Biaxial Optics

Covered in Chapter 7 of Nesse

Biaxial Minerals

- In Nesse, the listing of minerals is broken down as follows:
  - Isotropic 24 5
  - Uniaxial 41 6
  - Biaxial 133 ~10
- Biaxial minerals include those in the _____, _____ and _____ systems

Biaxial Minerals

- All biaxial minerals exhibit:
  - variable _____, reflecting,
  - variable _____, resulting
  - in variable _____
- These physical and chemical characteristics result in the variable optical properties - **what we observe with the microscope**

Biaxial Minerals

- Crystallographic properties of orthorhombic, monoclinic and triclinic minerals are specified with reference to the unit cell, which is measured along three crystallographic axes, **a**, **b** and **c**
- Also necessary to specify three different indices of refraction for biaxial minerals
  - n_α, n_β, n_γ, where $n_\alpha < n_\beta < n_\gamma$
- Maximum birefringence therefore is defined as: $n_\gamma - n_\alpha$

CLARIFICATION!

- It takes 3 indices of refraction to describe the optical properties of biaxial minerals, **however** light entering a biaxial mineral is split into two rays
- The two rays behave as the extraordinary ray did in uniaxial minerals, i.e. both rays are extraordinary and are referred to as the slow and fast rays
- Ordinary and extraordinary terminology is not used when discussing Biaxial Minerals

CLARIFICATION!

- _____ (Higher RI)
  - Since $n_\alpha < n_\beta < n_\gamma$
  - $n_{slow} = n_\gamma'$, and must be between n_β and n_γ
    - $n_\gamma \geq n_\gamma' \geq n_\beta$
- _____ (Lower RI)
  - Since $n_\alpha < n_\beta < n_\gamma$
  - $n_{fast} = n_\alpha'$, and must be between n_α and n_β
    - $n_\alpha \leq n_\alpha' \leq n_\beta$

Biaxial Indicatrix

- Similar to the uniaxial indicatrix, except now dealing with ____ principal indices of refraction, instead of two
- Indicatrix is constructed by plotting the principal indices along 3 mutually perpendicular axes
  - n_α plotted along the **X** axis
  - n_β plotted along the **Y** axis
  - n_γ plotted along the **Z** axis

Biaxial Indicatrix

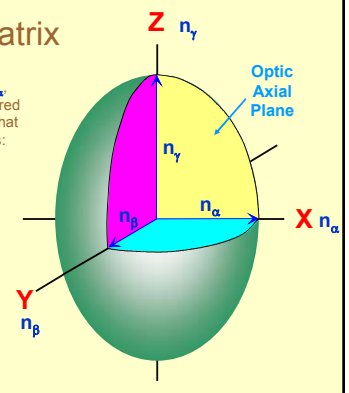
Biaxial minerals have 3 RIs (n_α, n_β, n_γ) each of which is measured along an indicatrix axis, such that the following relationship holds:

$n_\alpha < n_\beta < n_\gamma$

XZ plane with axes n_α and n_γ (**Optic Axial Plane**)

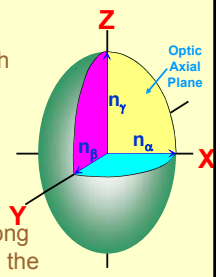
YZ plane with axes n_β and n_γ

XY plane with axes n_α and n_β



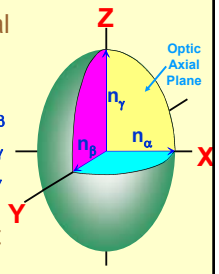
Biaxial Indicatrix

- Since $n_\alpha < n_\beta < n_\gamma$
- Then the indicatrix axes length must be:
  - **X** short axis
  - **Y** intermediate axis
  - **Z** long axis
- The resulting indicatrix is a _____ ellipsoid, _____ along the **Z** axis and _____ along the **X** axis



Biaxial Indicatrix

- Indicatrix has three principal sections, all of which are _____
  - **XY** plane radii = n_α and n_β
  - **XZ** plane radii = n_α and n_γ
  - **YZ** plane radii = n_β and n_γ
- Random sections through the indicatrix will also result in ellipses



