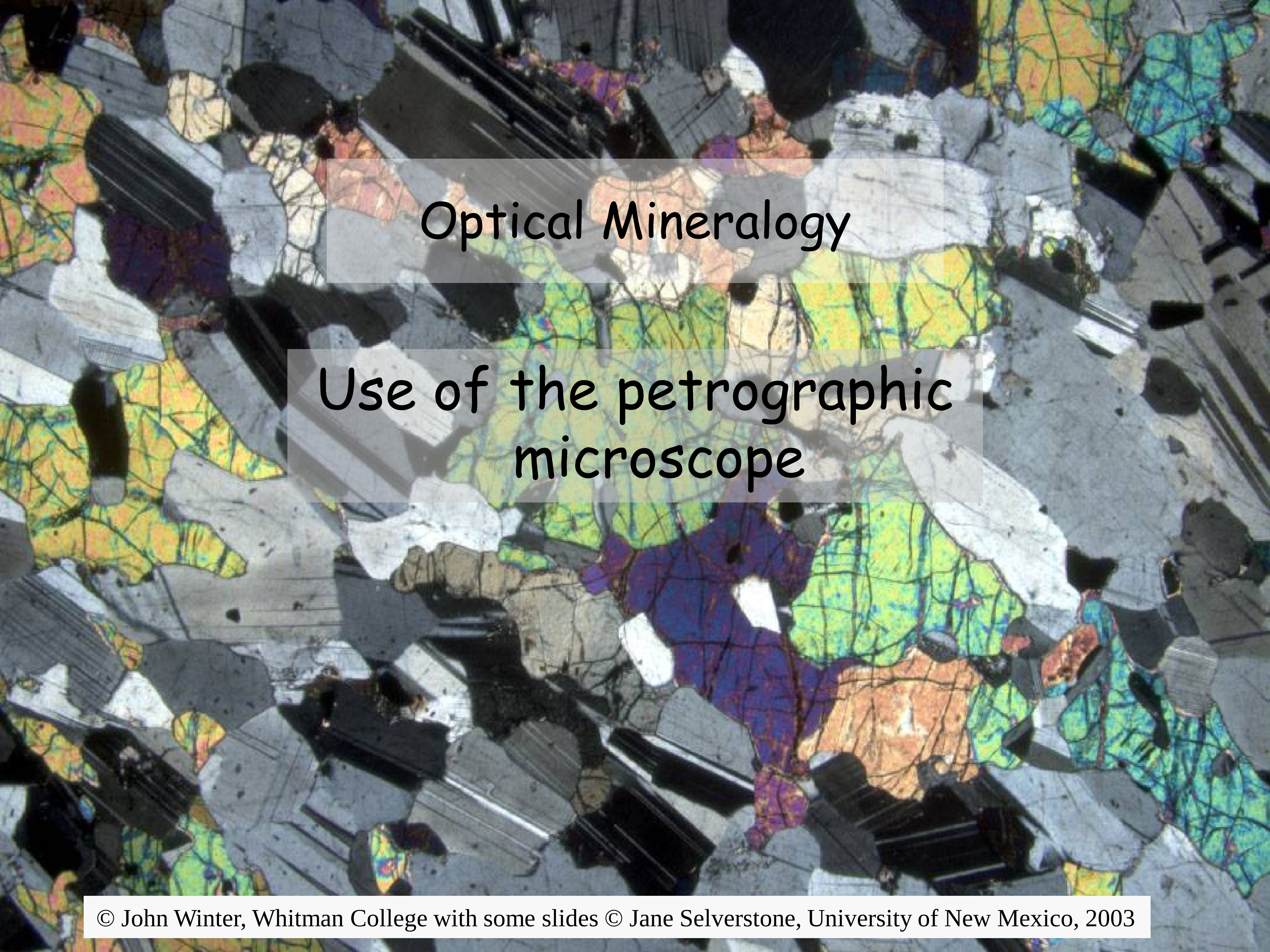
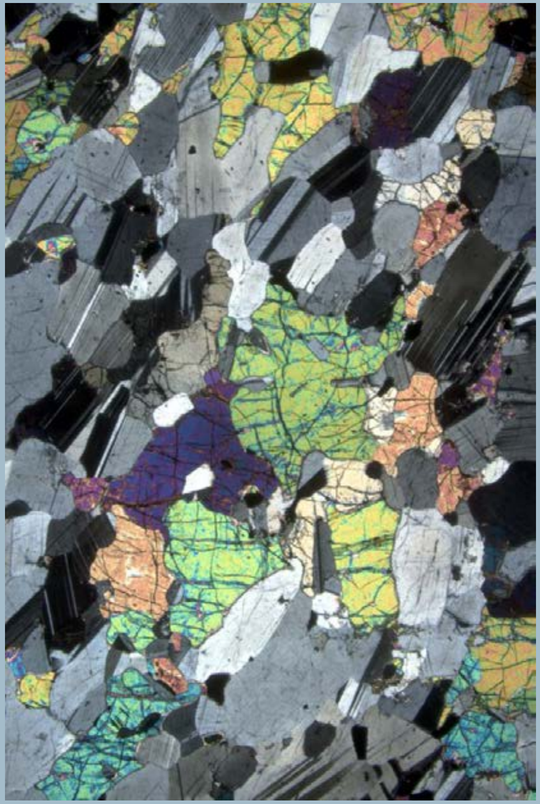


Optical Mineralogy

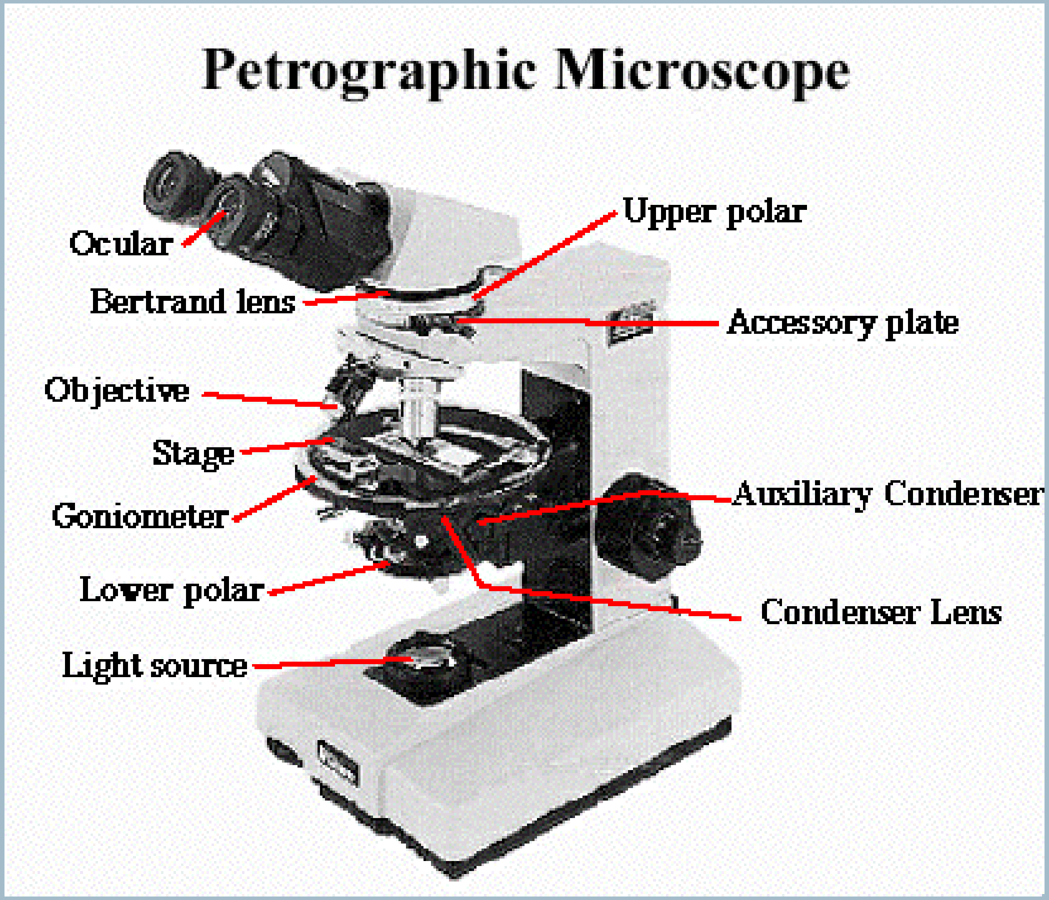
Use of the petrographic microscope

Why use the microscope??



- Identify minerals *(no guessing!)*
- Determine rock type
- Determine crystallization sequence
- Document deformation history
- Observe frozen-in reactions
- Constrain P-T history
- Note weathering/alteration

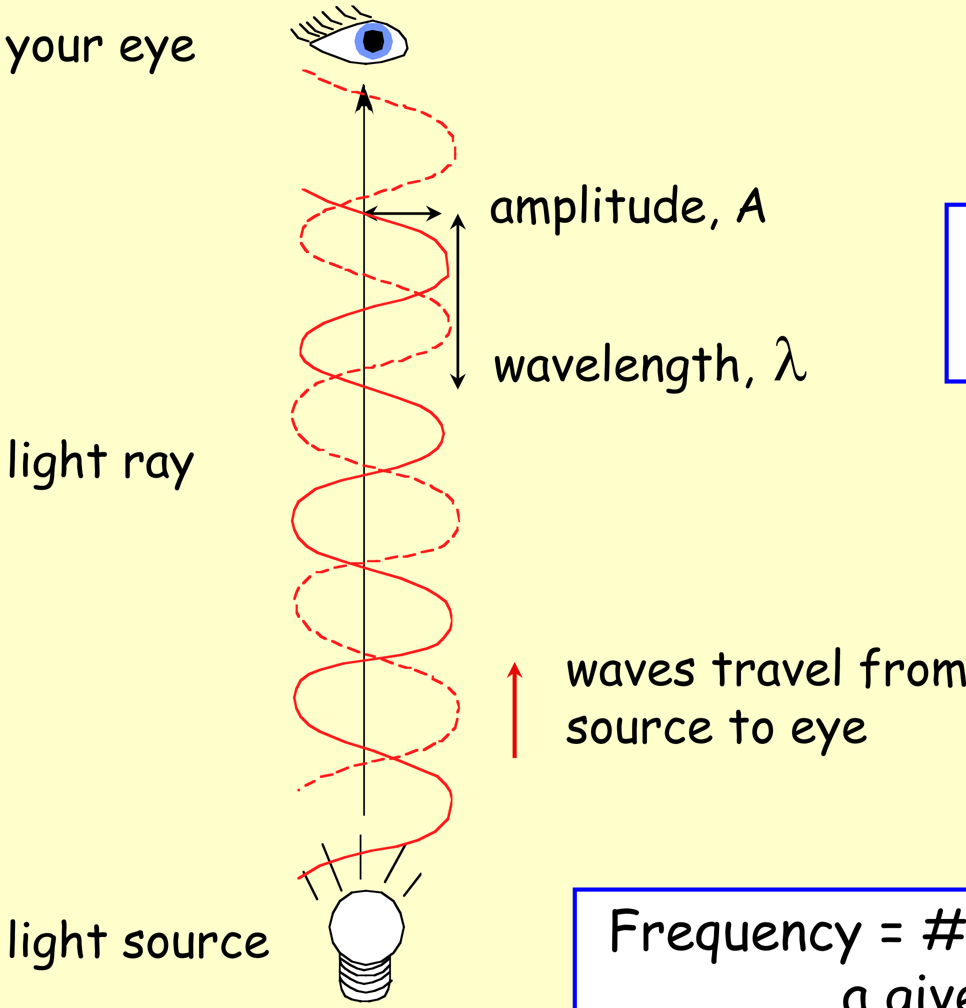
The petrographic microscope



Also called a polarizing microscope

In order to use the scope, we need to understand a little about the **physics of light**, and then learn some **tools and tricks**…

What happens as light moves through the scope?



