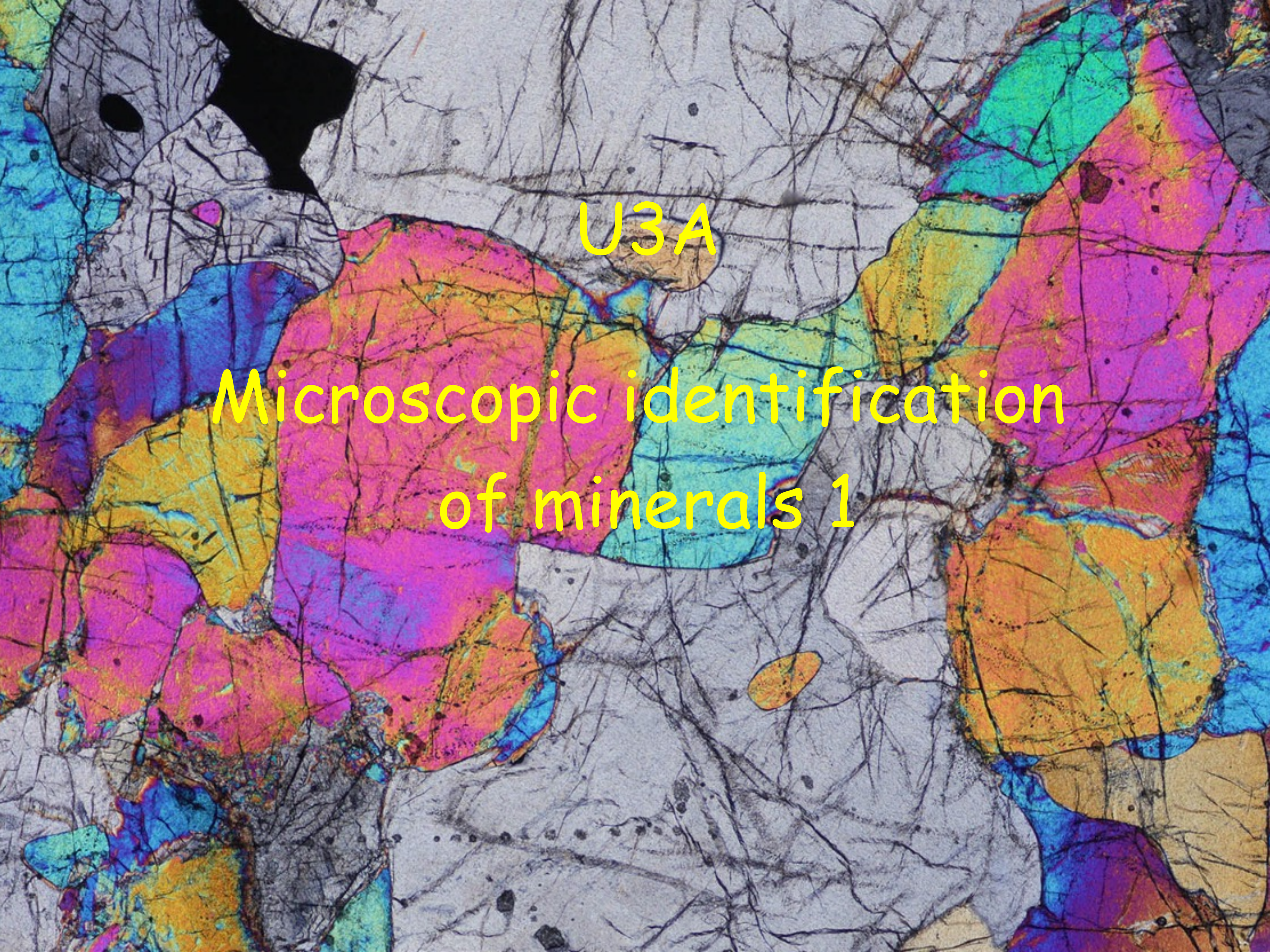


U3A

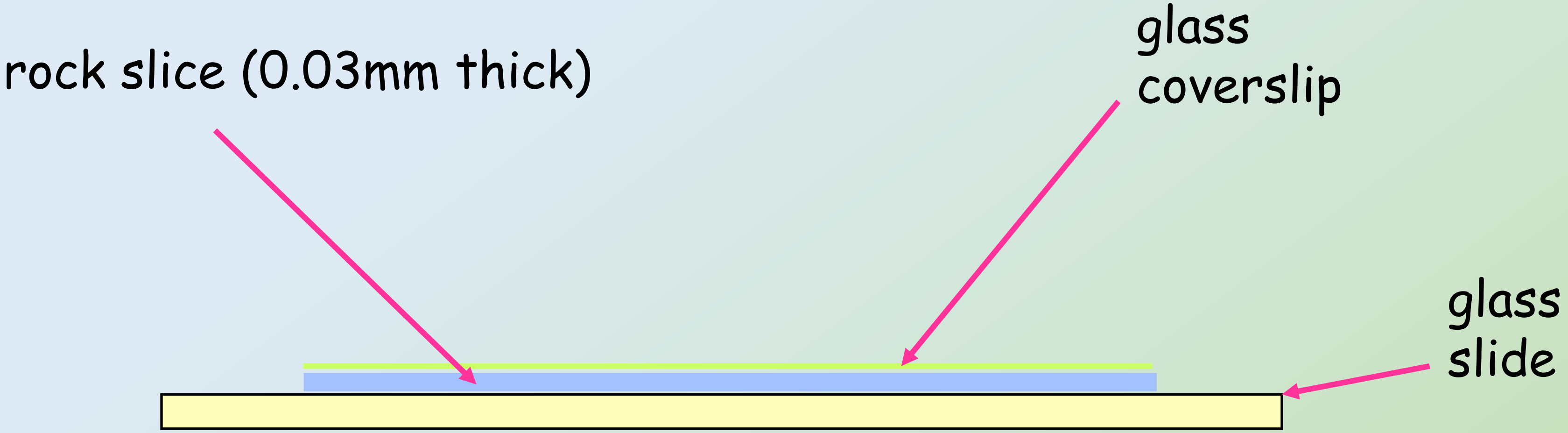
Microscopic identification of minerals 1

Introduction

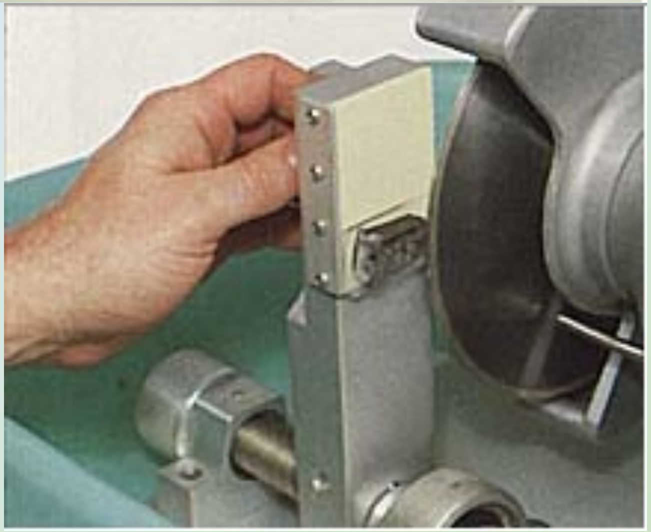
- Optical mineralogy is a very powerful tool in studying and identifying rocks and minerals using a petrographic microscope
- the petrographic microscope is similar to a biological microscope but with additional attachments
- rocks and minerals are analysed in transmitted light by viewing very thin slices glued to a glass slide
- to identify minerals, a list of optical properties are listed and referred to tables in the same way as physical properties

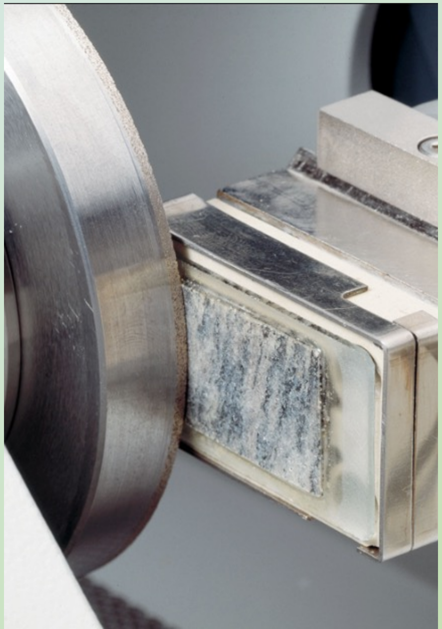
Thin section

- Rocks and minerals can be examined and identified in thin section
- thin section → glass slide containing thin (0.03mm) slice of rock or mineral with a glass coverslip

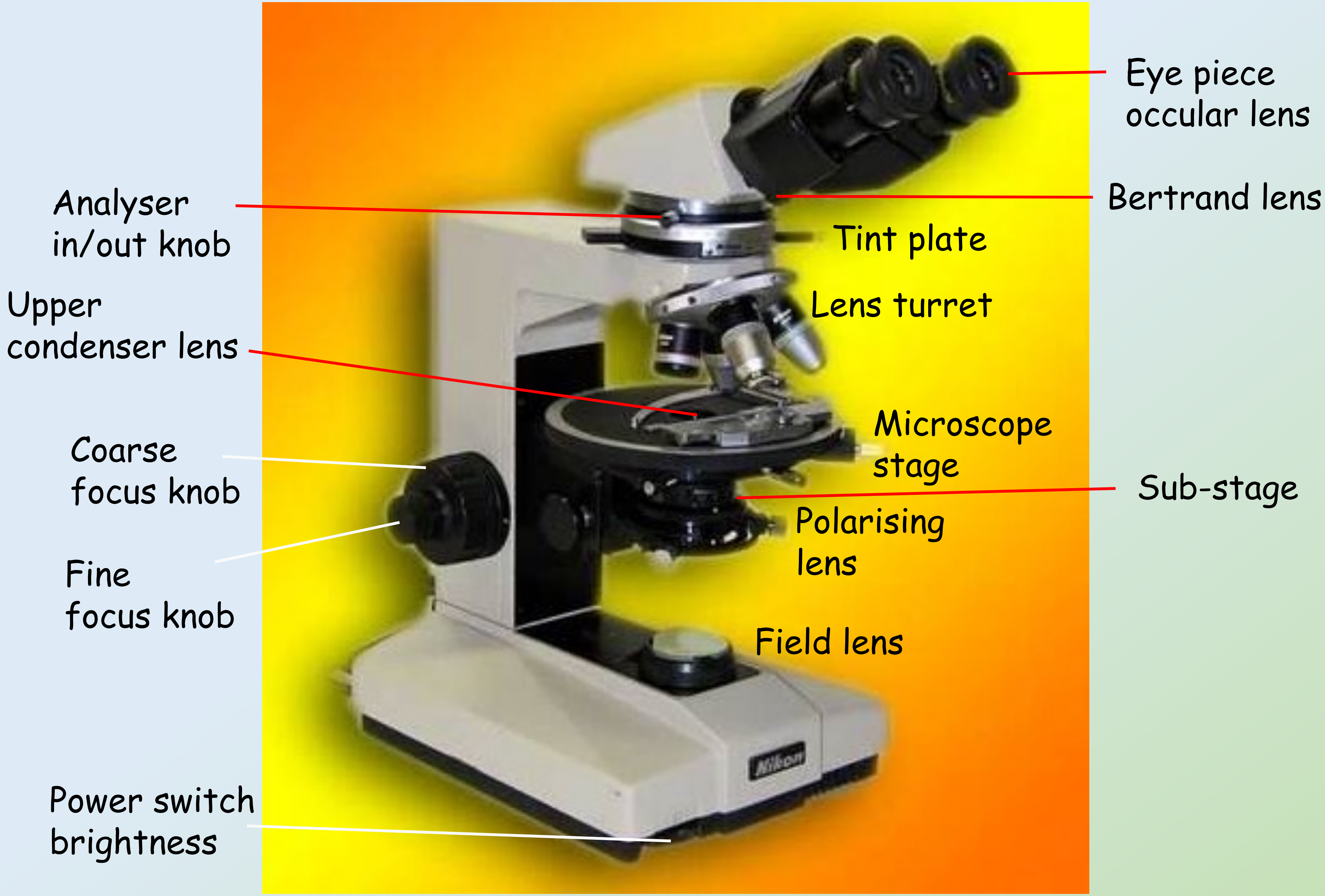


Making thin sections





Nikon petrographic microscope



List of physical and optical properties commonly used in mineral identification

Physical	Optical
lustre	relief
hardness	colour
streak	pleochroism
cleavage	birefringence
colour	crystal system
specific gravity	optic sign/axial angle
habit	cleavage
	dispersion
	extinction angle
	length fast/slow

Crystal systems

cubic	isotropic	
trigonal	uniaxial	anisotropic
tetragonal		
hexagonal		
orthorhombic	biaxial	
monoclinic		
triclinic		

Isotropic media

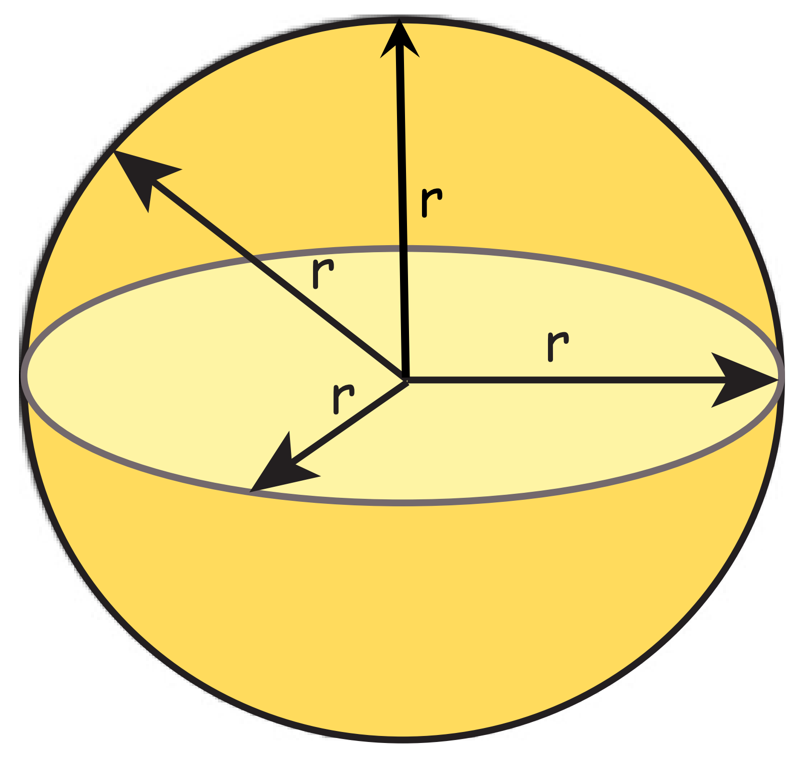
- Isotropic media have uniform physical properties in all directions within the media
- transmit light with equal velocity in all directions → the refractive index is uniform in all directions
- e.g. gases, glass, most liquids and minerals that crystallise in the cubic crystal system
- minerals that crystallise in the cubic crystal system are isotropic because there is a similar arrangement of atoms or molecules in all directions

Isotropic optical indicatrix

- Optical indicatrices show how RI varies with direction of monochromatic light rays in a medium
- vectors radiate from the point where a light ray enters the medium
- length of vectors → proportional in length to RI for light vibrating in the direction of the vector
- Indicatrix = surface connecting tips of vectors
- isotropic media have the same RI in all directions in the media

Isotropic indicatrix

- Refractive index is equal in all directions
- isotropic optical indicatrix is spherical

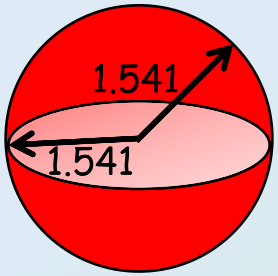


Isotropic indicatrix

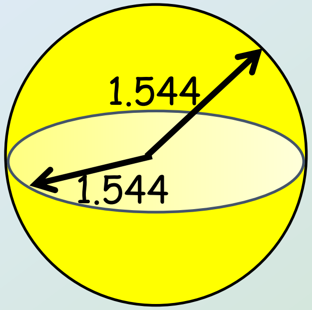
Since $c_A n_A$ = constant

Then the refractive index is the same in all directions and vectors drawn parallel to vibration directions and, proportional in length to the refractive index will define a sphere.

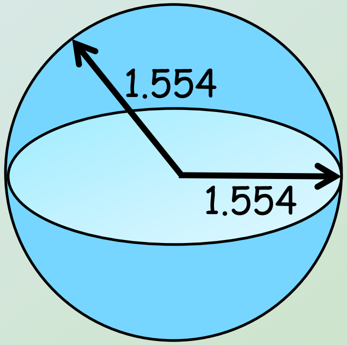
n_C for λ_C



n_D for λ_D

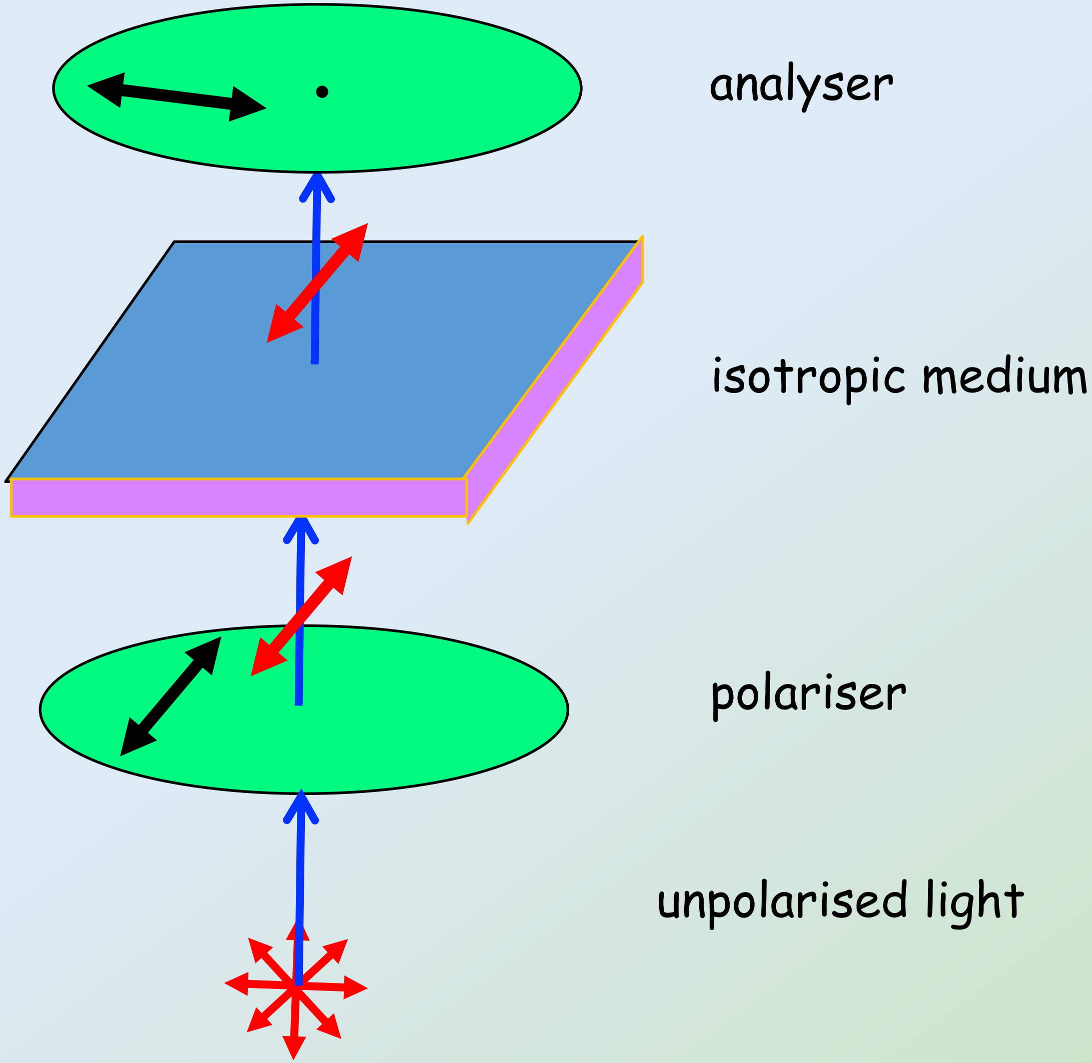


n_F for λ_F



These spheres are called optical indicatrices for isotropic minerals.

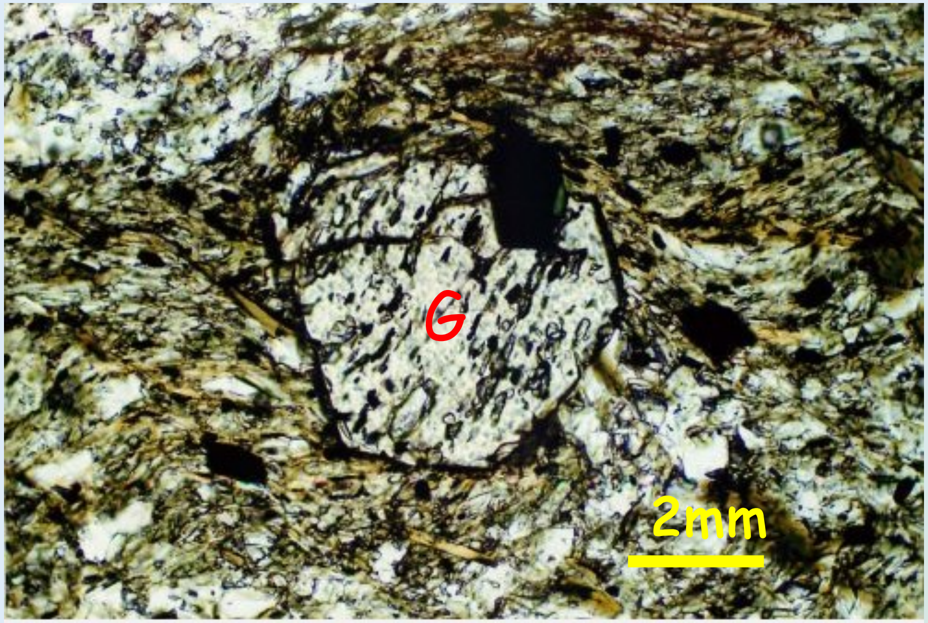
A plane polarised ray transmitted by an isotropic medium will have the same direction of polarisation when it leaves the plate as it had when it entered → extinct when analyser in optical pathway



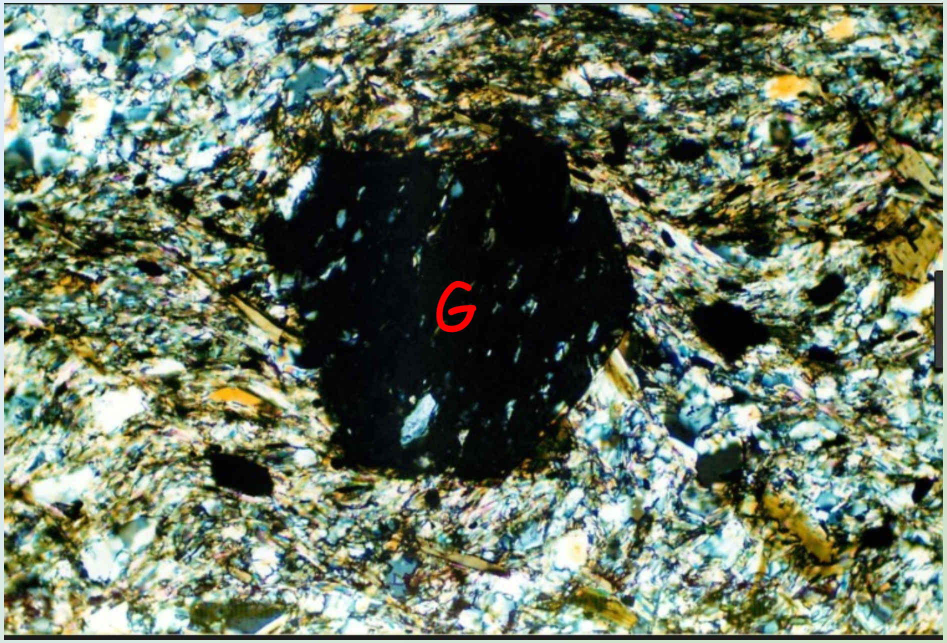
Isotropism - garnet

Isotropic minerals remain at extinction under crossed polars

e.g. garnet crystallises in the cubic crystal system ∴ isotropic

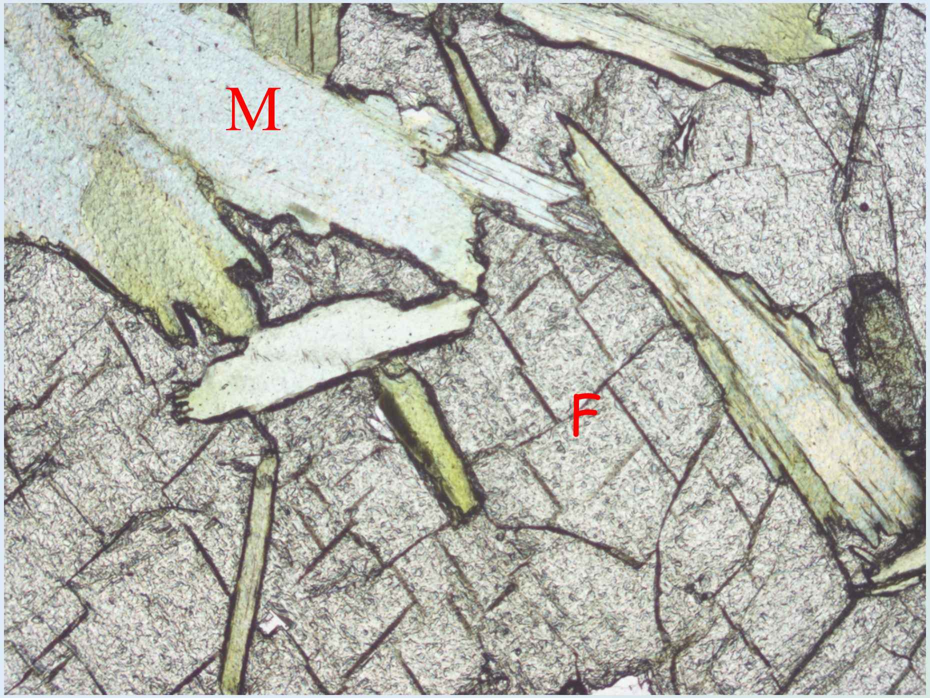


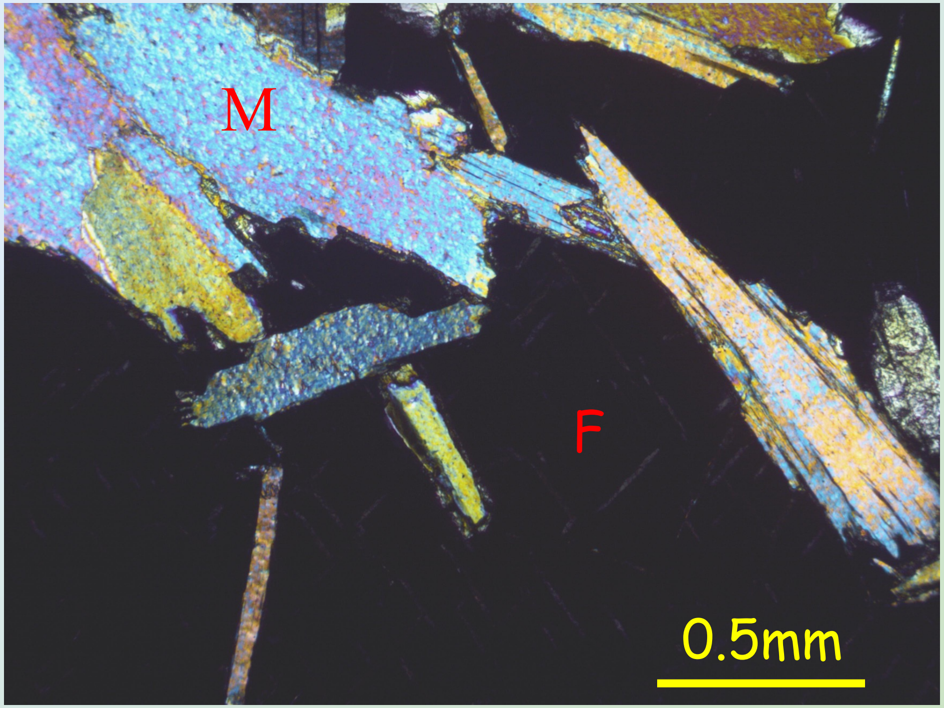
Garnet (G) in thin section
(plane polarised light)