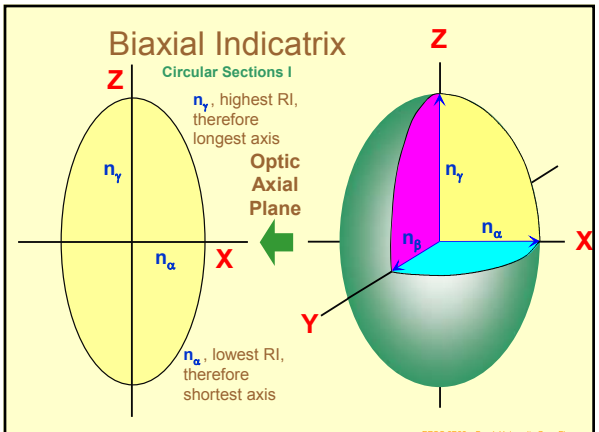
Biaxial Indicatrix

Circular Sections

- The uniaxial indicatrix exhibited a ____ circular section, with radius = n_ω, the biaxial indicatrix exhibits _____ circular sections with radius = n_β
- These sections must intersect along the **Y** axis, which by definition has a length = n_β

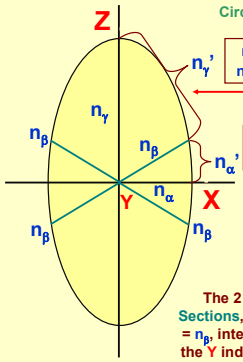
Biaxial Indicatrix

Circular Sections I



Biaxial Indicatrix

Circular Sections II



n_γ', where $n_\beta \leq n_\gamma' \leq n_\gamma$

n_α', where $n_\alpha \leq n_\alpha' \leq n_\beta$

The 2 Circular Sections, with radius = n_β, intersect along the Y indicatrix axis.

Optic Plane Section

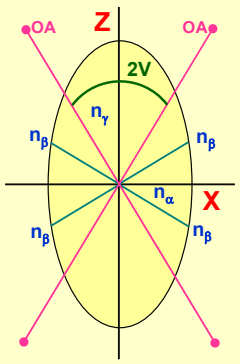
Radius along this edge of the ellipse varies from n_α to n_γ

Since $n_\alpha \leq n_\beta \leq n_\gamma$ the radius n_β must be present along this edge of the **XZ** plane (Optic Axial Plane)

There must be this same relationship ($n_\alpha < n_\beta < n_\gamma$) at three other points around the perimeter of this elliptical section.

Biaxial Indicatrix

Optic Axes



Optic Plane Section

The **Optic Axes** (**OA**) are perpendicular to the **Circular Sections** and lie within the **XZ** plane (**Optic Axial Plane**) of the indicatrix.

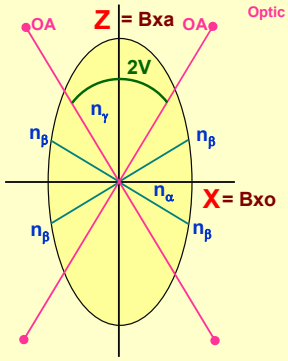
The **Optic Axial Plane** contains the 2 **OA**s and is at 90° to the **Y** indicatrix axis (Optic Normal)

The **OA**s are symmetrical about the **X** and **Z** indicatrix axes

The angle between the two **OA**s is the **Optic Angle** or **2V** angle

Biaxial Indicatrix

Optic Axes



Optic Plane Section

The acute angle between the **Optic Axes** is the Optic or **2V** angle

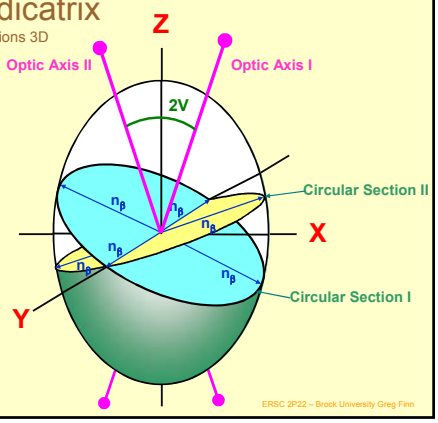
The Indicatrix Axis, either **X** or **Z**, that bisects the acute angle between the **Optic Axes** is the **Acute Bisectrix** or **Bxa**

The Indicatrix Axis, either **X** or **Z**, that bisects the obtuse angle between the Optic Axes is the **Obtuse Bisectrix** or **Bxo**

The **Y** indicatrix axis is perpendicular to the Optic Axial Plane and is the **Optic Normal**

