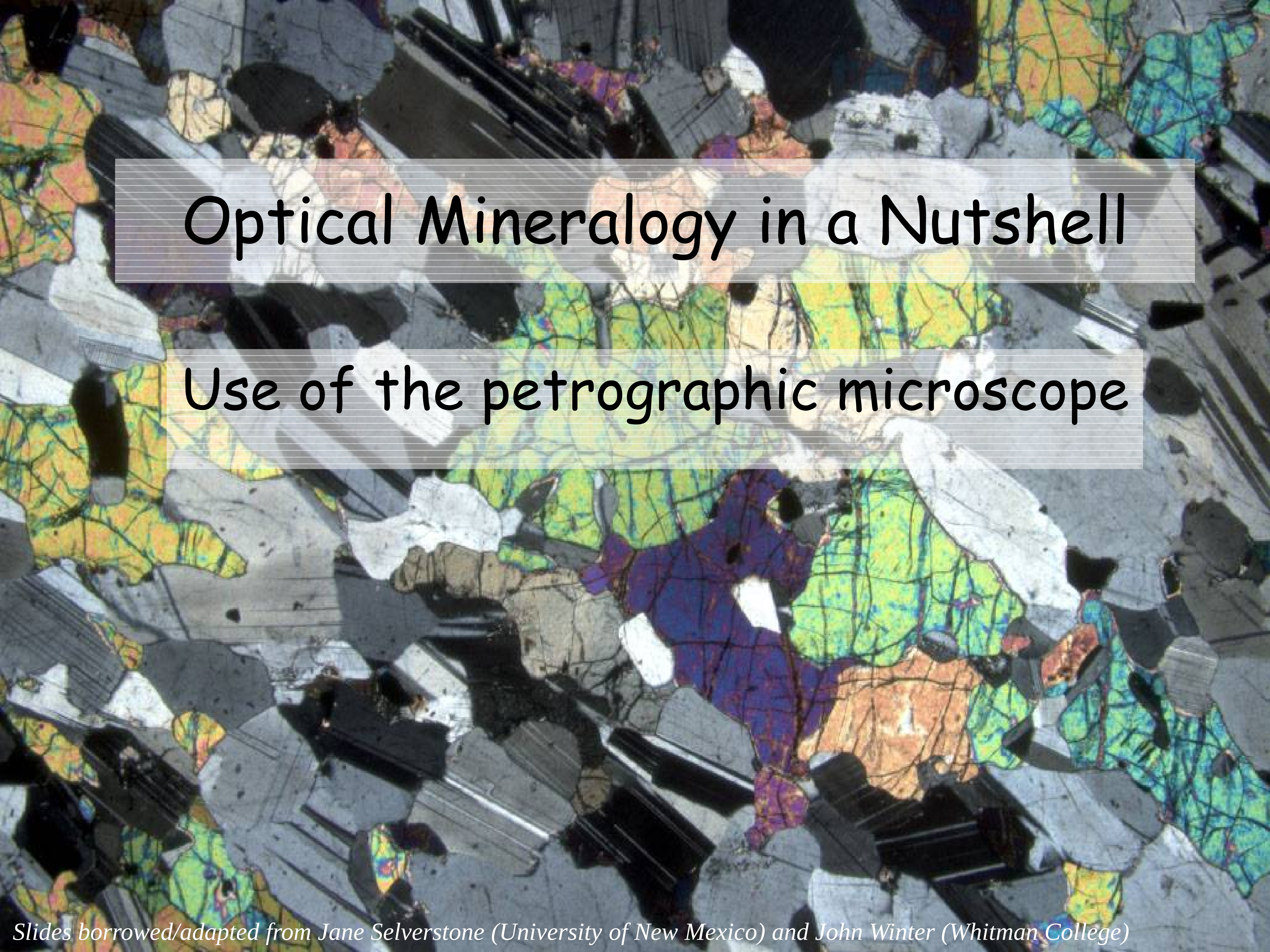
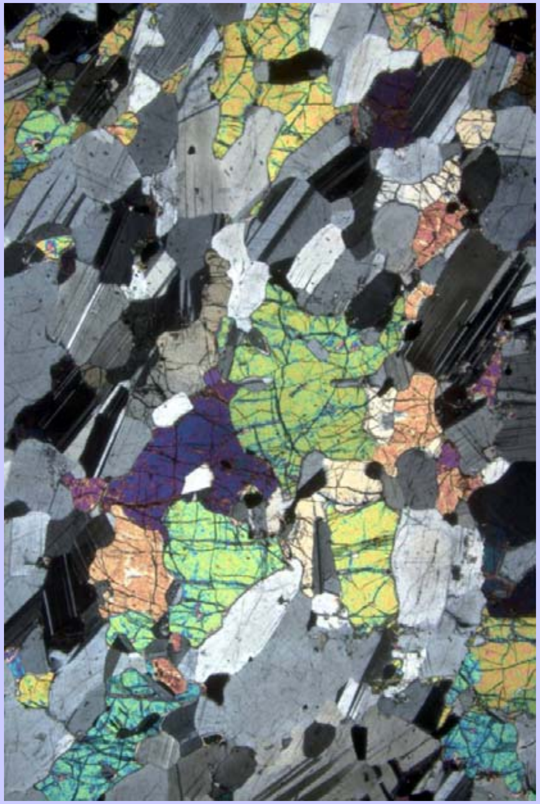
Optical Mineralogy in a Nutshell

Use of the petrographic microscope



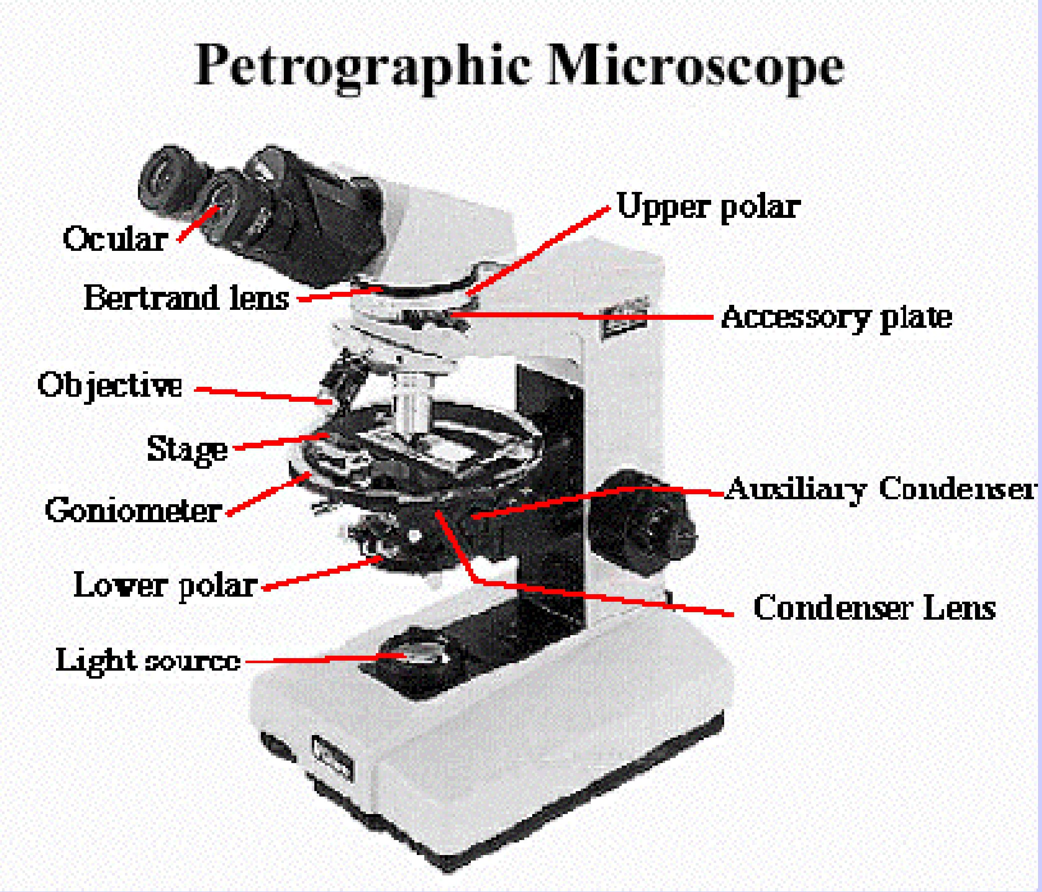
Slides borrowed/adapted from Jane Selverstone (University of New Mexico) and John Winter (Whitman College)

Why use the petrographic 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!

