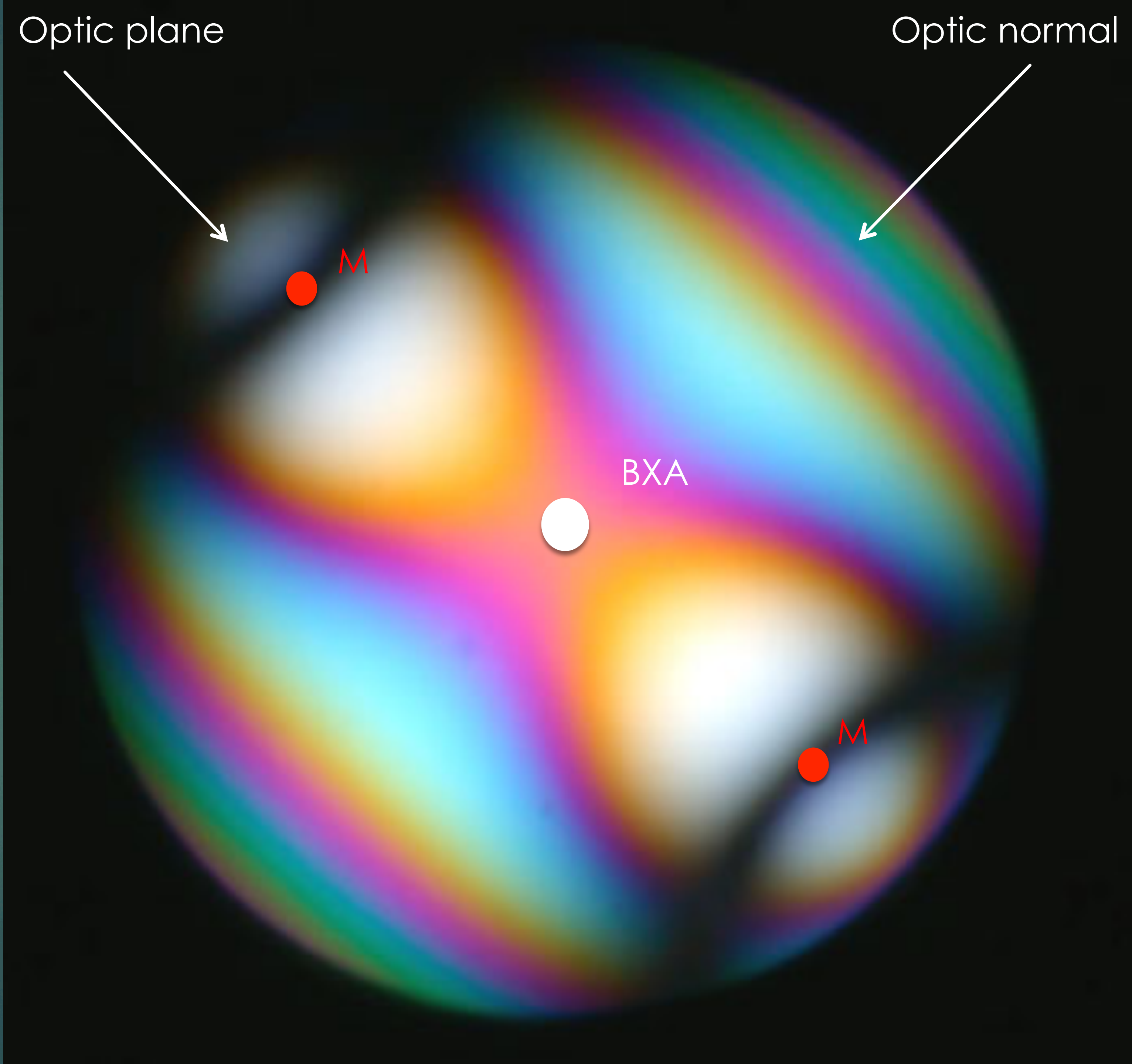
# Chapter 5: Optics of biaxial minerals

SARAH LAMBART



# Recap chapter 4

- **Optics of uniaxial minerals**
  - **Definition:**
    - 2 refractive indices: $\omega$ and $\varepsilon$
    - Crystal systems: hexagonal and tetragonal
  - **Optical indicatrix:** 3D representation of the variations of the refractive index in a substance.
    - Uniaxial indicatrix c-axis: $\varepsilon$ **vs.** a- and b-axes: $\omega$
    - Use of the uniaxial indicatrix

# Recap chapter 4

- **Optics of uniaxial minerals**
  - **Conoscope** light and interference figures: use of the Bertrand lens
  - **Optic sign**: Bertrand lens + analyzer + gypsum plate
  - Review on extinction angle and elongation sign
  - Review on pleochroism

# Content Chapter 5

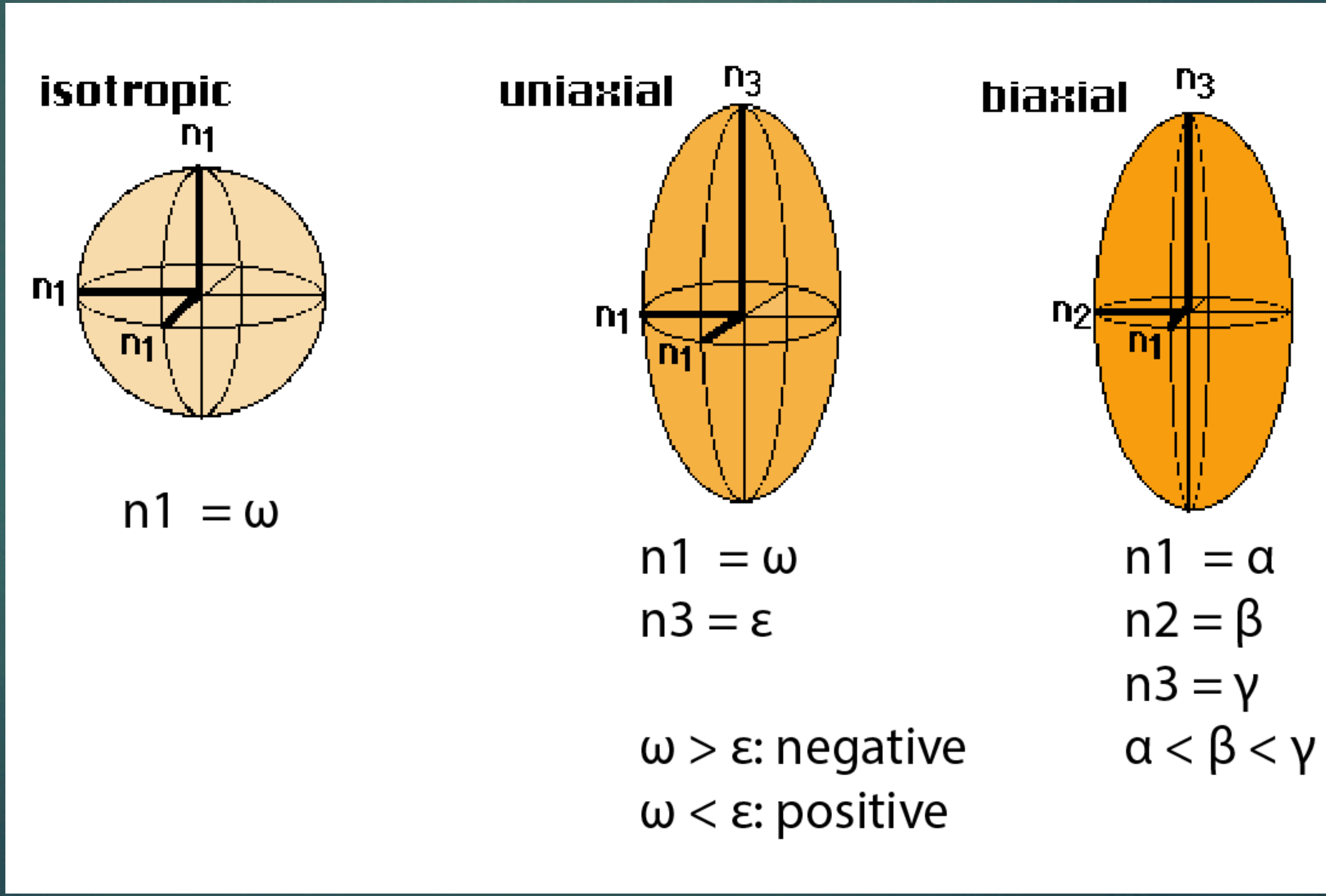
- **Optics of biaxial minerals**
  - **Definition**
  - **Biaxial indicatrix**
  - **Interference figures**
  - **Determination of the optic sign**
  - **Sign of elongation**

# UNIAXIAL MINERALS

- **Biaxial minerals:** anisotropic minerals that crystallize in orthorhombic, monoclinic, or triclinic systems. They are called biaxial because they have **two optic axes.**
- **Three** fixed values of **refractive indexes**:
  - The smallest refractive index is given the symbol $\alpha$ (or X).
  - The intermediate refractive index is given the symbol $\beta$ (or Y).
  - The largest refractive index is given the symbol $\gamma$ (or Z)

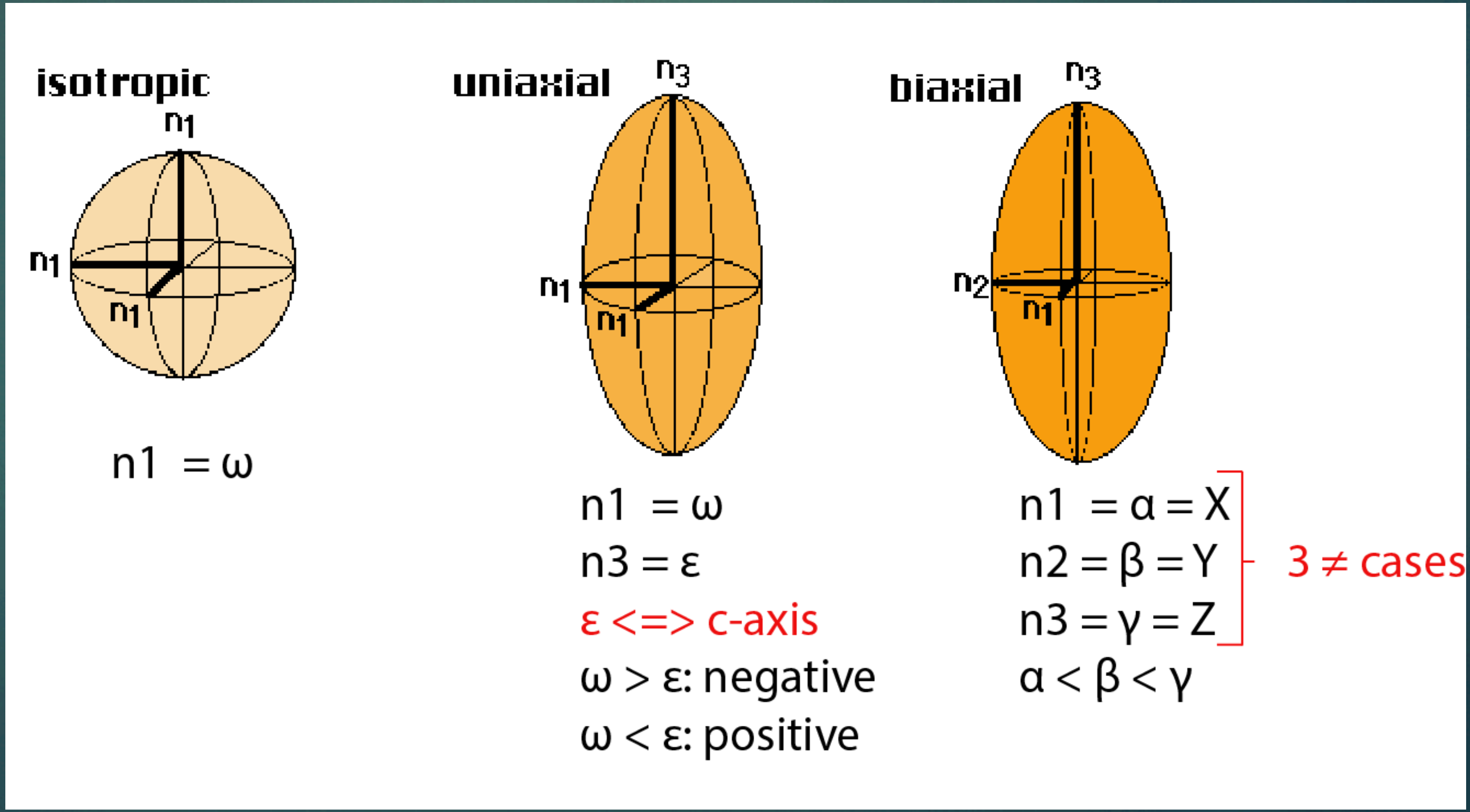
# OPTICAL INDICATRIX

- **Biaxial indicatrix:** 3D representation (ellipsoidal) of the variations of the refractive index in a substance. Each vector defining the ellipsoidal is proportional to n in the same direction.



