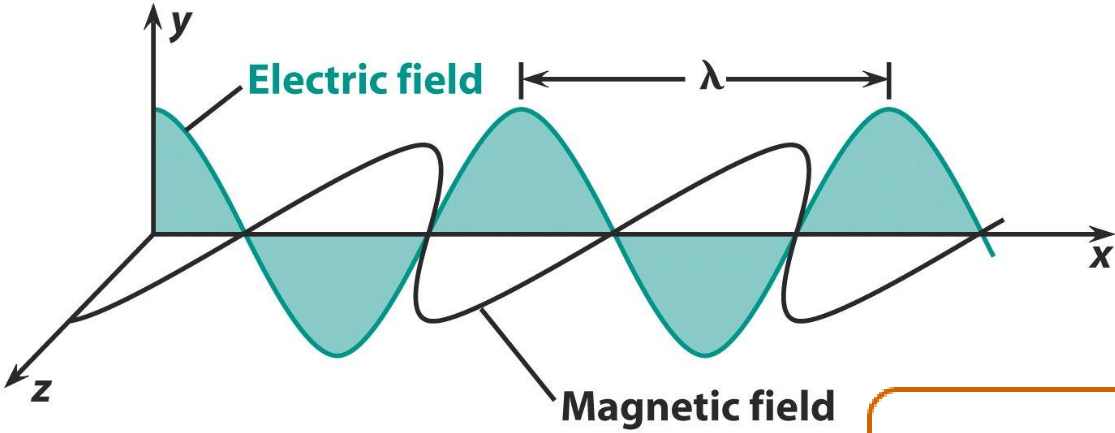
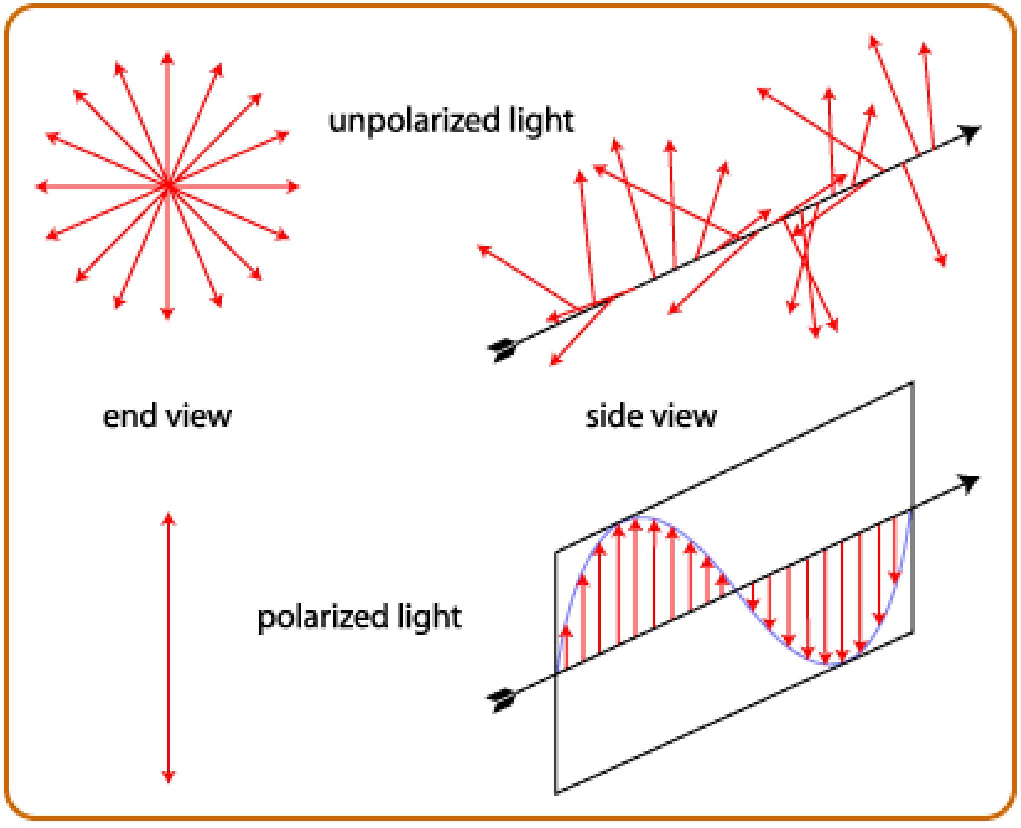
Lecture 10