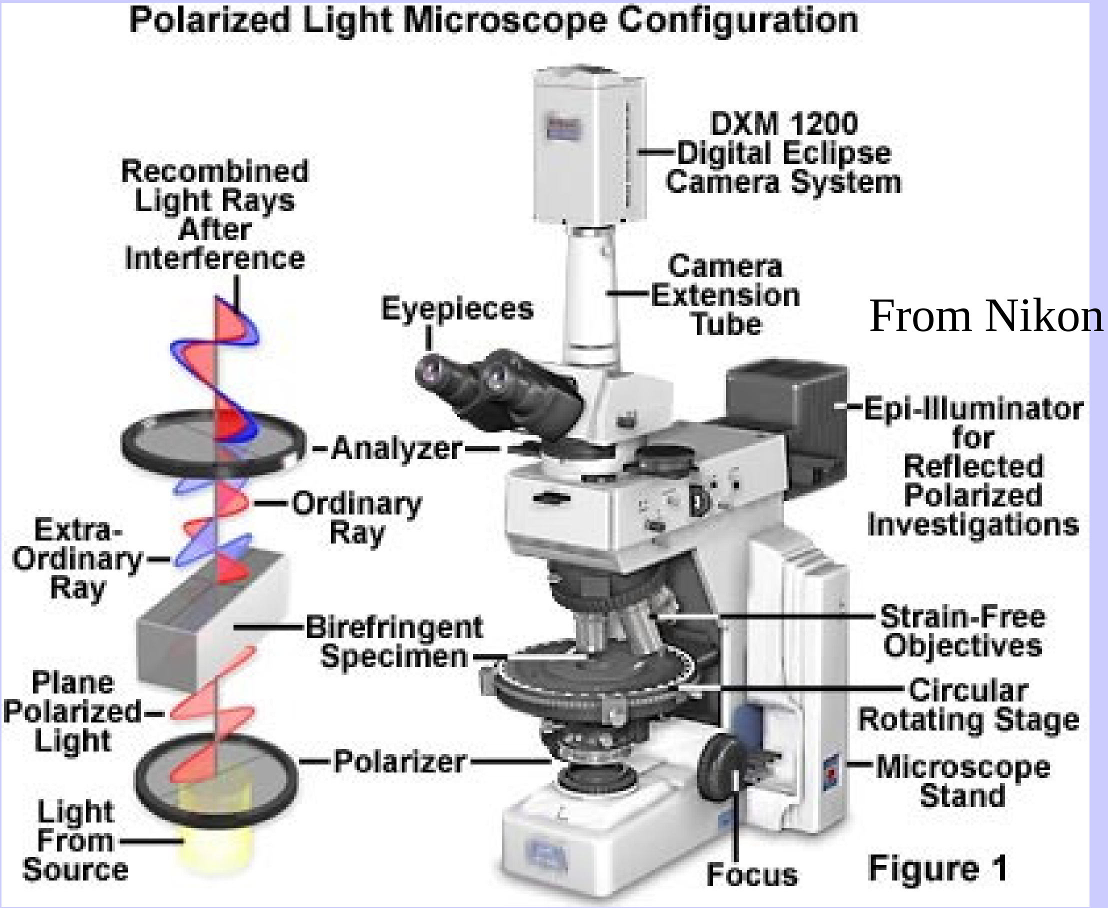
The petrographic microscope



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…

Polarized Light Microscopy

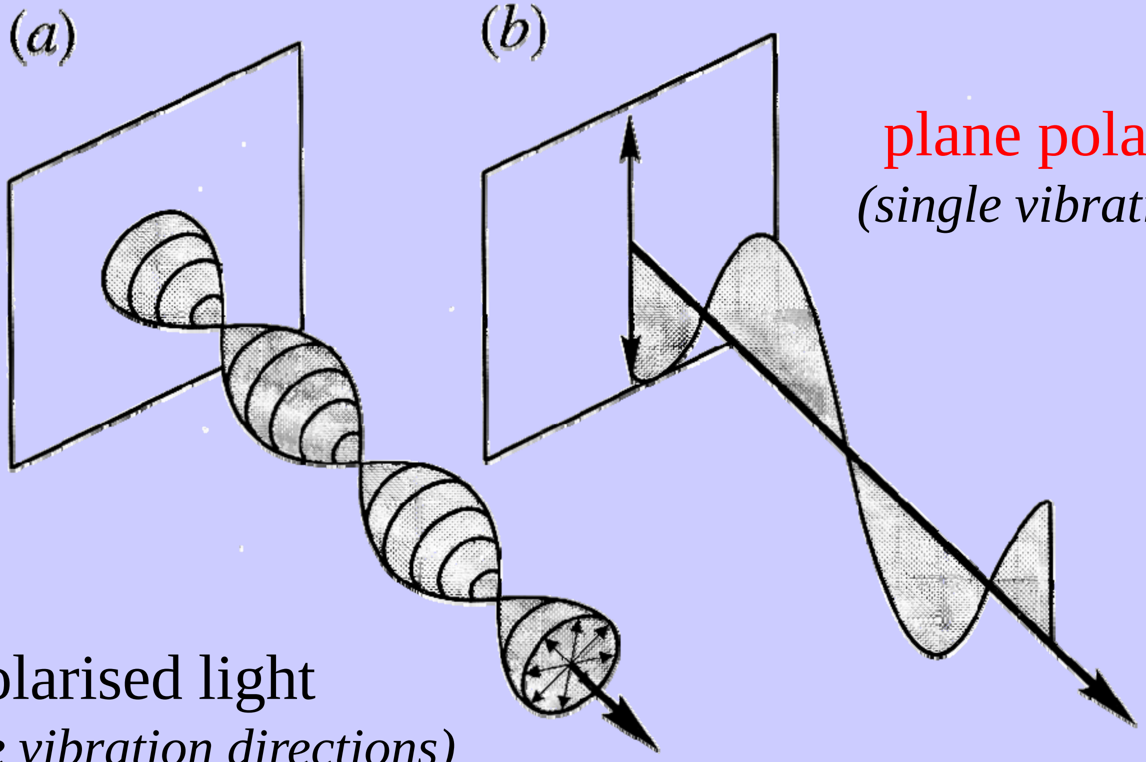


From Nikon

Isotropic materials, which include gases, liquids, unstressed glasses and cubic crystals, demonstrate the same optical properties in all directions. They have only one refractive index and no restriction on the vibration direction of light passing through them.

Anisotropic materials, in contrast, which include 90 percent of all solid substances, have optical properties that vary with the orientation of incident light with the crystallographic axes. Anisotropic materials act as beam splitters and divide light rays into two parts. The technique of polarizing microscopy exploits the interference of the split light rays, as they are re-united along the same optical path to extract information about these materials.

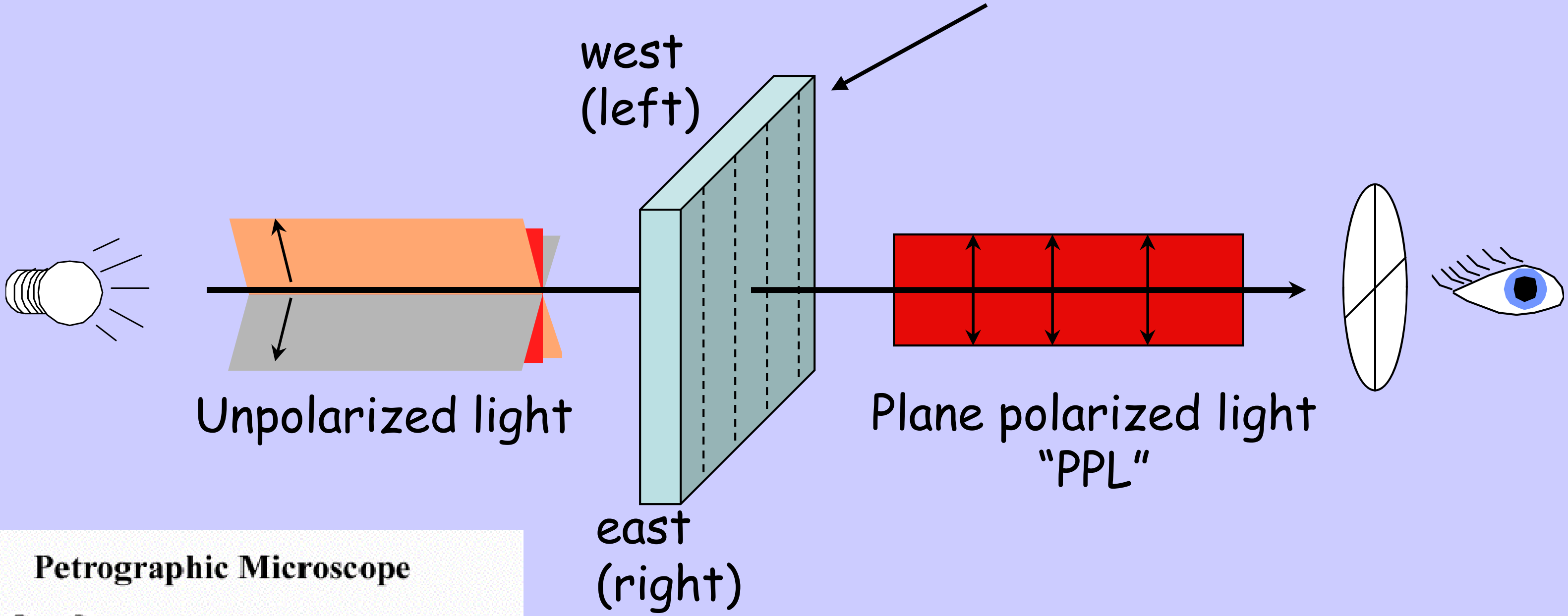
What happens as light moves through the scope?

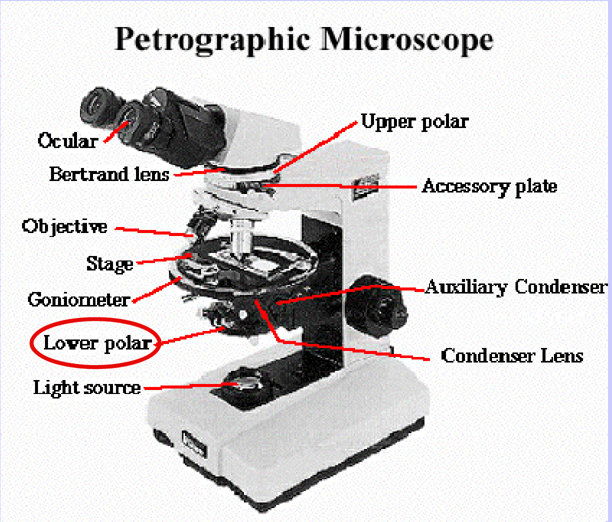


plane polarised light
(single vibration direction)

unpolarised light
(all possible vibration directions)

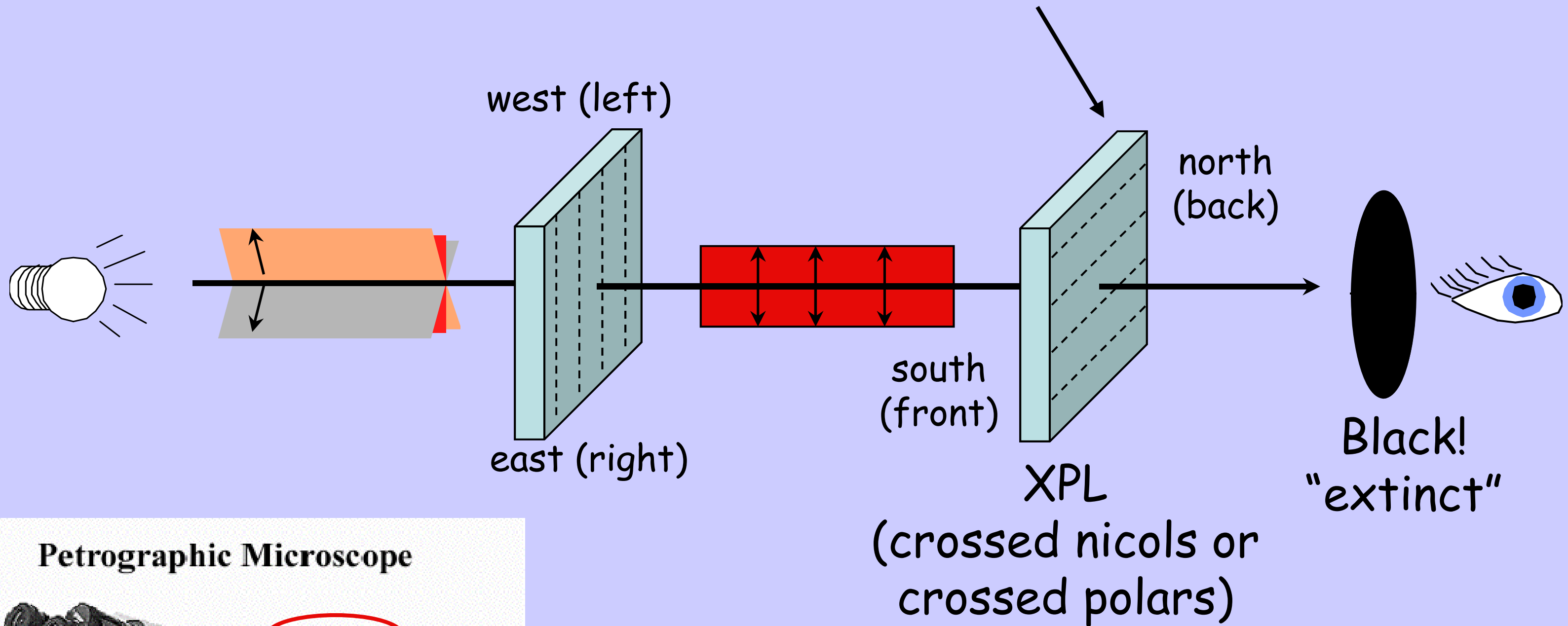
1) Light passes through the **lower polarizer**

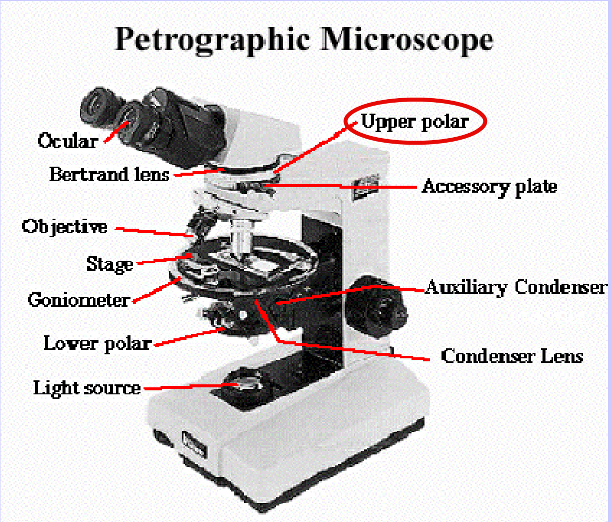




Only the component of light vibrating in E-W direction can pass through lower polarizer – **light intensity decreases**