light travels as waves

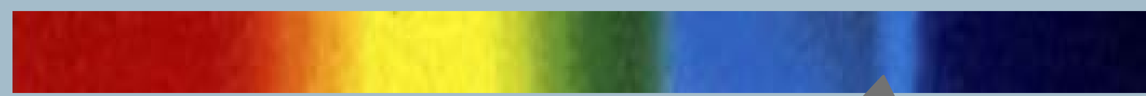
Frequency = # of waves/sec to pass a given point (hz)

$f = v/\lambda$ v = velocity

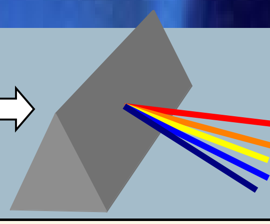
Electromagnetic spectrum & visible portion

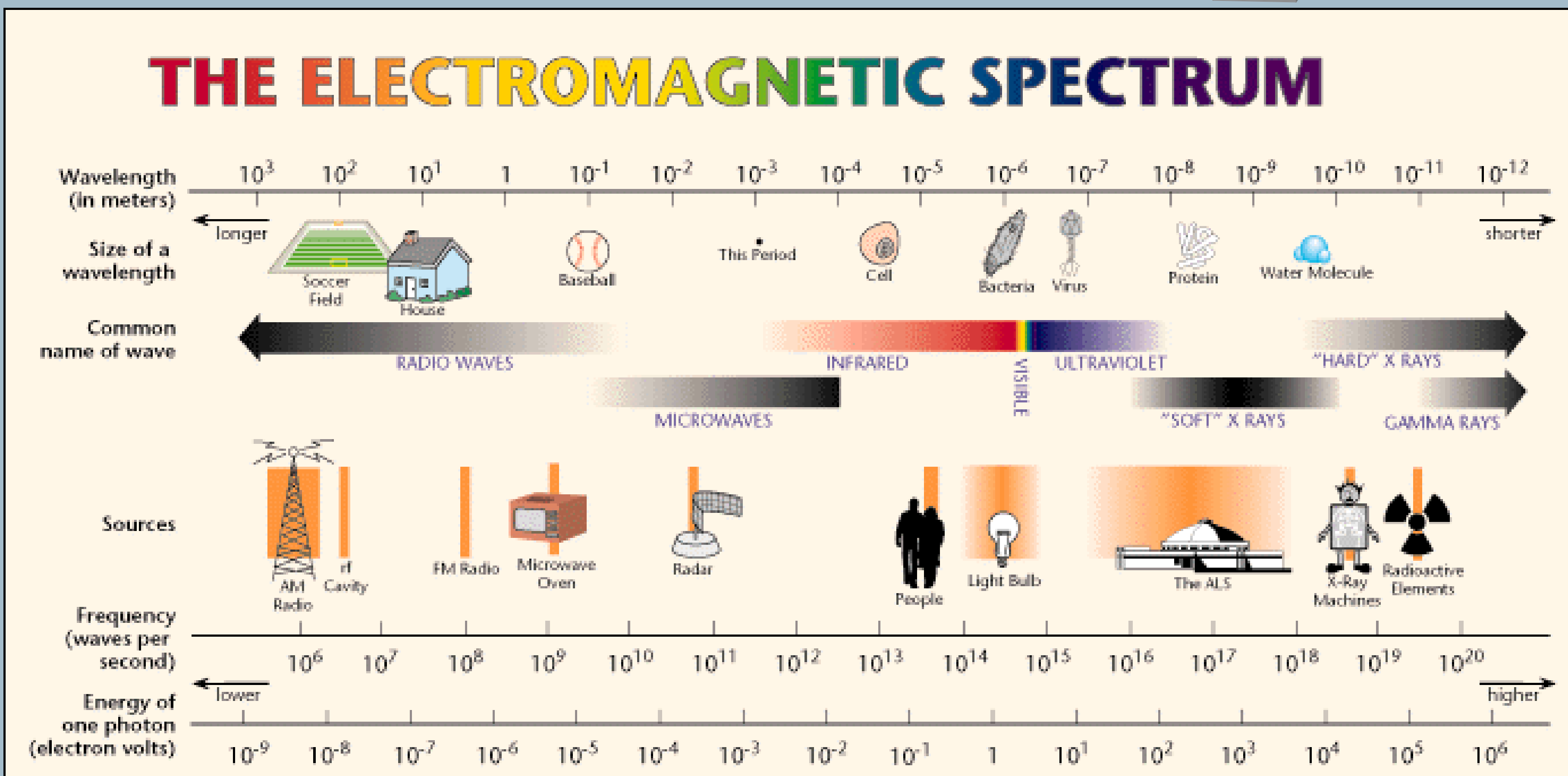
Violet (400 nm) → Red (700 nm)

White = ROYGBV



(can be separated by dispersion in a prism) ⇨





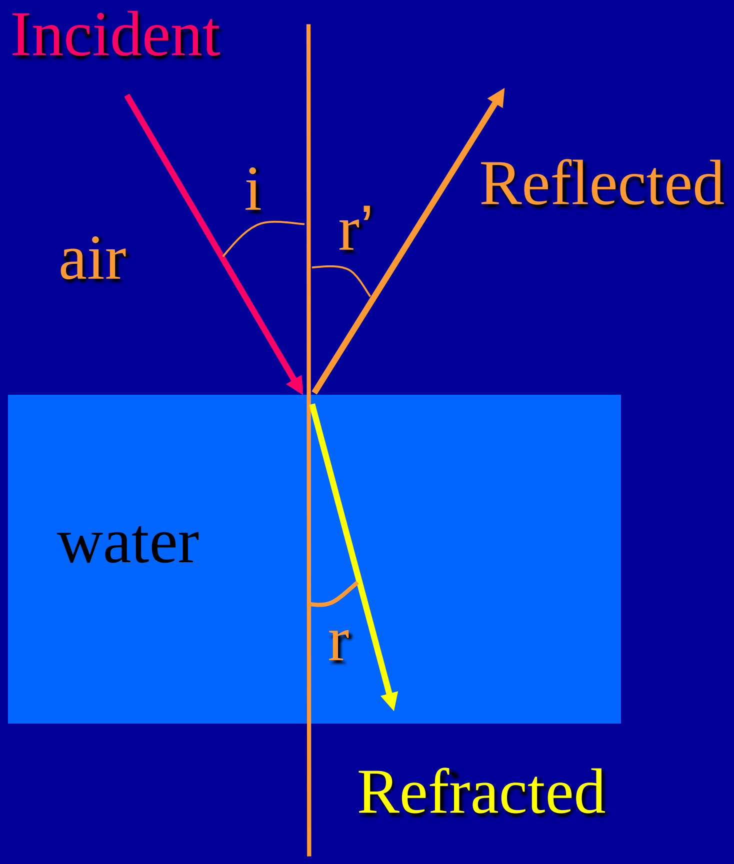
Refraction

Incident ray and reflected ray:

1) ∠ of incidence i = ∠ of reflection r'

2) coplanar "plane of incidence"

(⊥ plane of interface)



Refracted ray:

1) Slower in water (or glass)

2) ∠ r ≠ ∠ i

Depends on Δ velocity

Index of refraction

For a substance x:

$n_x = v_{air}/v_x$

n_{air} = ??

light is slower in water, glass, crystals

Is n_{water} greater or less than 1??

Larger n associated with slower V !!

Snells Law:

$$n_i \sin i = n_r \sin r$$

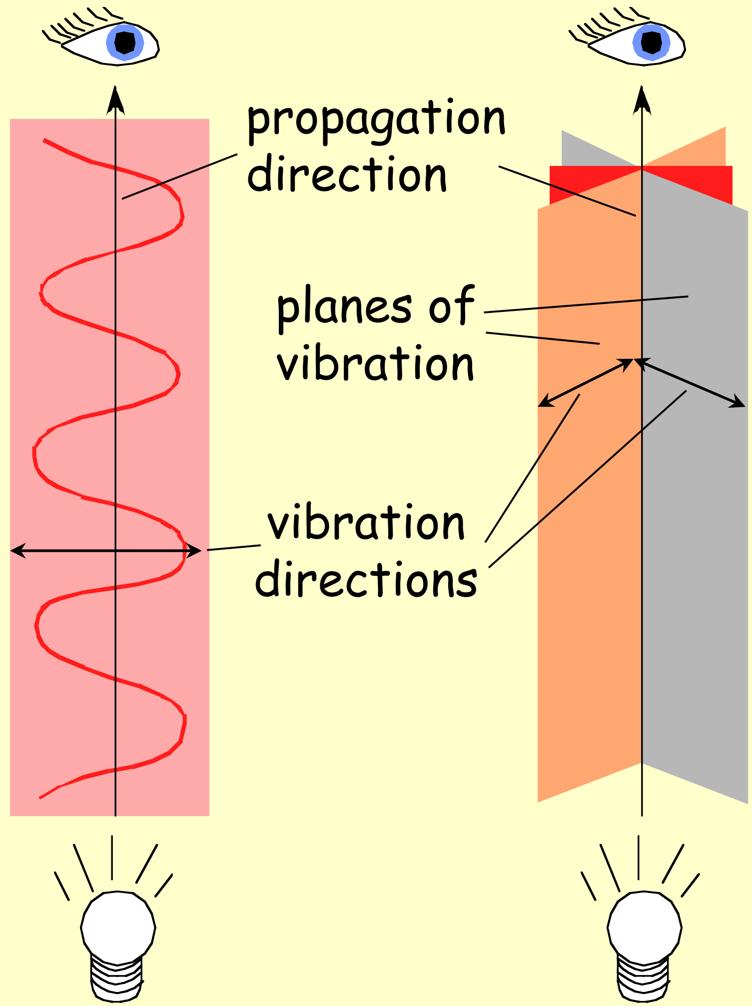
for 2 known media (air/water) $\sin i/\sin r = n_r / n_i = \text{const}$

So can predict angle change (or use $\angle$ to determine n_r)

What happens as light moves through the scope?

