Bharathidasan University
Tiruchirappalli – 620 023, Tamil Nadu

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

Course Code: MTIGT0306

CRYSTALLOGRAPHY AND MINERALOGY

UNIT–4 : OPTICAL MINERALOGY

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

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 - 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. Lean how minerals together form different types of rocks.

References:

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**

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 is it 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 Lens-3

Objective Tube-4

Objective Lenses-5

Rotating Stage -6

Section holding clip-7

Stage adjustment knob-8

Stage Clamp-9

Polarizer-10

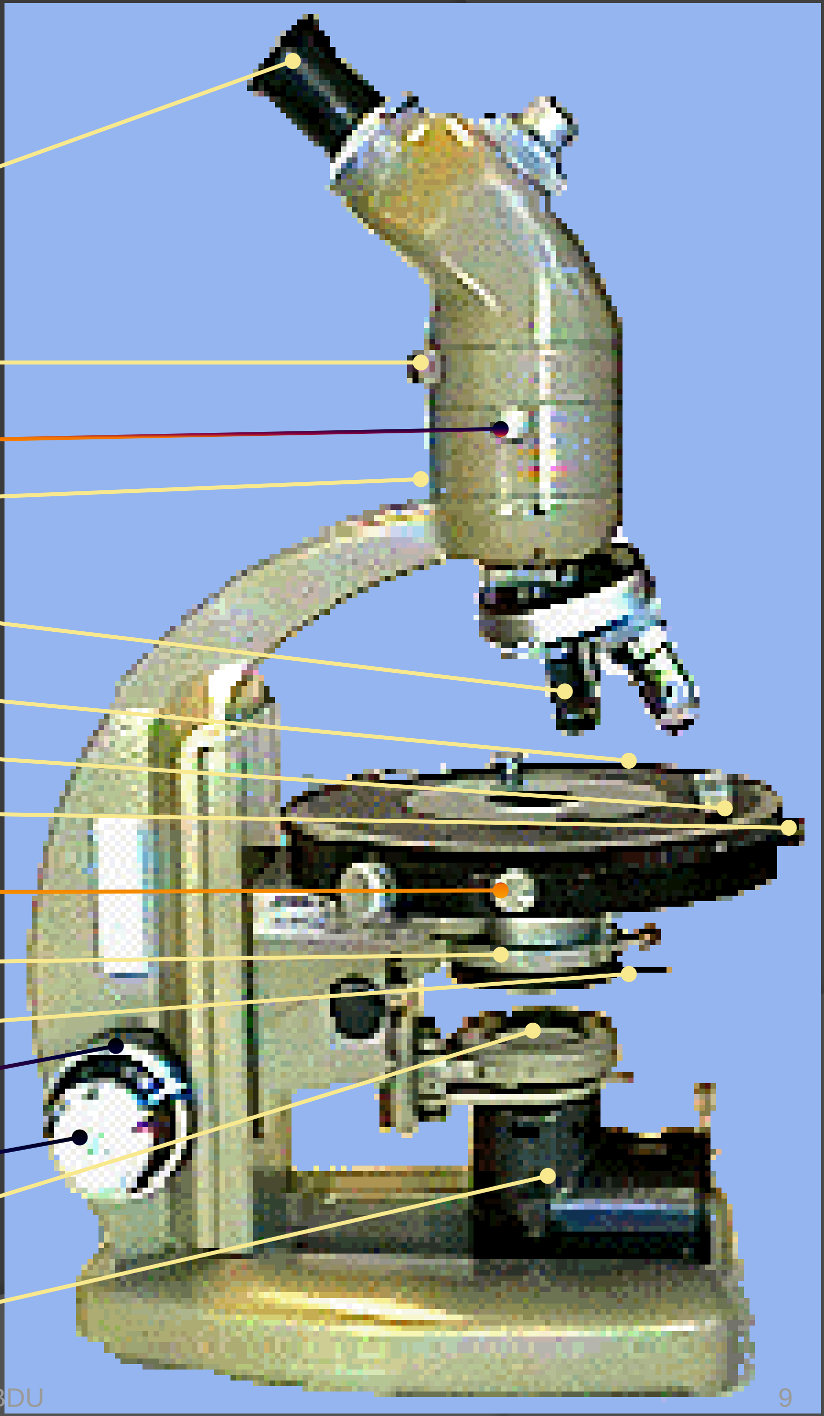
Diaphragm-11

Coarse Focus-12

Fine Adjustment-13

Mirror (Plain /Concave)-14

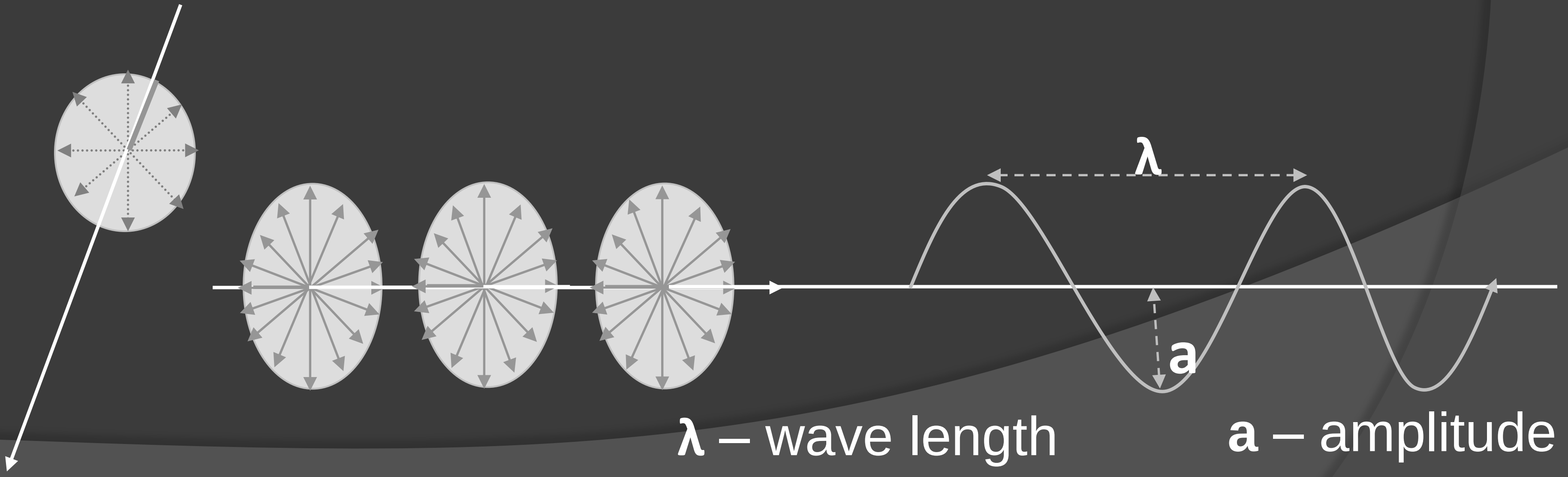
Light Source (Electric Bulb)-15



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

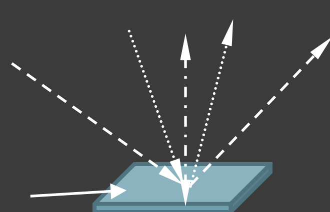
0.00039 mm to 0.00076 mm

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

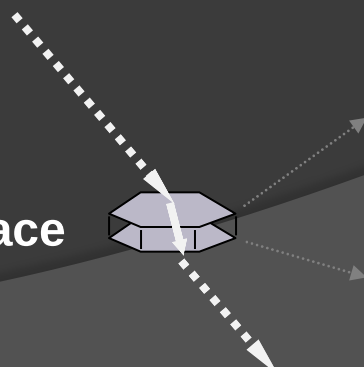
Two types of Minerals / media / substances:

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

Mineral surface

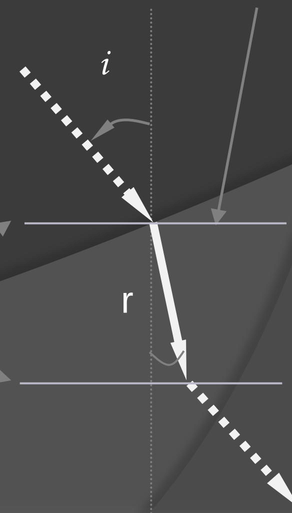


Mineral surface



Normal plane

Mineral surface



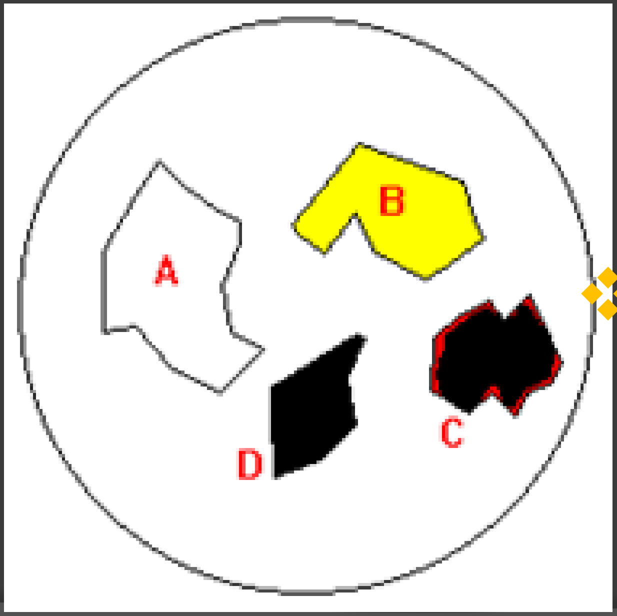
- **Refractive Index**: A constant value
- - the ratio between **sin i** and **sin r**
- For air = 1, Water = 1.33, Flourspar = 1.4, Canada balsam = 1.54, Crown glass = 1.53, Garnet = 1.77, Diamond = 2.42.
- R.I.s of two media is inversely proportional to the 'v'- velocities of light in them.
- Breaking 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 (OL)

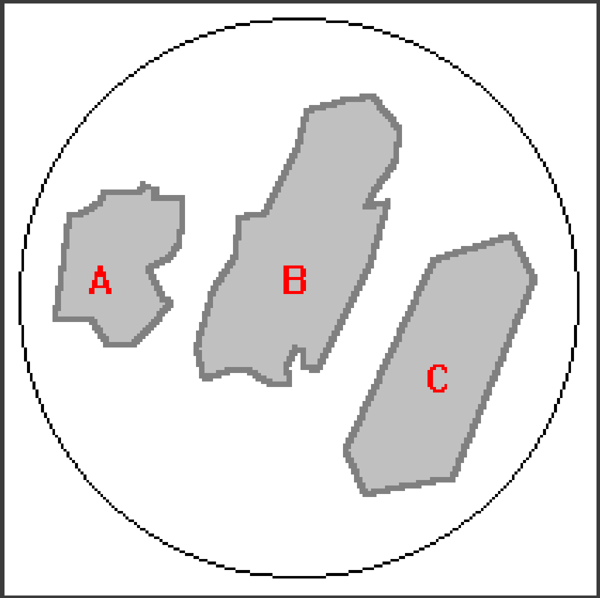
1. **Colour**
2. **Crystallinity / Form**
3. **Cleavage**
4. **Transparency**
5. **Relief**
6. **Inclusions and Alterations &**
7. **Refractive Index**

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 along 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 and opaque in thin section.

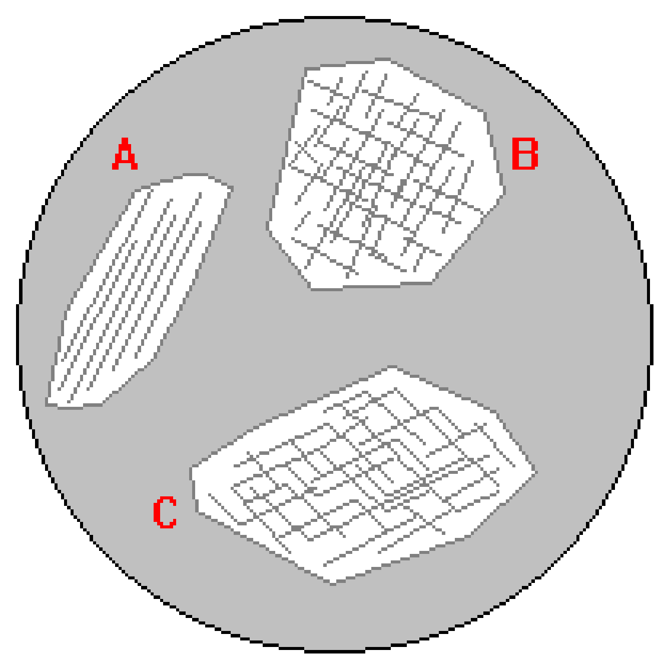


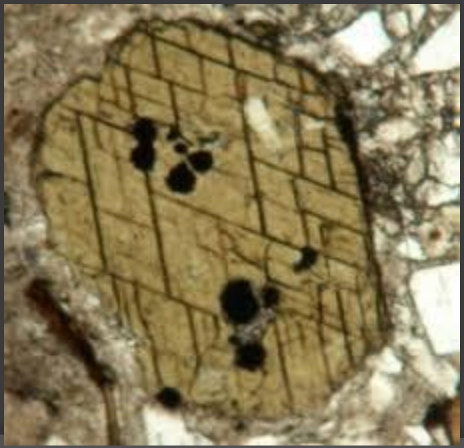
2. Crystal Form



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

3. Cleavage





(A) 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.

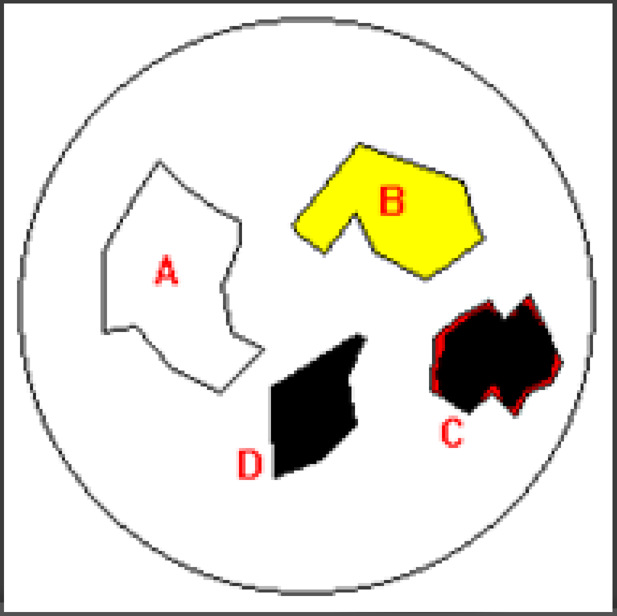
(B) Pyroxenes usually show the characteristic 87-degree cleavage.