# OPTICAL INDICATRIX

- **Crystal structure and the orientation of the indicatrix**



# OPTICAL INDICATRIX

- **Crystal structure and the orientation of the indicatrix**

- Orthorhombic

a≠b≠c; $\alpha = \beta = \gamma = 90°$

- Monoclinic

a≠b≠c; $\alpha = \gamma = 90° \neq \beta$

- Triclinic

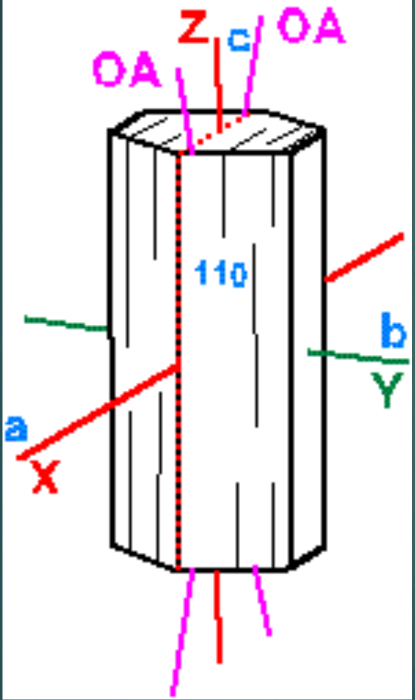
a≠b≠c;
$\alpha \neq \beta \neq \gamma \neq 90°$

# OPTICAL INDICATRIX

- **Crystal structure and the orientation of the indicatrix**

- Orthorhombic

$a \neq b \neq c; \ \alpha = \beta = \gamma = 90°$




Optical directions ⇔ crystallographic axes

Ex. sillimanite
a = X (or $\alpha$)
b = Y (or $\beta$)
c = Z (or $\gamma$)

- Monoclinic

$a \neq b \neq c; \ \alpha = \gamma = 90° \neq \beta$

- Triclinic

$a \neq b \neq c;$
$\alpha \neq \beta \neq \gamma \neq 90°$

# OPTICAL INDICATRIX

- **Crystal structure and the orientation of the indicatrix**

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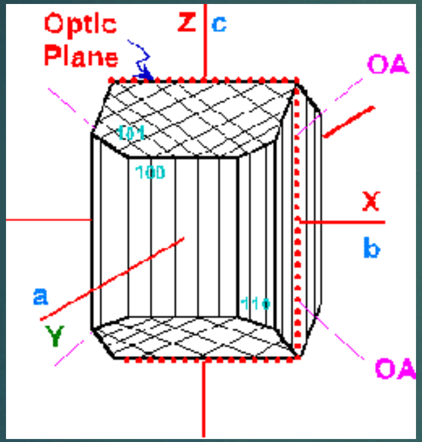



Ex. orthopyroxene
a = Y (or $\beta$)
b = X (or $\alpha$)
c = Z (or $\gamma$)

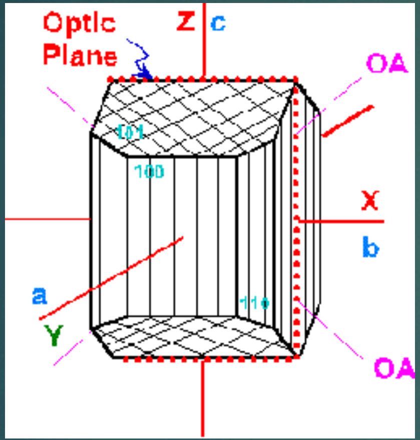
Optical directions ⇔ crystallographic axes

# OPTICAL INDICATRIX

- **Crystal structure and the orientation of the indicatrix**

- Orthorhombic

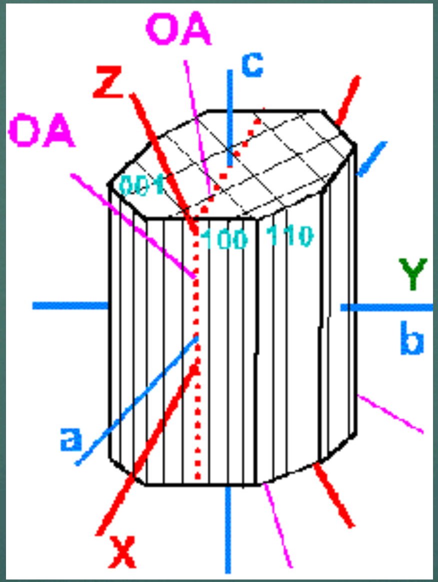
a≠b≠c; $\alpha = \beta = \gamma = 90°$




Optical directions ⇔ crystallographic axes

- Monoclinic

a≠b≠c; $\alpha = \gamma = 90° \neq \beta$




Ex. Clinopyroxene
b = Y (or $\beta$ )

**One** optical direction ⇔ b-axis

- Triclinic

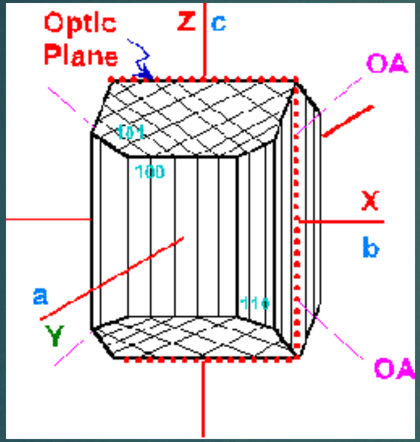
a≠b≠c;
$\alpha \neq \beta \neq \gamma \neq 90°$

# OPTICAL INDICATRIX

- **Crystal structure and the orientation of the indicatrix**

- Orthorhombic

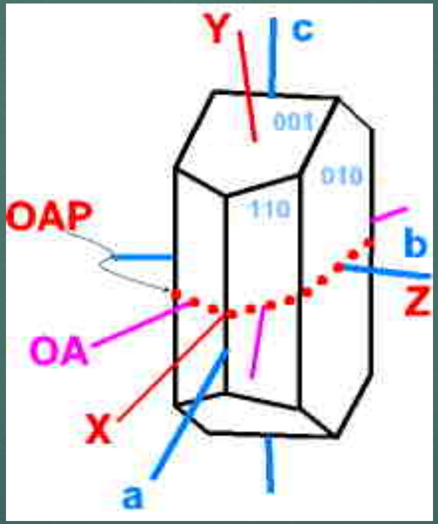
a≠b≠c; $\alpha = \beta = \gamma = 90°$




Optical directions ⇔ crystallographic axes

- Monoclinic

a≠b≠c; $\alpha = \gamma = 90° \neq \beta$




Ex. orthoclase
b = Z (or $\gamma$)

**One** optical direction ⇔ b-axis

- Triclinic

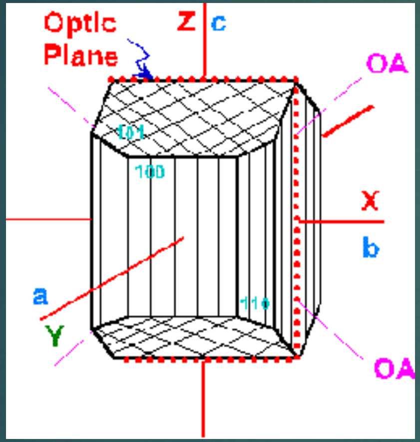
a≠b≠c;
$\alpha \neq \beta \neq \gamma \neq 90°$

# OPTICAL INDICATRIX

- **Crystal structure and the orientation of the indicatrix**

- Orthorhombic

a≠b≠c; $\alpha = \beta = \gamma = 90°$




Optical directions ⇔ crystallographic axes

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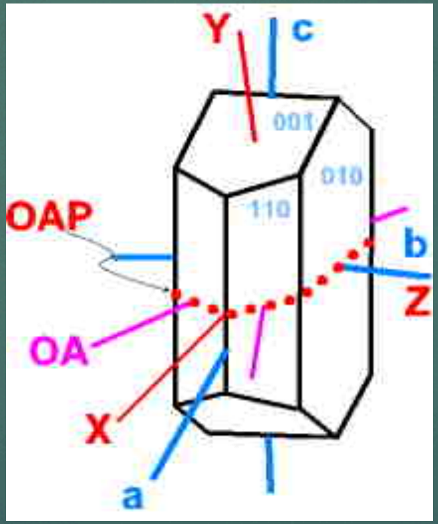


**One** optical direction ⇔ b-axis

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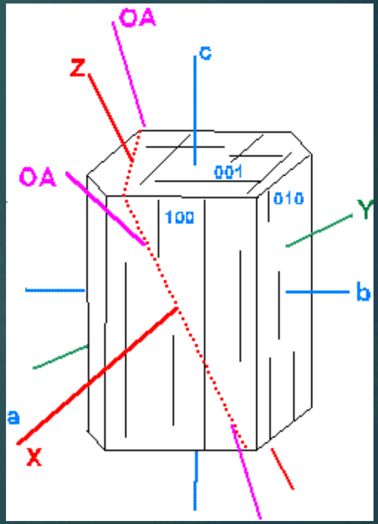


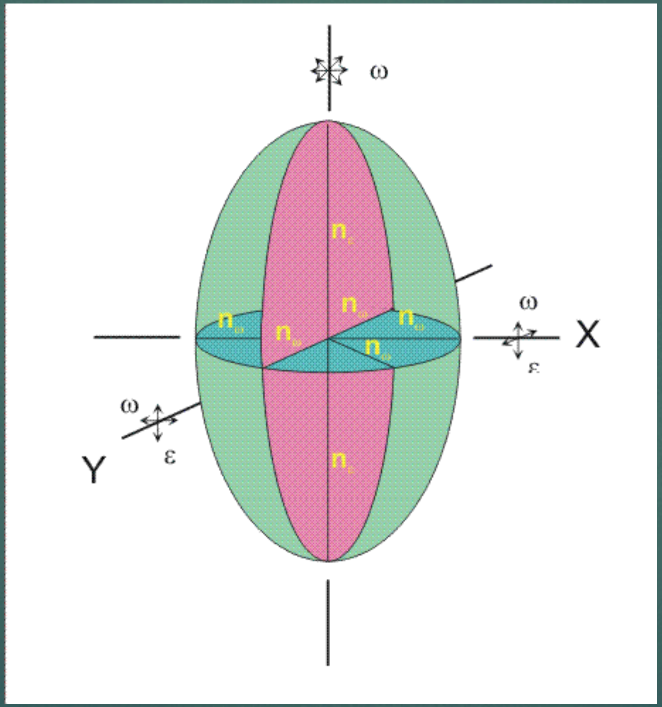

optical directions ⇎ crystallographic axes

Ex. kyanite

# OPTICAL INDICATRIX

- **Construction**
  - **Uniaxial**

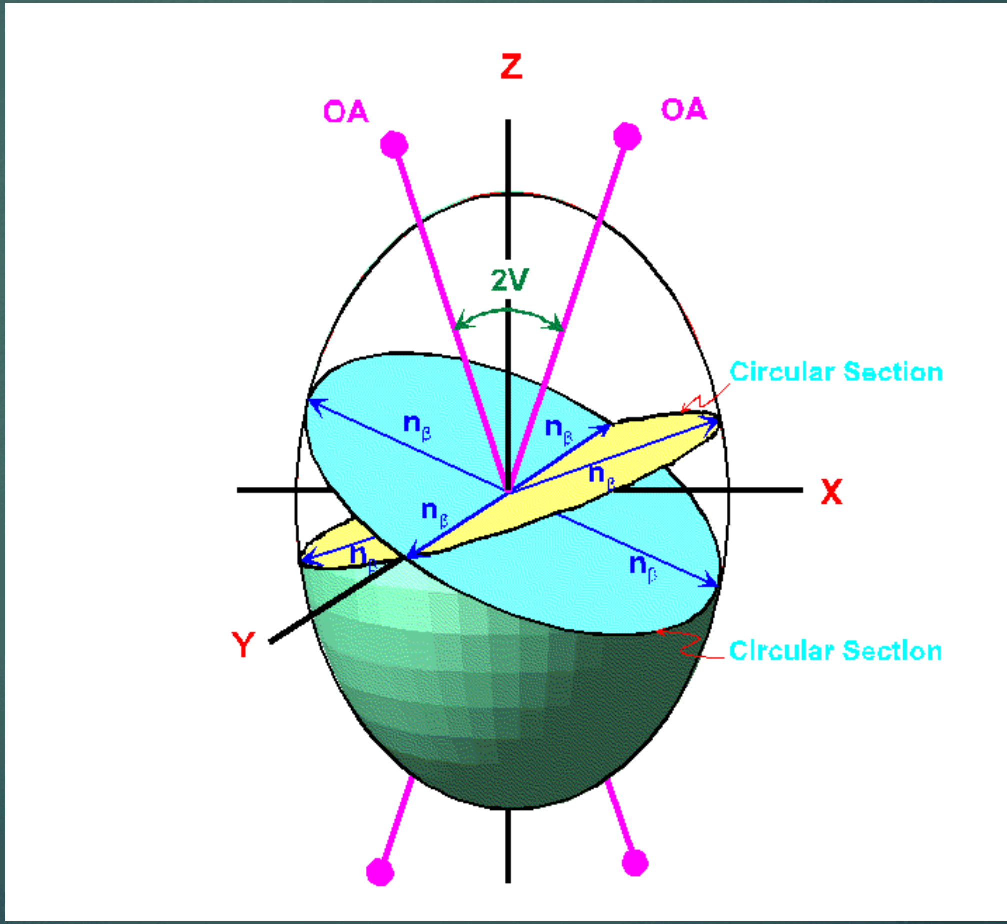
- 1 optic axis
- 1 ⊥ circular section
- $\Phi = \omega$