Plan Polarized Light and Interference

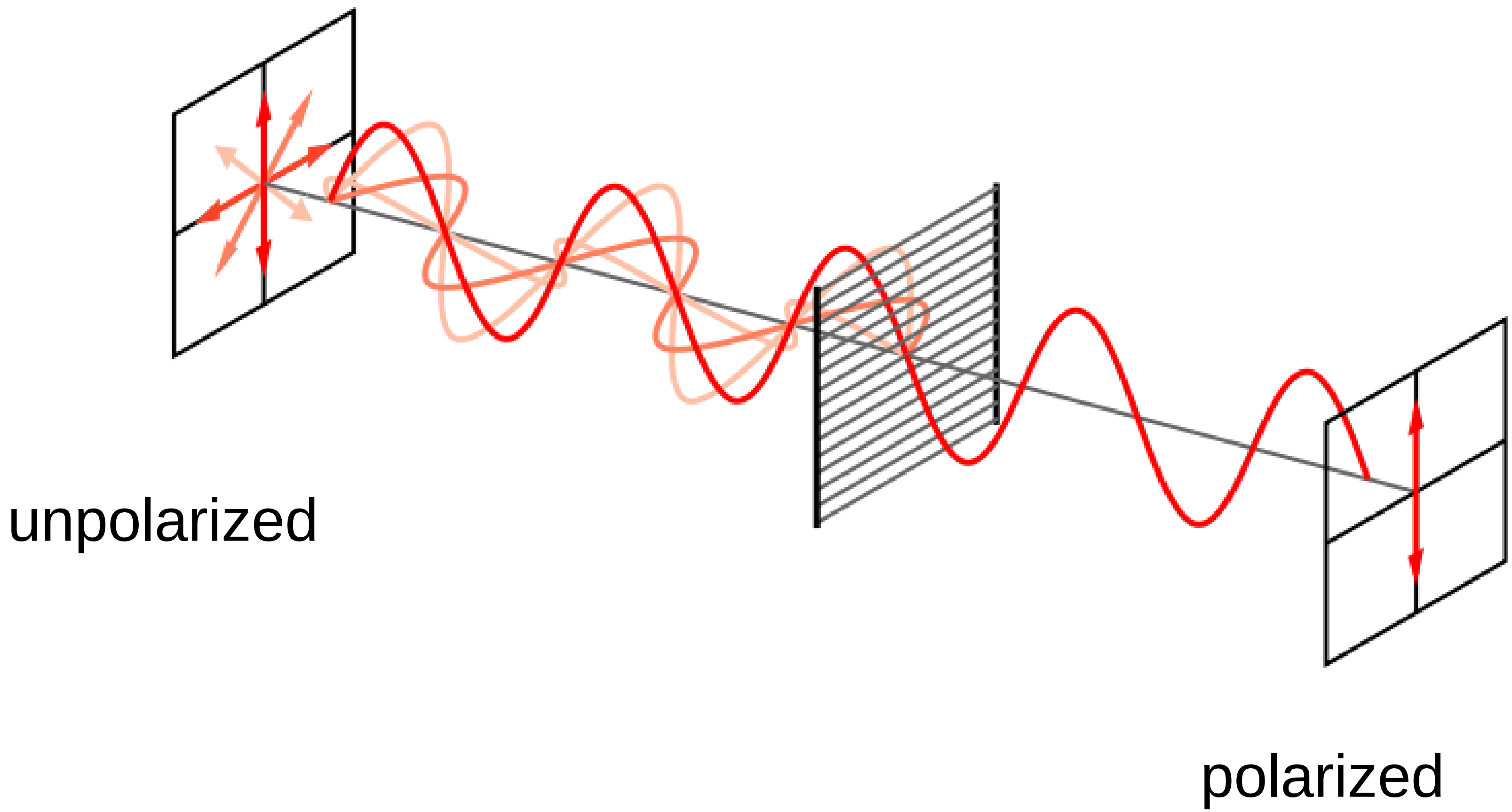
Unpolarized vs. Polarized Light



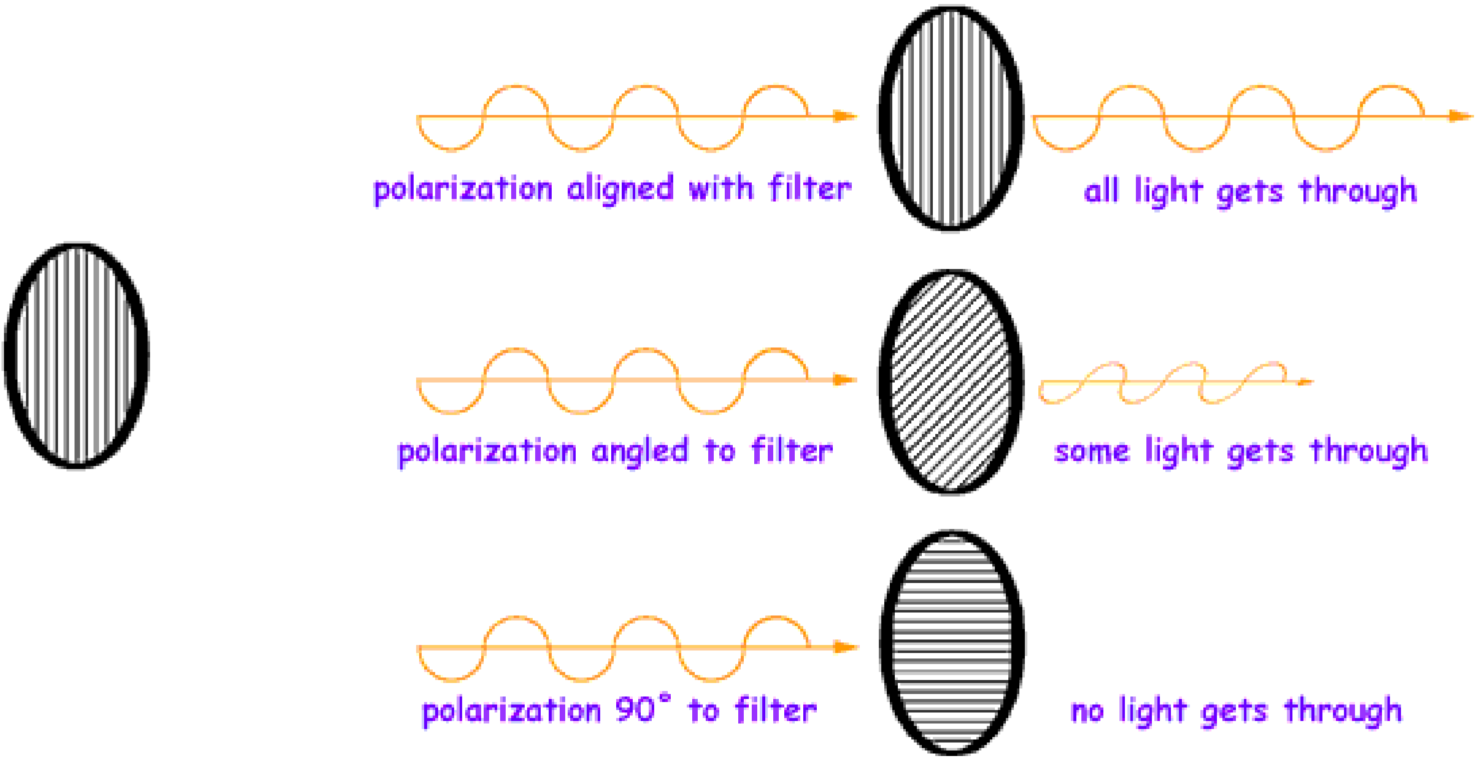