(C) while cross-sections of amphibole show the characteristic 56-degree cleavage.

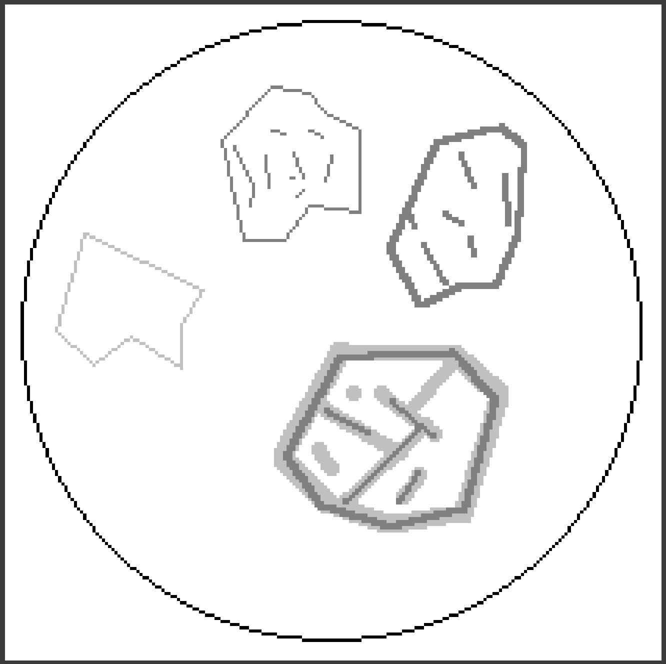
What you see will depend on the orientation of the grain. A true cross-section of an amphibole will show 56-degree cleavages but an oblique section will show other angles and a longitudinal section will show longitudinal cleavage as in (A).

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

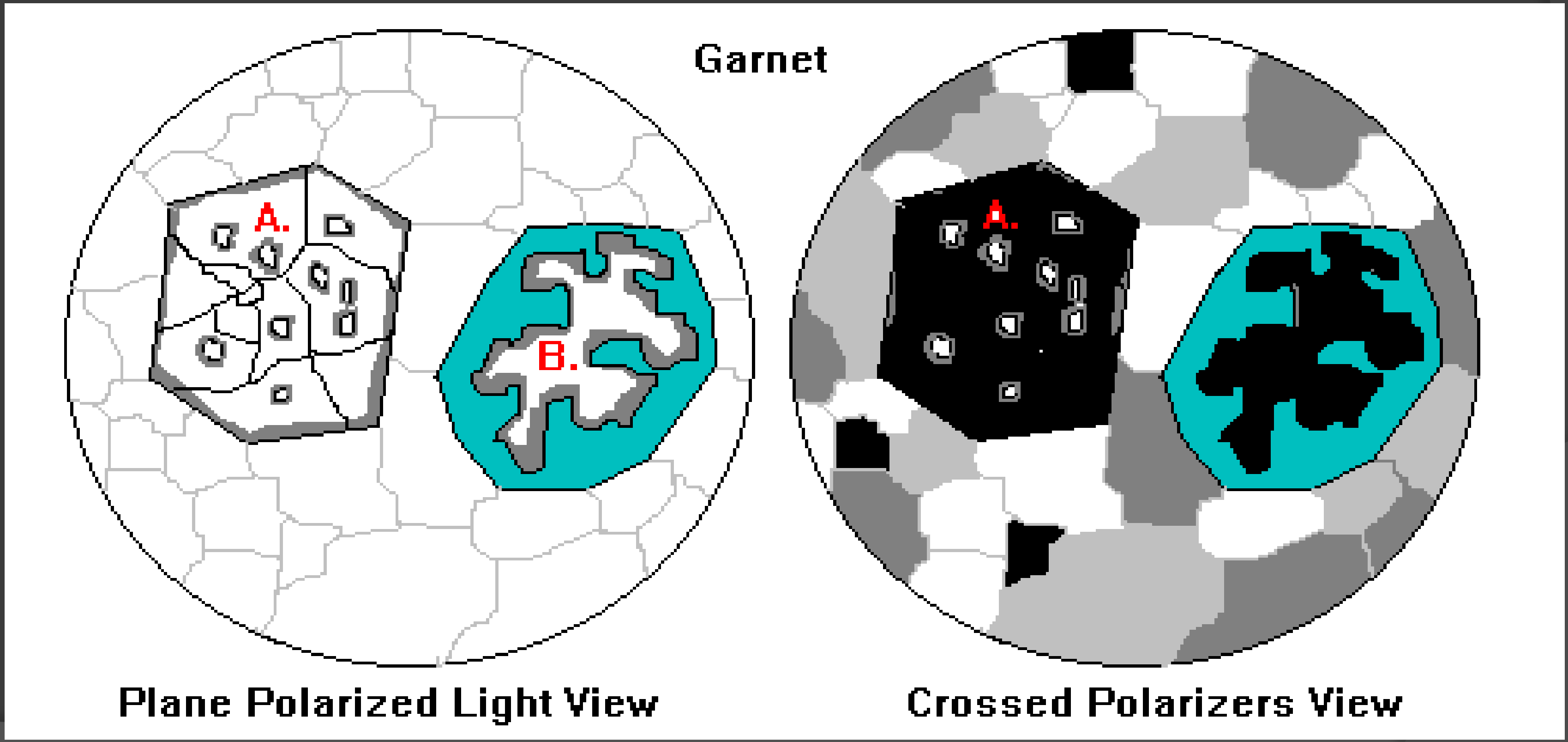


- Relief is the contrast between a mineral and its surroundings due to difference in refractive index.
- The four grains shown here show increasing relief clockwise from left.
- Relief is positive when the grain has higher refractive index than its surroundings, negative if lower.
- Negative relief compared 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

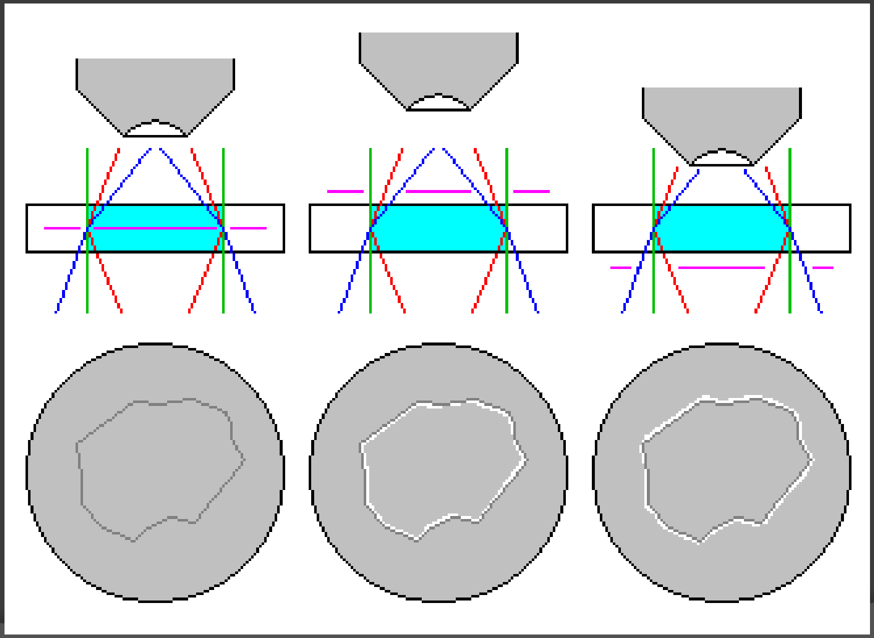
- Since the blue has the less R.I., it occurs nearest the normal and the red has the greatest R.I., it occurs farthest away from the normal.
- **Becke effect:** **Becke Line Test** – (1) using high power objective, (2) diaphragm (to cut off some of the light) in microscope,
- When the (3) Objective tube 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.

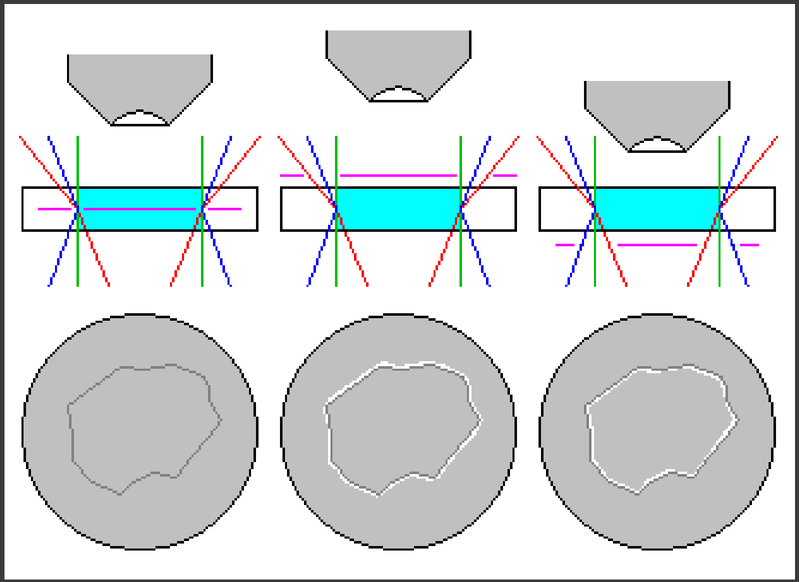
Higher refractive index



- 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

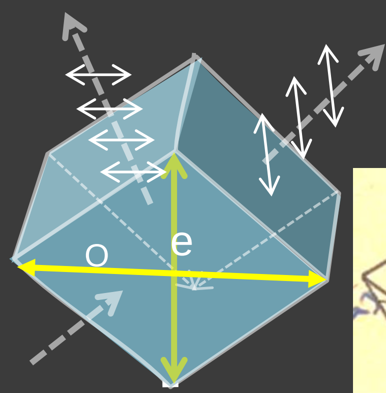
A grain that has **lower refractive index** than its surroundings will refract and reflect light outward like a crude diverging lens.

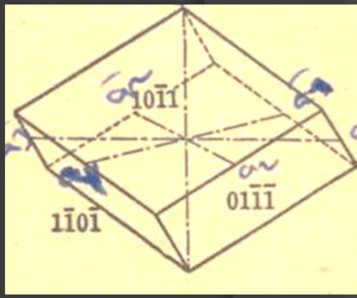


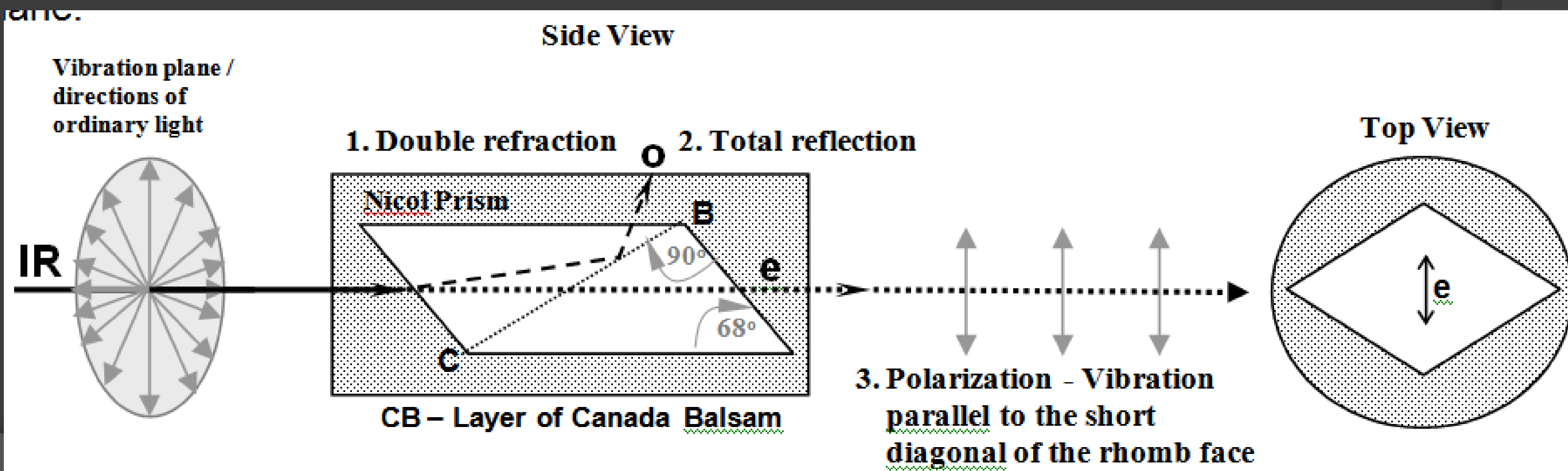
- If the focal plane of the microscope is centered within the thin section (purple line) the grain boundary is in sharp focus (left).
- If the focal plane is too high, rays that would normally appear at the grain boundary now appear outside it and a bright border appears outside the grain (center).
-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

- 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 (o)** consists of light vibrating parallel to the long diagonal of the rhomb face and
- The **extraordinary ray (e)** 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 or Isometric Cryst.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…

The optical properties studied under PPL condition are:

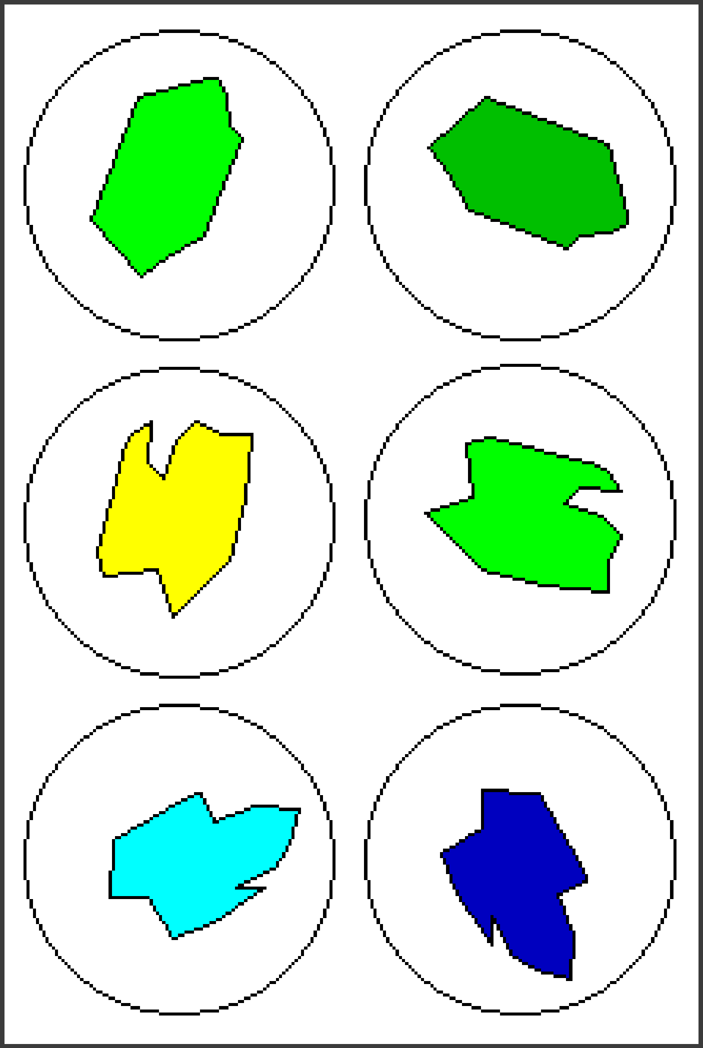
8. Pleochroism

9. Pleochroic Halos and

10. Twinkling.

- The properties discussed so far to be examined under ordinary light (from 1 to 7 opt. prop.) will be similar under PPL conditions too.
- But, the above three properties of minerals in thin sections can only be examined 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.

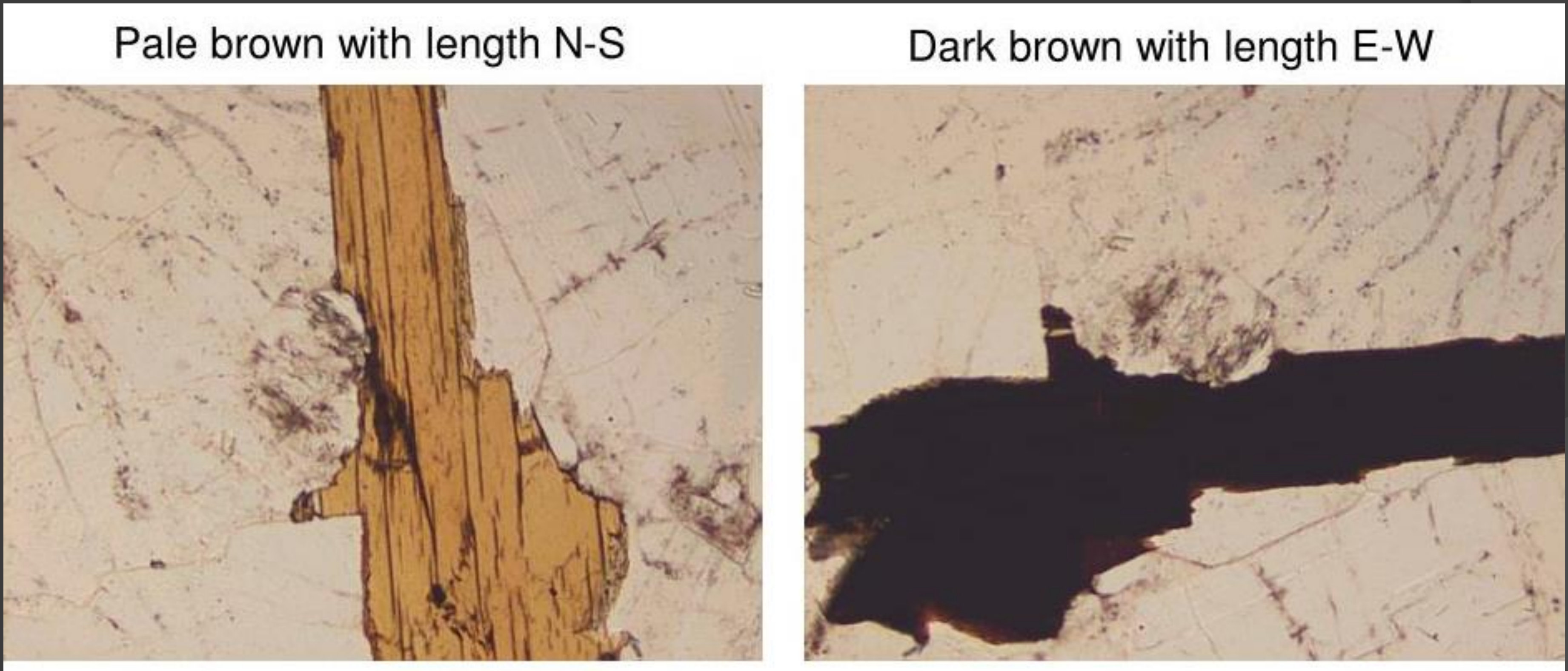
The mineral said to be Pleochroic or not is based on the colour change or colour intensity change while rotating the stage under PPL condition.

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.

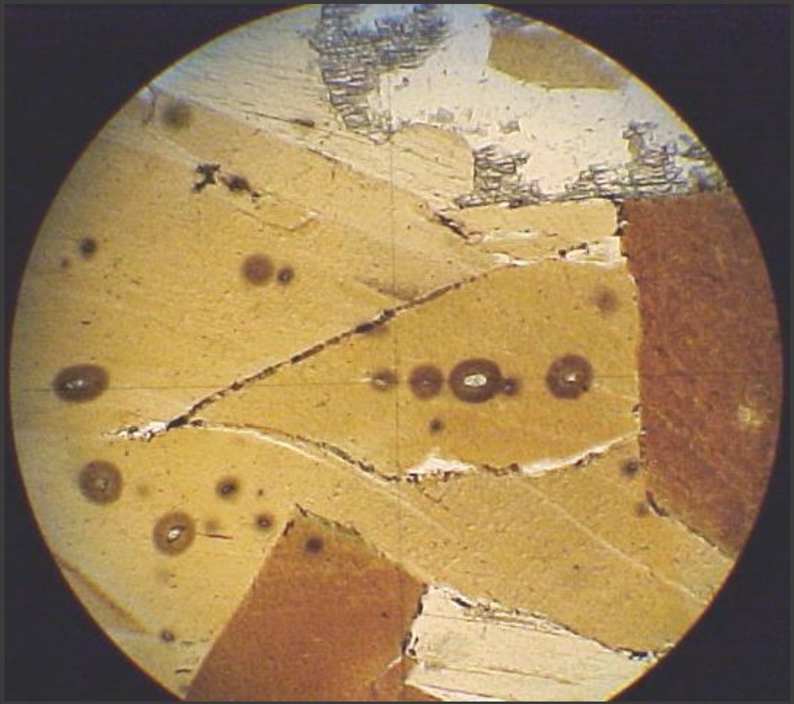
9. Twinkling

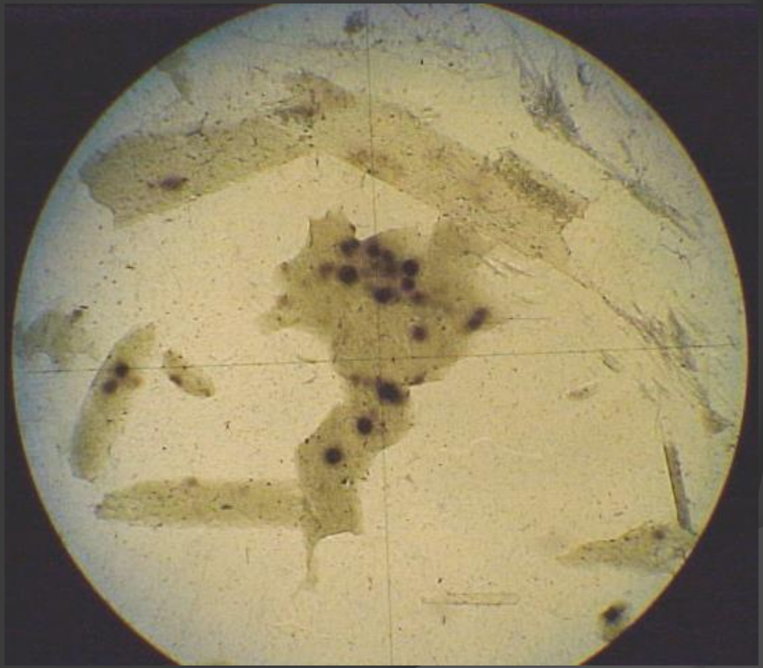
The pleochroic minerals said to have this property under PPL conditions due to colour change or colour intensity change. E.g. Biotite.



10. Pleochroic Haloes

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





C. Under Crossed Nicols (CN)

The properties of minerals in thin section under CN 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 (CL)

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

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

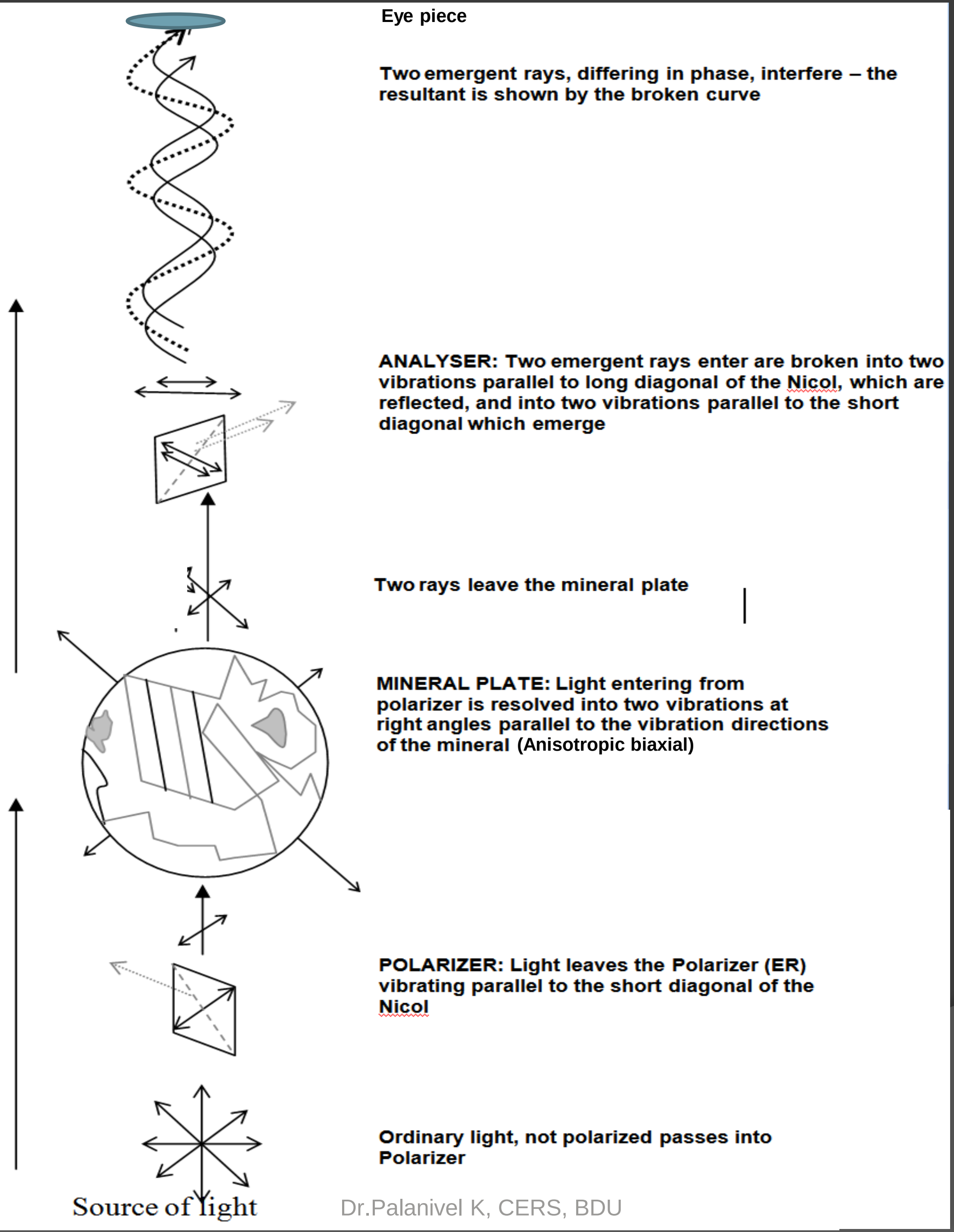
11. Isotropic / Anisotropic:

- 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.

