Chapter 7

Biaxial Optics

Biaxial mineral

- Include orthorhombic, monoclinic and triclinic crystal systems.
- 대칭률이 uniaxial mineral보다 낮음
- 모든 방향에 대해 다양한 결정 구조와 화학 결합을 갖는다
- 세 축의 길이가 모두 다름 = 3개의 서로 다른 굴절률을 갖음(α, β, γ) : 축간의 사이각과 혼란을 피하기 위해 n을 붙여 씀

Biaxial minerals

- n_a, n_b, n_c = n_α, n_β, n_γ = Nx, Ny, Nz = nX, nY, nZ = X, Y, Z = n_1, n_2, n_3 = n_p, n_m, n_g
- $n_\alpha < n_\beta < n_\gamma$
- The maximum birefringence of a mineral is always = $n_\gamma - n_\alpha$

Biaxial minerals

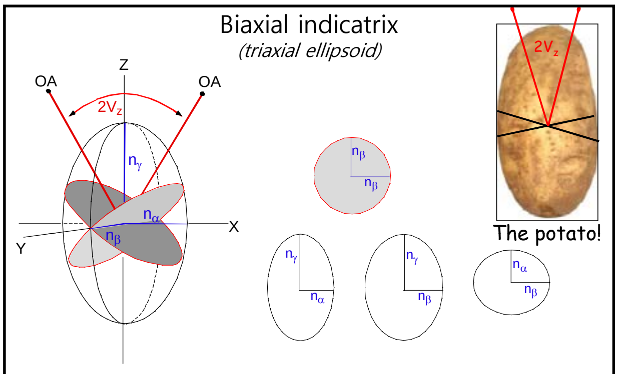
- 혼돈을 피하기 위한 방법
  - 이방성 광물을 통과하는 빛은 하나는 fast ray, 다른 하나는 slow ray로 갈라짐
  - Ordinary/extraodinary terminology(용어)가 이방성 광물에서는 쓰이지 않는다. 여기서 2개의 ray는 모두 일축성 광물에서 extraodinary ray와 동일
- Slow ray 굴절률 : n_γ' ($n_\beta \le n_\gamma' \le n_\gamma$)
- Fast ray 굴절률 : n_α ' ($n_\alpha \le n_\alpha' \le n_\beta$)

Biaxial indicatrix

- Uniaxial mineral과 동일한 방법으로 작도되고 유사한 방법으로 해석됨
- 주된 차이점 : indicatrix의 세 축의 길이가 모두 다르다.
- 세 축의 길이 =principal indices of refraction, 통과하는 빛의 굴절률, 진동방향
- 광물의 축은 직각이 아니더라도 indicatrix의 축은 항상 수직이 되도록 작도함

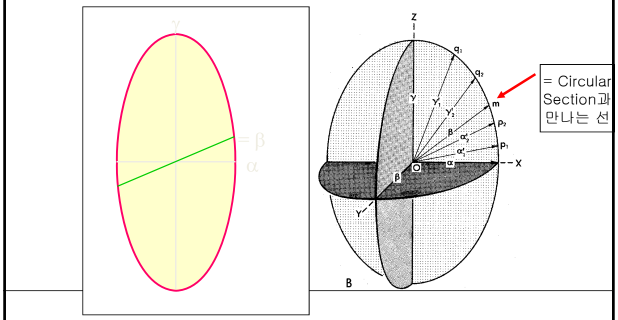
Biaxial indicatrix

(triaxial ellipsoid)

