Subject	Geology
Paper No and Title	**Crystallography and Mineralogy**
Module No and Title	Interference Figures
Module Tag	Min IIIc

Principal Investigator	Co-Principal Investigator	Co-Principal Investigator
Prof. Talat Ahmad ***Vice-Chancellor*** Jamia Millia Islamia Delhi	**Prof. Devesh K Sinha** Department of Geology University of Delhi Delhi	**Prof. P. P. Chakraborty** Department of Geology University of Delhi Delhi
Paper Coordinator	**Content Writer**	**Reviewer**
Prof. Naresh C. Pant Department of Geology University of Delhi Delhi	**Dr. Ashima Saikia** Department of Geology University of Delhi Delhi	**Prof. Santosh Kumar** Department of Geology Kumaun University Nainital

Table of Content

1. Learning outcomes

After studying this module, you shall be able to:

- Determine if a mineral is uniaxial or biaxial as per optical classification of minerals.
- Determine the optic sign of the mineral.

2. Interference figures

When certain sections of anisotropic minerals is observed under convergent polarized light between two polarizers and by using high power objective and Betrand lens an image is produced called interference figure. Optically uniaxial and biaxial minerals produce entirely different images. The Uniaxial mineral produce uniaxial interference figure and biaxial mineral produce biaxial interference figure.

Interference figures are used to determine optical character that is whether a mineral is uniaxial or biaxial and to determine the optic sign. If the mineral happens to be of biaxial class, interference figures may be used to measure the 2V angle. It can also be used to confirm certain mineral orientations.

3. How to view an interference figure

To view an interference figure the following steps are needed to be followed under the polarizing microscope

- ✓ Focus on a single mineral grain with high power objective lens.
- ✓ Auxiliary condensing lens has to be flipped in. If needed refocusing has to be carried out and one needs to open the aperture of diaphragm.
- ✓ Than the upper polarizer is inserted.
- ✓ This is followed by insertion of the Bertrand lens. The interference figure may also be observed without the Bertrand lens by removing the ocular and looking directly down the microscope tube.

The interference figure is formed near the top surface of the objective lens and consists of a pattern of interference colours called ***isochromes*** on which dark cross-called ***isogyres*** are superimposed.

The nature of the interference figure and its behavior as the stage is rotated depends on the optic orientation of the mineral grain belonging either to uniaxial or biaxial optical class.

4. Uniaxial interference figures

Optic axis interference figure

A mineral section cut normal to the optic axis of Uniaxial mineral produce the simplest and most important interference figure. A grain with a vertical optic axis should display the lowest interference colour of all grains in the sample. The interference figure consists of isogyres forming a dark cross superimposed on circular pattern of coloured rings called isochromes. The point in the center where the isogyres cross is called as melatope, which is the point of emergence of the optic axis. The interference colours increase in order outward from the melatope (**Fig. 1**).

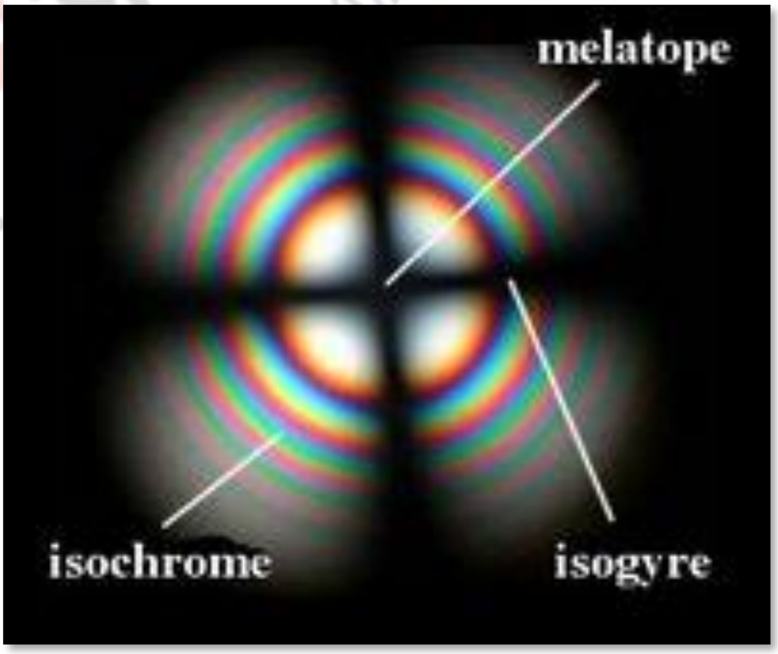

Fig. 1 Typical Uniaxial interference figure.

The formation of ***isochromes*** is shown in the **Fig. 2**. The auxillary condensing lens provides strongly convergent light that passes through the mineral and is collected by the objective lens. As can be seen in the figure light ray following path 1 is parallel to the optic axis, hence will not split into two rays and exits the mineral with zero retardation to form the melatope. Light following path 2 experiences moderate retardation and the light ray following the path 3 is at greater angle to the optic axis, so retardation is proprtionately greater. Because the optical properties are symmetric about the optic axis, rings of equal retardation and interference coloure are formed around the melatope. Minerals with high birefringence show more isochromes.