Electric filed



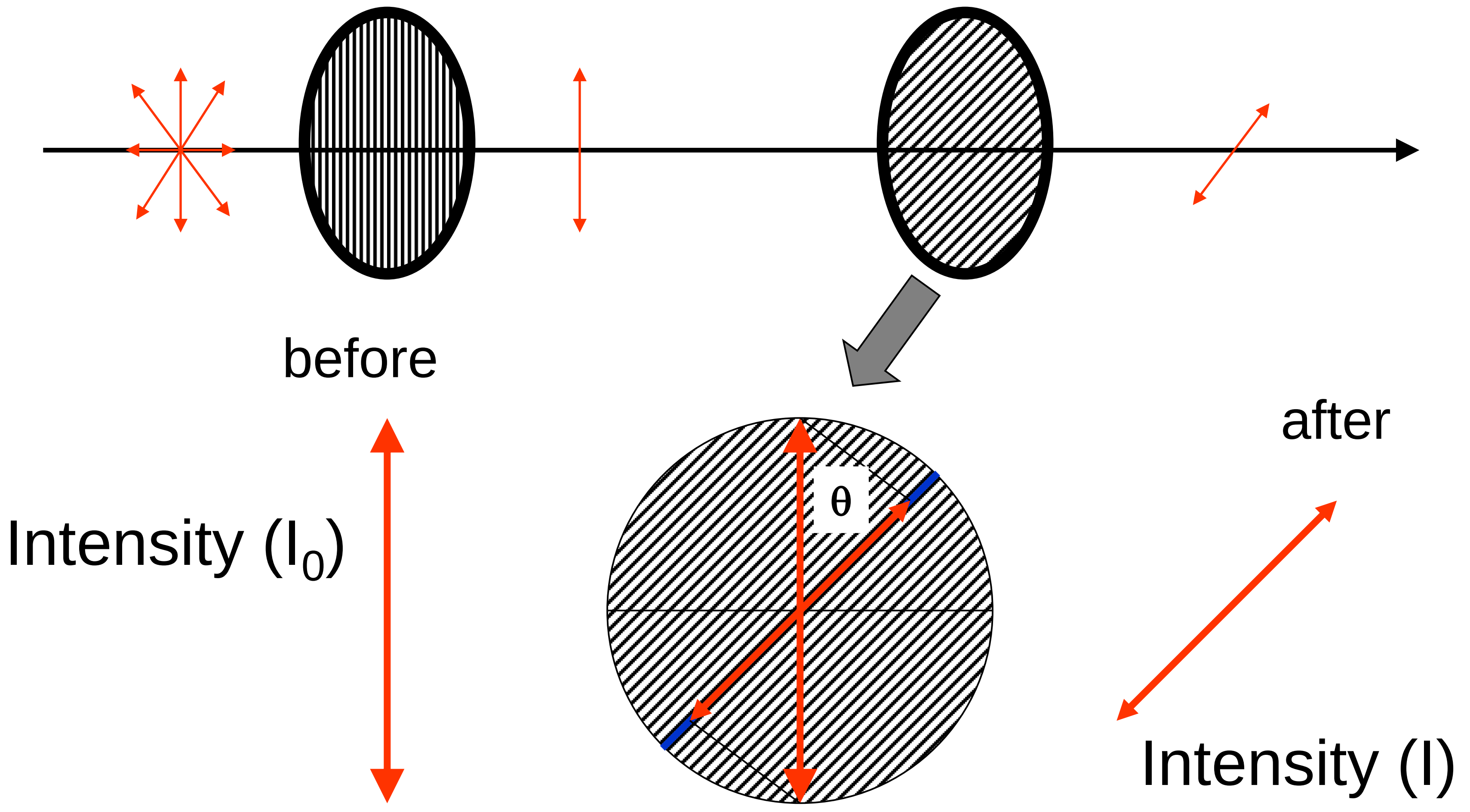
How to Make Polarized Light



Light After Two Polarizers

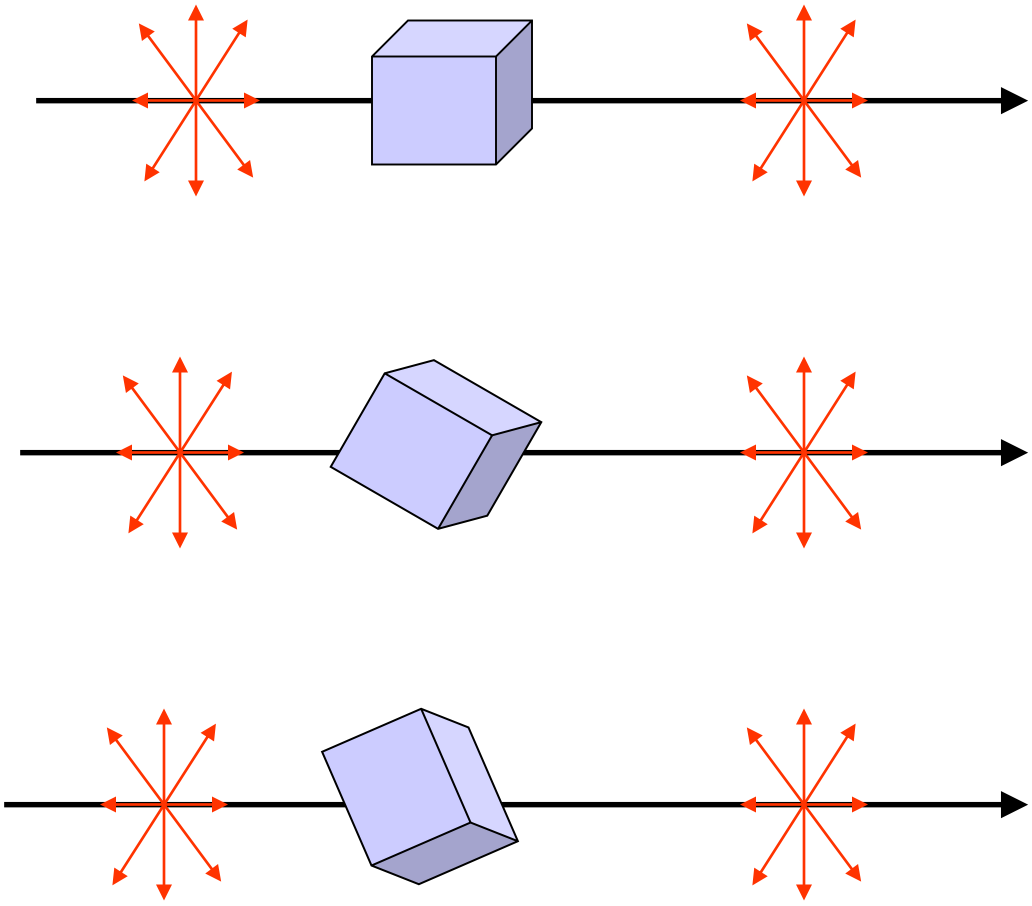