Each photon vibrates as a wave form in a single plane

Light beam = numerous photons, all vibrating in the same plane



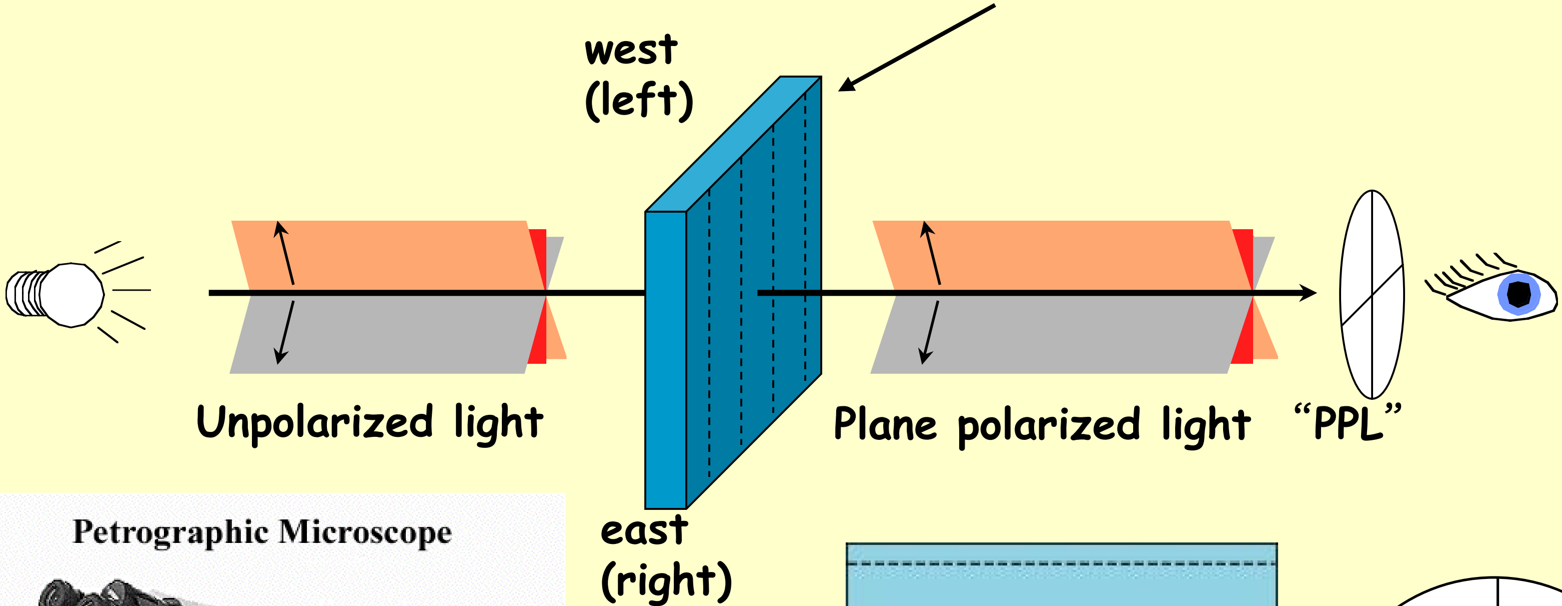
Polarized Light

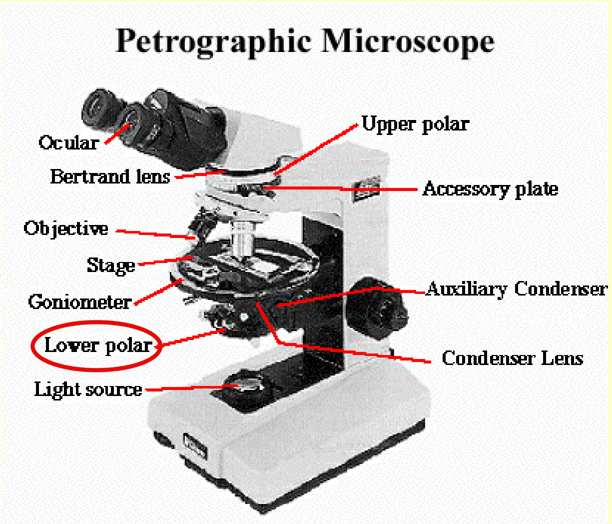
Unpolarized Light

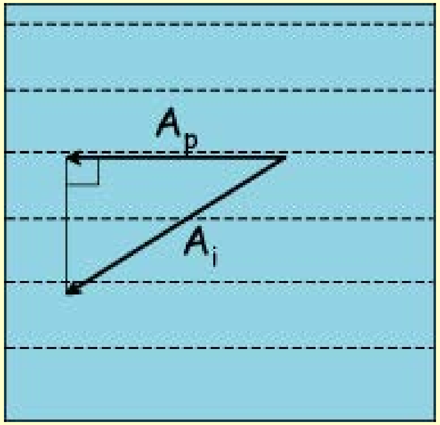
Light beam = numerous photons, each vibrating in a different plane

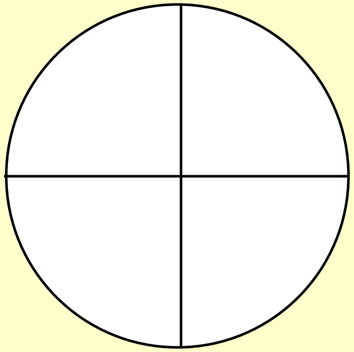
Vibration in all directions ~ perpendicular to propagation direction

1) Light passes through the **lower polarizer**



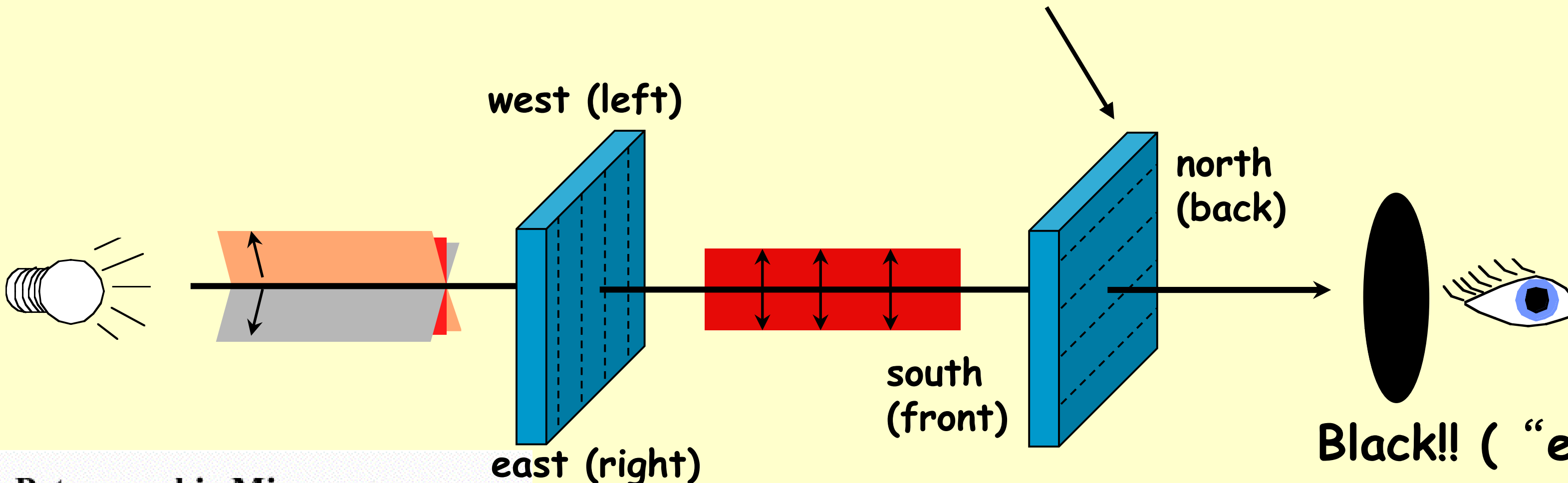




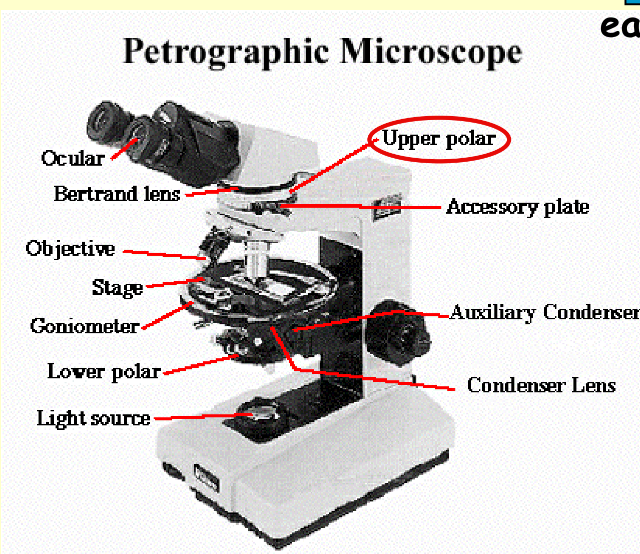


Only the component of light vibrating in E-W direction can pass through lower polarizer – **light intensity decreases**

2) Insert the **upper polarizer**



Black!! ("extinct")



XPL=crossed nicols
(crossed polars)

Now what happens?
What reaches your eye?

Why would anyone design a microscope that prevents light from reaching your eye???

The Optical Indicatrix

Shows how n_i varies with **vibration** direction.

- Vectors radiating from center
- Length of each proportional to n_i for light vibrating in the direction of the vector

Indicatrix = surface connecting tips of vectors

(a representational construct only!)

Isotropic media have all n_i the same (by definition)

What is the shape of an isotropic indicatrix?

Amorphous materials or isometric crystals are (optically) isotropic with a **spherical** indicatrix

The Isotropic Indicatrix

A section through the center of an indicatrix $\rightarrow$ all n for light propagating $\perp$ the section

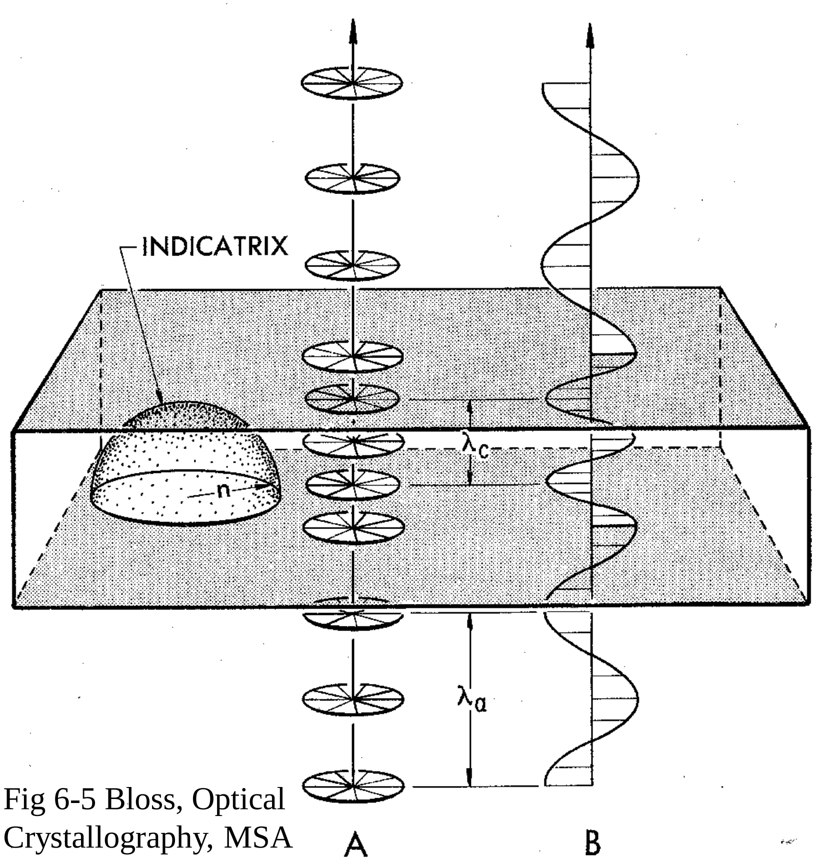


Fig 6-5 Bloss, Optical Crystallography, MSA

Conventions:

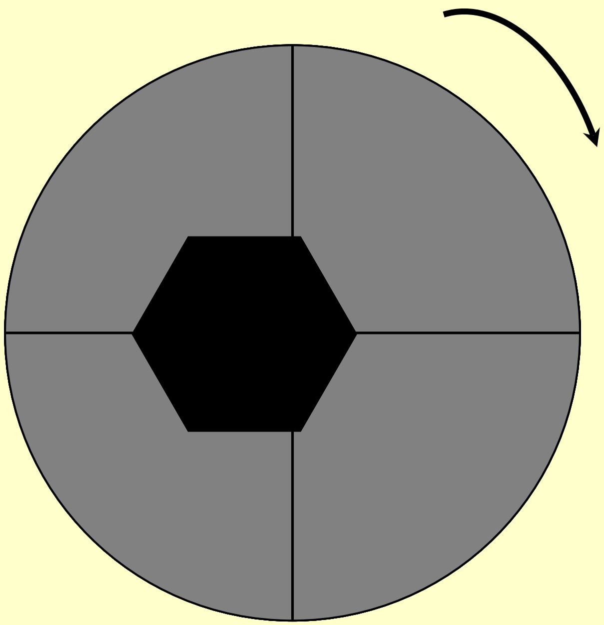
1) **Indicatrix** w/ center on interface surface
2) n (radial vectors of circular section in this case) same in all possible vibration directions

Incoming light can (and will) vibrate in the same direction(s) it did prior to entry

If unpolarized, it will remain so.

