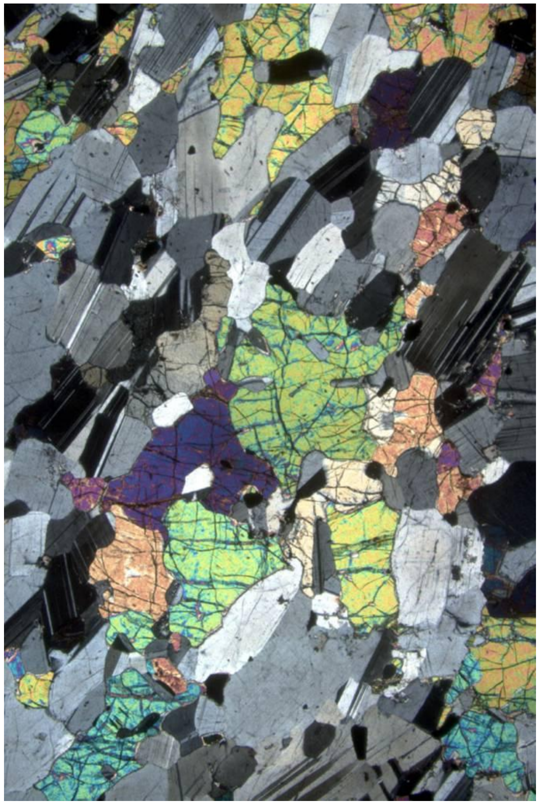
Optical Microscopy

- Study of how light passes through thin sections – rock cut and polished to about 0.3 mm thickness
- Use properties of light absorption and propogation through a mineral → affected by atomic arrangement and composition
- Learn the properties of light associated with techniques governing the use of a petrographic microscope

Why use the microscope??

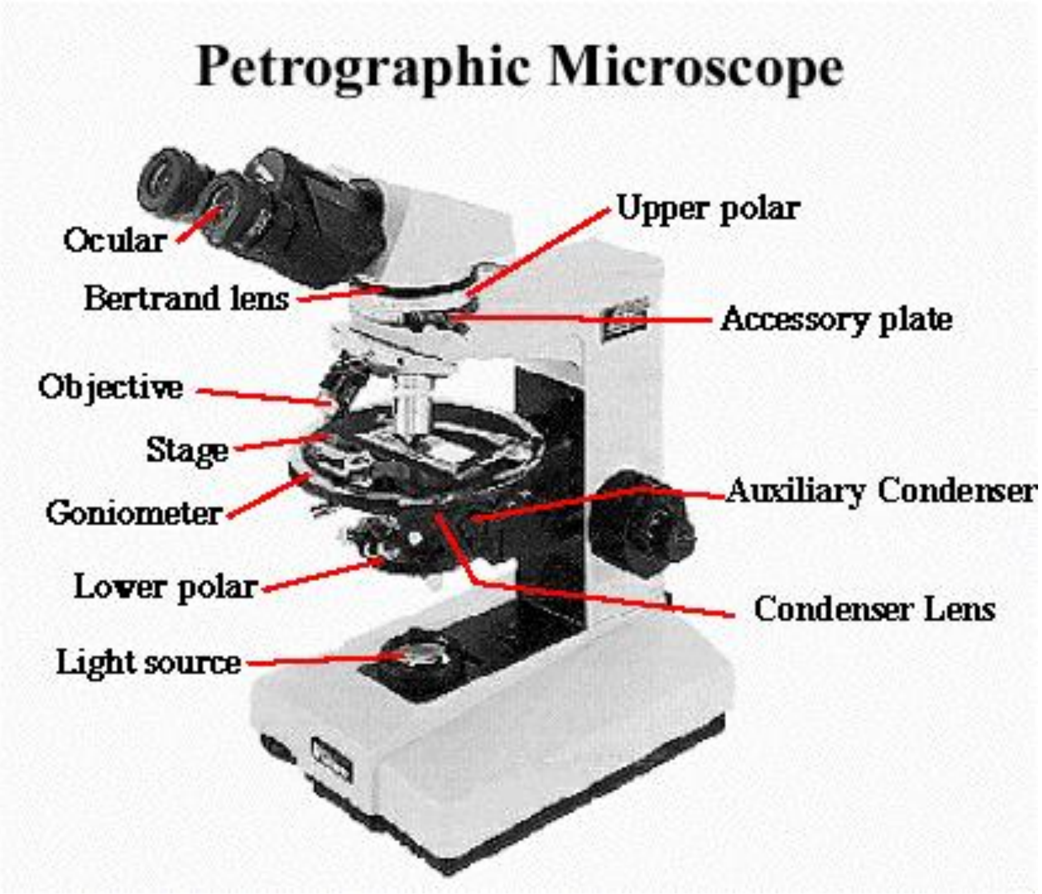


- Identify minerals *(no guessing!)*
- Determine rock type
- Determine crystallization sequence
- Document deformation history
- Observe frozen-in reactions
- Constrain P-T history
- Note weathering/alteration
- Fun, powerful, and cheap!

Minerals and propogation of light

- Opaque minerals – minerals in which light does not go through → always black even in thin sections. Typically these have molecules with higher atomic density (which includes many ore minerals). How light reflects off of these minerals is used to identify them with a reflected light microscope.
- Nonopaque minerals – minerals in which light does go through → use these properties to identify them with the petrographic microscope

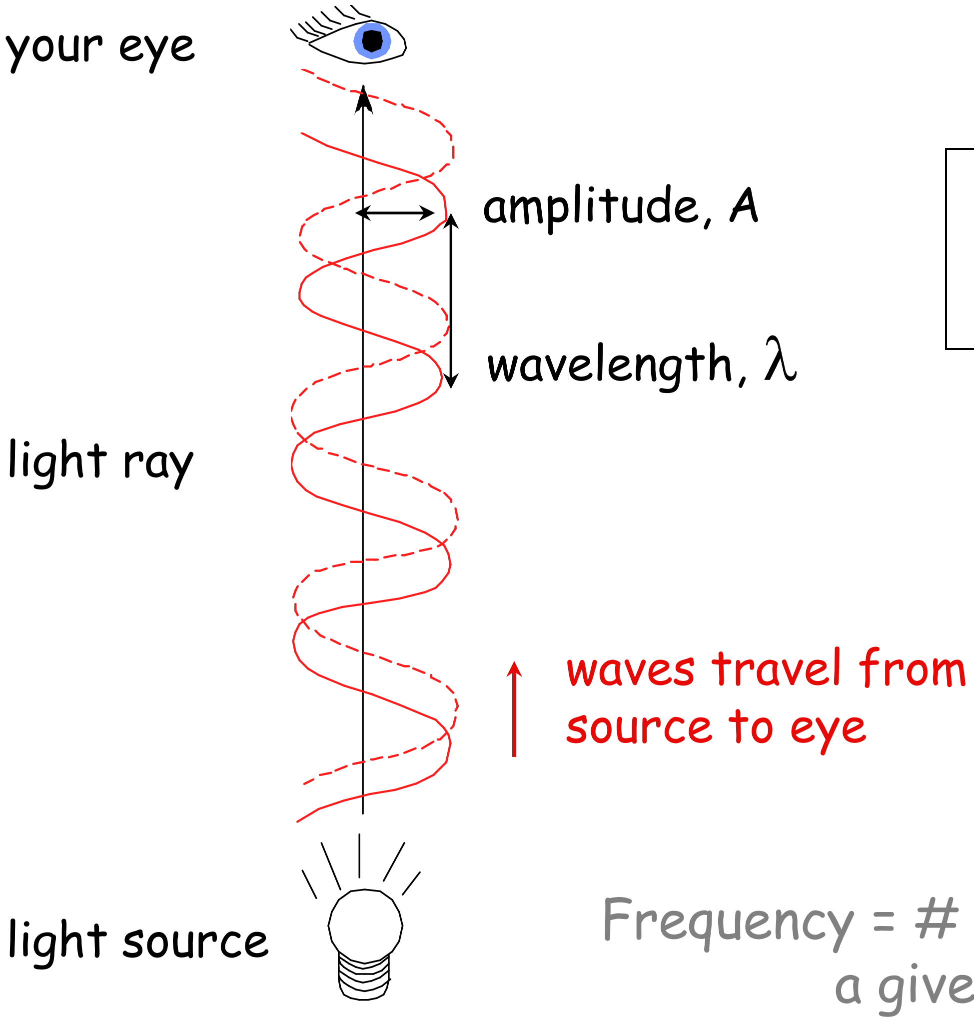
The petrographic microscope



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…

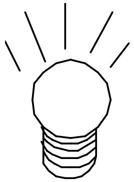
What happens as light moves through the scope?



light travels as waves

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

$f = v/\lambda$ $\quad$ v = velocity

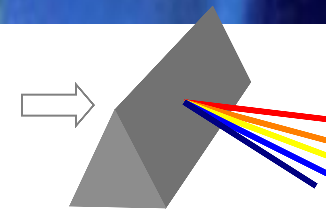


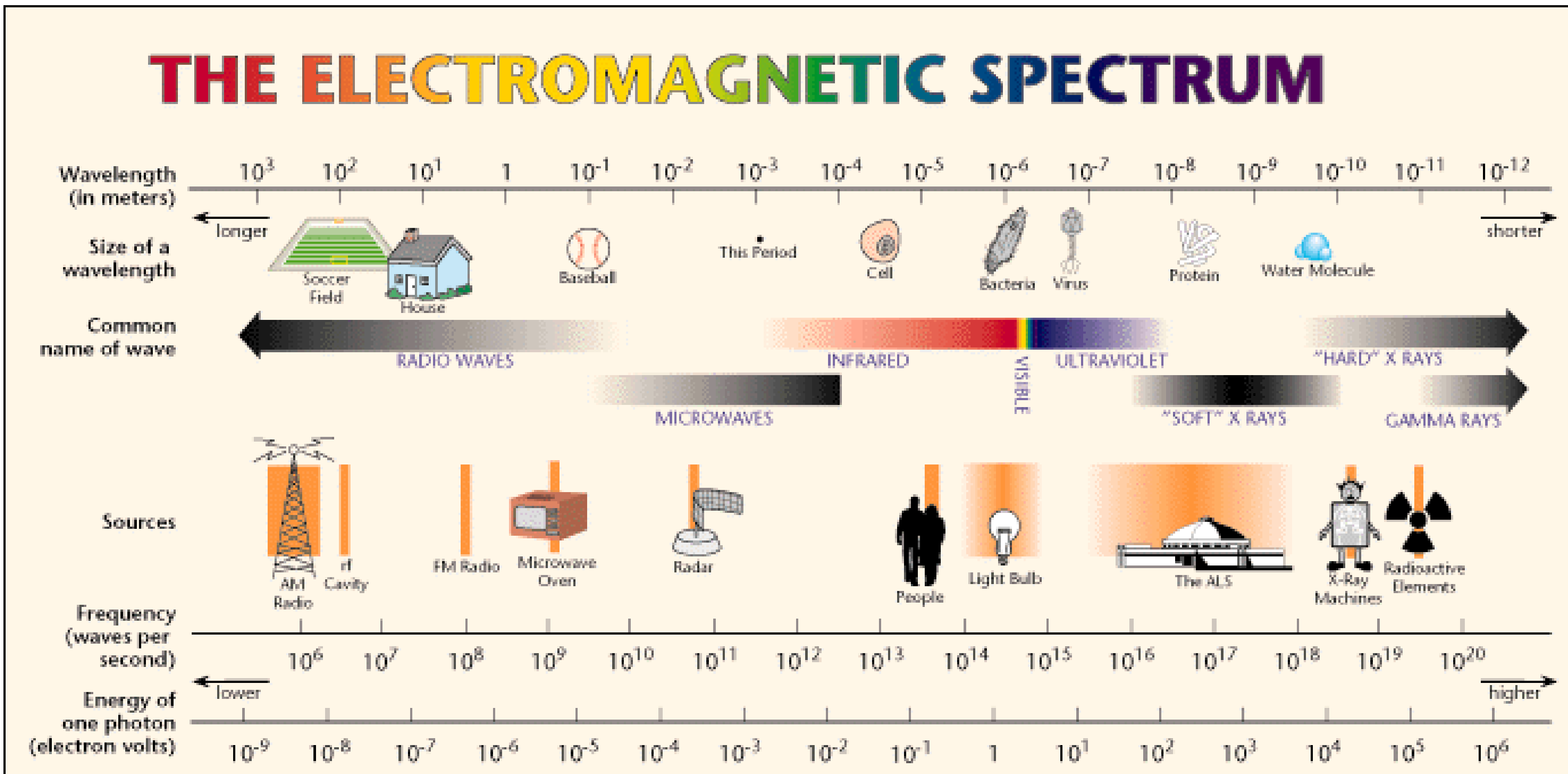
We are dealing with white light in microscopy:

