
    - Glaucophane - $Na_2Mg_3Al_2Si_8O_{22}(OH)$
    - Riebeckite (asbestos) - $Na_2Fe^{2+}{}_3Fe^{3+}{}_2Si_8O_{22}(OH)_2$
    - Arfvedsonite - $Na_3(Fe,Mg)_4FeSi_8O_{22}(OH)_2$

Cyclosilicates

- Cyclosilicates, or ring silicates, have linked tetrahedra with $(Si_xO_{3x})^{2x-}$ or a ratio of 1:3. These exists as 3-member $(Si_3O_9)^{6-}$, 4-member $(Si_4O_{12})^{8-}$ and 6-member $(Si_6O_{18})^{12-}$ rings.
- 3-member ring
  - Benitoite - $BaTi(Si_3O_9)$
- 4-member ring
  - Axinite - $(Ca,Fe,Mn)_3Al_2(BO_3)(Si_4O_{12})(OH)$
- 6-member ring
  - Beryl/Emerald - $Be_3Al_2(Si_6O_{18})$
  - Cordierite - $(Mg,Fe)_2Al_3(Si_5AlO_{18})$
  - Tourmaline - $(Na,Ca)(Al,Li,Mg)_{3-}(Al,Fe,Mn)_6(Si_6O_{18})(BO_3)_3(OH)_4$



Phyllosilicates

- Phyllosilicates (from Greek φύλλον *phyllon*, leaf), or sheet silicates, form parallel sheets of silicate tetrahedra with Si_2O_5 or a 2:5 ratio.

Kaolin

- Serpentine group
  - Antigorite - $Mg_3Si_2O_5(OH)_4$
  - Chrysotile - $Mg_3Si_2O_5(OH)_4$
  - Lizardite - $Mg_3Si_2O_5(OH)_4$
- Clay mineral group
  - Kaolinite - $Al_2Si_2O_5(OH)_4$
  - Illite - $(K,H_3O)(Al,Mg,Fe)_2(Si,Al)_4O_{10}[(OH)_2,(H_2O)]$
  - Smectite -
  - Montmorillonite - $(Na,Ca)_{0.33}(Al,Mg)_2(Si_4O_{10})(OH)_2 \cdot nH_2O$
  - Vermiculite - $(MgFe,Al)_3(Al,Si)_4O_{10}(OH)_2 \cdot 4H_2O$
  - Talc - $Mg_3Si_4O_{10}(OH)_2$
  - Palygorskite - $(Mg,Al)_2Si_4O_{10}(OH) \cdot 4(H_2O)$
  - Pyrophyllite - $Al_2Si_4O_{10}(OH)_2$

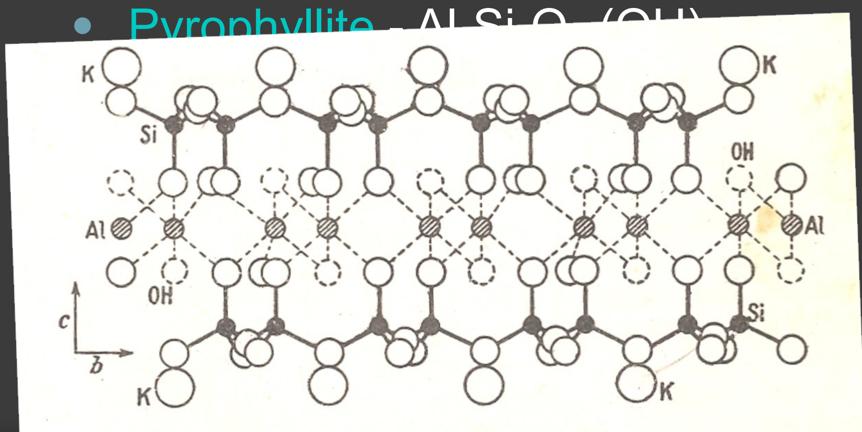


FIG. 126.—The structure of Muscovite, viewed parallel to the Si_4O_{10}-sheets. Each pair of sheets as shown is linked by Al-ions and is separated from the next pair by a layer of potassium ions.