Details of Light After Two Polarizers

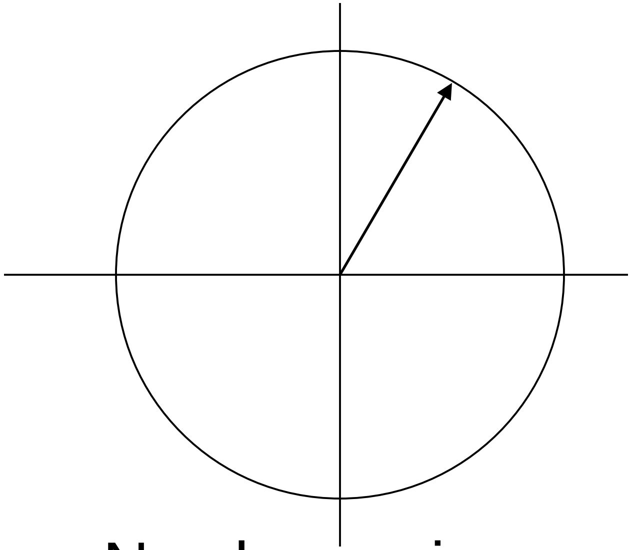


- Polarization was changed (angle)
- The intensity was reduced ($I = I_0\cos\theta$)