Violet (400 nm) → Red (700 nm)

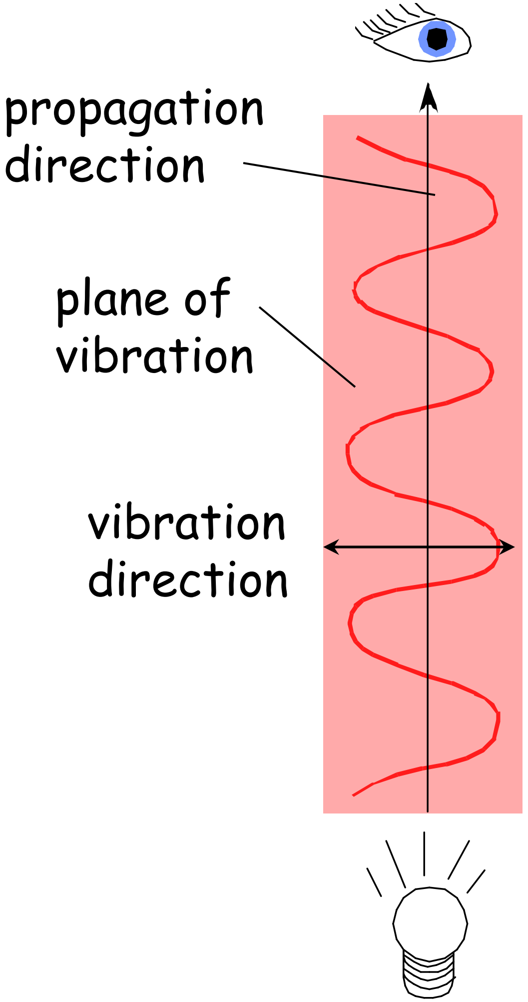
White = ROYGBV

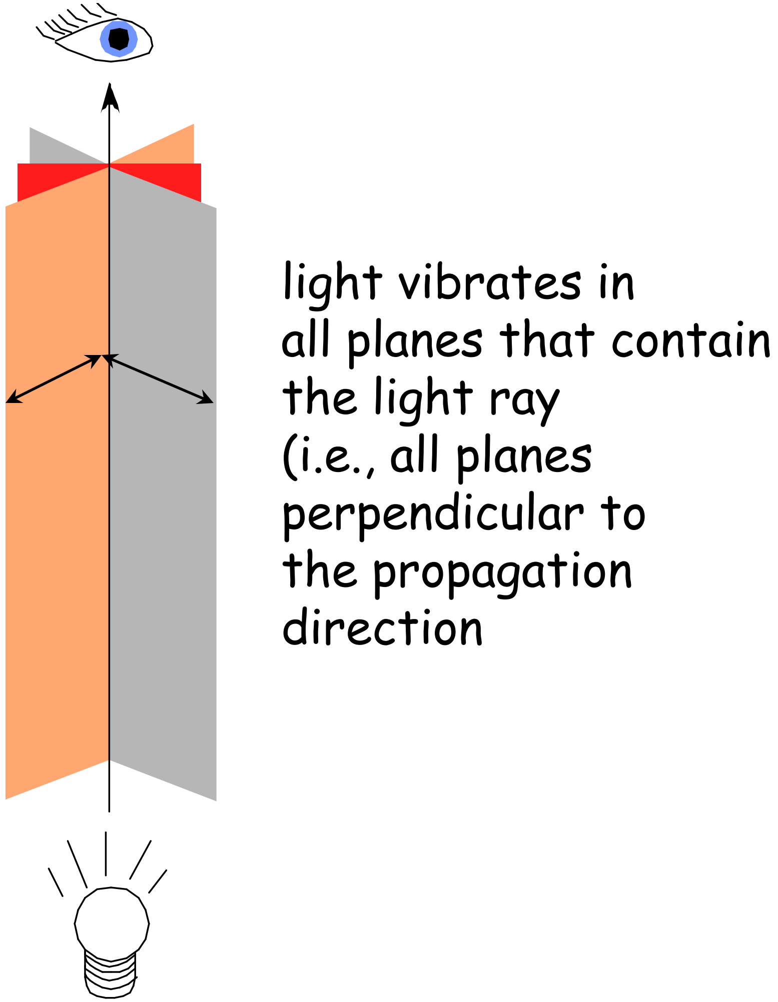
(can be separated by dispersion in a prism)



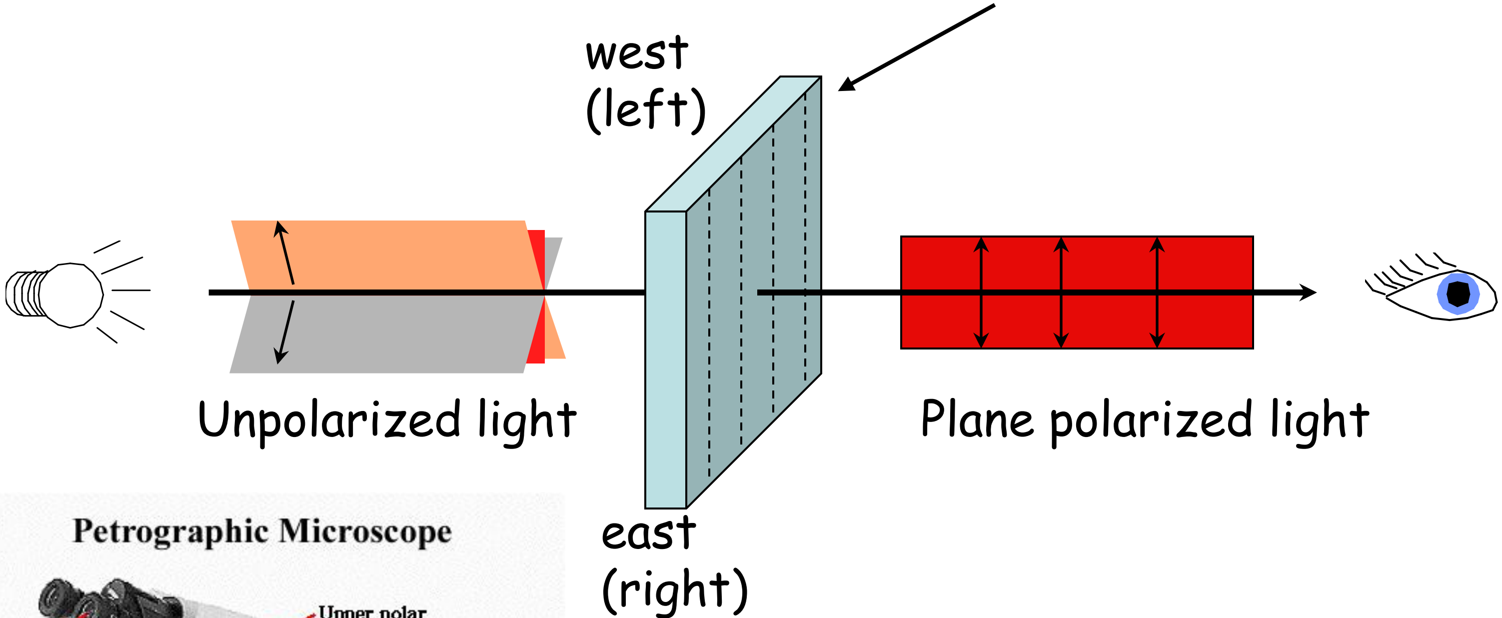


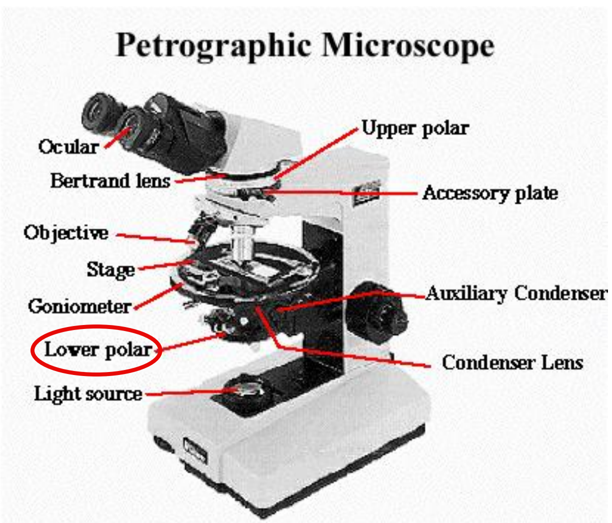
What happens as light moves through the scope?





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





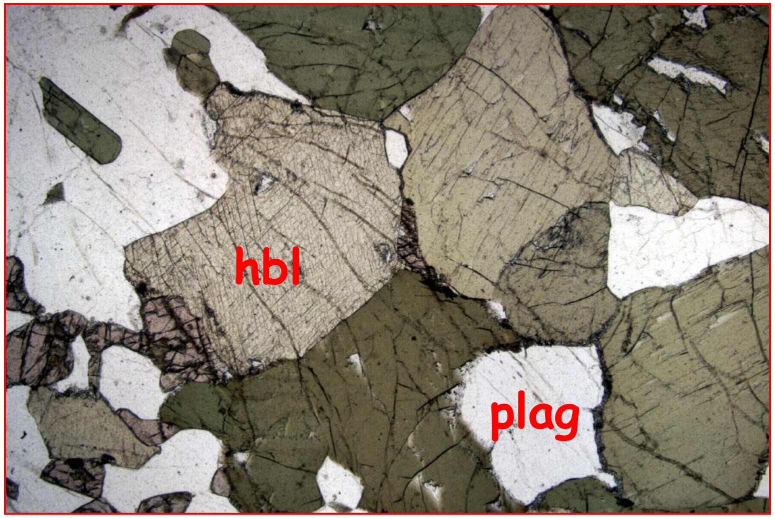
PPL=plane polarized light

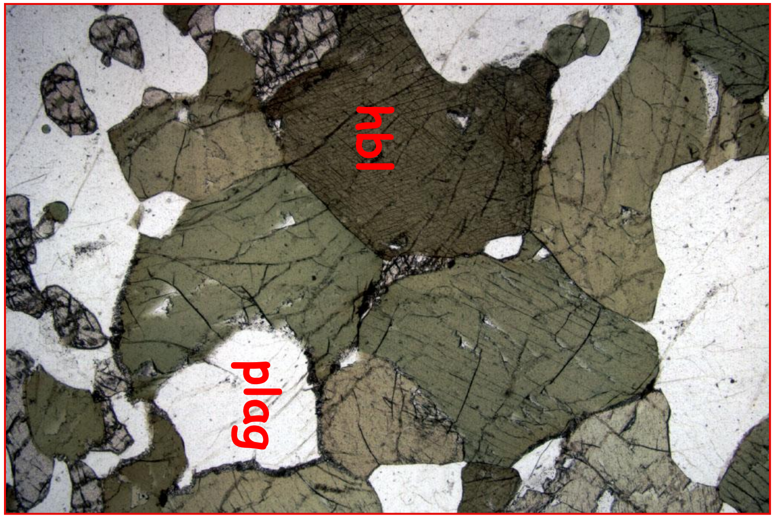
Only the component of light vibrating in E-W direction can pass through lower polarizer – **light intensity decreases**

Though polarized, still white light!