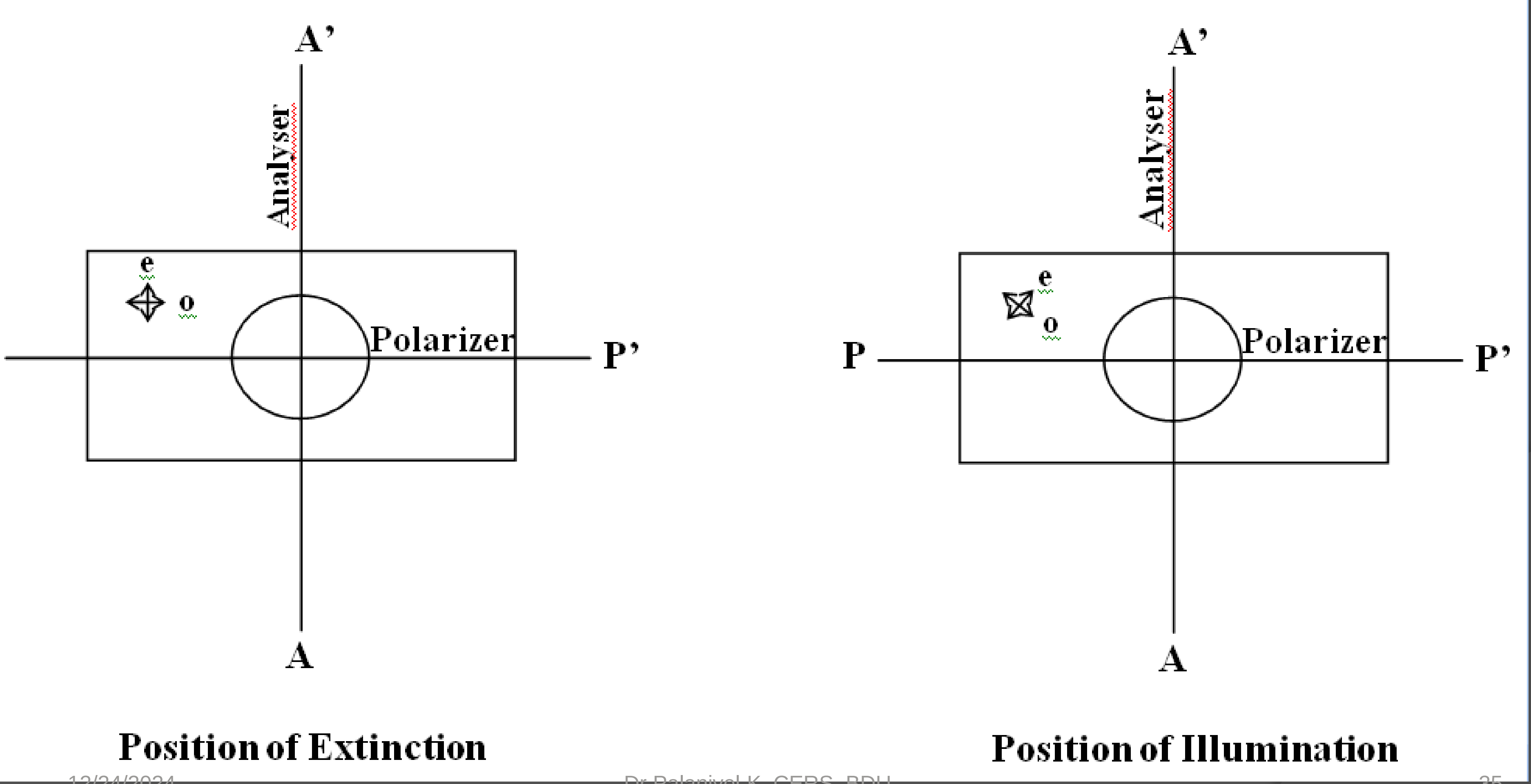
Anisotropic minerals between crossed Nicols:

- The anisotropic mnls. are doubly refracting, so that a ray of light entering an anisotropic mineral 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 directions** and one ray is the **fast ray** and the one **slow ray**.

Behaviour of Light Travelling inside the Polarizing Microscope

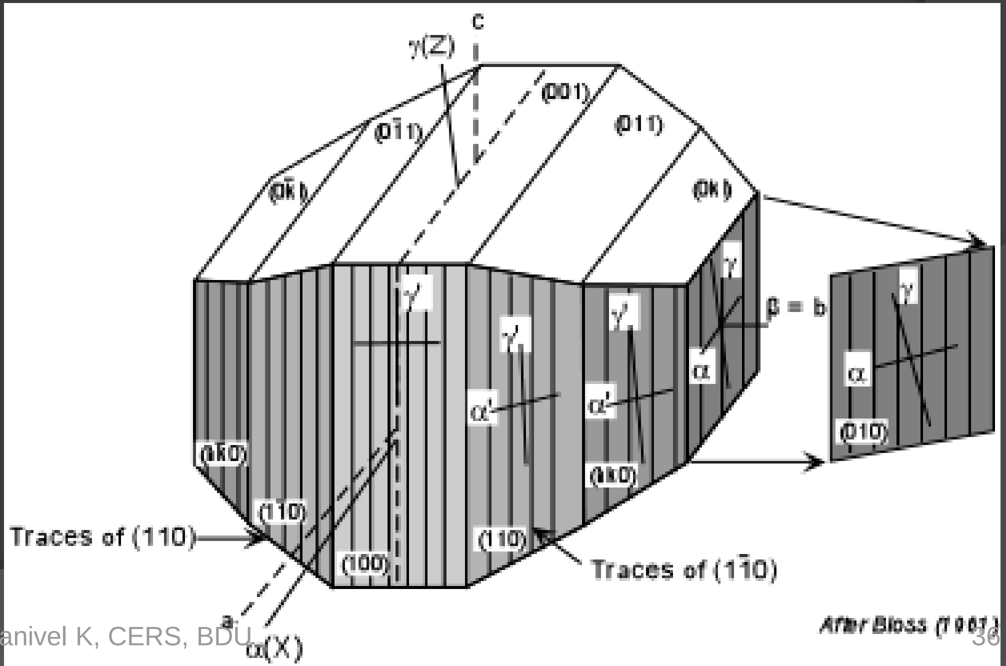


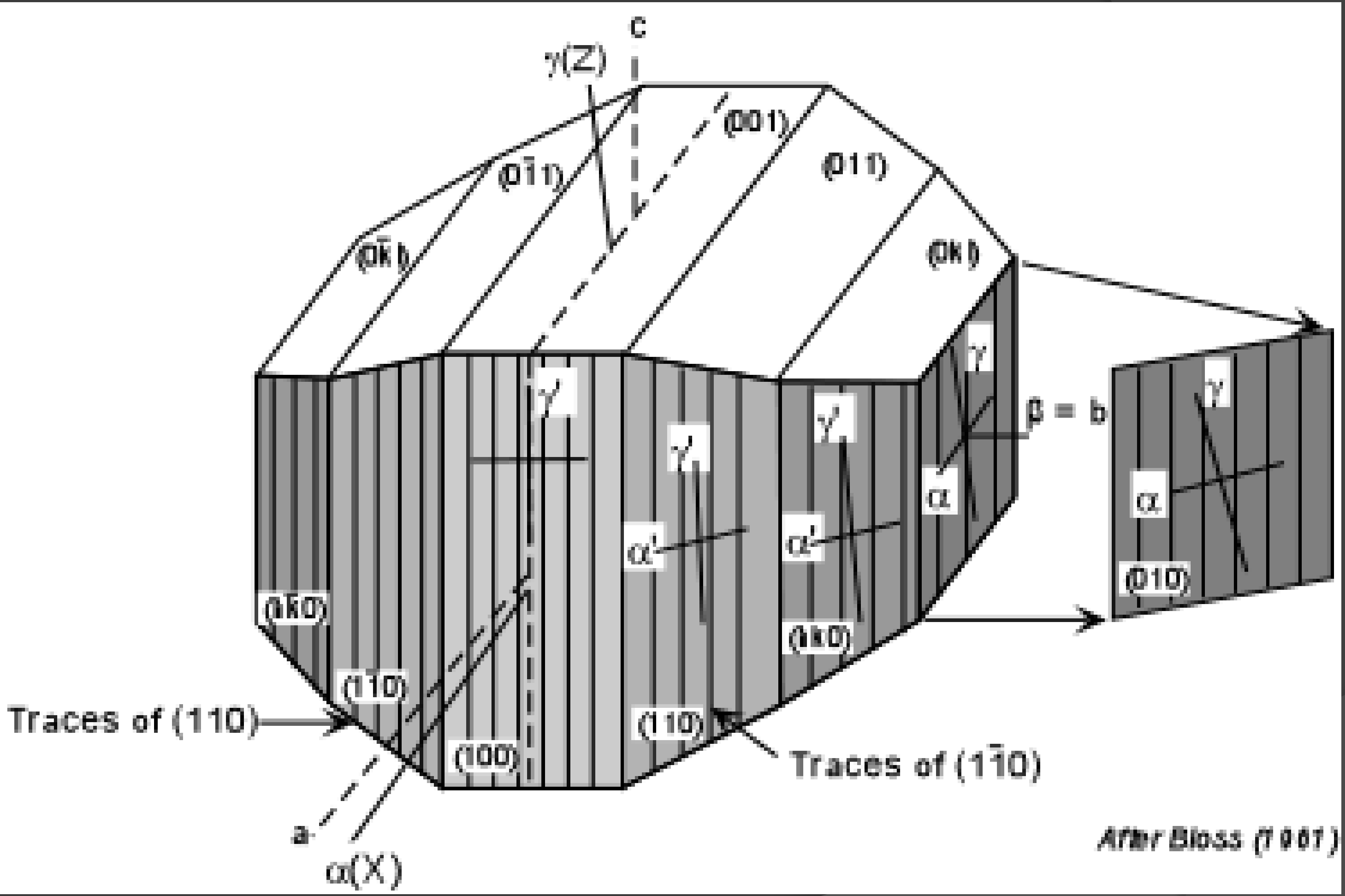
12. Extinction & angle of extinction



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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γ(Z)
(001)
(0$\bar{1}$1)
(011)
(0$\bar{k}$l)
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γ
β = b
α
α'
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Traces of (110)
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Traces of (1$\bar{1}$0)
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After Bloss (1961)

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.

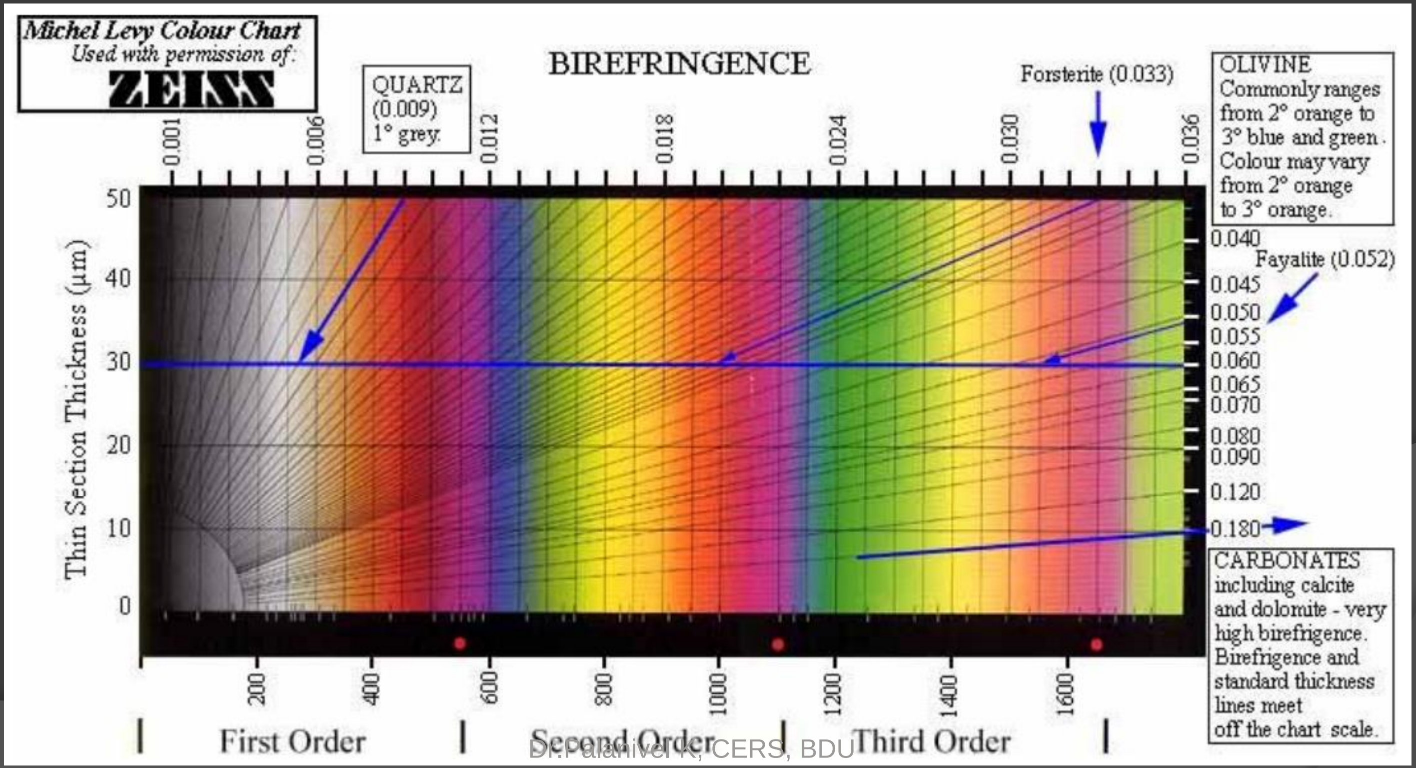
Undulatory Extinction in Quartz

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:

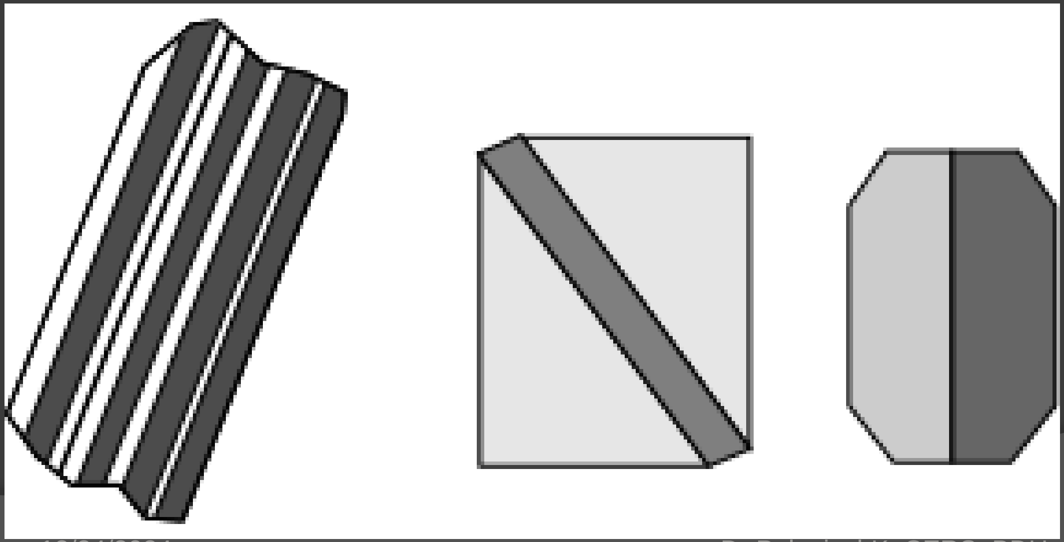
- The microscopic property of minerals producing darkness and maximum colour at different positions on inserting Quartz Wedge in between crossed Nicols in white light, due to various components of different wave-lengths for each light in series along the wedge, is known as **Newton's scale of interference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

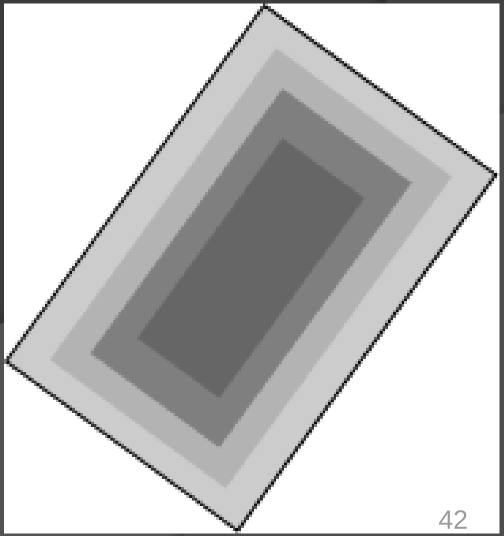
Thus, different parts of the crystal will go extinct at different times as a result of twin planes.