Unpolarized Light After Isotropic Crystal

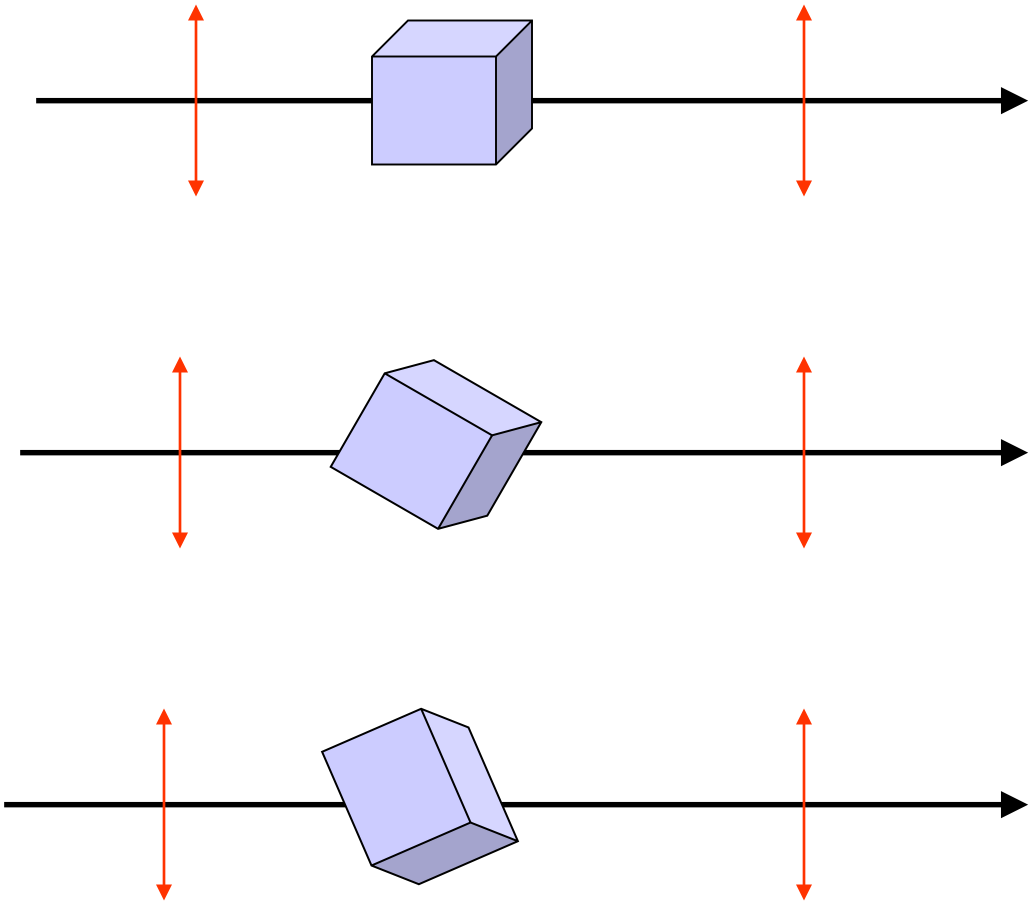


Isotropic regardless of orientation

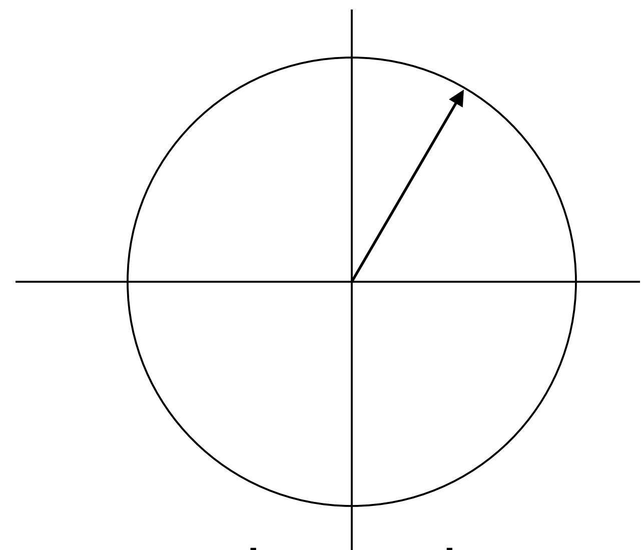


No change in ploarization

Polarized Light After Isotropic Crystal