Mineral properties: color & pleochroism

- Color is observed only in PPL
- Not an inherent property - changes with light type/intensity
- Results from selective absorption of certain λ of light
- Pleochroism results when different λ are absorbed differently by different crystallographic directions - rotate stage to observe



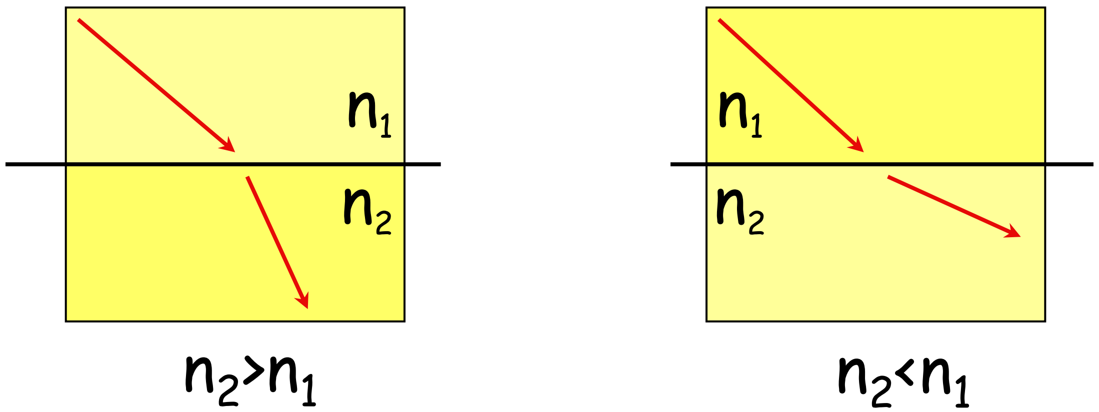


-Plagioclase is colorless
-Hornblende is pleochroic

Mineral properties: Index of refraction (R.I. *or* n)

$$n = \frac{\text{velocity in air}}{\text{velocity in mineral}}$$

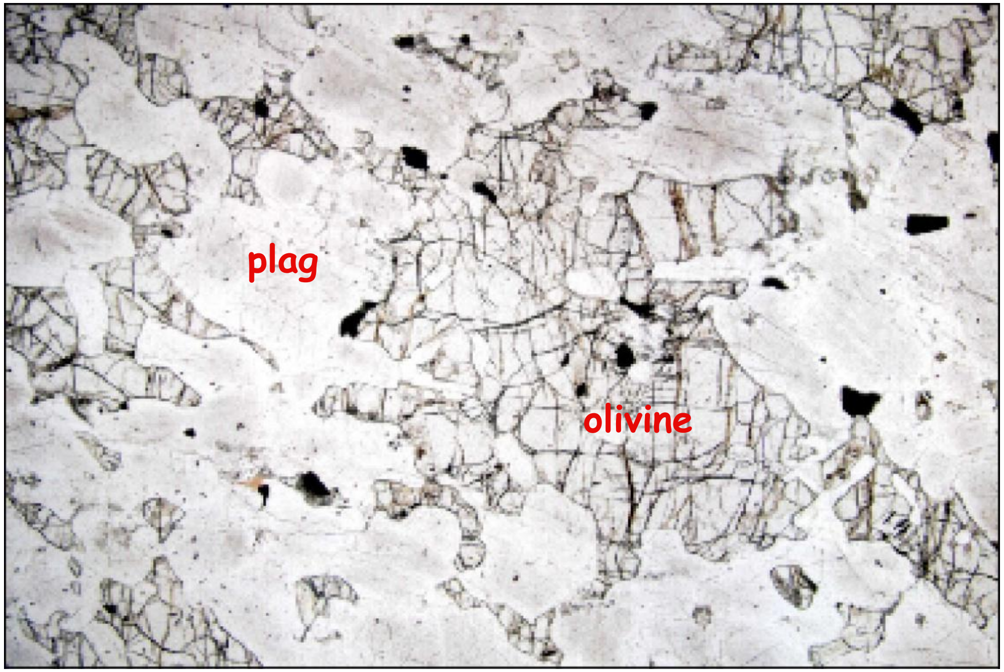
Light is refracted when it passes from one substance to another; refraction is accompanied by a change in velocity



- n is a function of crystallographic orientation in anisotropic minerals
  - ⇨ isotropic minerals: characterized by one RI
  - ⇨ uniaxial minerals: characterized by two RI
  - ⇨ biaxial minerals: characterized by three RI
- n gives rise to 2 easily measured parameters: **relief** & **birefringence**

Mineral properties: **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

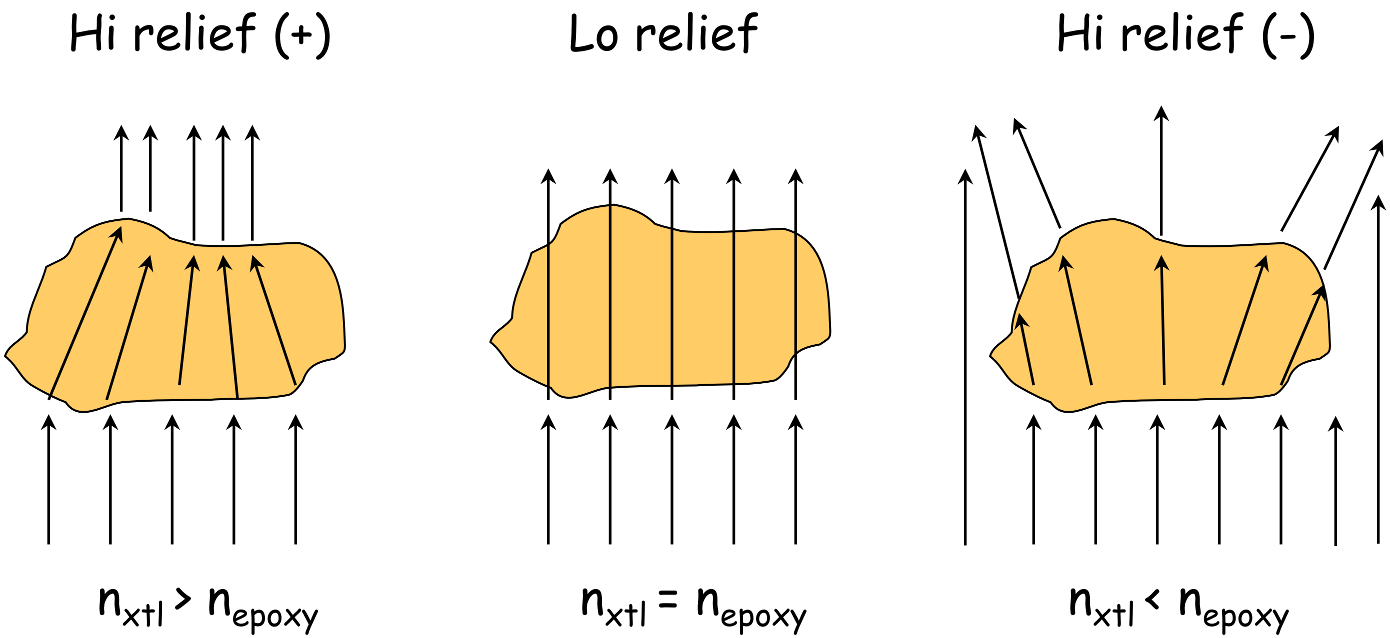


- Olivine has high relief
- Plag has low relief

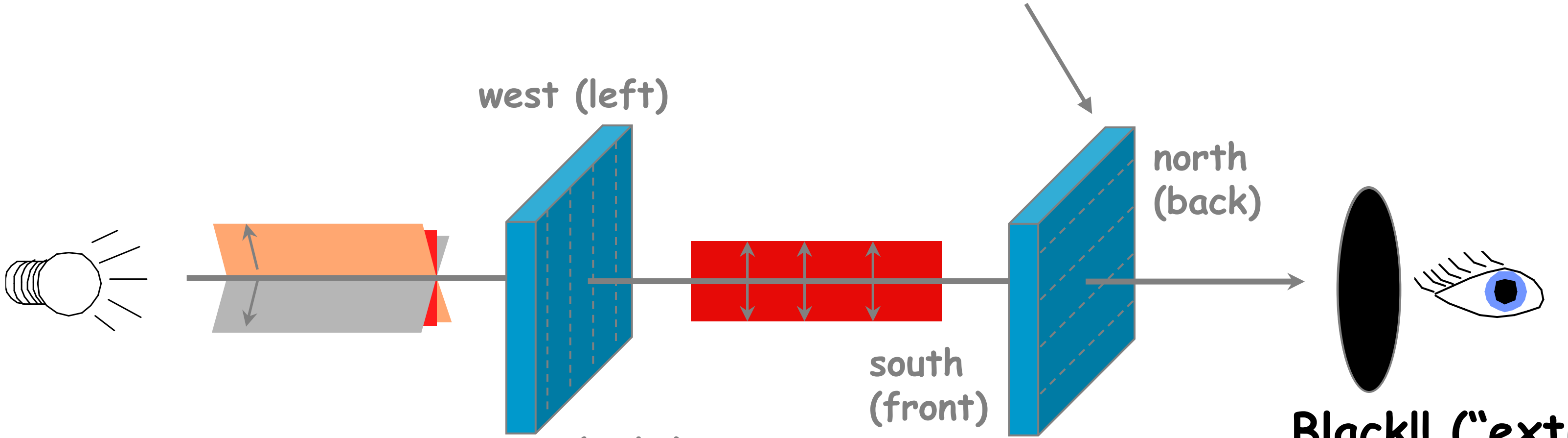
olivine:	n=1.64-1.88
plag:	n=1.53-1.57
epoxy:	n=1.54

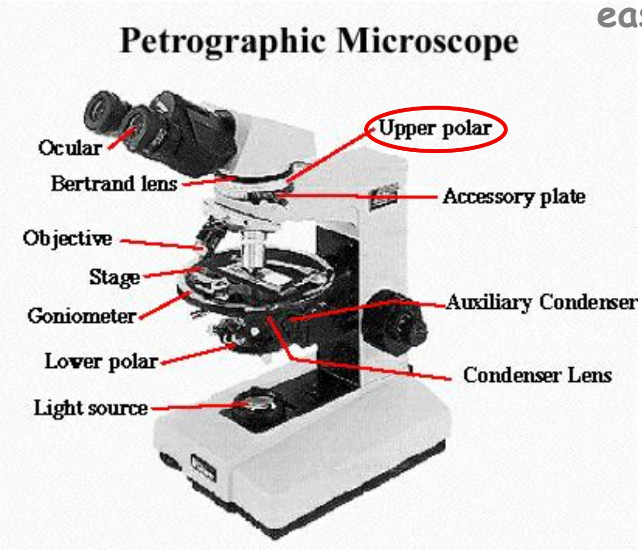
What causes relief?