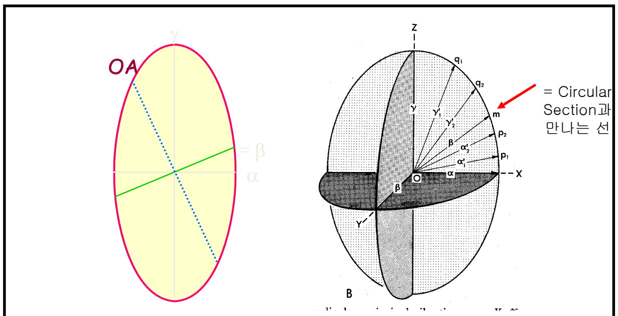


Principal section : X-Z, Y-Z, X-Y

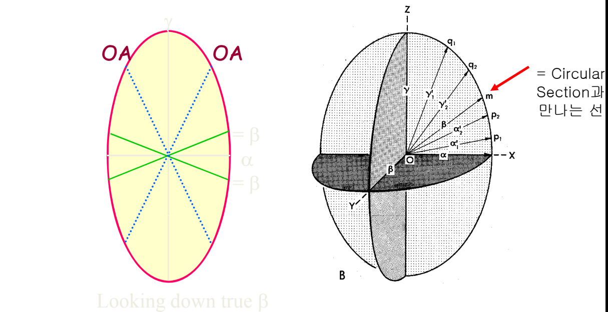
Two circular sections : Y-Y(항상 Y축 공유)



1. In the X-Z plane : nα ≤ nα' ≤ **nβ** ≤nγ' ≤ nγ
2. **X-Z plane 에서 nβ** 와 동일한 반경을 지시하는 직선의 수직선 = Optic axis(OA)
3. OA는 X-Z plane에서 두 개가 발생함
4. 두 OA 사이의 각도 = **2V angle** or **Optic angle**
5. X-Z plane은 OA를 포함하고 있기 때문에 Optic plane이라고도 불림



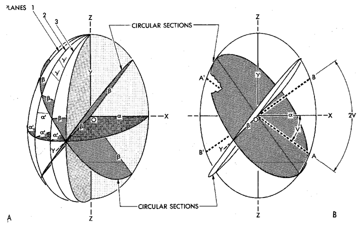
1. In the X-Z plane : nα ≤ nα' ≤ **nβ** ≤nγ' ≤ nγ
2. **X-Z plane 에서 nβ** 와 동일한 반경을 지시하는 직선의 수직선 = Optic axis(OA)
3. OA는 X-Z plane에서 두 개가 발생함
4. 두 OA 사이의 각도 = **2V angle** or **Optic angle**
5. X-Z plane은 OA를 포함하고 있기 때문에 Optic plane이라고도 불림



- In the X-Z plane : nα ≤ nα' ≤ **nβ** ≤nγ' ≤ nγ
- **X-Z plane 에서 nβ** 와 동일한 반경을 지시하는 직선의 수직선 = Optic axis(OA)

3. OA는 X-Z plane에서 두 개가 발생함
4. 두 OA 사이의 각도 = **2V angle** or **Optic angle**
5. X-Z plane은 OA를 포함하고 있기 때문에 Optic plane이라고도 불림

Biaxial Crystals



Nomenclature:

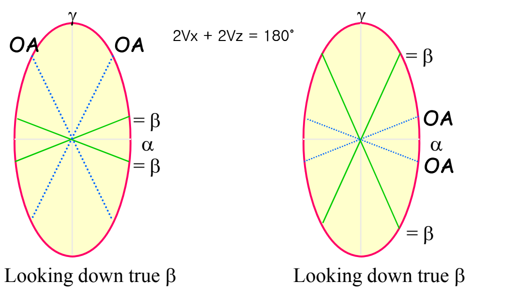
- 2 circular sections → 2 optic axes Must be in α–γ plane = Optic Axial Plane (OP)
- Y || β direction ⊥ OP = optic normal

Acute angle between OA's = 2V

The axis that bisects acute angle = acute bisectrix = Bxa

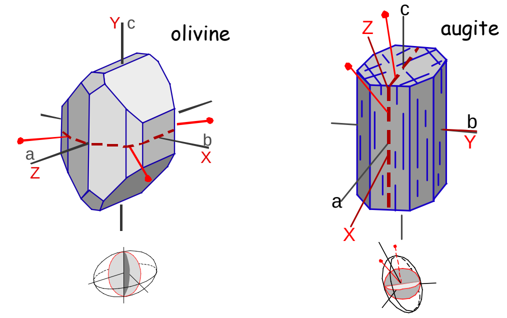
The axis that bisects obtuse angle = obtuse bisectrix = Bxo