Garnet (G) in thin section
(crossed polars)

Isotropism - fluorite (CaF_2)





Photomicrograph fluorite and muscovite → plane polarised light

Photomicrograph fluorite and muscovite → crossed polars

Anisotropic media

- Minerals that crystallise in crystal systems other than cubic
- anisotropic media transmit light with different velocities in different directions in the medium

∴ refractive index varies with direction → mineral said to be double refracting → birefringent

- when ordinary light enters an anisotropic medium, it is resolved into two mutually perpendicular vibrating rays → the medium polarises light in two specific directions
- when rays emerge from anisotropic media, they combine but do not necessarily vibrate in the same orientation as when they entered

Isotropic vs anisotropic minerals

Isotropic media

- transmit light with equal velocity in all directions
- ray surface is a sphere
- e.g. air, glass, water, minerals that crystallise in cubic system

Anisotropic media

- Minerals that crystallise in crystal systems other than cubic
- transmit light with different velocities in different directions
- light entering an anisotropic medium, it is resolved into two mutually perpendicular vibrating rays that have defined vibration directions
- ray vector surfaces are ellipsoids

Behaviour of light in uniaxial media

- When ordinary light enters an anisotropic medium, it is polarised into two mutually perpendicular vibrating rays
- in uniaxial minerals, one of those rays obeys Snell's Law (RI = sin*i*/sin*r*) for refraction, is called the ordinary ray (O-ray)
- the other ray does not obey Snell's Law (RI ≠ sin*i*/sin*r*) and is called the extraordinary ray (E-ray)
- effect can be seen by viewing images through a calcite rhomb
- the two rays pass through the crystal at different velocities with different refractive indices

Birefringence in calcite

- If images are viewed through a calcite rhomb, a double image appears
- one image is associated with ordinary rays and the other with extraordinary rays

Optical indicatrix for uniaxial crystals

The uniaxial indicatrix is a spheroid of rotation either prolate (+ve) or oblate (-ve)

ω = RI ordinary ray

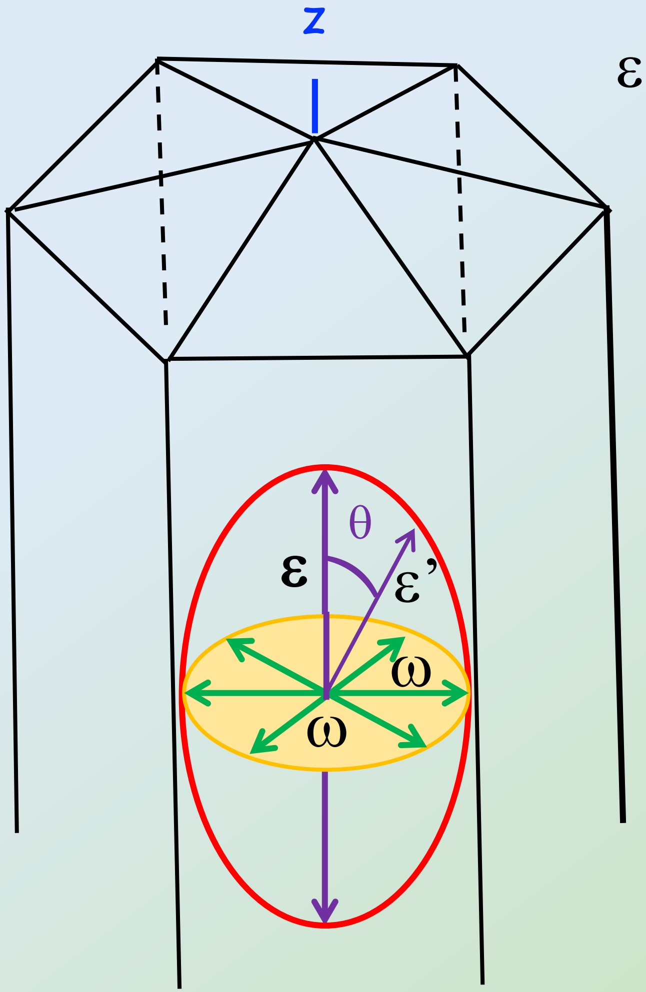
ε = RI extraordinary ray

$\varepsilon > \varepsilon' > \omega$

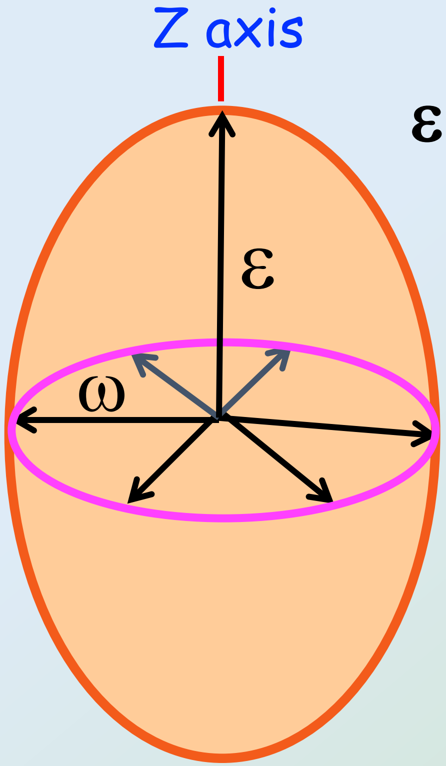
in prolate ellipsoid

$\omega > \varepsilon' > \varepsilon$

in oblate ellipsoid

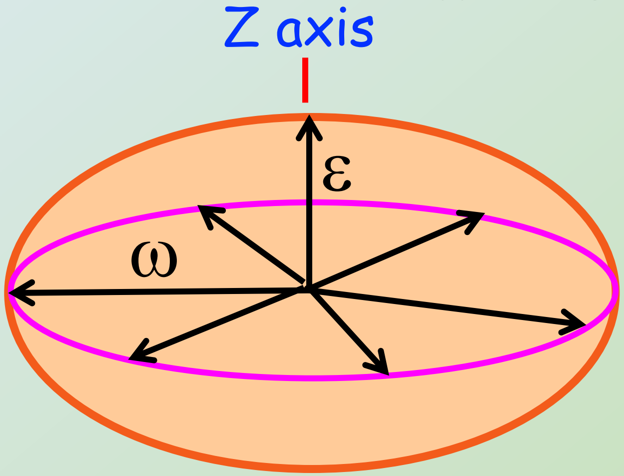


Optic sign in uniaxial minerals



ε > ω

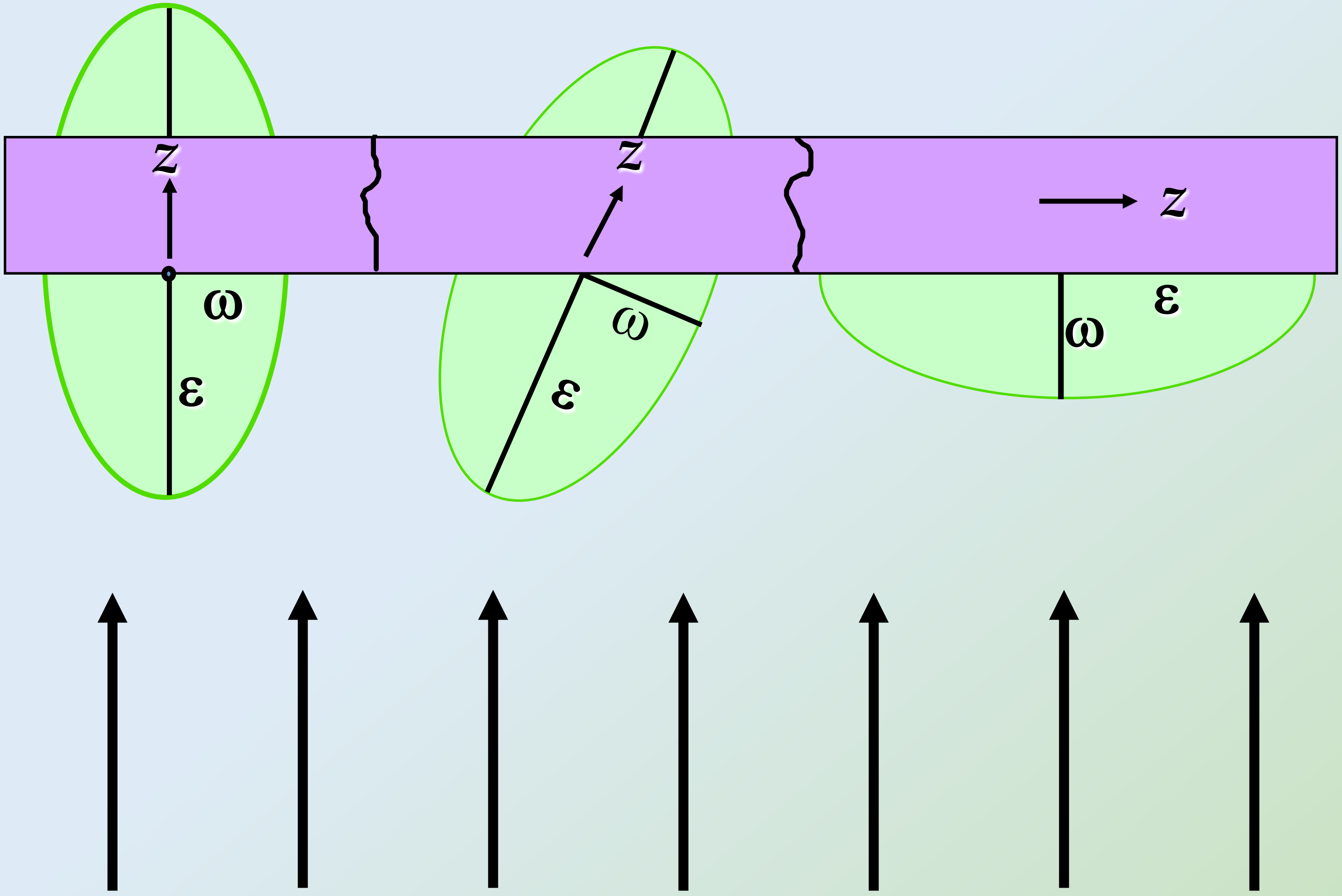
+ ve



ω > ε

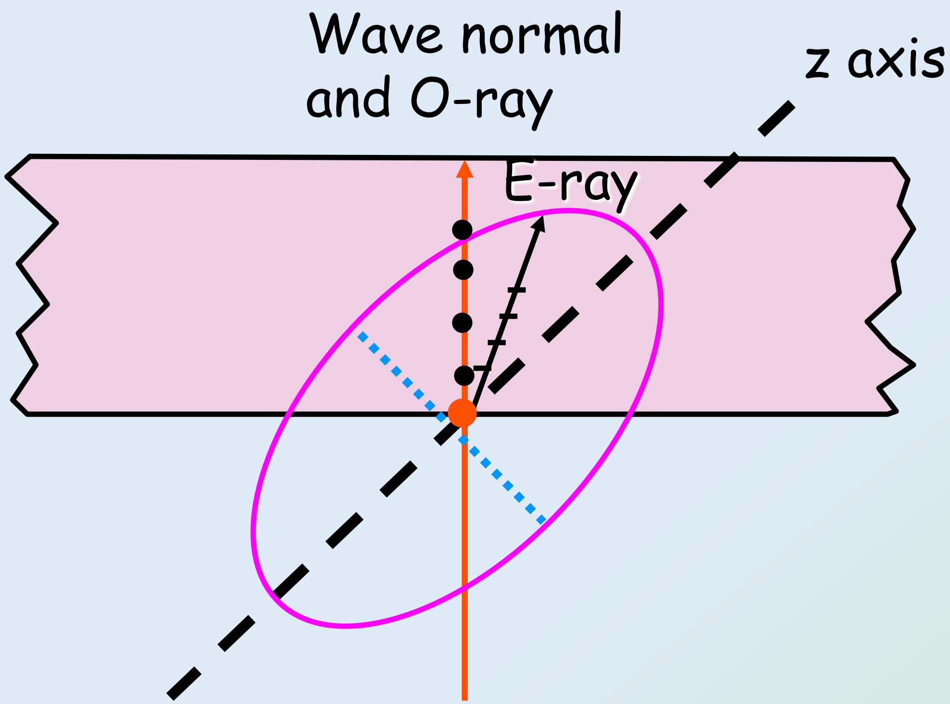
- ve

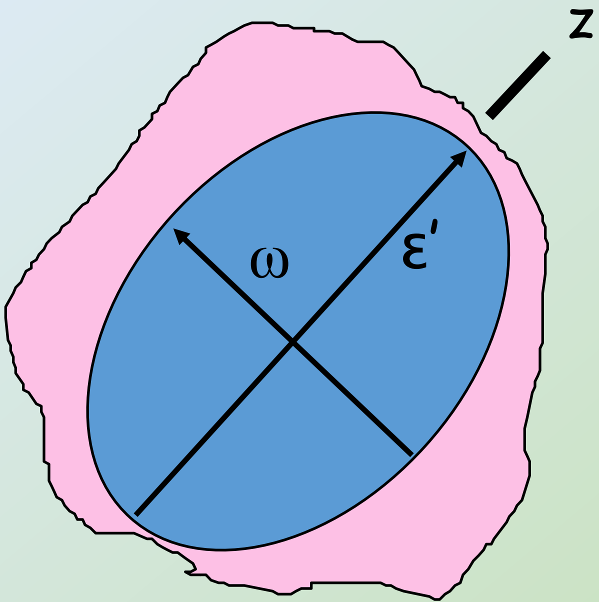
Light entering uniaxial crystals in random sections



Light

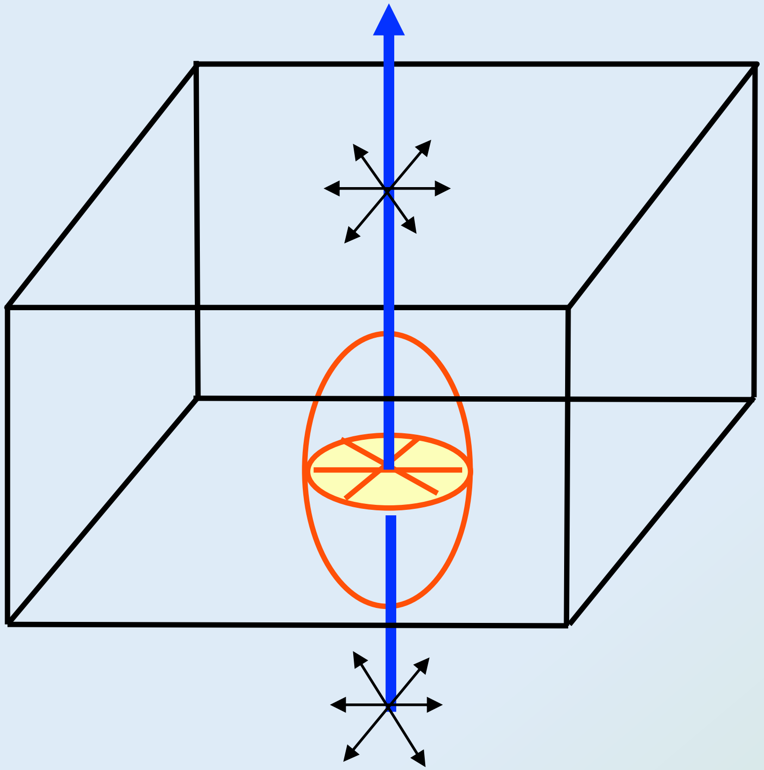
1. General case where z is neither parallel nor perpendicular to the plate

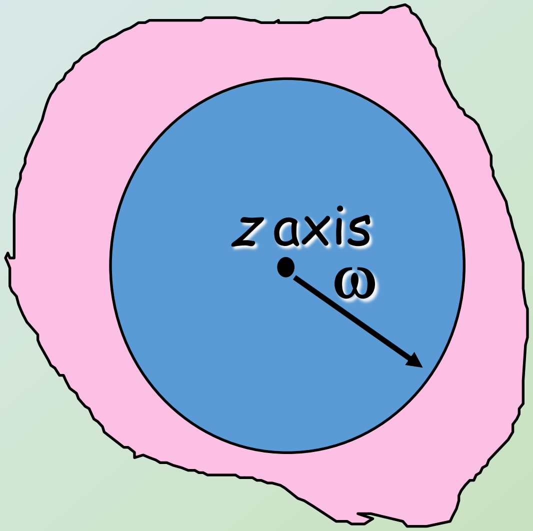




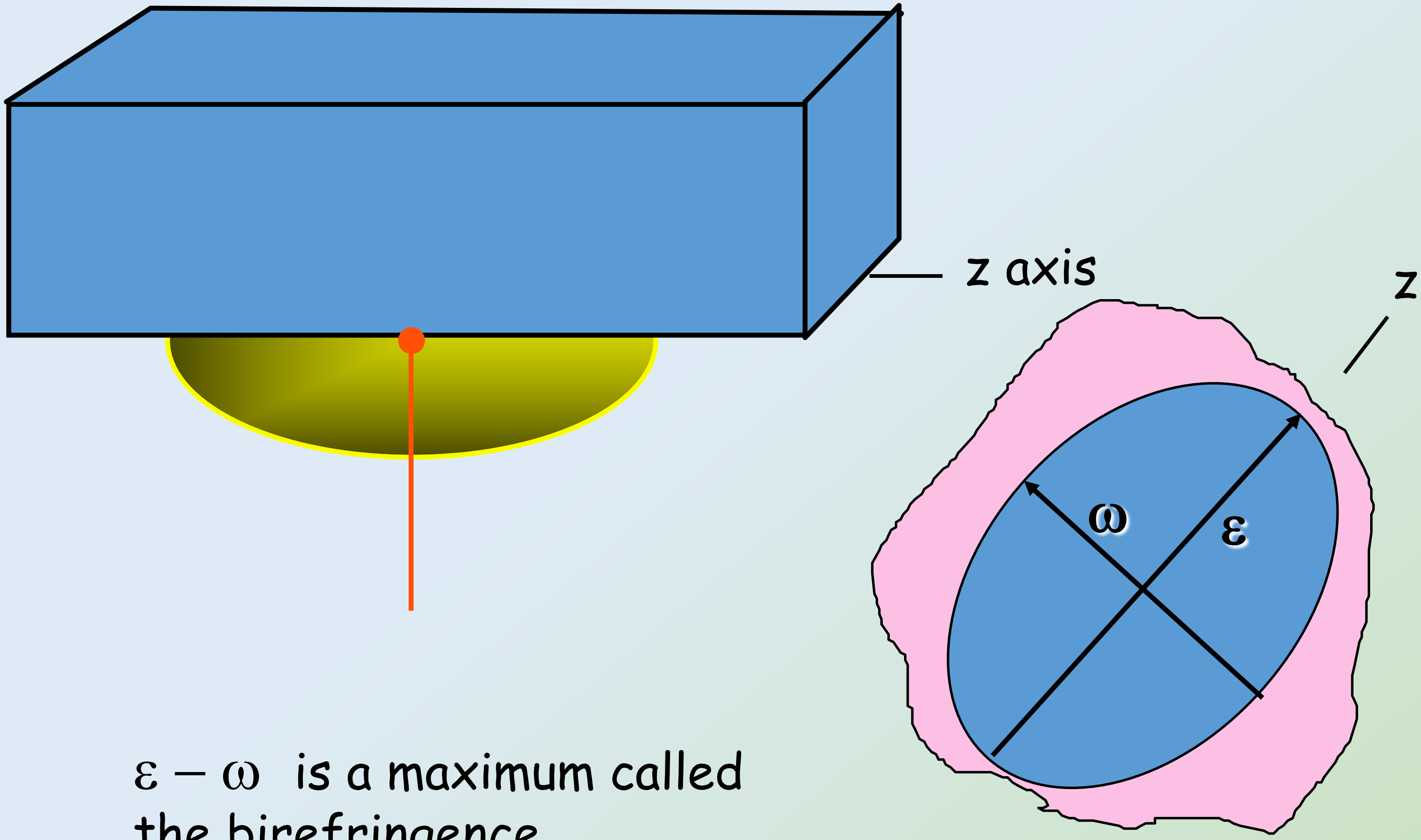
Light is constrained to vibrate in these two directions

2. When the section is cut perpendicular to the z axis



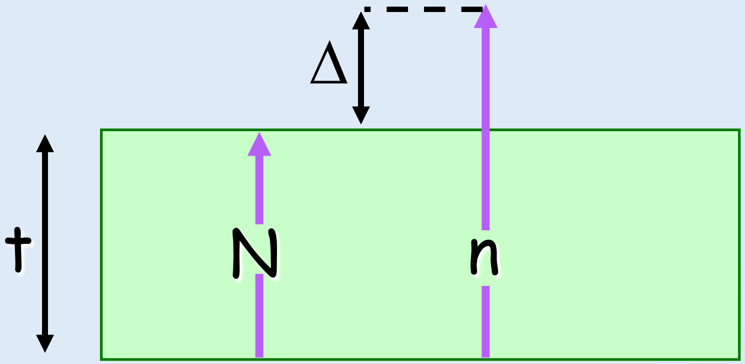


3. When the section is cut parallel to the z axis



$\varepsilon - \omega$ is a maximum called the birefringence

Path difference in anisotropic crystals



N = refractive index of slow ray

n = refractive index of fast ray

t = thickness of crystal plate

Δ = path difference

$$\Delta = t(N - n)$$

(birefringence)

Interference colours

- The path difference when expressed in terms of wavelength varies with wavelength
- consequently, the way in which fast and slow rays interfere on leaving crystal → varies with wavelength
- for a given path difference, some colours will be enhanced, others reduced by destructive interference
- light transmitted by analyser will appear coloured depending on degree of retardation

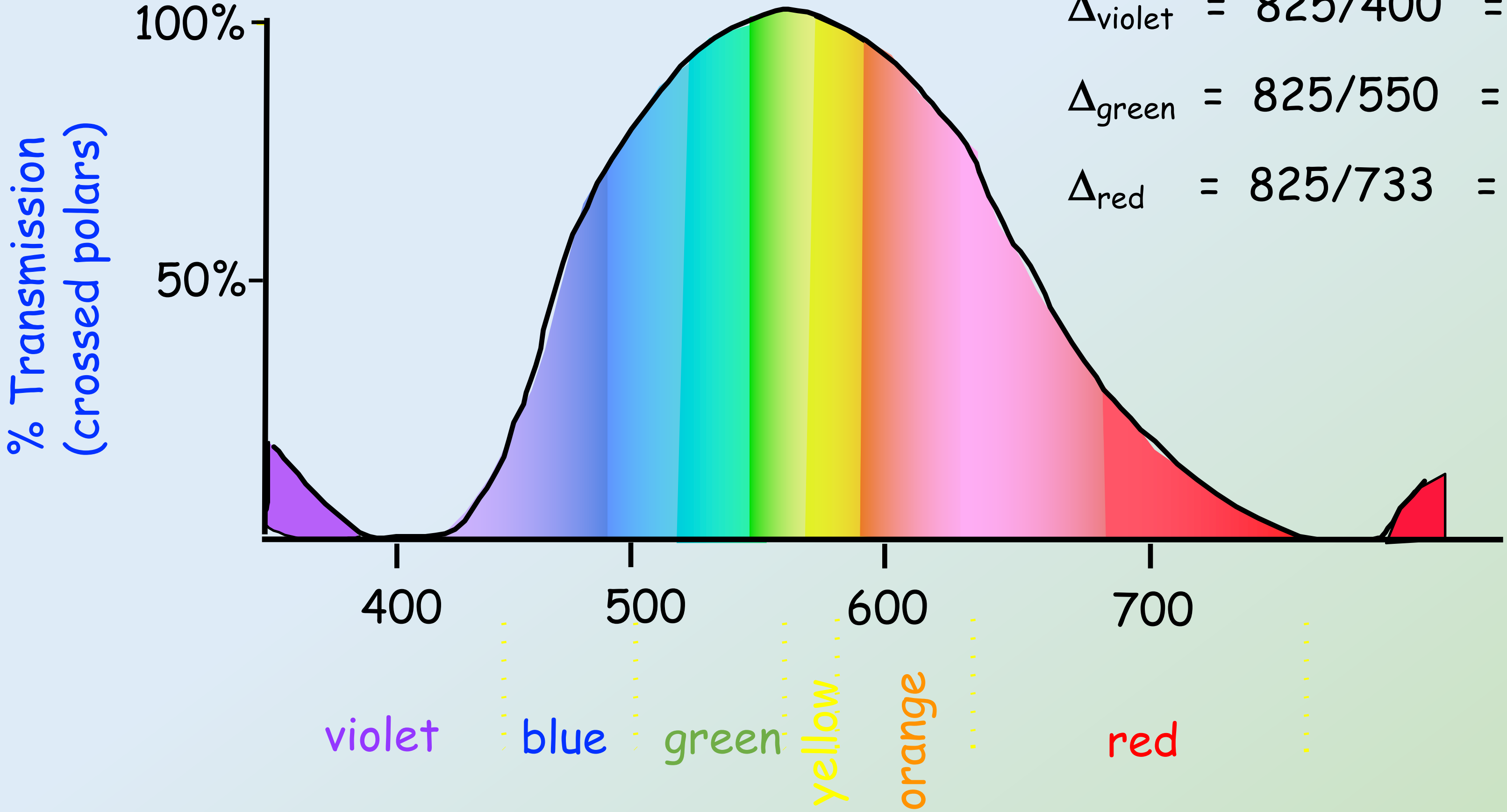
e.g. if Δ = 825nm difference expressed in terms of wavelength is:

λ_{violet}(400nm) = 825/400 =2λ λ_{green}(550nm) = 825/550 = 3/2λ

λ_{red}(733nm) = 825/733 = 9/8λ

Transmission curves (polychromatic light)

% Transmission is plotted against wavelength to give a transmission curve for white light rays with a path difference of 825nm



$\Delta_{violet} = 825/400 = 2\,\lambda$

$\Delta_{green} = 825/550 = {}^{3}/_{2}\,\lambda$

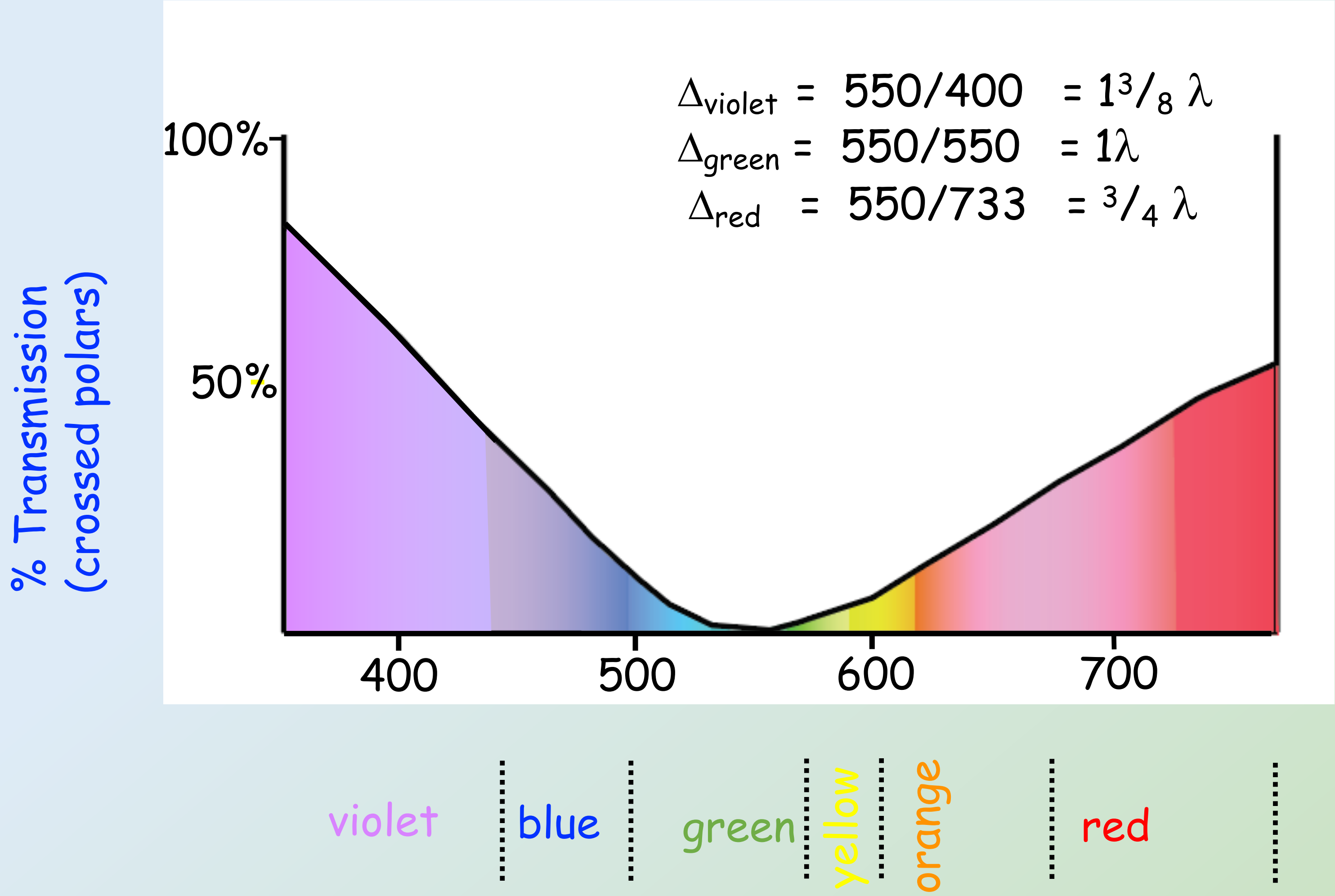
$\Delta_{red} = 825/733 = {}^{9}/_{8}\,\lambda$

Little violet and red light is transmitted

$\therefore$ the crystal appears greenish yellowish

Transmission curves (polychromatic light)

% Transmission is plotted against wavelength to give a transmission curve for white light rays with a path difference of 550nm



$\Delta_{violet} = 550/400 = 1^{3}/_{8}\ \lambda$

$\Delta_{green} = 550/550 = 1\lambda$

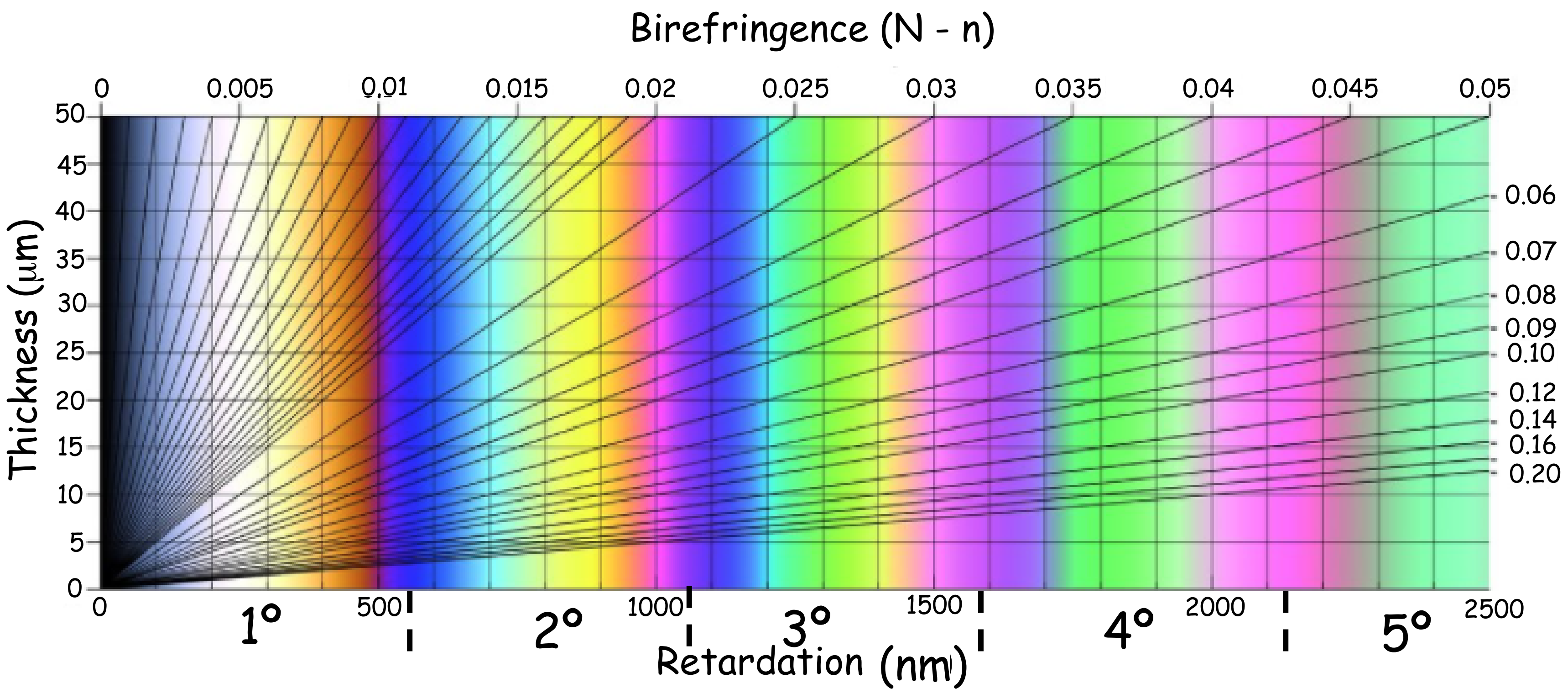
$\Delta_{red} = 550/733 = {}^{3}/_{4}\ \lambda$

Little yellow and green light is transmitted

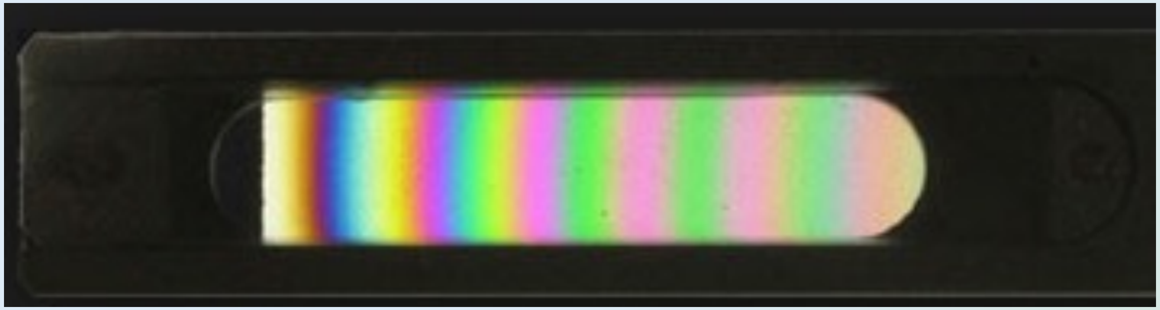
∴ the crystal appears reddish violet

Interference colour chart

A chart showing interference colours produced by passing white light through crystals of varying retardation can be used to determine birefringence of minerals



Quartz wedge under crossed polars



Glass slide

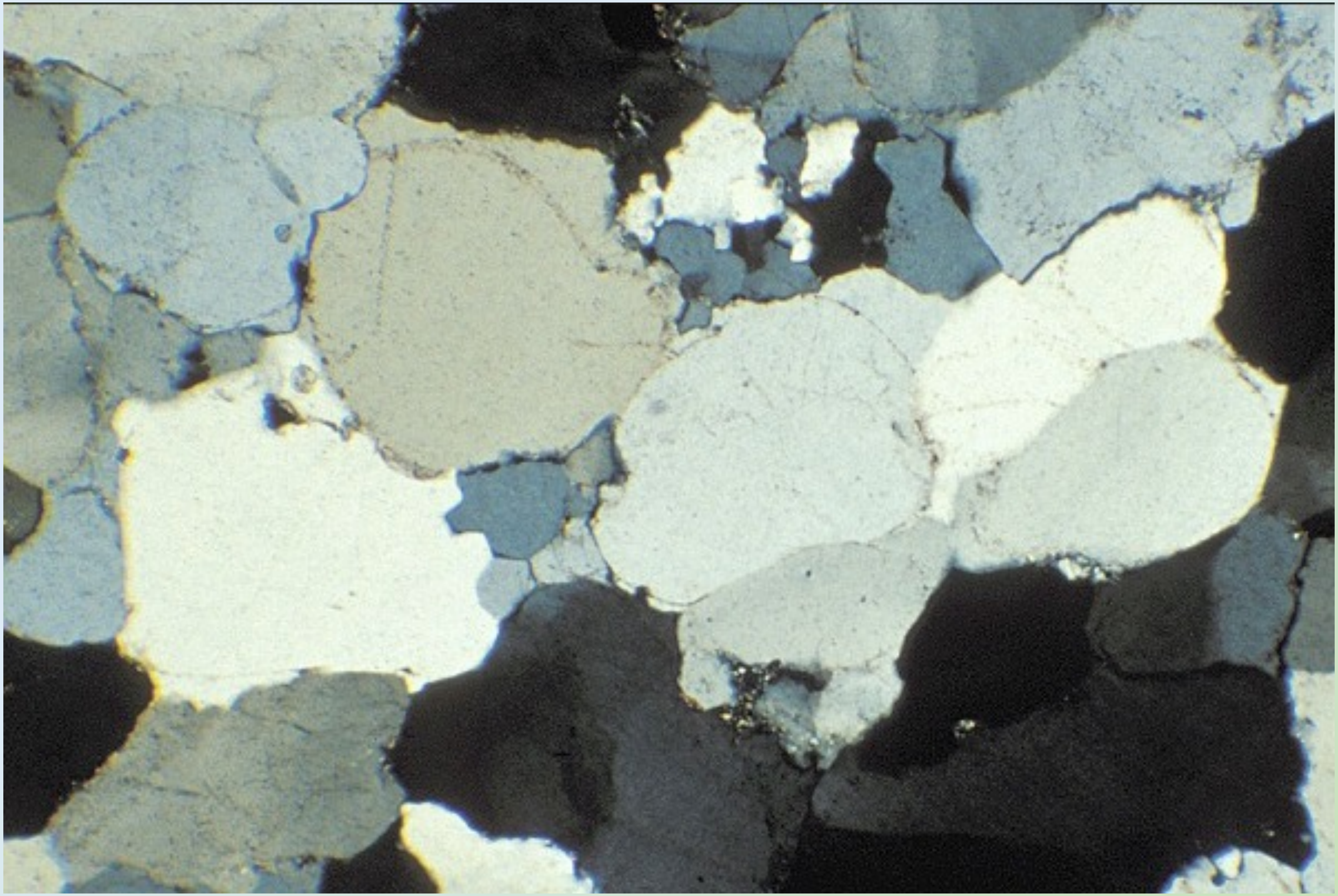
Quartz wedge

$$\Delta = t(N - n)$$

Photomicrograph - quartz crystals (crossed polars)

Quartz (uniaxial +ve) $N = \varepsilon = 1.553$ $n = \omega = 1.544$

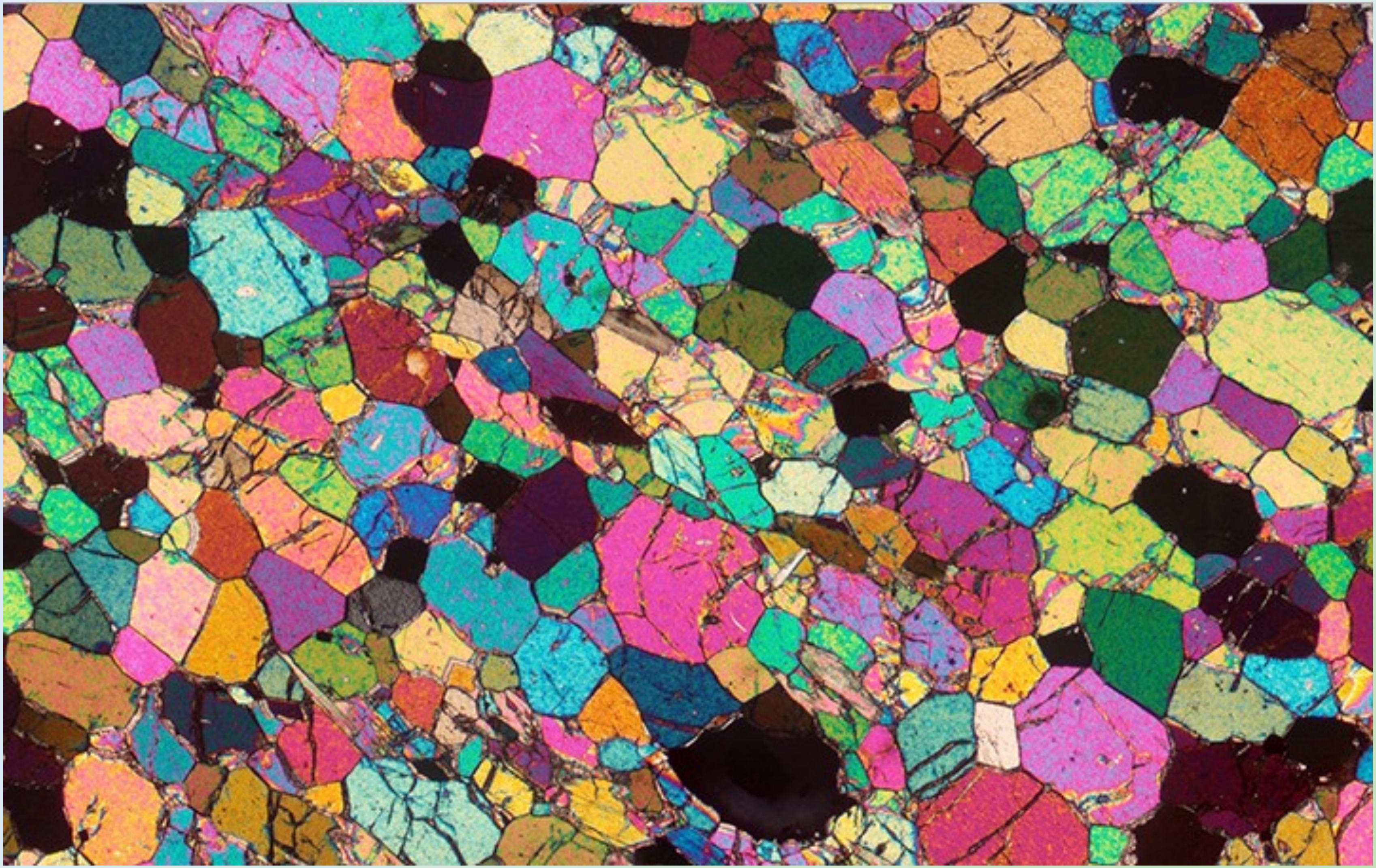
$(N - n) = 0.009$



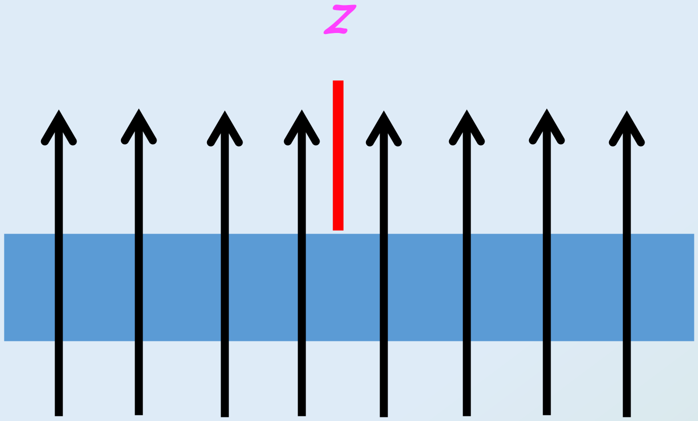
Photomicrograph - olivine crystals (crossed polars)

Olivine $N = 1.636\text{-}1.827$ $n = 1.669\text{-}1.879$

$(N - n) = 0.033\text{-}0.052$

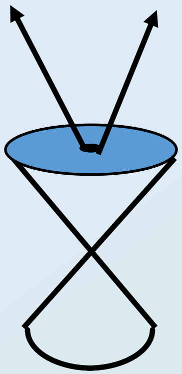


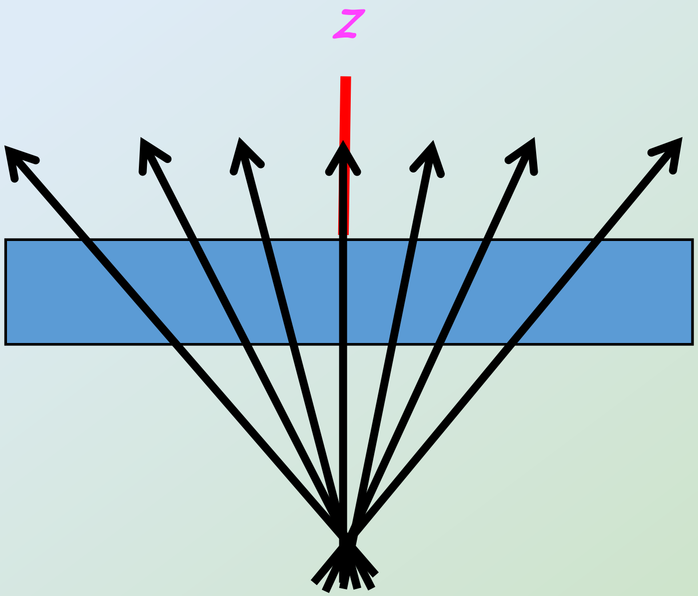
Orthoscopic vs conoscopic light



Orthoscopic light

$$\Delta = t(N - n)$$



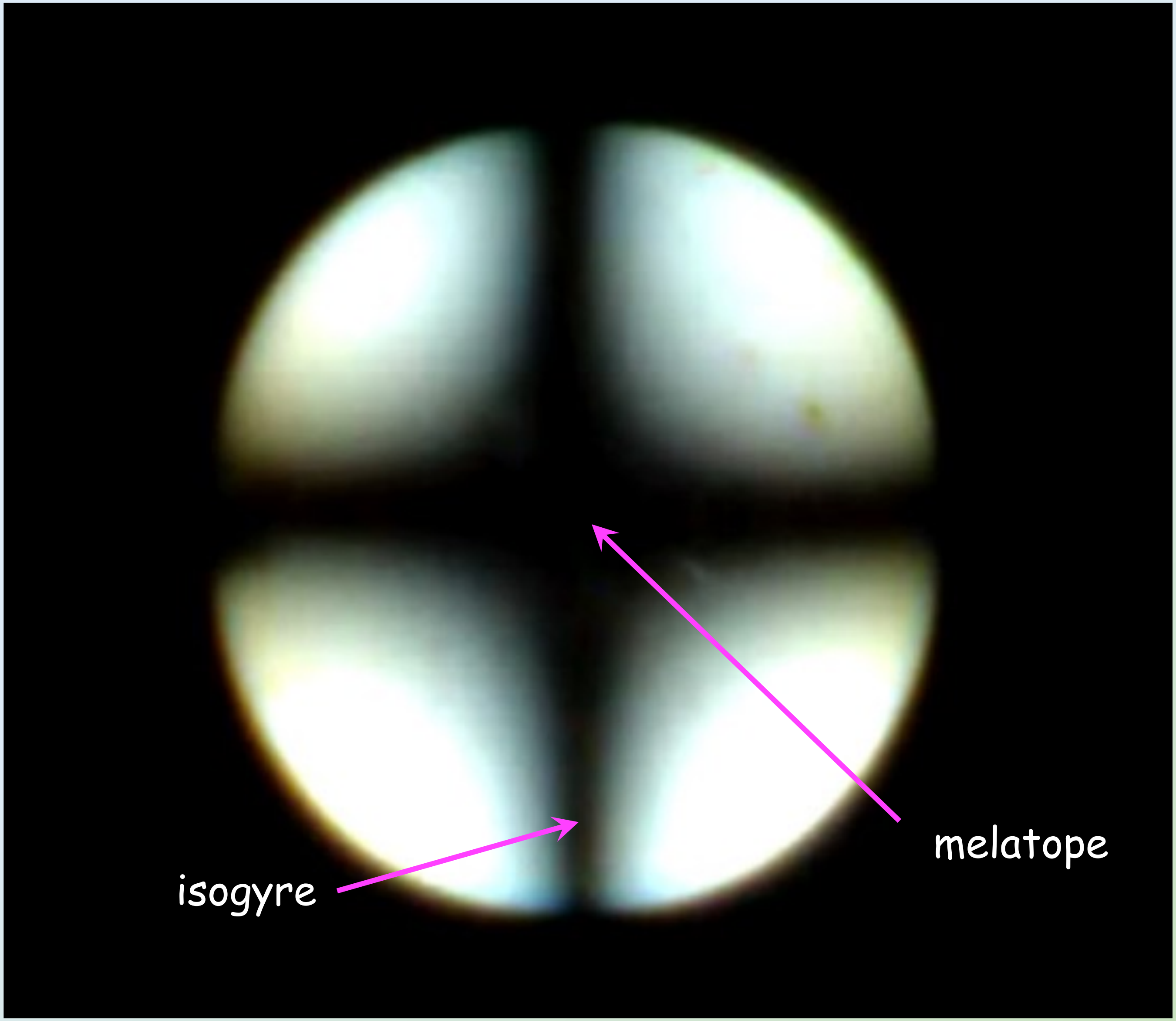


Conoscopic light

Determination uniaxial vs biaxial anisotropic mineral

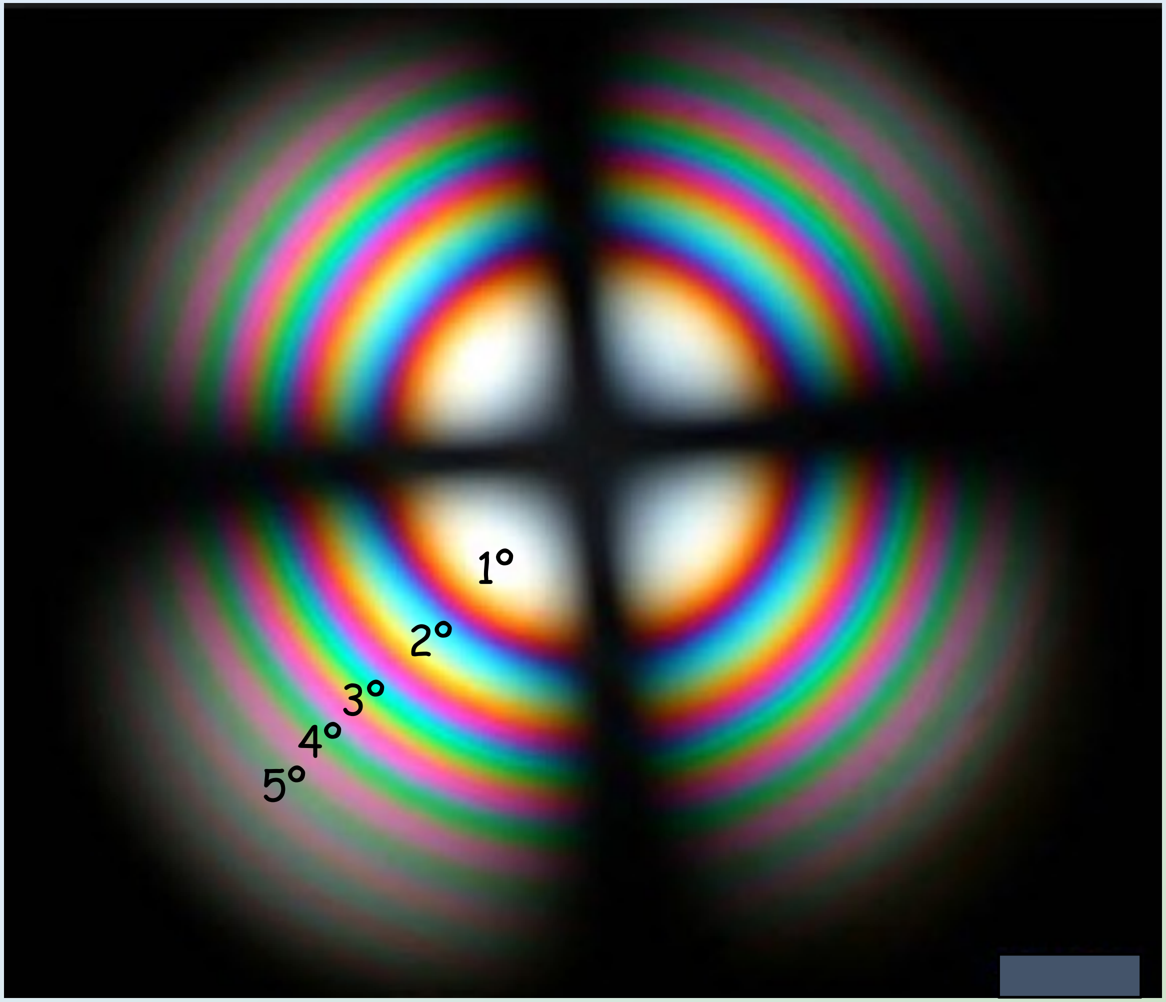
- Whether an anisotropic mineral is uniaxial or biaxial can be determined by viewing a grain cut perpendicular to the optic axis, in conoscopic light (i.e. a grain that remains at extinction) and inserting the Bertrand lens or using a pinhole lens
- if the mineral is uniaxial, then a dark cross will appear in the field of view
- minerals with low birefringence will show first order colours in each quadrant
- minerals with high birefringence will show concentric coloured spectral rings around the centre of the cross (melatope)

Uniaxial optic axis figure
(low birefringent mineral)



Isochromes

(high birefringent uniaxial mineral)



Circles of equal retardation around the melatop

Origin of isochromes

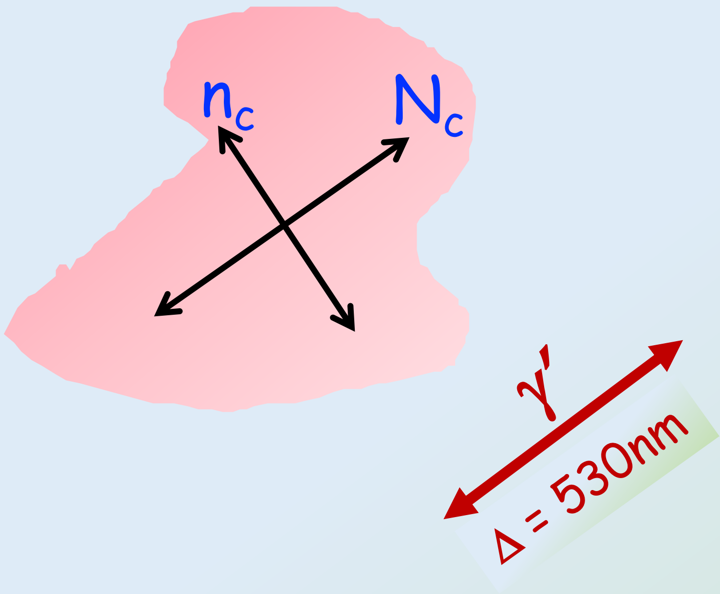
- If the thickness of crystal through which light passes increases so will the path differences

$$\Delta = t(N - n)$$

- with increasing angle between optic axis and the ray → corresponding increase in relative thickness of crystal
- there is also an increase in $(N – n)$ → ε' increases away from optic axis
- variation in path difference → concentric zones of equal retardation

Effect of insertion of the tint plate

(a) Addition



Slow direction in tint plate is parallel to the slow vibration direction in the crystal.