Only effect is slower velocity (rep. by closer symbol spacing)

Review: With any **isotropic** substance (spherical indicatrix), when the analyzer is inserted (= "crossed-nicols" or "**XPL**") no light passes → **extinct**, even when the stage is rotated



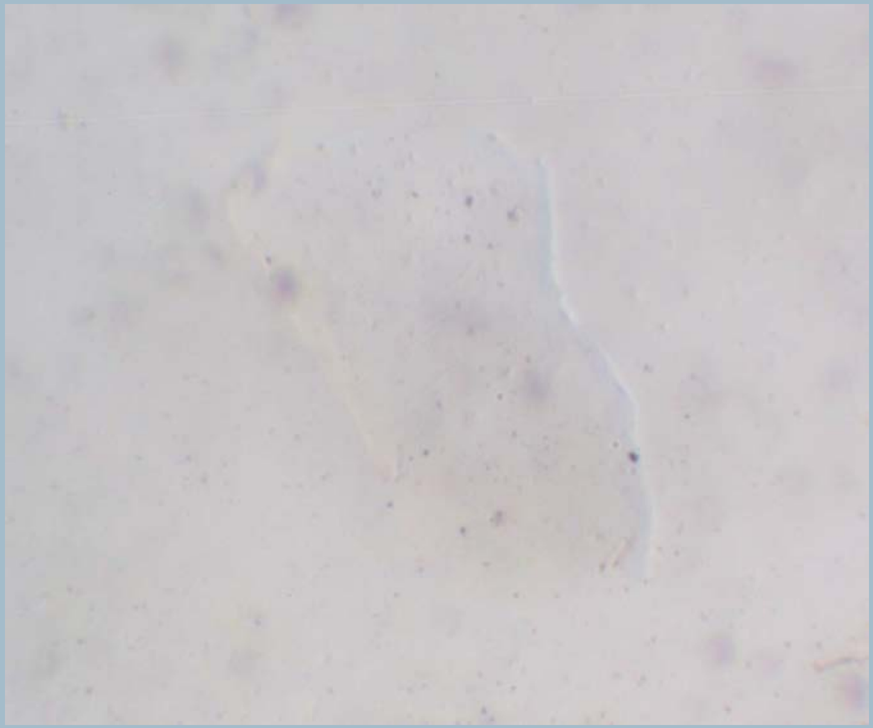
Note: the gray field should also be extinct (glass and epoxy of the thin section are also isotropic), but is left lighter for illustration

Liquids, gases, amorphous solids such as glass, and isotropic minerals (isometric crystal system) stay black in all orientations

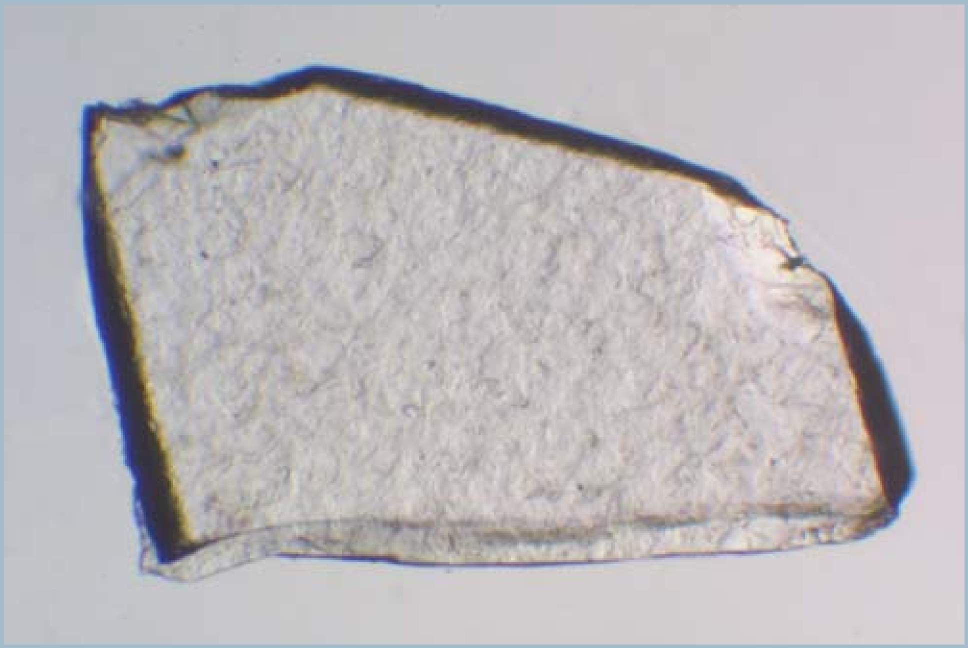
Mineral properties in PPL: **relief**

- Relief is a measure of the **relative** difference in **n** between a mineral grain and its surroundings
- Relief is determined visually, in PPL
- Relief is used to estimate n

garnet:	n = 1.72-1.89
quartz:	n = 1.54-1.55
epoxy:	n = 1.54



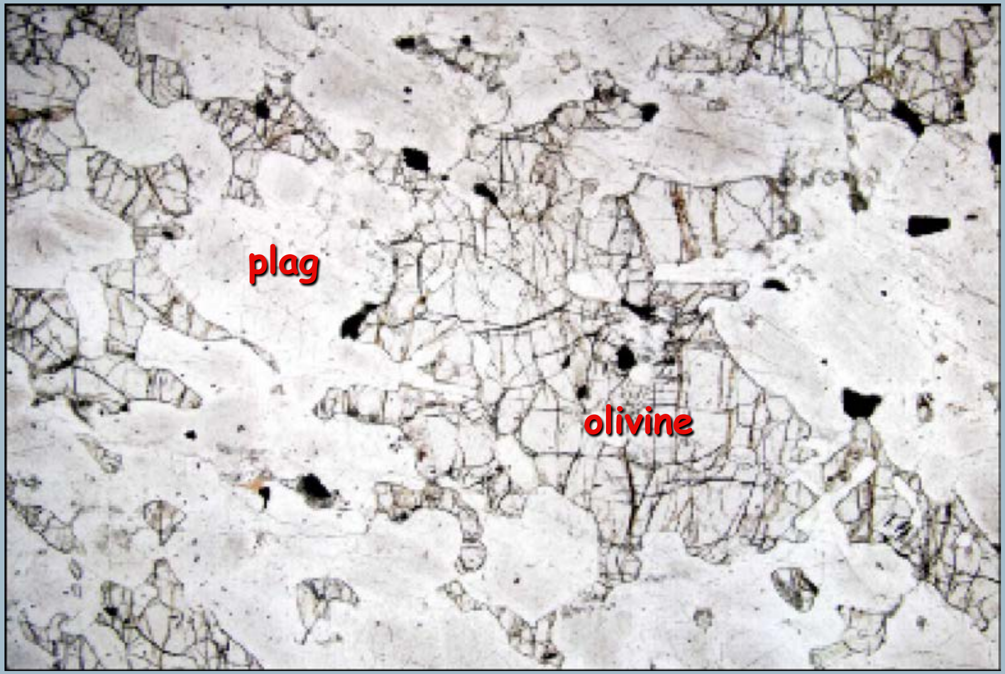
Quartz has low relief



Garnet has high relief

Mineral properties in PPL: relief

- Relief is a measure of the **relative** difference in **n** between a mineral grain and its surroundings
- Relief is determined visually, in PPL
- Relief is used to estimate n



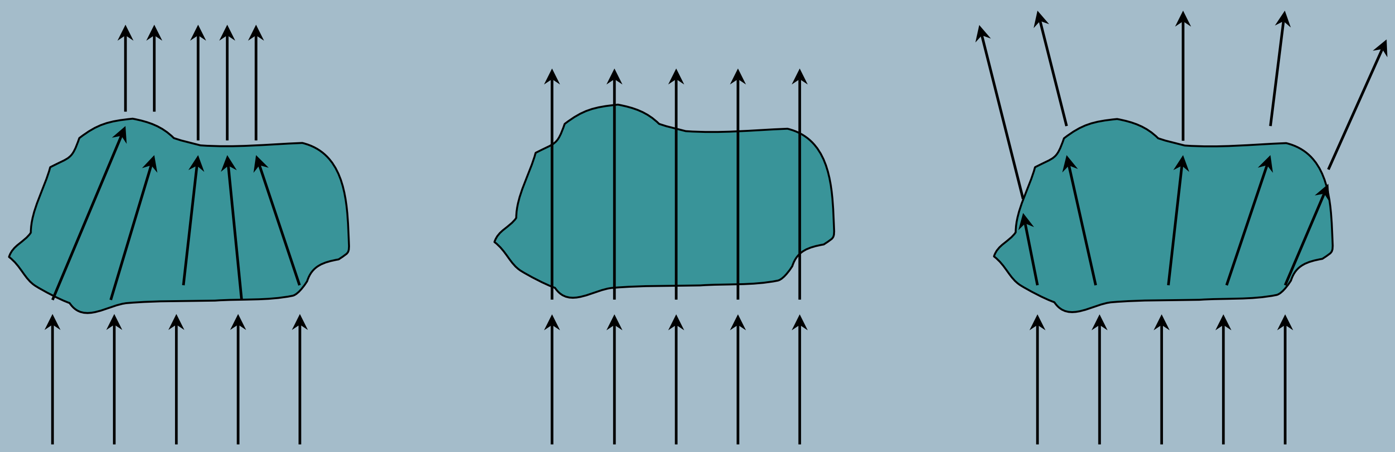
- Olivine has high relief
- Plagioclase has low relief

olivine:	n = 1.64-1.88
plag:	n = 1.53-1.57
epoxy:	n = 1.54

What causes relief?

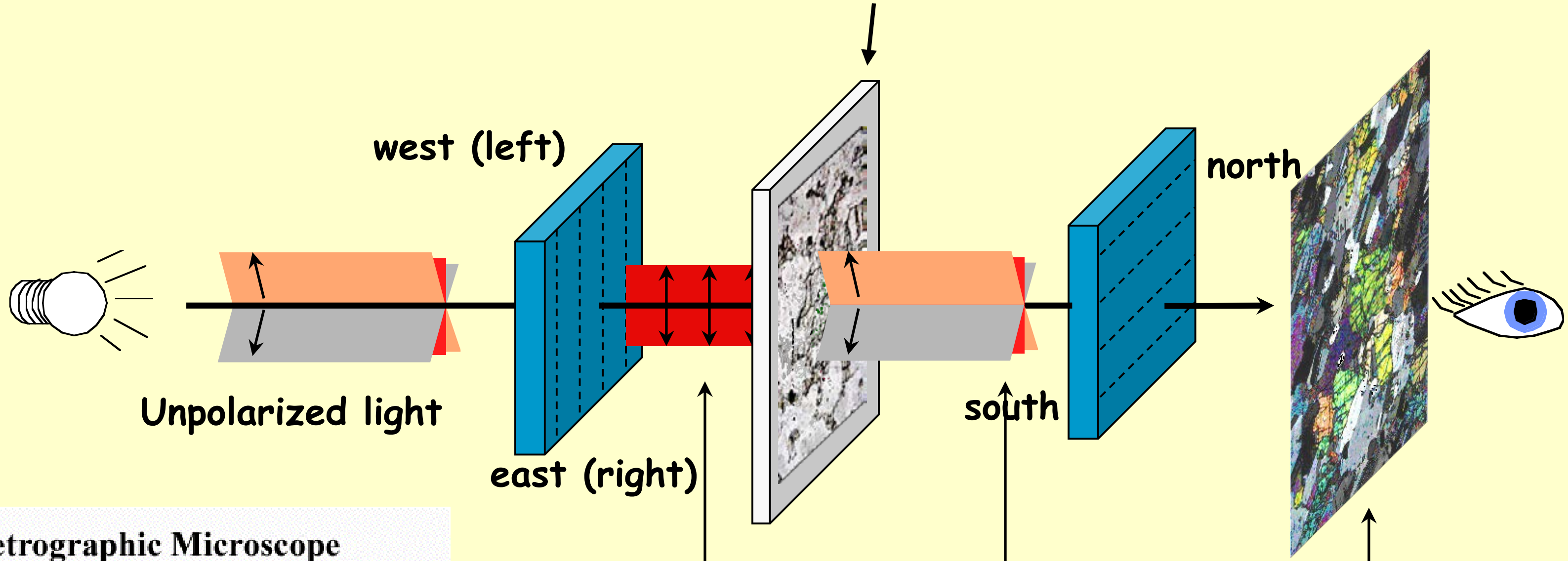
Difference in speed of light (n) in different materials causes refraction of light rays, which can lead to focusing or defocusing of grain edges relative to their surroundings