Biaxial Positive and Negative



B(+) defined as Z (γ) = Bxa	**B(-)** defined as X (α) = Bxa
Thus β closer to α than to γ	Thus β closer to γ than to α
2Vx > 90°, 2Vz < 90°	2Vx < 90°, 2Vz > 90°

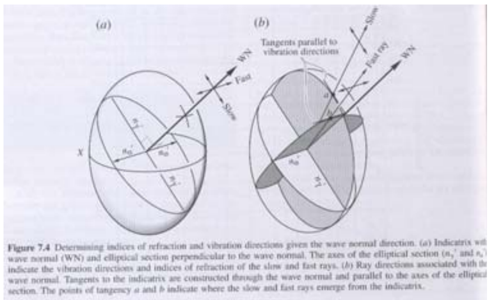
Alas, the potato (indicatrix) can have any orientation within a biaxial mineral…



- In the special case where 2V is exactly 90˚, the mineral is optically neutral.
- 이러한 명명법은 특히 화학적 성분의 변화로써 광학적으로 positive에서 negative까지 변화하는 광물을 위한 광학적 data를 표현하는데 유용하다.
- Uniaxial indicatrix는 biaxial indicatrix의 특수한 경우로 생각되는 수도 있다
  - na = nb 일 경우 : Z 축 = OA, X-Y plane = circular section(uniaxial positive)
  - nb = nc 일 경우 : X 축 = OA, Y-Z plane = circular section(uniaxial negative)

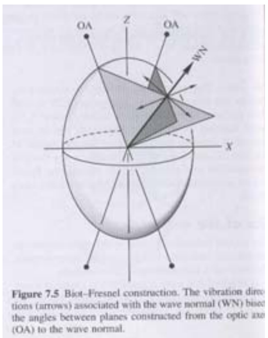
Use of the indicatrix

- Uniaxial indicatrix와 동일
- 작도시 좀더 주의 요망(WN : wave normal)
- Ray 작도 : page 79 참조



Biot-Fresnel Rule

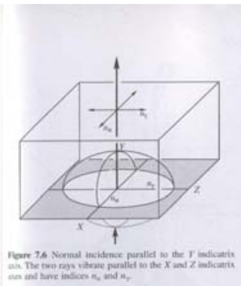
- WN과 관련된 진동 방향을 결정하기 위해 이용
- WN과 OA를 포함하는 두면을 작도
- WN을 통과하는 빛의 진동방향 : 두 면사이의 각도를 2등분 함



광물을 통과하는 빛의 유형

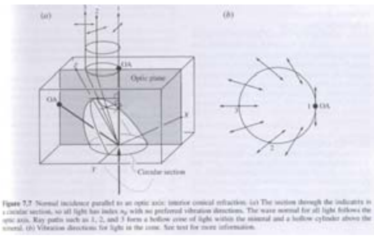
- Case 1 : 3축중 하나에 평행하게 빛이 입사
- Case 2 : OA에 평행하게 입사
- Case 3 : 불규칙하게 입사
- Case 4 : 경사져서 입사(WN 자체가 굴절됨 - 생략)

Case 1 : 3축중 하나에 평행하게 빛이 입사



- 통과 빛의 굴절률 : 타원의 장축
- WN // ray path

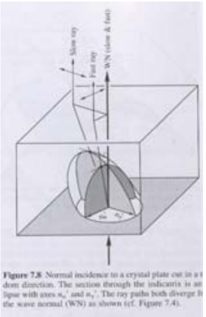
Case 2 : OA에 평행하게 입사



- Indicatrix 단면 : 원
- WN과 ray 경로가 평행하지 않음
- Cone 형태의 빛 발산(비 편광 입사 시)

- 작도는 Fig. 7.4와 동일한 방식으로 작도
- 위 그림은 약간 과장되게 표현한 것임 – 실제로는 Cone radius가 매우 작음(항상 검게 보임)