- Mica group
  - Biotite - $K(Mg,Fe)_3(AlSi_3O_{10})(OH)_2$
  - Muscovite - $KAl_2(AlSi_3O_{10})(OH)_2$
  - Phlogopite - $KMg_3Si_4O_{10}(OH)_2$
  - Lepidolite - $K(Li,Al)_{2-3}(AlSi_3O_{10})(OH)_2$
  - Margarite - $CaAl_2(Al_2Si_2O_{10})(OH)_2$
  - Glauconite - $(K,Na)(Al,Mg,Fe)_2(Si,Al)_4O_{10}(OH)_2$
- Chlorite group
  - Chlorite -

Tectosilicates

- Tectosilicates, or "framework silicates", have a three-dimensional framework of silicate tetrahedra with SiO_2 or a 1:2 ratio. This group comprises nearly 75% of the crust of the Earth. Tectosilicates, with the exception of the quartz group, are aluminosilicates.

Quartz

Lunar Ferroan Anorthosite #60025 (Plagioclase Feldspar). Collected by Apollo 16 from the Lunar Highlands near Descartes Crater.

- Quartz group
  - Quartz - SiO_2
  - Tridymite - SiO_2
  - Christobalite - SiO_2
- Feldspar group
  - Alkali-feldspars
    - Potassium-feldspars
      - Microcline - $KAlSi_3O_8$
      - Orthoclase - $KAlSi_3O_8$
      - Sanidine - $KAlSi_3O_8$
    - Anorthoclase - $(Na,K)AlSi_3O_8$
  - Plagioclase feldspars
    - Albite - $NaAlSi_3O_8$
    - Oligoclase - $(Na,Ca)(Si,Al)_4O_8$ (Na:Ca 4:1)
    - Andesine - $(Na,Ca)(Si,Al)_4O_8$ (Na:Ca 3:2)
    - Labradorite - $(Na,Ca)(Si,Al)_4O_8$ (Na:Ca 2:3)
    - Bytownite - $(Na,Ca)(Si,Al)_4O_8$ (Na:Ca 1:4)
    - Anorthite - $CaAl_2Si_2O_8$

- Feldspathoid group
  - Nosean - $Na_8Al_6Si_6O_{24}(SO_4)$
  - Cancrinite - $Na_6Ca_2(CO_3,Al_6Si_6O_{24}).2H_2O$
  - Leucite - $KAlSi_2O_6$
  - Nepheline - $(Na,K)AlSiO_4$
  - Sodalite - $Na_8(AlSiO_4)_6Cl_2$
    - Hauyne - $(Na,Ca)_{4-8}Al_6Si_6(O,S)24(SO_4,Cl)_{1-2}$
  - Lazurite - $(Na,Ca)_8(AlSiO_4)_6(SO_4,S,Cl)_2$
- Petalite - $LiAlSi_4O_{10}$
- Scapolite group
  - Marialite - $Na_4(AlSi_3O_8)_3(Cl_2,CO_3,SO_4)$
  - Meionite - $Ca_4(Al_2Si_2O_8)_3(Cl_2CO_3,SO_4)$
- Analcime - $NaAlSi_2O_6 \cdot H_2O$
- Zeolite group
  - Natrolite - $Na_2Al_2Si_3O_{10} \cdot 2H_2O$
  - Chabazite - $CaAl_2Si_4O_{12} \cdot 6H_2O$
  - Heulandite - $CaAl_2Si_7O_{18} \cdot 6H_2O$
  - Stilbite - $NaCa_2Al_5Si_{13}O_{36} \cdot 17H_2O$

Flowchart for the IDENTIFICATION OF MINERALS Step-wise using their properties and their uses