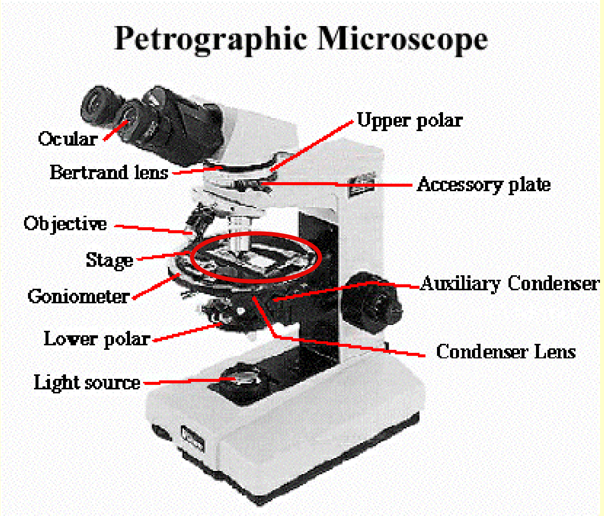
Hi relief (+) | Lo relief (+) | *Hi relief (-)*



$n_{xtl} > n_{epoxy}$ | $n_{xtl} = n_{epoxy}$ | $n_{xtl} < n_{epoxy}$

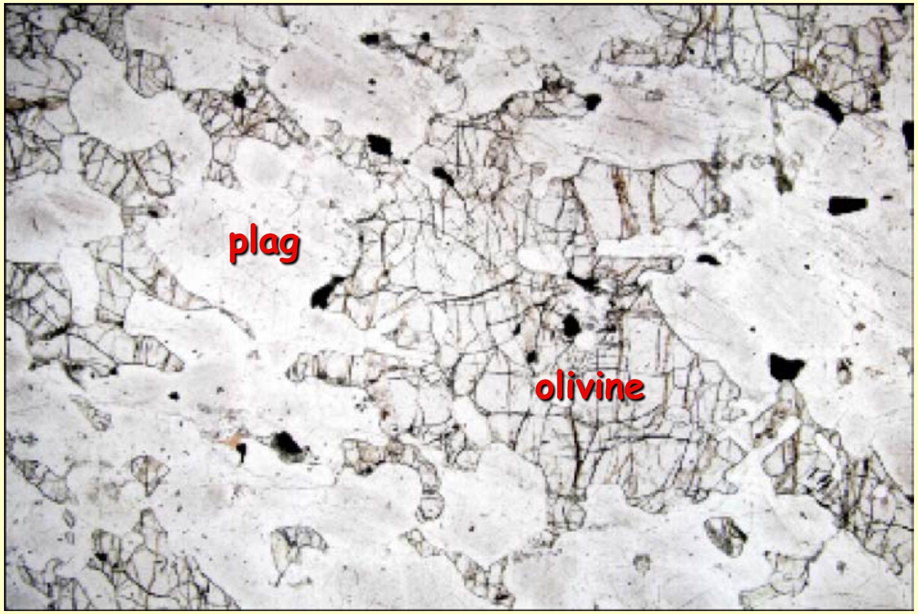
Now insert a **thin section** of a rock in XPL



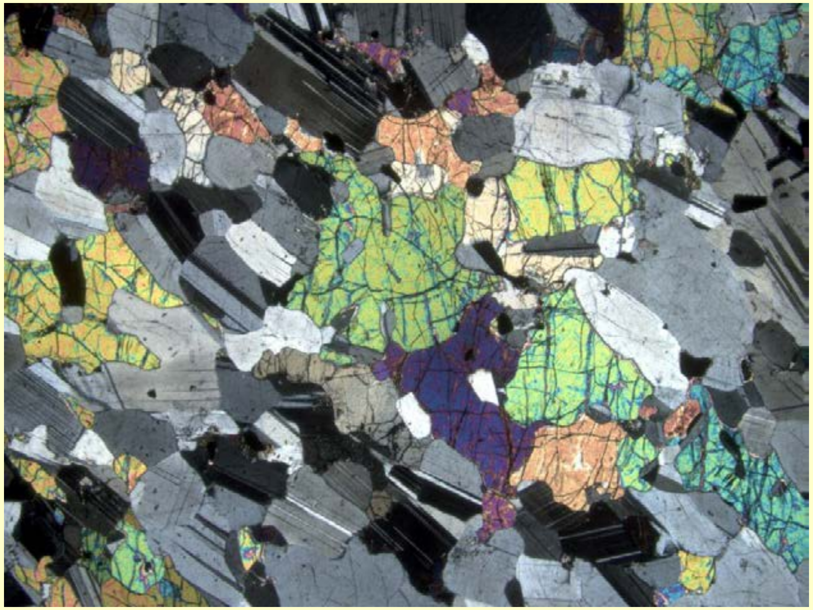


How does this work??

Conclusion has to be that minerals somehow **reorient** the planes in which light is vibrating; some light passes through the upper polarizer

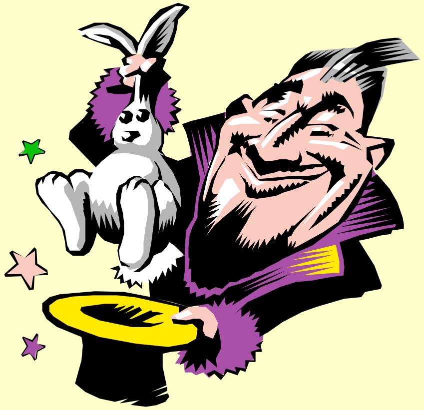


PPL



XPL

Minerals act as magicians!!



But, note that some minerals are better magicians than others (i.e., some grains stay dark and thus can't be reorienting light)

Anisotropic crystals

Calcite experiment and double refraction

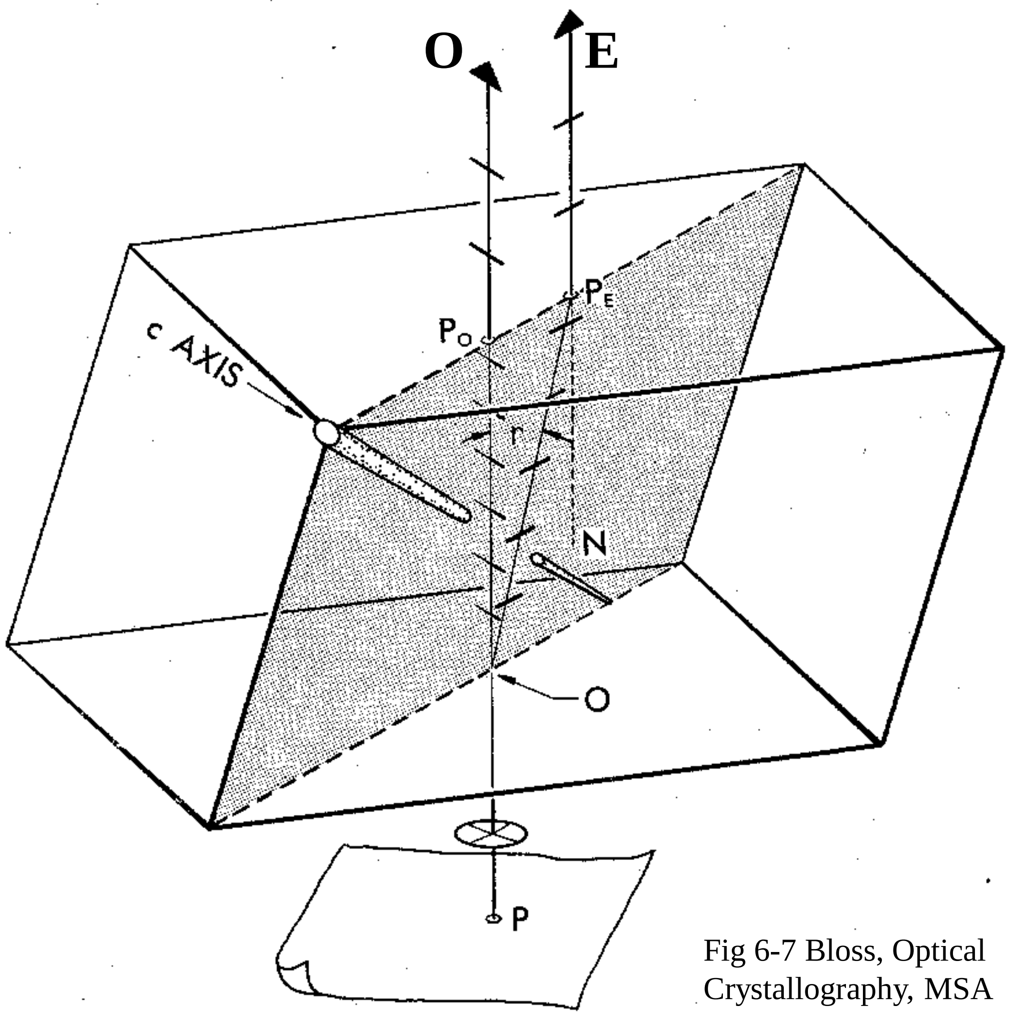


Fig 6-7 Bloss, Optical Crystallography, MSA

O-ray (Ordinary)

Obeys Snell's Law and goes straight

Vibrates ⊥ plane containing ray and c-axis ("optic axis")

E-ray (Extraordinary)

deflected

Vibrates in plane containing ray and c-axis

..also doesn't vibrate ⊥ propagation, but we'll ignore this as we said earlier

IMPORTANT: A given ray of incoming light is restricted to only 2 (mutually perpendicular) vibration directions once it enters an anisotropic crystal

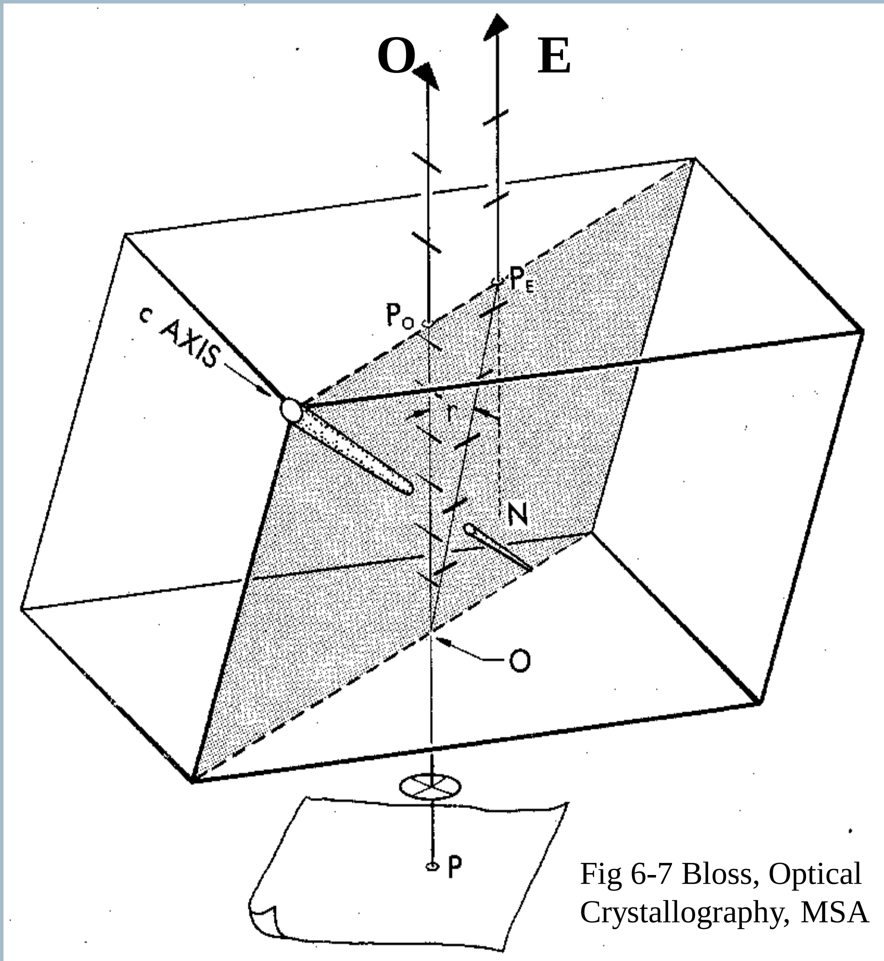


Fig 6-7 Bloss, Optical Crystallography, MSA

Called privileged directions

Each ray has a different n

$\omega = n_o$

$\varepsilon = n_E$

in the case of calcite $\omega < \varepsilon$

…which makes the O-ray dot appear above E-ray dot

Some generalizations and vocabulary

- Amorphous materials and isometric minerals (e.g., *garnet*) are **isotropic** – they cannot reorient light. These minerals are always extinct in crossed polars (XPL).
- All other minerals are **anisotropic** – they are all capable of reorienting light (acting as magicians).
- All **anisotropic** minerals contain one or two special *propagation* directions that do **not** reorient light.
  - Minerals with **one** special direction are called **uniaxial**
  - Minerals with **two** special directions are called **biaxial**

n > 1 for a

Indicatri

Indicatri

Not ... llipsoid.