Case 3 : 불규칙하게 입사



- Fig 7.4b와 동일하게 작도됨
- 가장 일반적인 형태의 빛 투과
- WN : 굴절 안됨
- Na<Na'<Nb
- Nb<Nc'<Nc
- 진동방향 // 타원의 축

Crystallographic orientation of indicatrix Axes

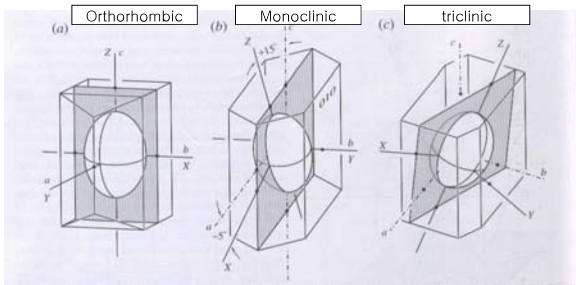


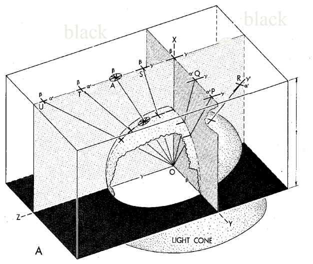
Figure 7.10 Relationship between crystal axes and indicatrix axes. The optic planes are shaded. (a) Orthorhombic. Crystal axes and indicatrix axes coincide. (b) Monoclinic. The b crystal axis coincides with one of the indicatrix axes. The other axes do not coincide except by chance. In this case b = Y, so the optic plane is parallel to (010). If b = X or Z, then the optic plane is at right angles to (010). (c) Triclinic. None of the crystal axes coincide with indicatrix axes except by chance.

Biaxial Interference Figures

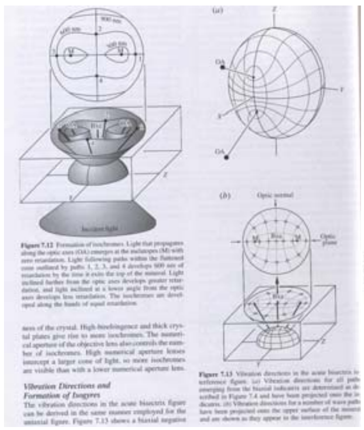
B_{xa} figure (B_{xa} is vertical on stage)

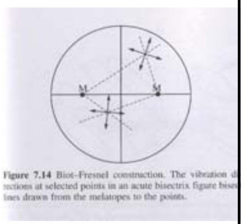
As in uniaxial, condensing lens causes rays to emanate out from O

OX → OS → OA
results in decreasing retardation (color) as
$\gamma \rightarrow \beta$
OA → OT → OU
Increase again, but now because $\beta \rightarrow \alpha$
OX → OQ → OP
⇒ incr retardation (interference colors)
OR is random with α' and γ'