LIGHT-COLORED NONMETALLIC MINERALS

Step 1: What is the mineral's hardness?	Step 2: What is the mineral's cleavage?	Step 3: Compare the mineral's physical properties to other distinctive properties below.	Step 4: Find mineral name(s) and check the mineral database for additional properties (Figure 2.25).
HARD (H > 5.5) Scratches glass Not scratched by masonry nail or knife blade	Cleavage excellent or good	White or gray; 2 cleavages at nearly right angles and with striations; H 6	Plagioclase feldspar
		Orange, brown, white, gray, green, or pink; H 6; 2 cleavages at nearly right angles; exsolution lamellae	Potassium feldspar
		Pale brown, white, or gray; Long slender prisms; 1 excellent cleavage plus fracture surfaces; H 6–7	Sillimanite
		Blue, very pale green, white, or gray; Crystals are blades; H 4–7	Kyanite
	Cleavage poor or absent	Colorless, white, gray, or other colors; Greasy luster; Massive or hexagonal prisms and pyramids; Transparent or translucent; H 7	Quartz Milky Quartz (white var.), Citrine Quartz (yellow var.), Rose Quartz (pink var.)
		Opaque gray or white; Luster waxy; H 7	Chert (variety of quartz)
		Colorless, white, yellow, light brown, or pastel colors; Translucent or opaque; Laminated or massive; Cryptocrystalline; Luster waxy; H 7	Chalcedony (variety of quartz)
		Pale olive green to yellow; Conchoidal fracture; Transparent or translucent; Forms short stout prisms; H 7	Olivine
SOFT (H ≤ 5.5) Does not scratch glass Scratched by masonry nail or knife blade	Cleavage excellent or good	Colorless, white, yellow, green, pink, or brown; 3 excellent cleavages; Breaks into rhombohedrons; Effervesces in dilute HCl; H 3	Calcite
		Colorless, white, gray, creme, or pink; 3 excellent cleavages; Breaks into rhombohedrons; Effervesces in dilute HCl only if powdered; H 3.5–4	Dolomite
		Colorless or white with tints of brown, yellow, blue, black; Short tabular crystals and roses; Very heavy; H 3–3.5	Barite
		Colorless, white, or gray; Massive or tabular crystals, blades, or needles; Can be scratched with your fingernail; H 2	Gypsum
		Colorless, white, gray, or pale green, yellow, or red; Spheres of radiating needles; Luster silky; H 5–5.5	Natrolite
		Colorless, white, yellow, blue, brown, or red; Cubic crystals; Breaks into cubes; Salty taste; H 2.5	Halite
		Colorless, purple, blue, gray, green, yellow; Cubes with octahedral cleavage; H 4	Fluorite
		Colorless, yellow, brown, or red-brown; Short opaque prisms; Splits along 1 excellent cleavage into thin flexible transparent sheets; H 2–2.5	Muscovite mica
	Cleavage poor or absent	Yellow crystals or earthy masses; Luster greasy; H 1.5–2.5	Sulfur
		Opaque pale blue to blue-green; Amorphous crusts or massive; Very light blue streak; H 2–4	Chrysocolla
		Opaque green, yellow, or gray; Dull or silky masses or asbestos; White streak; H 2–5	Serpentine
		Opaque white, gray, green, or brown; Can be scratched with fingernail; Greasy or soapy feel; H 1	Talc
		Opaque earthy white to very light brown; H 1–2	Kaolinite
		Colorless to white, orange, yellow, brown, blue, gray, green, or red; May have play of colors; Conchoidal fracture; H 5–5.5	Opal
		Colorless or pale green, brown, blue, white, or purple; Brittle hexagonal prisms; Conchoidal fracture; H 5	Apatite