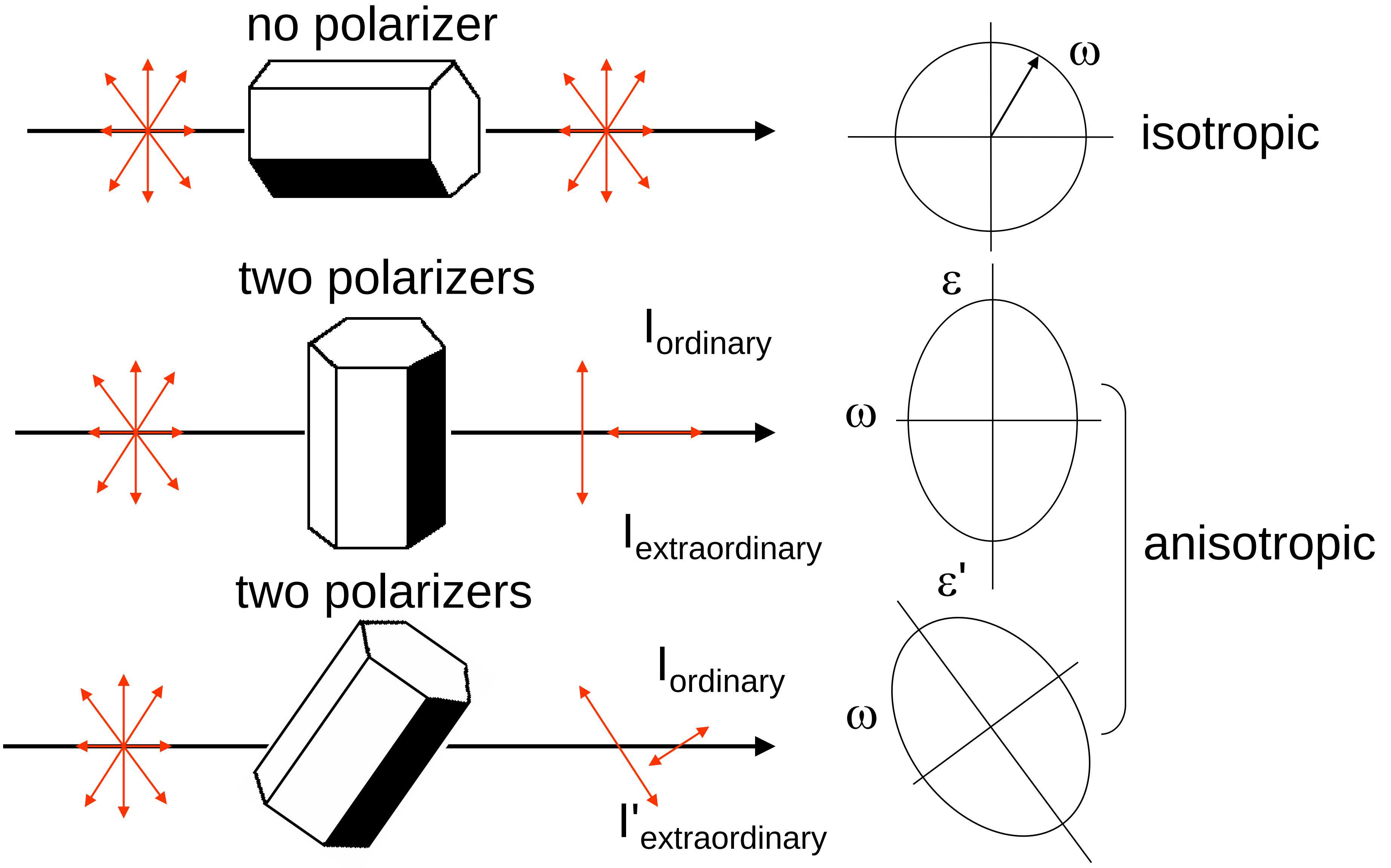


Isotropic regardless of orientation

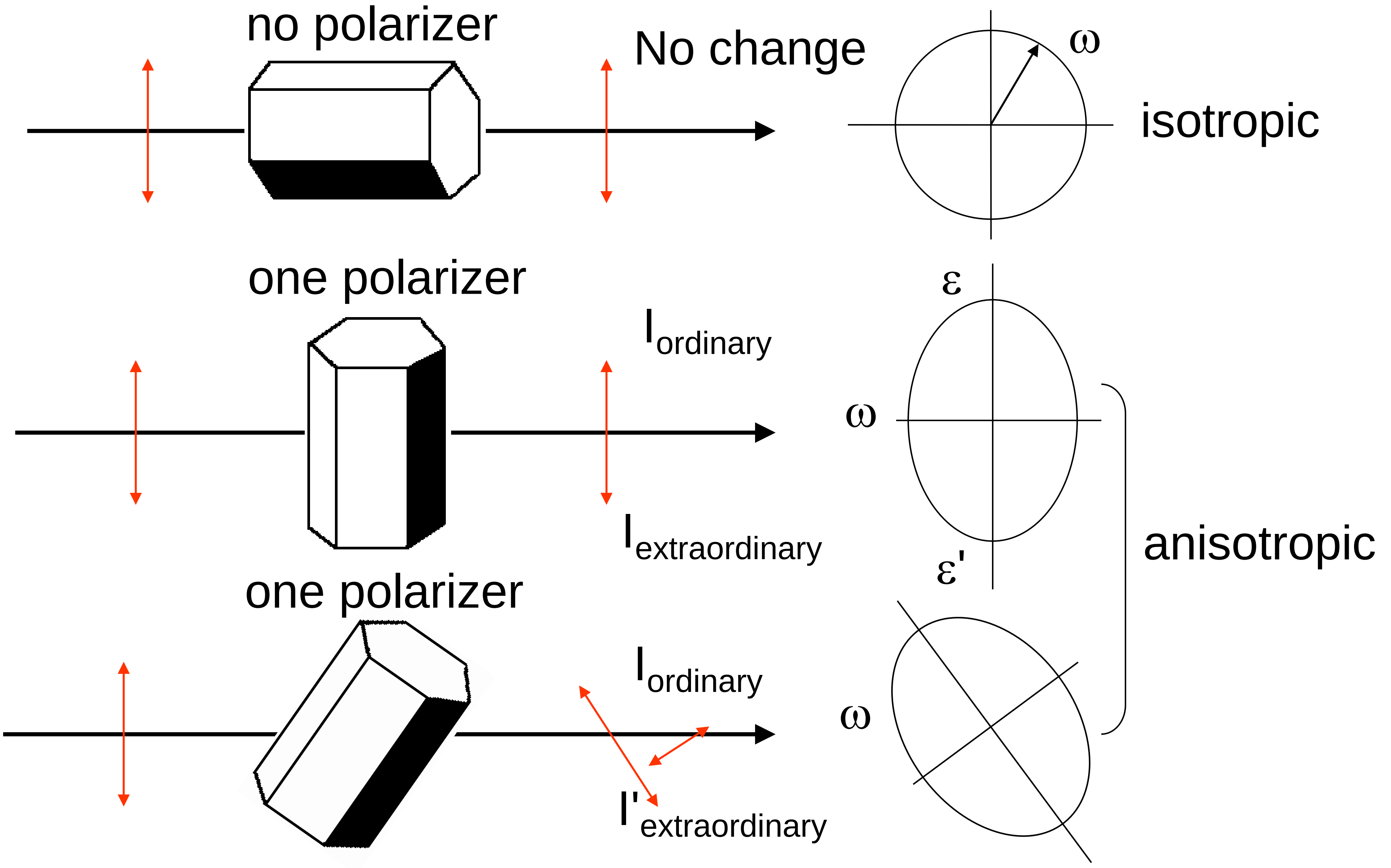


No change in ploarization

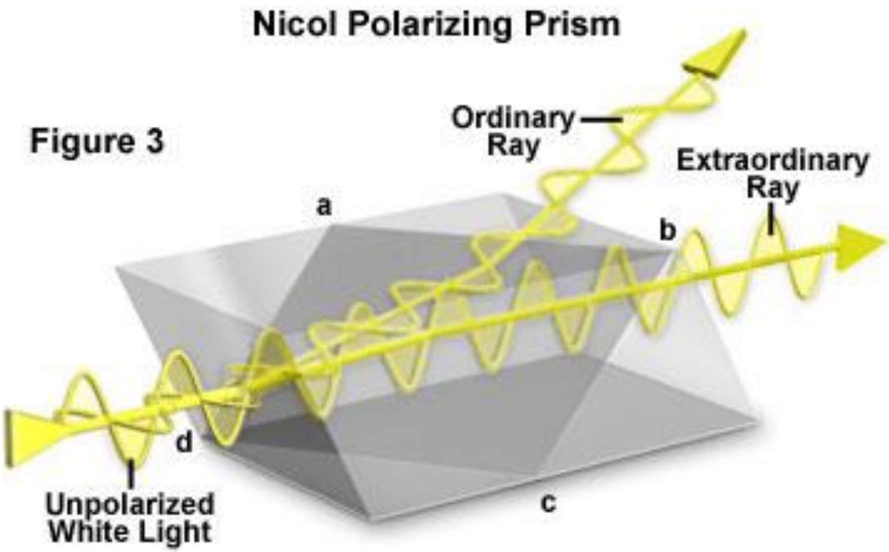
Unpolarized Light After Uniaxial Crystal: Orientation Dependence