Biaxial Indicatrix

Circular Sections 3D

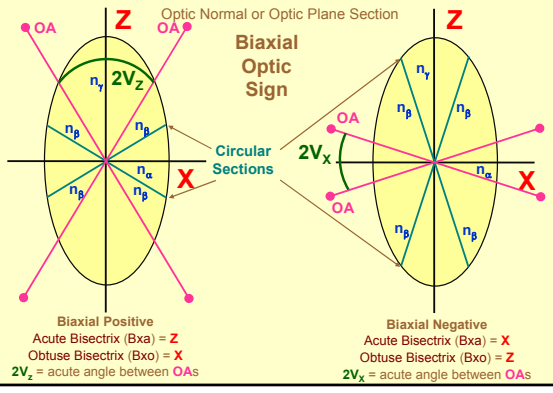


Biaxial Minerals

- Biaxial optic sign is dependant on whether the **X** or **Z** indicatrix axis is the _____ **(Bxa)**
  - If **Bxa** = **X**, mineral is optically _____
  - If **Bxa** = **Z**, mineral is optically _____
- In the special case where the 2V = ___ the mineral is optically _____

Biaxial Indicatrix

Optic Normal or Optic Plane Section



Biaxial Positive
Acute Bisectrix (Bxa) = **Z**
Obtuse Bisectrix (Bxo) = **X**
$2V_z$ = acute angle between **OA**s

Biaxial Negative
Acute Bisectrix (Bxa) = **X**
Obtuse Bisectrix (Bxo) = **Z**
$2V_x$ = acute angle between **OA**s

Biaxial Indicatrix

- Another convention used to identify the angle between the **OA**s bisected by:
  - the **X** axis as the $2V_X$ angle
  - the **Z** axis as the $2V_Z$ angle
- Angle can vary from 0 to 180°, where:

$$2V_X + 2V_Z = 180°$$

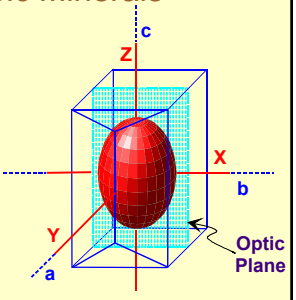
- If $2V_Z < 90°$, mineral is positive
- If $2V_Z > 90°$, mineral is negative

Crystallographic Orientation

- Examine the orientation of the indicatrix within the three crystal systems that comprise the biaxial minerals
  - **Orthorhombic**
  - **Monoclinic**
  - **Triclinic**

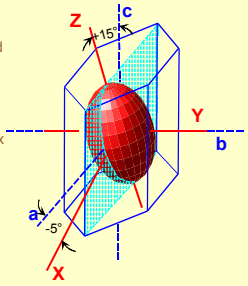
Orthorhombic Minerals

- 3 mutually perpendicular crystallographic axes of unequal length
- 3 mutually perpendicular symmetry planes which correspond to the Principal Sections of the Indicatrix
- Crystallographic axes must coincide with the Indicatrix Axes
  - Any indicatrix axis may correspond with any crystallographic axis
- Examples
  - Olivine, **X**=**a**, **Y**=**c**, **Z**=**b**
  - OPX, **X**=**b**, **Y**=**a**, **Z**=**c**



Monoclinic Minerals

- **b**-axis coincides with a single two-fold rotation axis and is perpendicular to a single mirror plane (010)
- **a** and **c** axes are perpendicular to **b** and intersect in an obtuse angle
- One indicatrix axis (**X**, **Y** or **Z**) coincides with the **b**-axis, the remaining two lie in the (010) mirror plane, but are not parallel to **a** or **c**, except by chance
- Angle between **a** and **c** and an indicatrix axis is:
  - +ve, if **X**, **Y** or **Z** lies in the obtuse angle
  - -ve, if **X**, **Y** or **Z** lies in the acute angle
- Examples
  - Cpx, **Y**=**b**, **Z**^**c**=+35 to +48°, **X**^**a**=-12 to -33°
  - Hbl, **Y**=**b**, **X**^**a**=+3 to -12°, **Z**^**c**=+12 to +34°



Triclinic Minerals

- 3 crystallographic axes, all with differing lengths, none of which are at 90° to each other
- No symmetry elements, other than centre
- Indicatrix axes are not parallel to the crystallographic axes, except by chance
- Examples
  - Microcline
  - Plagioclase