2) Insert the **upper polarizer**

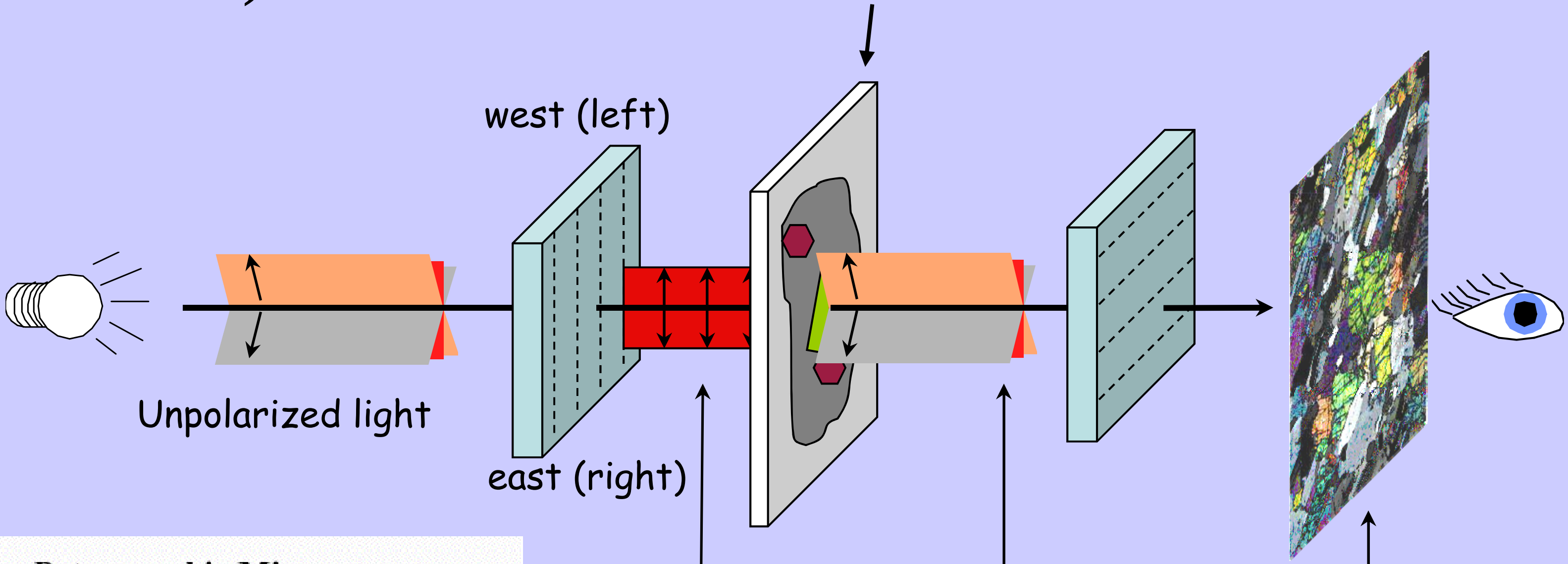


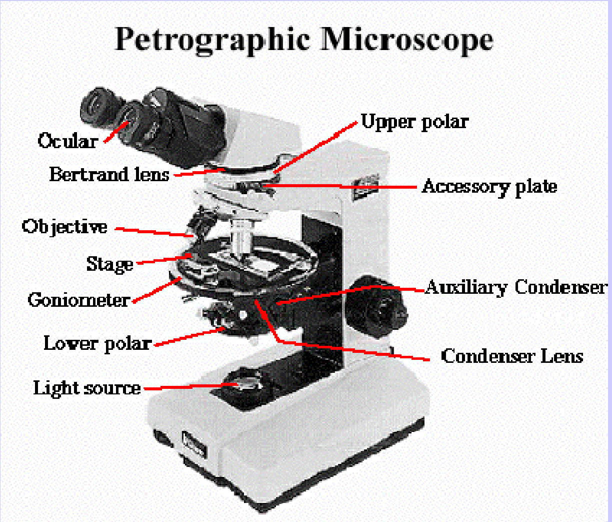


Now what happens?
What reaches your eye?

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

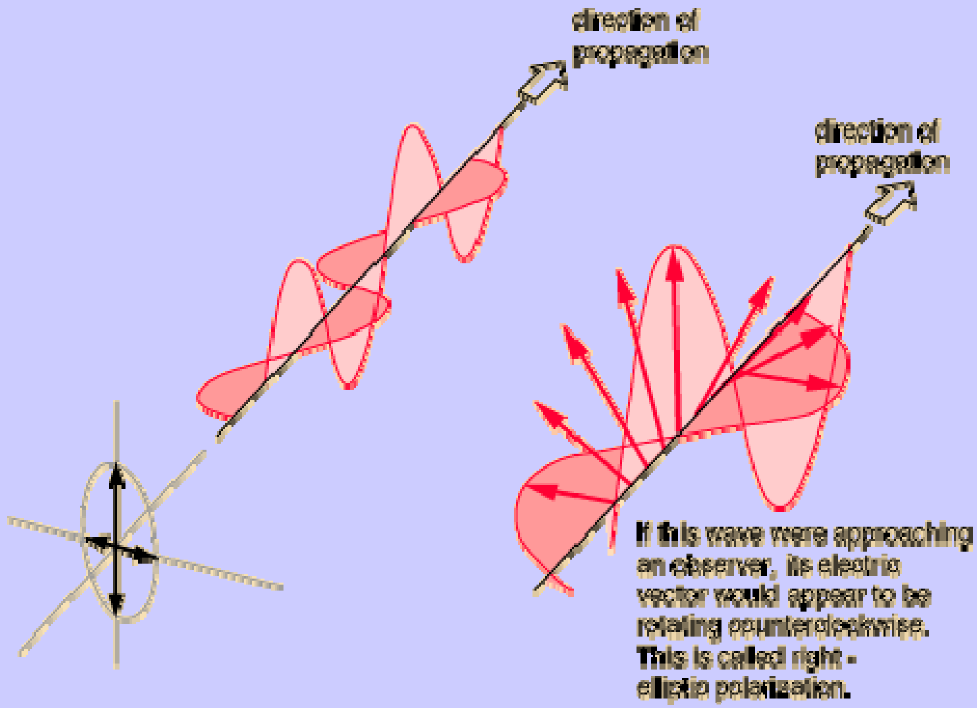
3) Now insert a **thin section** of a rock

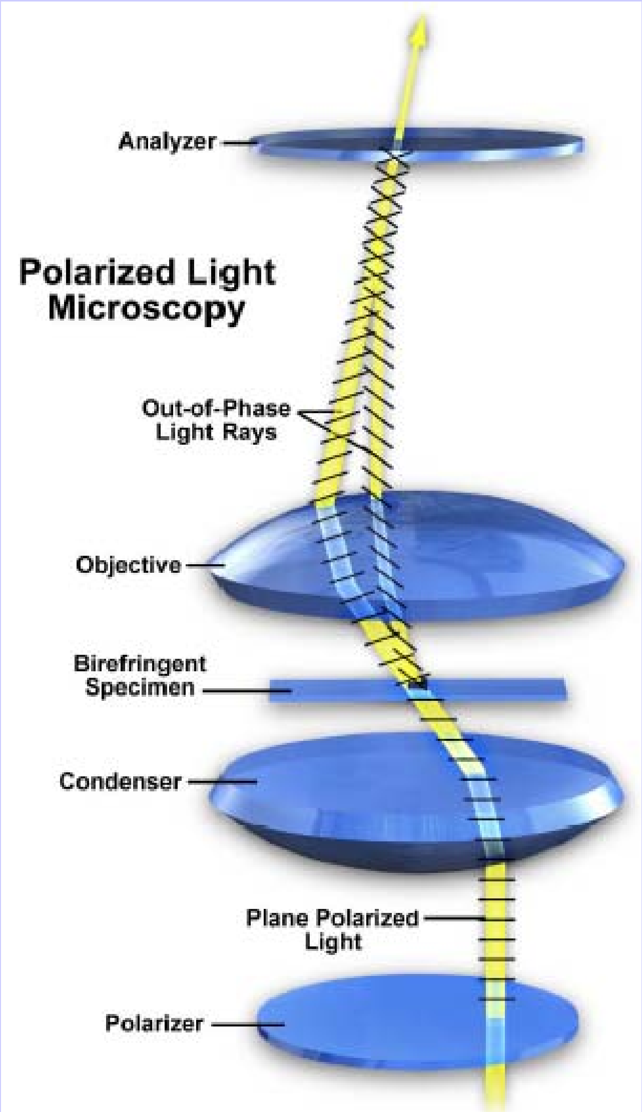




How does this work?

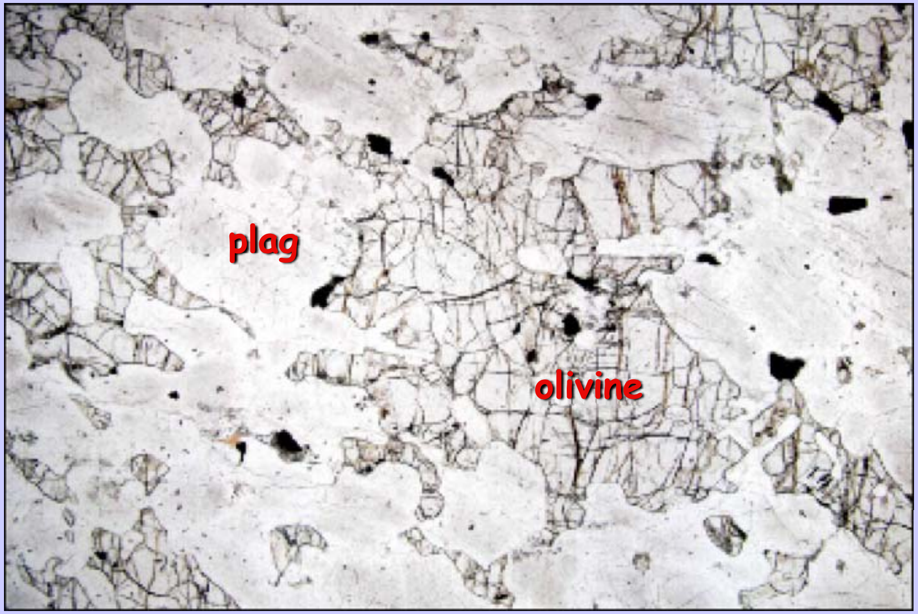
Polarized Light Microscopy



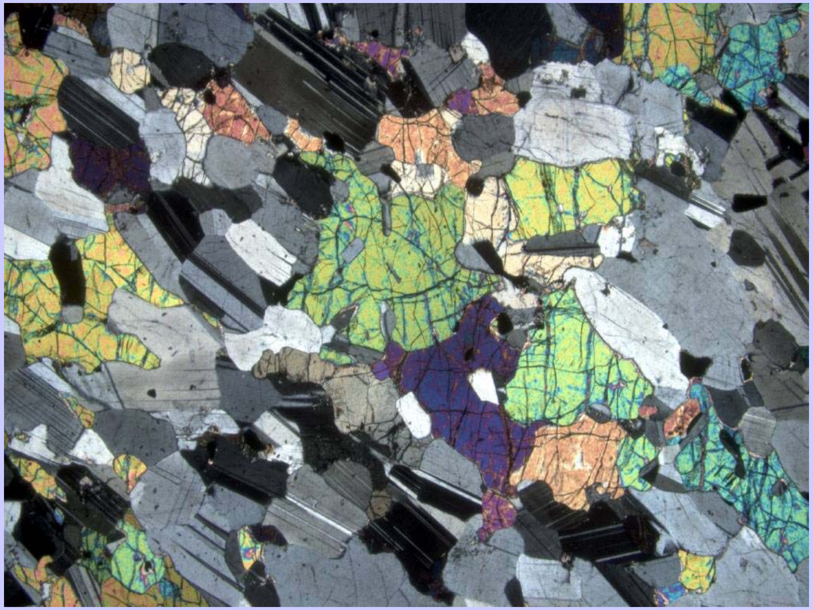


- The Light source is polarized before entering the specimen
- The analyzer pass the light with polarization angle perpendicular to the source light
- The contrast of birefringent material in the specimen would be enhanced

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



PPL



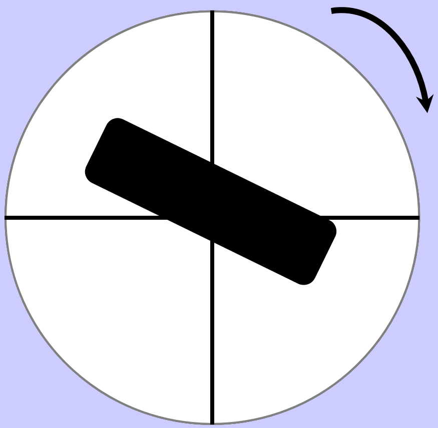
XPL

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)