- c-axis
  = ε direction
  = optical axis

# OPTICAL INDICATRIX

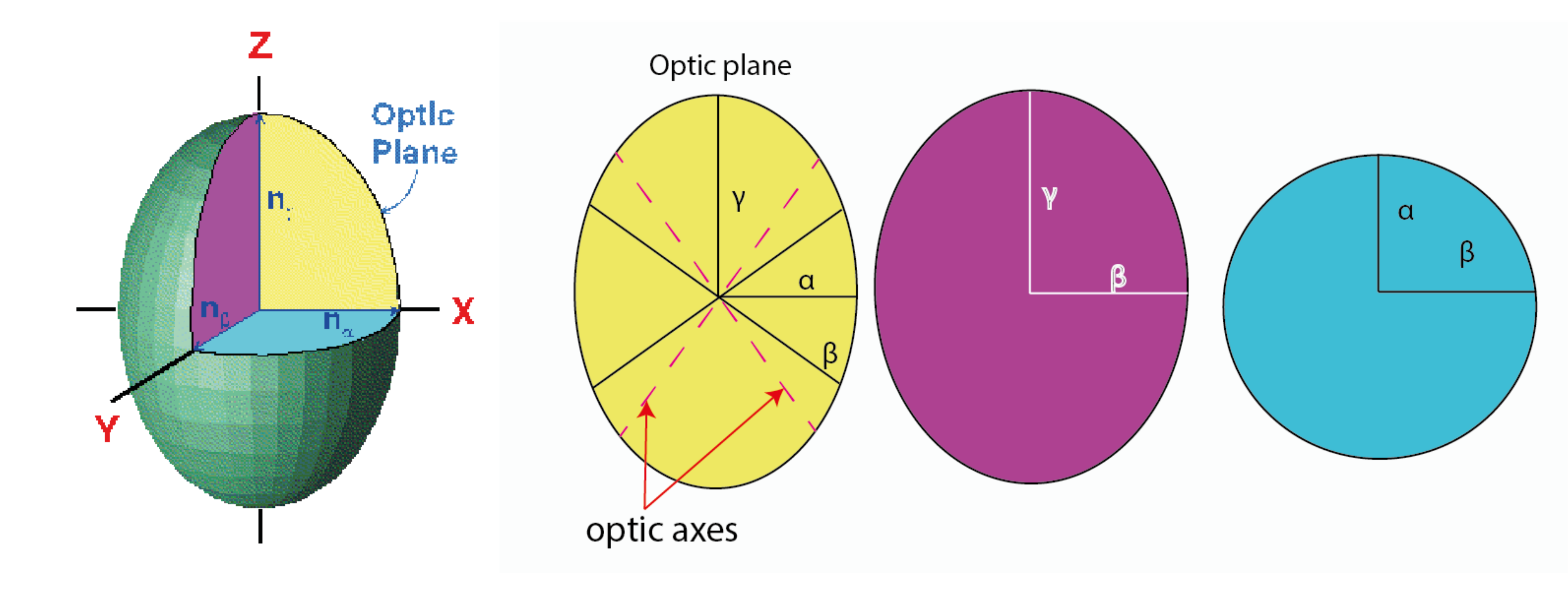
- **Construction:**
  - **Biaxial**




- 2 optic axes
- 2 ⊥ circular sections
- $\Phi = \beta$

# OPTICAL INDICATRIX

- **Construction:**
  - Biaxial
  - 3 principal sections

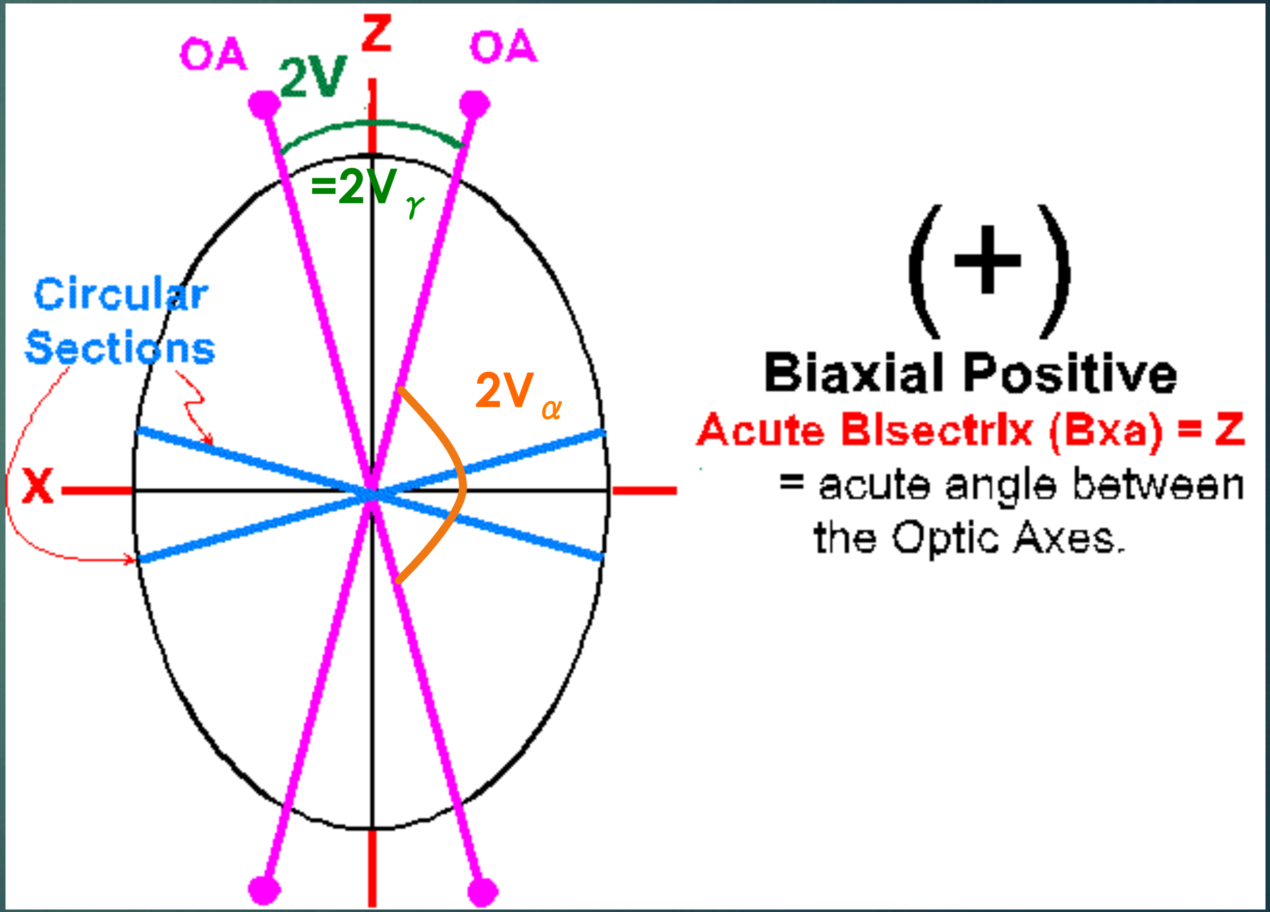


# OPTIC SIGN OF BIAXIAL MINERALS

- The optic sign of biaxial minerals depends on whether the $\beta$ refractive index is closer to that of $\alpha$ or to $\gamma$.

# OPTIC SIGN OF BIAXIAL MINERALS

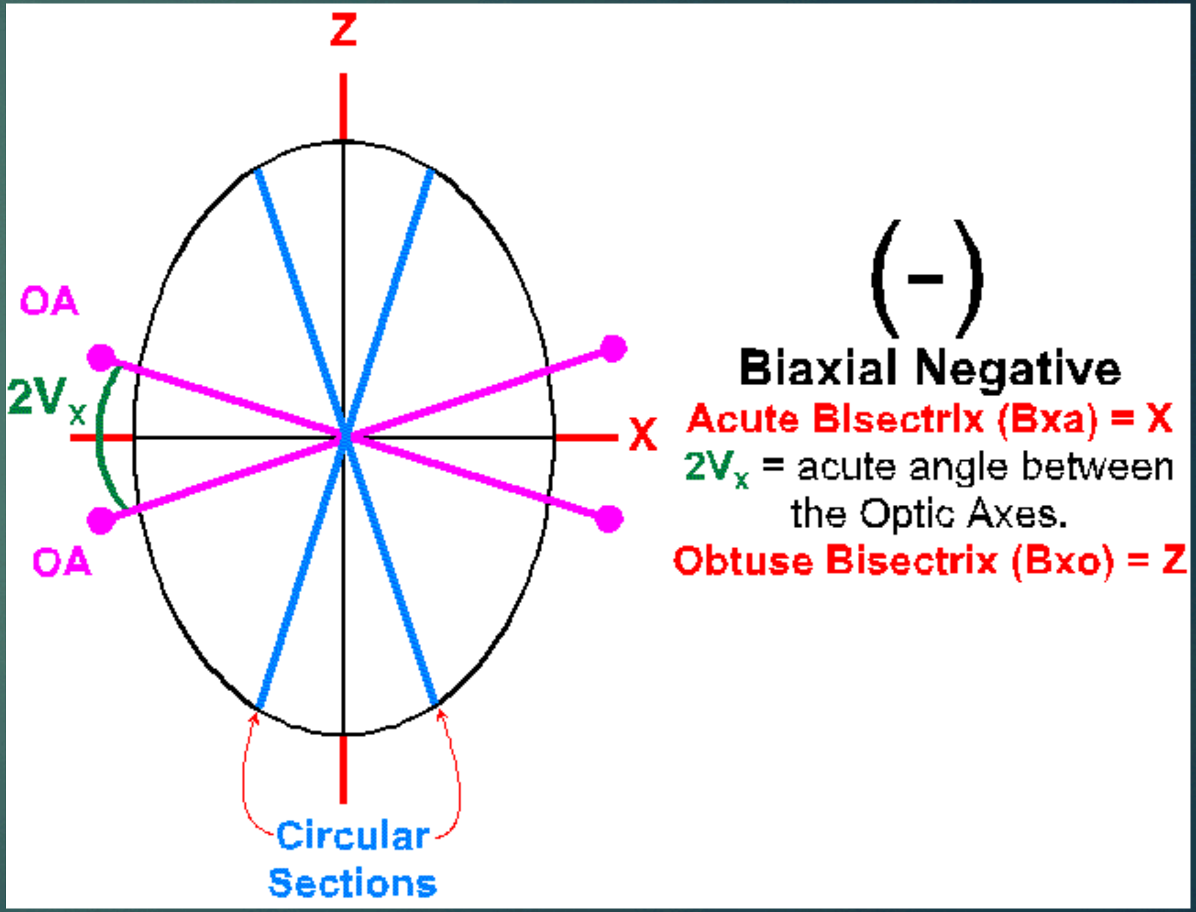
- **Biaxial positive**
- $\beta$ closer to $\alpha$ than $\gamma$ ( $\alpha < \beta << \gamma$ )
- $\gamma$ is the acute bisectrix (BXA) ( ⇔ 2V bisected by the $\gamma$ refractive index direction)
- Ex.: clinopyroxene




*Credits: Greg Finn, Brock University*

# OPTIC SIGN OF BIAXIAL MINERALS

- **Biaxial negative**
- $\beta$ closer to $\gamma$ than $\alpha$ ( $\alpha << \beta < \gamma$ )
- $\gamma$ is the acute bisectrix (BXA) ( ⇔ 2V bisected by the $\gamma$ refractive index direction)
- Ex.: - Sanidine, Orthoclase, Microcline
  - Muscovite, Biotite

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# OPTIC SIGN OF BIAXIAL MINERALS