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.

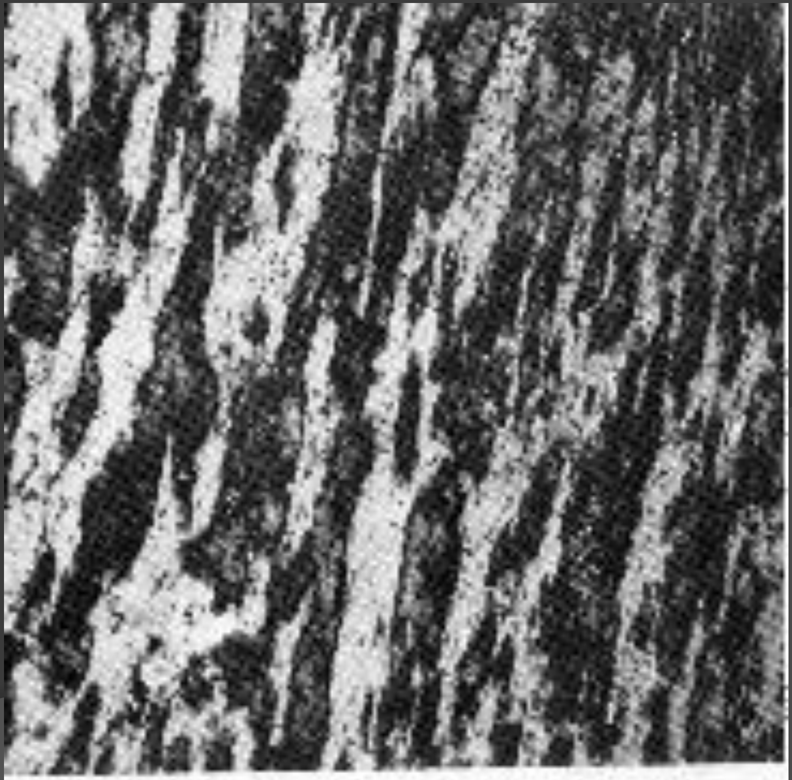
15. Alteration and Zoning

- 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 Figure (or) Conoscopic Interference Pattern

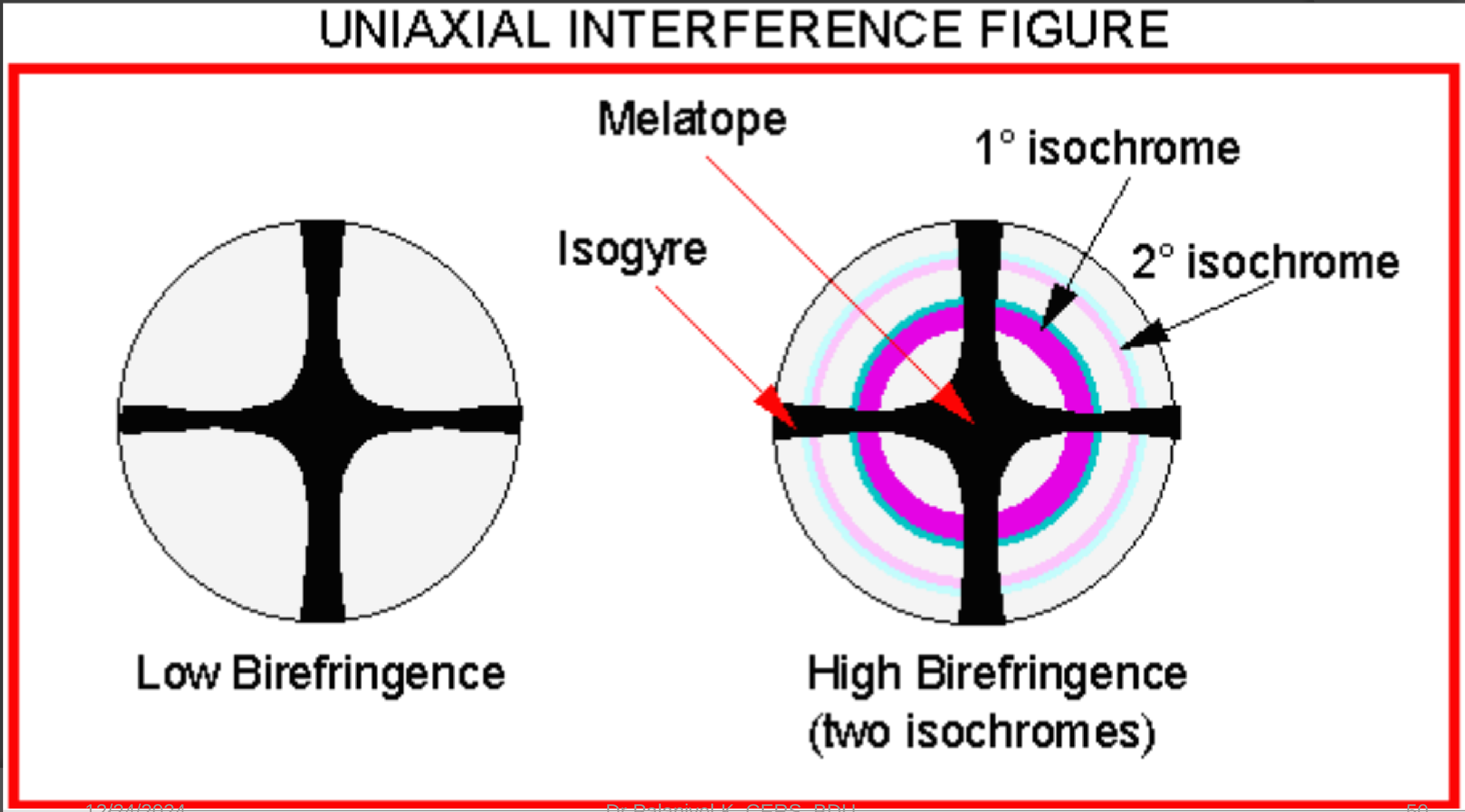
- A pattern of birefringent colours crossed by dark bands (or isogyres), which can be produced using a geological petrographic microscope for the purposes of mineral identification and investigation of mineral optical and chemical properties.
- The figures are produced by optical interference when diverging light rays travel through an optically non-isotropic substance - that is, one in which the substance's refractive index varies in different directions within it.
- The figure can be thought of as a "map" of how the birefringence of a mineral would vary with viewing angle away from perpendicular to the slide, where the central colour is the birefringence seen looking straight down, and the colours further from the centre equivalent to viewing the mineral at ever increasing angles from perpendicular.
- The dark bands correspond to positions where optical extinction (apparent isotropy) would be seen. In other words, the interference figure presents all possible birefringence colours for the mineral at once.
- Viewing the interference figure is a foolproof way to determine if a mineral is optically uniaxial or biaxial. If the figure is aligned correctly, use of a sensitive tint plate in conjunction with the microscope allows the user to determine mineral optic sign and optic angle.

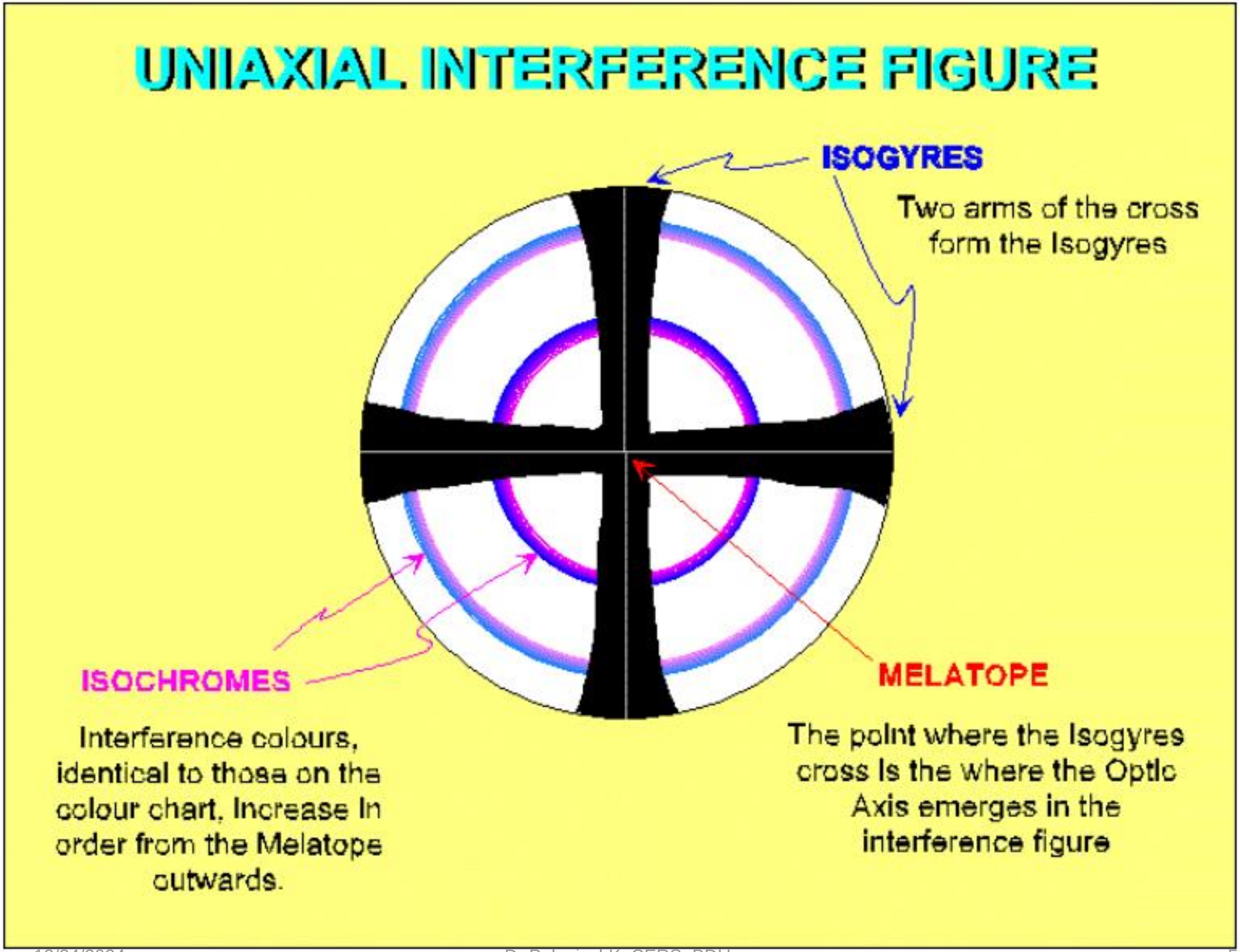
How to obtain Interference Figure ? (or) Conoscopic Interference Pattern ?

- The **Crossed Nicol condition / **Cross-polarised light is used to view the interference pattern.
- The **microscope's condenser** is brought up close underneath the specimen to produce a wide divergence of polarised rays through a small point, and light intensity increased as much as possible (e.g., turning up the bulb and opening the diaphragm).
- A **high power objective lens** is typically used. This both maximises the solid angle subtended by the lens, and hence the angular variation of the light intercepted, and also increases the likelihood that only a single crystal will be viewed at any given time.
- To view the figure, the light rays leaving the microscope must emerge more or less in parallel. This is typically achieved either by **pulling out the eyepiece** altogether (if possible), or by **placing a Bertrand lens** (Emile Bertrand, 1878) between the objective lens and the eyepiece.

- Any crystal section can in principle produce an interference pattern.
- However, in practice, only a few different crystallographic orientations are both :
- 1. convenient to identify, to allow a figure to be produced, and
- 2. able to produce reliable information about crystal properties.
- Typically, the most useful and easily obtainable orientation is one looking down the optic axis of a crystal section, which yields a figure referred to as an **optic axis figure**.
- Such crystal orientations are findable in thin section by looking for slices through minerals which are not isotropic but that nevertheless appear uniformly black or very dark grey under normal cross-polarised light at all stage angles (i.e., are "extinct").
- If you are far from looking down an optic axis, a flash figure may be seen - a higher order birefringence colour, interrupted four times as the stage is rotated through 360 degrees by "flashes" of black which sweep across the field of view –i.e., Off-centered Interference Figure.