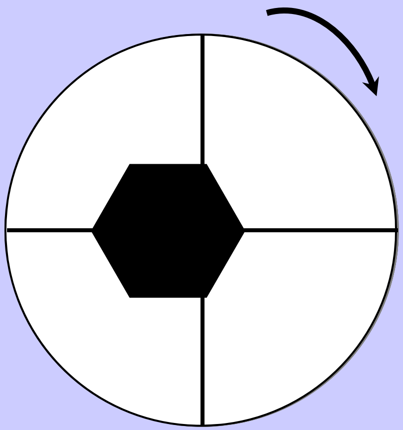
Note the effect of **rotating the stage**

Most mineral grains change to black as the stage is rotated; they go black 4 times in a 360° rotation - exactly every 90°



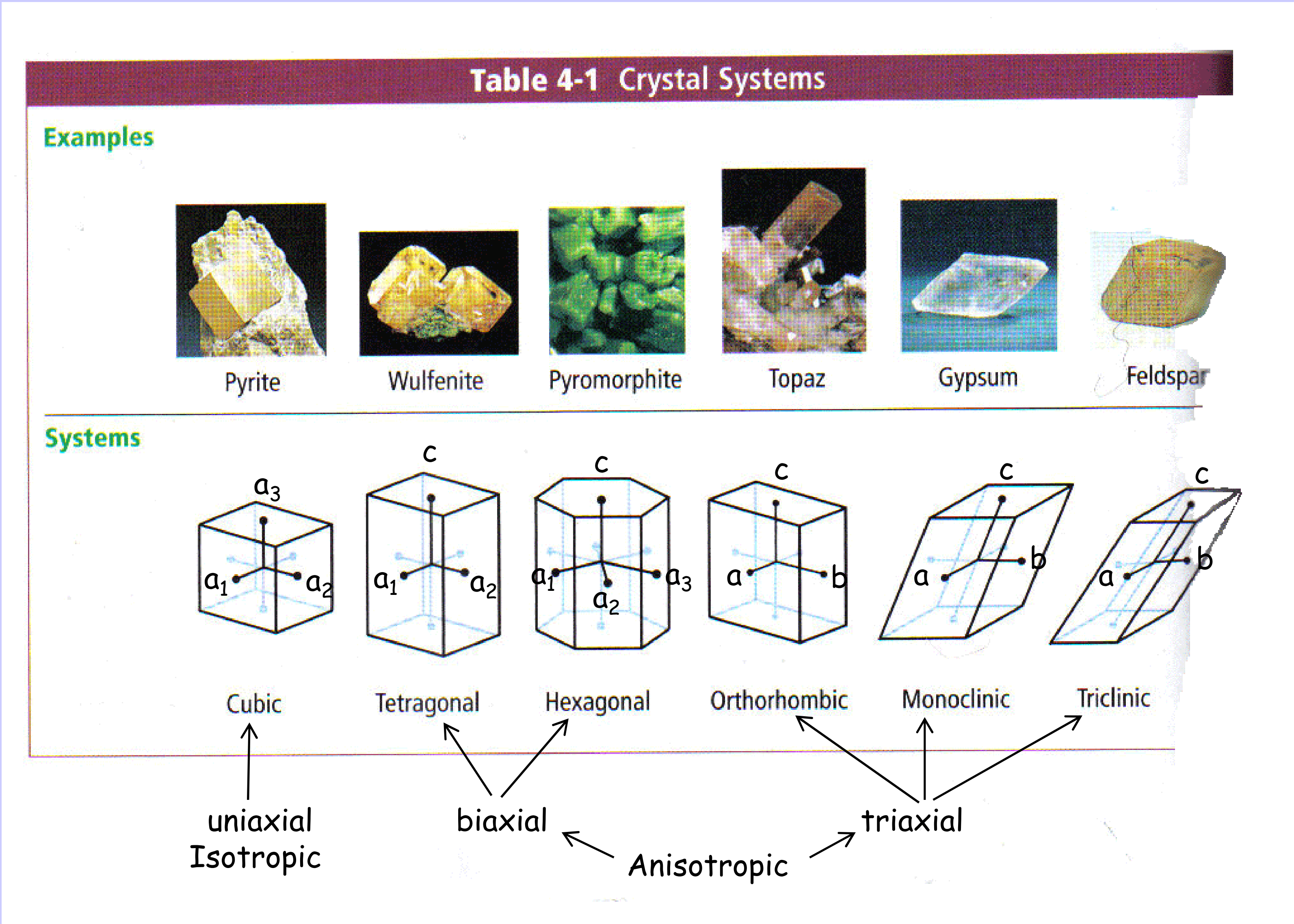
Such minerals are anisotropic

However, glass, a few isotropic minerals, liquids (e.g., fluid inclusions), and gases (e.g., air bubbles) stay black in all orientations



Such minerals are isotropic

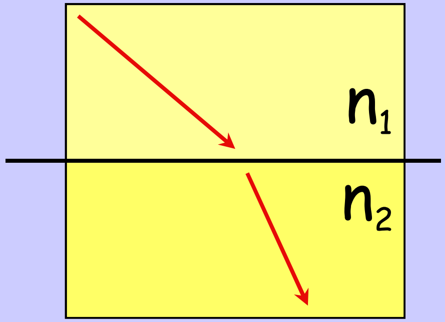
Types of crystals



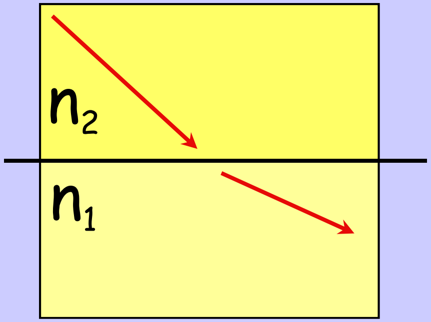
Mineral properties: Index of refraction (R.I. *or* n)

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

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



$n_2 > n_1$

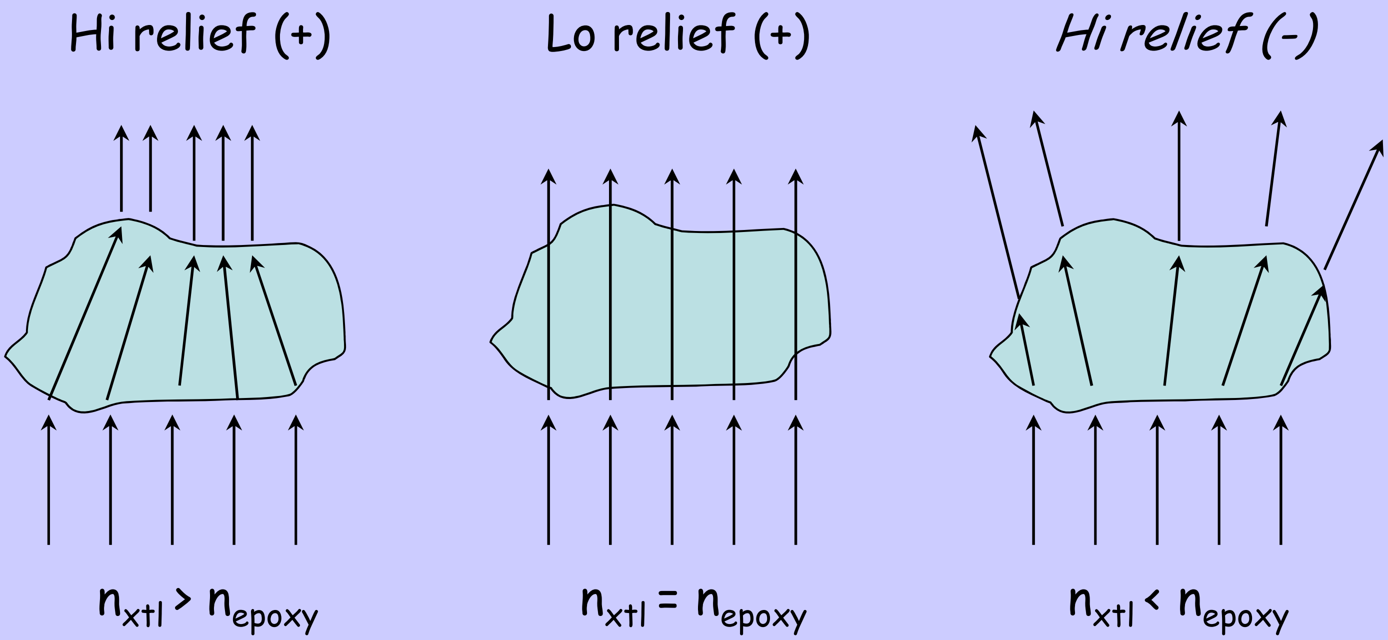


$n_2 < n_1$

- 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

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



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

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

Mineral properties: **relief**

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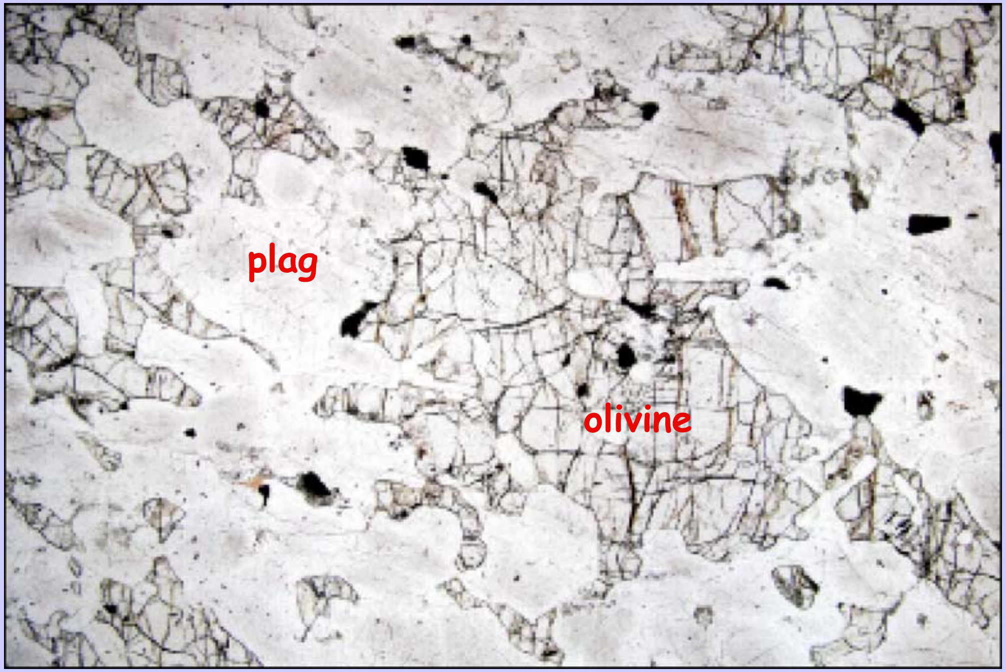
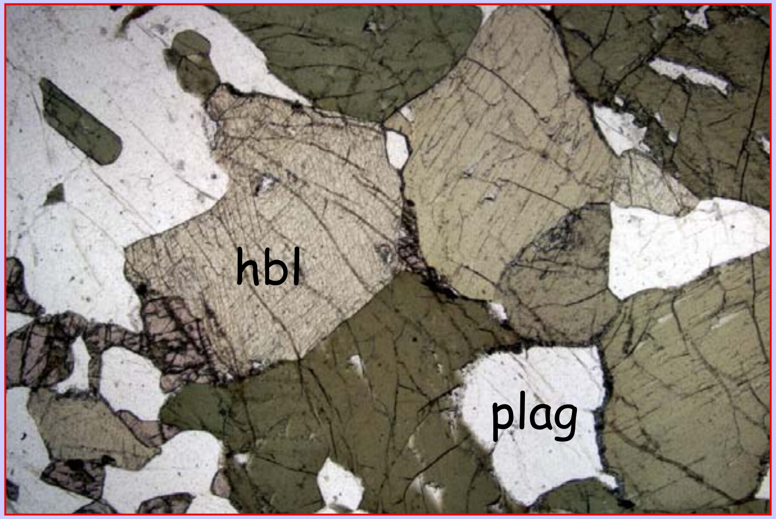