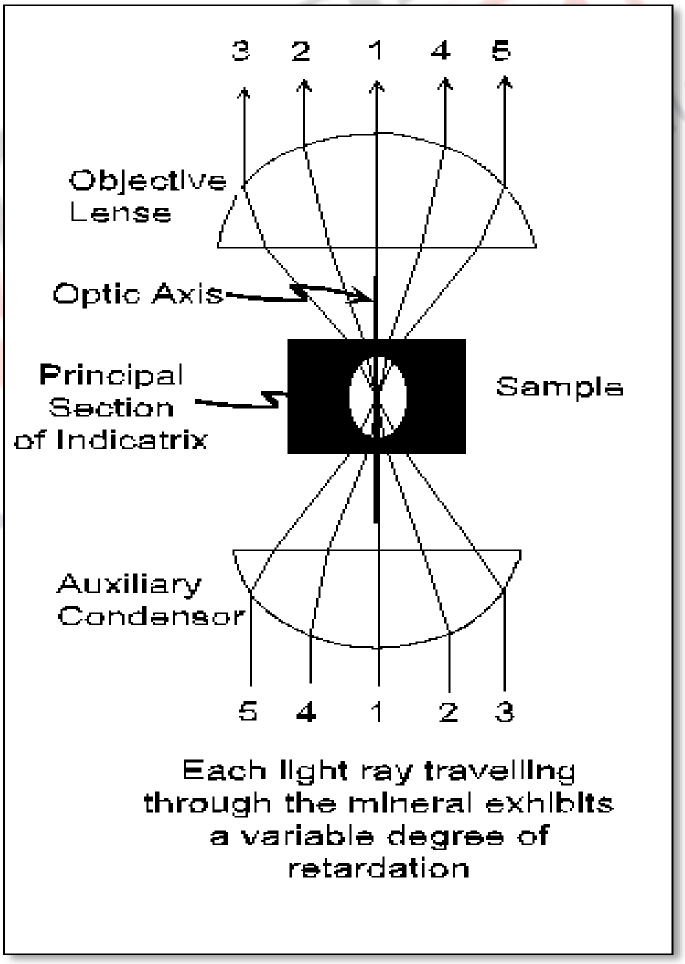

Fig. 2 Formation of Isochromes**.**

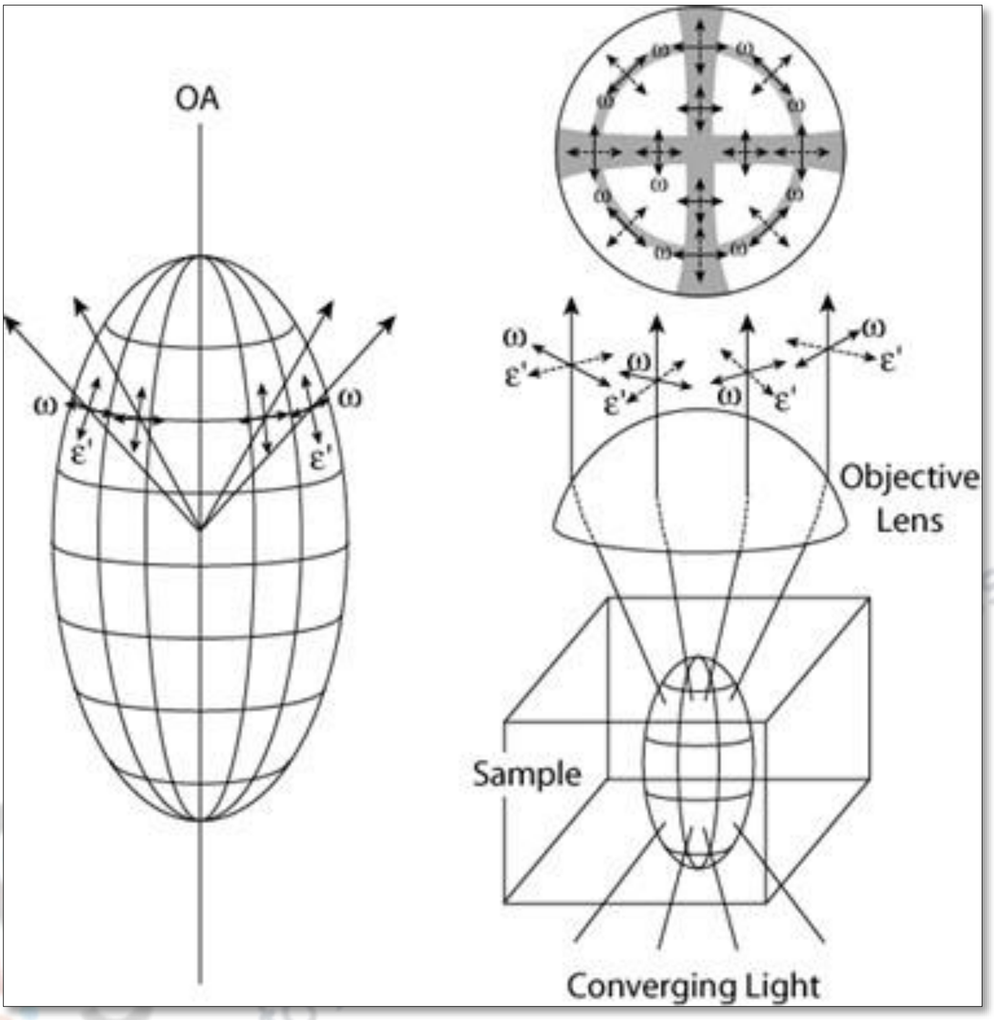

Fig. 3 Schematic illustrating formation of isogyres.

The isogyres forming the dark cross are the locus point at which the transmitted rays have zero amplitude of vibration. **Figure 3** shows schematic representation of formation of ***isogyres***. We can see the vibration directions for light emerging from the center of a uniaxial indicatrix when a strongly convergent light that passes through a mineral whose optic axis is vertical.. Extraordinary rays vibrate parallel to lines of longitude and ordinary rays vibrate parallel to lines of latitude on the indicatrix. Extraordinary rays vibrate along radial lines symmetric about the melatope and ordinary rays vibrate tangent to the circular isochromes. The isogyres are formed where the vibration directions in the interference figure are N-S and E-W. Hence along these two lines condition for extinction are obtained. The mineral is dark along these two lines. The darkness fades out progressively on the two sides of each line.

Off-Center interference figure

If the optic axis is inclined from the vertical, the interference figure will no longer be centered in the field of view. When the optic axis is within about 30 degree of being vertical, the meltaope is visible in the field of view resulting in ***off–center optic axis figure***. The isogyres still form a NS-EW dark cross-centered on the melatope that swings in an arc around the field of view as the stage is rotated and can still be used to determine optical character and optic sign.