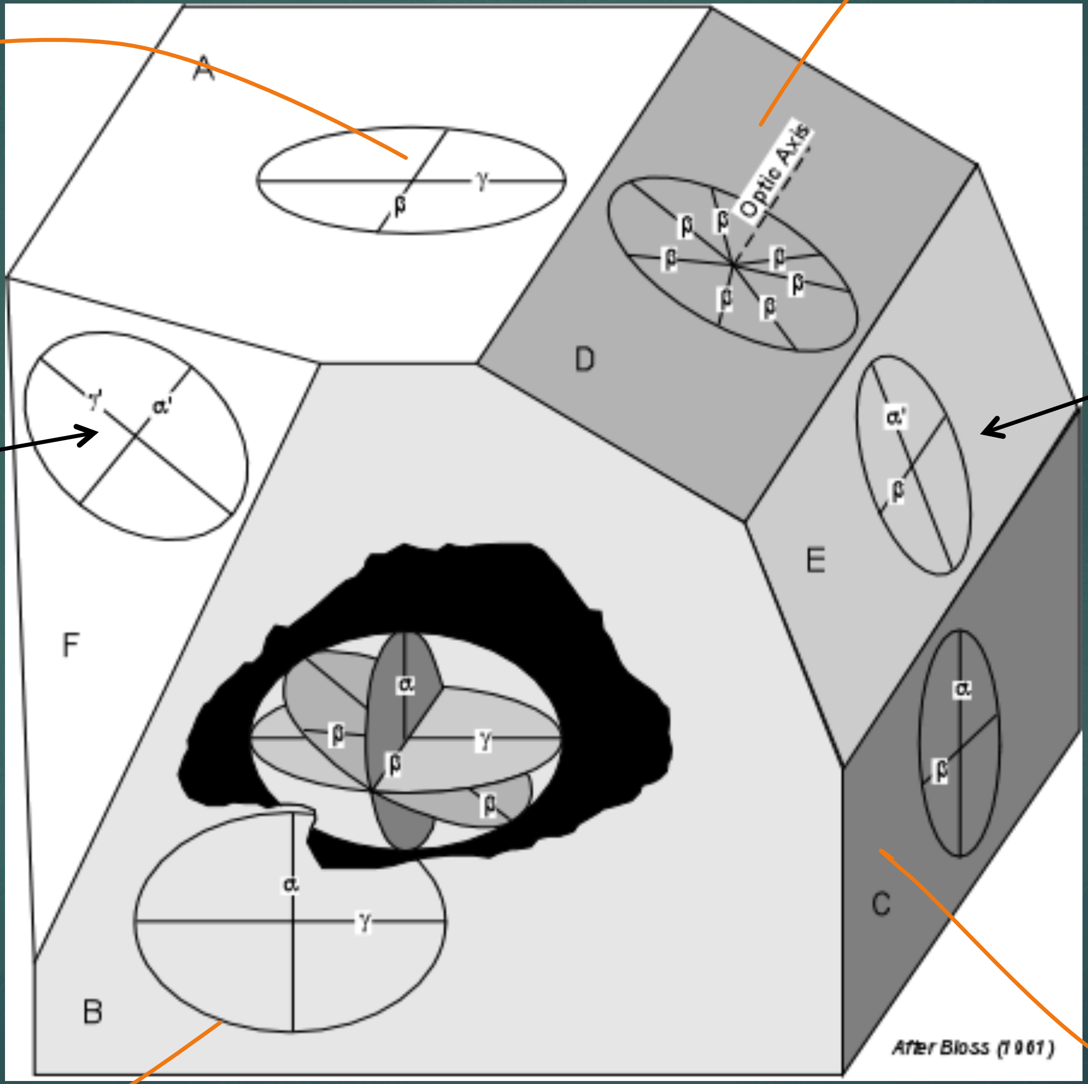
- $2V\alpha + 2V\beta = 180°$
- If 2V = 90° the mineral has no optic sign.
- If 2V = 0° the mineral is uniaxial.

# OPTICAL ORIENTATIONS

Extinct when $\beta$ or $\gamma$ oriented E-W
Birefringence colors: $(\gamma - \beta)$

Random vibration direction:
Relief between $\beta < \gamma'$

Extinct when $\alpha$ or $\gamma$ oriented E-W
Optic planes parallel to the stage
**Maximum birefringence colors: $(\gamma - \alpha)$**




Extinct
No change of relied = $\beta$
(Optic axis perpendicular to the stage)

Random vibration direction:
Relief between $\alpha' < \beta$

Extinct when $\alpha$ or $\beta$ oriented E-W
Birefringence colors: $(\beta - \alpha)$

# BIAXIAL INTERFERENCE FIGURES

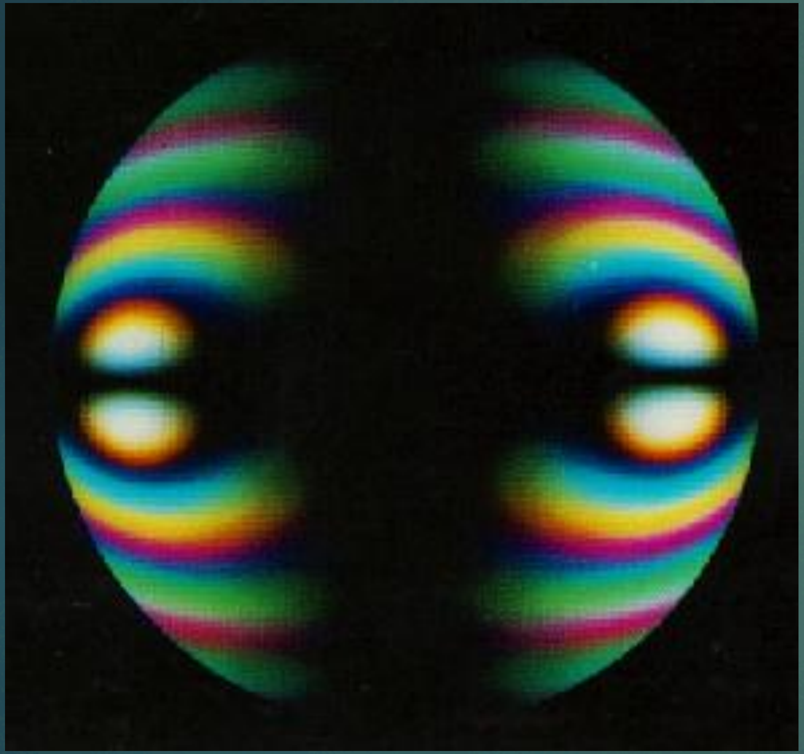
- **To obtain an interference figure**
  - 1- focus with the high-power objective on a grain with no fractures or inclusions
  - 2- Insert the condensor  - conoscope
  - 3- Switch in the analyser
  - 4- Switch in the Bertrand lens

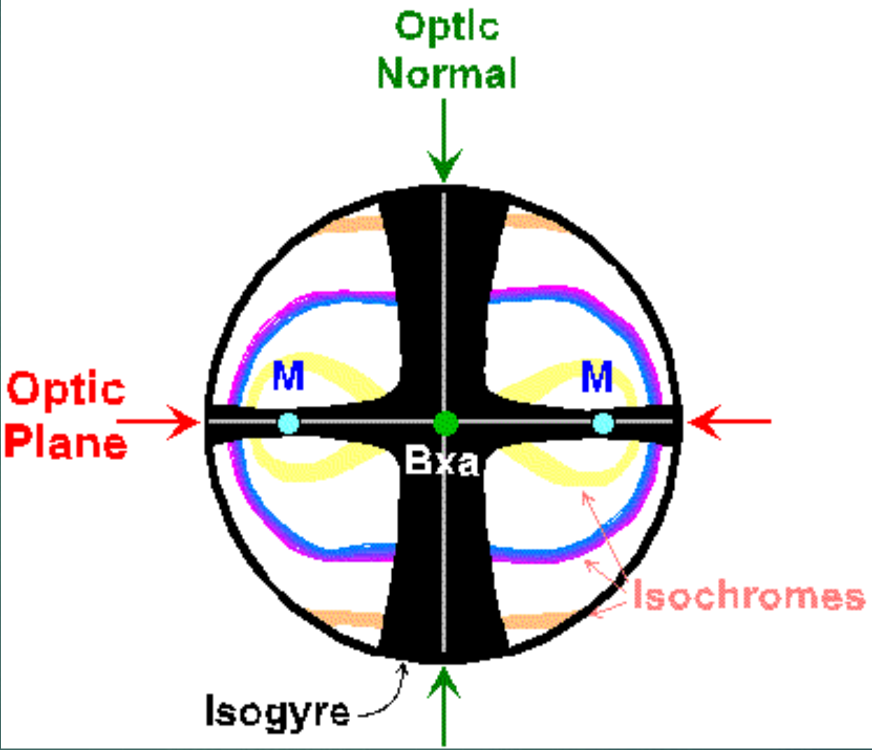
# BIAXIAL INTERFERENCE FIGURES

- **5 interference figures:**
- Centered Acute Bisectrix
- Centered Biaxial Optic Axis
- Centered Obtuse Bisectrix
- Centered Optic Normal or Biaxial Flash Figure
- Random Orientations: off-centered

# BIAXIAL INTERFERENCE FIGURES

- **Acute Bisectrix Figure ($BX_A$) :**



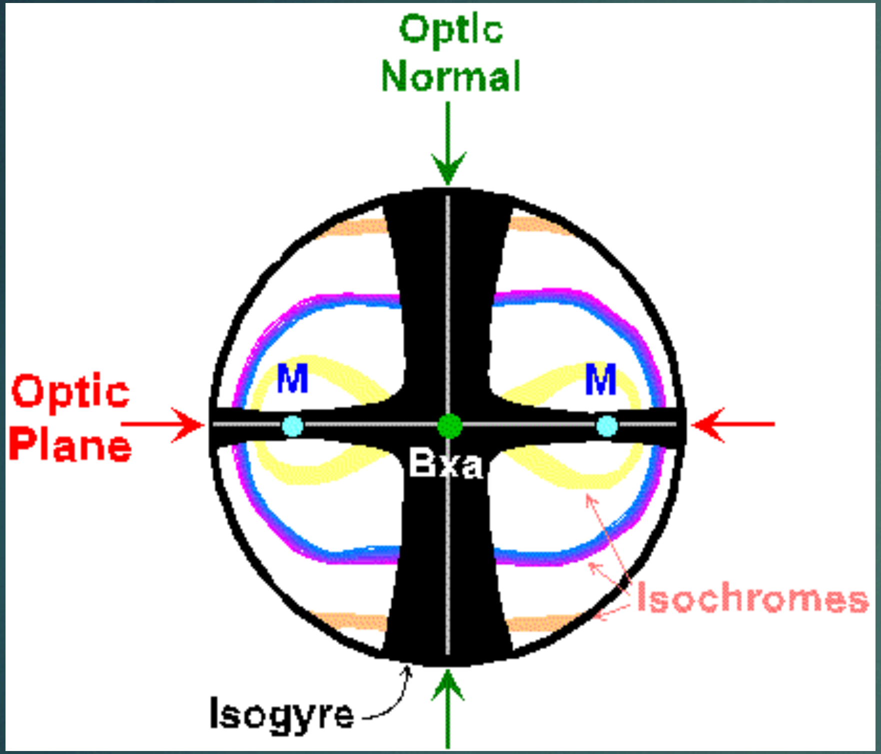


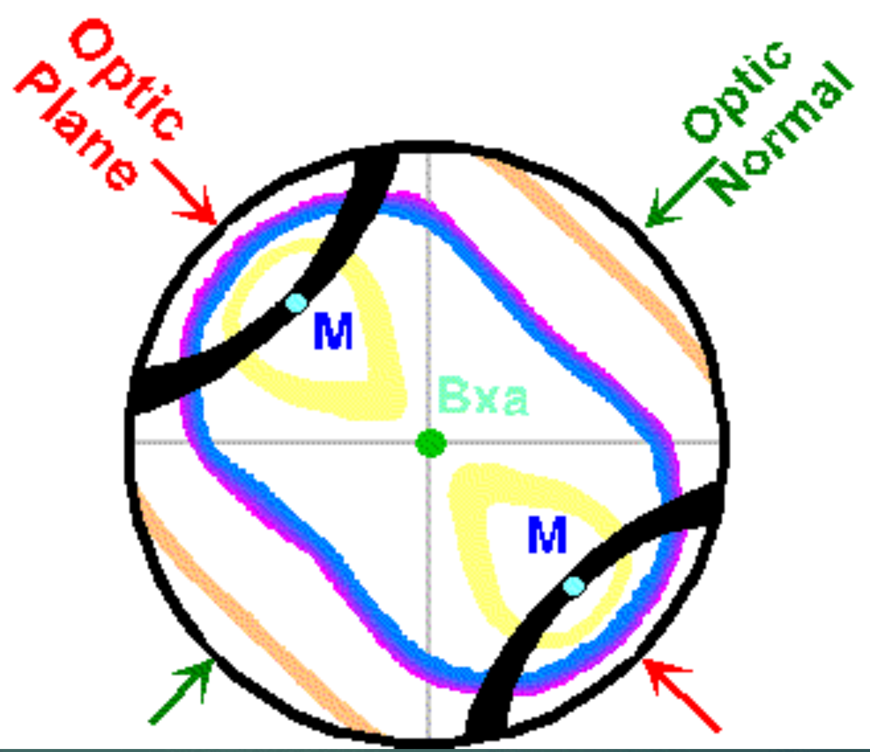

Cross polarized light: the mineral is extinct.