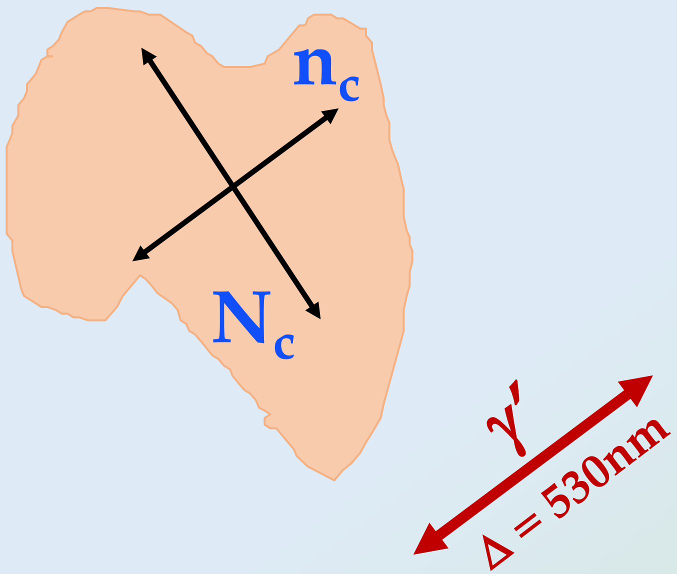
Addition occurs

$$\Delta_{total} = 530 + 530$$
$$= 1060\text{nm}$$
$$= 2^{\circ}\ \text{red}$$

Accessory tint plate → gypsum plate cut so that Δ between slow and fast rays is 530nm

Effect of insertion of the tint plate

(b) Compensation



Slow direction in tint plate is parallel to the fast vibration direction in the crystal.

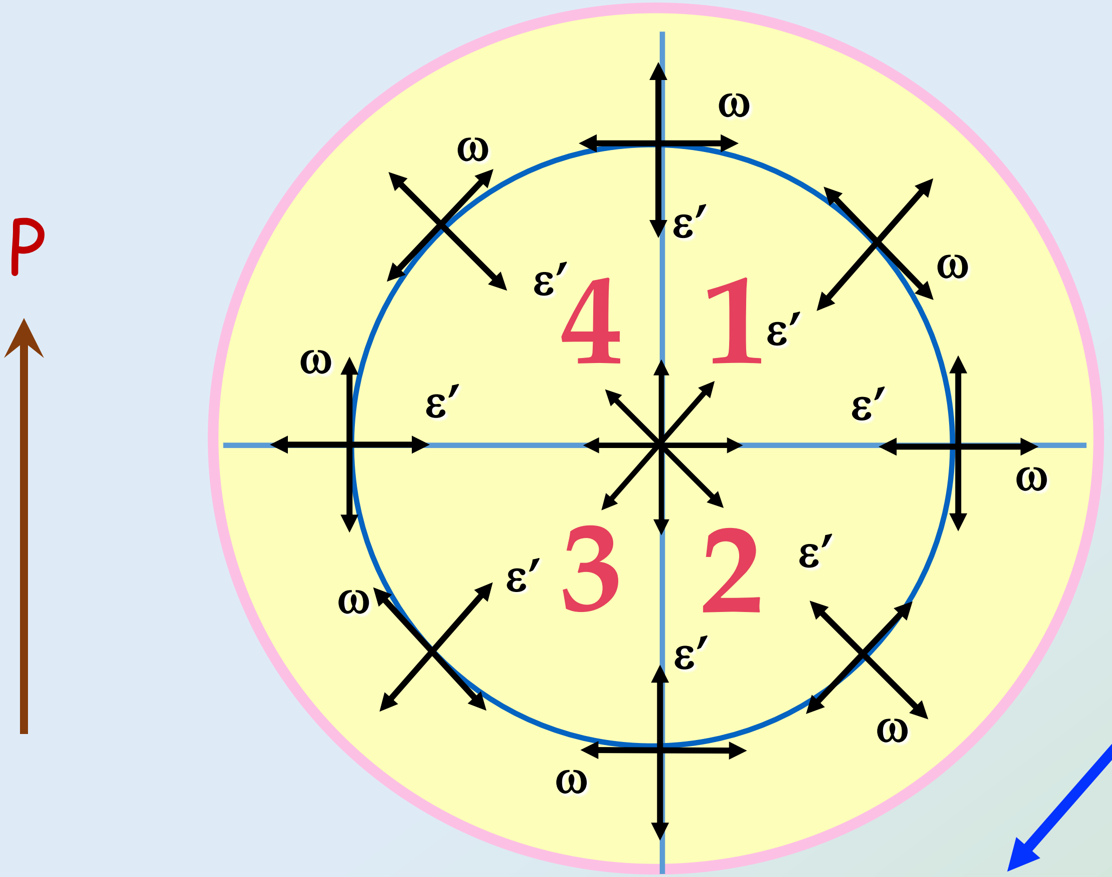
Compensation occurs

Δ_{total} = 530 - 530

= 0nm

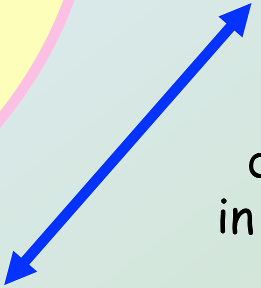
= extinction

Vibration directions in optic axis figures



Quadrants 1&3
ε′ // slow vibration
direction in tint plate

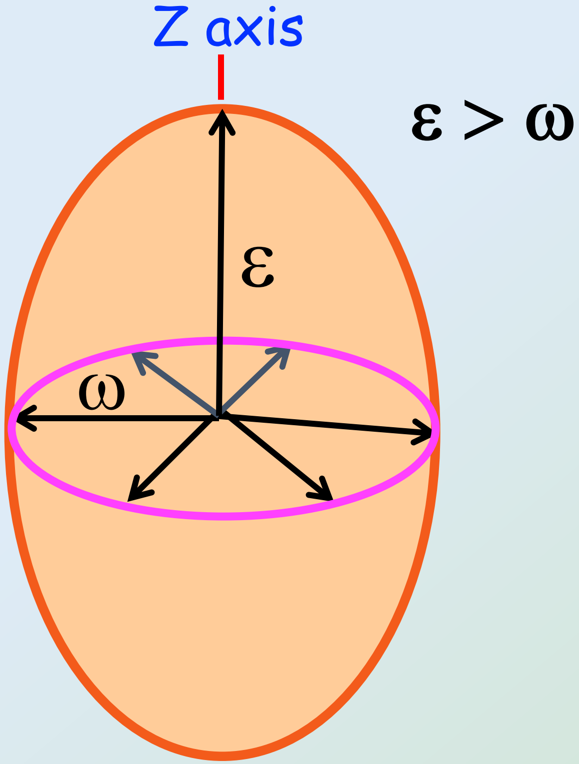
Quadrants 2&4
ω // slow vibration
direction in tint plate



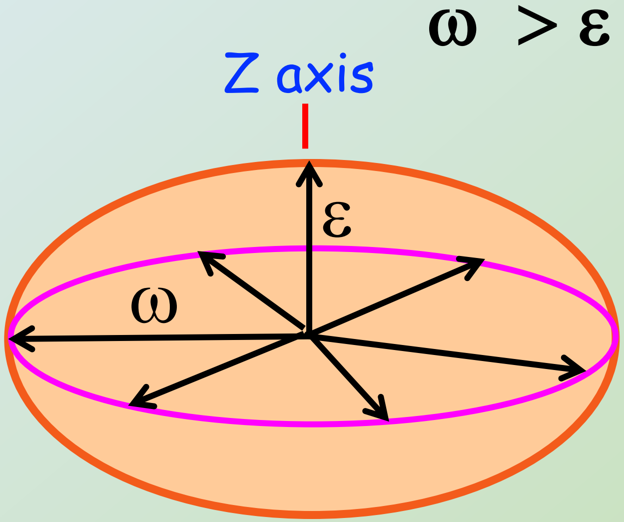
Slow
direction
in tint plate

Only along EW and NS diameters, are vibrations parallel to privileged vibration directions in analyser and polariser.

Optic sign in uniaxial minerals



+ ve



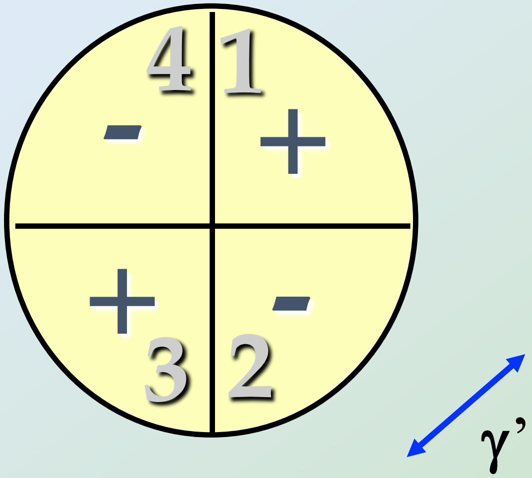
- ve

Optic sign in uniaxial minerals

Uniaxial positive ($\varepsilon > \omega$)

ε = slow ray

ω = fast ray

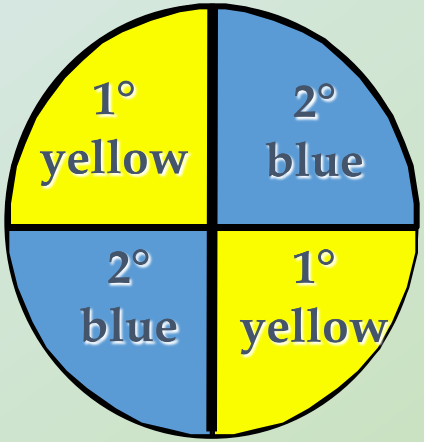


∴ Insertion of the tint plate will produce addition in quadrants 1 and 3 and compensation in quadrants 2 and 4.

For a path difference of 150nm

$\Delta_{\text{(quadrants 1\&3)}}$ =

150nm + 530nm = 680nm (2° blue)



$\Delta_{\text{(quadrants 2\&4)}}$ =

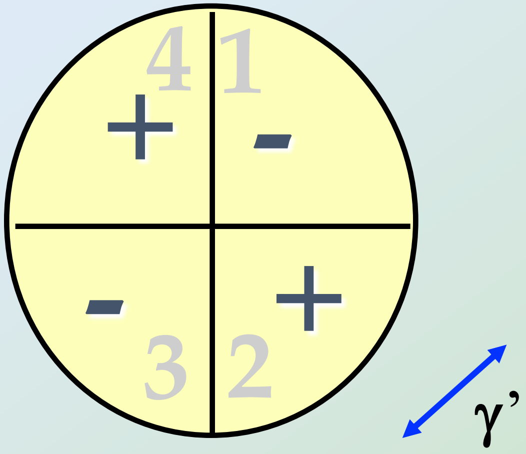
150nm - 530nm = 380nm (1° yellow)

Optic sign in uniaxial minerals

Uniaxial negative ($\omega > \varepsilon$)

ε = fast ray

ω = slow ray



∴ Insertion of the tint plate will produce compensation in quadrants 1 and 3 and addition in quadrants 2 and 4.

For a path difference of 150nm

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150nm - 530nm = 380nm (1° yellow)

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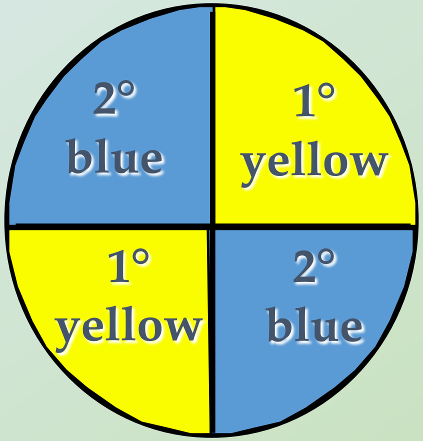
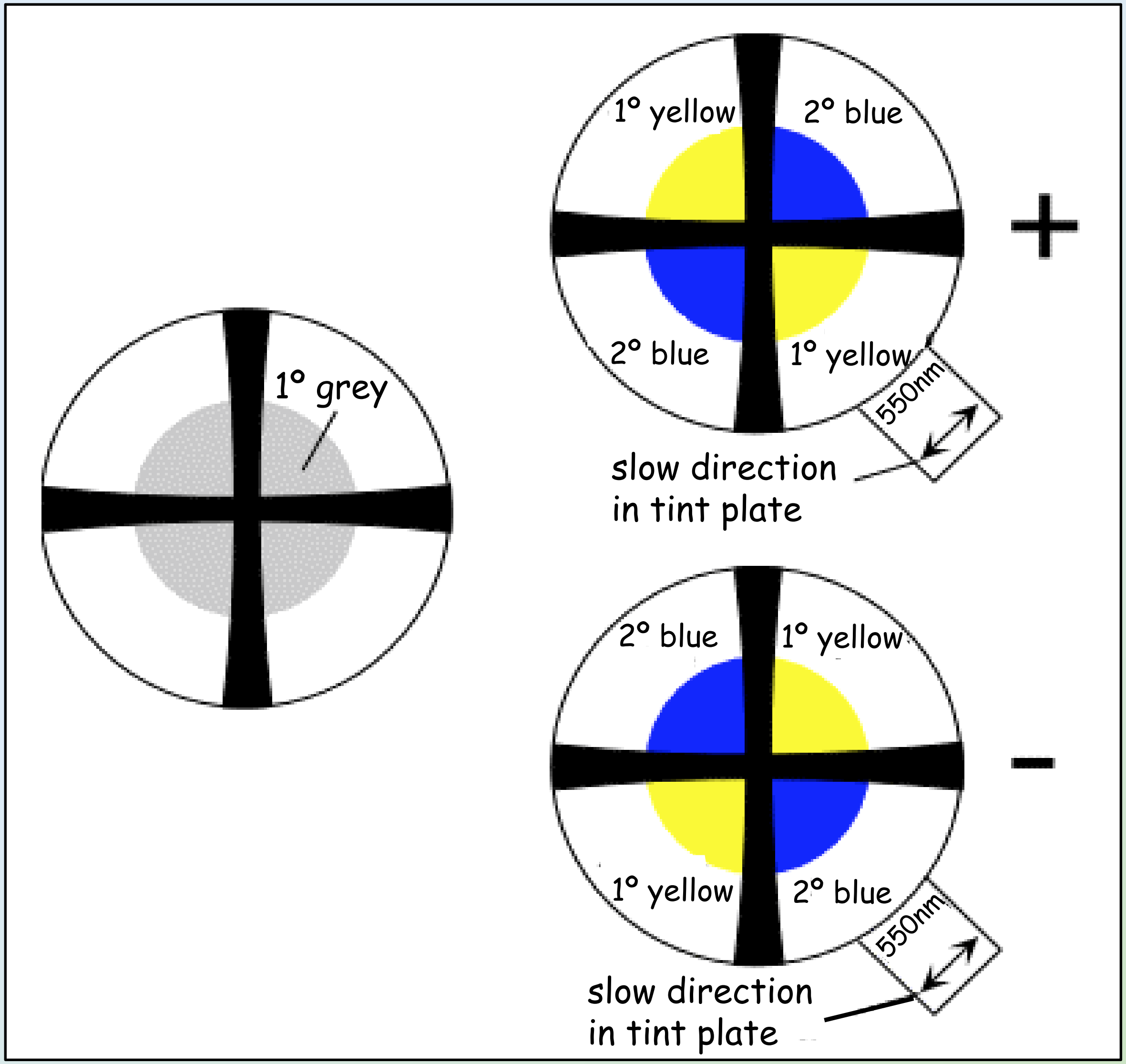
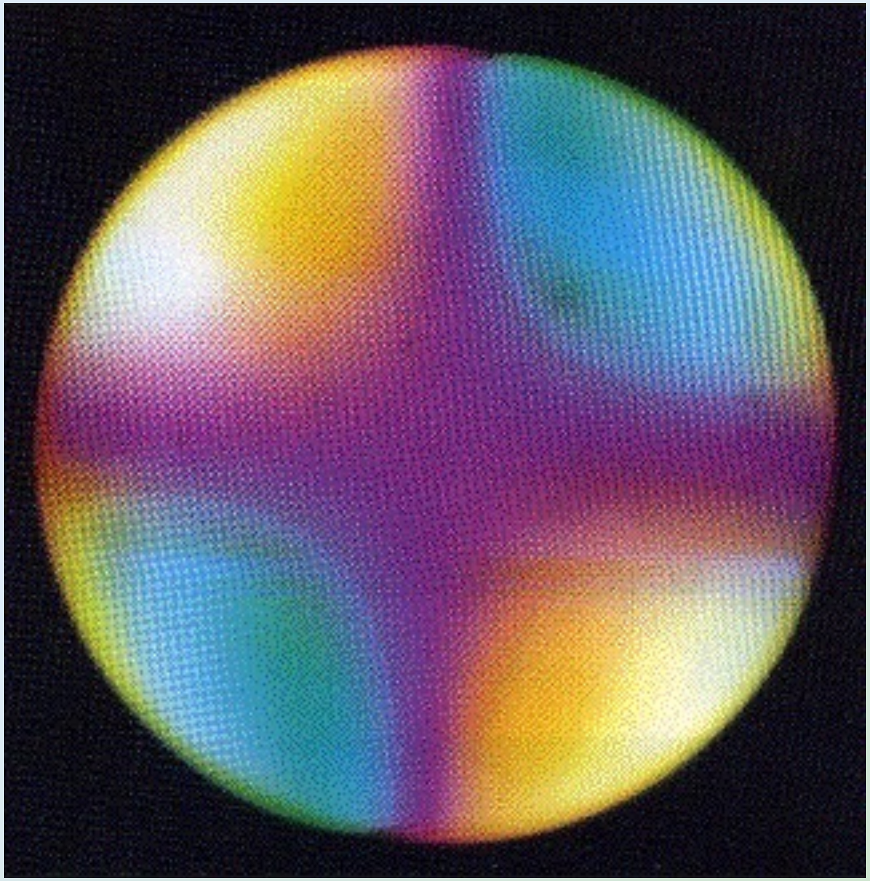
150nm + 530nm = 680nm (2° blue)



Uniaxial optic axis figures



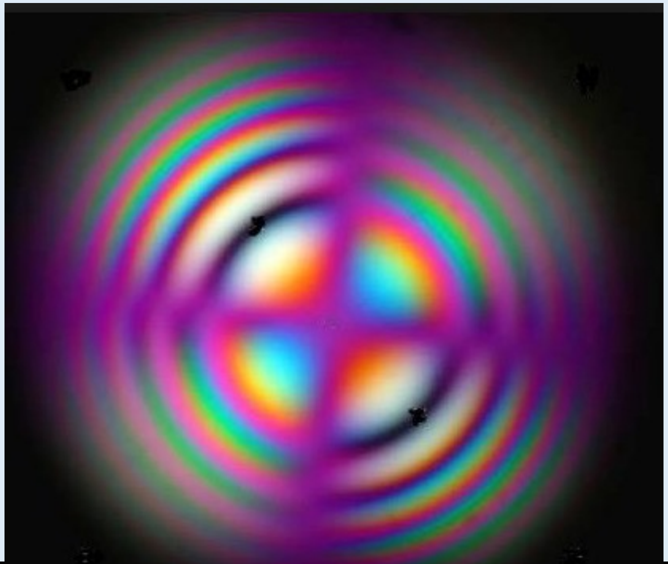
Optic sign in low birefringent uniaxial crystals



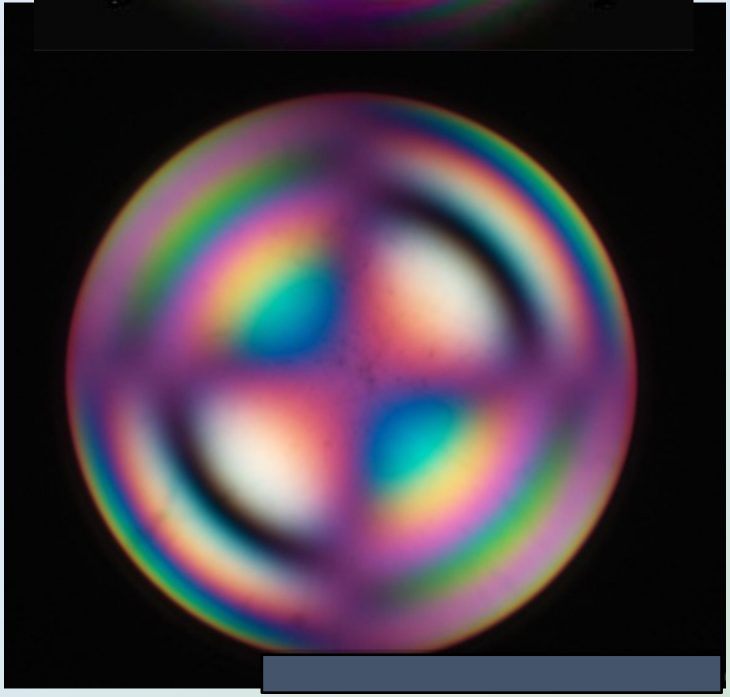
Uniaxial +ve

Optic sign in high birefringent uniaxial crystals

+ve



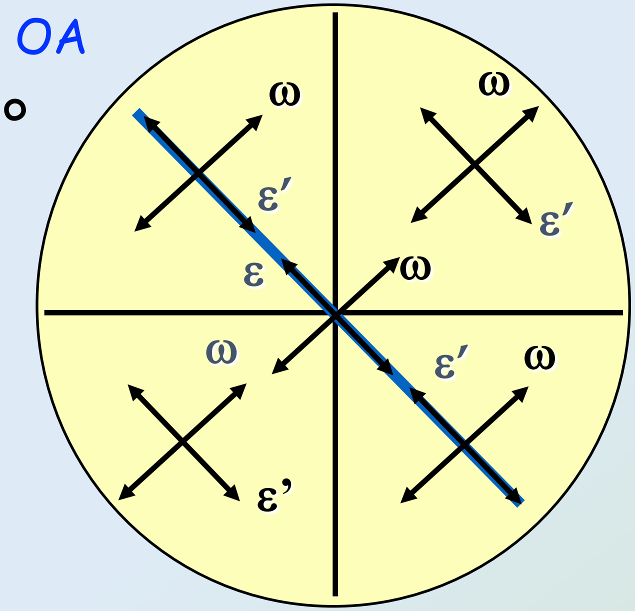
-ve



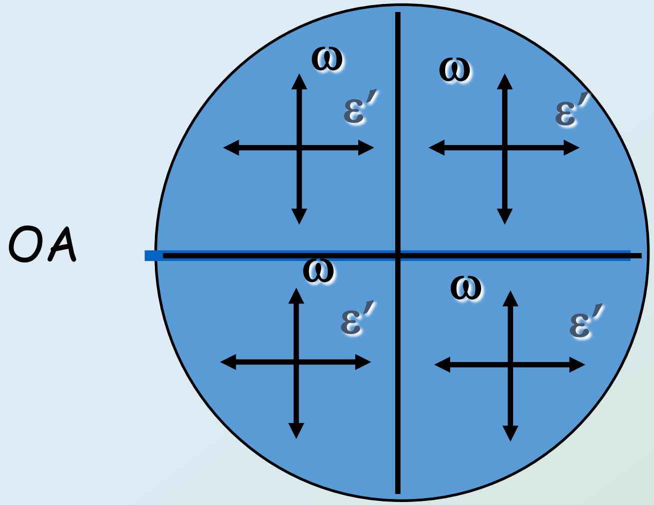
For highly birefringent minerals, isochromes may be present. Since the effects of addition and compensation are most noticeable for first order colours, then the colour changes should be noted for the innermost isochromes adjacent to the melatope.