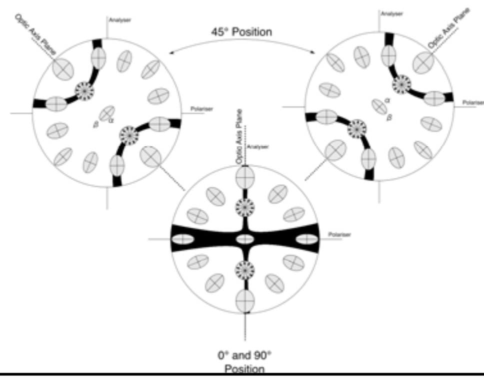


간섭상

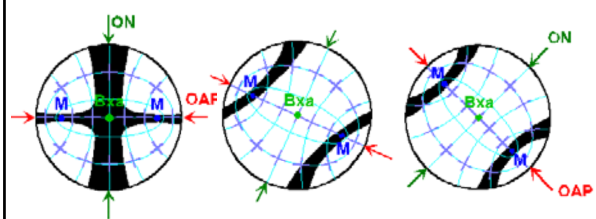




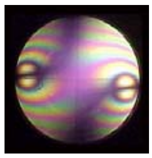
Acute bisectrix figure



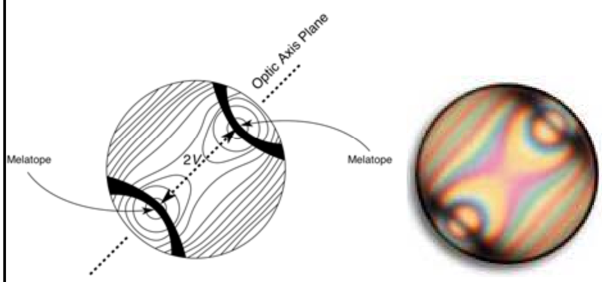
Bxa figure(2V < 40°)



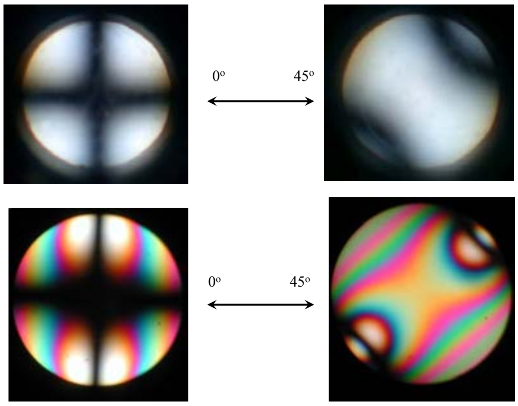
- M : melatope
- Isochrome : 8자 모양
- Isogyre : 회전시 변화함

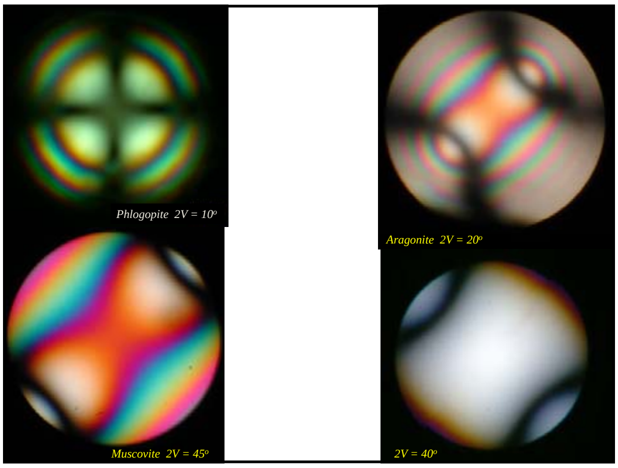


Acute bisectrix figure



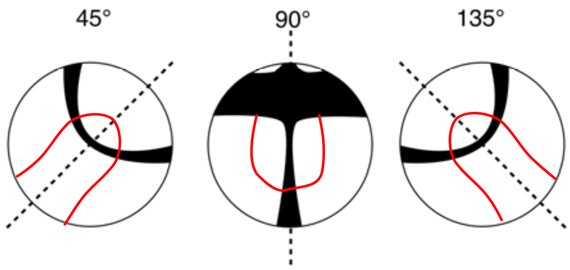
Biaxial Acute Bisectrix Figure (BXA)