Hexagona ... ne unique crystallo

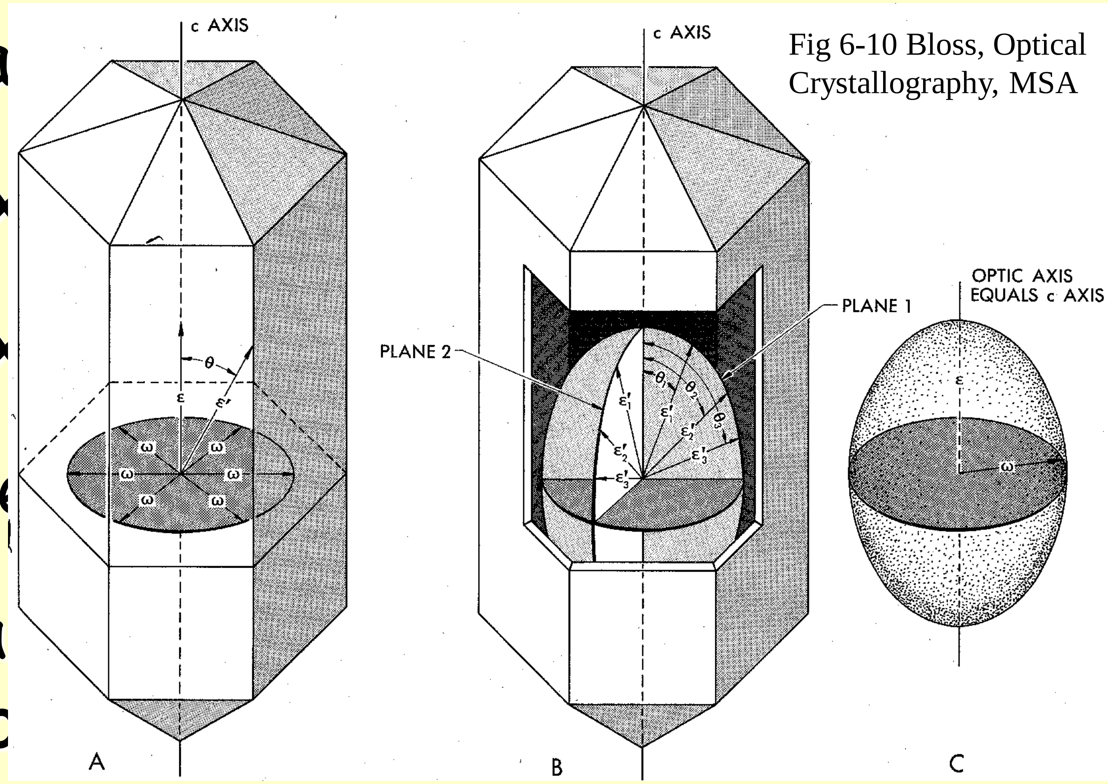
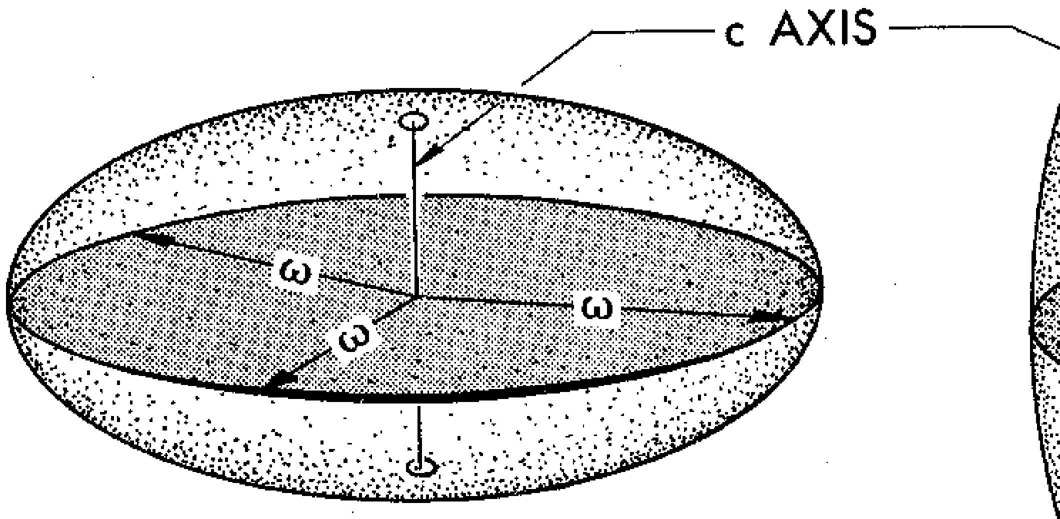


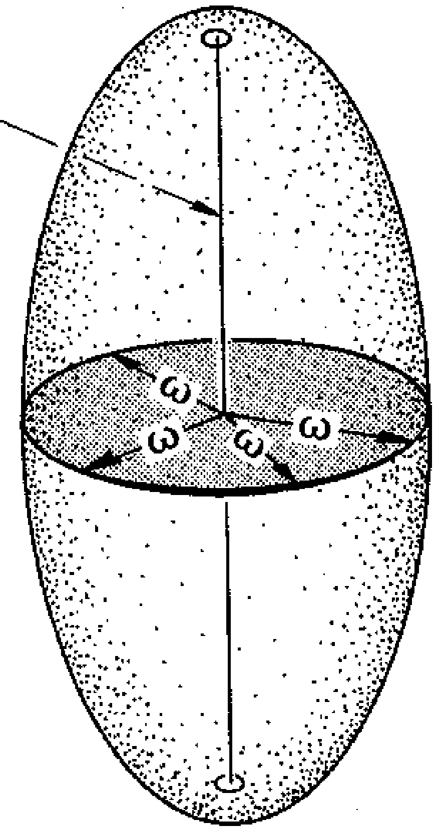
Fig 6-10 Bloss, Optical Crystallography, MSA

The optical properties reflect this as well: **ellipsoid of rotation about c** (optically **uniaxial**) and c = the **optic axis**

Uniaxial ellipsoid and conventions:

Fig 6-11 Bloss, Optical Crystallography, MSA





(-) crystal: ▬

ω > ε

→ oblate

(+) crystal:

ε > ω

→ prolate

Depending on light propagation we can have:

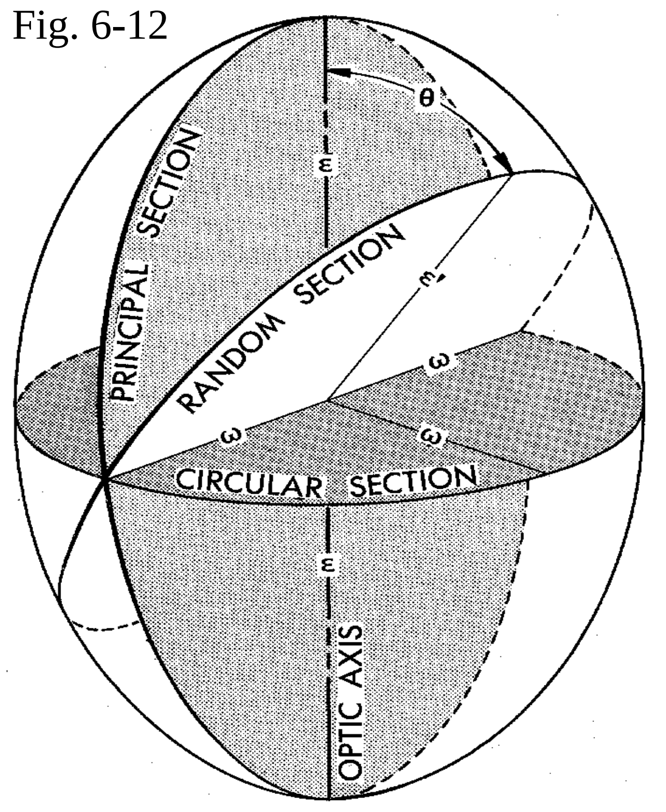


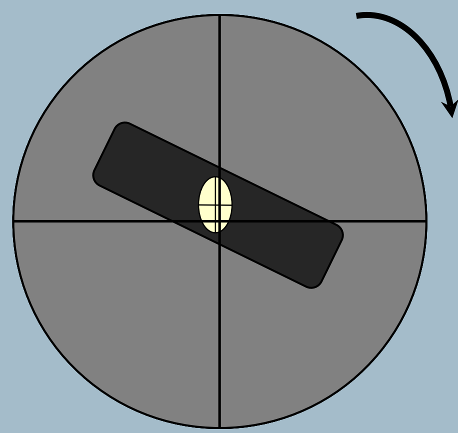
Fig. 6-12

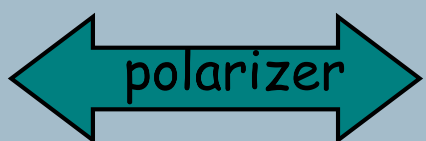
- Circular Section
  - $\perp$ optic axis: all ω's
- Principal Sections
  - have ω and true ε: max & min n's
- Random Sections (ε' and ω)
- *All sections have ω!!*

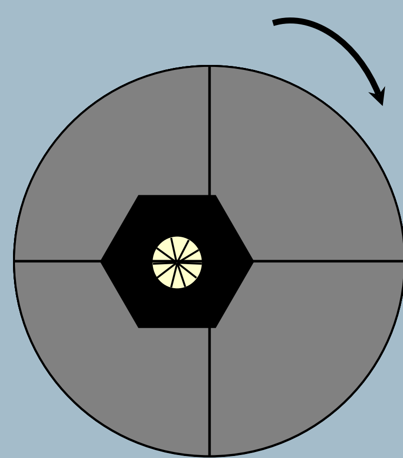
Any non-circular cut through the center of a uniaxial indicatrix will have ω as one *semiaxis and* ε' (or true ε) as the other

Rotating the stage

Anisotropic minerals **with an elliptical indicatrix section** change color as the stage is rotated; these grains go black 4 times in 360° rotation-**exactly every 90°**