*Credits: Greg Finn, Brock University*

# BIAXIAL INTERFERENCE FIGURES

- **Acute Bisectrix Figure ($BX_A$) :**

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# BIAXIAL INTERFERENCE FIGURES

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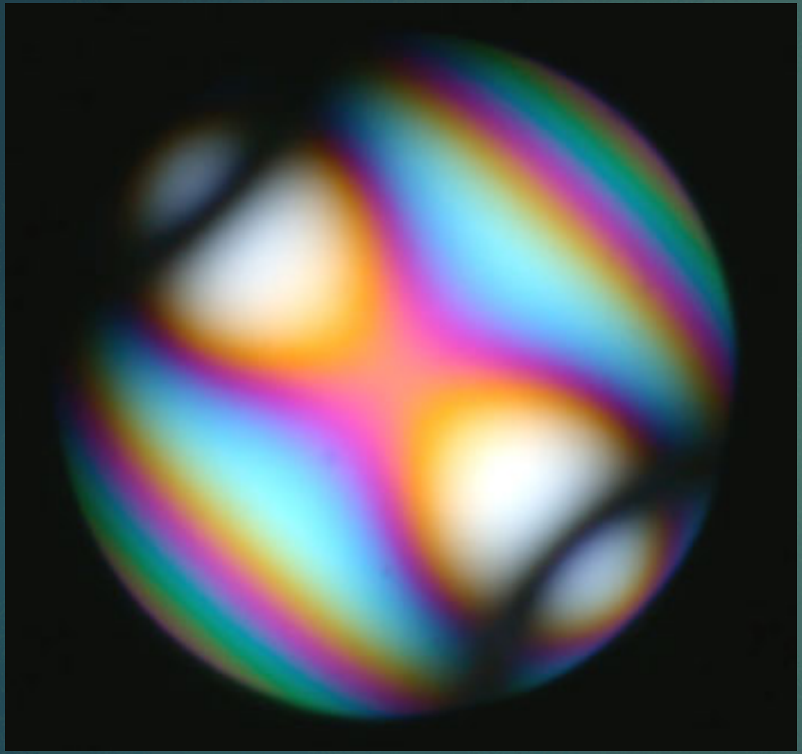
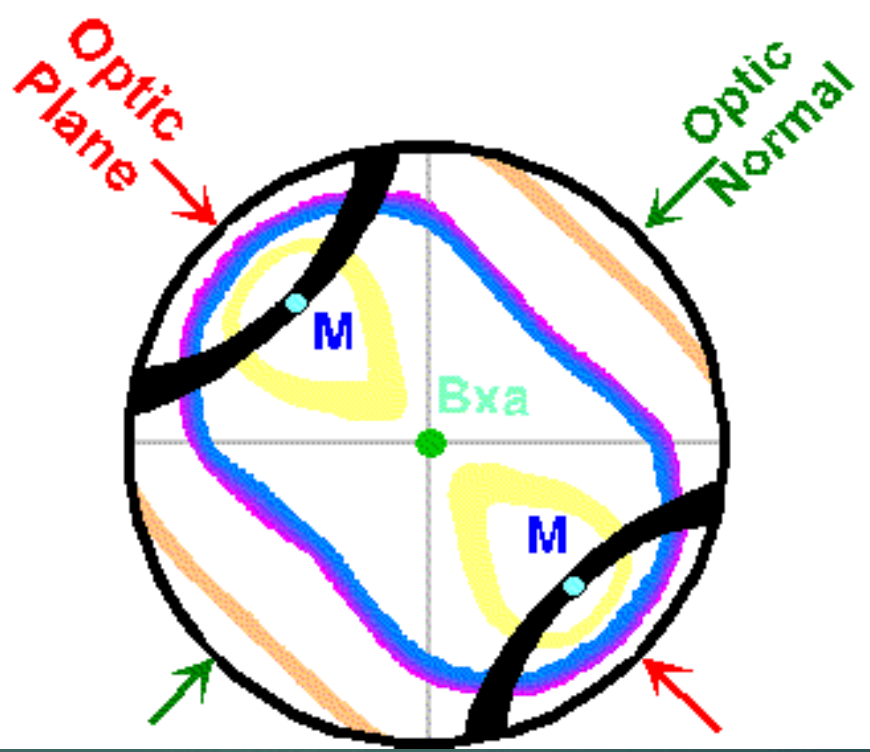


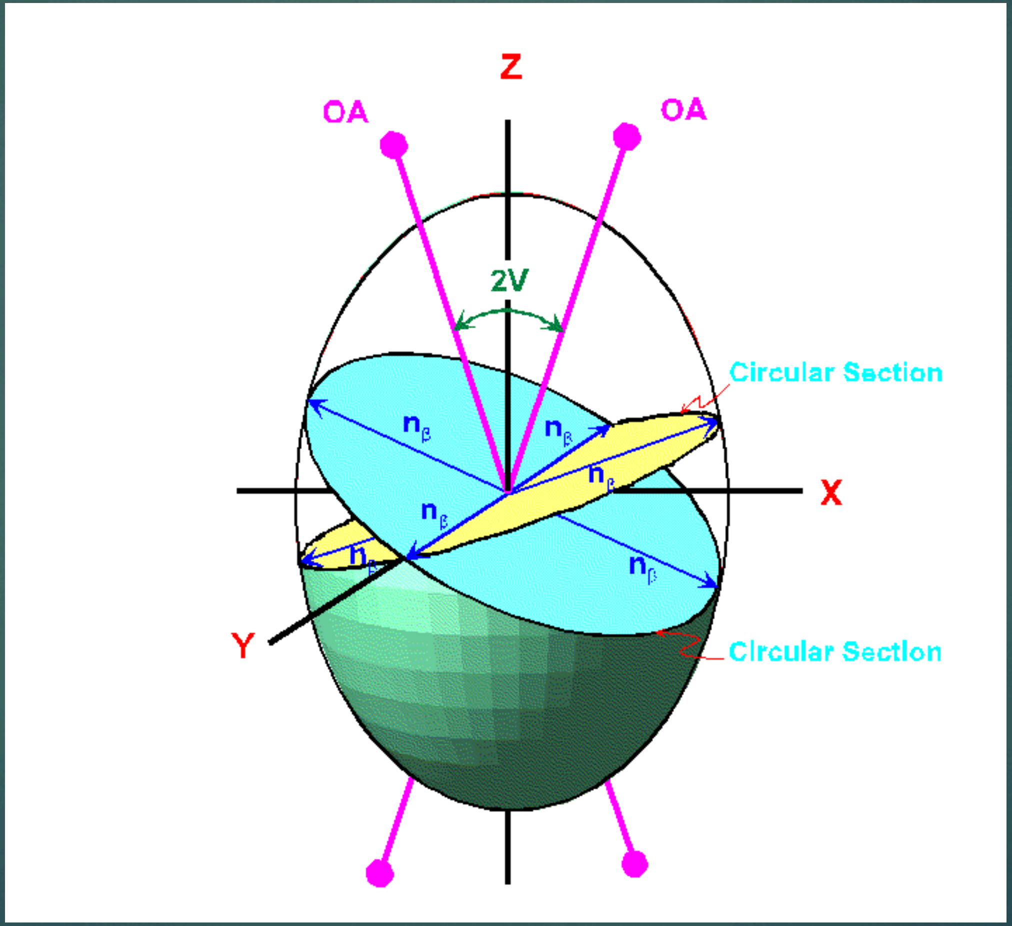



Cross polarized light: the mineral is extinct.

*Credits: Greg Finn, Brock University*

# BIAXIAL INTERFERENCE FIGURES

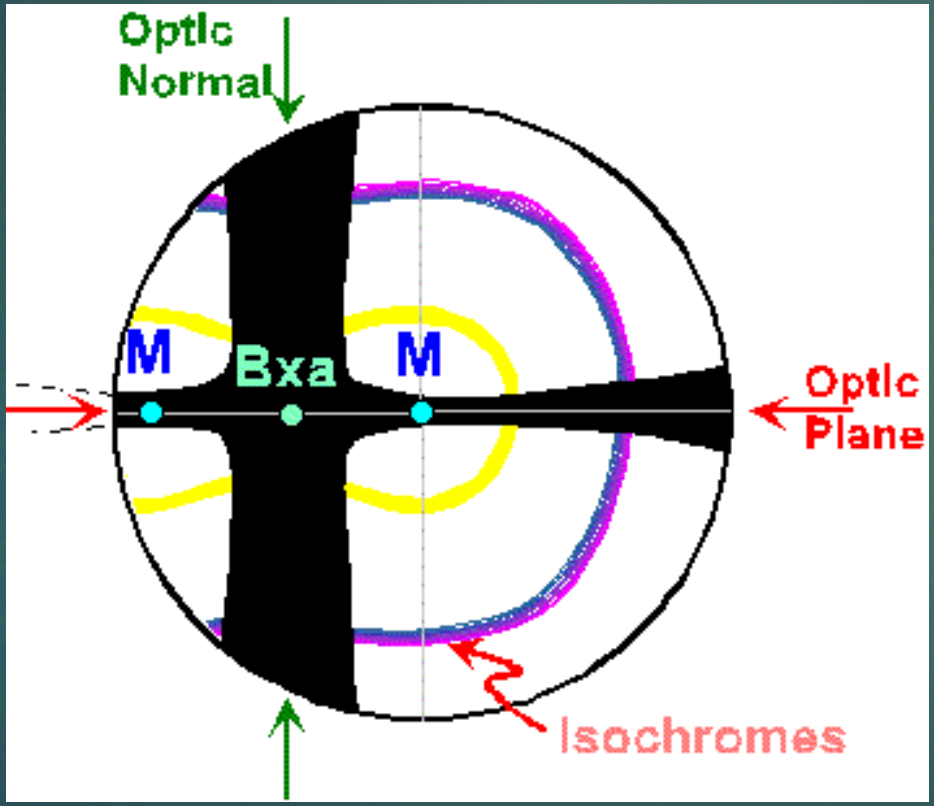
- **Optic axis figures (OA):** optic axis perpendicular to the stage