Flash figures

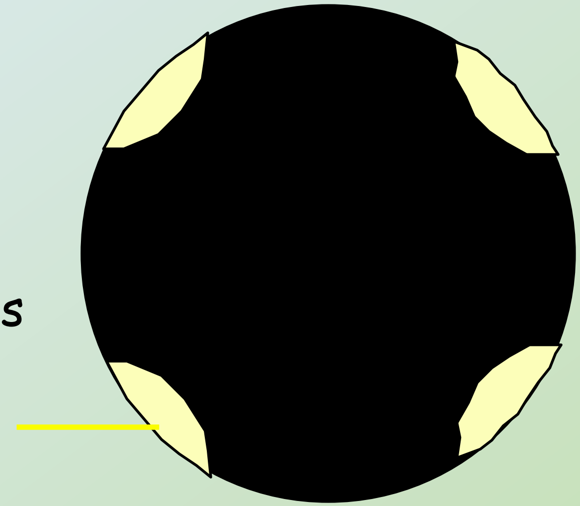
(a) Optic axis at 45°



(b) Optic axis in EW
orientation



(c) Flash figure



Some light passes through and we therefore see a broad cross

Biaxial crystals

- Minerals that crystallise in the orthorhombic, monoclinic and triclinic crystal systems are biaxial i.e. they have two optic axes.

- all rays are essentially extraordinary rays.

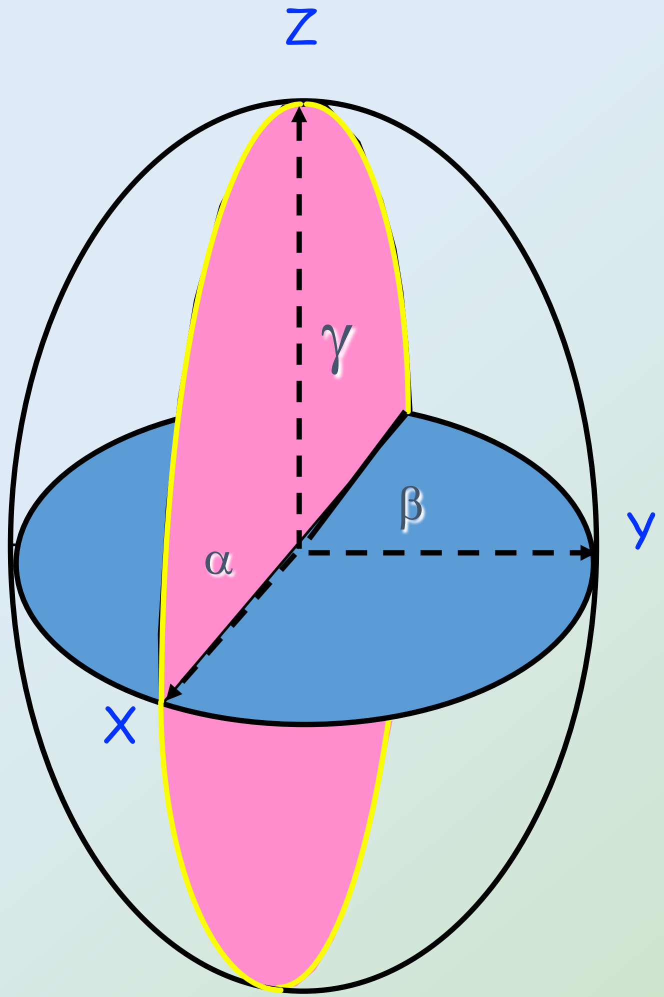
- biaxial minerals are characterised by three unique crystallographic axes x, y and z

- they have three distinct refractive indices γ, β and α defined such that:

$$\gamma > \beta > \alpha$$

Biaxial indicatrix

- A biaxial indicatrix is a triaxial ellipsoid with axes γ, β and α
- These 3 directions are called the principal vibration directions X, Y and Z



$\gamma > \beta > \alpha$

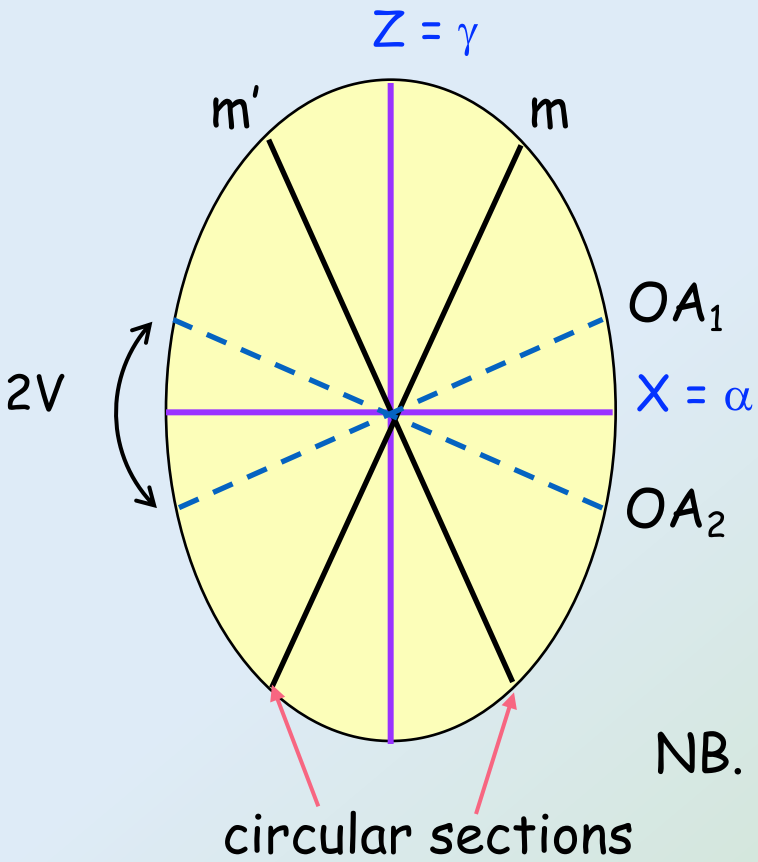
$n_\gamma > n_\beta > n_\alpha$

$c_\gamma < c_\beta < c_\alpha$

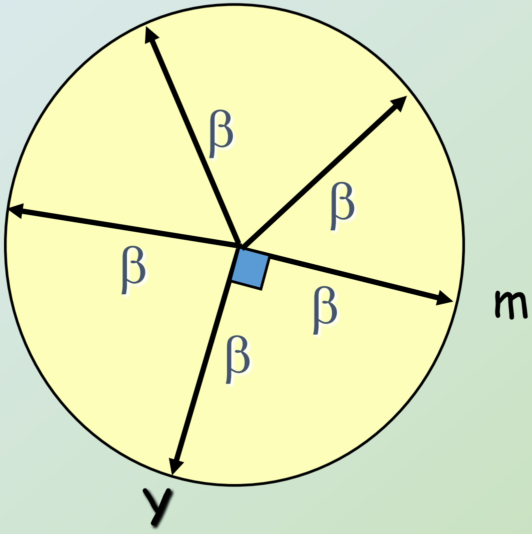
Sections through the biaxial indicatrix

With two important exceptions, sections through the centre of the triaxial ellipsoid are ellipses

Optic axial (XZ) plane



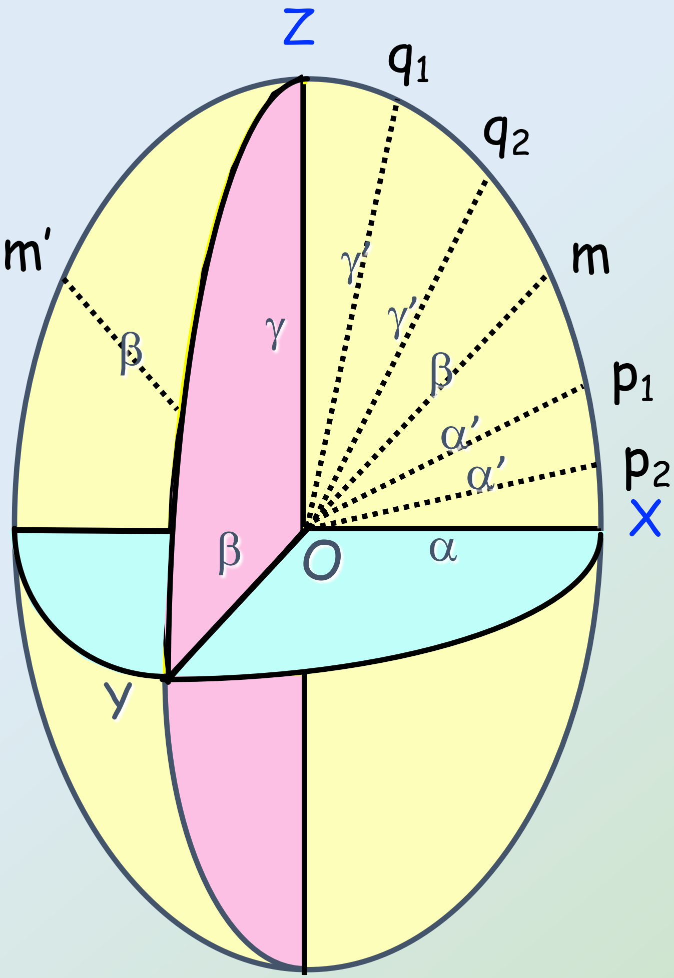
Circular section (perpendicular to optic axis)



NB. (i) Optic axes lie in XZ plane

(ii) β vibrates perpendicular to the OAP

Vibration directions in the XZ plane



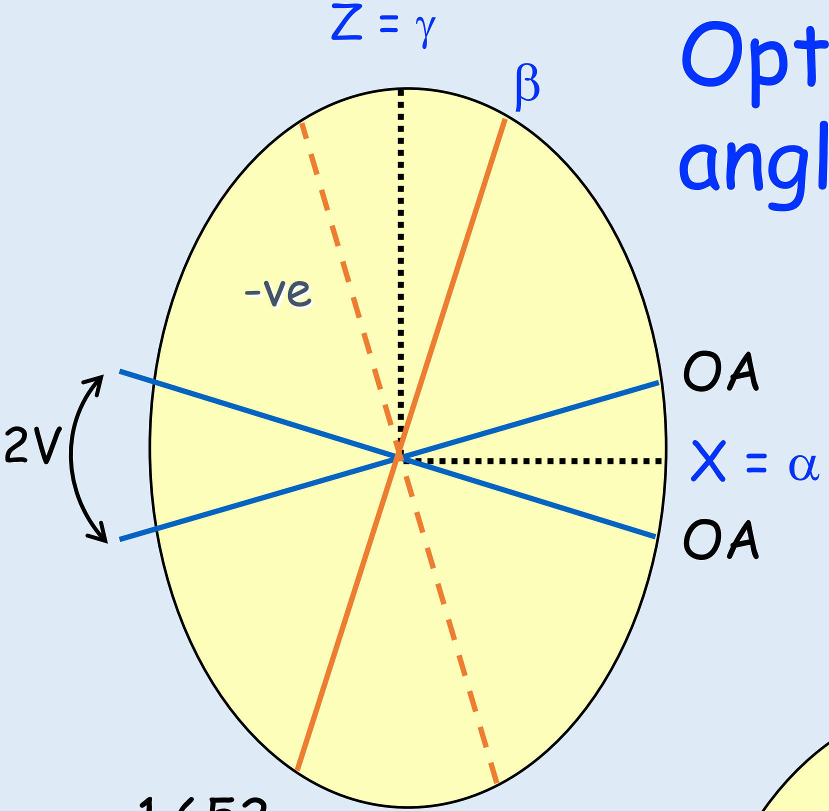
OZ = γ
$Oq_1 = \gamma'$
$Oq_2 = \gamma'$
Om = β
$Op_1 = \alpha'$
$Op_2 = \alpha'$
OX = α

γ' is a RI between γ & β and α' a RI between α & β

Optic axial angle

- The XZ plane containing the two optic axes is called the optic axial plane
- the angle between the two optic axes varies depending on the relative values of β, α and γ
- the acute angle between the optic axes is called the optic axial angle or 2V
- the principal vibration direction that bisects the acute optic axial angle is called the acute bisectrix or BXa
- the principal vibration direction that bisects the obtuse optic axial angle is called the obtuse bisectrix or BXo

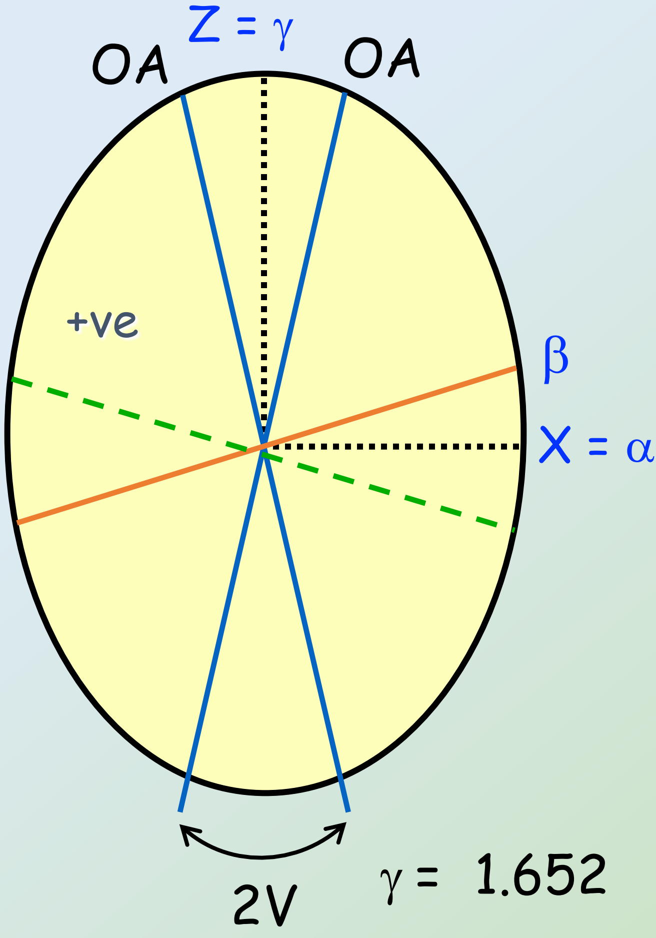
Optic axial angle and sign



γ = 1.652

β = 1.630

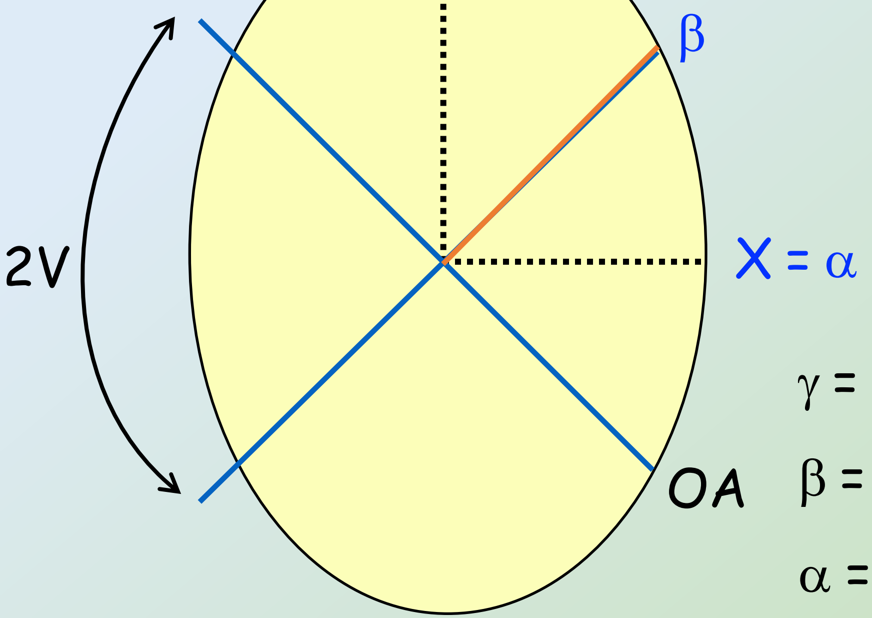
α = 1.530



γ = 1.652

β = 1.535

α = 1.530



γ = 1.652

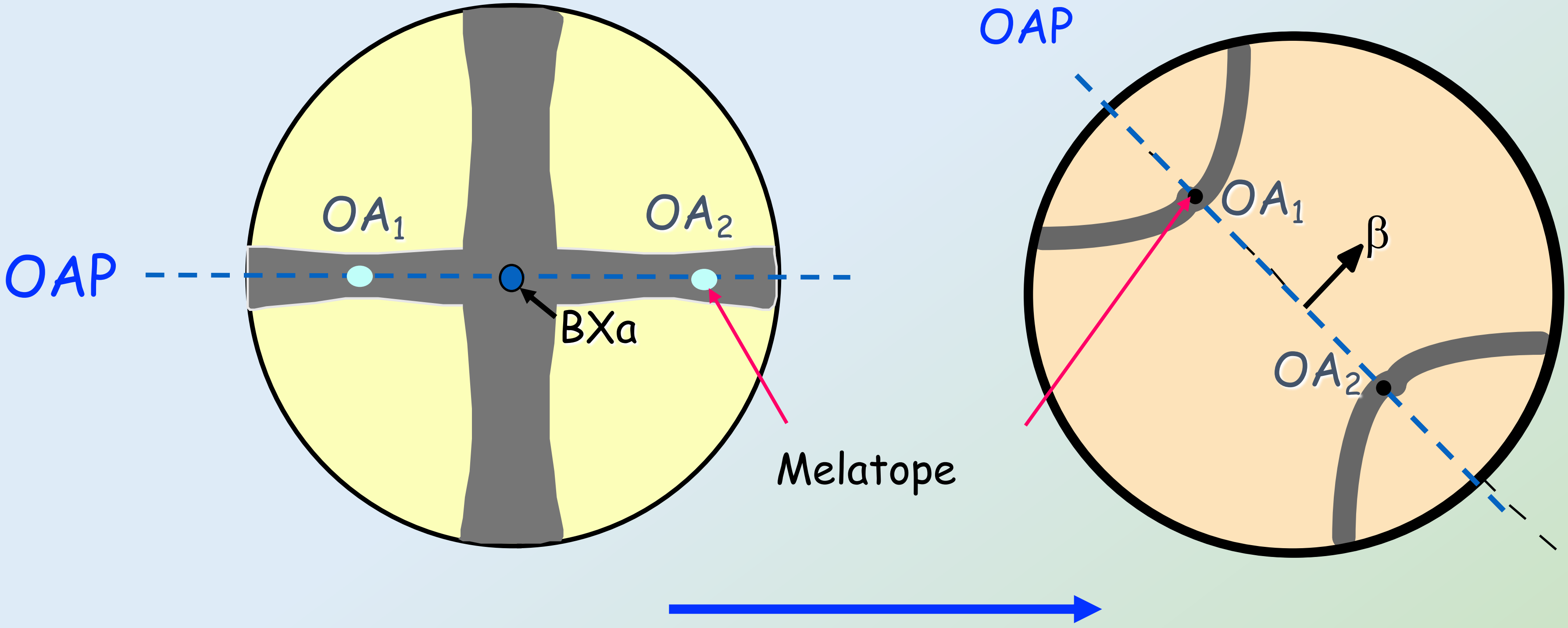
β = 1.591

α = 1.530

Summary of optic axial angles

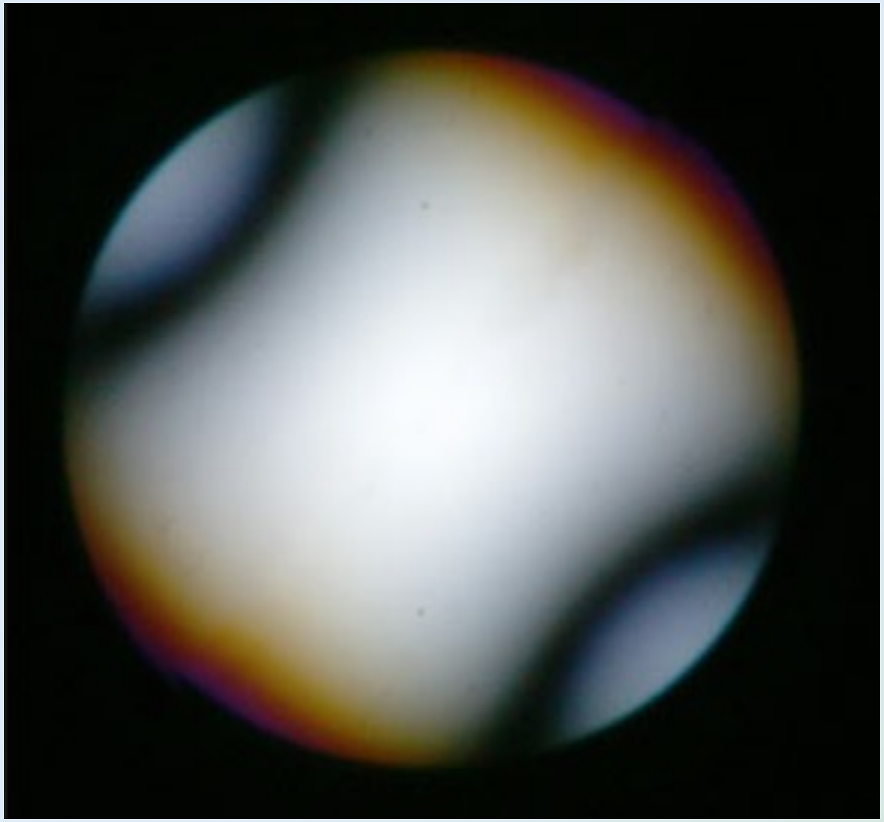
- A principal vibration direction that bisects an acute angle between optic axes is called the acute bisectrix or Bxa
- a principal vibration direction that bisects an obtuse angle between optic axes is called the obtuse bisectrix or Bxo
- when X (α) is the Bxa the mineral is biaxial negative and Z (γ) is the BXo
- When Z (γ) is the Bxa the mineral is biaxial positive and X (α) is the BXo
- When the 2V = 90° then the mineral is neither positive nor negative

Bxa interference figures

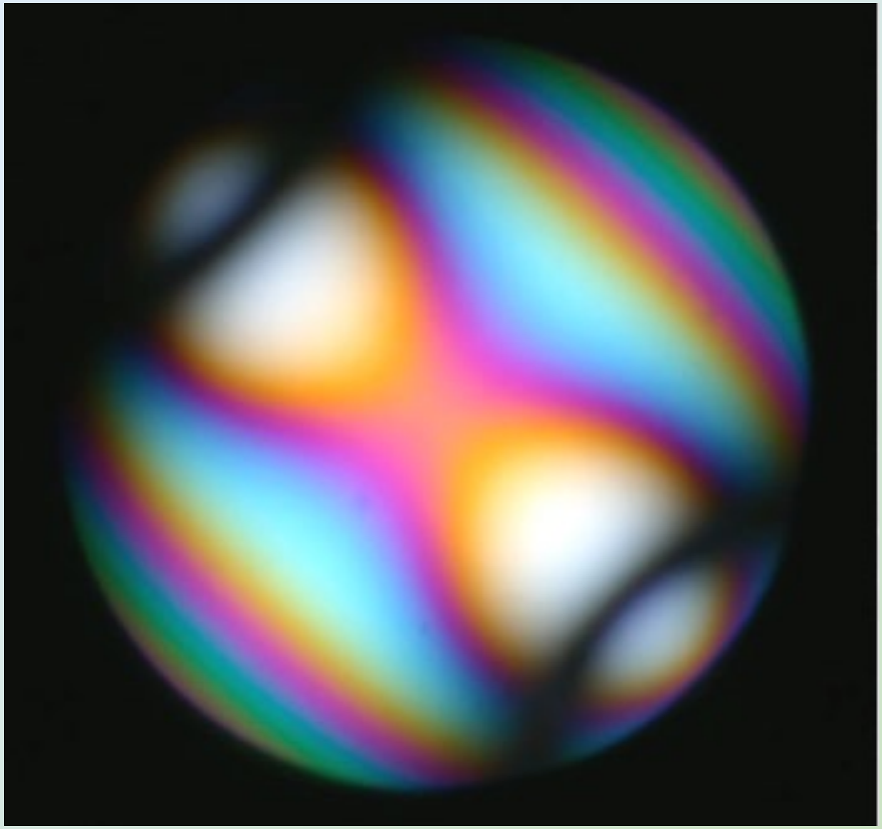


Rotate 45° clockwise

Bxa figure

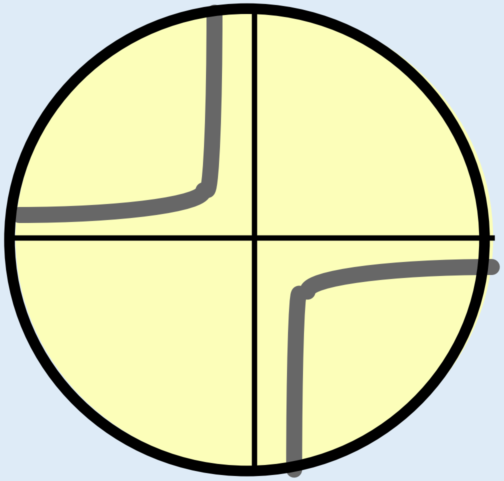


Bxa figure in low birefringent biaxial mineral

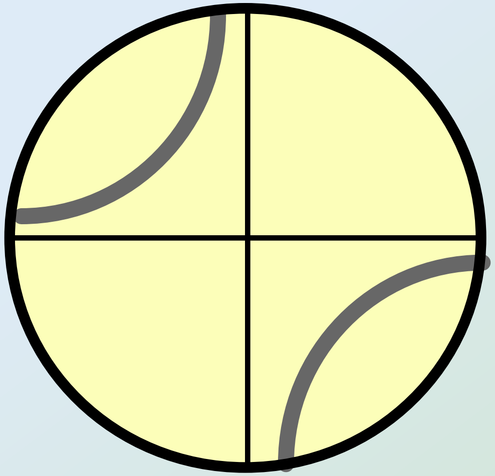


Bxa figure in high birefringent biaxial mineral

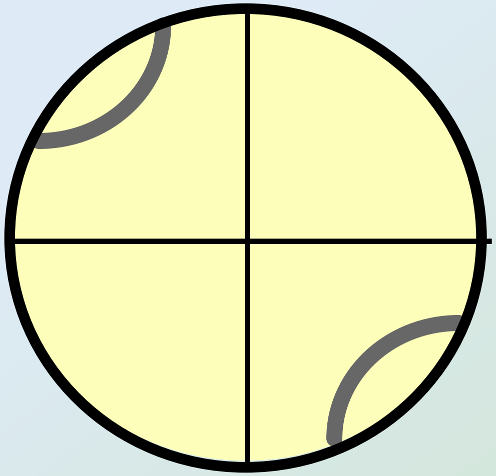
Estimation of 2V from Bxa figures



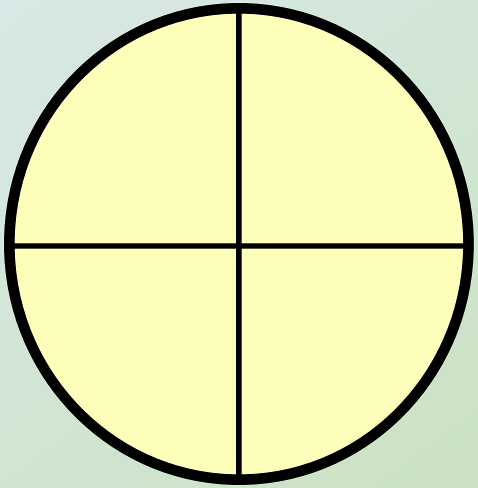
15°



30°



45°



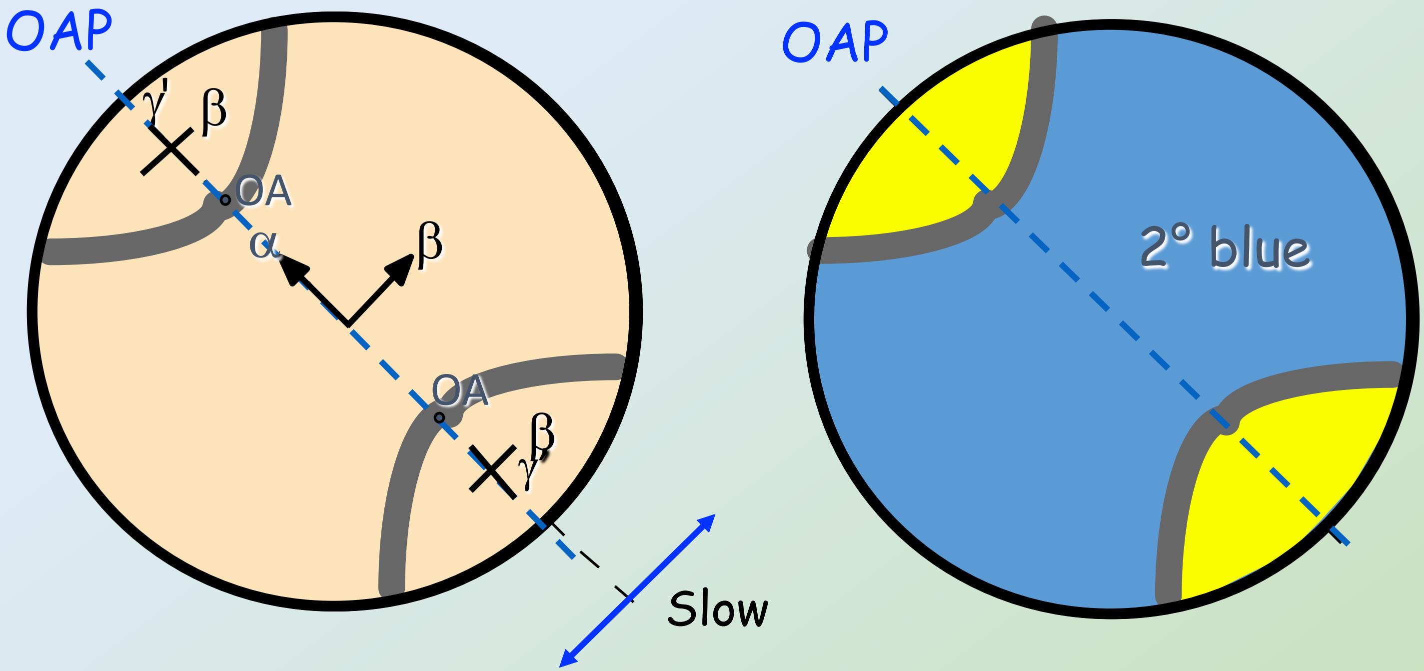
60°

Optic sign from BXa interference figures

Biaxial +ve

γ is the acute bisectrix

$\therefore$ β is the slow ray and addition occurs on convex side of the isogyres when the tint plate is inserted.