Interference figures



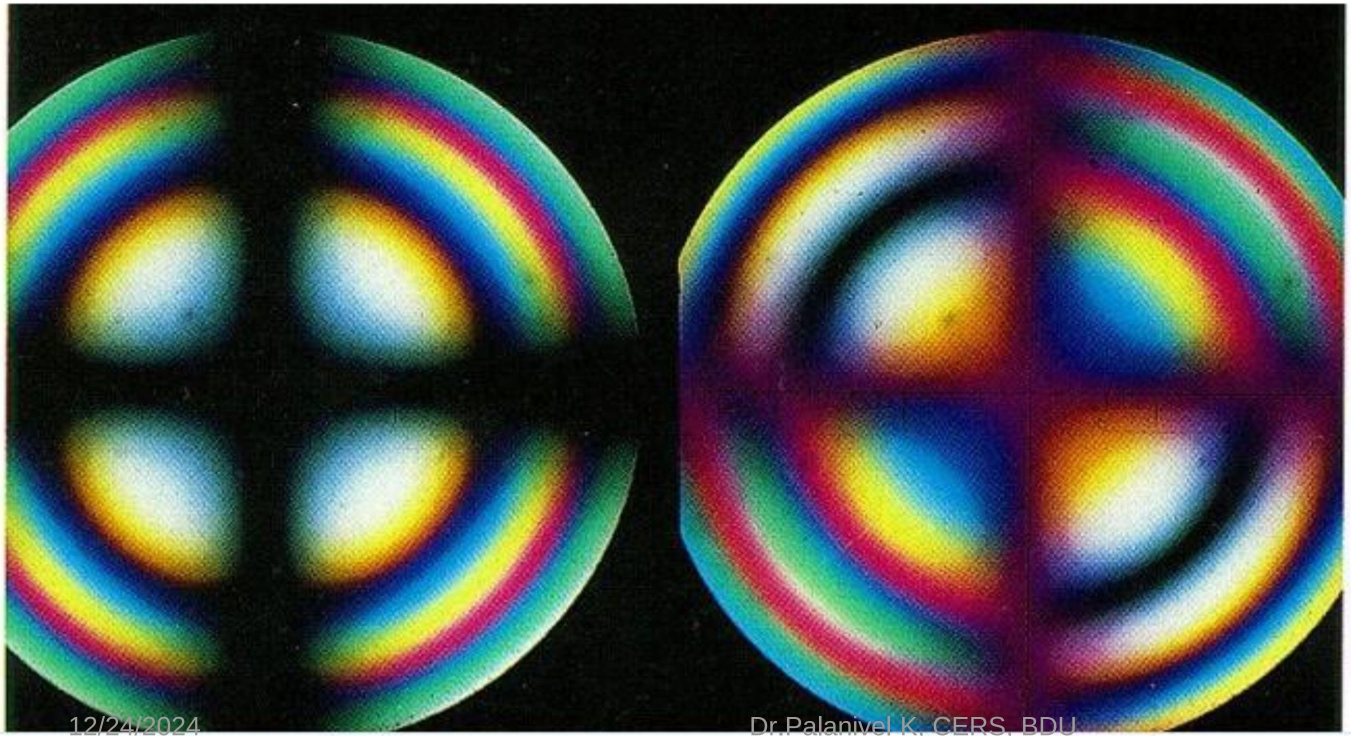

UNIAXIAL INTERFERENCE FIGURE
ISOGYRES
Two arms of the cross form the Isogyres
ISOCHROMES
Interference colours, identical to those on the colour chart. Increase in order from the Melatope outwards.
MELATOPE
The point where the Isogyres cross is the where the Optic Axis emerges in the interference figure

How to obtain Interference Figure?

To obtain and observe an interference figure using the microscope.

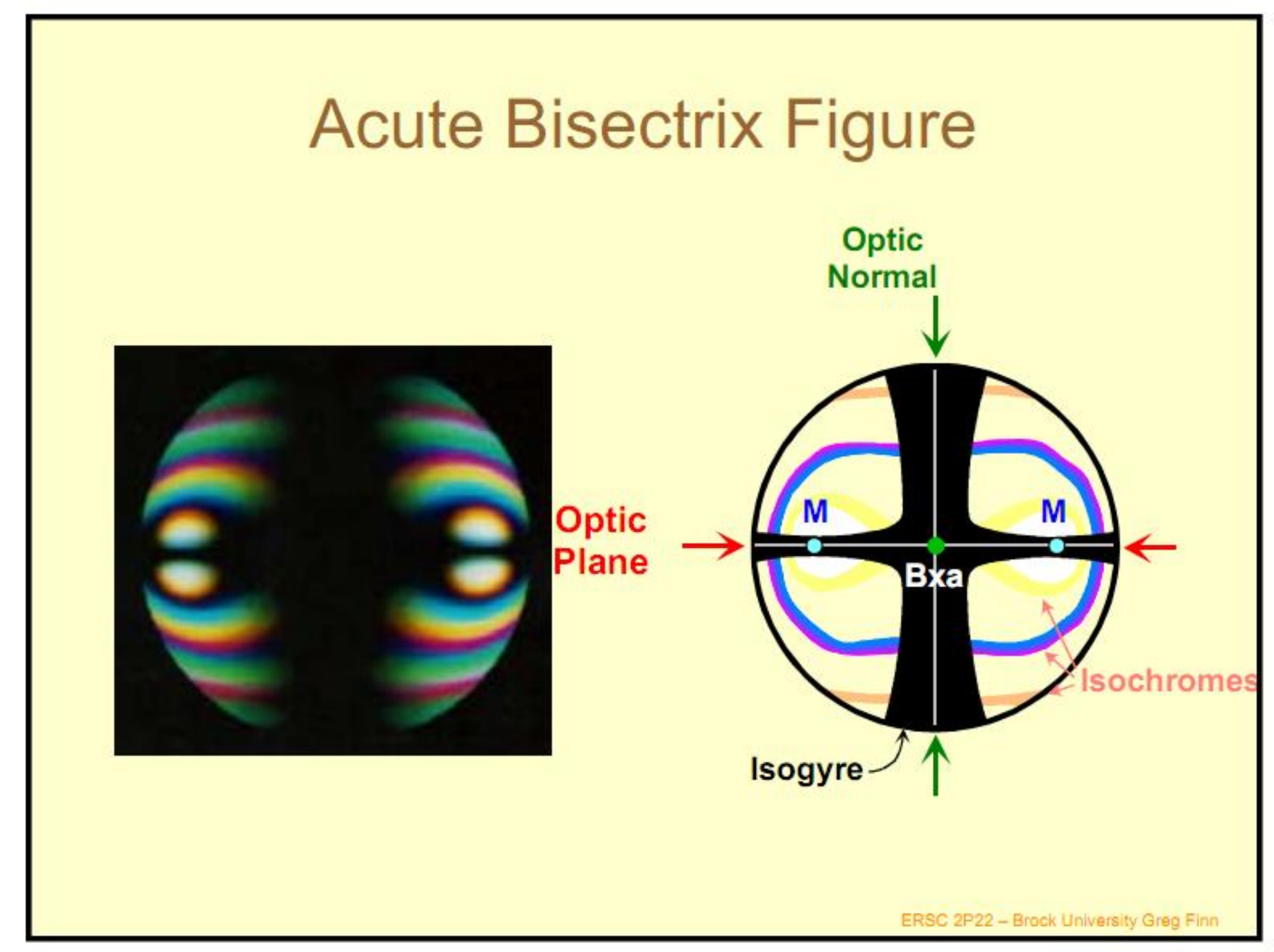
1. With high power, focus on a mineral grain free of cracks and inclusions
2. Flip in the auxiliary condensor and refocus open aperture diaphragm up to its maximum.
3. Cross the polars
4. Insert the Bertrand lens or remove the ocular and look down the microscope tube.

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

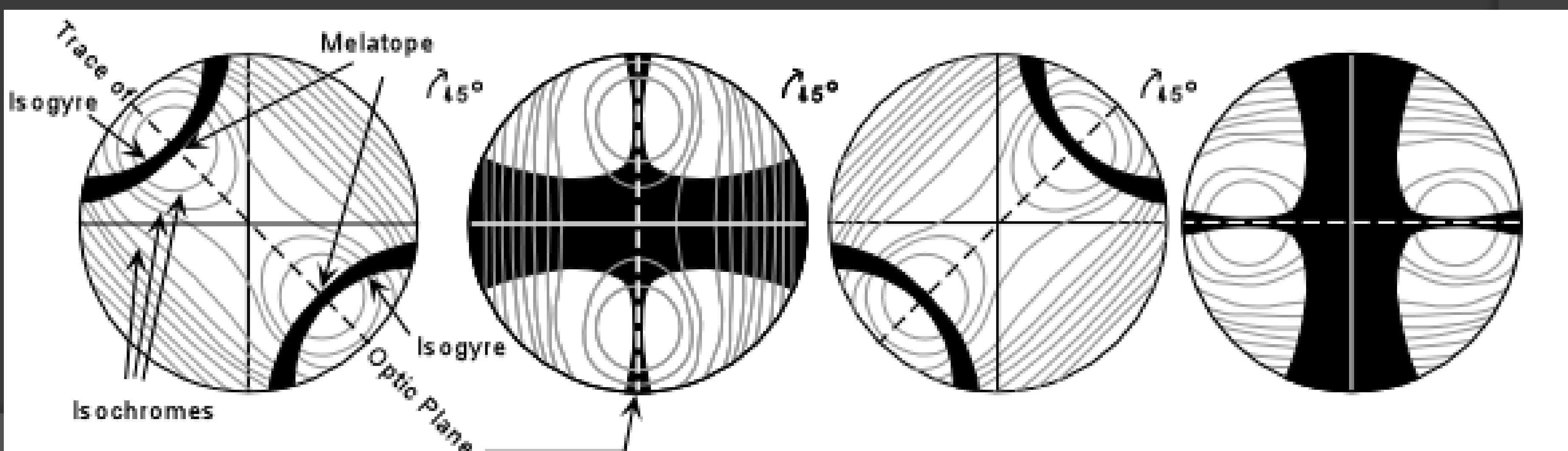


The interference figure consists of a pattern of interference colours and a black band which may form a cross. Nature and pattern for the figure is dependent on the orientation of the grain.

Biaxial Interference Figure



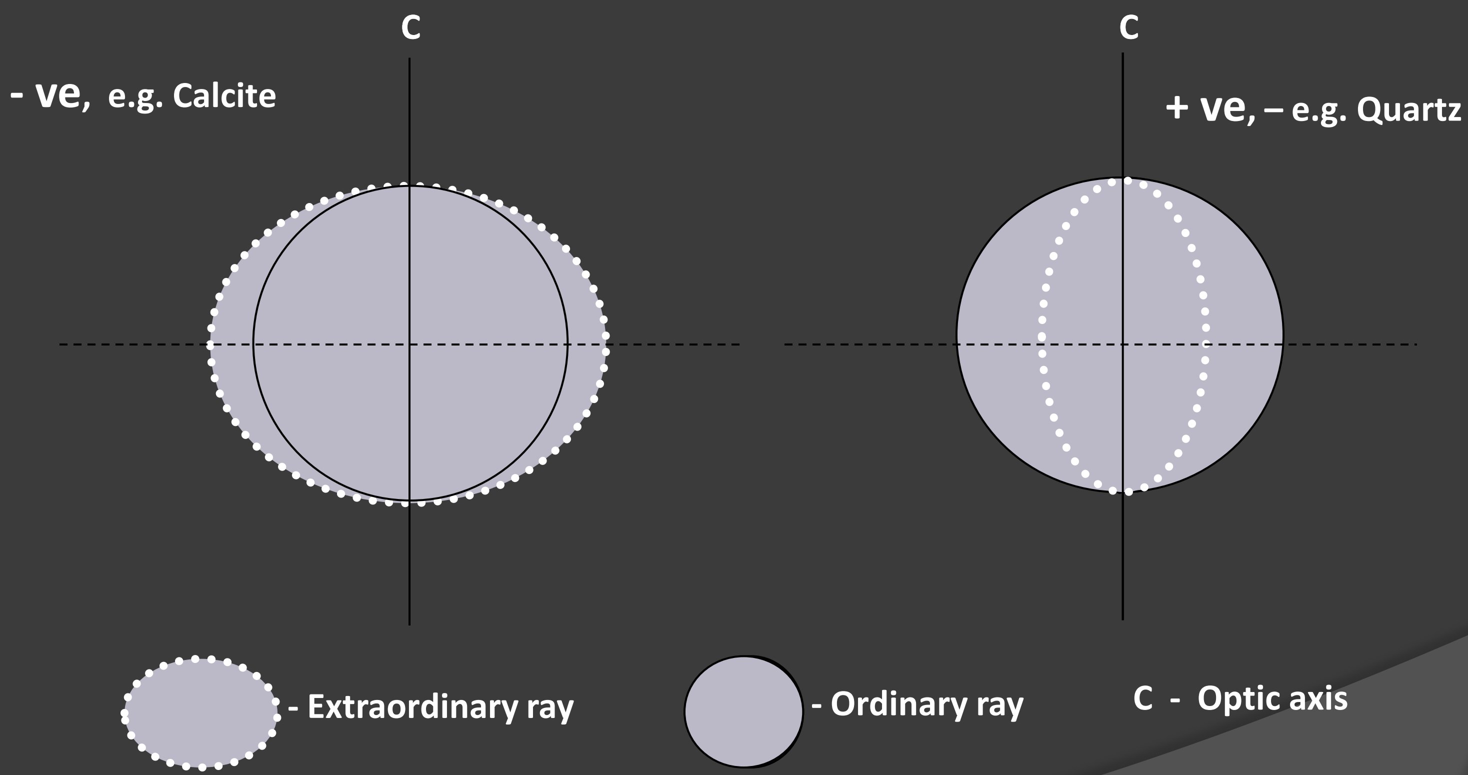
- The dark isogyres mark the positions where light vibrating parallel to the polarizer has passed through the crystal.
- At the points of maximum curvature of the isogyres are the two melatopes that mark the positions where rays that traveled along the optic axis emerge from the field of view.
- Note 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.