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



2) Insert the **upper polarizer**



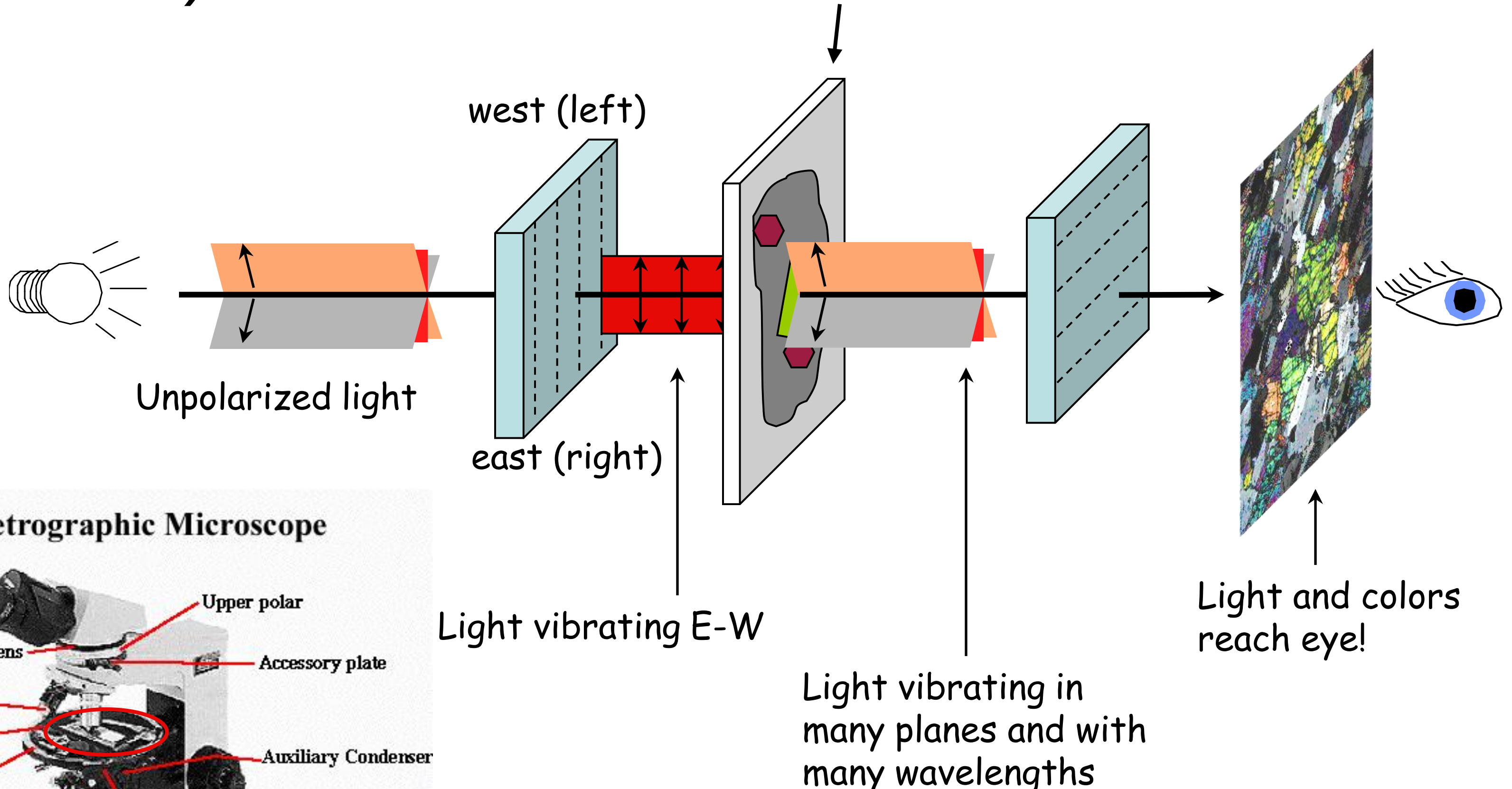


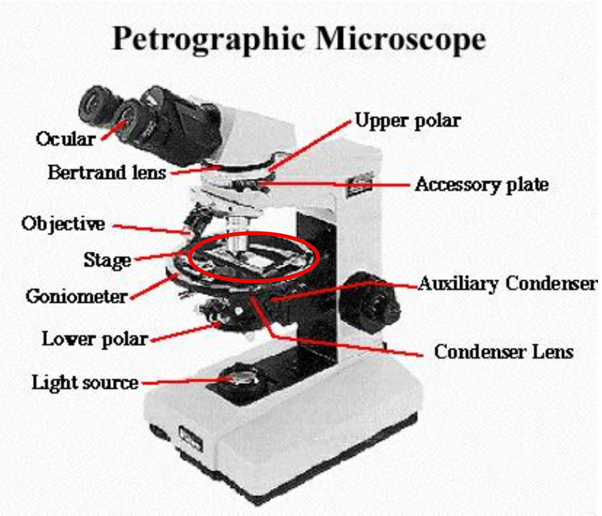
XPL=crossed nicols
(crossed polars)

Now what happens?
What reaches your eye?

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

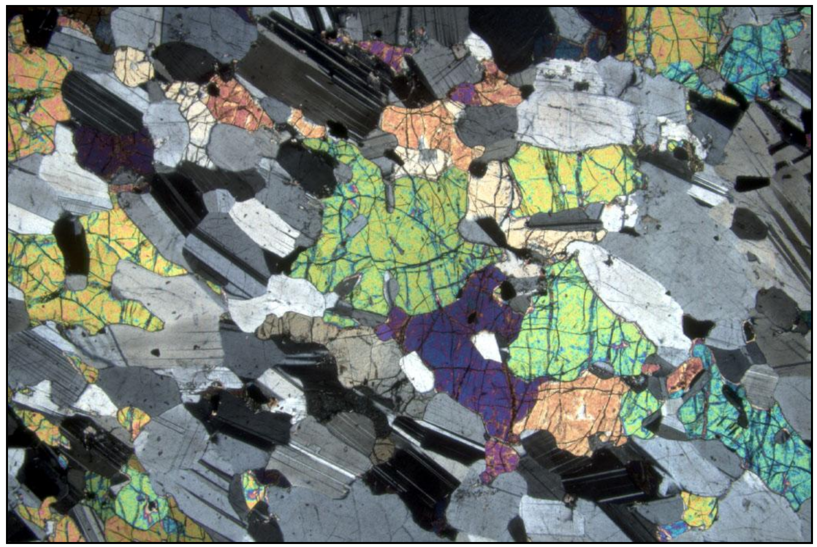
3) Now insert a **thin section** of a rock





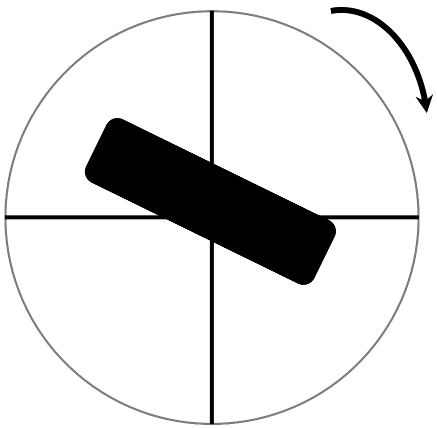
How does this work??

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



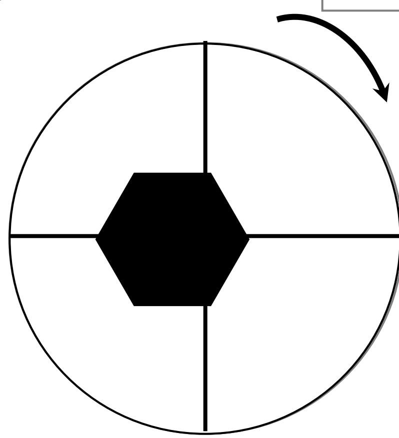
4) Note the **rotating stage**

Most mineral grains **change color** as the stage is rotated;
these grains go **black** 4 times in 360° rotation-
exactly every 90°



These minerals are anisotropic

Glass and a few minerals stay black in all orientations



These minerals are isotropic

Some generalizations and vocabulary

- All isometric minerals (e.g., *garnet*) are **isotropic** – they cannot reorient light. Light does not get rotated or split; propagates with same velocity in all directions
  - These minerals are always black in crossed polars.
- All other minerals are **anisotropic** – they are all capable of reorienting light (transmit light under cross polars).
- All anisotropic minerals contain one or two special directions that do **not** reorient light.
  - Minerals with **one** special direction are called **uniaxial**
  - Minerals with **two** special directions are called **biaxial**

How light behaves depends on crystal structure

Isotropic → Isometric

- All crystallographic axes are equal

Uniaxial → Hexagonal, tetragonal

- All axes ⊥ c are equal but c is unique

Biaxial → Orthorhombic, monoclinic, triclinic

- All axes are unequal

- Isotropic minerals: light does not get rotated or split; propagates with same velocity in all directions

- Anisotropic minerals:
    - Uniaxial - light entering in all but **one** special direction is resolved into 2 plane polarized components that vibrate perpendicular to one another and travel with different speeds
    - Biaxial - light entering in all but **two** special directions is resolved into 2 plane polarized components…
  - Along the special directions ("optic axes"), the mineral thinks that it is isotropic - i.e., no splitting occurs
  - Uniaxial and biaxial minerals can be further subdivided into optically positive and optically negative, depending on orientation of fast and slow rays relative to xtl axes

‘Splitting’ of light → what does it mean?

- For some exceptionally clear minerals where we can see this is hand sample this is double refraction → calcite displays this
- Light is split into 2 rays, one traveling at a different speed, and this difference is a function of thickness and orientation of the crystal → Norden Bombsight patented in 1941 utilized calcite in the lenses to gauge bomb delivery based on speed, altitude of plane vs target
- ALL anisotropic minerals have this property, and we can ‘see’ that in thin sections with polarized light!