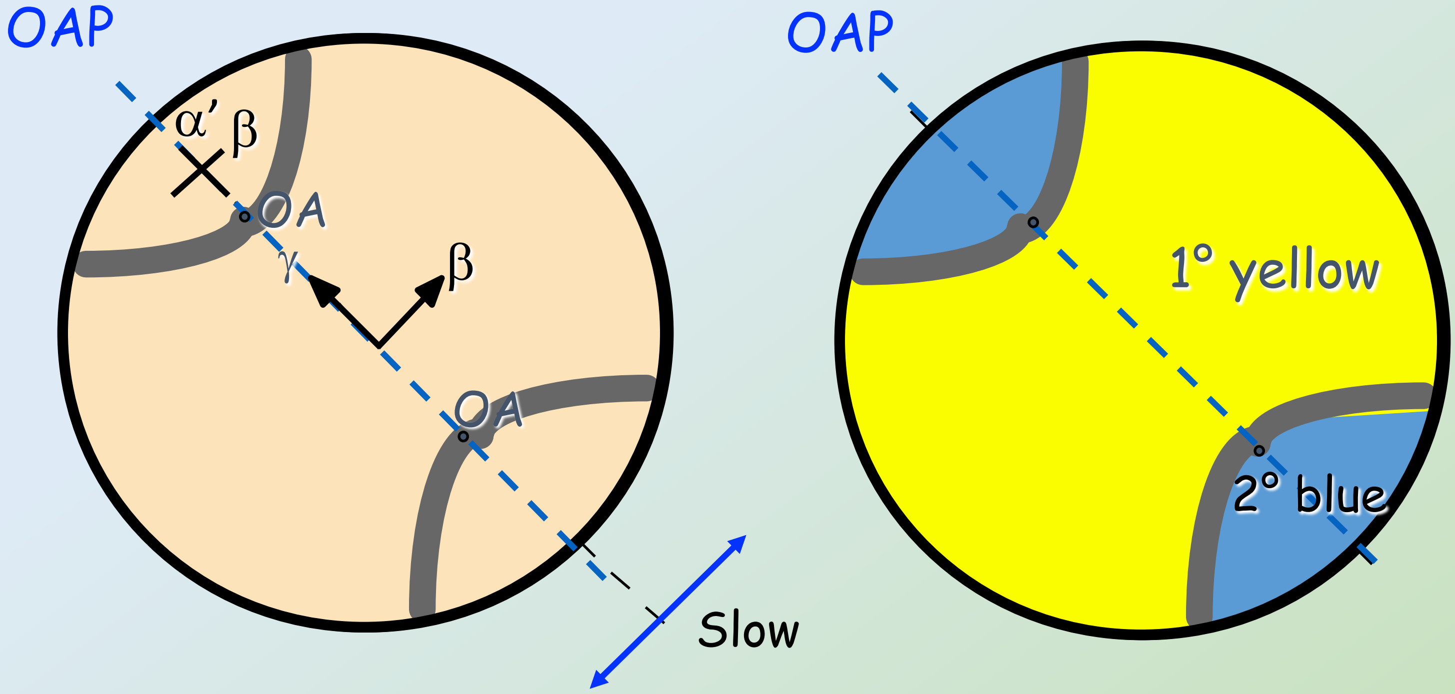


Optic sign from BXa interference figures

Biaxial -ve

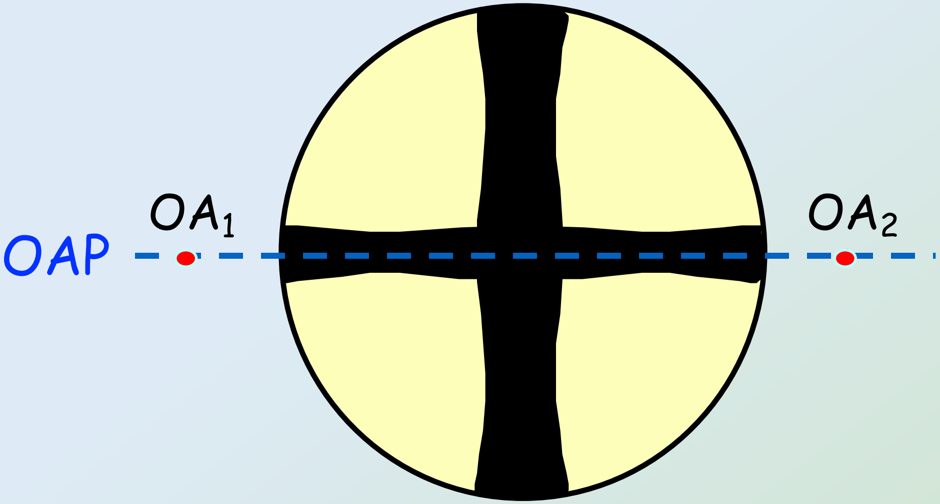
α is the acute bisectrix

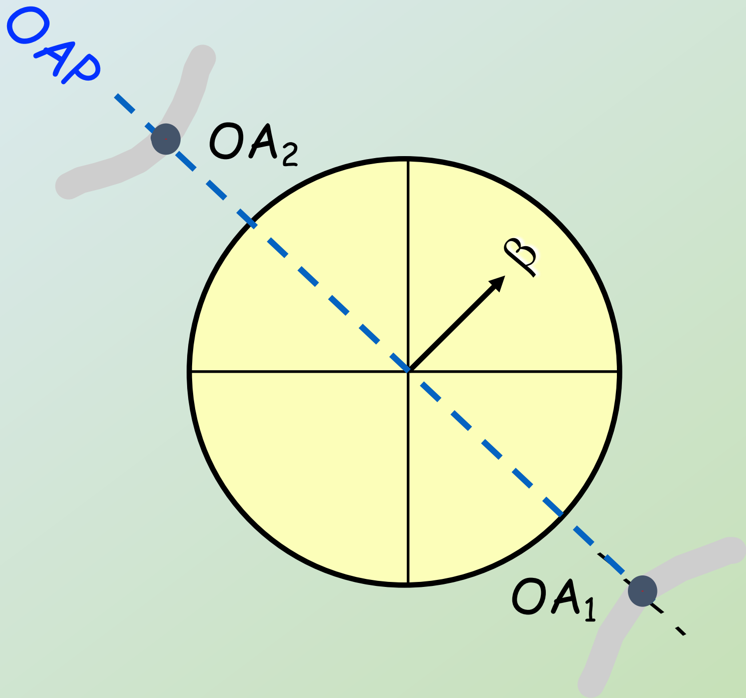
$\therefore$ β is the fast ray and compensation occurs on convex side of the isogyres when the tint plate is inserted.



BXo figures

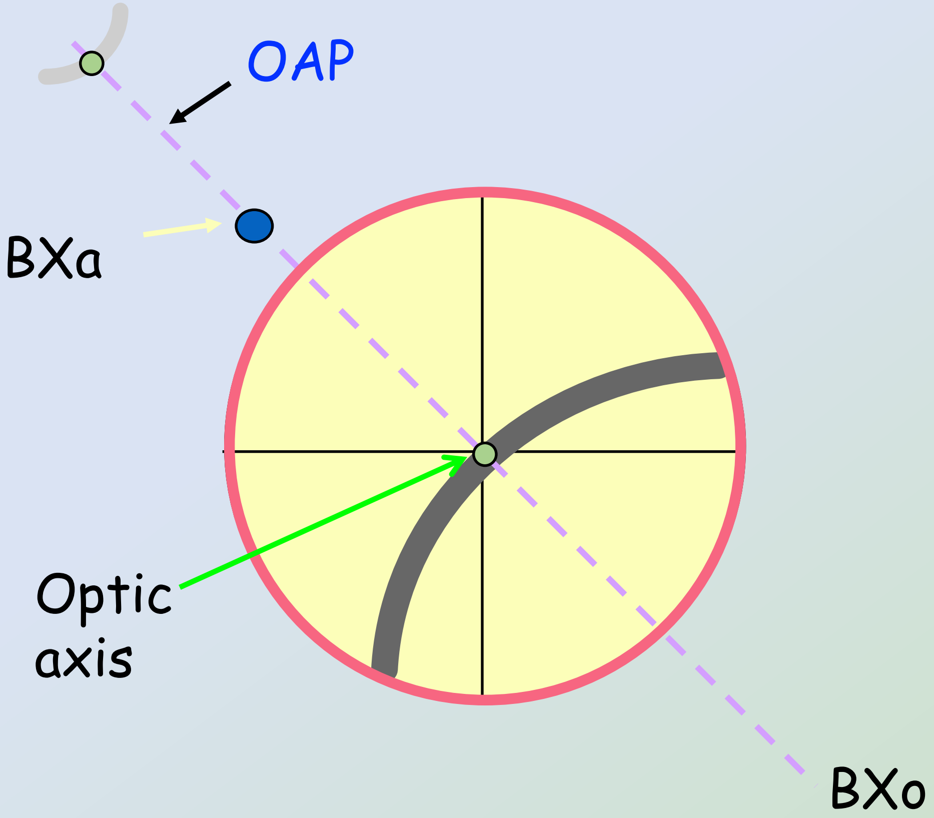
- As 2V increases from 0° to 60° the separation of isogyres increases
- for values above 60° → isogyres leave field of view
- for high 2V → isogyres leave field of view rapidly on rotation
- high 2V Bxa figures difficult to distinguish from Bxo figure

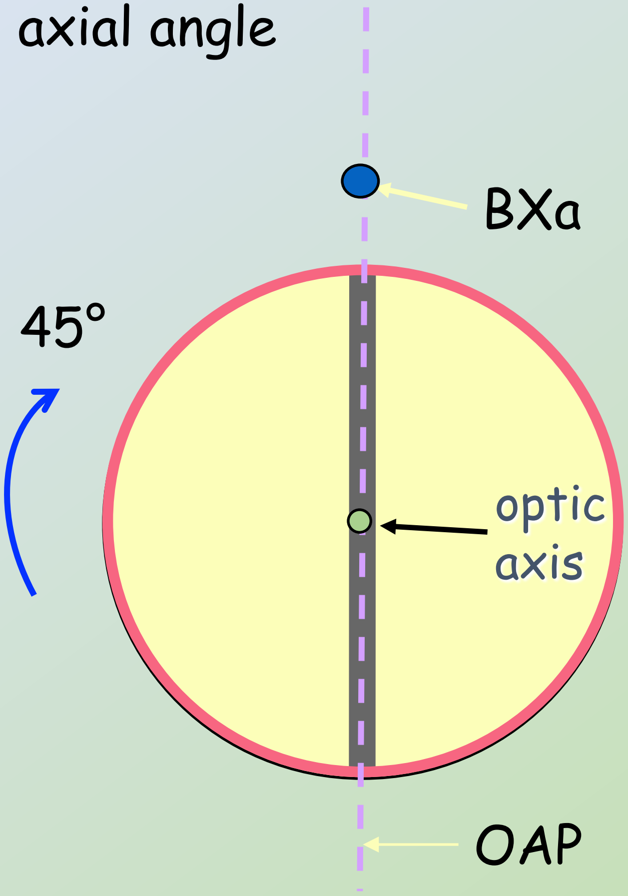




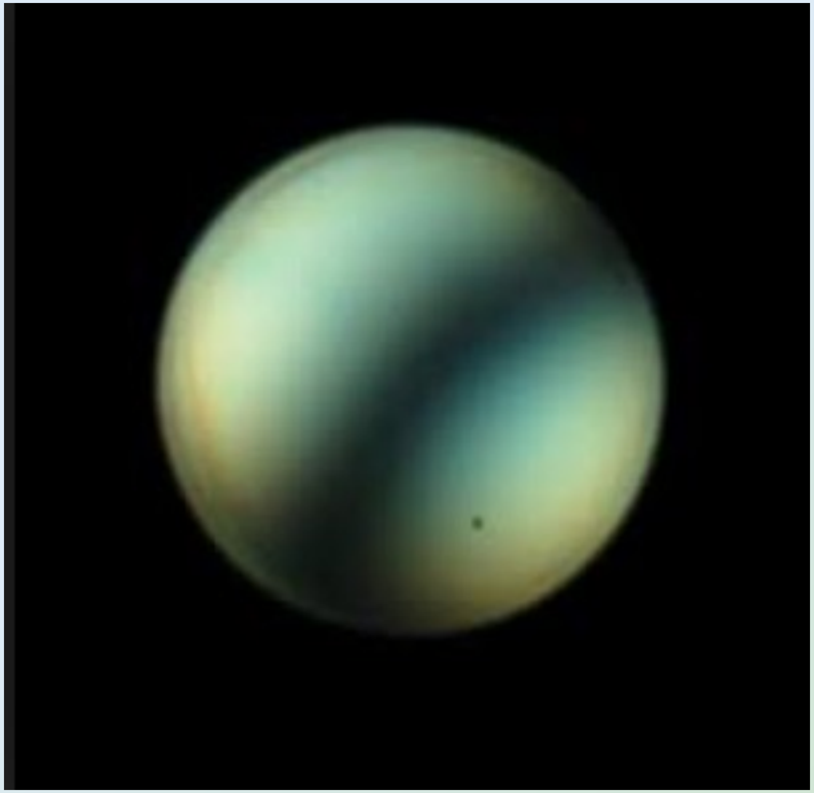
Optic axis figures

- Most useful biaxial interference figure for determining optic properties are grains that remain at extinction under crossed polars
- these figures are called optic axis figures
- N.B. acute bisectrix is on convex sides of isogyre
- can determine → optic sign, estimate optic axial angle

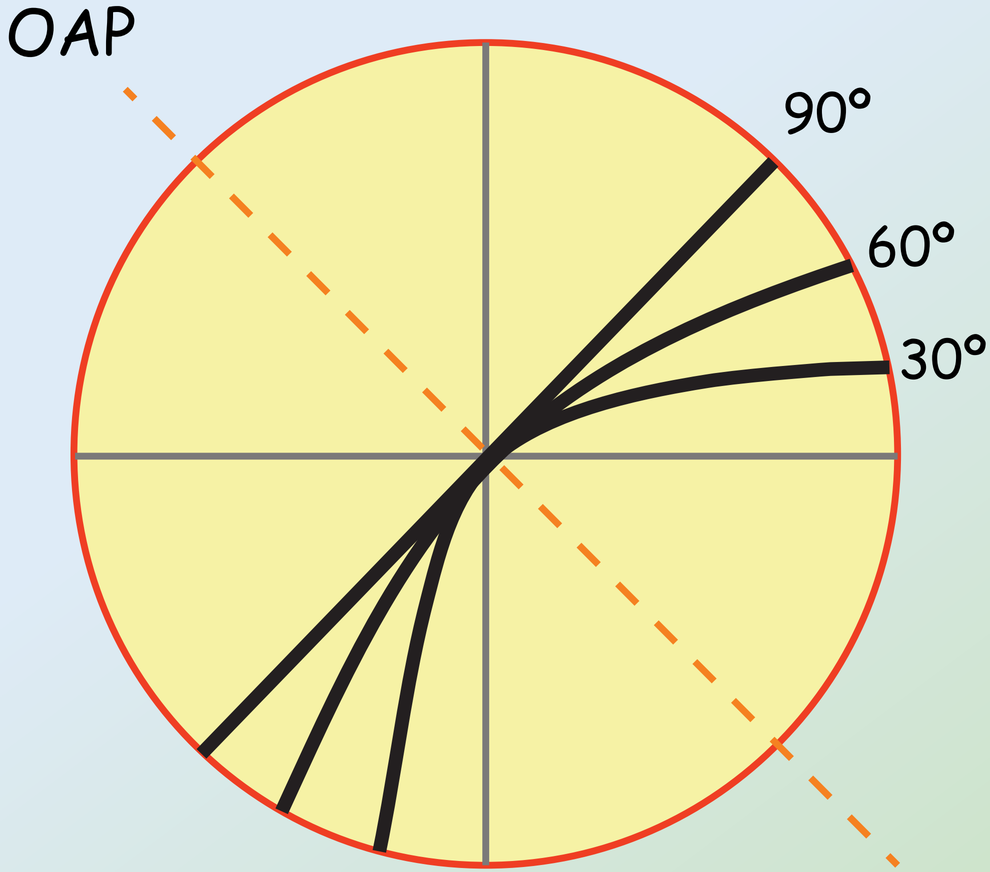




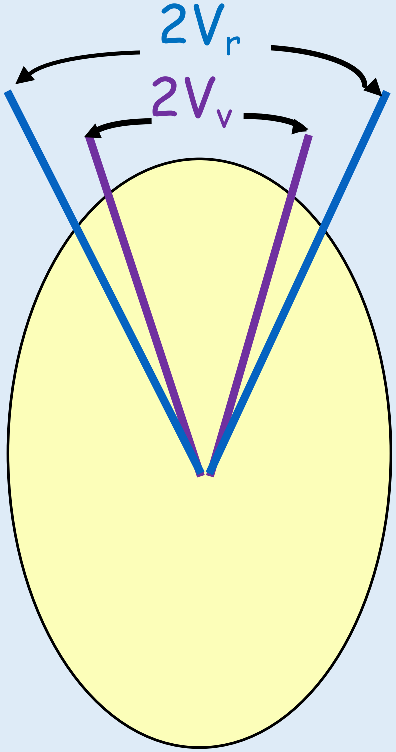
Biaxial optic axis figure



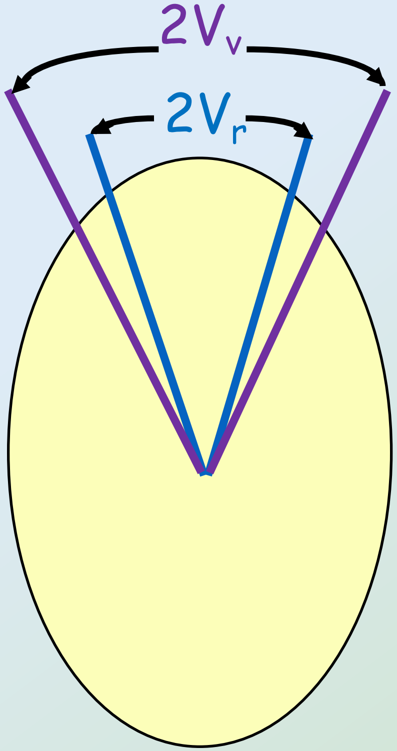
Estimation of 2V from optic axis figures



Optic axis dispersion



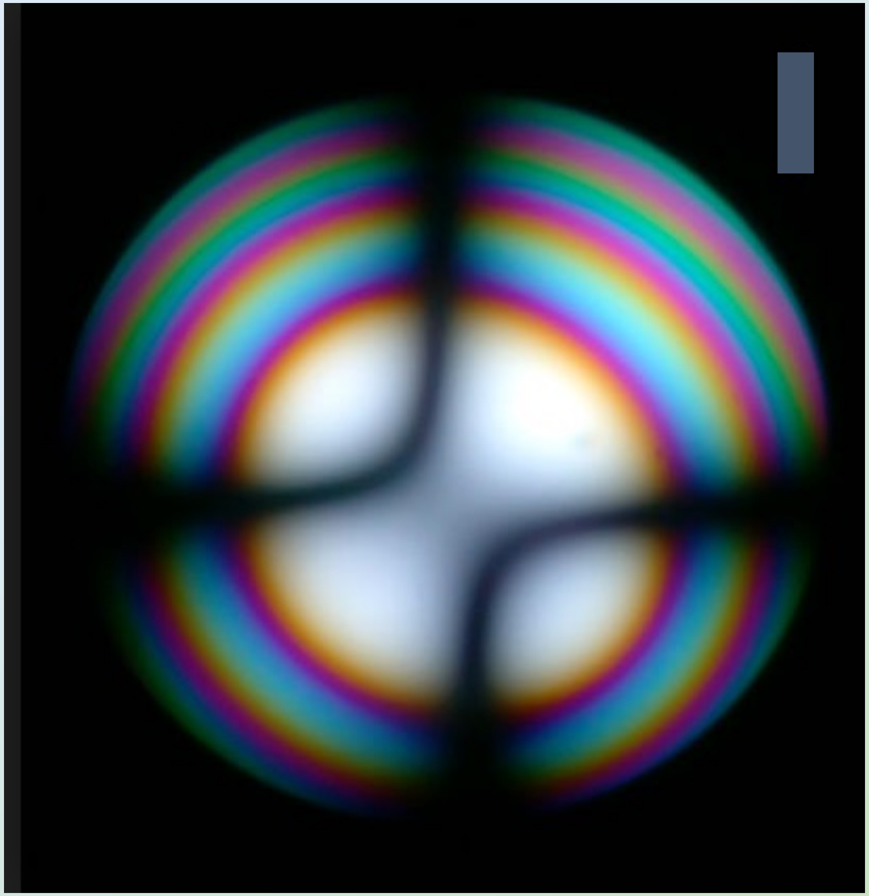
$r > v$ or $\rho > v$



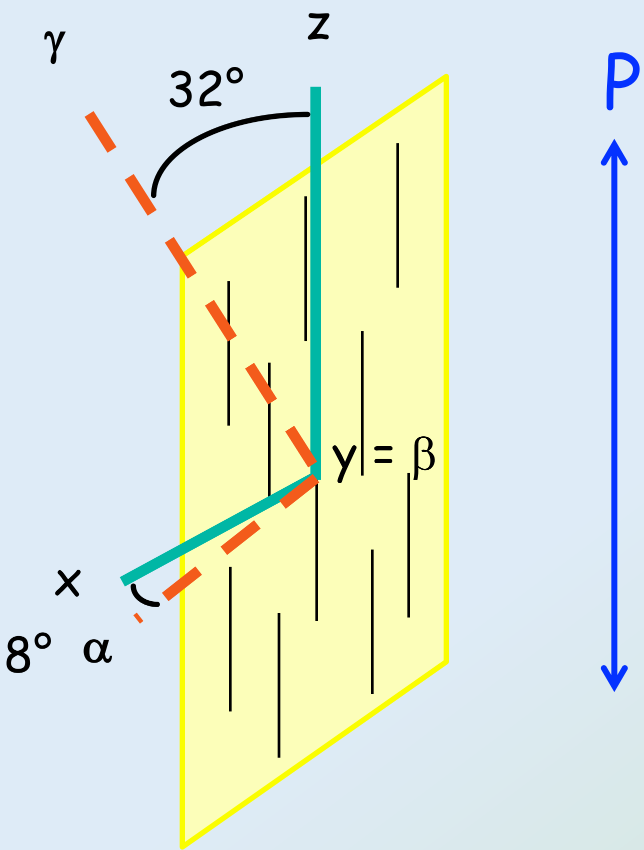
$r < v$

Optic axis dispersion in Bxa figure

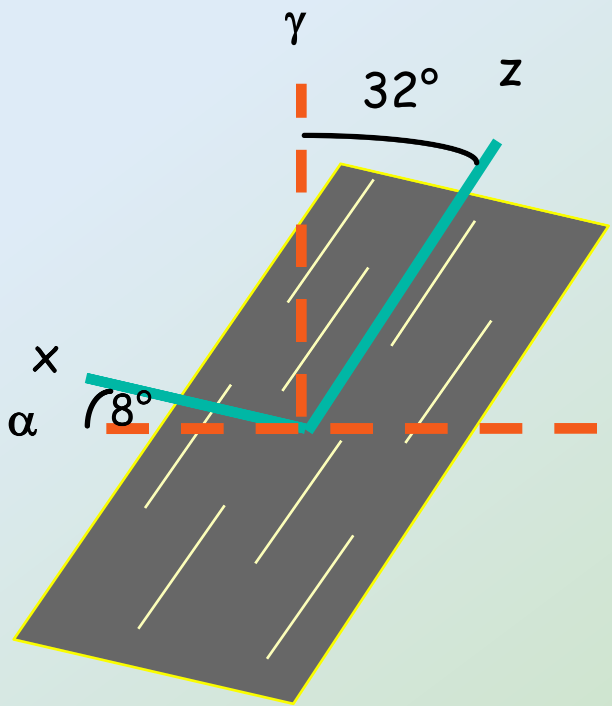
In biaxial minerals, dispersion may cause 2V to vary continuously with wavelength. This phenomenon is called *optic axis dispersion.*



Extinction angles in monoclinic crystals



When the cleavage is parallel to the polariser privileged vibration direction, the grain is not at extinction.