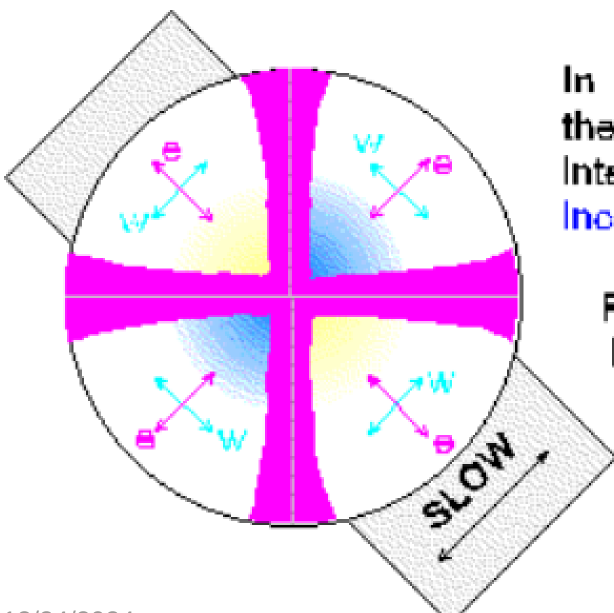
How to determine option sign?

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



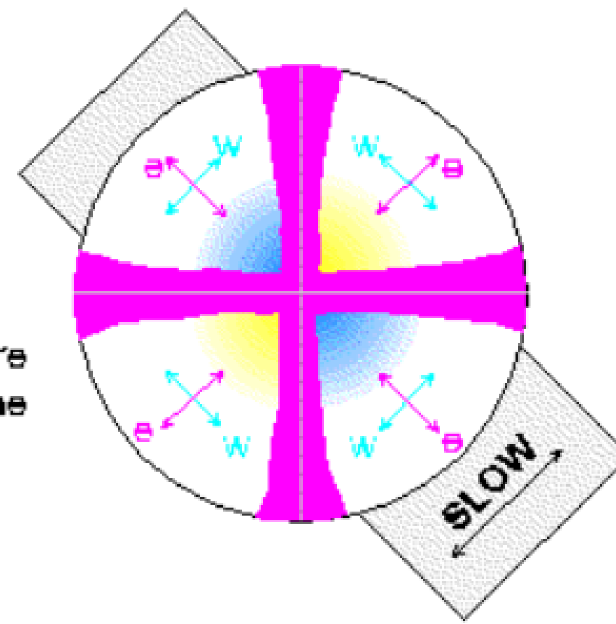
In opposite quadrants of the interference figure the interference colours either increase or decrease.

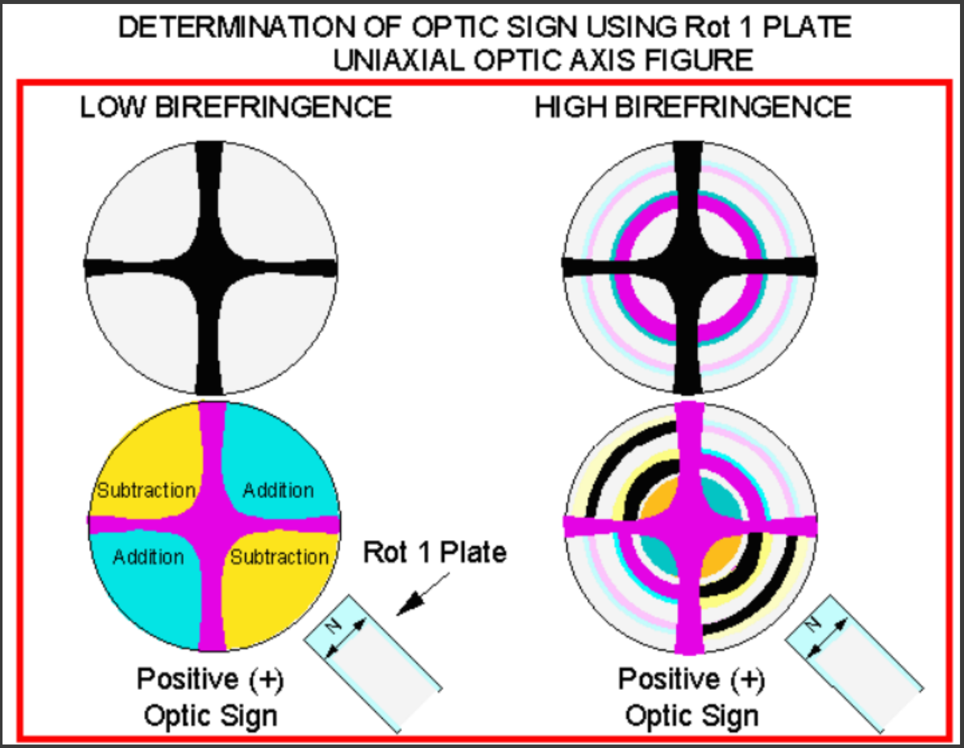
$Slow_{min} + Slow_{acc}$ = Increase

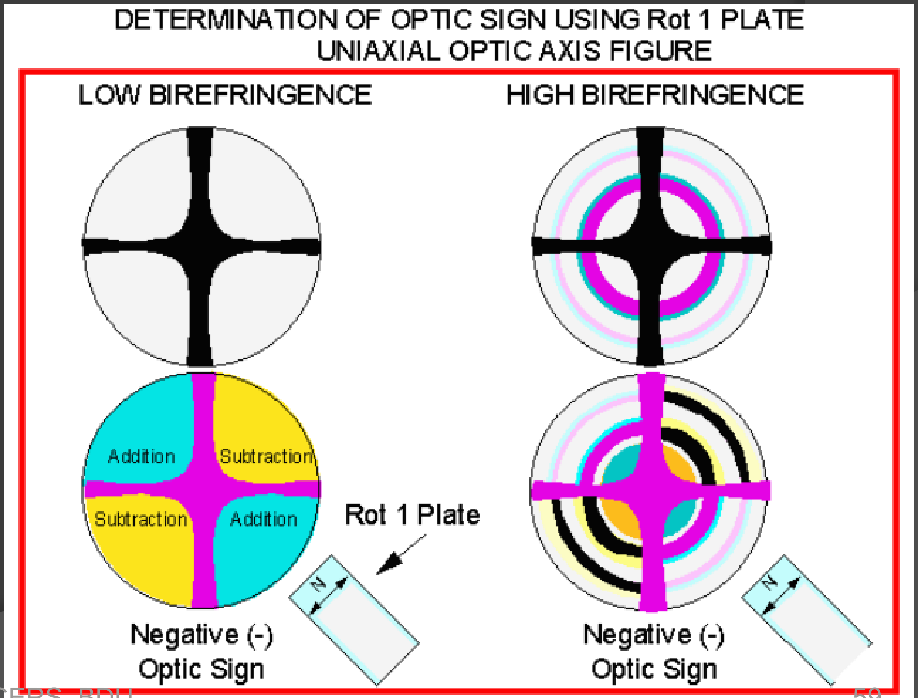
$Fast_{min} + Slow_{acc}$ = Decrease.

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

-ve

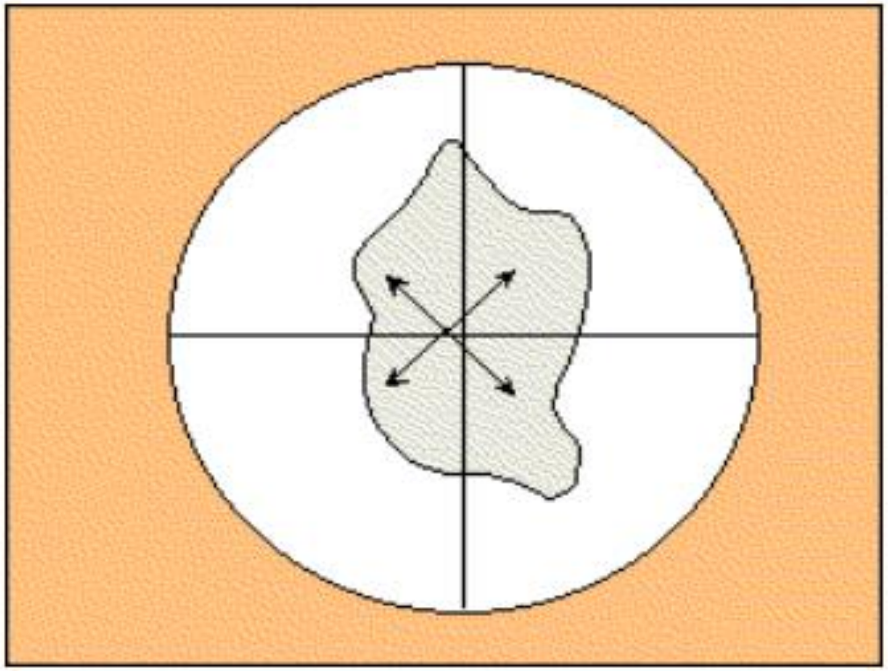



DETERMINATION OF OPTIC SIGN USING Rot 1 PLATE
UNIAXIAL OPTIC AXIS FIGURE
LOW BIREFRINGENCE
HIGH BIREFRINGENCE
Subtraction
Addition
Addition
Subtraction
Rot 1 Plate
N
Positive (+)
Optic Sign
Positive (+)
Optic Sign


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
Negative (-)
Optic Sign

OPTIC SIGN USING THE GYPSUM PLATE

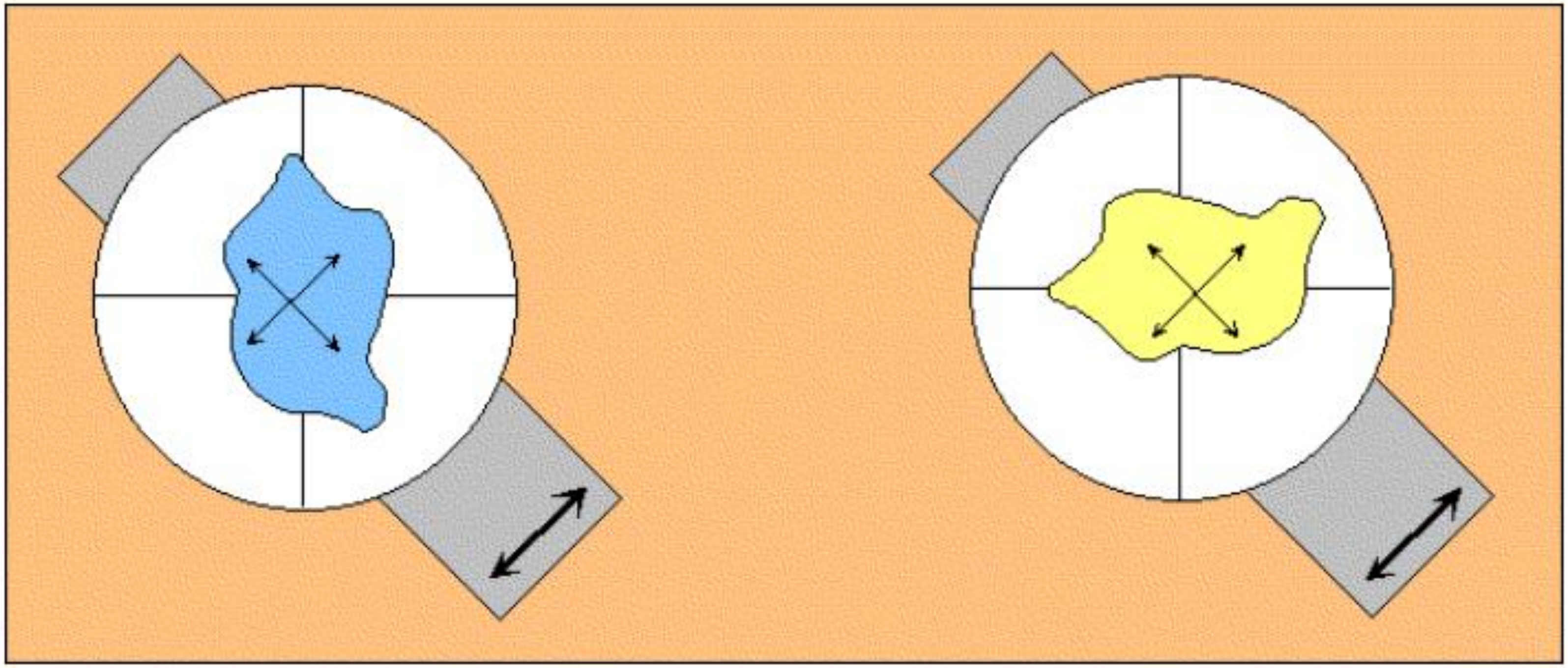
Under crossed polars, without the gypsum plate, a first order grey interference colo
retardation of approximately 200 nm.



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.