If the optic axis is inclined more than 30 degrees from the vertical axis, melatope will form away from field of view and the interference figure is called an ***off-center figure***. The four-isogyre arms sweep across the field of view sequentially as the stage is rotated (**Fig.4**).

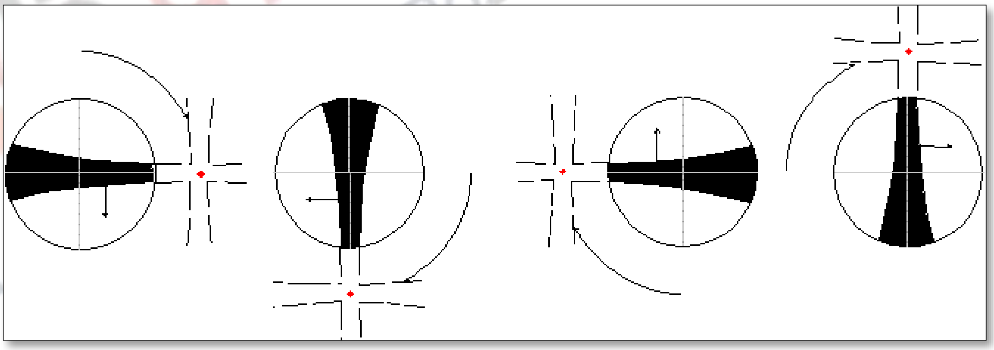

Fig. 4 If the melatope is well outside the field of view the isogyres sweep across the field of view in sequence as the stage is rotated - with the isogyres always remaining parallel to the crosshairs. By noting the direction and sequence of how the isogyres pass through the field of view, as the stage 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 ordinary and extraordinary ray in the NE quadrant of the interference figure. Marked in red is the melatope.

Optic Normal interference figure

If a mineral grain is oriented with the optic axis parallel to the microscope stage, an optic normal interference figure is produced. As these figures display maximum retardation, they are characterized by broad fuzzy isogyres that occupy nearly the entire field of view when the trace of the optic axis is either E-W or N-S. On rotation of the stage by only a few degrees, the isogyre splits into two segments that exit the field of view from the quadrants into which the optic axis is being rotated. As the isogyre appear and disappear rapidly with stage rotation, they are also called ***flash figures*** (**Fig.5**).