Rotation of the grain 32° clockwise causes the grain to go to extinction. the extinction angle is 32°

γ Λ z = 32°   α Λ x = 8°

Optical properties for mineral identification

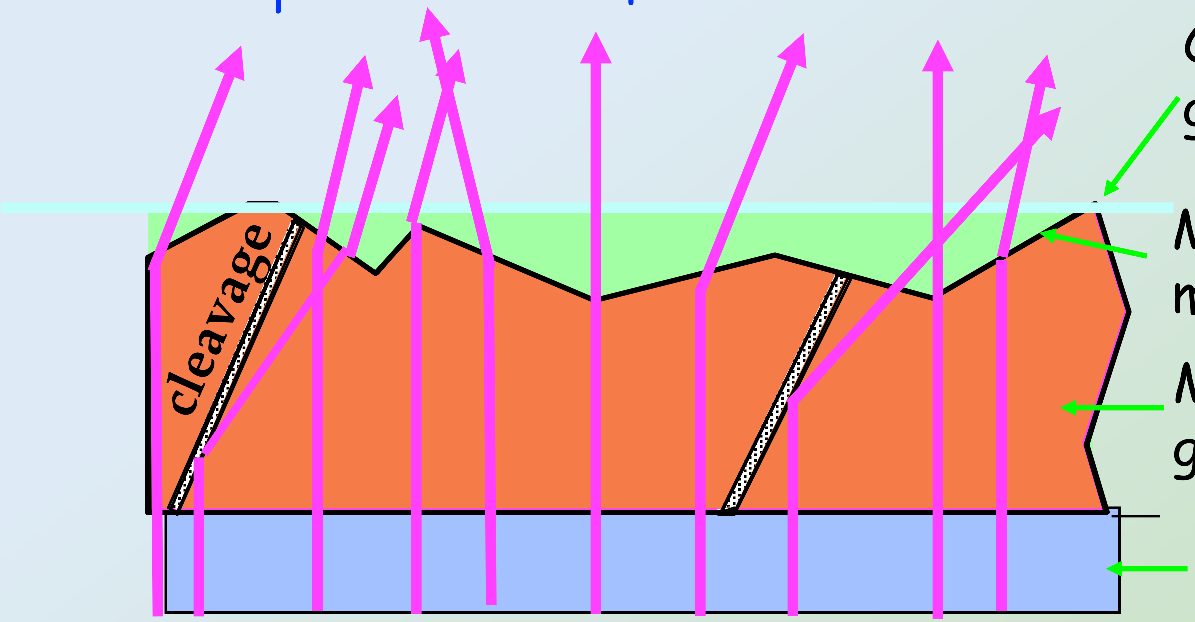
Plane polarised light		Crossed polars
	low birefring. grain	Isotropic or anisotropic
colour		uniaxial, biaxial
relief (est. RI)		optic sign
cleavage (angles)		2V for biaxial minerals
pleochroism		dispersion
crystal shape		birefringence
	high	extinction angles
		length fast or length slow

Relief

- Definition of grain is a consequence of difference in RIs of grain an
  mounting medium
- irregular surface → refraction → uneven distribution of light → rough appearance called relief

Light patch

Dark patch



Cover glass

Mounting medium

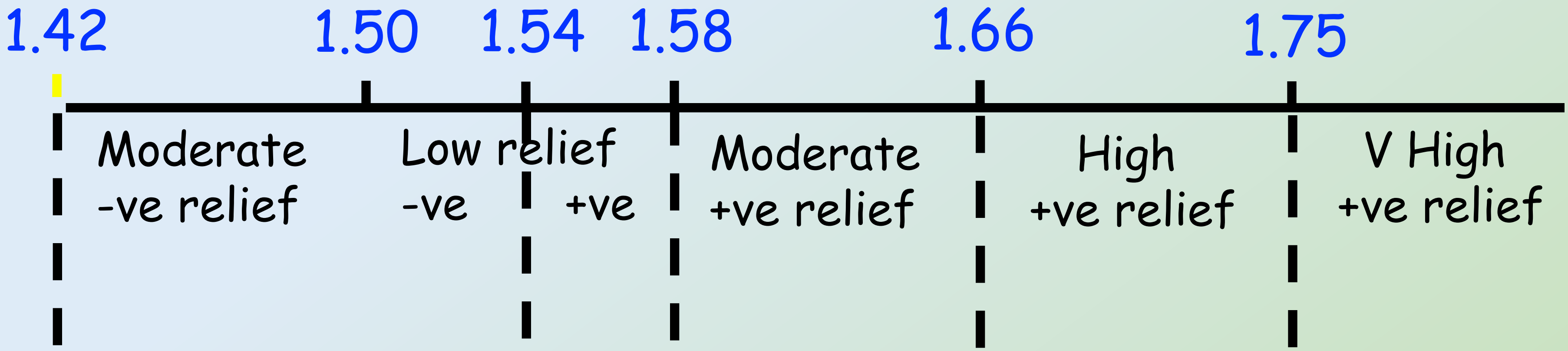
Mineral grain

glass slide

Light from sub-stage condenser of microscope

Relief

In optical mineralogy we do not normally measure the refractive index of minerals but we can estimate them from their relief



1.42 1.50 1.54 1.58 1.66 1.75

Moderate
-ve relief

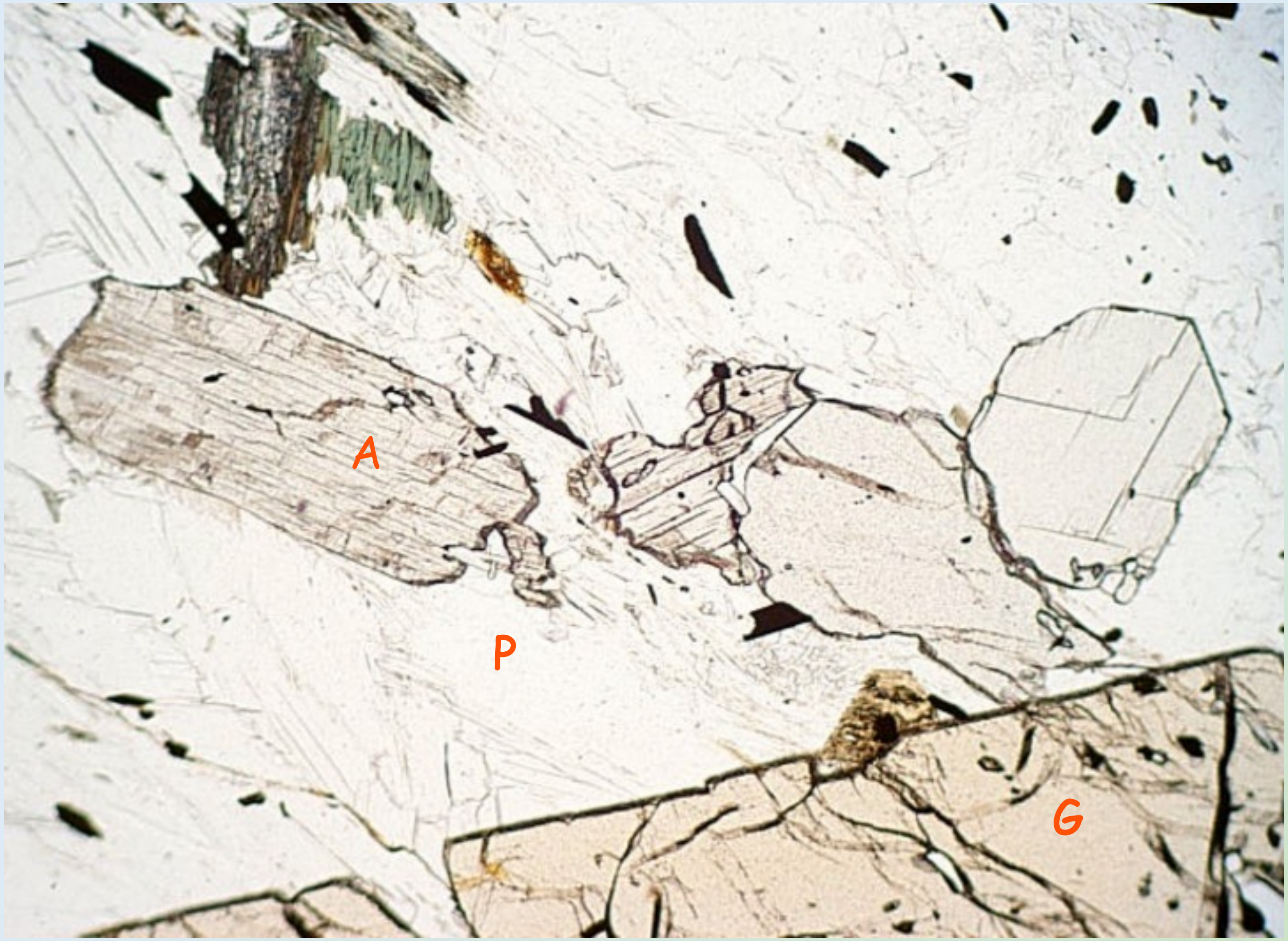
Low relief
-ve +ve

Moderate
+ve relief

High
+ve relief

V High
+ve relief

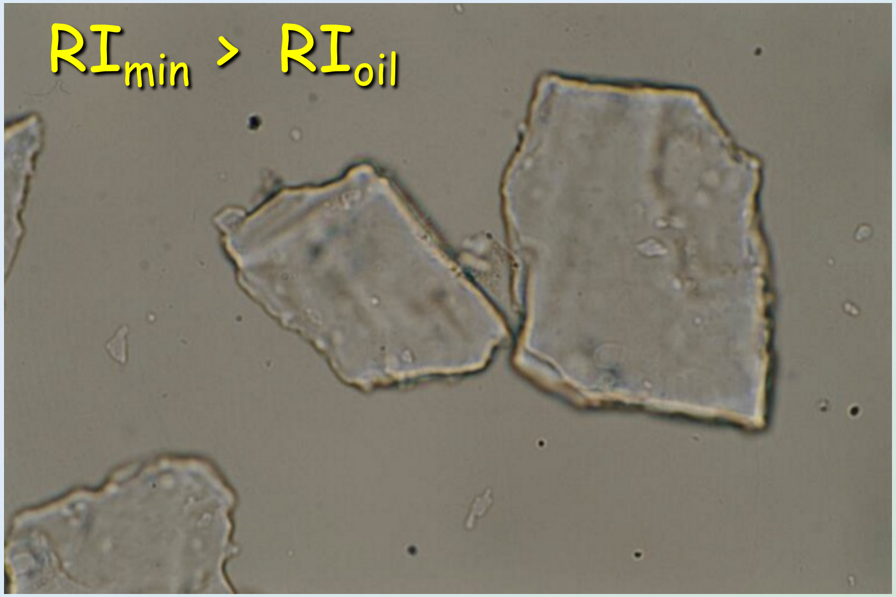
Relief



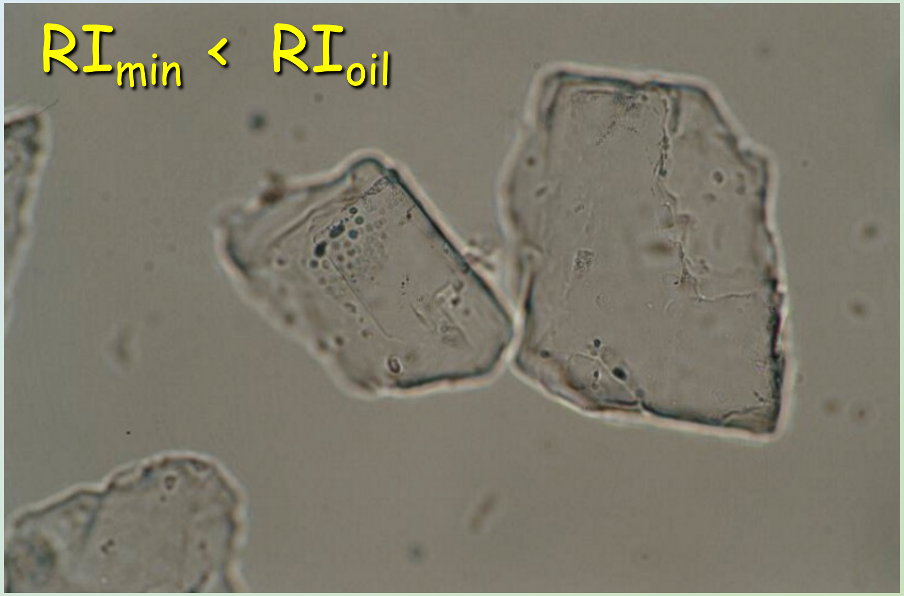
A = amphibole   G = garnet   P = plagioclase

Becke line movement

- Mineral grains are generally thicker in middle → act as crude lenses
- a concentration of bright light (Becke line) forms parallel to grain boundary
- upon lowering the microscope stage, the bright Becke line moves into the medium with the higher refractive index (RI)



$RI_{min} > RI_{oil}$

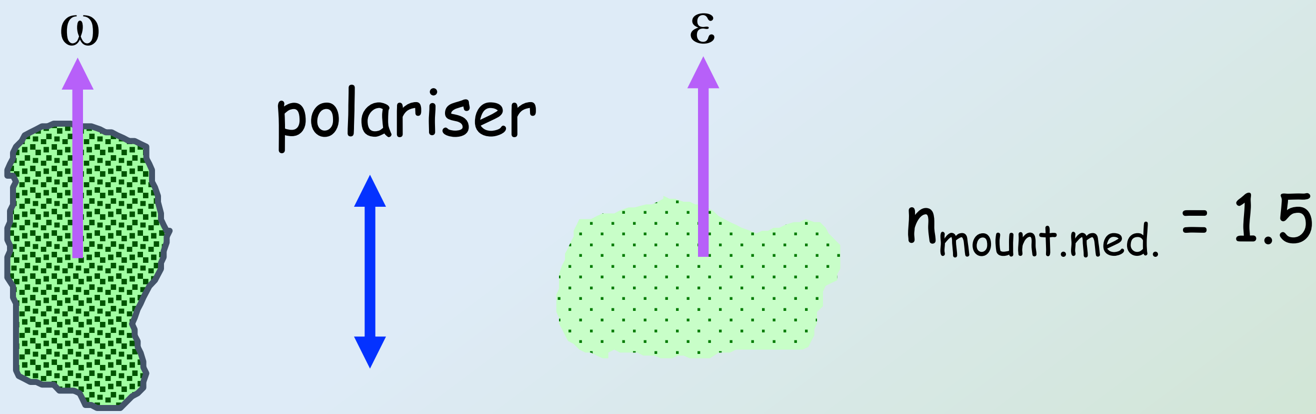


$RI_{min} < RI_{oil}$

Refractive indices of calcite

$\omega = 1.658$ $\varepsilon = 1.486$

$\omega > \varepsilon$ ∴ the mineral is optically -ve



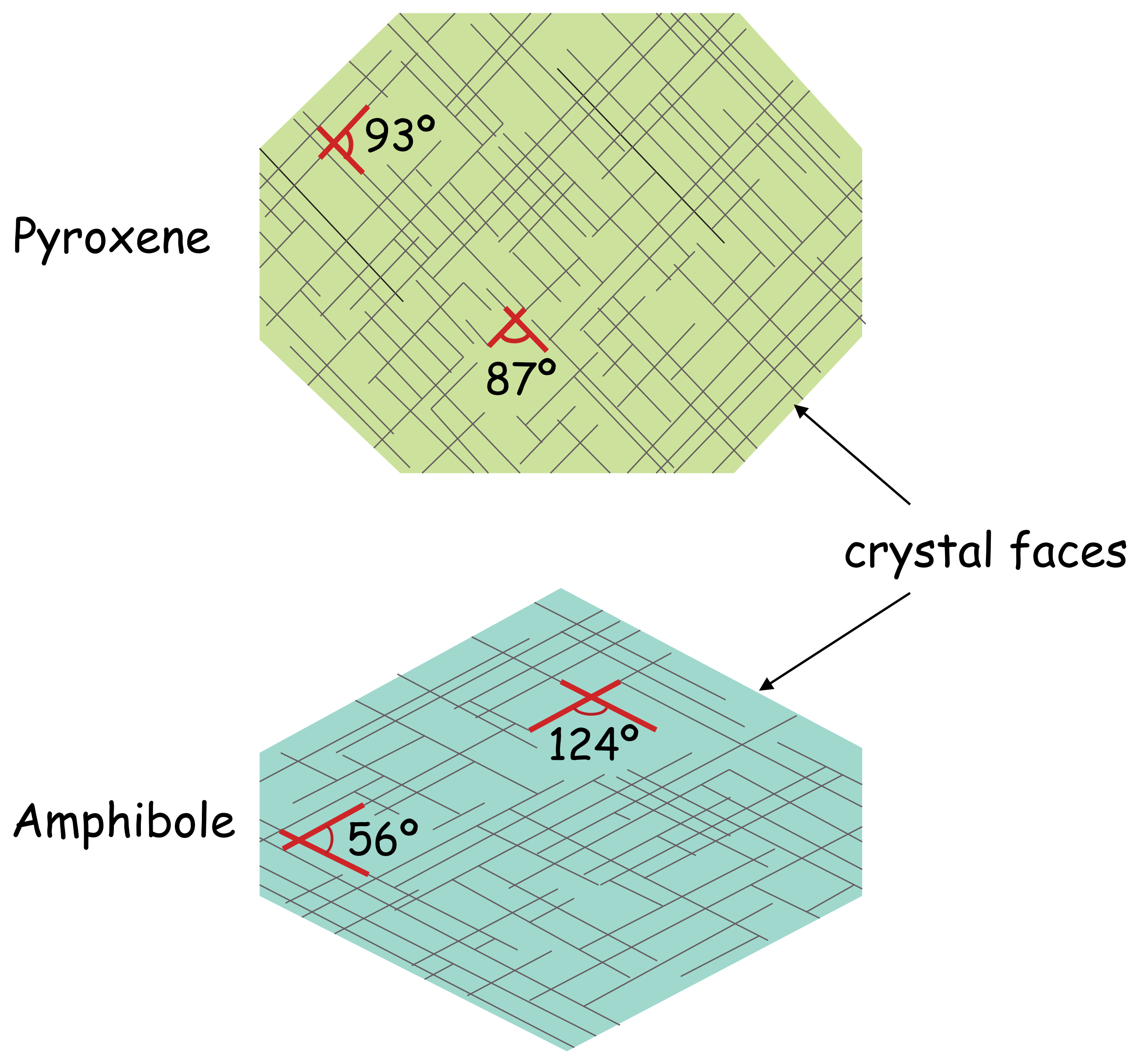
The degree to which the relief changes will depend on:

(a) $\varepsilon - \omega$ = birefringence for calcite

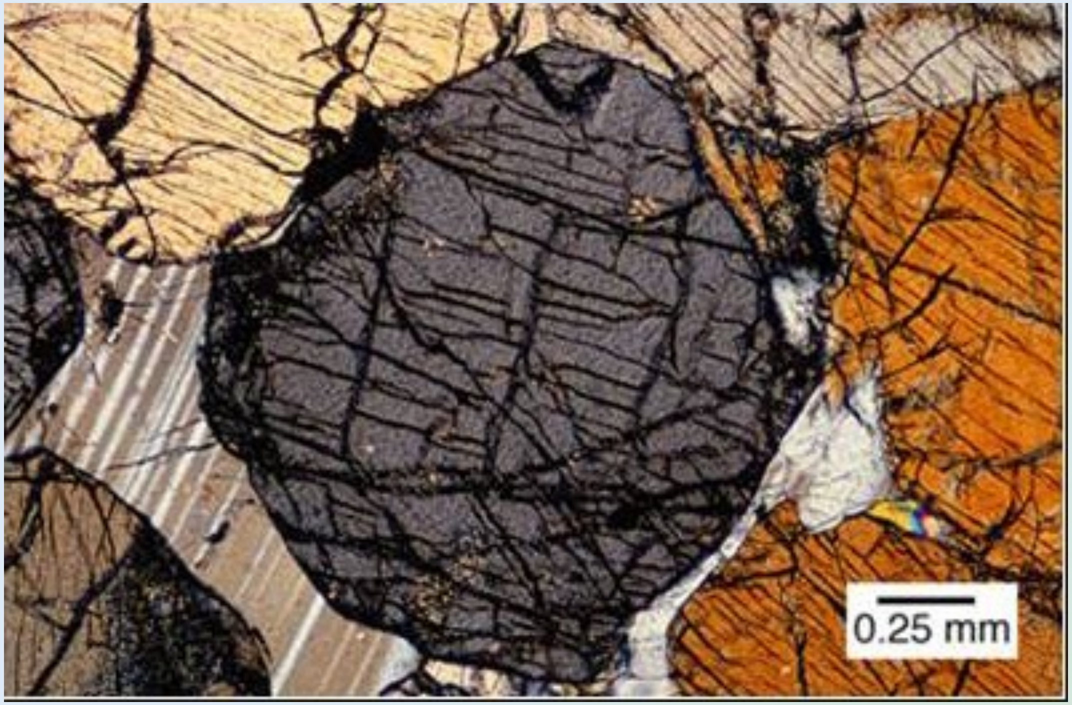
(b) the orientation of *z* with respect to the plane of the section

as ε' ---> ω there is little change in the relief
ε' ---> ε there is a major change in relief

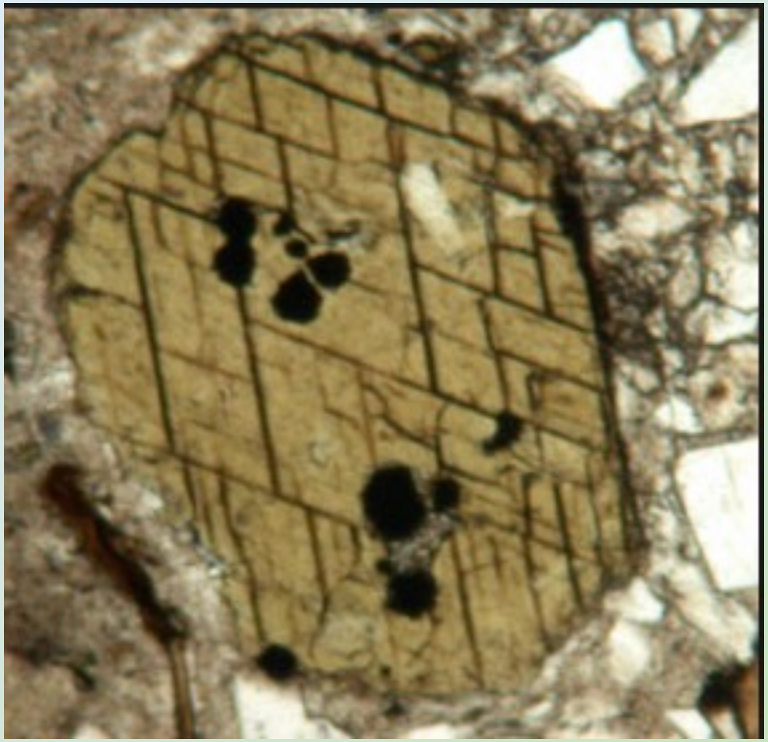
Mineral cleavage in thin section



Mineral cleavage in thin section

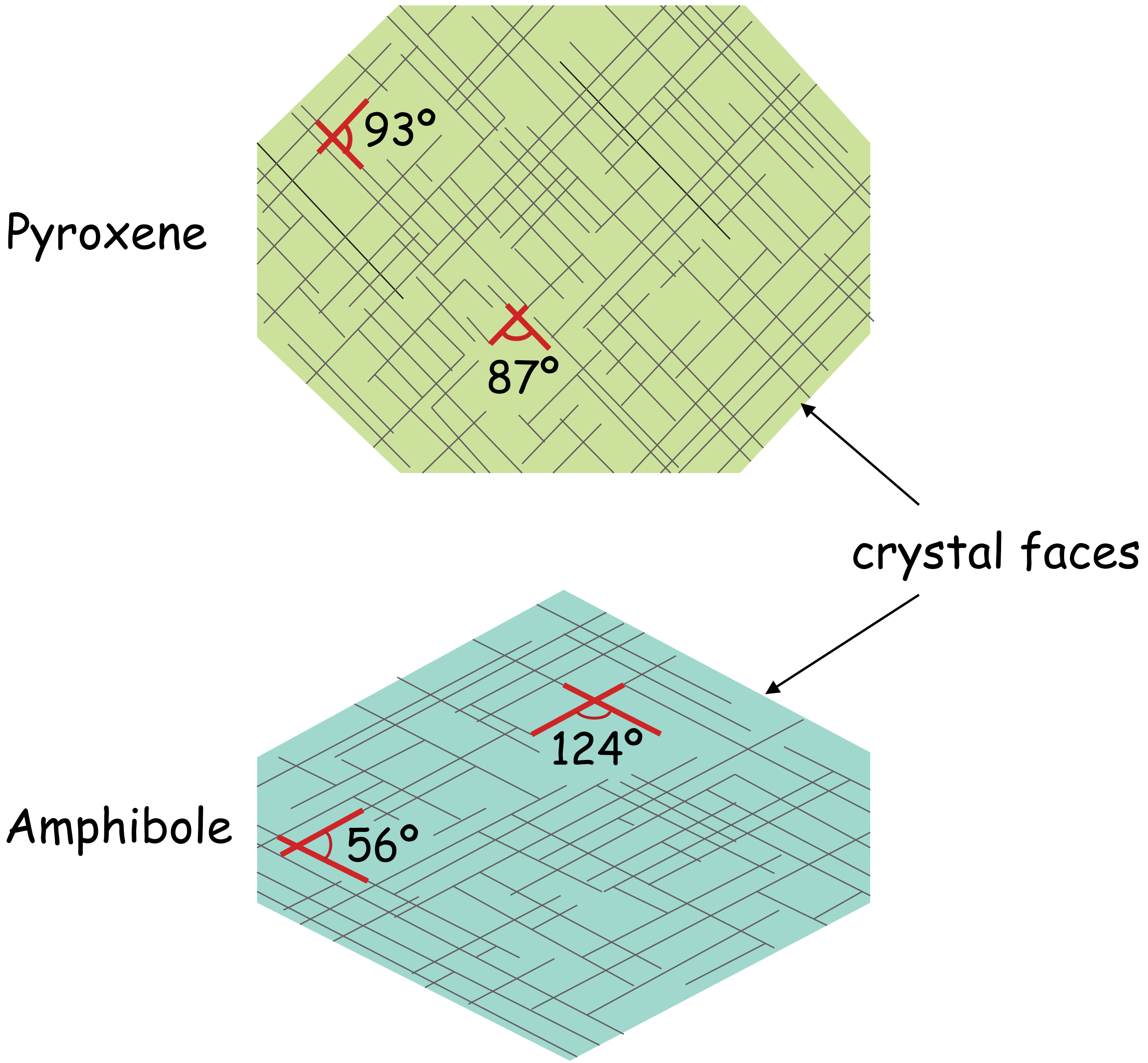


Photomicrograph of clinopyroxene
(crossed polars)