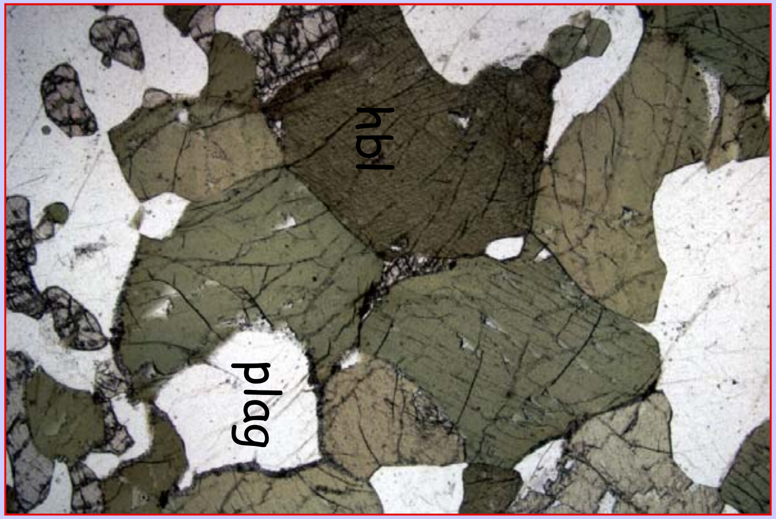
- Olivine has high relief
- Plag has low relief

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

Color and 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

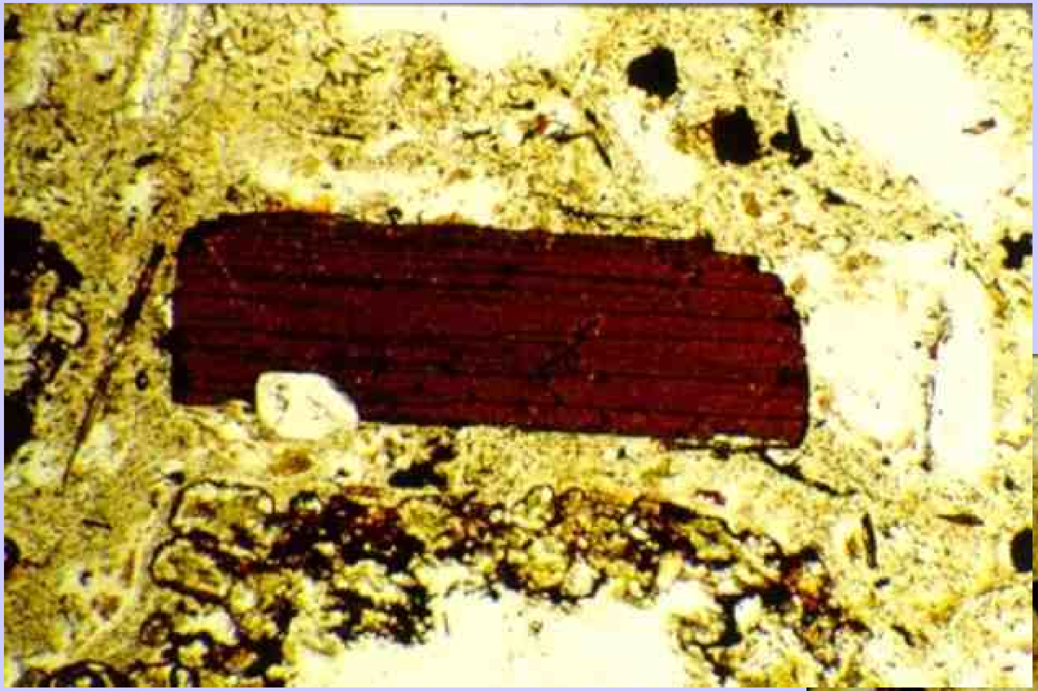
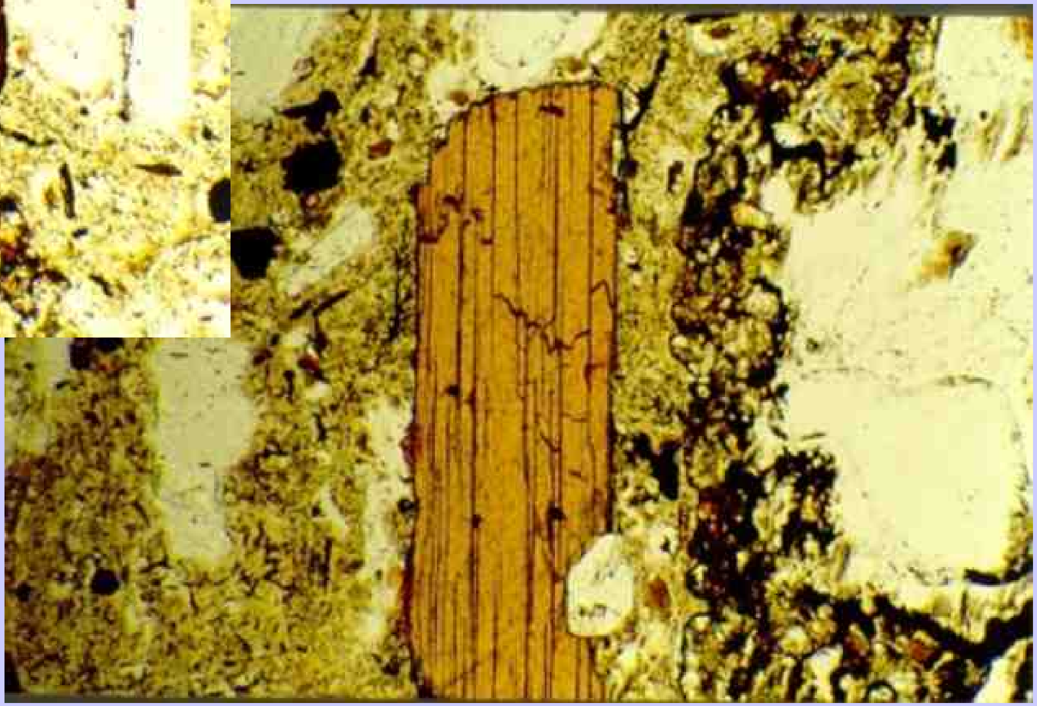




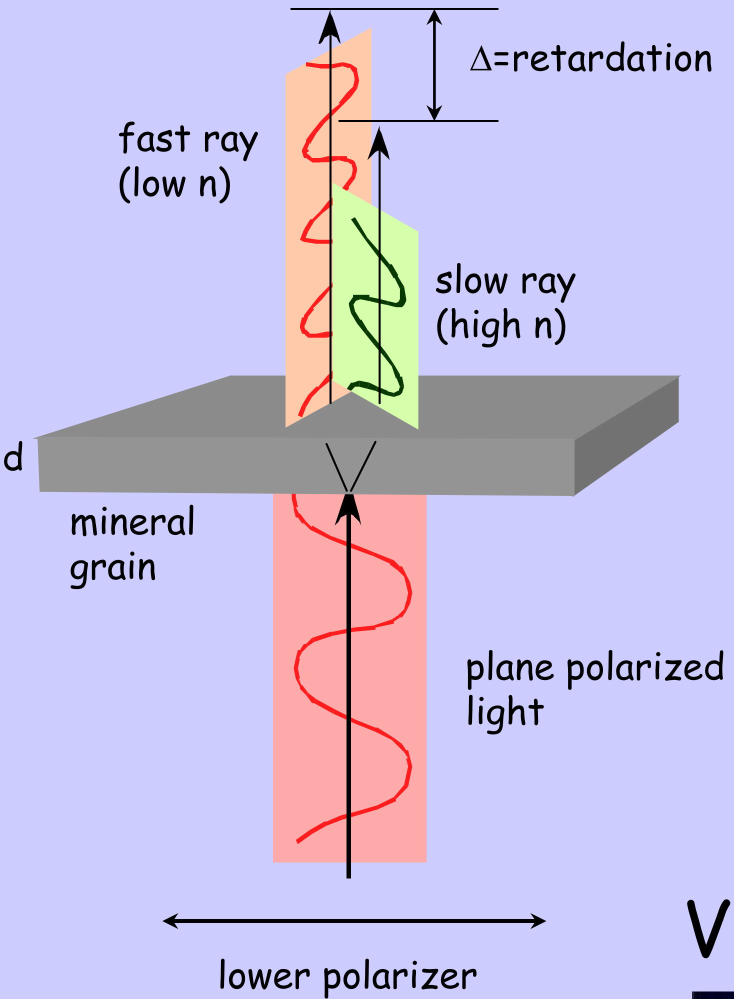
-Plagioclase is colorless
-Hornblende is pleochroic in olive greens

Color and pleochroism

Biotite

Birefringence (possessing more than one index of refraction)/interference colors



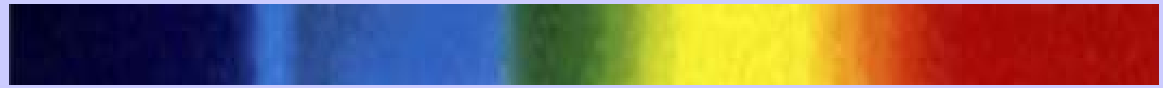
Observation:
frequency of light remains unchanged during splitting, regardless of material

$F = V/\lambda$

if light speed changes, λ must also change

λ is related to color; if λ changes, color also changes

Violet (400 nm) → Red (700 nm)



Anisotropic crystals

Calcite experiment and double refraction

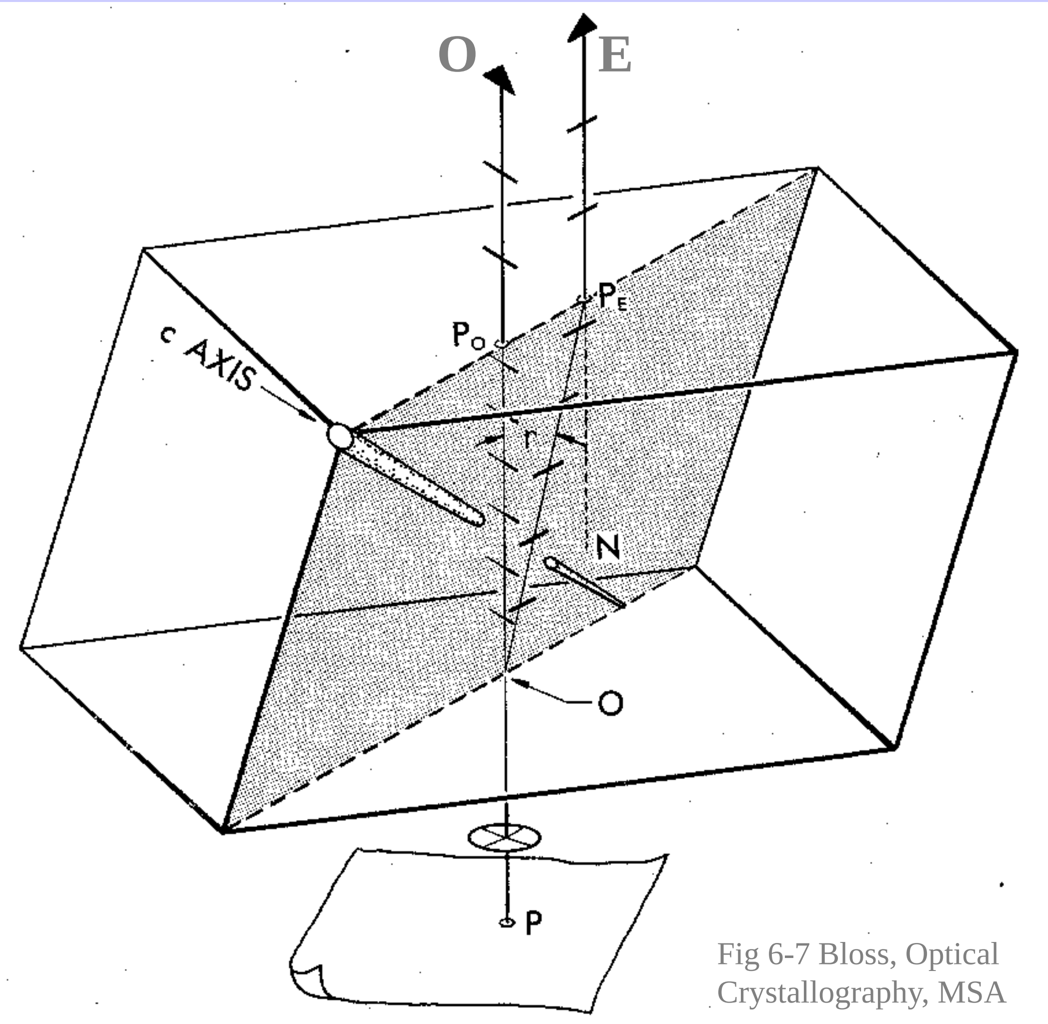


Fig 6-7 Bloss, Optical Crystallography, MSA

Double images

Ray → 2 rays with different propagation and vibration directions

Each is polarized (⊥ each other)