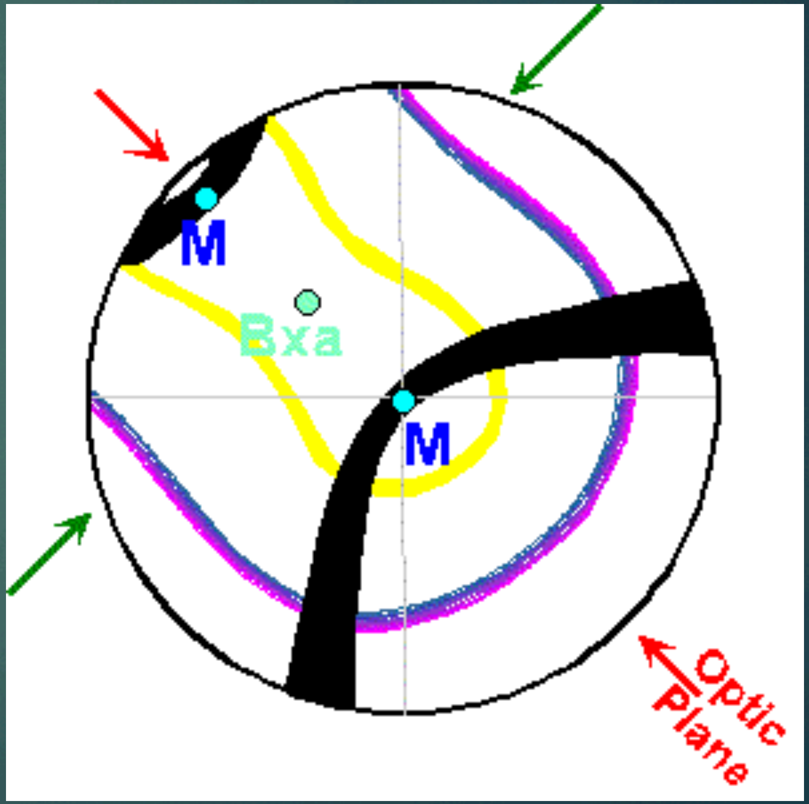



Cross polarized light:
extinct on 360°

# BIAXIAL INTERFERENCE FIGURES

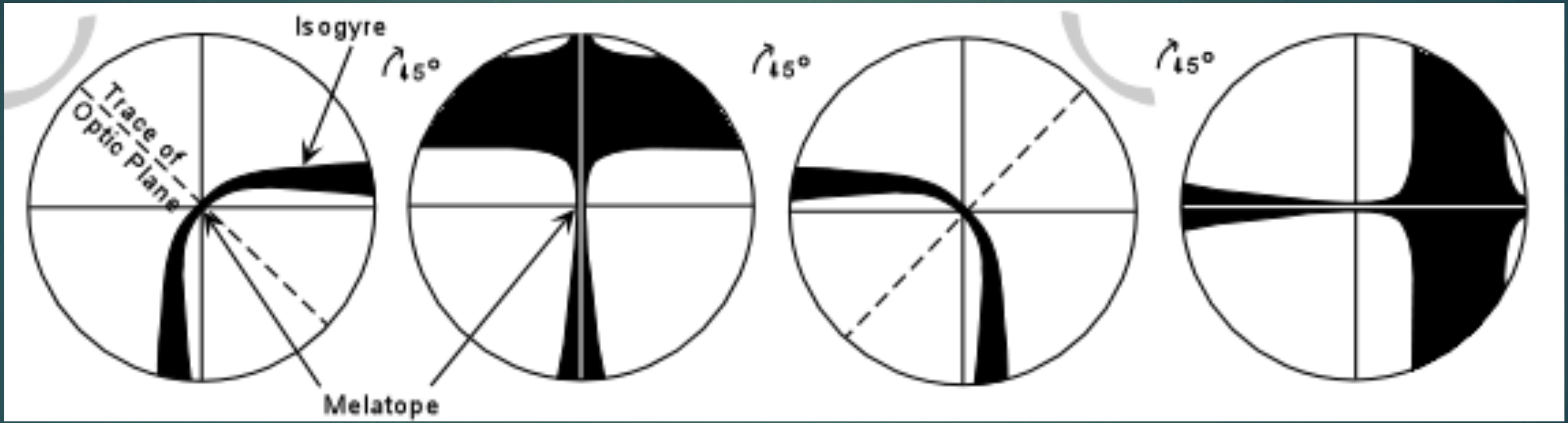
- **Optic axis figures (OA):**
- 2V<30°



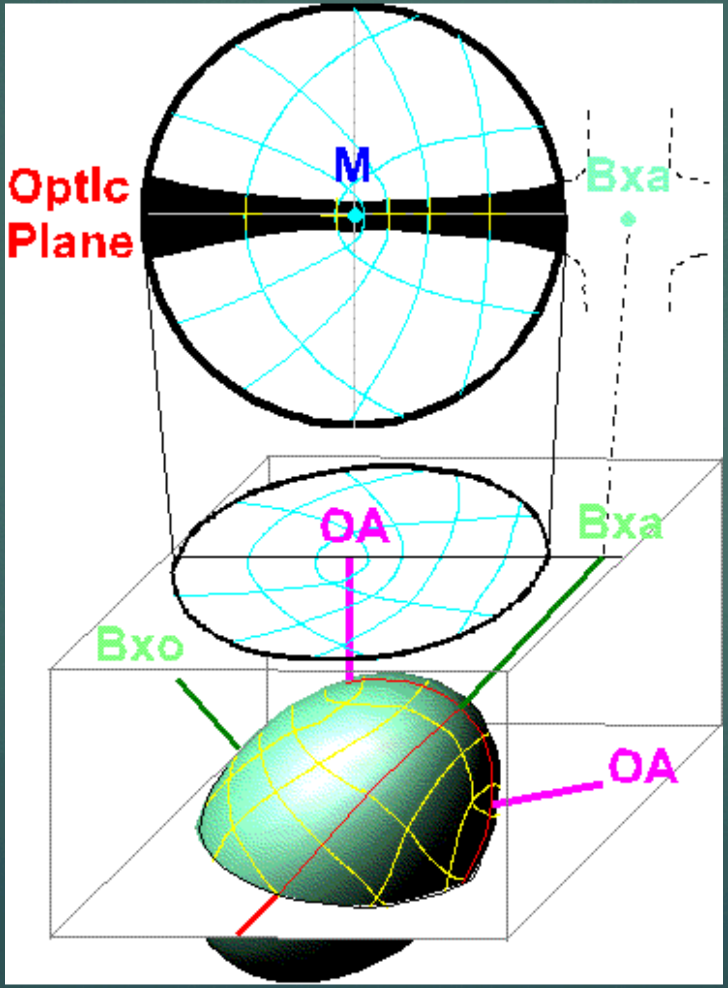
# BIAXIAL INTERFERENCE FIGURES

- **Optic axis figures (OA):**
- 30°<2V<50°



# BIAXIAL INTERFERENCE FIGURES

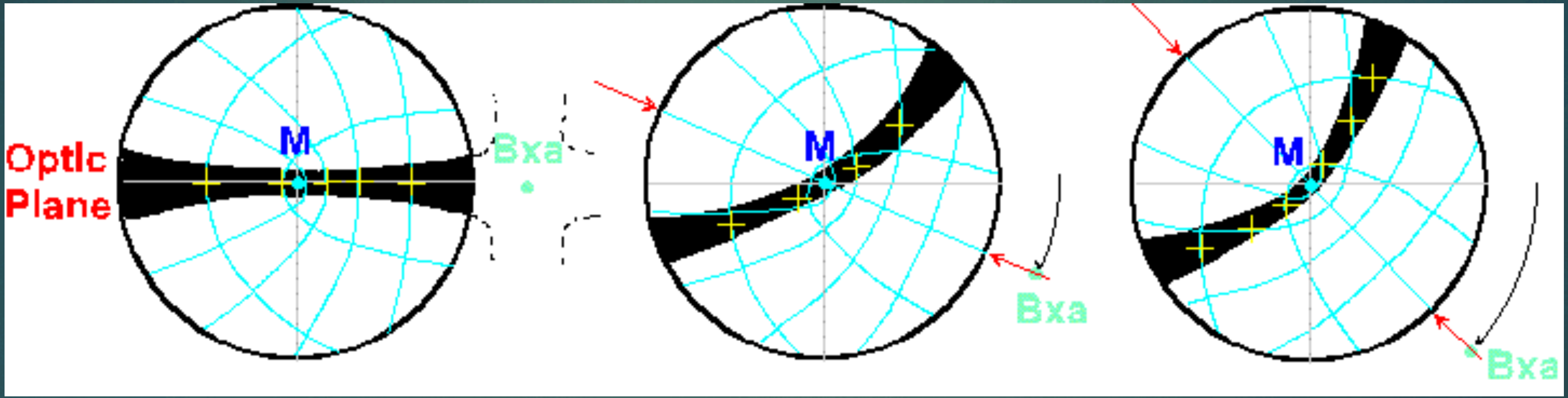
- **Optic axis figures (OA):**
- 2V>50°




Optic plane oriented E-W

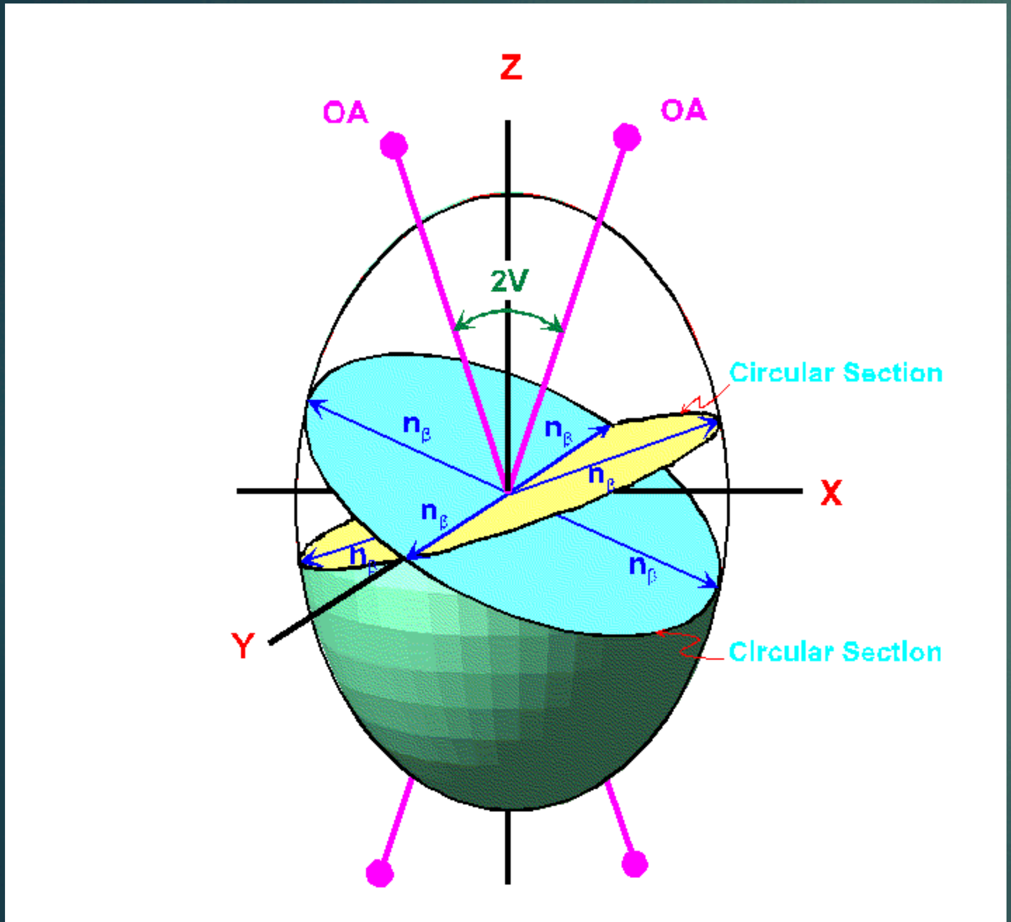
# BIAXIAL INTERFERENCE FIGURES

- **Optic axis figures (OA):**
- 2V>50°



# BIAXIAL INTERFERENCE FIGURES

- **Obtuse Bisectrix Figure ($BX_O$)**



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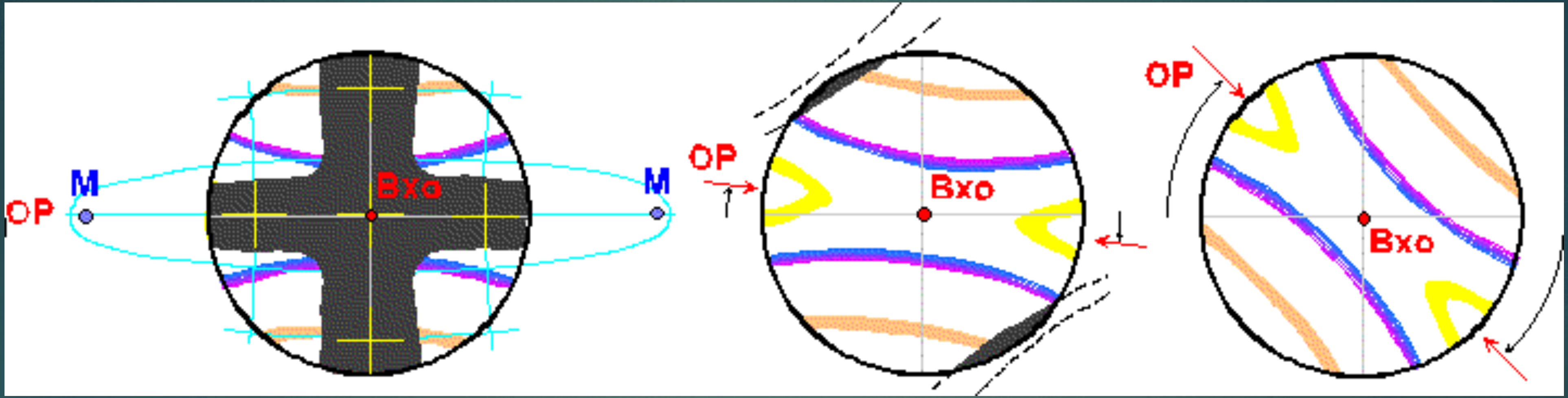
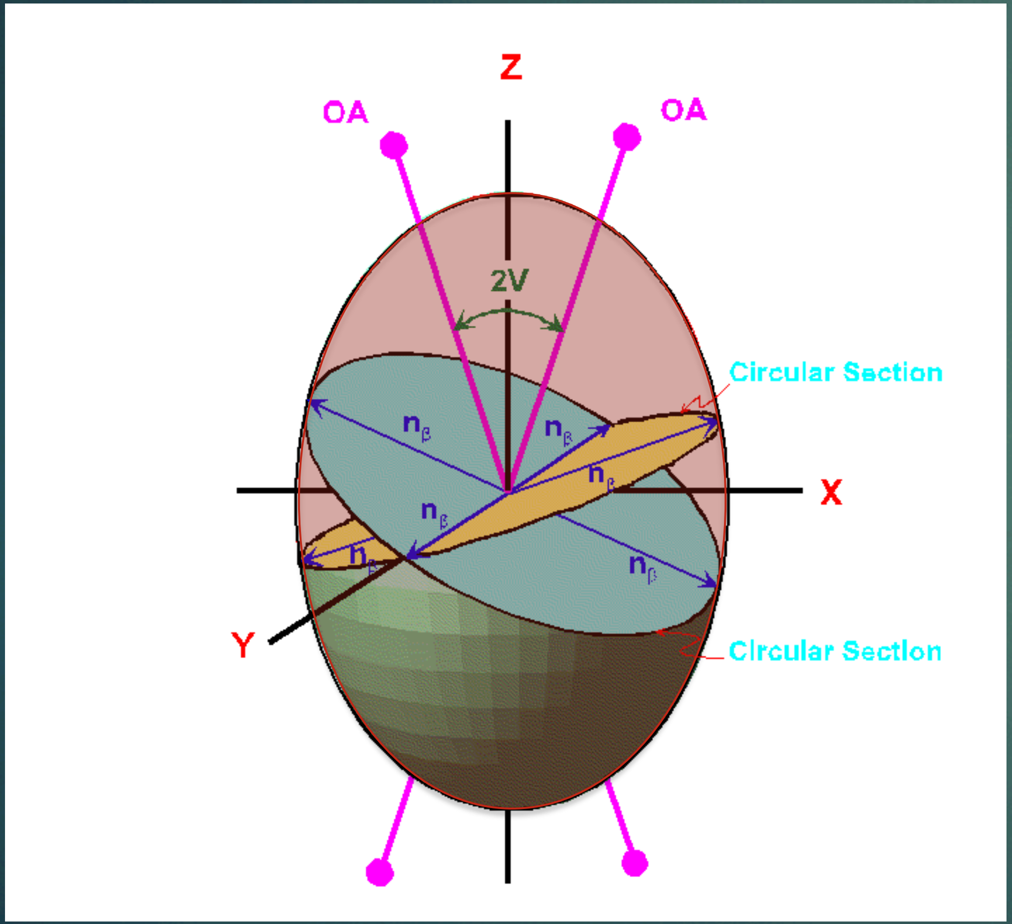
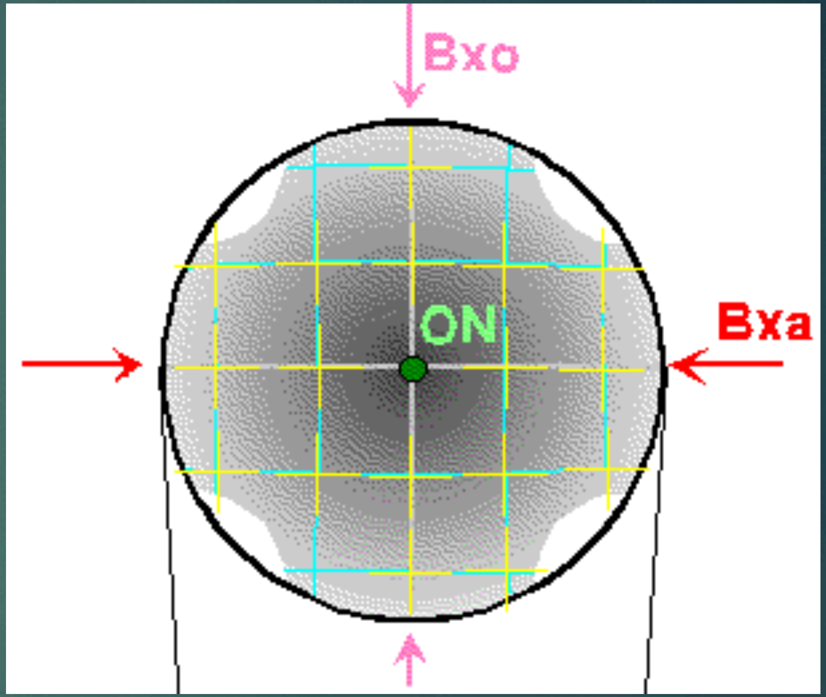