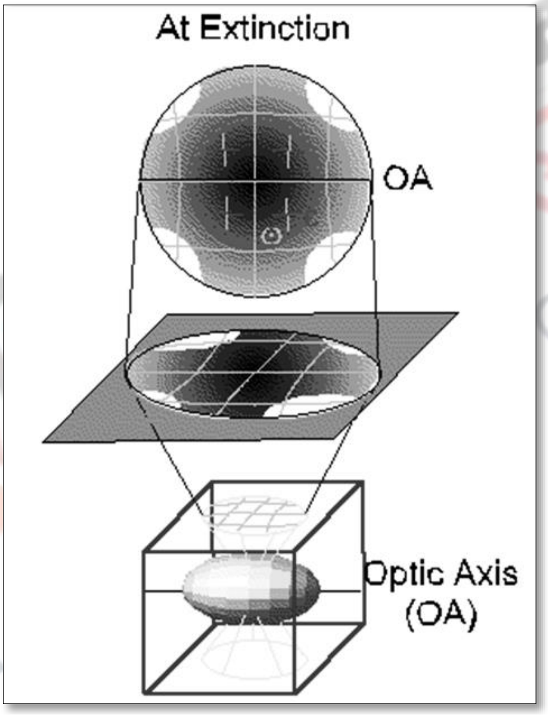

Fig. 5 Uniaxial flash figure. The mineral is oriented with the optic axis horizontal. The resulting isogyre is a broad fuzzy cross, which nearly fills the field of view because the vibration directions in all but the outer parts of the four quadrants are essentially parallel to the vibration directions of the nicols.

Optic sign determination using uniaxial interference figures

The optic axis interference figure is used to determine optic sign because the vibration directions of ordinary and extraordinary rays are known at each point in the figure. The ordinary rays vibrate NE-SW and the extraordinary rays vibrate NW-SE. If a length fast accessory plate is inserted and the retardations in the SE and NW quadrants substract (interference color order decreases) the ordinary ray must be fast ray and hence the mineral is optically positive. If the retardations add i.e., interference colour order increases the ordinary ray must be slow and the mineral is optically negative (**Fig. 6**).

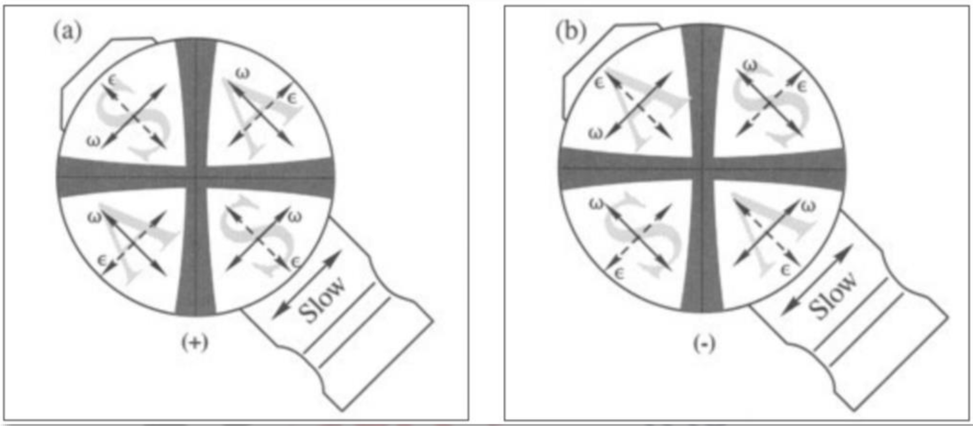

Fig. 6 Schematic showing optic sign determination in uniaxial minerals. For this, an optic axis interference figure is required. On insertion of length fast accessory plate if retardation substract in alongside quadrants than the mineral is optically positive, if retardations add on alongside quadrants than the mineral is optically negative. (a) Optically positive (b) Optically negative marked in A and S are addition and substraction of interference colour.

5. Biaxial interference figures

Acute Bisectrix Figure

An acute bisectrix interference figure is produced if the acute bisectrix i.e., X or Z depending on the optic sign is oriented perpendicular to the microscope stage. Given the optic axial angle, 2V is less than 50 to 60 degrees, the melatopes (point of emergence of optic axes) will be in the field of view and the interference figure will have two isogyres, which will change as the stage is rotated.

Isochromes will also be visible superimposed on the isogyres. These isochromes usually form an oval shape about the meltaopes. Only the light ray that are parallel to the optic axes will experience zero retardation. Any light ray inclined to the optic axes will experience increasing birefringence so retardation increase away from the melatopes resulting in the oval pattern. The pattern of isochromes remains fixed relative to the melatopes on rotation of the microscope stage (**Fig. 7**).

The isogyres form a pattern that changes as the microscope stage is rotated. If the optic plane is oriented E-W, isogyres forms a cross with the arm parallel to the trace of the optic normal being wider than the isogyre parallel to the trace of the optic plane. The positions of the melatopes are marked by a narrowing of the isogyres. If the optic plane is rotated away from the E-W, the cross-shaped isogyre splits into two separate segments that appear to pivot about the positions of the melatopes.