Anisotropic crystals

Calcite experiment and double refraction

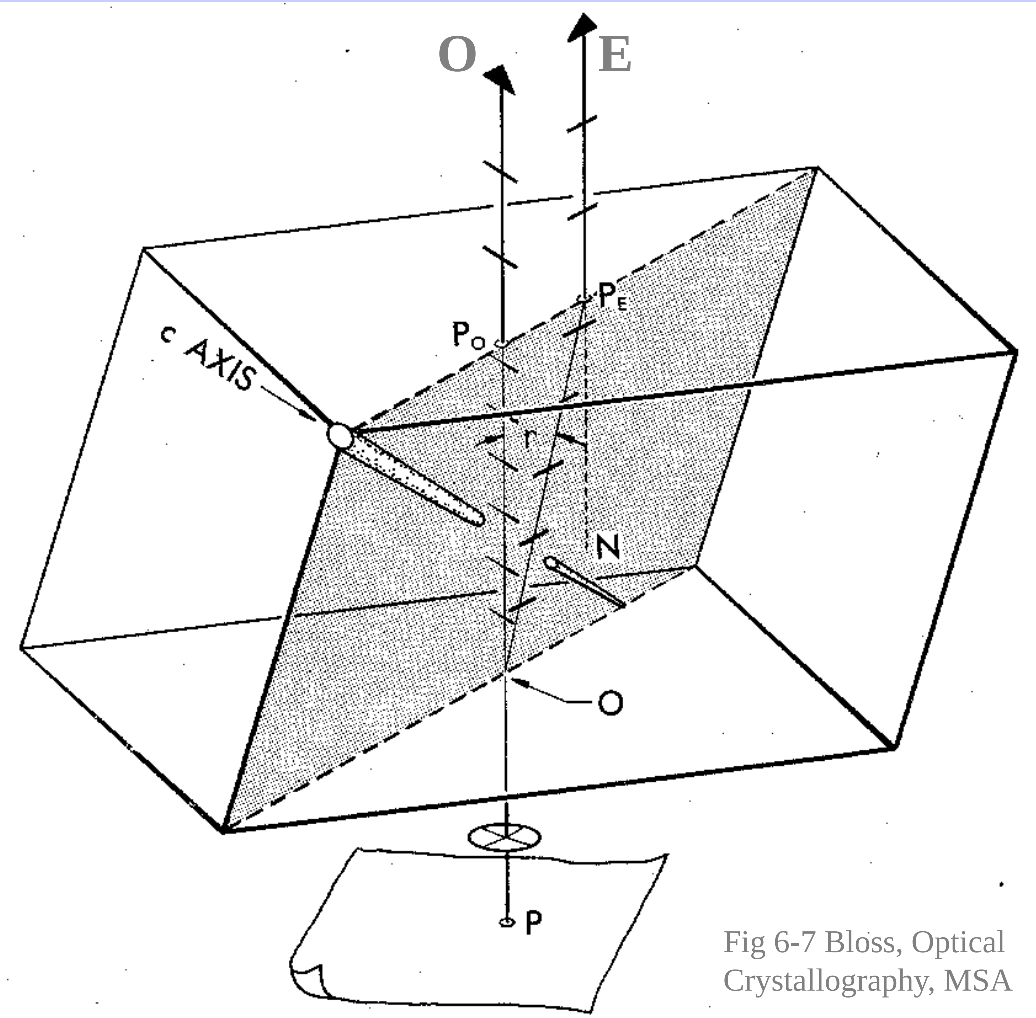


Fig 6-7 Bloss, Optical Crystallography, MSA

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

Interference phenomena

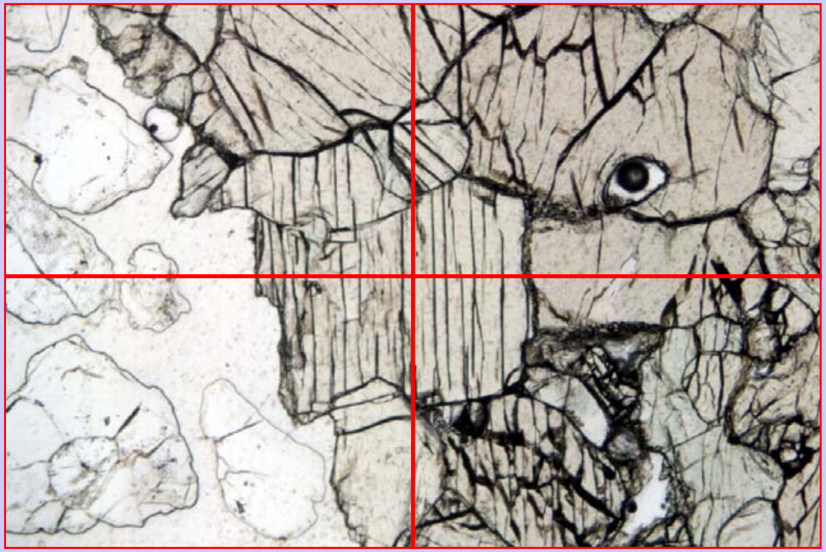
- Light waves may be in phase or out of phase when they exit xtl
- When out of phase, some component of light gets through upper polarizer and displays an interference color
- When one of the vibration directions is parallel to the lower polarizer, no light gets through the upper polarizer and the grain is "at extinction" (=black) For uniaxial crystals extinction is "parallel" to the polarizers, for biaxial crystals extinction is "inclined" to the polarizers.

Examples of extinction angle – parallel extinction

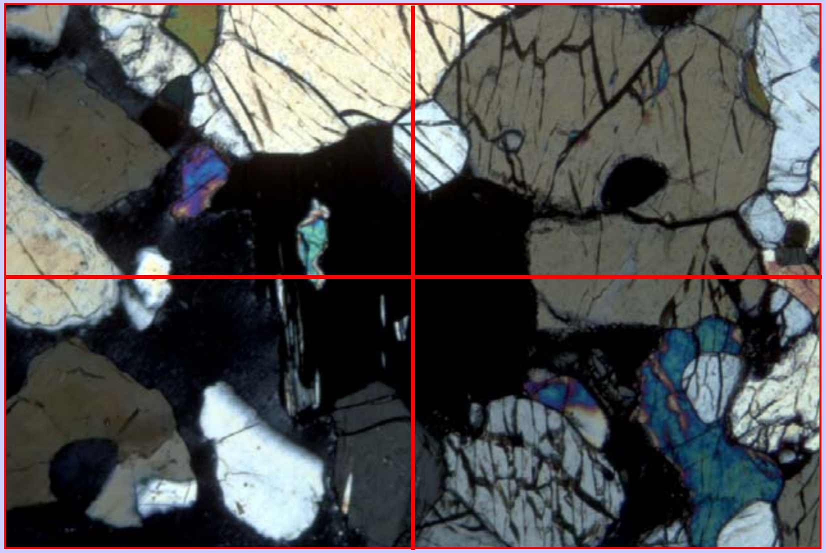
- All uniaxial minerals show parallel extinction
- Orthorhombic minerals show parallel extinction

(this is because xtl axes and indicatrix axes coincide)

orthopyroxene



PPL

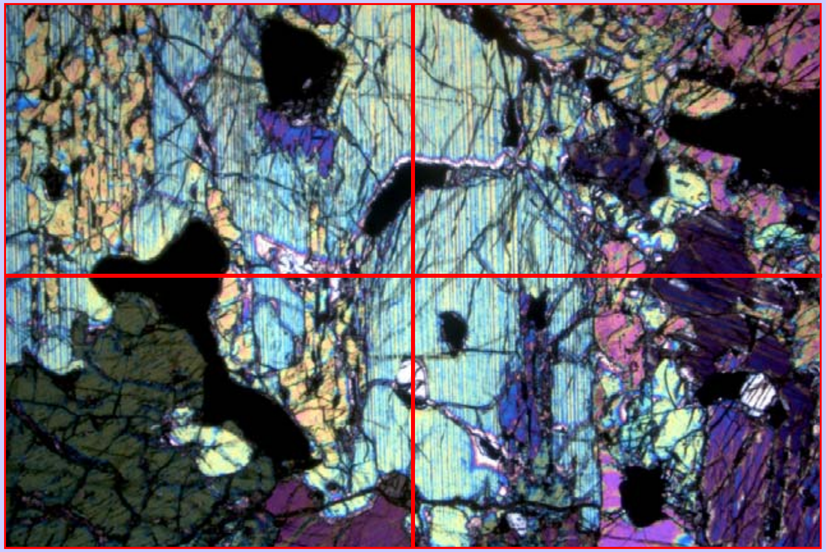


XN

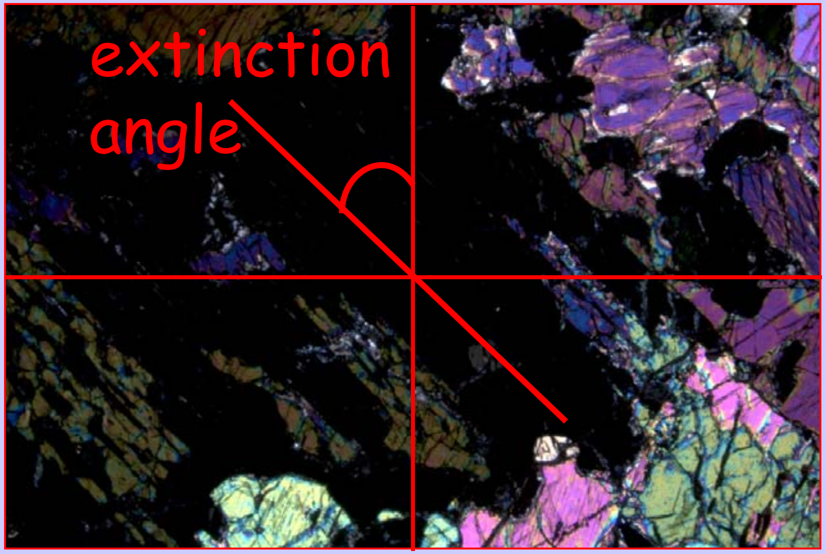
Examples of extinction angle - inclined extinction

Monoclinic and triclinic minerals:
indicatrix axes do not coincide with crystallographic axes