- If 2V = 90° the mineral has no optic sign: $BX_A = BX_O$ – the mineral is optically neutral
- If 2V ≤ 5° : $BX_O$ looks like an optic normal figure or flash figure

# BIAXIAL INTERFERENCE FIGURES

- **Optic normal (ON) = flash figure:** $\beta$ perpendicular to the stage



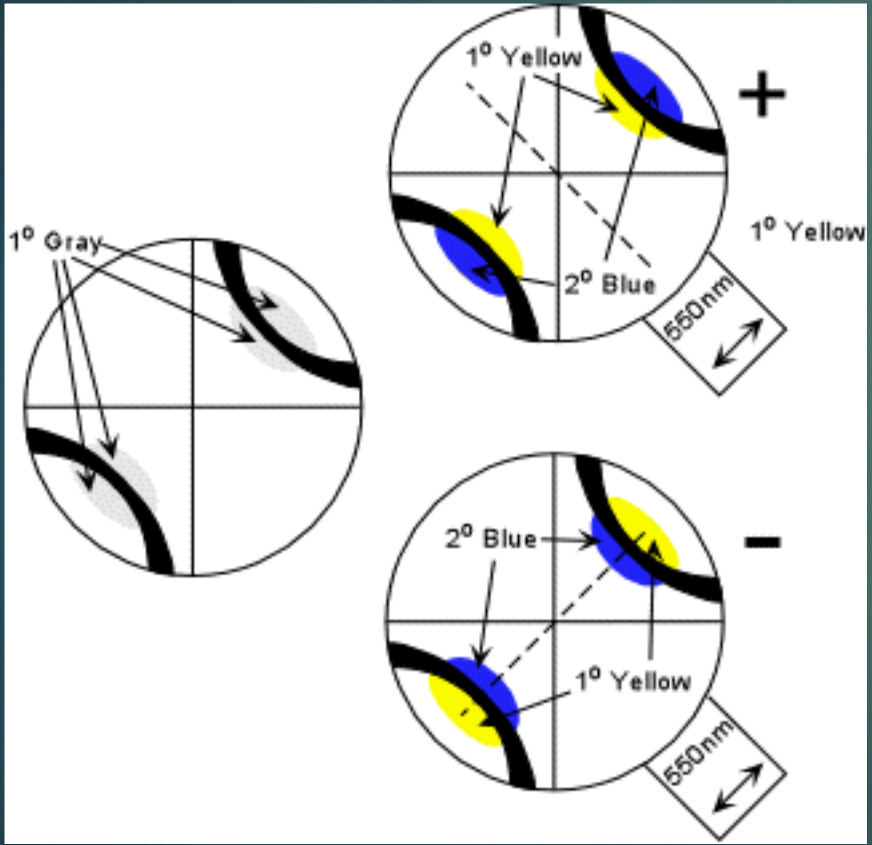

Maximal interference colors when this "cross" appears

# BIAXIAL INTERFERENCE FIGURES

- **Off-centered: bad news…**
  - Any combination of orientations is possible for off-centered figures.

# OPTIC SIGN

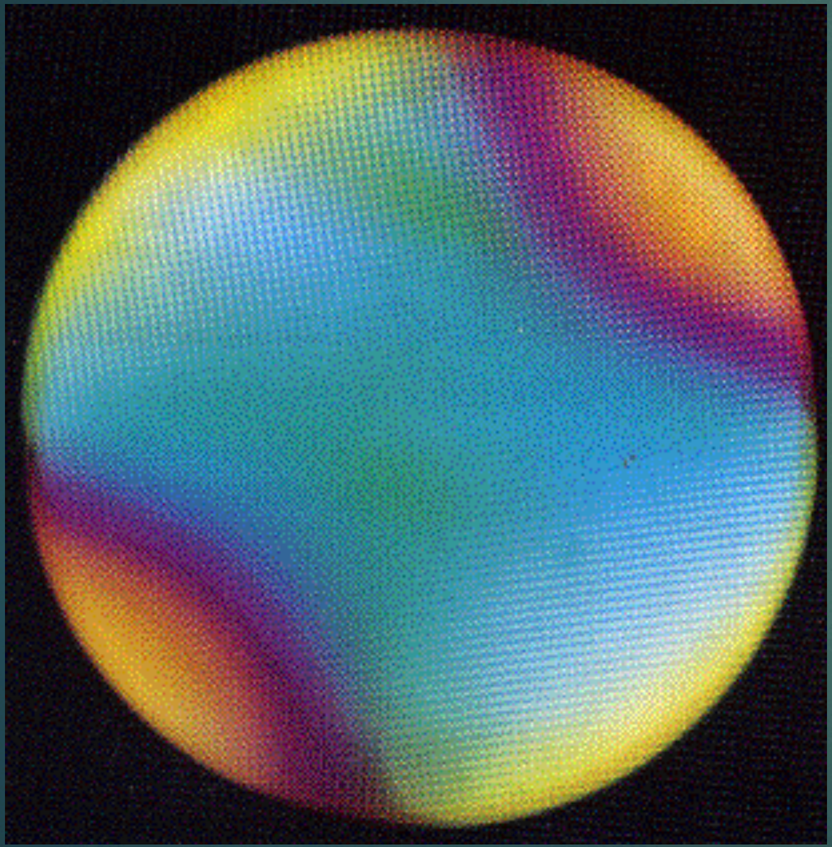
- **$BX_A$**




- One the Bertrand lens inserted, rotate the stage such as the melatopes are in the NE-SW quadrants
- Look close to the melatope sand identify the 1° gray area.
- Insert the gypsum plate:
  - if the 1° gray inside the isogyres turn yellow: negative
  - if the 1° gray inside the isogyres turn blue: positive

# OPTIC SIGN

- **$BX_A$**



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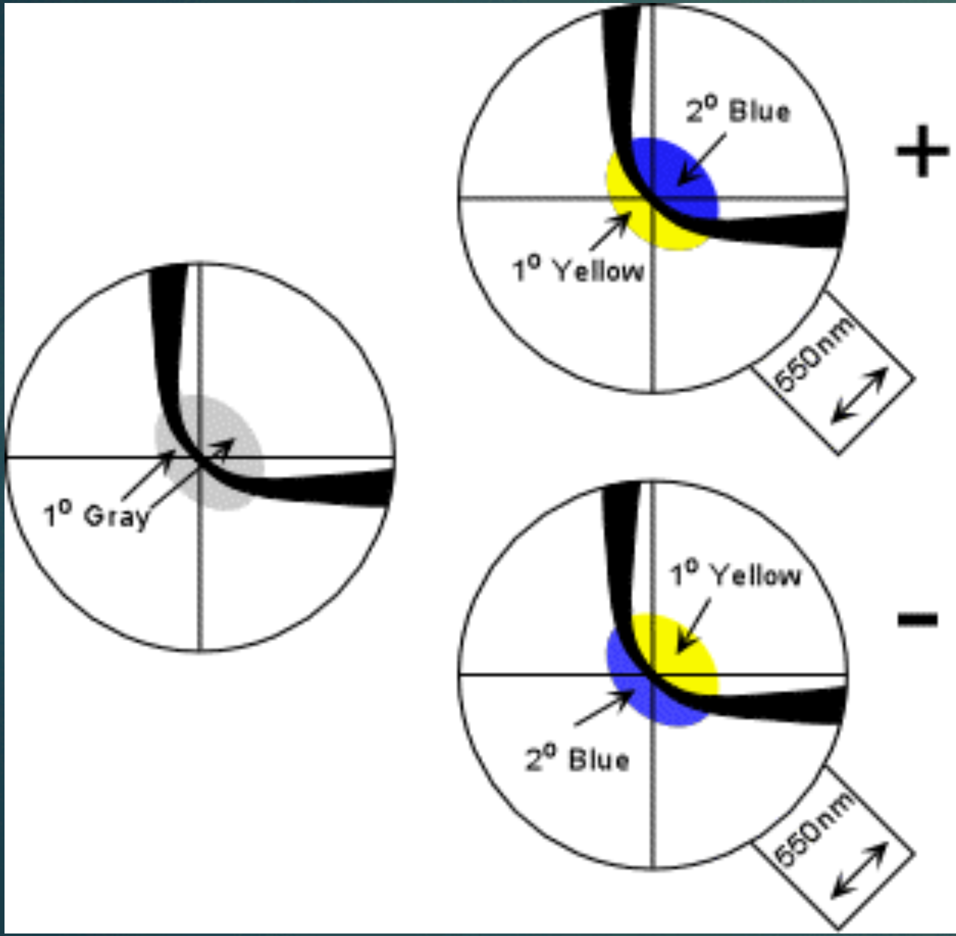
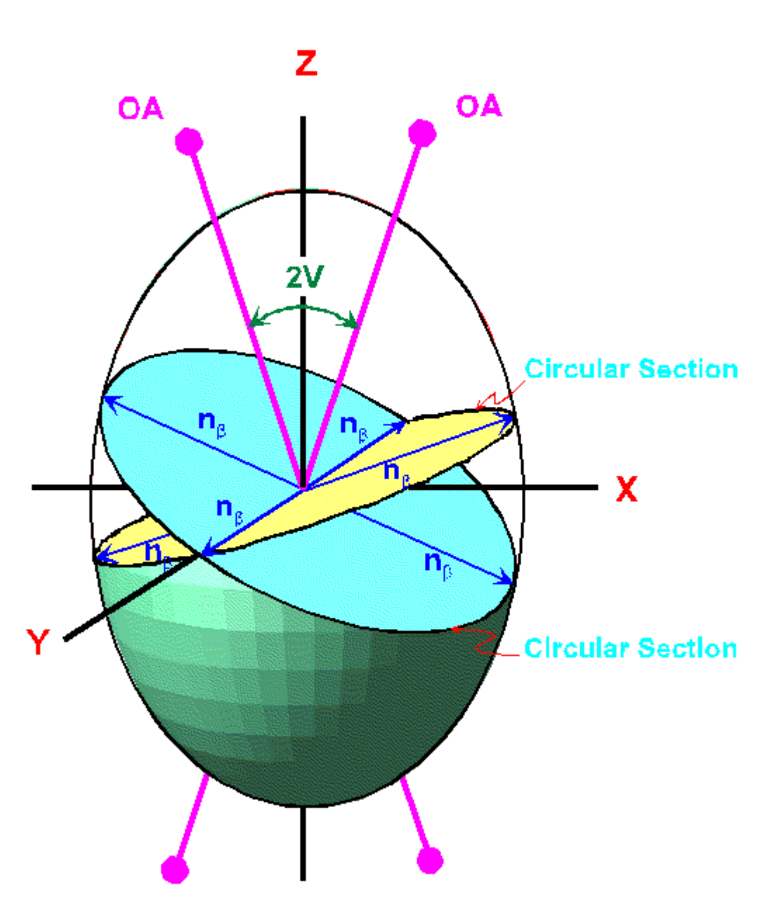
# OPTIC SIGN

- **OA**




- One the Bertrand lens inserted, rotate the stage such the inside of the isogyre is in the NW quadrant
- Look close to the melatope sand identify the 1° gray area.
- Insert the gypsum plate:
  - if the 1° gray inside the isogyres turn yellow: negative
  - if the 1° gray inside the isogyres turn blue: positive