Light-coloured minerals with non-metallic luster

DARK-COLORED NONMETALLIC MINERALS

Step 1: What is the mineral's hardness?	Step 2: What is the mineral's cleavage?	Step 3: Compare the mineral's physical properties to other distinctive properties below.	Step 4: Find mineral name(s) and check the mineral database for additional properties (Figure 2.25).
HARD (H > 5.5) Scratches glass Not scratched by masonry nail or knife blade	Cleavage excellent or good	Translucent dark gray, blue-gray, or black; may have silvery iridescence; 2 cleavages at nearly 90° and with striations; H 6	Plagioclase feldspar
		Translucent brown, gray, green, or red; 2 cleavages at nearly right angles; exsolution lamellae; H 6	Potassium feldspar
		Opaque dark green in long prisms or needles; 2 cleavages at about 60° and 120°; H 5.5	Actinolite (Amphibole)
		Opaque black; 2 cleavages at about 60° and 120°; H 5.5	Hornblende (Amphibole)
		Opaque black; 2 cleavages at nearly 90°; H 5.5–6	Augite (Pyroxene)
	Cleavage poor or absent	Transparent or translucent gray, brown, or purple; Greasy luster; Massive or hexagonal prisms and pyramids; H 7	Quartz Smoky Quartz (black/brown var.), Amethyst (purple var.)
		Transparent, translucent, or opaque red-gray, or gray; Short hexagonal prisms with striated flat ends; H 9	Corundum
		Opaque red-brown or brown; Luster waxy; Cryptocrystalline; H 7	Jasper (variety of quartz)
		Transparent to translucent dark red to black; H 7	Garnet
		Opaque gray; Luster waxy; Cryptocrystalline; H 7	Chert (variety of quartz)
		Opaque black; Luster waxy; Cryptocrystalline; H 7	Flint (variety of quartz)
		Black or dark green; Long striated prisms; H 7–7.5	Tourmaline
		Transparent or translucent olive green; Conchoidal fracture; Transparent or translucent, H 7	Olivine
		Opaque green; Poor cleavage; H 6–7	Epidote
		Opaque brown prisms that interpenetrate to form crosses; H 7	Staurolite
SOFT ($H \leq 5.5$) Does not scratch glass Scratched by masonry nail or knife blade	Cleavage excellent or good	Translucent to opaque yellow-brown to brown; may appear submetallic; Octahedral cleavage; H 3.5–4	Sphalerite
		Purple cubes or octahedrons with octahedral cleavage; H 4	Fluorite
		Black short opaque prisms; Splits easily along 1 excellent cleavage into thin sheets; H 2.5–3	Biotite mica
		Green short opaque prisms; Splits easily along 1 excellent cleavage into thin sheets; H 2–3	Chlorite
	Cleavage poor or absent	Opaque rusty brown or yellow-brown; Massive and amorphous; Yellow-brown streak; H 1.5–5.5	Limonite
		Opaque rusty brown to brown-gray rock with shades of gray, yellow, and white; Contains pea-sized spheres that are laminated internally; Pale brown streak; H 1–3	Bauxite
		Deep blue; Crusts, small crystals, or massive; Light blue streak; H 3.5–4	Azurite
		Opaque green or gray-green; Dull or silky masses or asbestos; White streak; H 2–5	Serpentine
		Opaque green in laminated crusts or massive; Streak pale green; Effervesces in dilute HCl; H 3.5–4	Malachite
		Translucent or opaque dark green; Can be scratched with your fingernail; Feels greasy or soapy; H 1	Talc
		Opaque earthy red; red to red-brown streak; H 1.5–6	Hematite
		Transparent or translucent green, brown, blue, or purple; Brittle hexagonal prisms; Conchoidal fracture; H 5	Apatite

Dark-coloured minerals with non-metallic luster

MINERAL DATABASE (Alphabetical Listing)