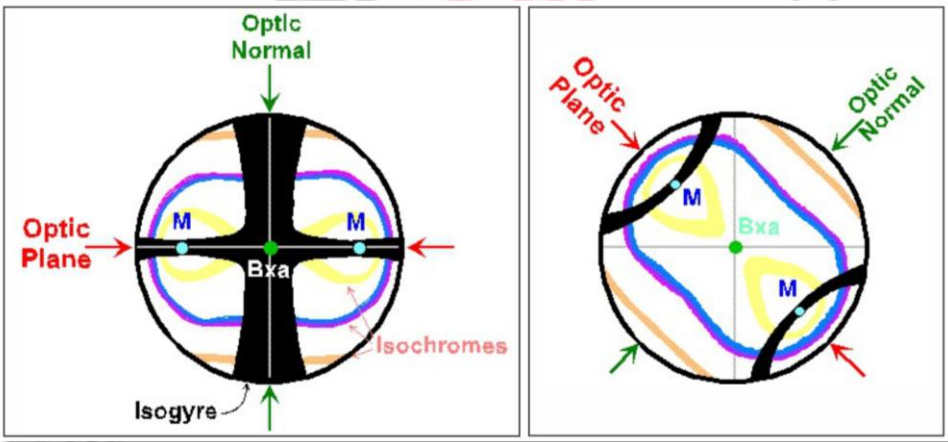

Fig. 7 Left image is a drawing of an acute bisectrix figure with its component parts labelled. At extinction, left image above, the isogyres will form a cross with arms parallel with the crosshairs. On rotating the stage to the 45° position, right image above, the cross will split and the isogyres will form two hyperbole, which will lie in opposite quadrants of the field of view. The melatopes and/or isogyres will always leave the field of view along the optic axial plane when the stage is rotated and the figure breaks up.

Optic axis figure

It is observed on mineral grains cut normal to optic axis. The figure consists of a single isogyre at the center of which is the emergence of the optic axis.

When the optic plane is parallel to vibration direction of either polars, the isogyre crosses the center of the field as a straight bar. As the microscope stage is rotated, it swings across the field forming a hyperbola in the 45-degree position (**Fig. 8**).

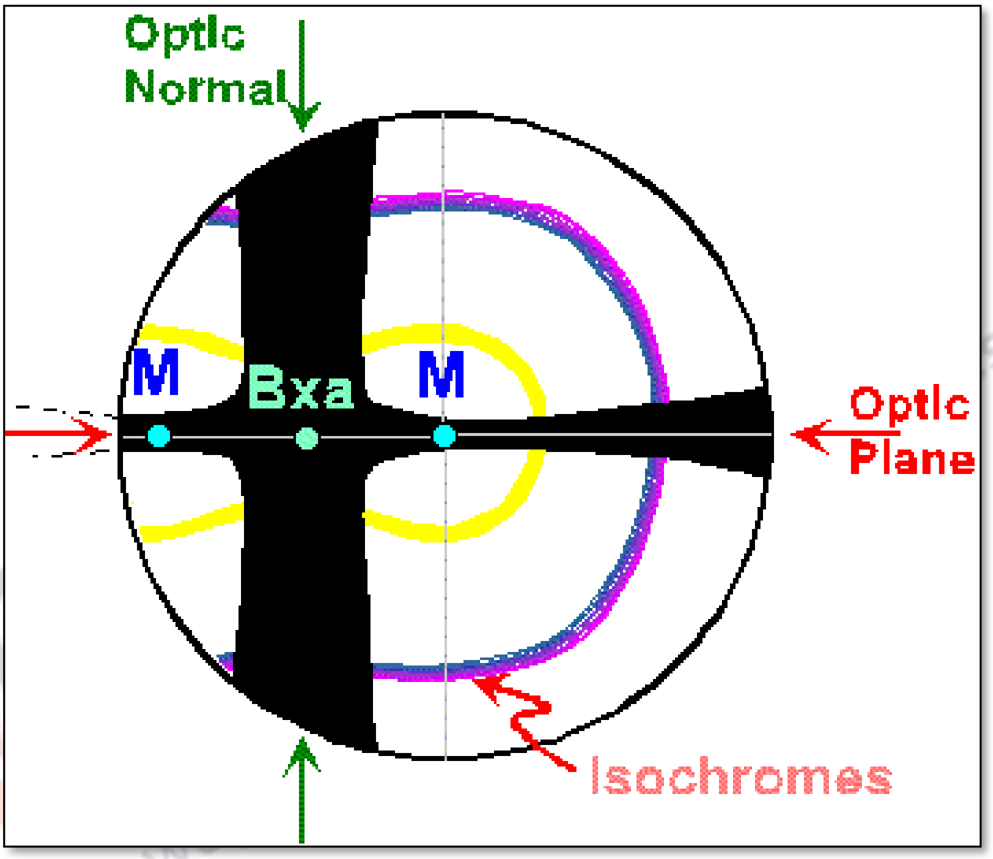

Fig. 8 The Centered Optic Axis Figure is produced when one optic axis is vertical, and correspondingly the second optic axis and the acute bisectrix are inclined to vertical.