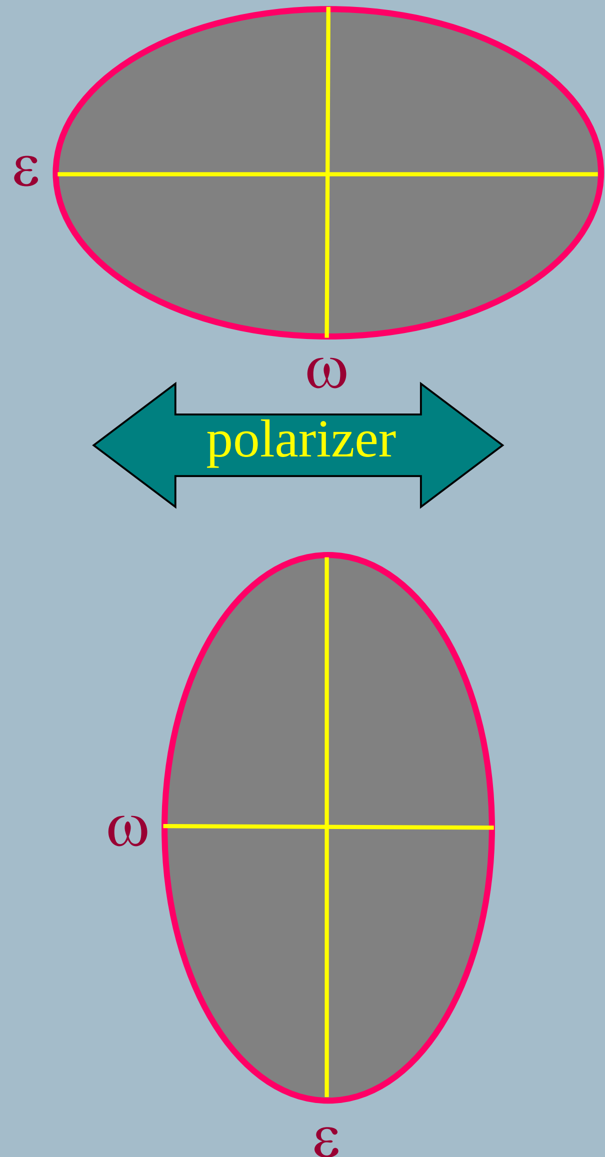






Isotropic: glass or isometric minerals or look down optic axis of anisotropic minerals

Consider rotating the crystal as you watch:



B = polarizer vibration direction parallel ε

→ only E-ray

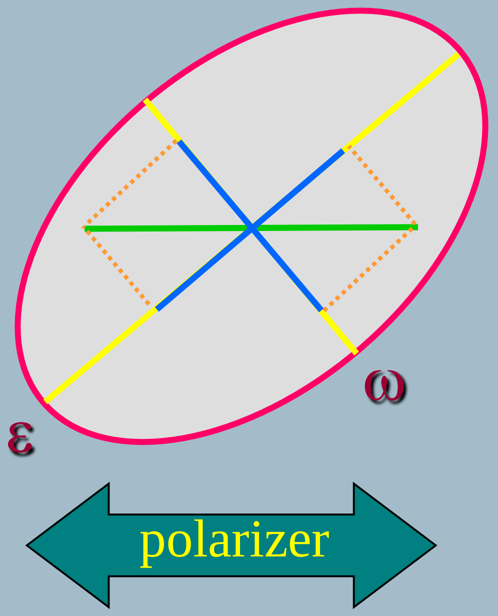
Analyzer in → **extinct**

C = polarizer vibration direction || ω

→ only O-ray

also → **extinct** with analyzer

Consider rotating the crystal as you watch:



D

Polarized light has a component of each

Splits → two rays

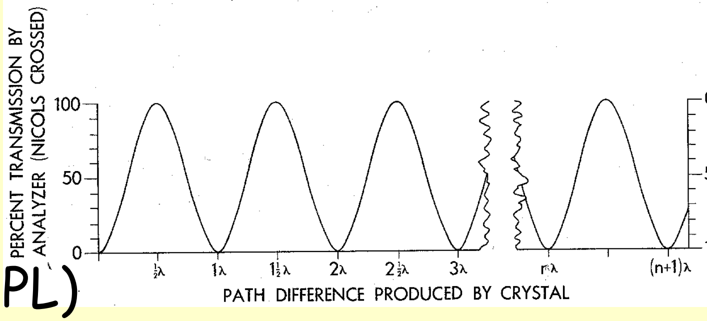
one is O-ray with n = ω

other is E-ray with n = ε

When the rays exit the crystal they

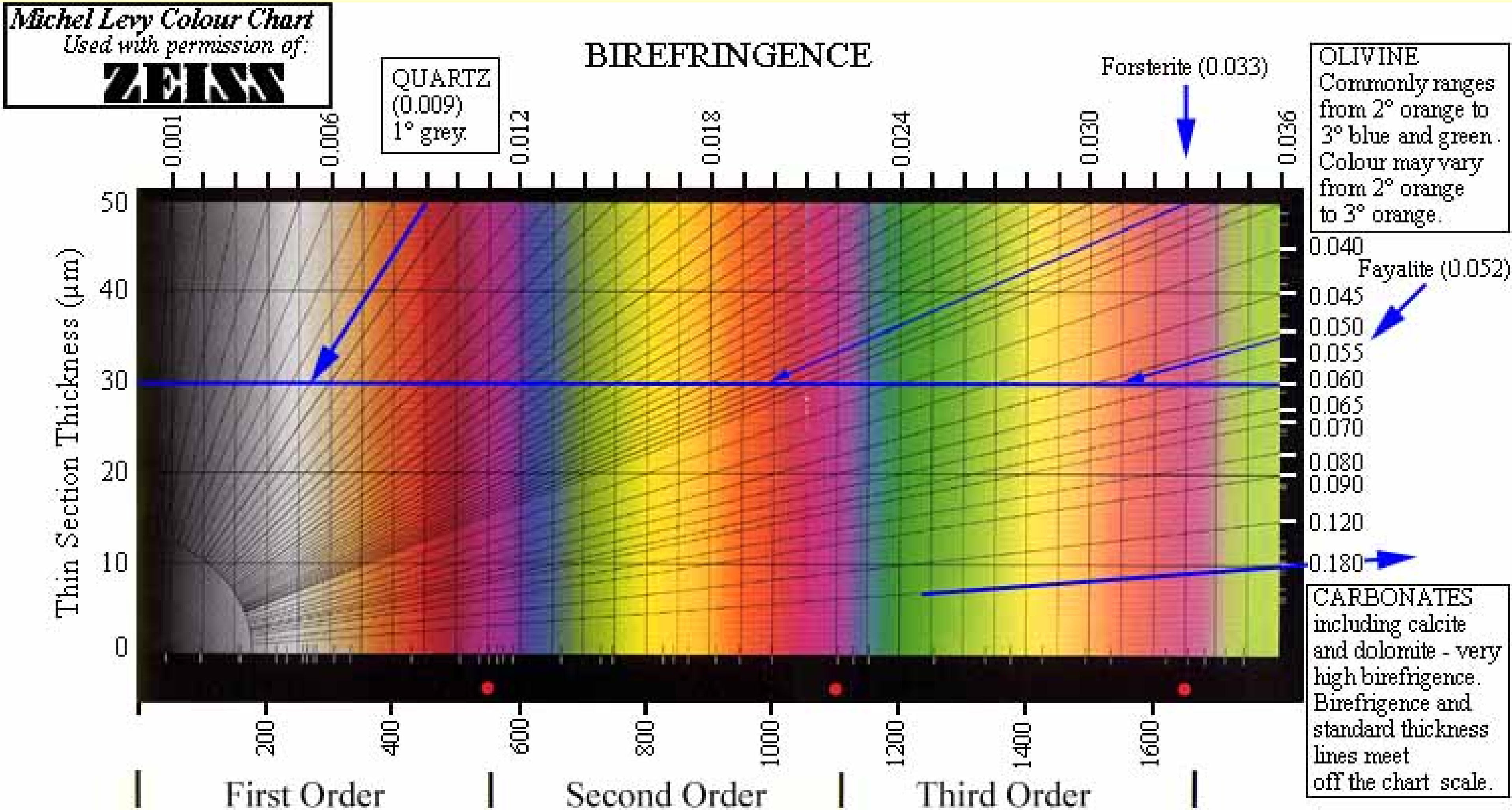
recombine

Color chart



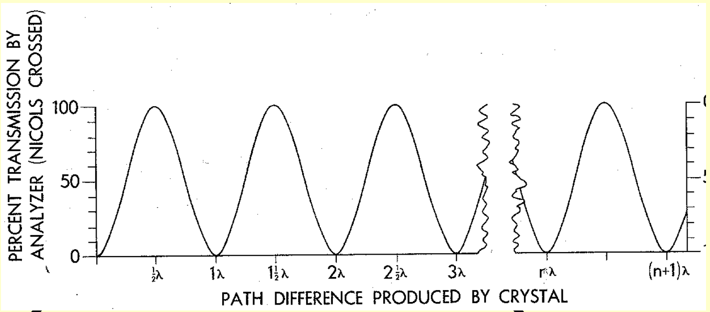
Colors one observes when polars are crossed (XPL)

Color can be quantified numerically: $\delta = n_{high} - n_{low}$



Color chart

Shows the relationship between retardation, crystal thickness, and interference color



550 µm → red violet

800 µm → green

1100 µm → red-violet again (note repeat ↑)

0-550 µm = "1st order" 550-1100 µm = 2nd order 1100-1650 µm = 3rd order…

Higher orders are more pastel

Estimating birefringence

1) Find the crystal of interest showing the highest colors (Δ depends on orientation)
2) Go to color chart

   thickness = 30 microns

   use 30 micron line + color, follow radial line through intersection to margin & read birefringence

Suppose you have a mineral with second-order green

What about third order yellow?

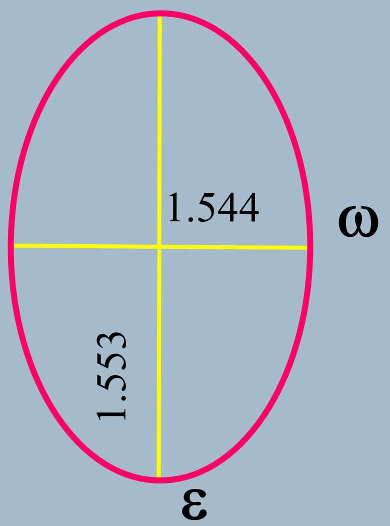
Example: Quartz ω = 1.544 ε = 1.553

SILICA MINERALS

Quartz, Tridymite, Cristobalite

SiO_2

	QUARTZ	TRIDYMITE	CRISTOBALITE
	Trigonal (+)	Orthorhombic (+)	Tetragonal? (−)
	ω 1·544	α 1·471–1·479	ϵ 1·484
	ϵ 1·553	β 1·472–1·480	ω 1·487
		γ 1·474–1·483	
	δ 0·009	0·002$_5$–0·004	0·003
$2V_\gamma$		66°–90°	
Orientation:		O.A.P. (100), $\alpha = y$	
D	2·65	2·27	2·33
H	7	7	6–7
Cleavage:	none	poor prismatic cleavage	none
Twinning:	(1) Twin axis z (2) Twin plane $\{11\bar{2}0\}$ (3) Twin plane $\{11\bar{2}2\}$ Twinning rarely seen in thin section.	common on {110}	Spinel-type twins on {111}.
Colour:	Colourless, white, or variable; black purple, green, etc.	Colourless or white.	Colourless, white or yellowish.
	Colourless in thin section		
Unit cell:	a (Å) 4·913	9·88	4·97
	b (Å)	17·1	
	c (Å) 5·405	16·3	6·92
	c/a 1·1001		1·395
	Z 3	64	8
Space group:	$P3_121$ or $P3_221$	Fmm, $Fmmm$ or $F222$	$P4_12_1$ or $P4_32_1$



Data from Deer et al
Rock Forming Minerals
John Wiley & Sons

Example: Quartz $\omega = 1.544$ $\varepsilon = 1.553$

Sign??