Mineral	Luster	Hardness	Streak	Distinctive Properties	Some Uses
ACTINOLITE (amphibole)	Nonmetallic (NM)	5.5–6	White	Color dark green or pale green; Forms needles, prisms, and asbestose fibers; Good cleavage at 56° and 124°; SG = 3.1	Gemstone (Nephrite), Asbestose products
AMPHIBOLE: See HORNEBLENDE and ACTINOLITE					
APATITE $Ca_5F(PO_4)_3$ calcium fluorophosphate	Nonmetallic (NM)	5	White	Color pale or dark green, brown, blue, white, or purple; Sometimes colorless; Transparent or opaque; Brittle; Conchoidal fracture; Forms hexagonal prisms; SG = 3.1–3.4	Used for pesticides and fertilizers
ASBESTOSE: fibrous varieties of AMPHIBOLE and SERPENTINE					
AUGITE (pyroxene) calcium ferromagnesian silicate	Nonmetallic (NM)	5.5–6	White to pale gray	Color green to black; Forms opaque, short, 8-sided prisms; Two good cleavages that intersect at 87° and 93° (nearly right angles); SG = 3.2–3.5	Some pyroxene mined as an ore of lithium, for making steel
AZURITE $Cu_3(CO_3)_2(OH)_2$ hydrous copper carbonate	Nonmetallic (NM)	3.5–4	Light blue	Color a distinctive deep blue; Forms crusts of small crystals, opaque earthy masses, or short and long prisms; Brittle; Effervesces in dilute HCl; SG = 3.7–3.8	Ore of copper for pipes, electrical circuits, coins, ammunition, gemstone
BARITE $BaSO_4$ barium sulfate	Nonmetallic (NM)	3–3.5	White	Colorless to white, with tints of brown, yellow, blue, or red; Forms short tabular crystals and rose-shaped masses (Barite roses); Brittle; Cleavage good to excellent; Very heavy, SG = 4.5	Used in rubber, paint, glass, oil-well drilling fluids
BAUXITE Mixture of aluminum hydroxides	Nonmetallic (NM)	1–3	White	Brown earthy rock with shades of gray, white, and yellow; Amorphous; Often contains rounded pea-sized structures with laminations; SG = 2.3	Ore of Aluminum
BIOTITE MICA ferromagnesian potassium, hydrous aluminum silicate	Nonmetallic (NM)	2.5–3	Gray-brown	Color black, green-black, or brown-black; Cleavage excellent; Forms very short prisms that split easily into very thin, flexible sheets; SG = 2.7–3.1	Used for fire-resistant tiles, rubber, paint
BORNITE Cu_5FeS_4 copper-iron sulfide	Metallic (M)	3	Dark gray to black	Color opaque silvery blue or copper-red; Tarnishes to iridescent purple and blue; Forms dense, brittle masses; Cleavage poor to absent	Ore of copper for pipes, electrical circuits, coins, ammunition, brass, bronze
CALCITE $CaCO_3$ calcium carbonate	Nonmetallic (NM)	3	White	Usually colorless, white, or yellow, but may be green, brown, or pink; Opaque or transparent; Excellent cleavage in 3 directions not at 90°; Forms prisms, rhombohedrons, or scalenohedrons that break into rhombohedrons; Effervesces in dilute HCl; SG = 2.7	Used to make antacid tablets, fertilizer, cement; Ore of calcium
CHALCEDONY SiO_2 cryptocrystalline quartz	Nonmetallic (NM)	7	White	Colorless, white, yellow, light brown, or other pastel colors in laminations; Often translucent; Conchoidal fracture; Luster waxy; Cryptocrystalline; SG = 2.5–2.8	Used as an abrasive; Used to make glass, gemstones (agate, chrysoprase)

Alphabetical list of minerals with their distinctive physical / optical properties and uses

MINERAL DATABASE (Alphabetical Listing)

Mineral	Luster	Hardness	Streak	Distinctive Properties	Some Uses
CHALCOPYRITE $CuFeS_2$ copper-iron sulfide	Metallic (M)	3.5–4	Dark gray	Color golden or brassy yellow; Tarnishes brown, or iridescent blue, green, and red; Forms elongate tetrahedra; Brittle; Cleavage poor; SG = 4.1–4.3	Ore of copper for pipes, electrical circuits, coins, ammunition, brass, bronze
CHERT SiO_2 cryptocrystalline quartz	Nonmetallic (NM)	7	White	Opaque gray or white; Luster waxy; Conchoidal fracture; SG = 2.5–2.8	Used as an abrasive; Used to make glass, gemstones
CHLORITE ferromagnesian aluminum silicate	Nonmetallic (NM)	2–2.5	White	Color dark green; Cleavage excellent; Forms short prisms that split easily into thin flexible sheets; Luster shiny or dull; SG = 2–3	Used for fire-resistant tiles, rubber, paint, art sculpture medium
CHROMITE $FeCr_2O_4$ iron-chromium oxide	Metallic (M)	5.5–6	Dark brown	Color silvery black to black; Tarnishes gray; Forms octahedrons; Brittle; No cleavage; May be weakly magnetic; SG = 4.6–4.8	Ore of chromium for making chrome, stainless steel, mirrors, paint and used in leather tanning
CHRYSOCOLLA $CuSiO_3 \cdot 2H_2O$ hydrated copper silicate	Nonmetallic (NM)	2–4	Very light blue	Color pale blue to blue-green; Opaque; Forms amorphous crusts or may be massive; Conchoidal fracture; Luster shiny or earthy; SG = 2.0–2.4	Ore of copper for pipes, electrical circuits, coins, ammunition; gemstone
COPPER (NATIVE COPPER) Cu copper	Metallic (M)	2.5–3	Copper	Color copper; Tarnishes brown or green; Forms distorted cubes octahedrons, and dendritic (root-like) masses; Malleable; Opaque; Cleavage absent; SG = 8.8–8.9	Ore of copper for pipes, electrical circuits, coins, ammunition, brass, bronze
CORUNDUM Al_2O_3 aluminum oxide	Nonmetallic (NM)	9	White	Color gray, blue, red, brown; Transparent or opaque; Forms short hexagonal prisms with striated flat ends; Cleavage absent; SG = 3.9–4.1	Used for abrasive powders to polish lenses; gemstones (red ruby, blue sapphire)
DOLOMITE $CaMg(CO_3)_2$ magnesian calcium carbonate	Nonmetallic (NM)	3.5–4	White	Color white, gray, creme, or pink; Usually opaque; Cleavage excellent in 3 directions; Breaks into rhombohedrons; Resembles calcite, but will effervesce in dilute HCl only if powdered; SG = 2.8–2.9	Ore of magnesium metal; soft abrasive; used to make paper
EPIDOTE complex silicate	Nonmetallic (NM)	6–7	White	Color pale or dark green to yellow-green; Massive or forms striated prisms; Cleavage poor, SG = 3.3–3.5	Gemstone
FELDSPAR: See PLAGIOCLASE (Na-Ca Feldspars) and POTASSIUM FELDSPAR (K-Spar)					
FLINT SiO_2 cryptocrystalline quartz	Nonmetallic (NM)	7	White	Color black to very dark gray; Opaque to translucent; Conchoidal fracture; Crypto-crystalline; SG = 2.5–2.8	Used as an abrasive; Used to make glass, gemstones
FLUORITE CaF_2 calcium fluoride	Nonmetallic (NM)	4	White	Colorless, purple, blue, gray, green, or yellow; Cleavage excellent; Crystals usually cubes; Transparent or opaque; Brittle; SG = 3.0–3.3	Source of fluorine for processing aluminum; flux in steel making