Obtuse Bisectrix figure

It is obtained on a crystal section cut normal to the obtuse bisectrix. As the angle between obtuse bisectrix and optic axes are greater than 45 degree, in this case the melatopes will be outside the field of view. The pattern of isochromes and geometry of vibration directions are essentially the same as for the obtuse bisectrix figure, except the melatopes are well out of the field of view (**Fig. 9 image on left**).

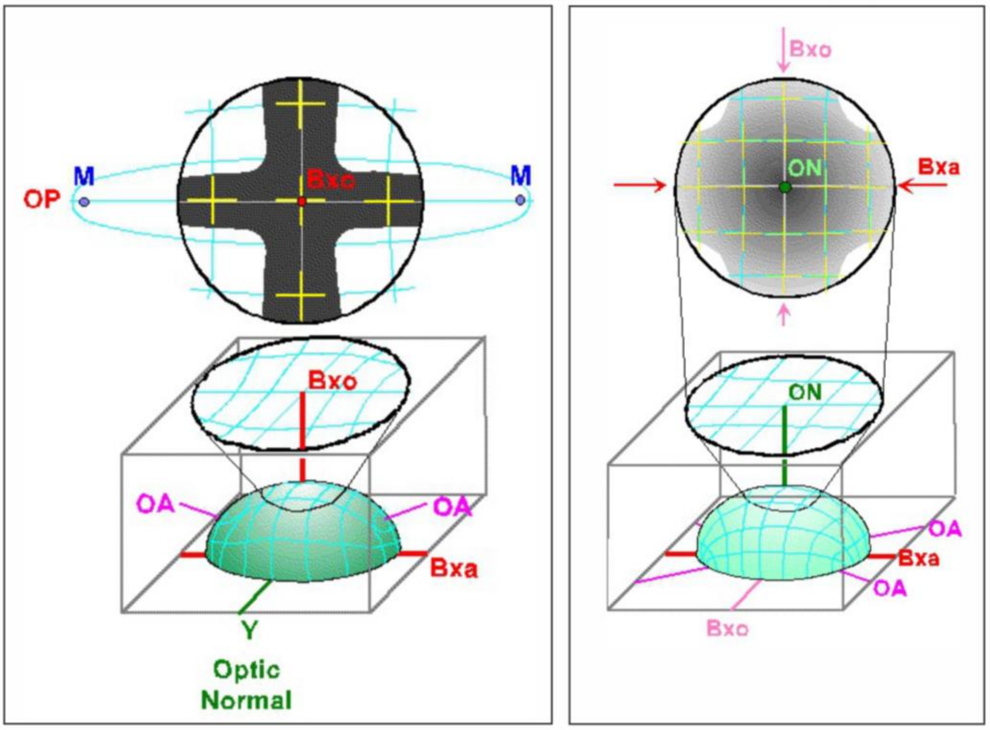

Fig. 9 Left: The Obtuse Bisectrix Interference Figure is produced when the obtuse bisectrix (Bxo) of the indicatrix is perpendicular to microscope stage. The angle between the Bxo and the optic axes is > 45°. The result is that the melatopes will always lie outside the field of view. **Right:** A biaxial optic normal figure is similar to the uniaxial flash figure, and is produced when the optic normal (ON) is vertical. In this orientation the optic plane, containing the Acute bisectrix (Bxa), Obtuse Bisectrix (Bxo) and optic axes, is horizontal.

Optic normal figure

Optic normal (flash) figure is produced when the optic normal is vertical. Grains oriented to produce this figure display maximum retardation as the X and Z indicatrix axes are horizontal. When the X and Z-axes optical directions are parallel to the vibration directions of the polars, the figure is a poorly defined cross. On slight rotation of the microscope stage, the isogyres split into two hyperbolas moving rapidly from out of the field in the quadrants containing the acute bisectrix (**Fig. 9 image on right**).

Off center figure

Grains in random orientations display off centered figures whose pattern of isogyres and isochromes depends on the details of orientation. As the stage is rotated, the isochromes pivot about the center and isogyres sweep sequentially across the field of view. Off center figures are of no particular value except that it indicates the mineral is biaxial.

Optic sign determination using biaxial interference figure

To determine whether the X or Z-axis is the acute bisectrix, and therefore whether the mineral is optically negative or positive, the interference figure must be rotated such that the optic plane is oriented NE-SW.

The steps to follow to determine the optic sign are:

a) Obtain an acute bisectrix interference figure. Rotate the stage so that the trace of the optic plane is oriented NE-SW, i.e., the isogyre cross will split and move into the NE and SW quadrants.