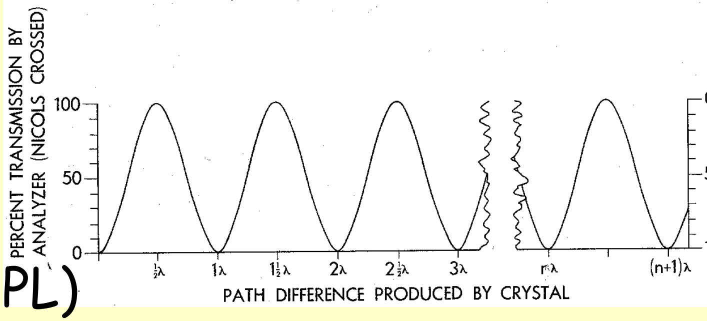
(+) because $\varepsilon > \omega$

$\varepsilon - \omega = 0.009$ called the **birefringence** (δ)

= **maximum** interference color (when seen?)

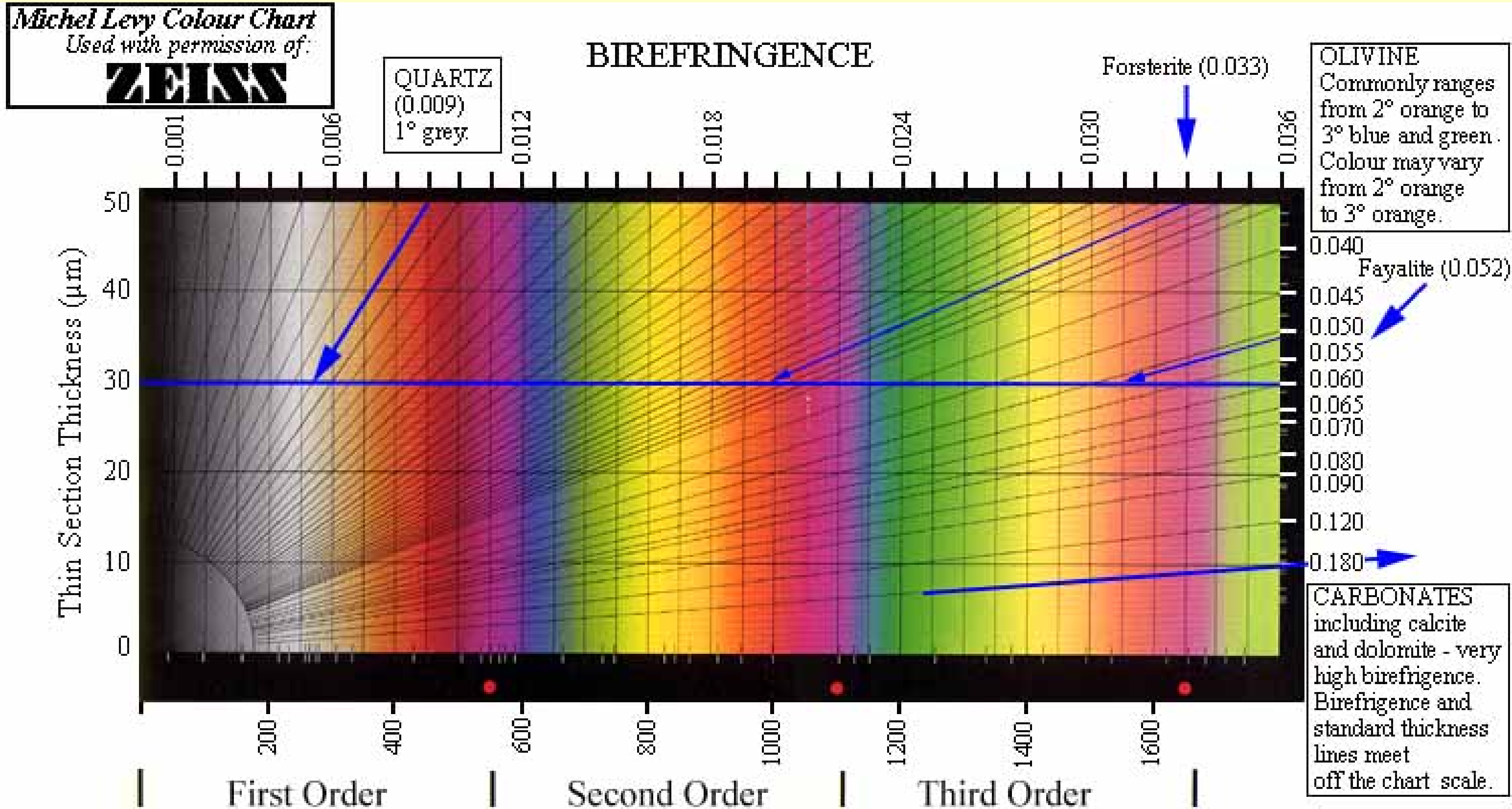
What color is this?? Use your chart.

Color chart



Colors one observes when polars are crossed (XPL)

Color can be quantified numerically: $\delta = n_{high} - n_{low}$



Example: Quartz $\omega = 1.544$ $\varepsilon = 1.553$

Sign??

(+) because $\varepsilon > \omega$

$\varepsilon - \omega = 0.009$ called the **birefringence** (δ)

= **maximum** interference color (when see this?)

What color is this?? Use your chart.

For other orientations get $\varepsilon' - \omega \rightarrow$ progressively lower color

Rotation of the stage changes the intensity, but not the hue

Extinct when either privileged direction N-S (every 90°) and maximum interference color brightness at 45°

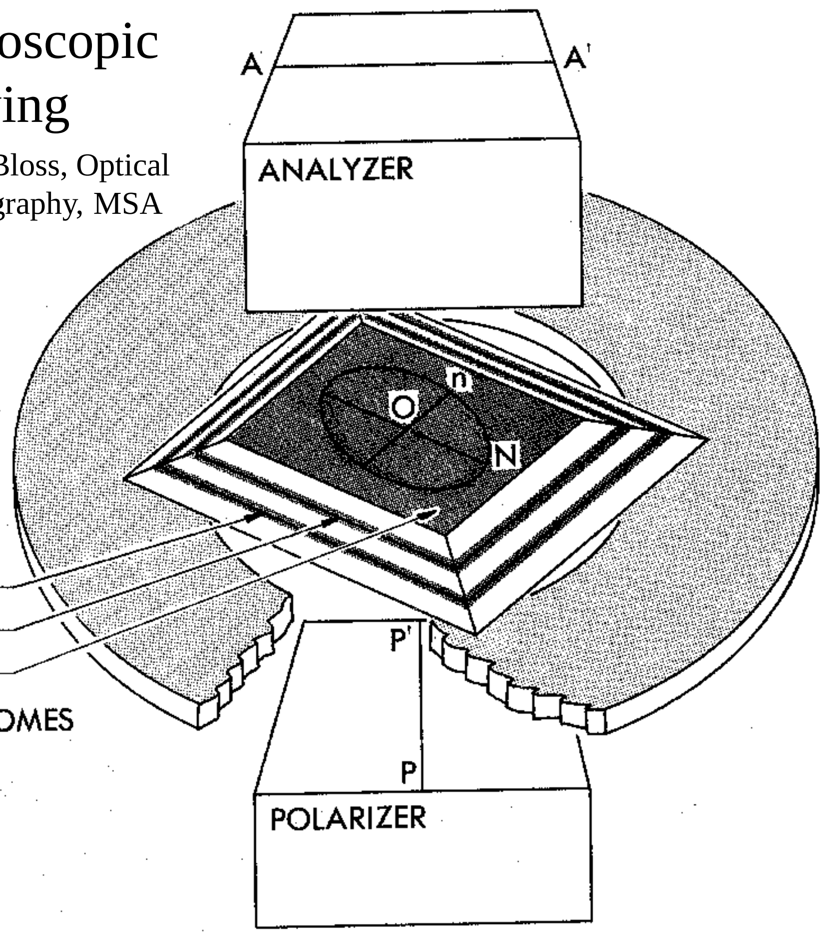
360° rotation $\rightarrow$ 4 extinction positions exactly 90° apart

So far, all of this has been **orthoscopic** (the normal way)

All light rays are ~ parallel and vertical as they pass through the crystal

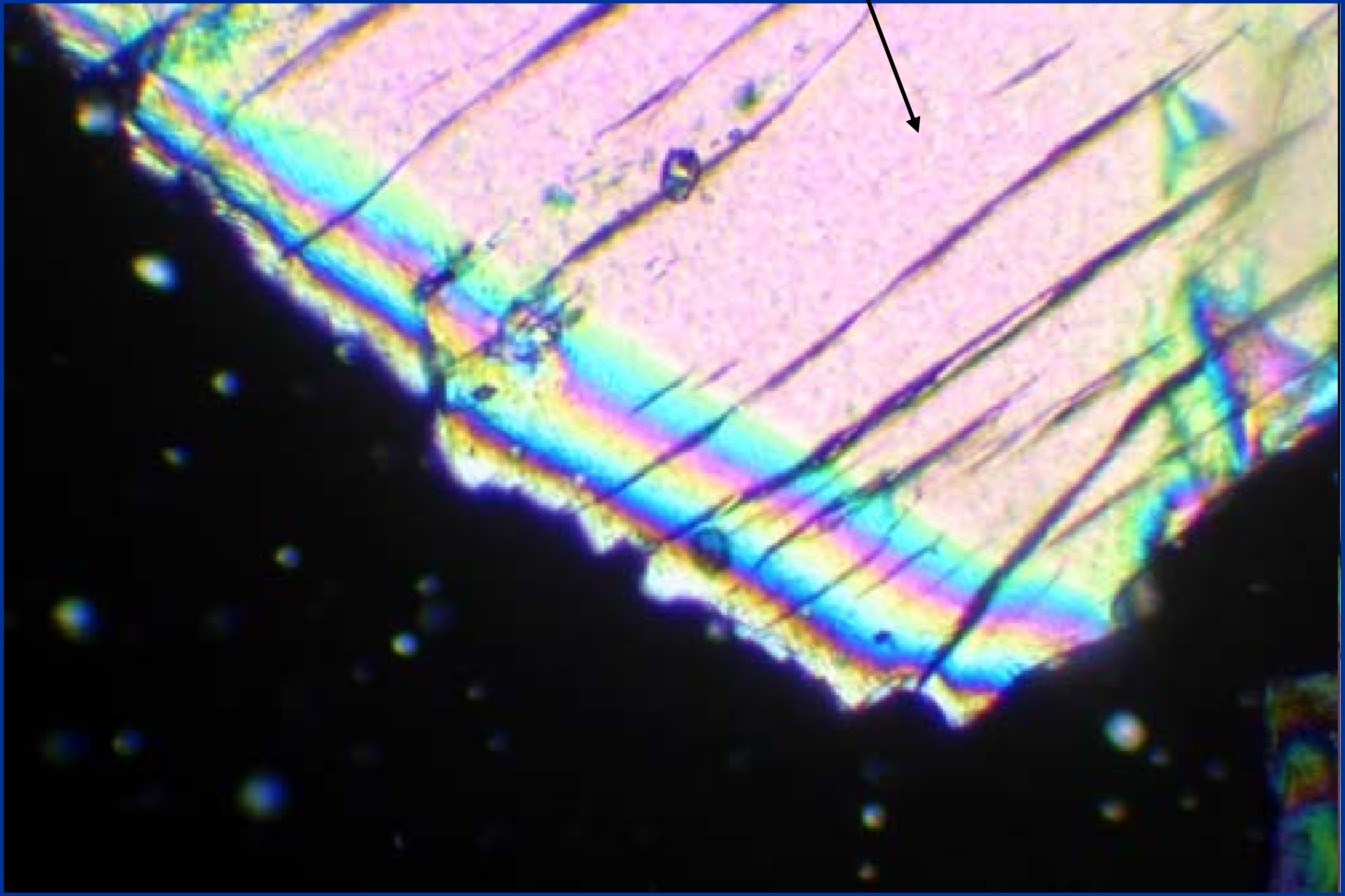
Orthoscopic viewing

Fig 7-11 Bloss, Optical Crystallography, MSA



- xl has particular interference color = f(biref, t, orientation)
- Points of equal thickness will have the same color
- **isochromes** = lines connecting points of equal interference color
- At thinner spots and toward edges will show a lower color
- Count isochromes (inward from thin edge) to determine order

What interference color is this?



If this were the maximum interference color seen, what is the birefringence of the mineral?