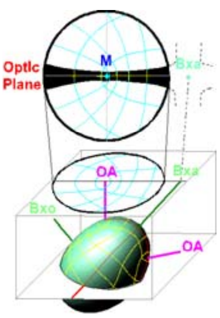


Optic axis figure

항상 검게 보임
Melatope 중 하나가 항상 현미경 십자선 중앙에 놓임

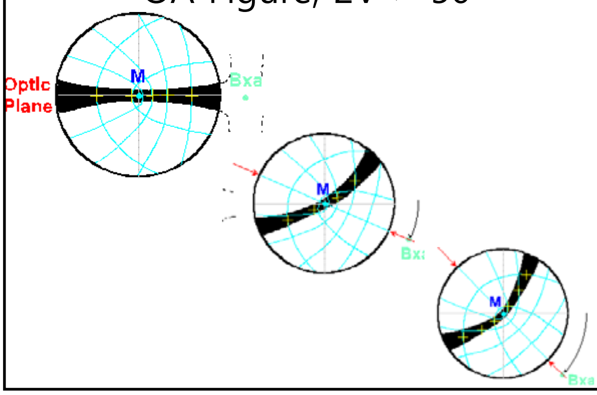


OA Figure, 2V > 50° Diagram

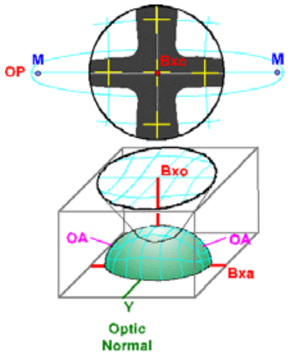


- With a 2V > ~ 50° only one melatope with it's isogyre is visible within the field of view
- The center of the cross representing the position of the B_{xa} will lie outside the field of view

OA Figure, 2V > 50°

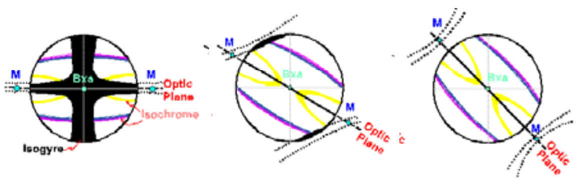


Obtuse Bisectrix Figure, B_{XO}

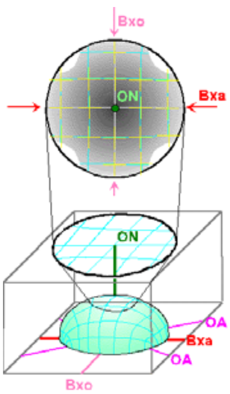


- Bxo 가 스테이지의 수직으로 놓인 경우
- M이 시야 밖에 존재
- 약간만 스테이지를 회전시켜도 Isogyre가 사라짐

Obtuse Bisectrix Figure, B_{XO}

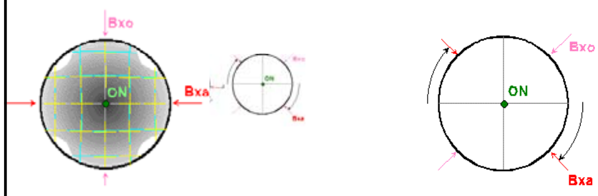


ON Figure



- The vibration directions for the two rays exiting in figure are similar to those for a uniaxial flash figure
- When the X & Z indicatrix axes parallel the polarization directions, the flash figure is a broad fuzzy cross with only the outer edges of each quadrant of the field of view allowing some light to pass

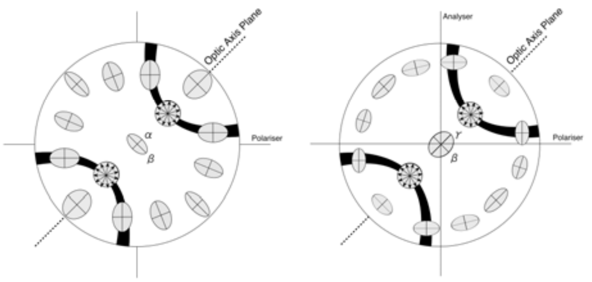
ON Figure, Small Rotation



Optic sign determination

Positive

Negative



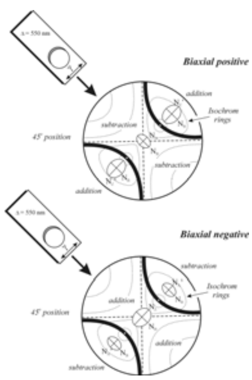
BURP still applies!