Anisotropic crystals

Calcite experiment and double refraction

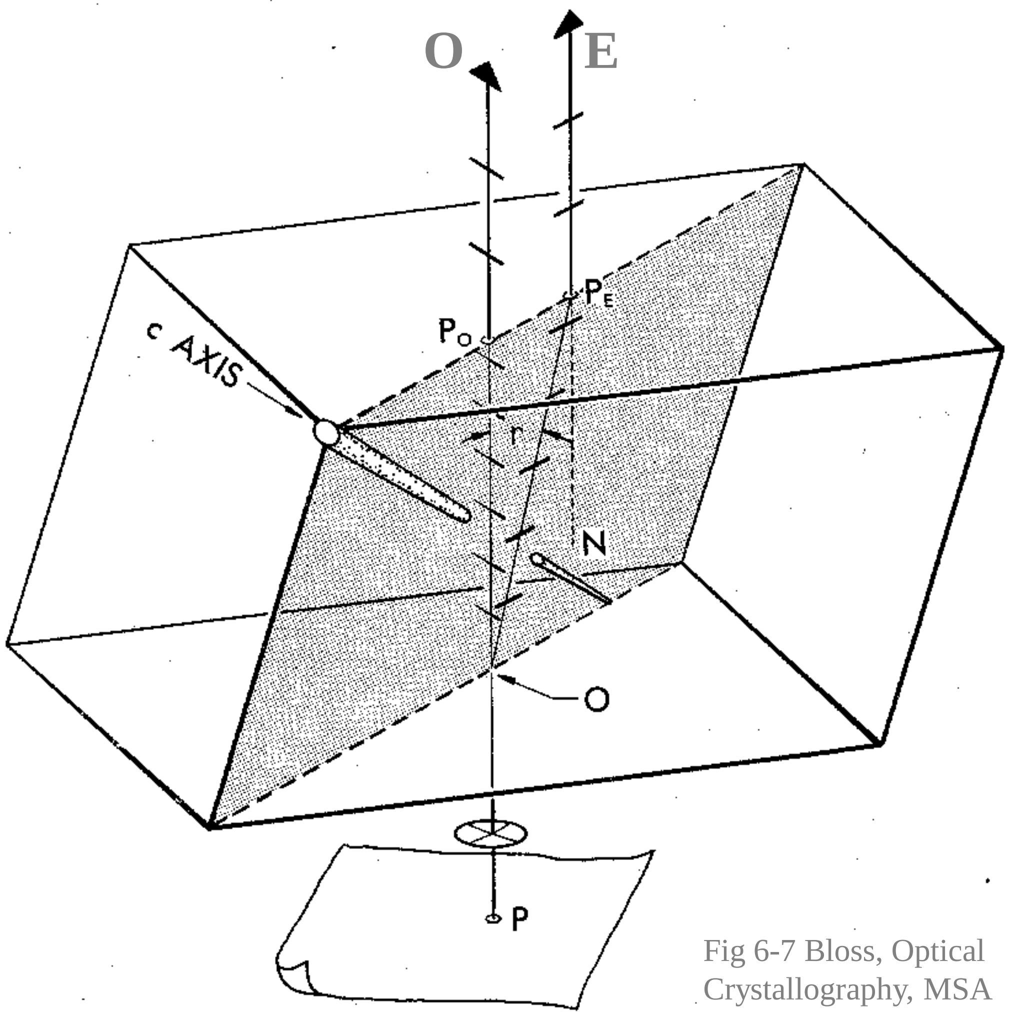


Fig 6-7 Bloss, Optical Crystallography, MSA

O-ray (Ordinary) → ω

Obeys Snell's Law and goes straight

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

E-ray (Extraordinary) → ε

deflected

Vibrates **in** plane containing ray and c-axis

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

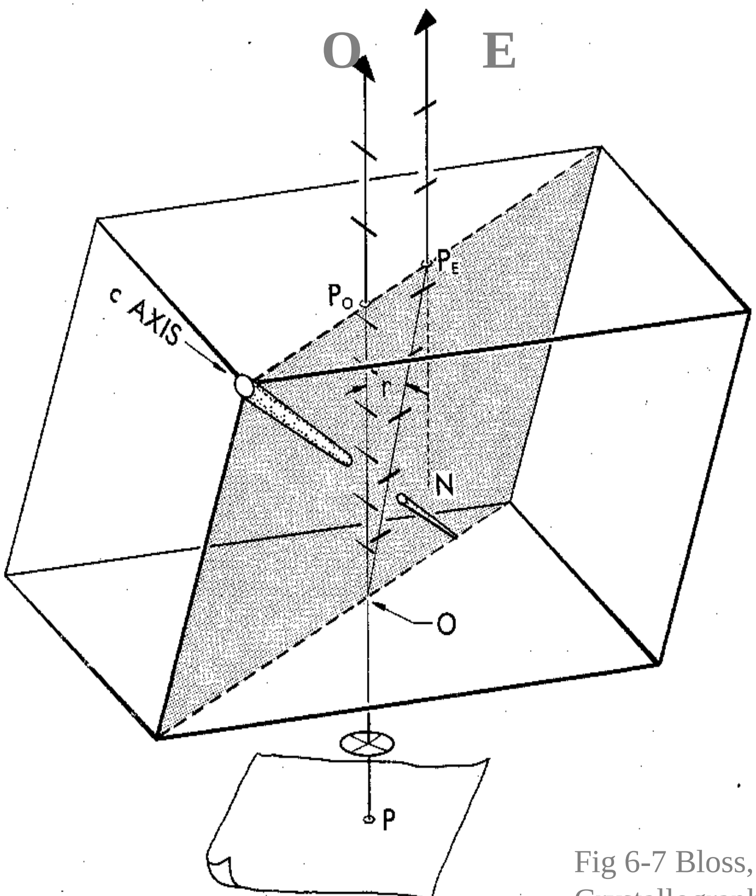


Fig 6-7 Bloss, Optical Crystallography, MSA

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

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

Different rays going different speeds means they are at different wavelengths

- If I slow down 1 ray and then recombine it with another ray that is still going faster, what happens??

Difference between our 2 rays

- Apparent birefringence – δ – difference in refractive index (speed) between the 2 rays
- Retardation – Δ → distance separating the 2 rays
- Retardation therefore is a function of the apparent birefringence and the thickness of the crystal → ideally all thin sections are 0.3 mm, but mistakes do happen…

Polarized light going into the crystal splits → into

two rays, going at different velocities and

therefore at different wavelengths (colors)

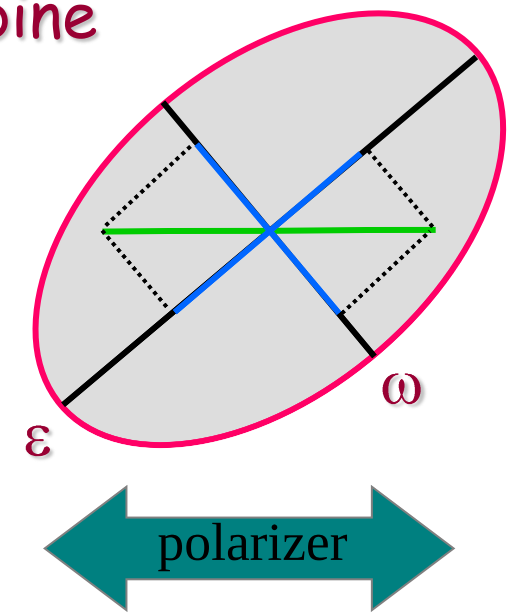
one is O-ray with $n = \omega$

other is E-ray with $n = \varepsilon$

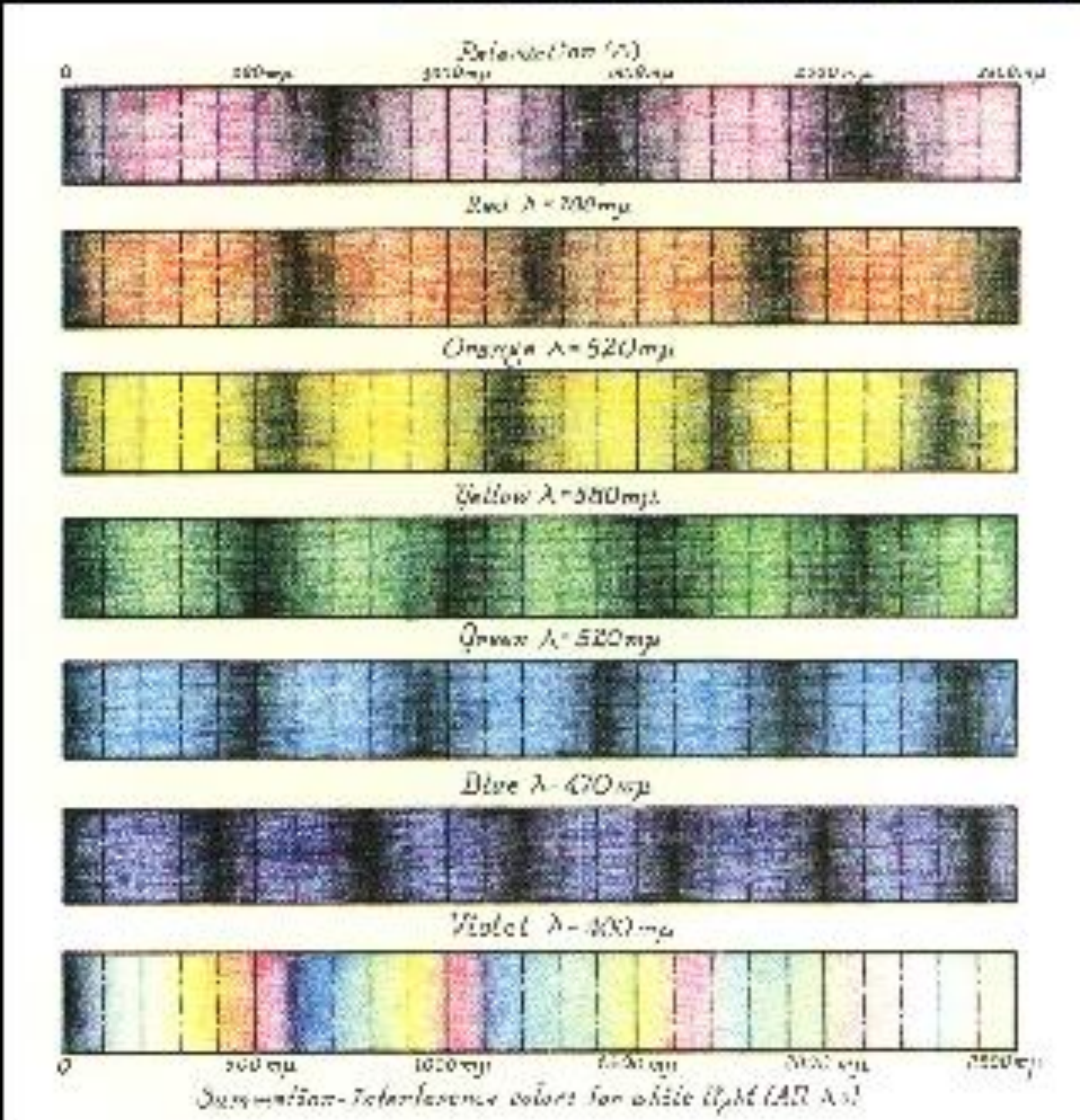
When the rays exit the crystal they **recombine**

When rays of different wavelength

combine → what things happen?