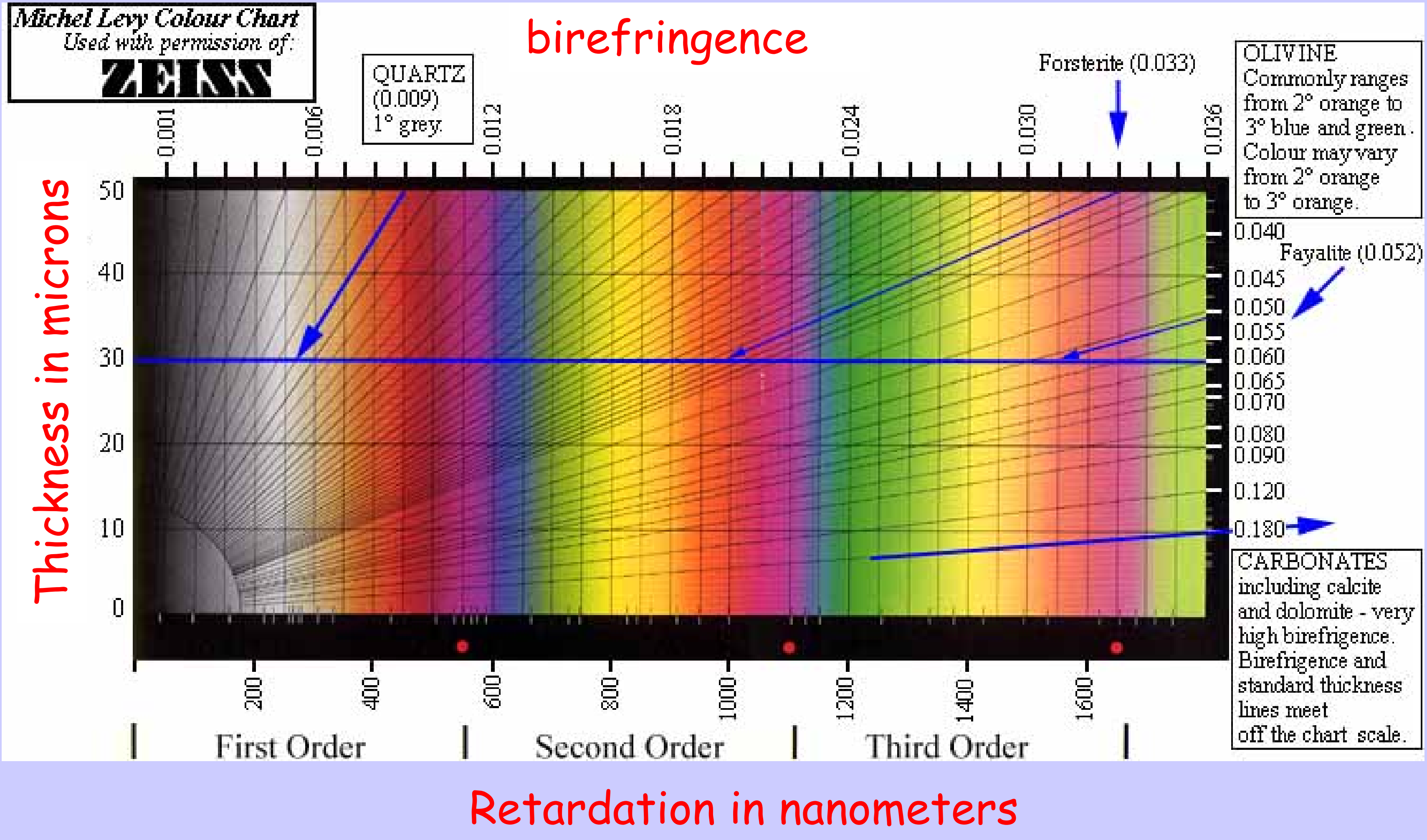
These minerals have inclined extinction
(and extinction angle helps to identify them)



clinopyroxene



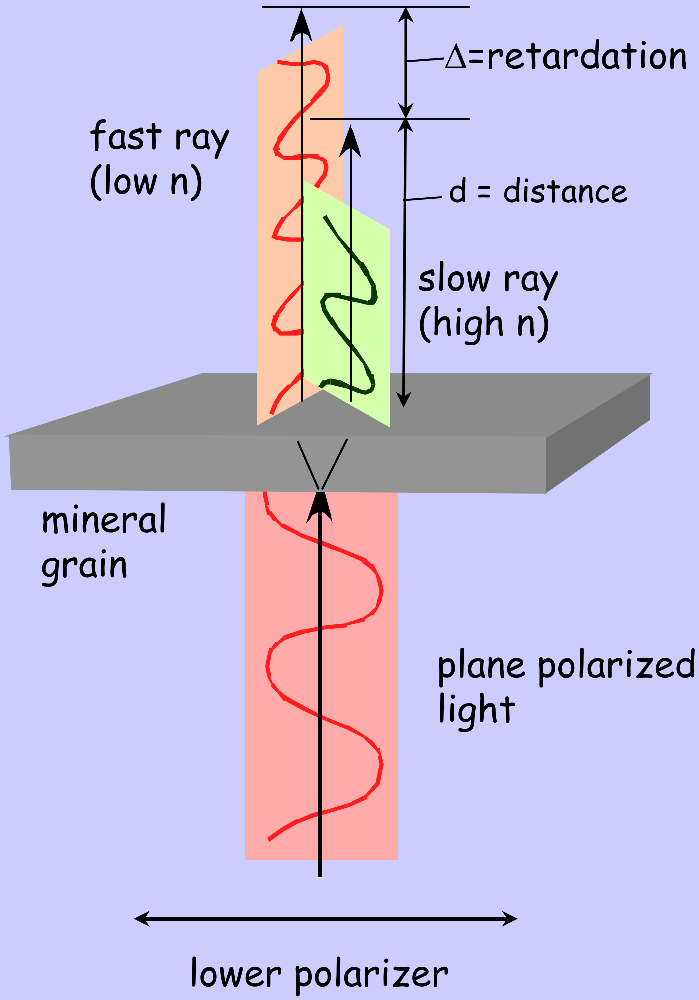
Birefringence/interference colors



At time t, when slow ray 1st exits xtl:

Slow ray has traveled distance d

Fast ray has traveled distance d+Δ



time = distance/rate

Slow ray: $t = d/V_{slow}$

Fast ray: $t = d/V_{fast} + \Delta/V_{air}$

Therefore: $d/V_{slow} = d/V_{fast} + \Delta/V_{air}$

$\Delta = d(V_{air}/V_{slow} - V_{air}/V_{fast})$

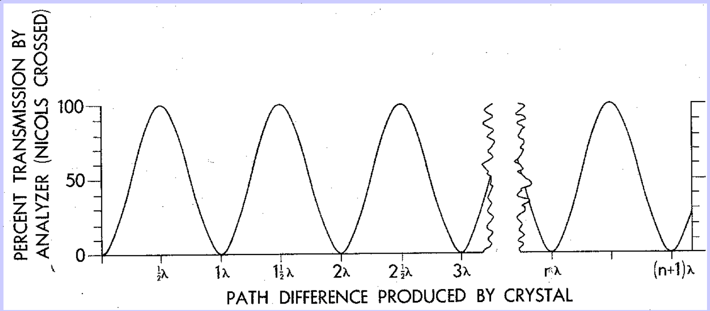
$\Delta = d(n_{slow} - n_{fast})$

$\Delta = d\ \delta$

Δ = thickness of t.s. x birefringence

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

FYI: Miller Indices (definition)

the rules for Miller Indices are:

Determine the intercepts of the face along the crystallographic axes, *in terms of unit cell dimensions.*

Take the reciprocals

Clear fractions

Reduce to lowest terms

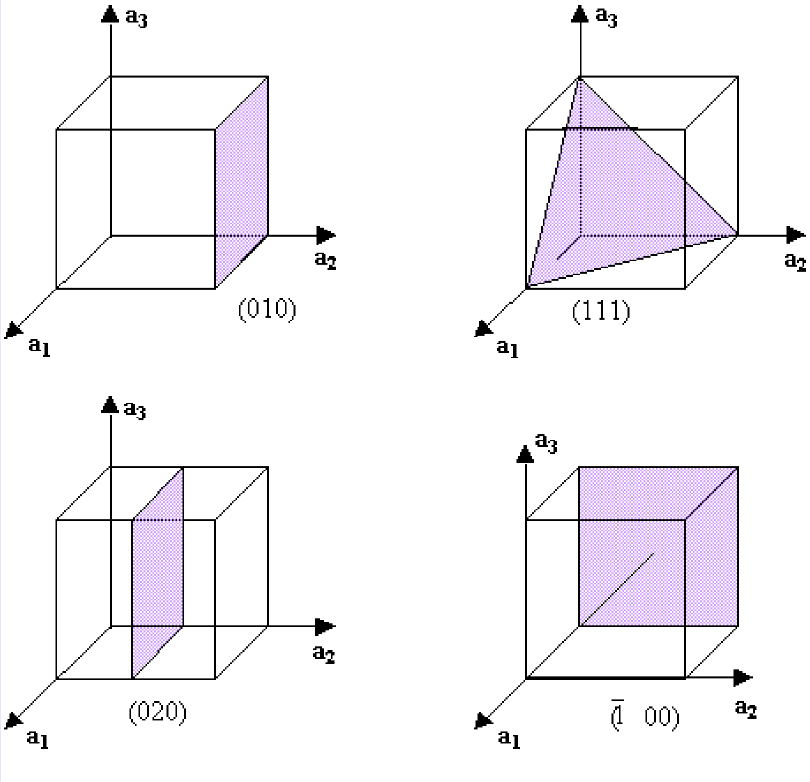
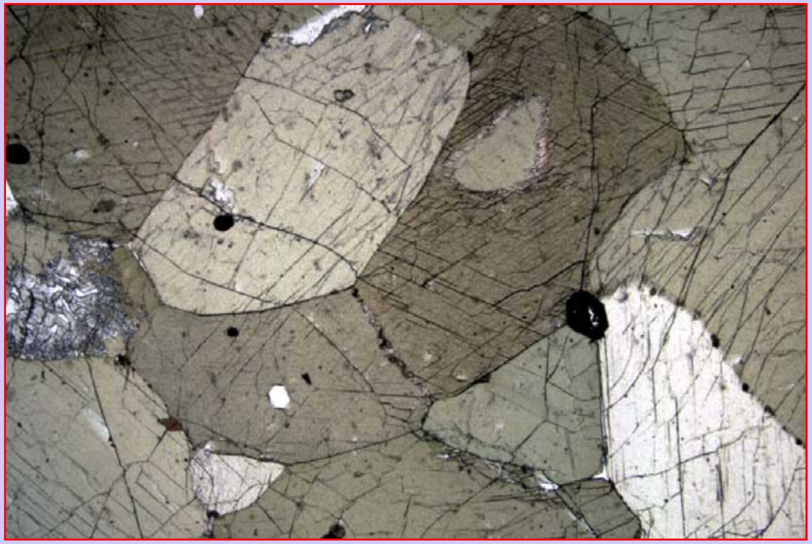


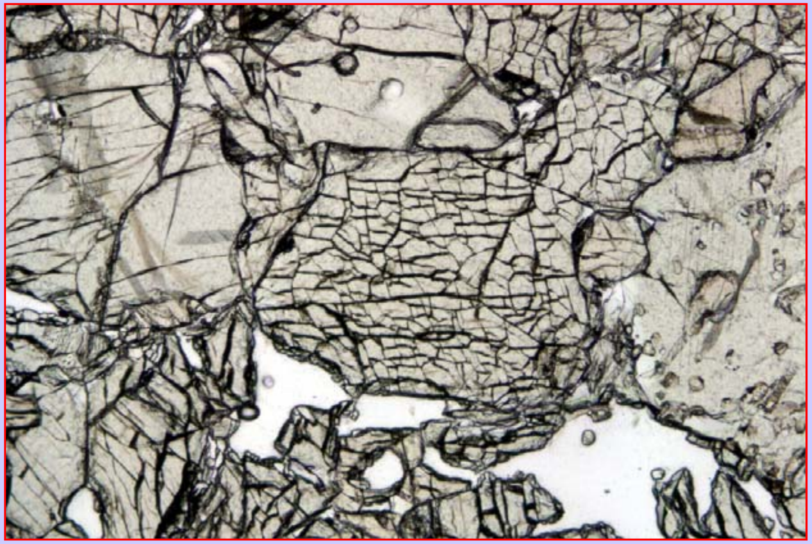
Figure 20: Miller indices of some planes in cubic crystal.