Determination of Optic Sign with a BXA Interference Figure:

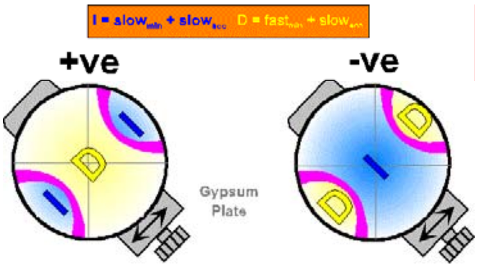
The optic sign of a biaxial mineral is commonly determined by using the accessory plate to distinguish the relative orientations of N_{big} or N_{small} in the region between the two parabolic isogyres of the BXA interference figure in the 45º position, as compared to the regions outside them. In the 45º position, η_{β} is oriented between the two isogyres, while either η_{α} (+) or η_{γ} (-) is oriented along the optic plane joining the two optic axes and thus bisecting the two parabolic isogyres. The question then becomes; is η_{β} equal to N_{big} or N_{small} compared to the vibration direction along the optic plane.

If η_{β} is N_{big}, then the other is η_{α}, and you are looking down $\eta\gamma$ and thus the mineral is biaxial positive.

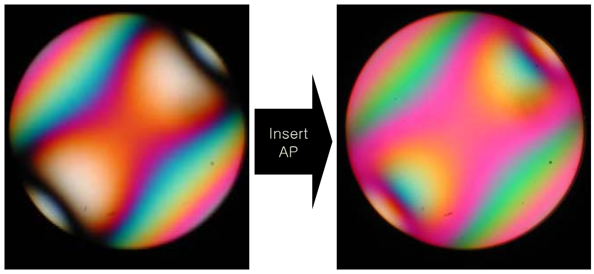
If η_{β} is N_{small}, then the other is η_{γ}, and you are looking down $\eta\alpha$ and thus the mineral is biaxial negative.



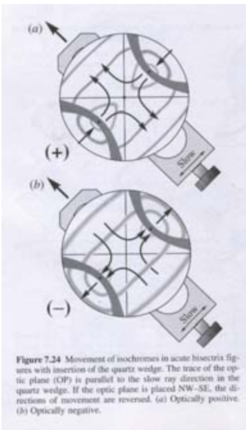
Biaxial optic sign acute bisectrix figure



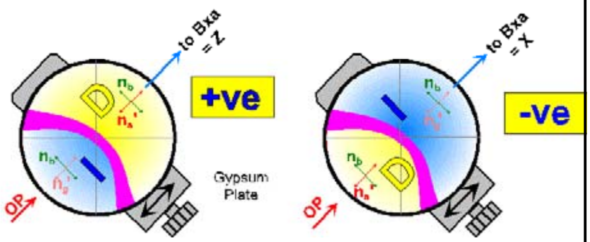
Biaxial negative figure



Qtz wedge



Optic axis figure



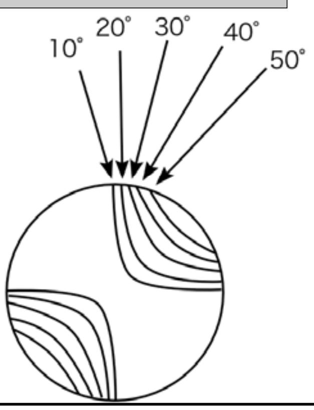
2*V* determination

Separation of melatopes is a measure of 2*V*

Angular width of field of view is around 55–60°.

Remember: if mineral is positive, you are measuring $2V_\gamma$.

If negative, you are measuring $2V_\alpha$.