Alphabetical list of minerals with their distinctive physical / optical properties and uses

MINERAL DATABASE (Alphabetical Listing)

Mineral	Luster	Hardness	Streak	Distinctive Properties	Some Uses
GALENA PbS lead sulfide	Metallic (M)	2.5	Gray to dark gray	Color silvery gray; Tarnishes dull gray; Forms cubes and octahedrons; Brittle; Cleavage good in three directions, so breaks into cubes; SG = 7.6	Ore of lead for TV glass, auto batteries, solder, ammunition, paint
GARNET complex silicate	Nonmetallic (NM)	7	White	Color usually red, black, or brown; sometimes yellow, green, pink; Forms dodecahedrons; Cleavage absent; Brittle; Translucent to opaque; SG = 3.5–4.3	Used as an abrasive; gemstone
GOETHITE FeO (OH) hydrous iron oxide	Metallic (M)	5–5.5	Yellow-brown	Color dark brown to black; Tarnishes yellow-brown; Forms layers of radiating microscopic crystals; SG = 4.3	Ore of iron for steel, brass, bronze, tools, vehicles, nails and bolts, bridges, etc.
GRAPHITE C carbon	Metallic (M)	1	Dark gray	Color silvery gray to black; Forms flakes, short hexagonal prisms, and earthy masses; Greasy feel; Very soft, Cleavage excellent in 1 direction; SG = 2.1–2.3	Used as a lubricant (as in graphite oil), pencil leads, fishing rods
GYPSUM $CaSO_4 \cdot 2H_2O$ calcium sulfate	Nonmetallic (NM)	2	White	Colorless, white, or gray; Forms tabular crystals, prisms, blades, or needles (satin spar variety); Transparent to translucent; Very soft; Cleavage good; SG = 2.3	Plaster-of-paris, wallboard, drywall, art sculpture medium (alabaster)
HALITE NaCl sodium chloride	Nonmetallic (NM)	2.5	White	Colorless, white, yellow, blue, brown or red; Transparent to translucent; Brittle; Forms cubes; Cleavage excellent in 3 directions, so breaks into cubes; Salty taste; SG = 2.1–2.6	Table salt, road salt; Used in water softeners and as a preservative; Sodium ore
HEMATITE Fe_2O_3 iron oxide	Metallic (M) or Nonmetallic (NM)	1.5–6	Red to red-brown	Color silvery gray, black, or brick red; Tarnishes red; Opaque; Soft (earthy) and hard (metallic) varieties have same streak; Forms thin tabular crystals or massive; SG = 2.1–2.6	Red pigment; Ore of iron for steel tools, vehicles, nails and bolts, bridges, etc.
HORNBLENDE (amphibole) calcium ferromagnesian aluminum silicate	Nonmetallic (NM)	5.5	Gray-green or white	Color dark green to black; Opaque; Forms prisms with good cleavage at 60° and 120°; Brittle; Splintery or asbestos forms; SG = 3.0–3.3	Fibrous varieties used for fire-resistant clothing, tiles, brake linings
JASPER SiO_2 cryptocrystalline quartz	Nonmetallic (NM)	7	White	Color red-brown, or yellow; Opaque; Waxy luster; Conchoidal fracture; Cryptocrystalline; SG = 2.5–2.8	Used as an abrasive; Used to make glass, gemstones
KAOLINITE $Al_4(Si_4O_{10})(OH)_8$ hydrous aluminum silicate	Nonmetallic (NM)	1–2	White	Color white to very light brown; Commonly forms earthy, microcrystalline masses; Cleavage excellent but absent in hand samples; SG = 2.6	Used for pottery, clays, polishing compounds, pencil leads, paper
K-SPAR: See POTASSIUM FELSDPAR					
KYANITE $Al_2(SiO_4)O$ aluminum silicate	Nonmetallic (NM)	4–7	White	Color blue, pale green, white, or gray; Translucent to transparent; Forms blades; SG = 3.6–3.7	High temperature ceramics, spark plugs