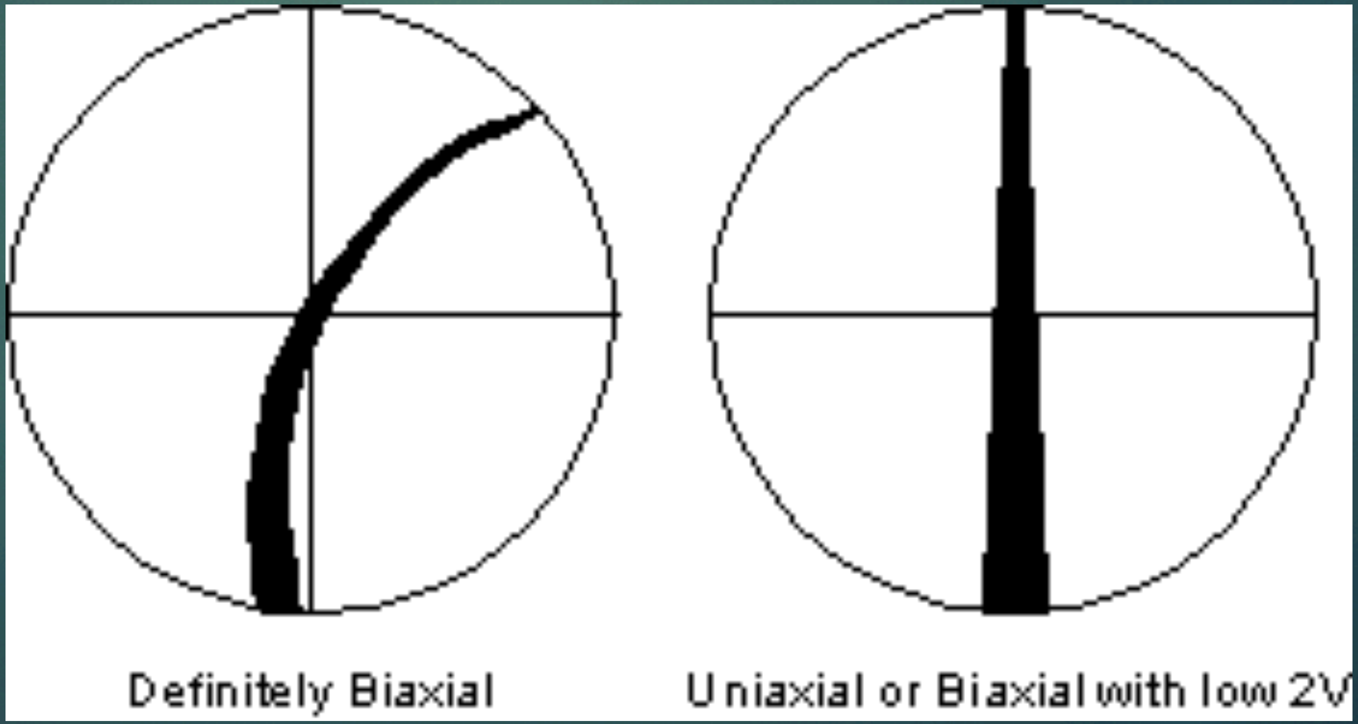
# IDENTIFY THE INTERFERENCE FIGURE




| Type of Interference Figure | Level of Interference colors |
|---|---|
| O.N. | Maximum |
| BXO | Relatively High |
| BXA | Relatively Low |
| O.A. | None |
| Off-centered O.A. | Very Low |

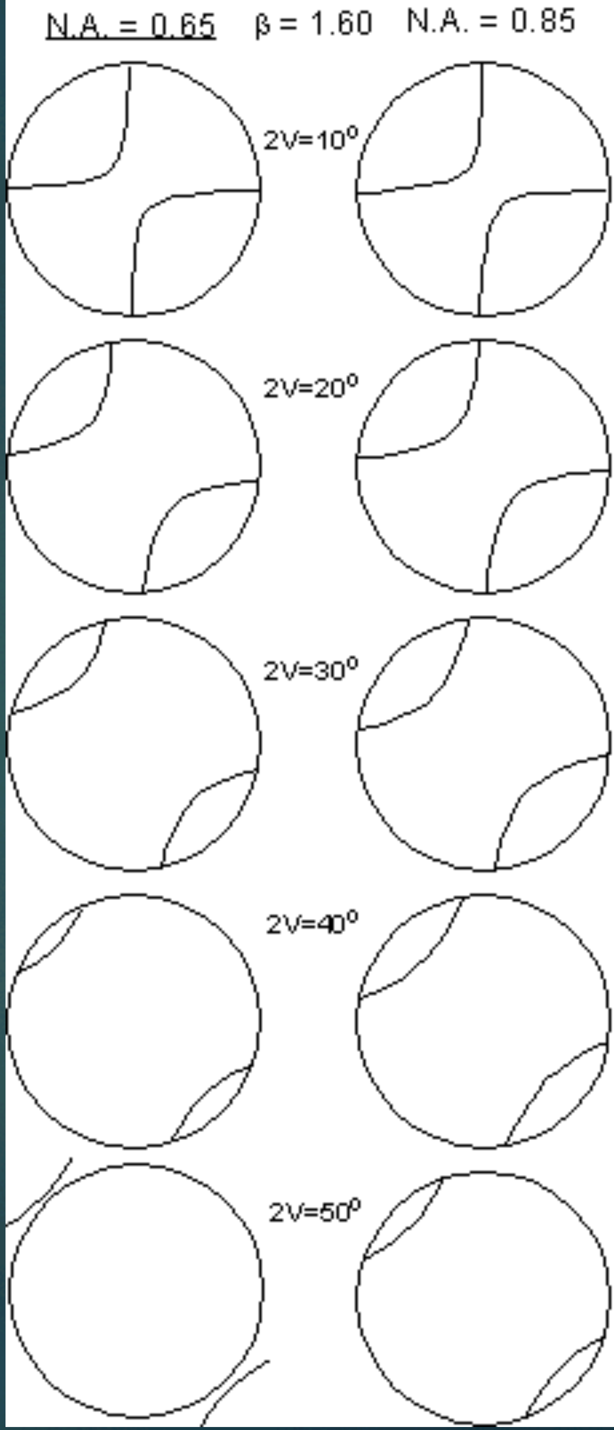
# BIAXIAL vs. UNIAXIAL

- Rotate the stage to place the isogyre at the intersection of the cross hairs:
  - Curvature: biaxial
  - No curvature: uniaxial or biaxial with small 2V



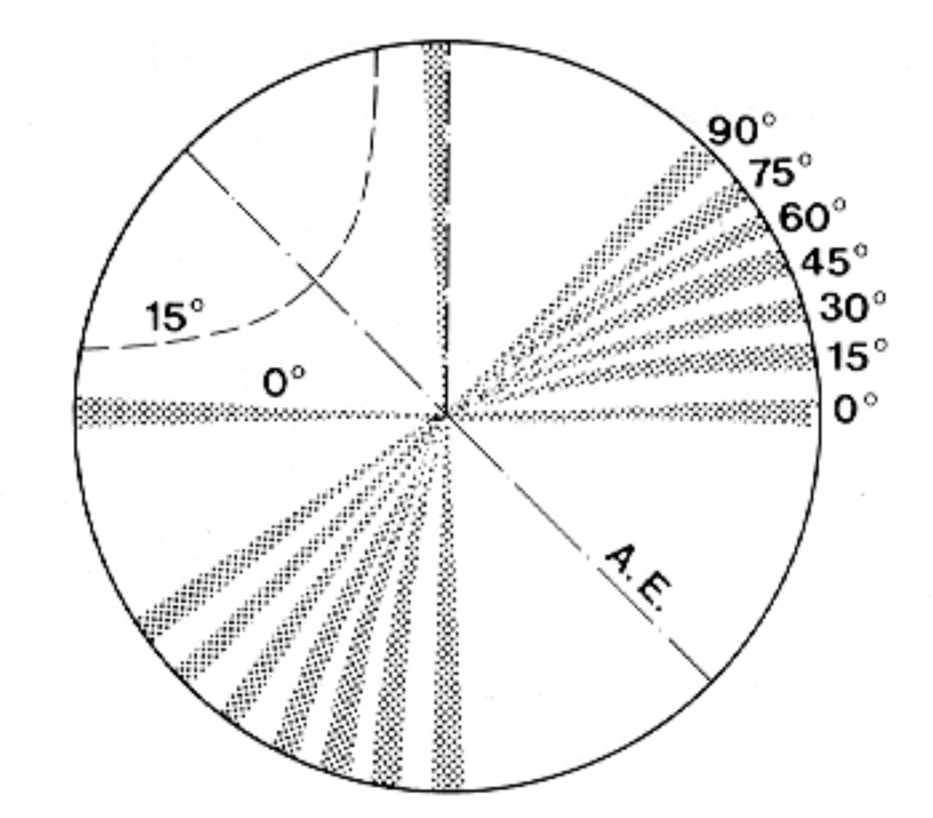
# DETERMINATION OF 2V

- **BXA**
  - Using the distance between the isogyres



# DETERMINATION OF 2V

- **OA**
  - Using the curvature
  - Highest curvature for smallest 2V
  - 2V = 0 ⇔ uniaxial mineral ⇒ cross
  - 2V = 90° ⇒ straight line

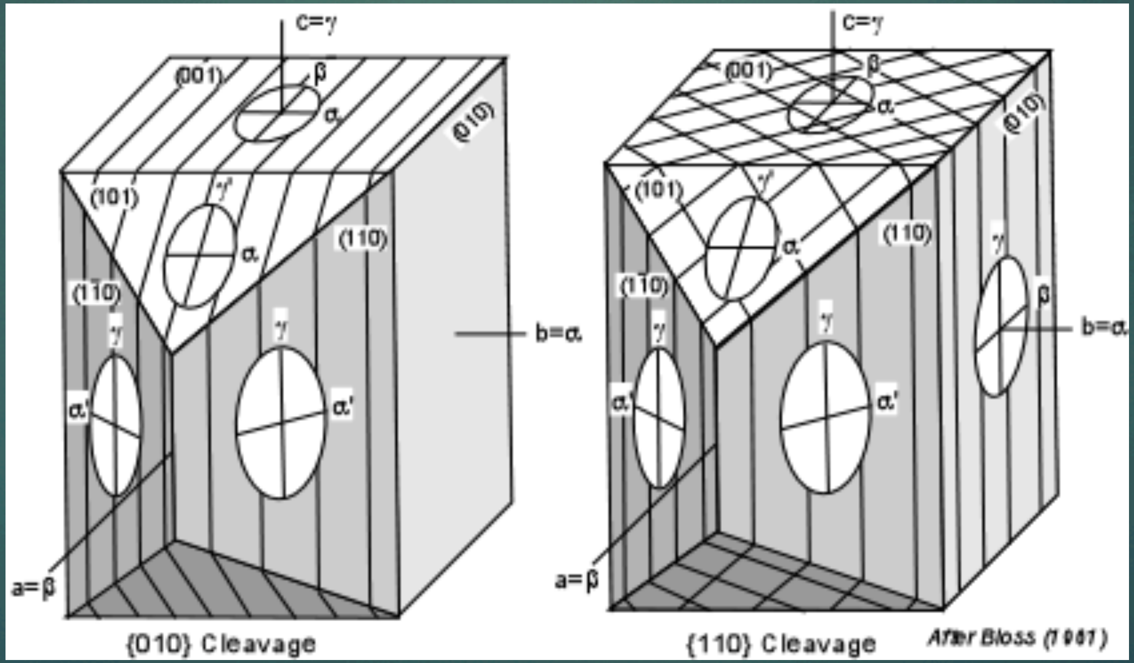


# EXTINCTION ANGLE

- **Uniaxial minerals:** parallel or symmetrical
- **Biaxial minerals:** parallel, symmetrical or inclined

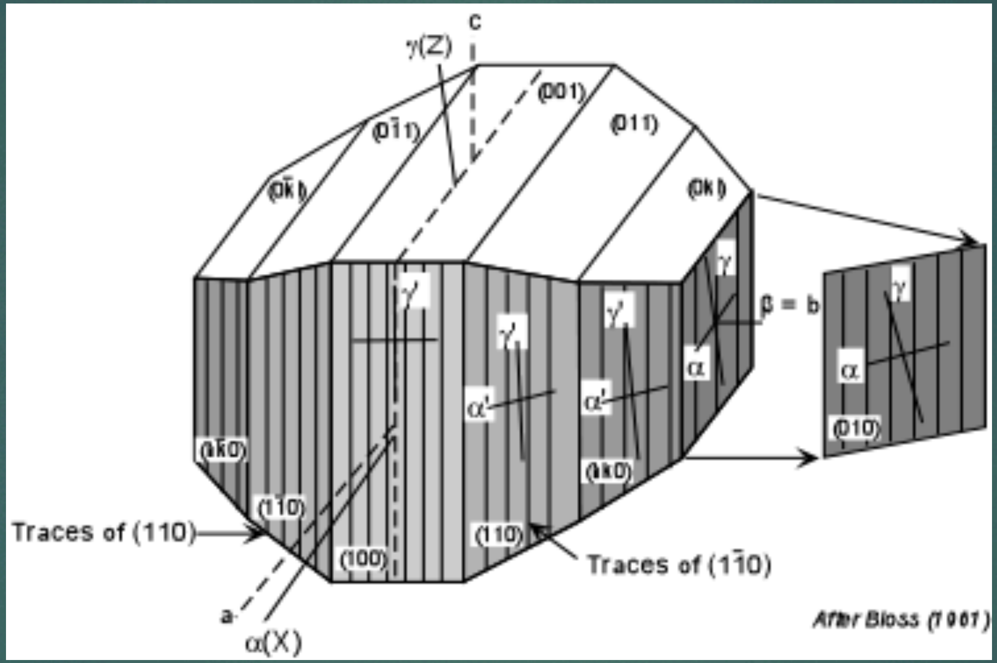
# EXTINCTION ANGLE

- **orthorhombic:** Optical directions ⇔ crystallographic axes ⇒ cleavages parallel to a crystallographic axis will show extinction parallel to (or at 90° to) such a cleavage.



# EXTINCTION ANGLE

- **monoclinic:** only one section with parallel extinction




- **triclinic:** inclined extinction on most sections