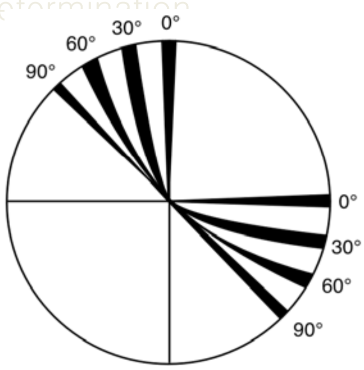
Optic sign and 2*V* determination

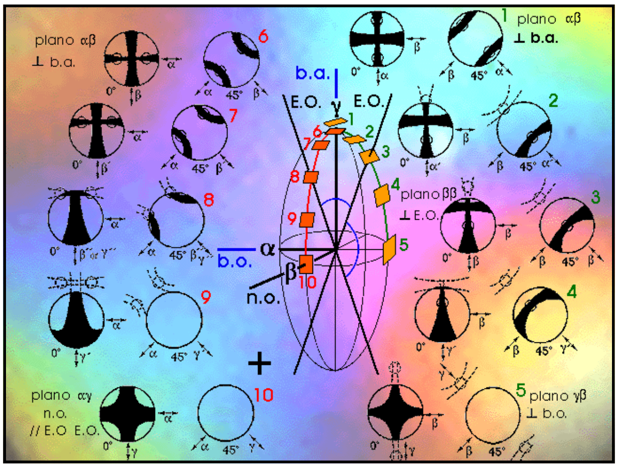
As long as the isogyre curves in the 45° position, the rest of the figure can be imagined and the BURP rule applied.

Curvature varies with 2*V*.

2*V* = 0 Isogyre curves through 90° (i.e. is a uniaxial figure).

2*V* = 90° Isogyre shows no curvature (sign cannot be determined, since it is neither +ve or −ve).

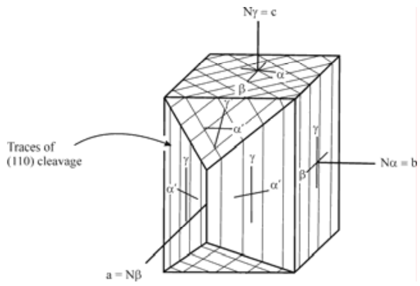




Extinction Angle:

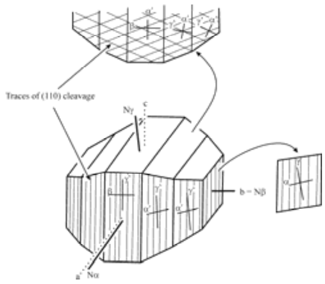
Orthorhombic minerals typically exhibit parallel or symmetric extinction.

Extinction angles in orthorhombic pyroxene:

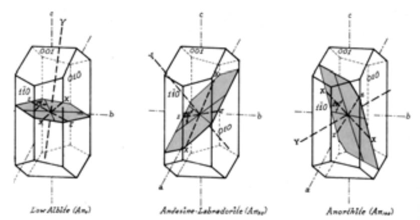


Monoclinic minerals will only exhibit parallel extinction in orientations in which the b crystallographic axis (and the 2 fold symmetry axis) lies in the plane of the microscope stage. In other orientations, monoclinic minerals will typically exhibit inclined extinction. The extinction angle will typically be greatest in orientations in which the b crystallographic axis is perpendicular to the microscope stage. By knowing which of the principle vibration directions coincides with the b crystallographic axis, one can use the corresponding interference figure to obtain grains of the right orientation, and then measure the exact angle of extinction, which will be characteristic of the mineral.

Extinction angles in monoclinic pyroxene:



Triclinic minerals exhibit inclined extinction. In some cases, most notably plagioclase (Lab. 8), a measurement of the extinction angle can be used to determine the composition of the mineral.



Whenever an extinction angle is noted, the following information is required to properly interpret it:

- The vibration direction that the angle is measure to, ie; η_γ, η_β, or η_α, or just ηbig versus ηsmall.
- The linear feature being measured to, ie: crystal length, cleavage, twin plane, etc.
- The orientation of the grain being measured; typically a centered interference figure, but sometimes the trace of a vertical crystallographic plane corresponding to a cleavage or twin plane.

Pleochroism in biaxial minerals

- Since 3 indices of refraction; 3 colors (1 per axis)
- Light parallel to X axis is least strongly absorbed. Z is most strongly absorbed
- Hornblende x = yellow y = pale green, z = dark green

Pleochroism in biaxial minerals

- For Y, find grain nearly isotropic, uncross polars
- For X and Z, find grain with highest interference colors
- Rotate to extinction, then 45° clockwise, slide in accessory plate, determine if addition or subtraction
  - If color increases, addition, slow ray, Z ray
- Rotate another 45° clockwise, uncross polars and note color
- For other axis, rotate 90° from here