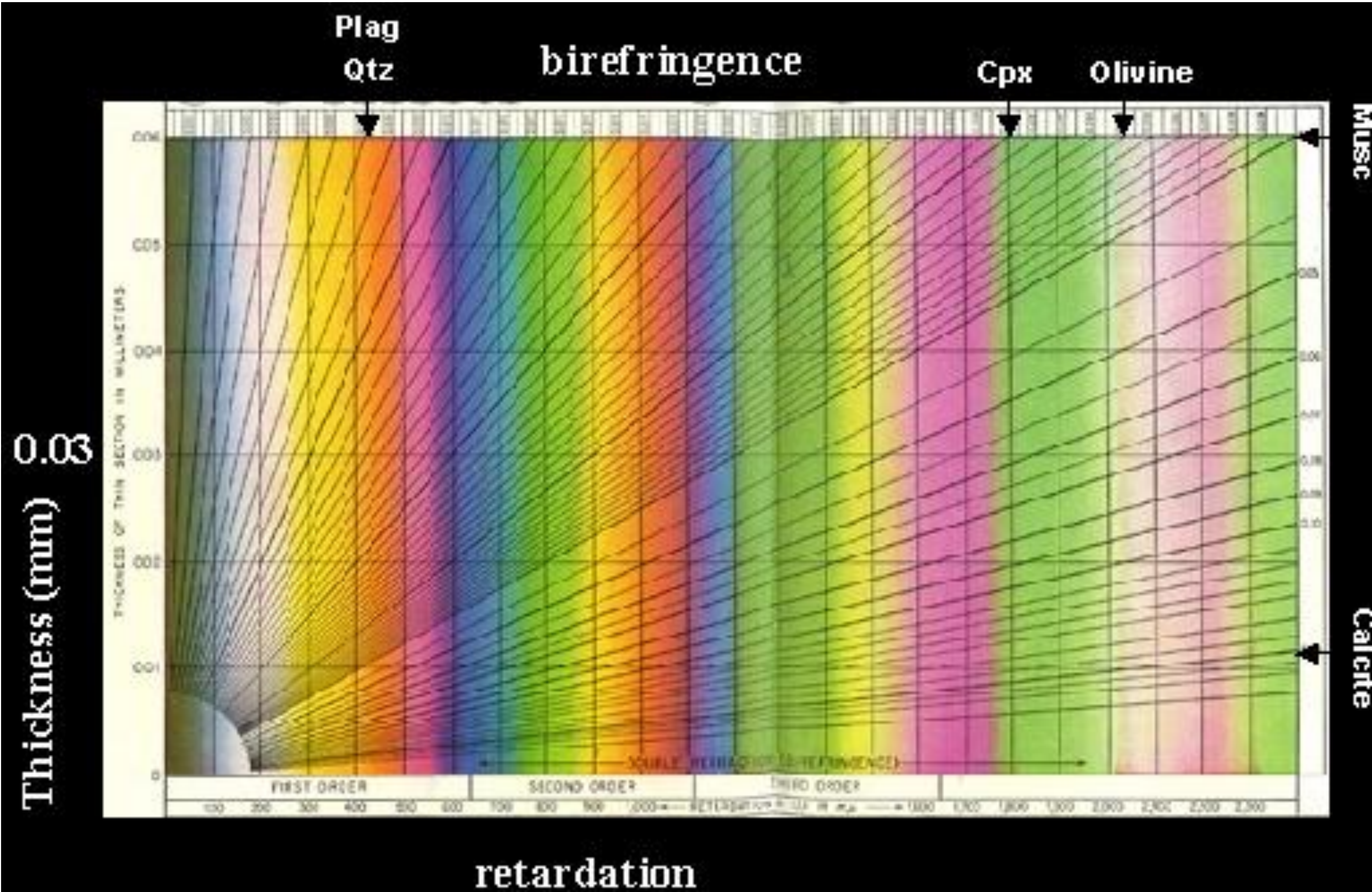


Interference Colors



Constructive (bright) and Destructive Interference (black) for different colors sums to the interference colors (at the bottom) for white light

Michel-Lévy Color Chart – Plate 4.11



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?

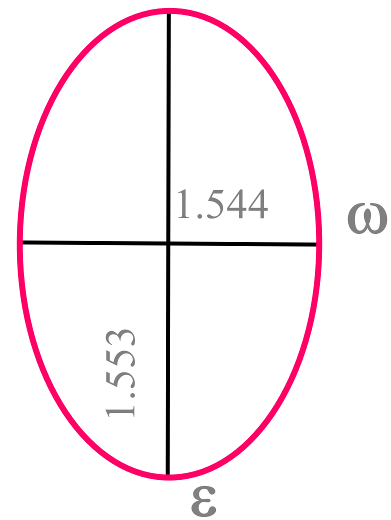
Example: Quartz $\omega = 1.544$ $\varepsilon = 1.553$

SILICA MINERALS

Quartz, Tridymite, Cristobalite

SiO_2

	QUARTZ	TRIDYMITE	CRISTOBALITE
	Trigonal (+)	Orthorhombic (+)	Tetragonal ? (−)
	ω 1·544 ϵ 1·553	α 1·471–1·479 β 1·472–1·480 γ 1·474–1·483	ϵ 1·484 ω 1·487
	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??

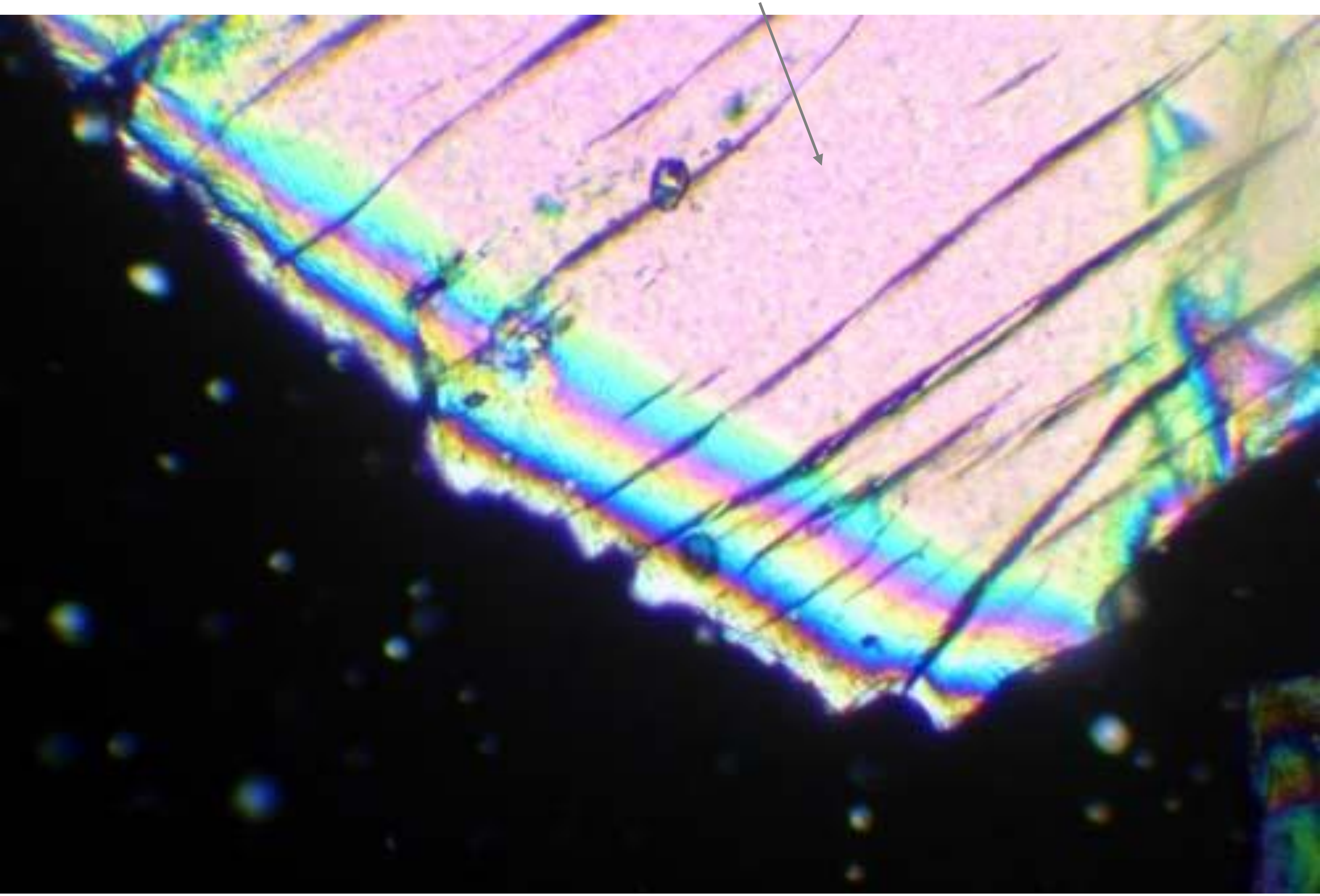
(+) because $\varepsilon > \omega$

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

= maximum interference color (when seen?)

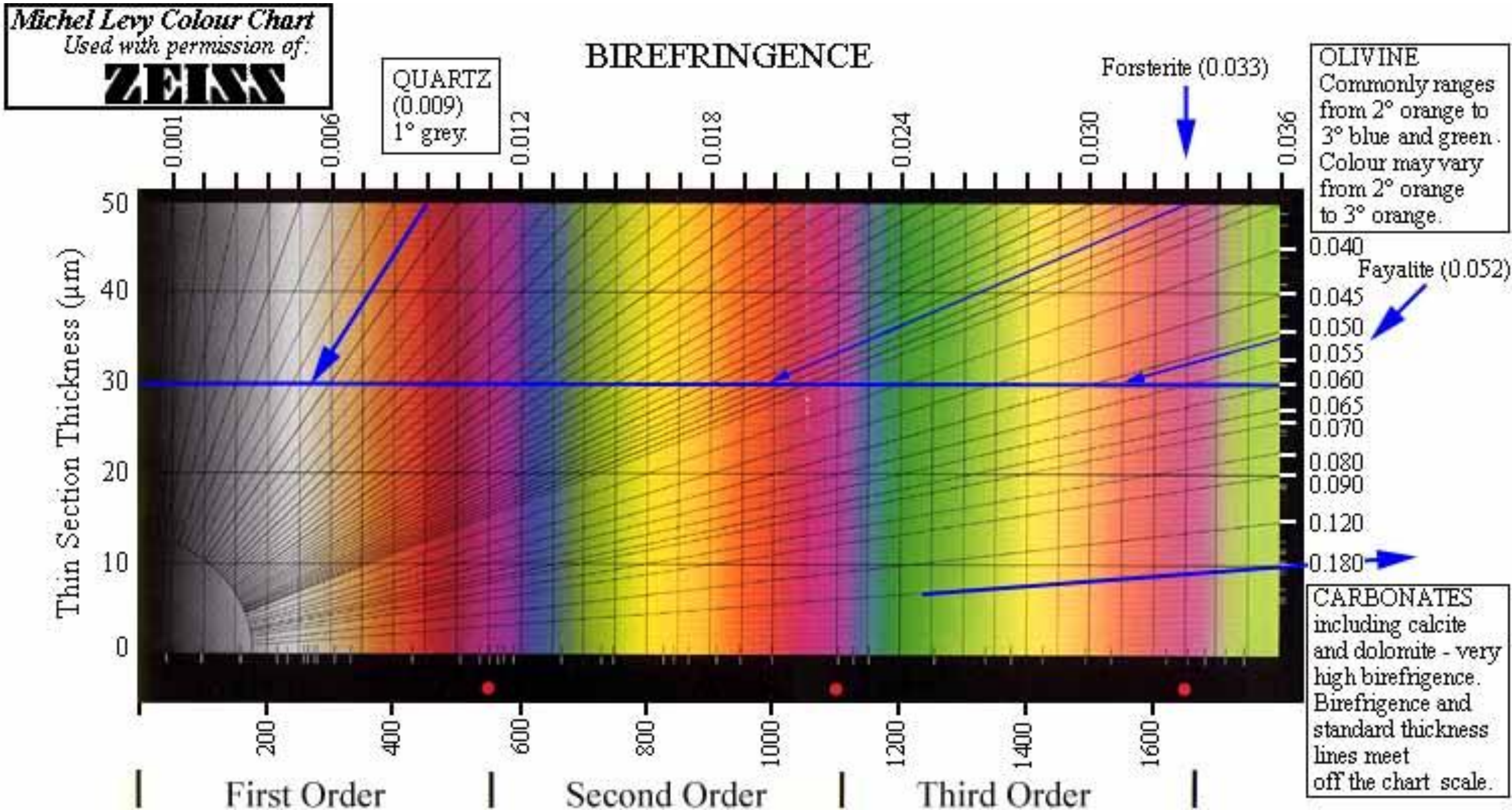
What color is this?? Use your chart.