- If 2V (optic axial angle) is small, < ~40°, both isogyres will be visible in field of view.
- If 2V (optic axial angle) is large, > ~40°, the isogyres will lie outside the field of view.

b) Insert accessory plate. With the interference figure in the 45° position, the optic plane is oriented NE-SW, such that it is parallel with the slow vibration direction of the accessory plate. Observe the colour change that results.

c) If the interference colours between the melatopes decrease the ray vibrating parallel to Obtuse Bisectrix, (Bxo) (parallel to optic plane) must be the fast ray so Bxo = X axis (X = fast ray) and Acute Bisectrix, (Bxa), which is vertical, = Z axis. The mineral is optically positive. If the interference colours between the melatopes increase, the ray vibrating parallel to Bxo must be the slow ray, so Bxo = Z-axis, and Bxa = X-axis. The mineral is optically negative. If the trace of the optic plane is placed such that it lies in the NW-SE, the areas of addition and substraction observed for the interference colours will be reversed.

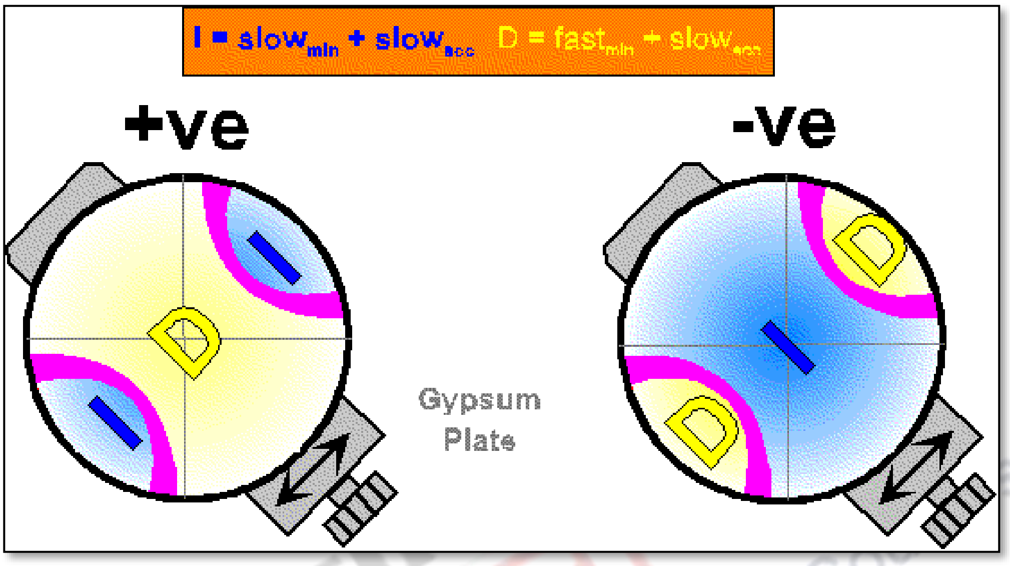

Fig. 10 Optic sign determination of biaxial mineral using gypsum plate.

If the interference figure displays few to no isochromes use the gypsum plate to determine the optic sign. With the gypsum plate inserted, the area between the isogyres will exhibit either:

- ✓ A decrease in colours, from white to yellow, (shown on the left above) indicates that the vibration direction in the interference figure, which is parallel to the optic plane, is the FAST RAY. This colour change tells us that the ray, which is vibrating parallel to the optic plane, has a *low index of refraction* and must correspond to n_{alpha} as measured along the X indicatrix axis. Therefore, the Z indicatrix axis must be the Bxa (**Fig. 10**).
- ✓ An increase in colours, from white to blue, (shown on the right above) indicates that the vibration direction in the interference figure, which is parallel to the optic plane, is the SLOW RAY. This colour change tells us that the ray, which is vibrating parallel to the optic plane, has a *high index of refraction* and must correspond to n_{gamma} as measured along the Z indicatrix axis. Therefore, the X indicatrix axis must be the Bxa.

6. Summary

Uniaxial interference figure

Optic axis Figure: The thin section is perpendicular to the c axis = optic axis. The mineral appears isotropic, or nearly isotropic under crossed polars, exhibiting a very low first order grey to black interference colour.

Off centered Optic Axis Figure: The c axis (optic axis) is not vertical, but inclined from the vertical axis of the microscope. Will only see isogyre in the field of view at a time, which will sweep out of the field of view parallel to one crosshair to be replaced by a new isogyre, which sweeps into the field of view parallel to the other crosshair. This orientation will exhibit an intermediate colour, between the lowest and highest colour exhibited by this mineral in the thin section being examined.

Flash Figure: The c axis is parallel to stage. The isogyres split and leave field of view rapidly with only a slight rotation, <10°.The maximum interference colour will be observed under crossed polars.

Sign determination:

- + ve $n_{omega} < n_{epsilon}$ slow ray = epsilon, fast ray = omega
- -ve $n_{omega} > n_{episilon}$ slow ray = omega, fast ray = epsilon.