FYI: Cleavage = the way a mineral preferentially breaks (reflects internal structure)

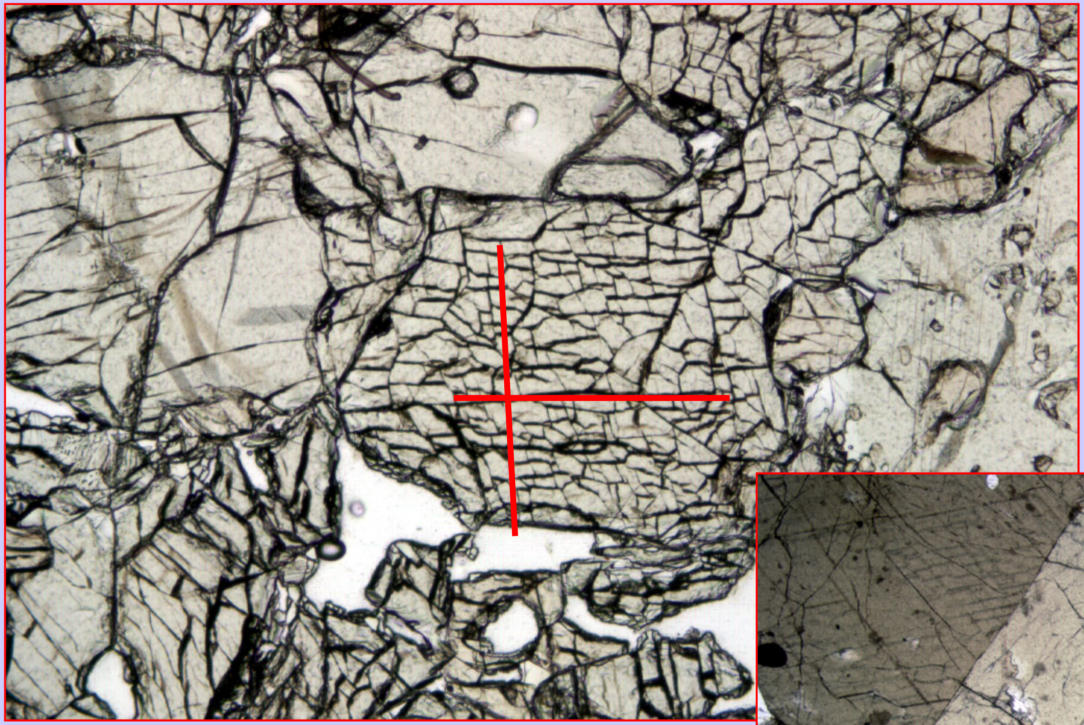
Most easily observed in PPL (upper polarizer out), but visible in XN as well

- No cleavages: quartz, olivine
- 1 good cleavage: micas
- 2 good cleavages: pyroxenes, amphiboles

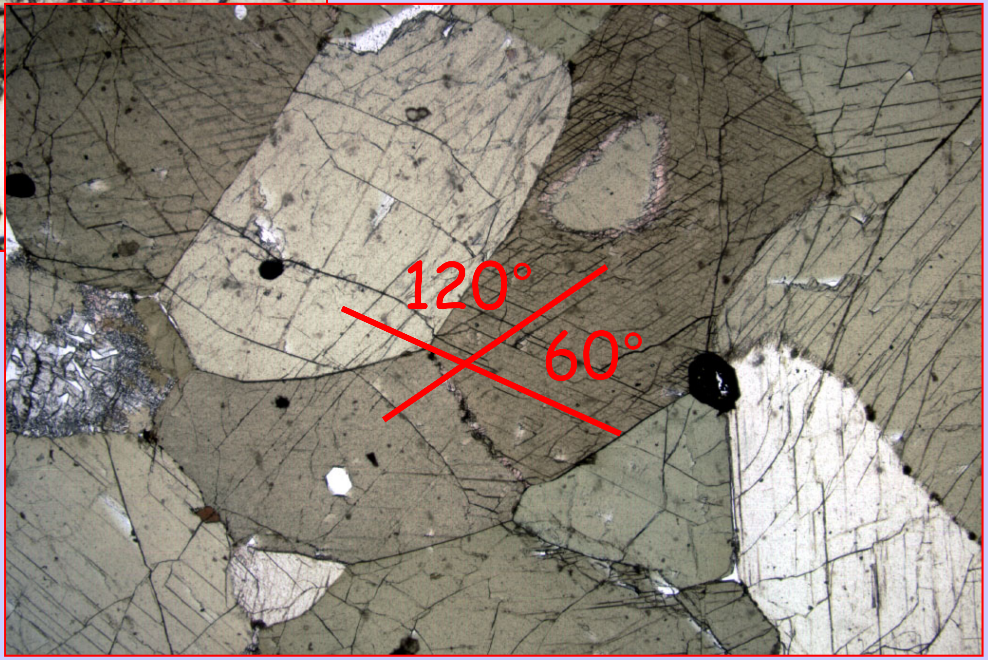




FYI: Cleavage examples

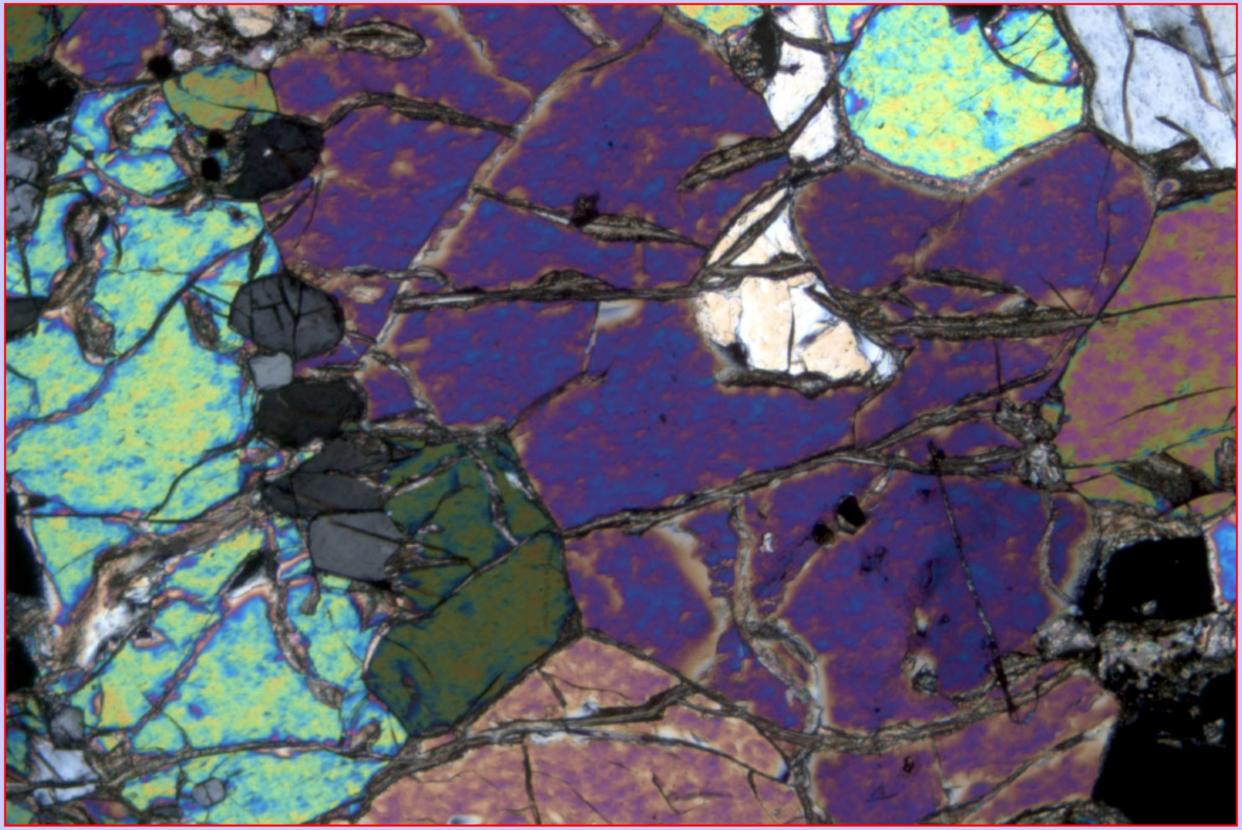


2 cleavages intersecting at ~90°
pyroxene



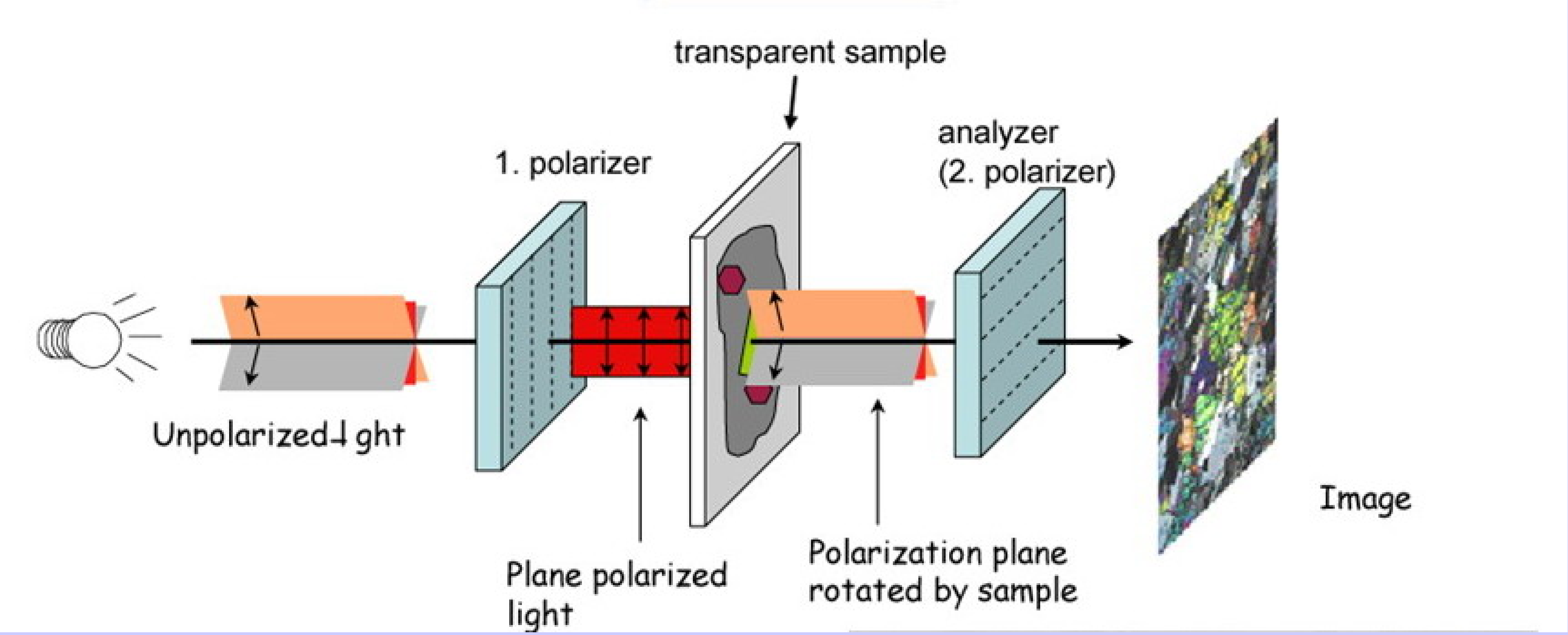
2 cleavages intersecting at 60°/120°:
amphibole

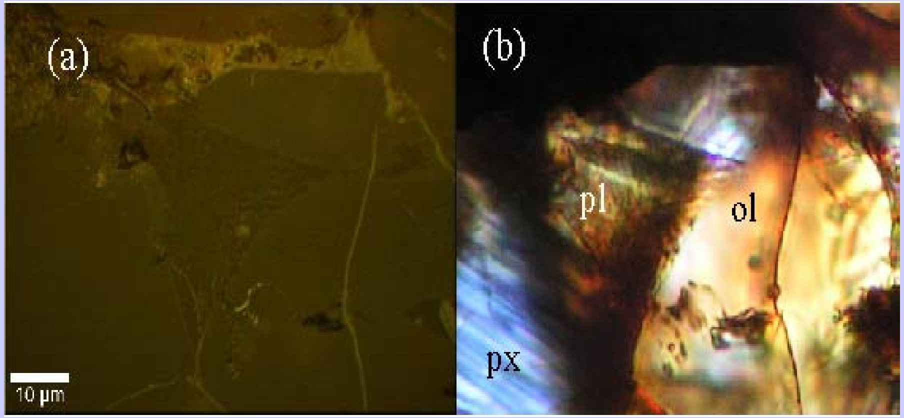
FYI: Cleavage examples



random fractures,
no cleavage:
olivine

Polarized Light Microscopy





Reflected (a) and cross polarized transmitted (b) light images of RC 05: *ol* = olivine; *pl* = plagioclase; *px* = pyroxene.