What interference color is this?



Colors one observes when polars are crossed (XPL)

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



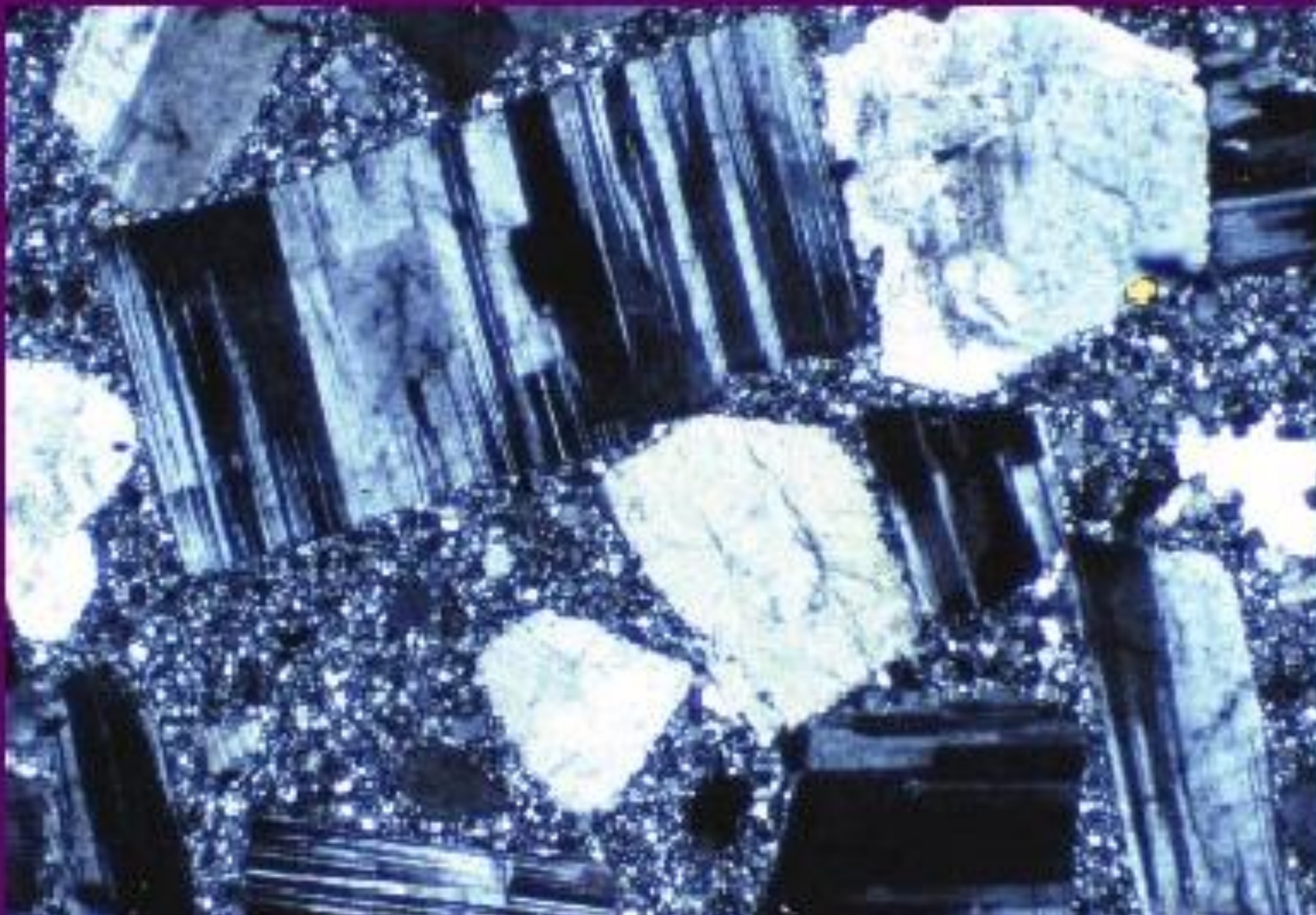
Rotation of crystal?

- Retardation also affected by mineral orientation!
- As you rotate a crystal, observed birefringence colors change
- Find maximum interference color for each **in practice**

Extinction

- When you rotate the stage → extinction relative to the cleavage or principle direction of elongation is extinction angle
- Parallel, inclined, symmetric extinction
- Divided into 2 signs of elongation based on the use of an accessory plate made of gypsum or quartz (which has a retardation of 550 nm) which changes the color → for a grain at 45º from extinction look for yellow (fast) or blue (slow)

Appearance of Minerals between Crossed Polars (in XPL)

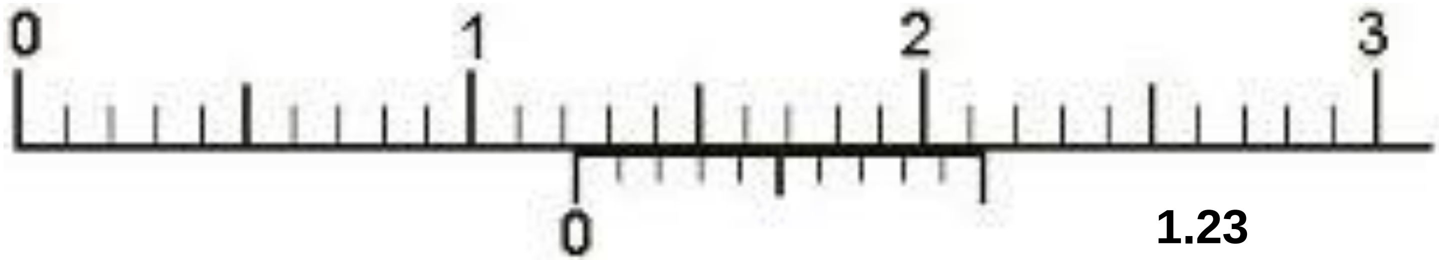


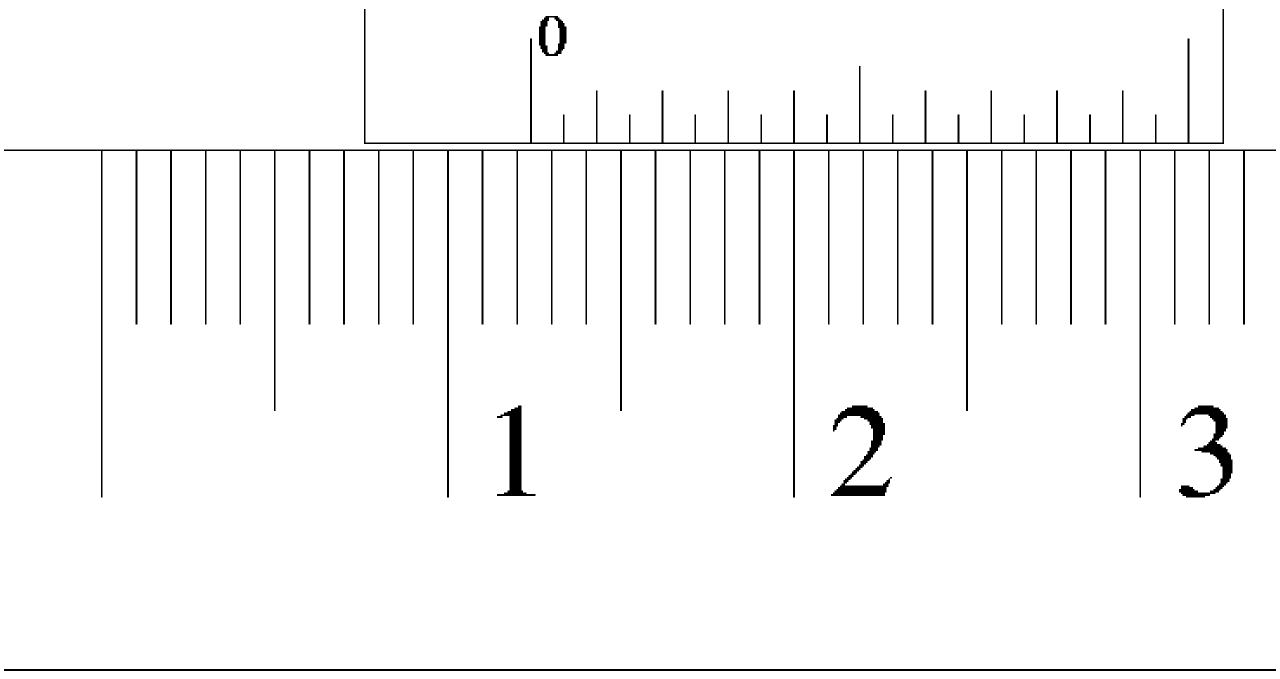
Plagioclase has low (white to gray) birefringence

Twinning and Extinction Angle

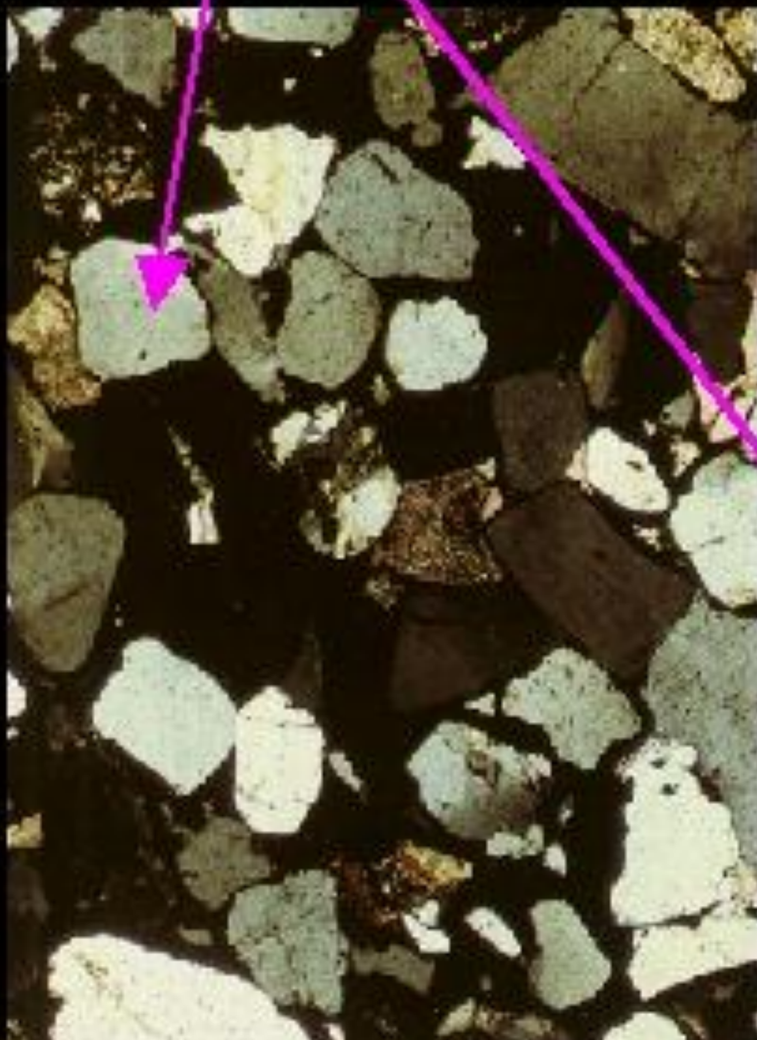
- Twinning is characteristic in thin section for several common minerals – especially feldspars
- The twins will go from light to dark over some angle
- This is characteristic of the composition
- Stage of the petrographic microscope is graduated in degrees with a vernier scale to measure the angle of extinction precisely