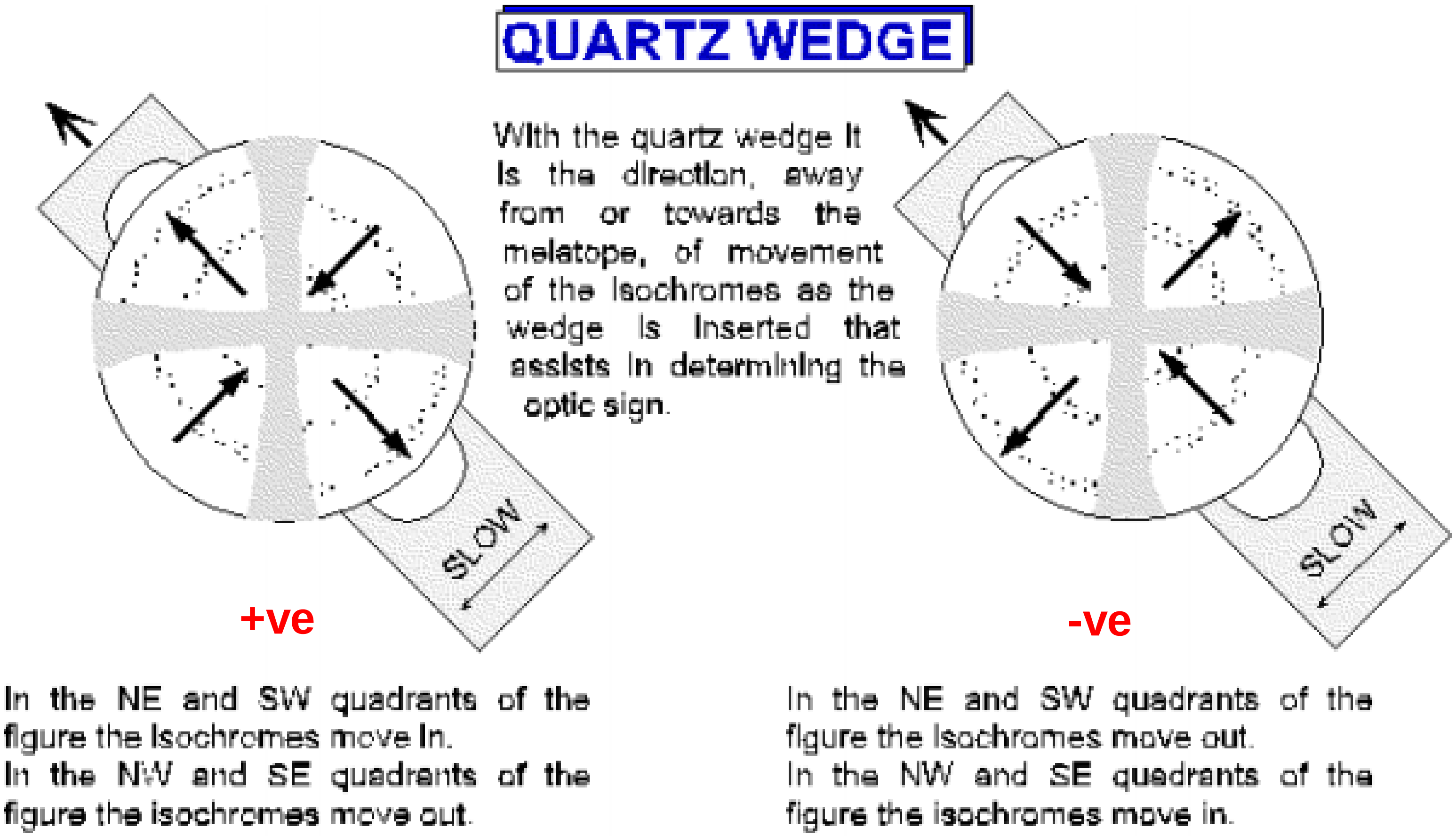


The blue or green colour results from the addition of the slow vibration direction of plate to the slow vibration direction of mineral.

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

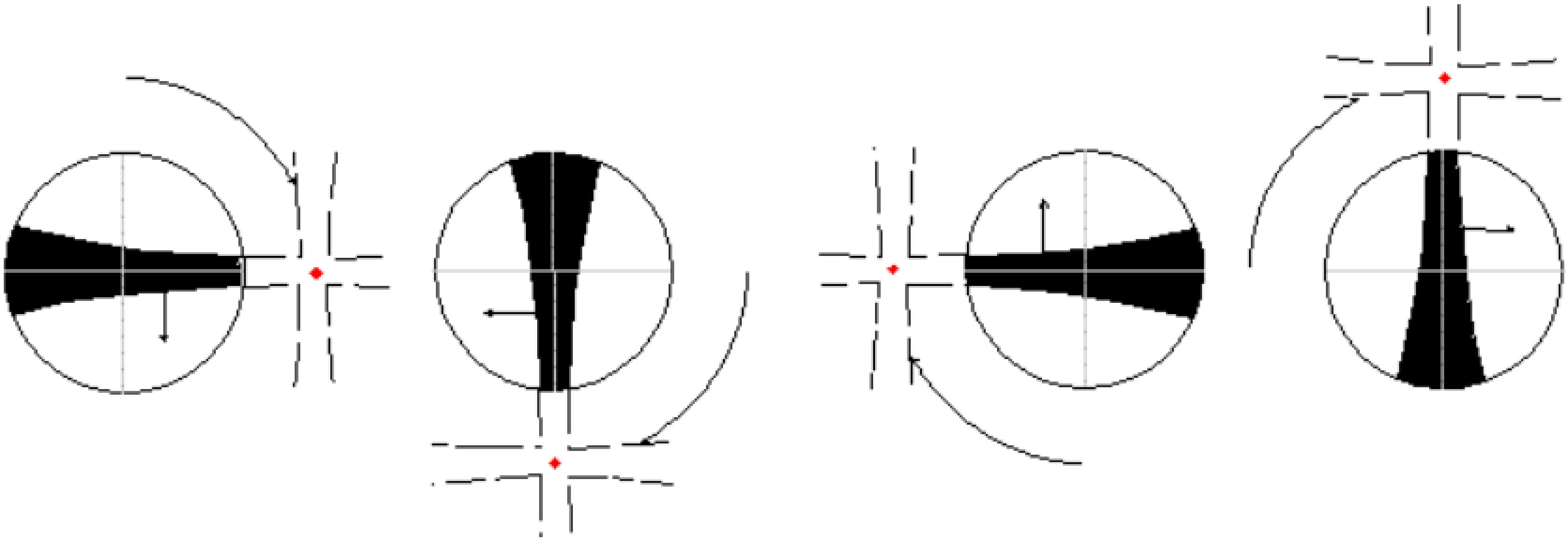
If the interference figure displays numerous isochromes colour changes produced with gypsum plate become difficult to detect. In this case the quartz wedge is used.



Interference figure from Off-Centered optic axis

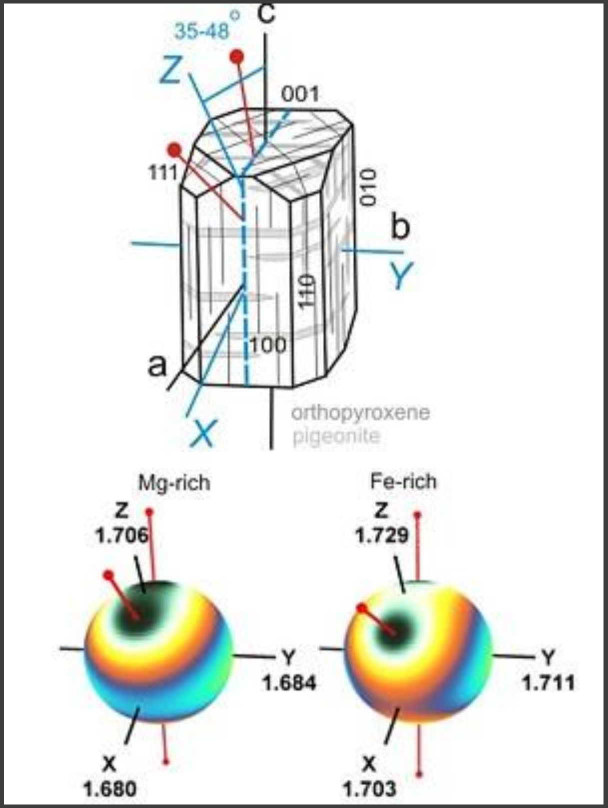
If the melatope is just in the field of view the optic sign can easily be determined, using the technique outlined above.

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.



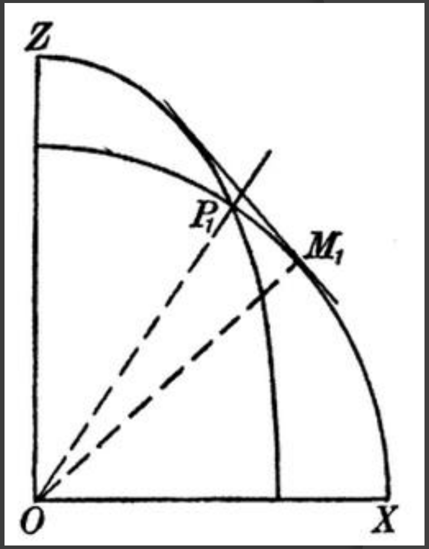
By noting the direction and sequence of how the isogyres pass through the field of view, as the stage is rotated, it is possible to identify which quadrant is being viewed and therefore the optic sign may be determined, knowing the vibration directions of omega & epsilon, in the NE quadrant of the interference 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** (no 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.

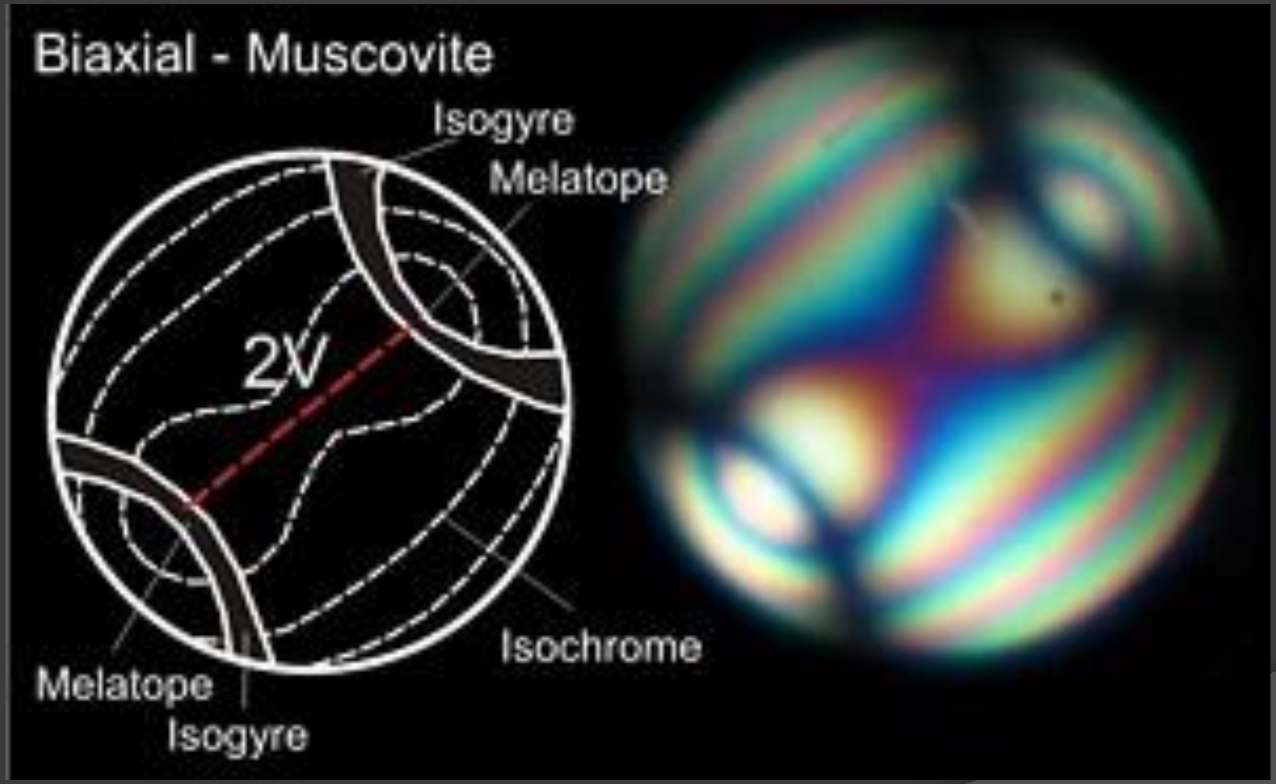
Optic Orientation

- 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.

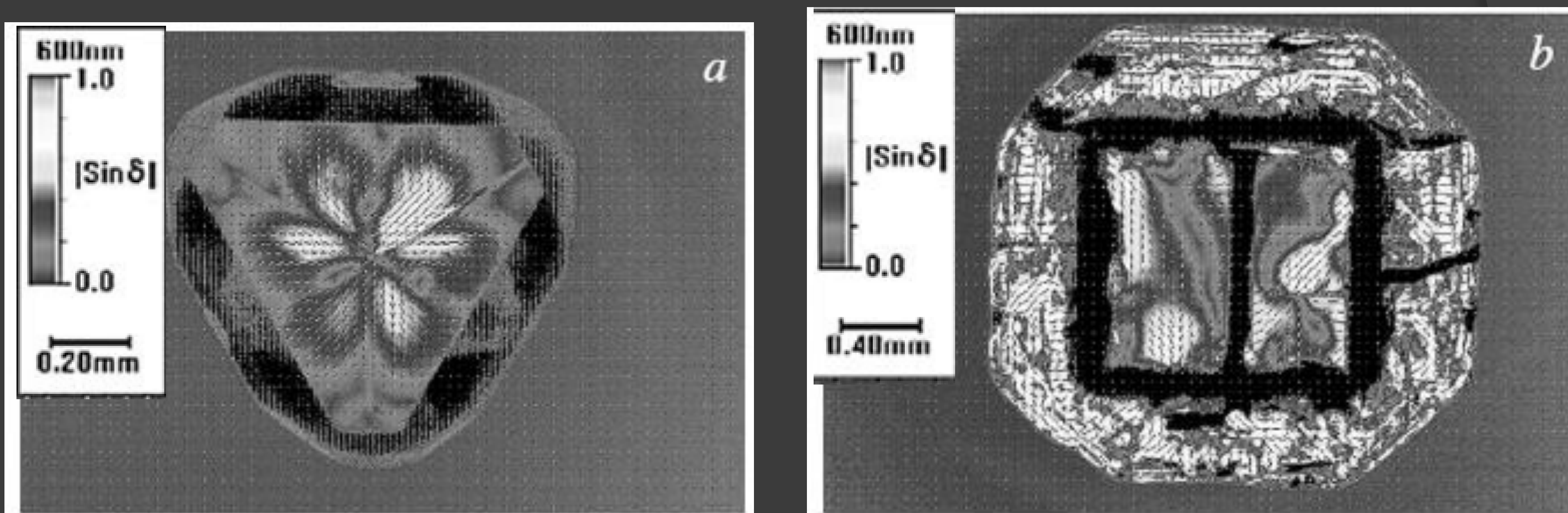


In a centered Bxa figure, the closer the melatopes and the stronger curvature of the isogyres, the lower the 2V angle.

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 $\delta = 2\pi \Delta n L/\lambda$, $\Delta n = n_{\perp} - n_{\parallel}$, 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 (VIBGYOR) , 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.

Thank you

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Let us enjoy using Crystals and Minerals more efficiently, effectively & SUSTAINABLY too…