Biaxial interference figure

Acute Bisectrix Figure: It is obtained when the acute bisectrix is oriented perpendicular to microscope stage. If the 2V angle of the mineral is low, than the melatopes lie within the field of view as the stage is rotated. The isochromes form an oval or Fig. 8 pattern around the melatopes, while the pattern of the isogyres changes as the stage is rotated.

Optic Axis Figure: It is produced when one optic axis is vertical, and correspondingly the second optic axis and the bxa are inclined to vertical. The melatope corresponding to the vertical optic axis will be positioned directly beneath the crosshairs. This orientation is produced in a grain, which displays the lowest interference colour for that mineral in the thin section being examined.

Obtuse Bisectrix Figure: It is produced when the obtuse bisectrix (Bxo) of the indicatrix is perpendicular to microscope stage. The angle between the Bxo and the optic axes is > 45°. The result is that the melatopes will always lie outside the field of view.

Optic normal figure: It is produced when the optic normal (ON) is vertical. In this orientation, the optic plane, containing the obtuse and acute bisectrix and optic axes, is horizontal. The grain, which produces this interference figure, will display the maximum interference colour for this mineral in the thin section.

Off center figure: Most interference figures examined during routine microscope work are off-centered figures. In these instances, none of the indicatrix or optic axes is vertical. Any combination of orientations is possible for off-centered figures.

Sign determination:

For optically positive minerals, the obtuse bisectrix is the X-axis and $n_{Bxo}= n_{alpha}$, and corresponds to the fast ray, remember that ($n_{alpha}<n_{beta}<n_{gamma}$).

For optically negative minerals, obtuse bisectrix is the Z-axis and $n_{Bxo}= n_{gamma}$, and corresponds to the slow ray.

Frequently Asked Questions-

Q1. What is the difference between a uniaxial and biaxial interference figure?

Ans. Uniaxial interference figure is characterized by a dark spot, which consists of two uniform isogyres parallel to the vibration direction polarizer and analyzer. When the mineral plate is rotated, the form and cross remain unchanged. Biaxial interference figures contains two different isogyres one is broader than the other. On rotation, the isogyres splits into two elliptical curves. The isochromes are elliptical too for the biaxial minerals.

Q2. Why isogyres form in an interference figure?

Ans. Isogyres form where vibration directions in the interference figures are N-S and E-W and are hence areas of extinction. Ordinary (ω) rays vibrate parallel to lines of latitude and extraordinary (ε') rays vibrate parallel to lines of longitude on the indicatrix. These vibration directions are carried up into the indicatrix Extraordinary (ε') rays vibrate along radial lines symmetric about the melatope and ordinary (ω) rays vibrate tangent to the circular isochromes. The isogyres become wider and have more diffuse edges further from the melatope.

Q3. Describe formation of isochromes?

Ans. Isochromes form by light rays that are split into two directions (because they are not parallel to the optic axis). With increasing angle away from the optic axis, the retardation becomes greater and hence the interference colors increase. Because optic properties are symmetric about the optic axis, rings of equal retardation and interference color are formed about the melatope.

Q4. Define melatopes?

Ans. The point in the center where the isogyres cross is called the melatope. It marks the point of emergence of the optic axis. Light following the optic axis is not split into two rays, exits the mineral with zero retardation, and hence looks black. The presence of a single melatope indicates that the mineral is uniaxial. Biaxial minerals have by definitions two melatopes.

Multiple Choice Questions-

1. Melatopes are point of emergence of

a) Optic axial plane
b) Optic axis
c) Acute bisectrix

Ans: b

2. In optically positive uniaxial minerals

a) Ordinary rays are slow rays
b) No splitting of rays occur
c) Extraordinary rays are slow rays

Ans: c

3. Uniaxial interference figures have two isogyres which

a) Remains constant on rotation but can move away from field of view
b) Splits on rotation
c) Remains constantly at the center of field of view

Ans: a

4. Which of the following figure is used for optic sign determination in biaxial minerals

a) Off center figure
b) Optic normal figure
c) Acute bisectrix figure

Ans: c

5. When the X vibration direction is acute bisectrix, the mineral is

a) Biaxial positive
b) Uniaxial positive
c) Biaxial negative

Ans: c

Suggested Readings:

1. Bloss, F. Donald (1971). Crystallography and Crystal Chemistry. Holt, Rinehart and Winston, New York. ISBN: 0030851556, 9780030851551.
2. Klien, Cornelis and Dutrow, Barbara, (2008). Manual of Mineral Sciences (Manual of Mineralogy), 23rd Edn. John Wiley & Sons, New York. ISBN: 0471721573, 978-0471721574.
3. Nesse, William D. (2016). Introduction to Mineralogy, 3rd Edn. Oxford University press. ISBN: 9780190618353.
4. Nesse, William D. (2012). Introduction to Optical Mineralogy, 4th Edn. Oxford University press. ISBN: 9780199846276.
5. Perkins, D. (2015). Mineralogy, 3rd Edn. Pearson Education India. ISBN: 9789332550421, 9332550425.