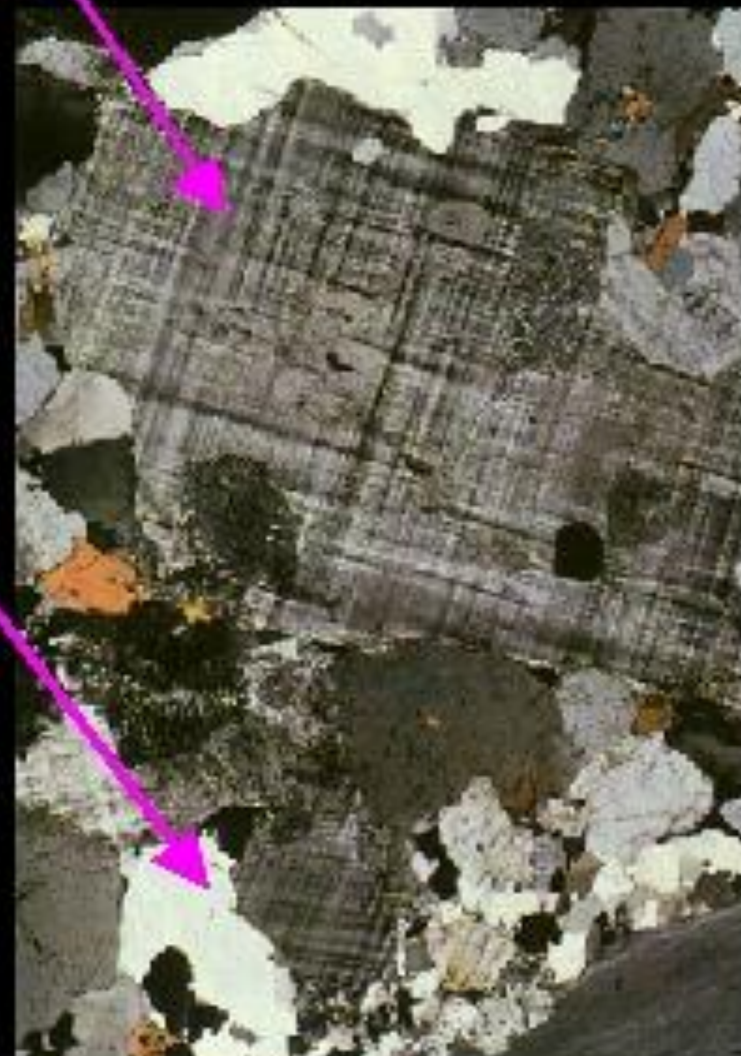
Vernier scale





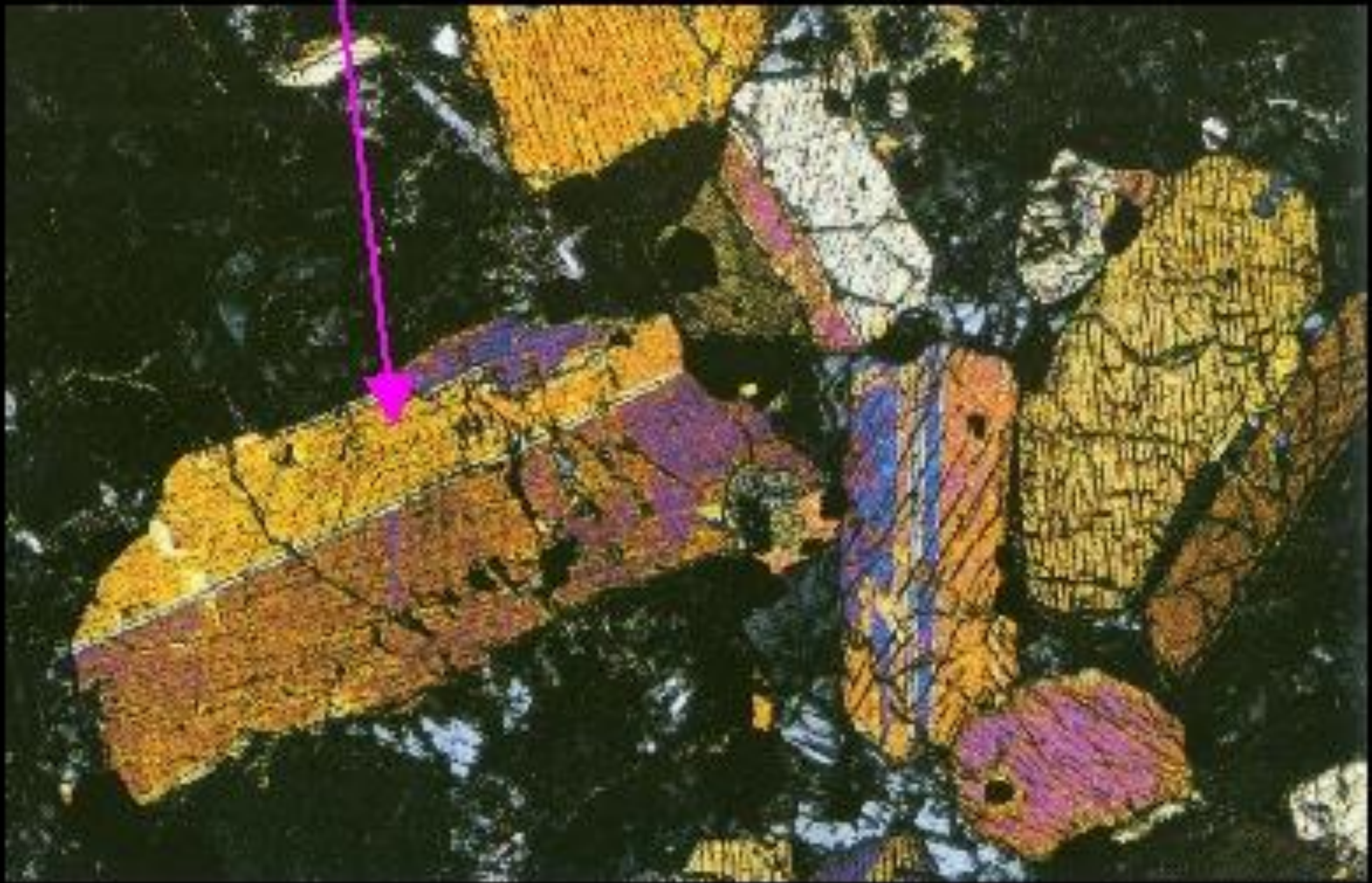
Quartz and Microcline have Low Birefringence





Olivine has High Relief (in PPL) and Moderate-High Birefringence (in XPL)

Pyroxene has Moderate Birefringence (in XPL)



Calcite and Sphene have Extremely High Birefringence

Appearance of crystals in microscope

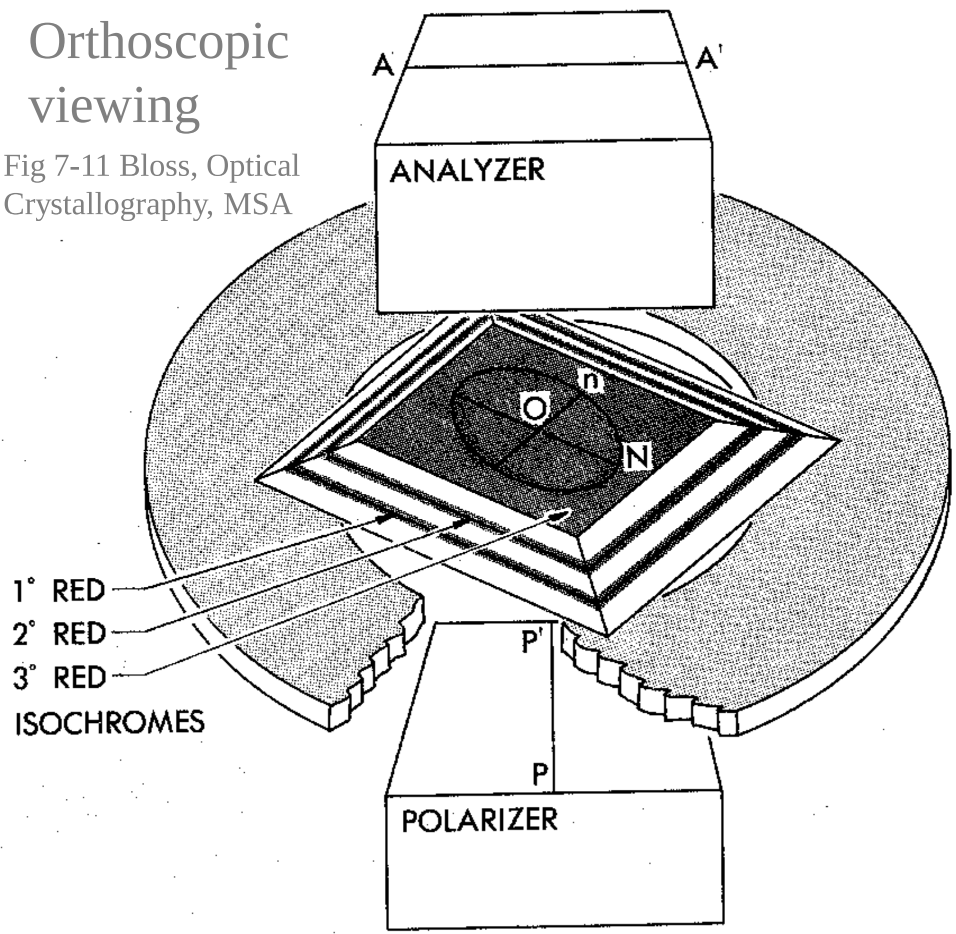
- Crystal shape – how well defined the crystal shape is
  - Euhedral – sharp edges, well- defined crystal shape
  - Anhedral – rounded edges, poorly defined shape
  - Subhedral – in between anhedral and euhedral
- Cleavage – just as in hand samples!
- Physical character – often note evidence of strain, breaking, etching on crystals – you will notice some crystals show those features better than others…

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