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MINERAL DATABASE (Alphabetical Listing)

Mineral	Luster	Hardness	Streak	Distinctive Properties	Some Uses
LIMONITE $Fe_2O_3 \cdot nH_2O$ hydrous iron oxide	Metallic (M) or Nonmetallic (NM)	1.5–5.5	Yellow-brown	Color yellow brown to dark brown; Tarnishes yellow to brown; Amorphous masses; Luster dull or earthy; Hard or soft; SG = 3.6–4.0	Yellow pigment; Ore of iron for steel tools, vehicles, nails and bolts, bridges, etc.
MAGNETITE Fe_3O_4 iron oxide	Metallic (M)	6	Dark gray	Color silvery gray to black; Opaque; Forms octahedrons; Tarnishes gray; No cleavage; Attracted to a magnet and can be magnetized; SG = 5.2	Ore of iron for steel, brass, bronze, tools, vehicles, nails and bolts, bridges, etc.
MALACHITE $Cu_2CO_3(OH)_2$ hydrous copper carbonate	Nonmetallic (NM)	3.5–4	Green	Color green, pale green, or gray green; Usually in crusts, laminated masses, or microcrystals; Effervesces in dilute HCl; SG = 3.9–4.0	Ore of copper for pipes, electrical circuits, coins, ammunition; gemstone
MICA: See BIOTITE and MUSCOVITE.					
NATIVE COPPER: See COPPER.					
NATIVE SULFUR: See SULFUR.					
NATROLITE (ZEOLITE) $Na_2(Al_2Si_3O_{10}) \cdot 2H_2O$ hydrous sodium aluminum silicate	Nonmetallic (NM)	5–5.5	White	Colorless, white, gray, or pale green, yellow, or red; Forms masses of radiating needles; Silky luster; SG = 2.2–2.4	Water softeners
MUSCOVITE MICA potassium hydrous aluminum silicate	Nonmetallic (NM)	2–2.5	White	Colorless, yellow, brown, or red-brown; Forms short opaque prisms; Cleavage excellent in 1 direction, can be split into thin flexible transparent sheets; SG = 2.7–3.0	Computer chip substrates, electrical insulation, roof shingles, facial makeup
OLIVINE $(Fe,Mg)_2SiO_4$ ferromagnesian silicate	Nonmetallic (NM)	7	White	Color pale or dark olive-green to yellow, or brown; Forms short flat prisms; Conchoidal fracture; Cleavage absent; Brittle; SG = 3.3–3.4	Gemstone (peridot); Ore of magnesium metal
OPAL $SiO_2 \cdot nH_2O$ hydrated silicon dioxide	Nonmetallic (NM)	5–5.5	White	Colorless to white, orange, yellow, brown, blue, gray, green, or red; may have play of colors (opalescence); Amorphous; Cleavage absent; Conchoidal fracture; SG = 1.9–2.3	Gemstone
PLAGIOCLASE FELDSPAR $NaAlSi_3O_8$ to $CaAl_2Si_2O_8$ calcium-sodium aluminum silicate	Nonmetallic (NM)	6	White	Colorless, white, gray, or black; may have iridescent play of color from within; Translucent; Forms striated tabular crystals or blades; Cleavage good in two directions at nearly 90°; SG = 2.6–2.8	Used to make ceramics, glass, enamel, soap, false teeth, scouring powders
POTASSIUM FELDSPAR $KAlSi_3O_8$ potassium aluminum silicate	Nonmetallic (NM)	6	White	Color orange, brown, white, green, or pink; Forms translucent prisms with subparallel exsolution lamellae; Cleavage excellent in two directions at nearly 90°; SG = 2.5–2.6	Used to make ceramics, glass, enamel, soap, false teeth, scouring powders
PYRITE ("fool's gold") FeS_2 iron sulfide	Metallic (M)	6–6.5	Dark gray	Color brass yellow; Opaque; Tarnishes brown; Forms cubes or octahedrons; Brittle; No cleavage; SG = 5.0	Ore of sulfur, for sulfuric acid, explosives, fertilizers, pulp processing, insecticides