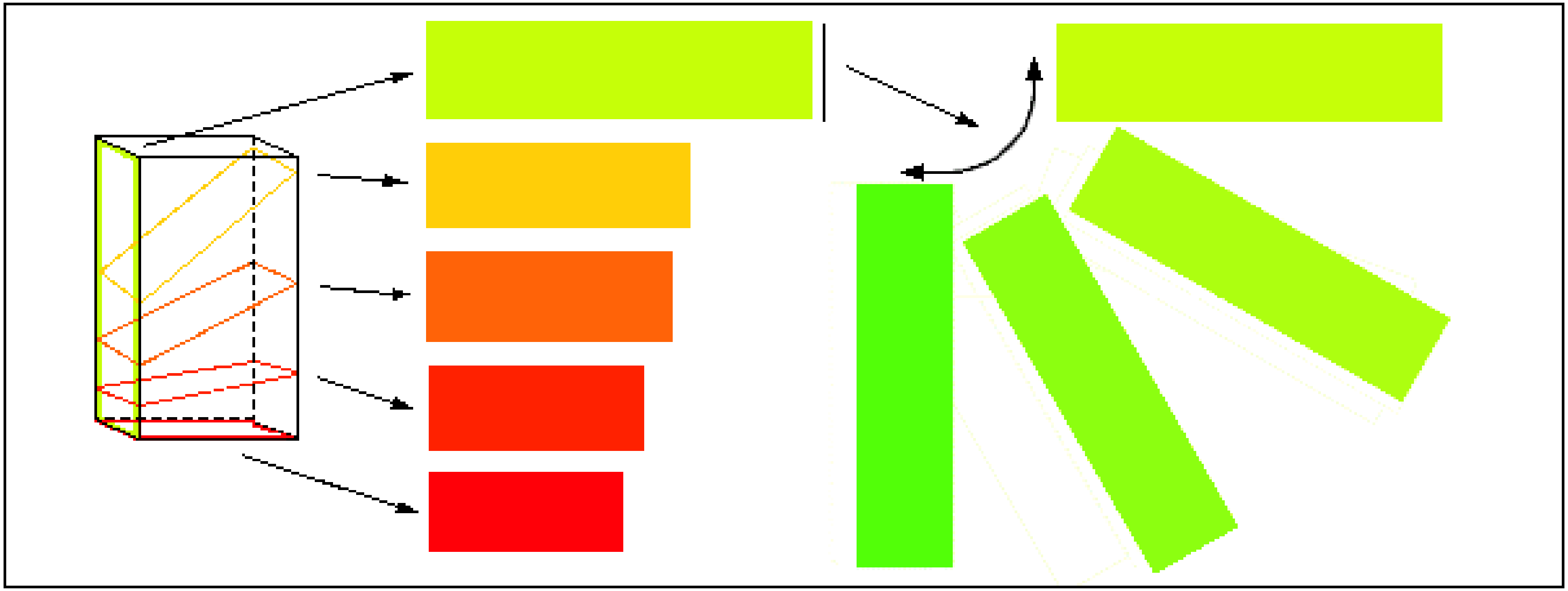


Polarized Light After Uniaxial Crystal: Orientation Dependence

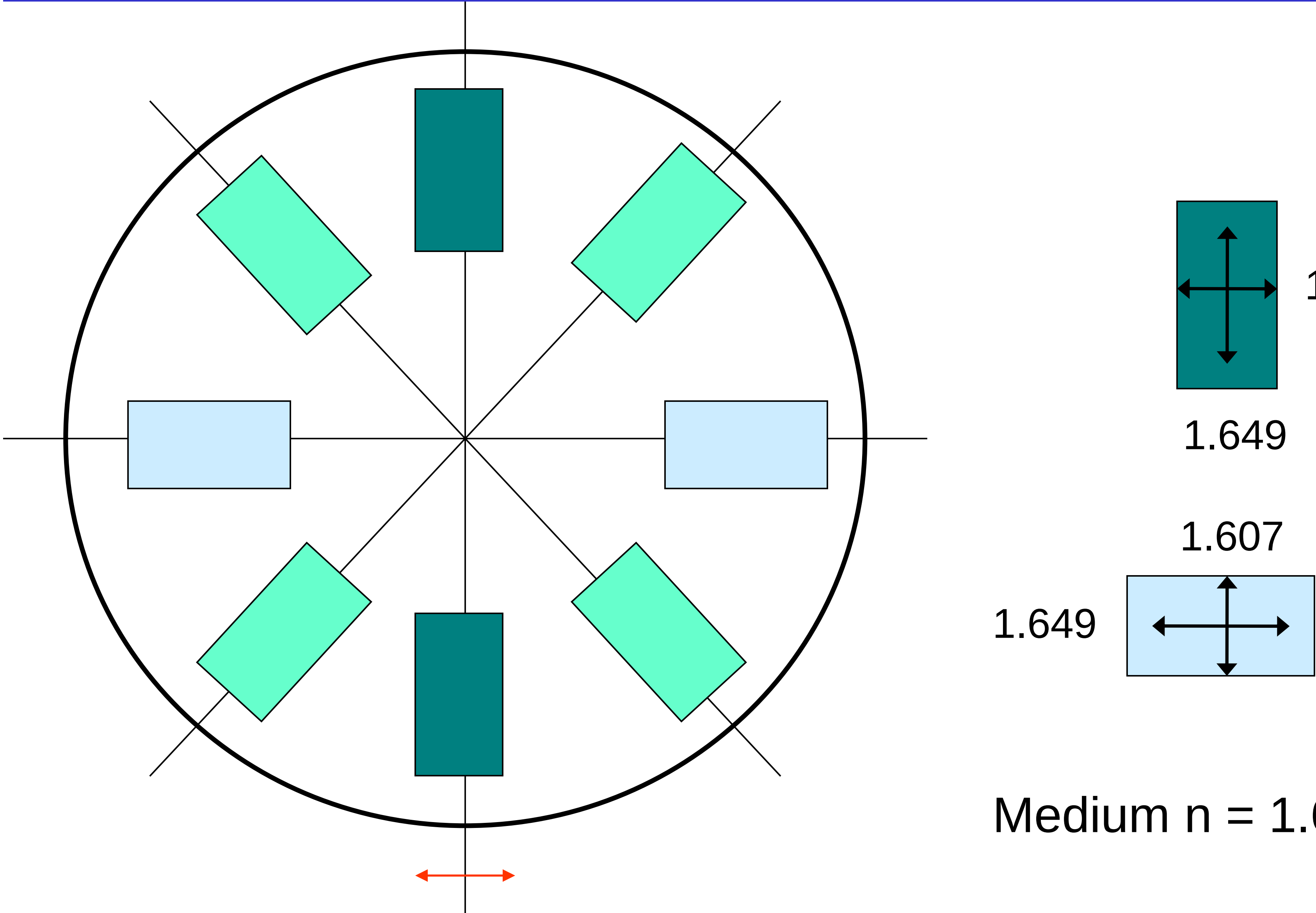


Demo: Images after Calcite (Uniaxial Crystal) and Polarizer