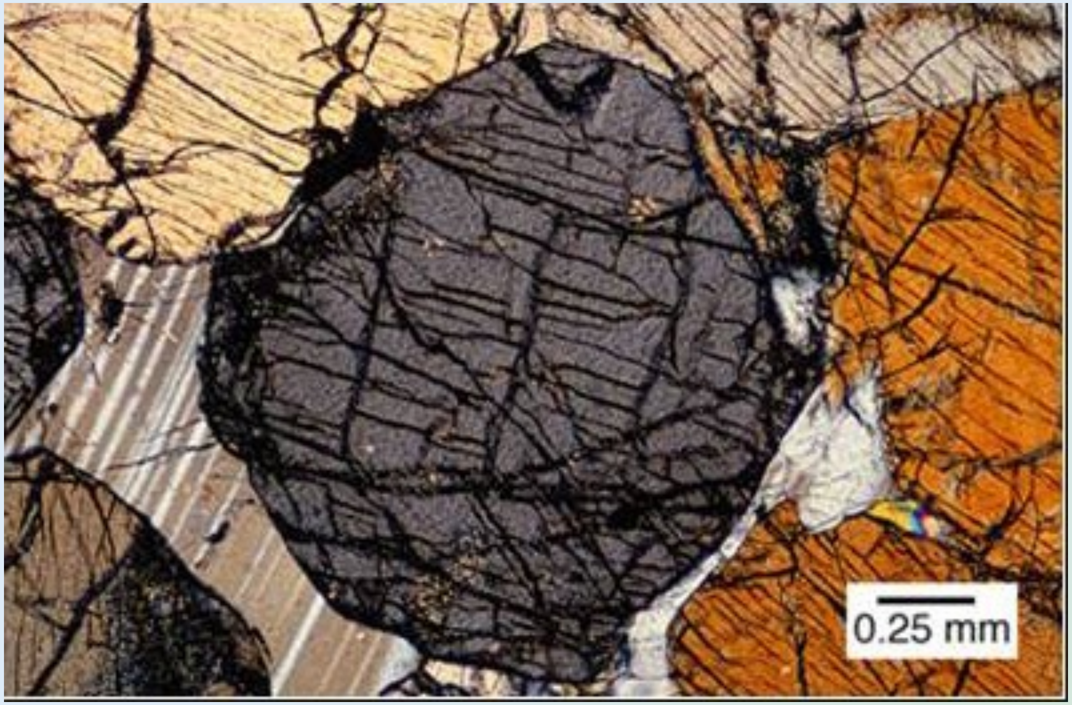


Photomicrograph of hornblende
(plane polarised light)

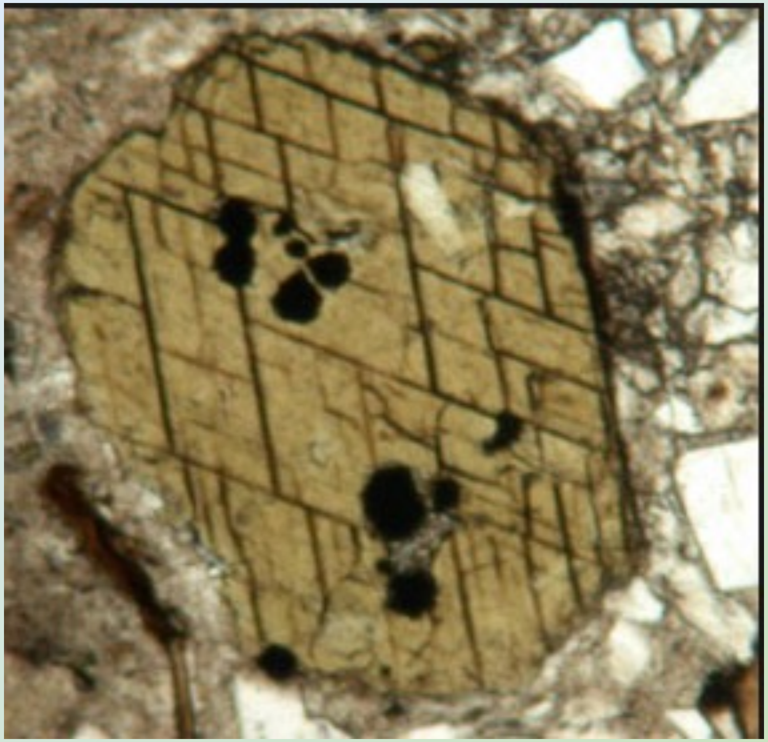
Mineral cleavage in thin section



Mineral cleavage in thin section



Photomicrograph of clinopyroxene
(crossed polars)



Photomicrograph of hornblende
(plane polarised light)

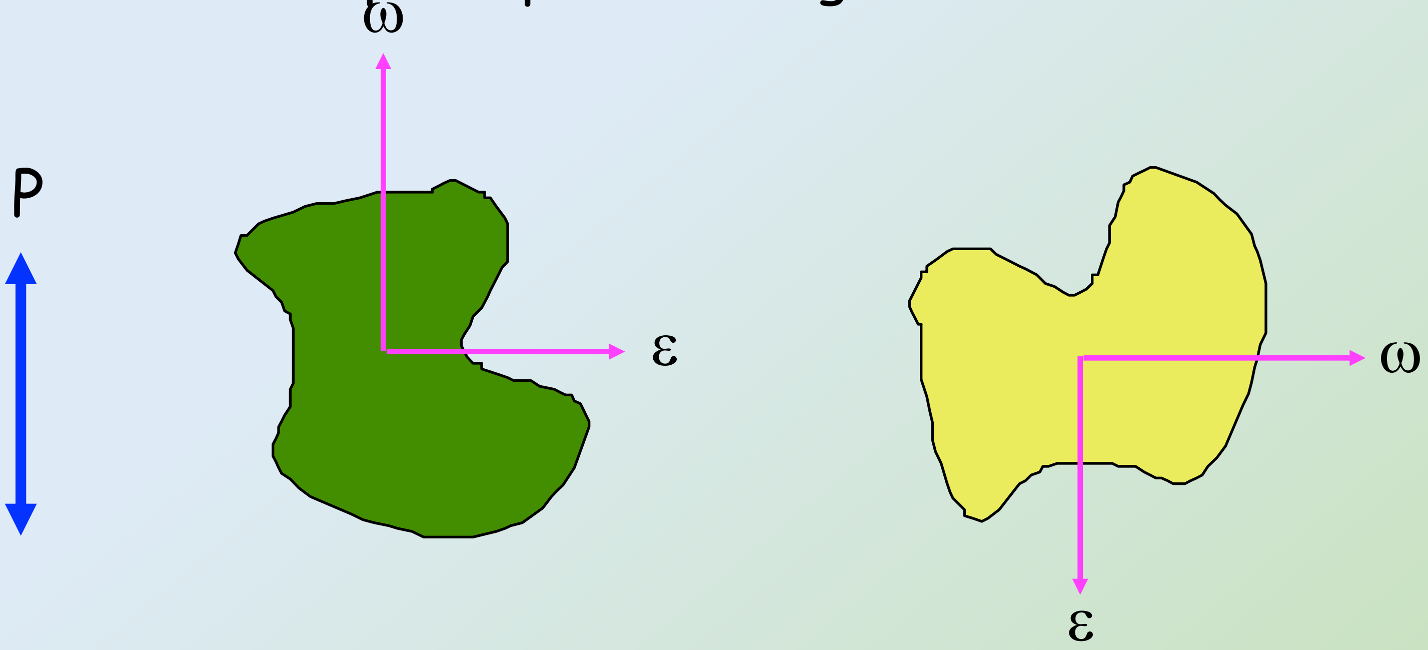
Colour and pleochroism

Colour

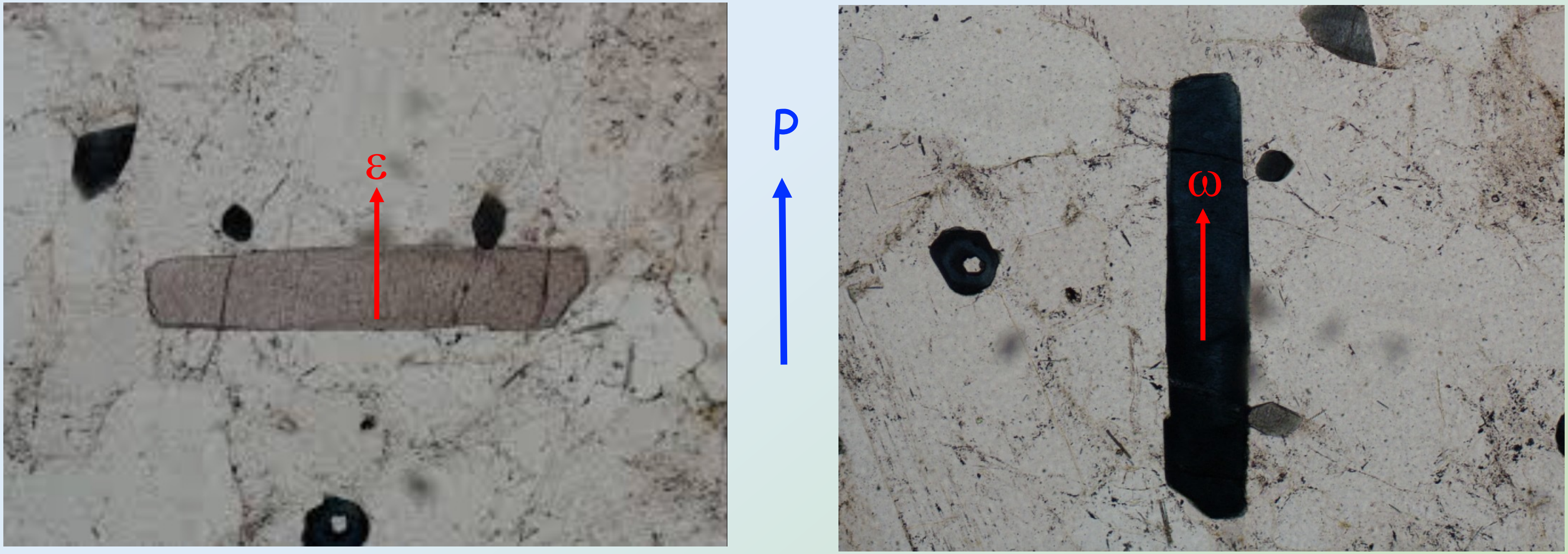
The effect of preferential absorption and transmission of certain wavelengths

Pleochroism

- Differential absorption of ordinary and extra-ordinary rays
- only observed in plane polarised light

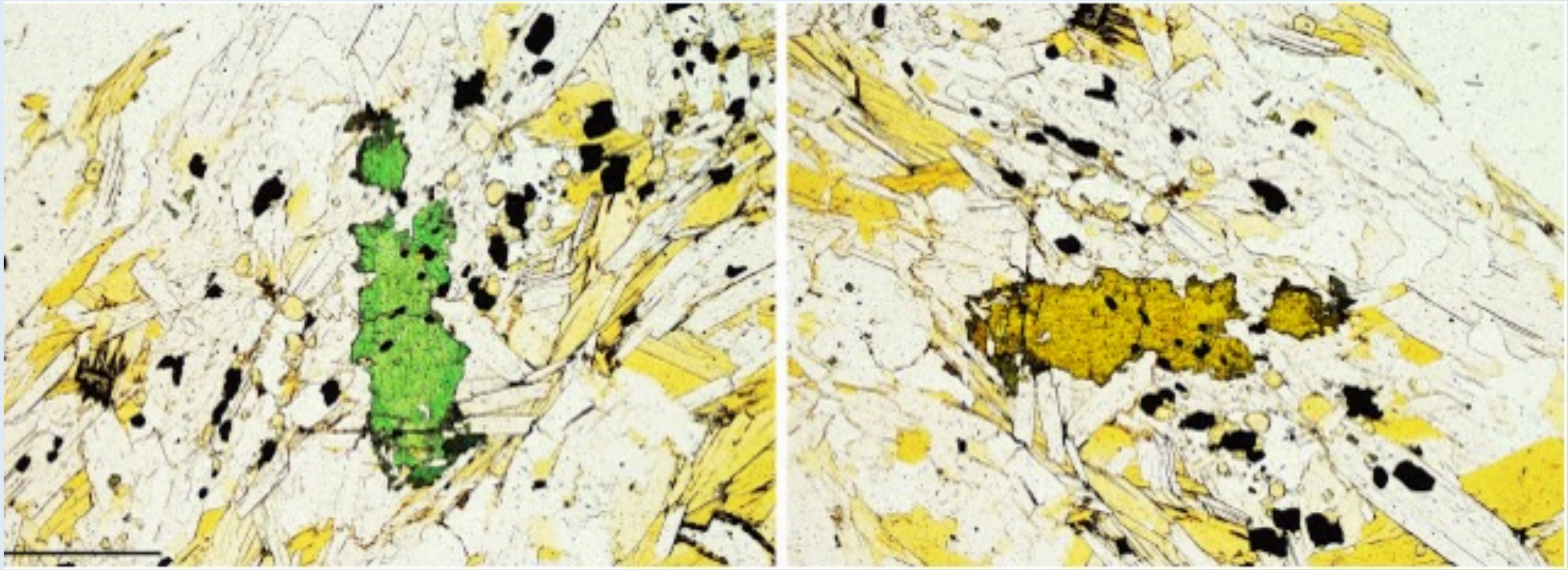


Pleochroism - tourmaline



Pleochroism in tourmaline (plane polarised light)

Pleochroism - viridine



Pleochroism in viridine (plane polarised light)

Strategy for mineral identification using optical methods

1. Examine grains of unknown mineral using colour, relief and crystal shape to distinguish it. You need to insert and remove the analyser and rotate the stage as required

2. In plane polarised light, note relief, colour, pleochroism, crystal shape and cleavage (measure cleavage angle when 2 cleavages are present).

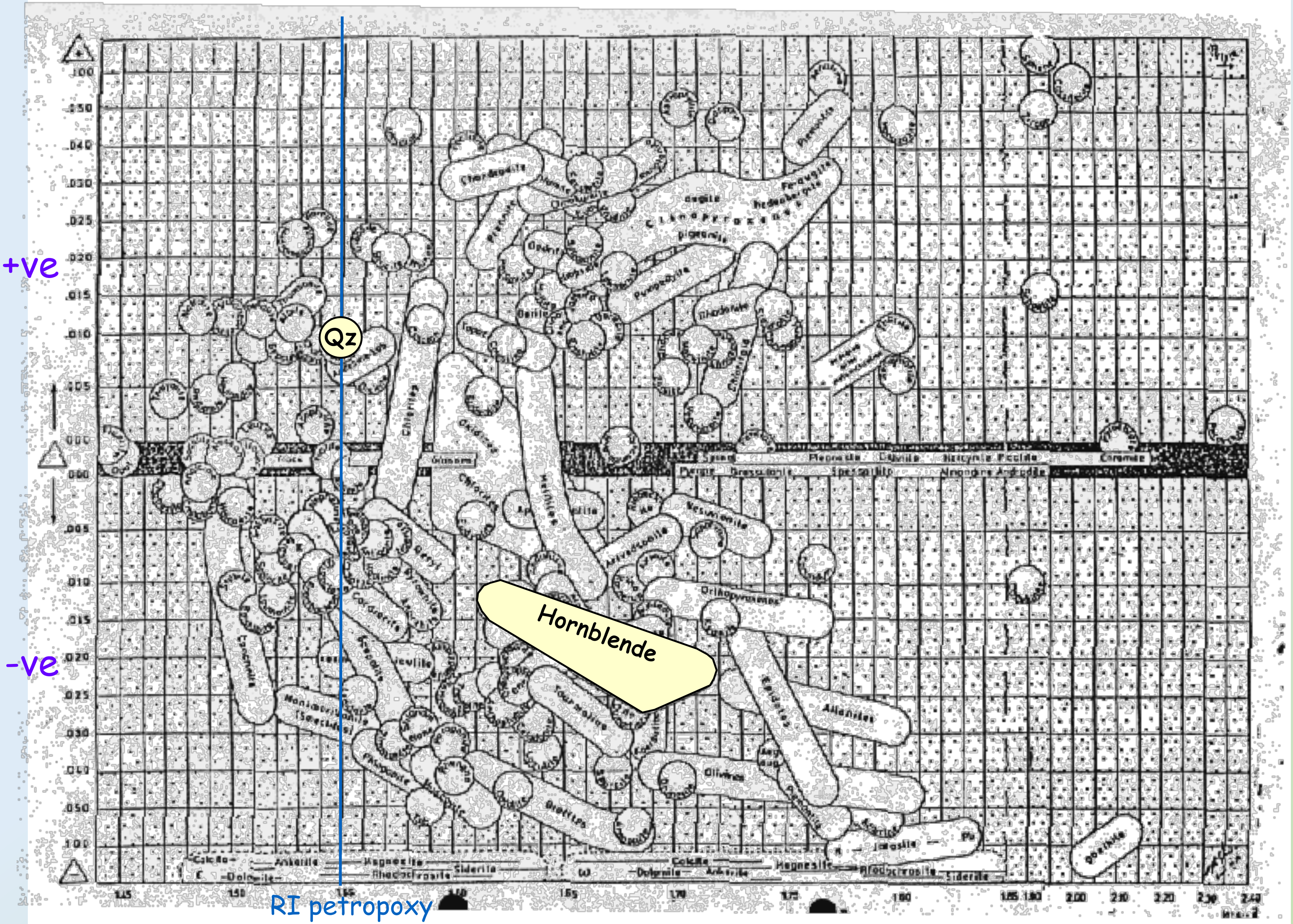
3. Under crossed polars, note whether mineral is isotropic or anisotropic.

4. If anisotropic find grain with lowest interference colour (preferably extinct). View using conoscopic light and determine if uniaxial or biaxial, optic sign, 2V (if biaxial) and dispersion (if evident).

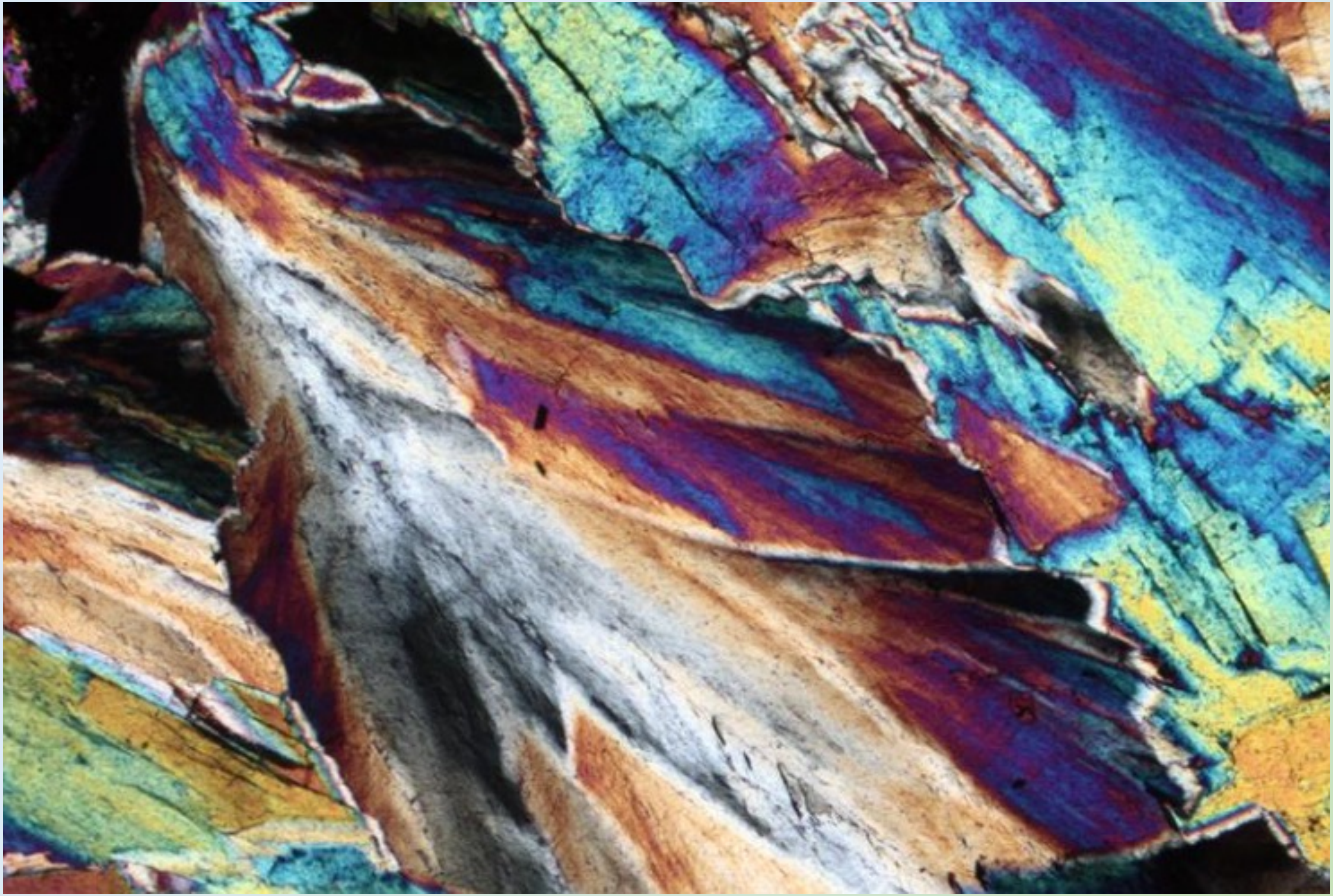
5. Find grain with maximum interference colour determine birefringence. If mineral is elongate or has a single cleavage and inclined extinction, measure extinction angles and determine sign of elongation.

6. Consult identification chart and textbook

Optical mineral identification chart



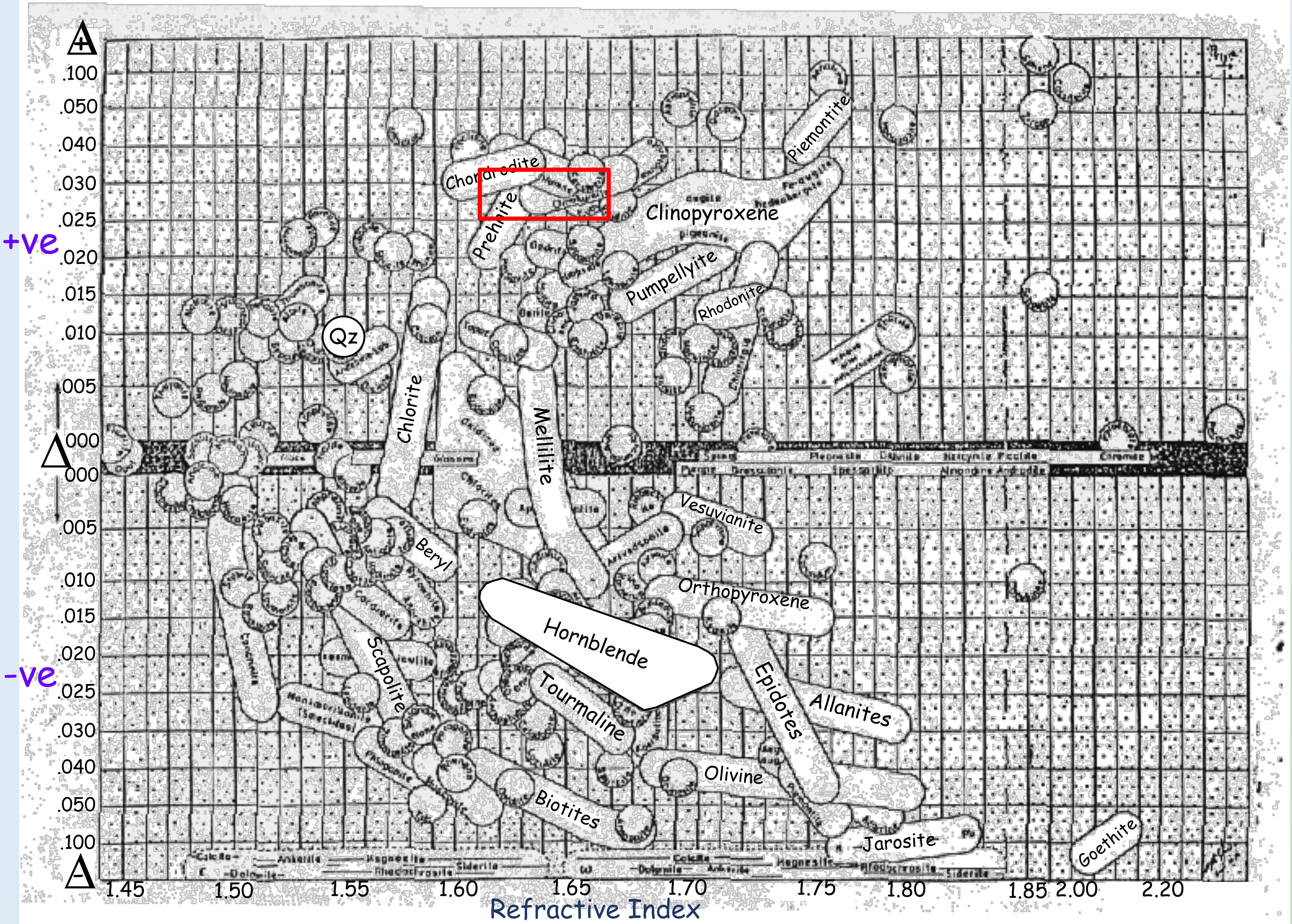
Unknown mineral



Optical properties of unknown mineral

relief ->	moderate
colour:	colourless
Optics:	biaxial
$\gamma - \alpha$	0.028
cleavage:	1 good
optic sign	+ve
2V:	~65°
straight extinction	
radiating crystals	

Optical mineral identification chart



Possibilities from chart

chondrodite X	inclined extinction, rounded shaped grains
prehnite	
clinohumite X	inclined extinction, poor cleavage
sillimanite X	low 2V, 20° - 30°, acicular aggregates or blocky
cummingtonite X	inclined extinction (monoclinic), ~60° cleavage
diopside X	2 good cleavages at 90°, pleochroic green, inclined extinction
forsterite X	equant crystals, cleavage not evident, v. high 2V
viridine X	strongly pleochroic green to yellow