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MINERAL DATABASE (Alphabetical Listing)

Mineral	Luster	Hardness	Streak	Distinctive Properties	Some Uses
PYROXENE: See AUGITE.					
QUARTZ SiO_2 silicon dioxide	Nonmetallic (NM)	7	White	Usually colorless, white, or gray but uncommon varieties occur in all colors; Transparent to translucent; Luster greasy; No cleavage; Forms hexagonal prism and pyramids; SG = 2.7	Used as an abrasive; Used to make glass, gemstones
SERPENTINE $Mg_6Si_4O_{10}(OH)_8$ hydrous magnesian silicate	Nonmetallic (NM)	2–5	White	Color pale or dark green, yellow, gray; Forms dull or silky masses and asbestos forms; No cleavage; SG = 2.2–2.6	Fibrous varieties used for fire-resistant clothing, tiles, brake linings
SILLIMANITE $Al_2(SiO_4)O$ aluminum silicate	Nonmetallic (NM)	6–7	White	Color pale brown, white, or gray; One good cleavage plus fracture surfaces; Forms slender prisms; SG = 3.2	High-temperature ceramics
SPHALERITE ZnS zinc sulfide	Metallic (M) or Nonmetallic (NM)	3.5–4	White to pale yellow-brown	Color usually yellow-brown to brown or black; Luster submetallic to non-metallic; Forms misshapen tetrahedrons or dodecahedrons; Cleavage excellent; SG = 3.9–4.0	Ore of zinc for die-cast automobile parts, brass, galvanizing, batteries
STAUROLITE iron magnesium zinc aluminum silicate	Nonmetallic (NM)	7	White to gray	Color brown to gray-brown; Tarnishes dull brown; Forms prisms that interpenetrate to form natural crosses; Cleavage poor; SG = 3.7–3.8	Gemstone crosses called "fairy crosses"
SULFUR (NATIVE SULFUR) S sulfur	Nonmetallic (NM)	1.5–2.5	Pale yellow	Color bright yellow; Forms transparent to translucent crystals or earthy masses; Cleavage poor; Luster greasy to earthy; Brittle; SG = 2.1	Used for drugs, sulfuric acid, explosives, fertilizers, pulp processing, insecticides
TALC $Mg_3Si_4O_{10}(OH)_2$ hydrous magnesian silicate	Nonmetallic (NM)	1	White	Color white, gray, pale green, or brown; Forms cryptocrystalline masses that show no cleavage; Luster silky to greasy; Feels greasy or soapy (talcum powder); Very soft; SG = 2.7–2.8	Used for talcum powder, facial makeup, ceramics, paint, sculptures
TOURMALINE complex silicate	Nonmetallic (NM)	7–7.5	White	Color usually opaque black or green, but may be transparent or translucent green, red, yellow, pink or blue; Forms long striated prisms with triangular cross sections; Cleavage absent; SG = 3.0–3.2	Crystals used in radio transmitters; gemstone
ZEOLITE: A group of calcium or sodium hydrous aluminum silicates. See NATROLITE.					

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Thank you

Dr. K.Palanivel
Associate Professor
Centre for Remote Sensing
Bharathidasan University
Tiruchirappalli – 620 023
Email : kkpvlcers@bdu.ac.in;
H. Ph.: 94433 78145

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