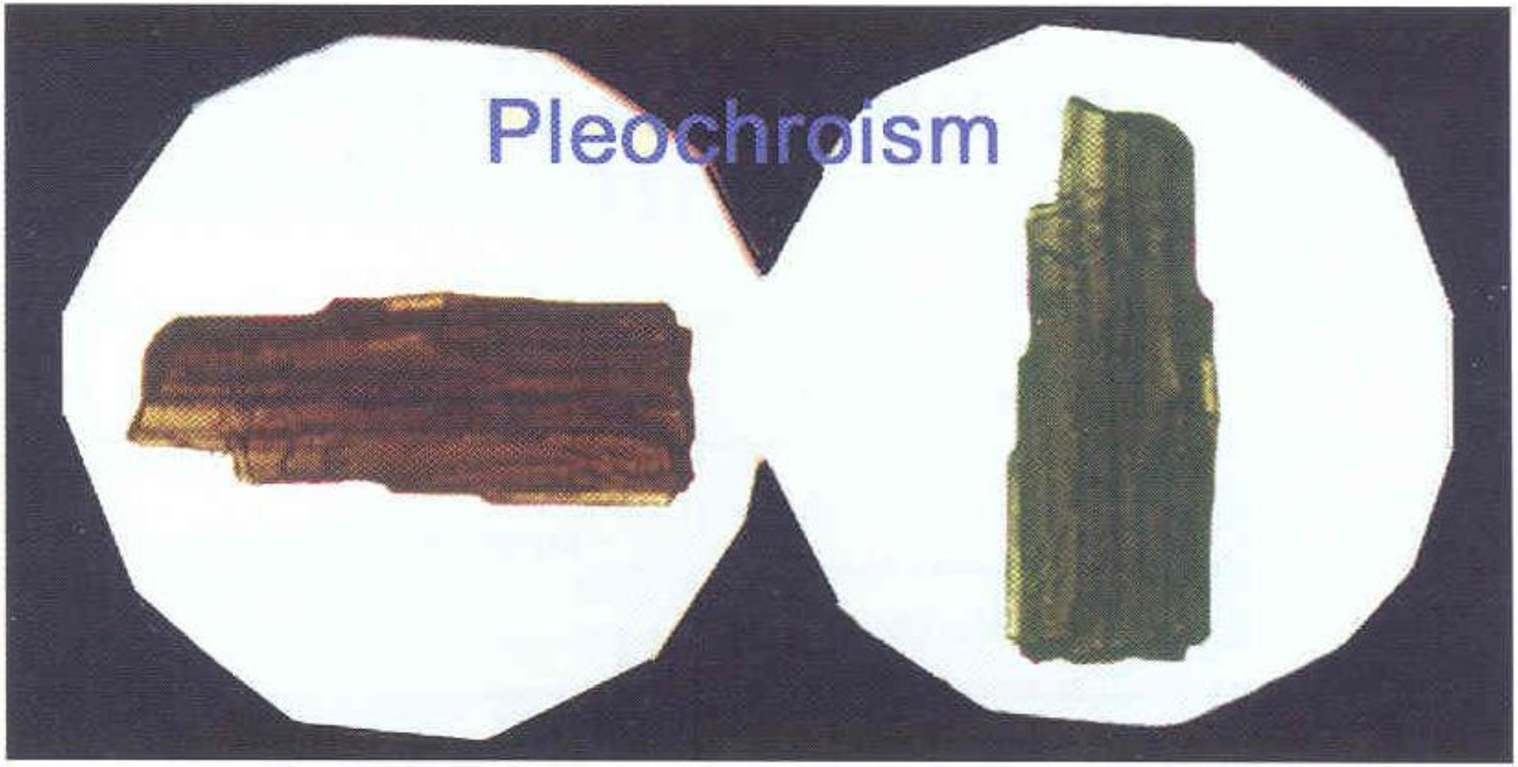


Pleochroism: Change in Contrast and Colors of Crystal Particles under Polarized Light

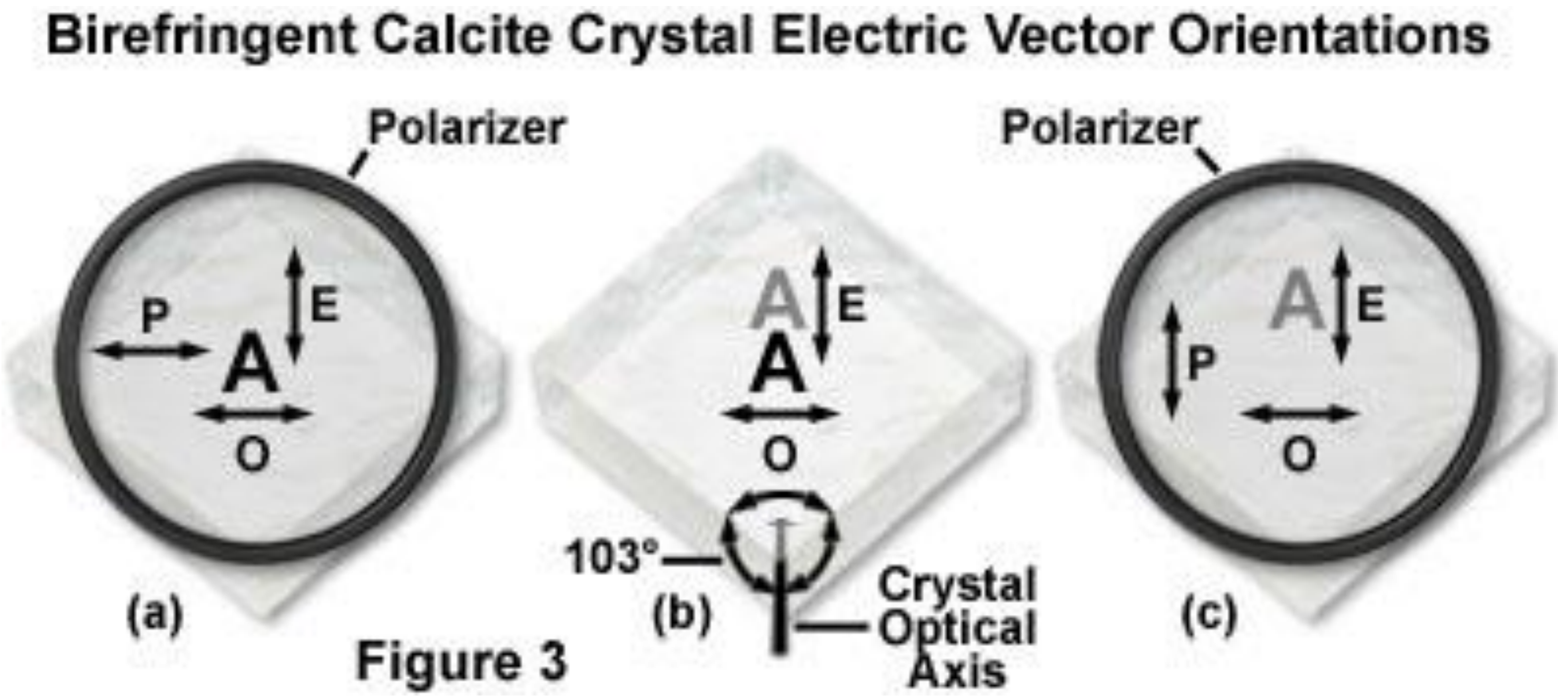


Medium n = 1.662

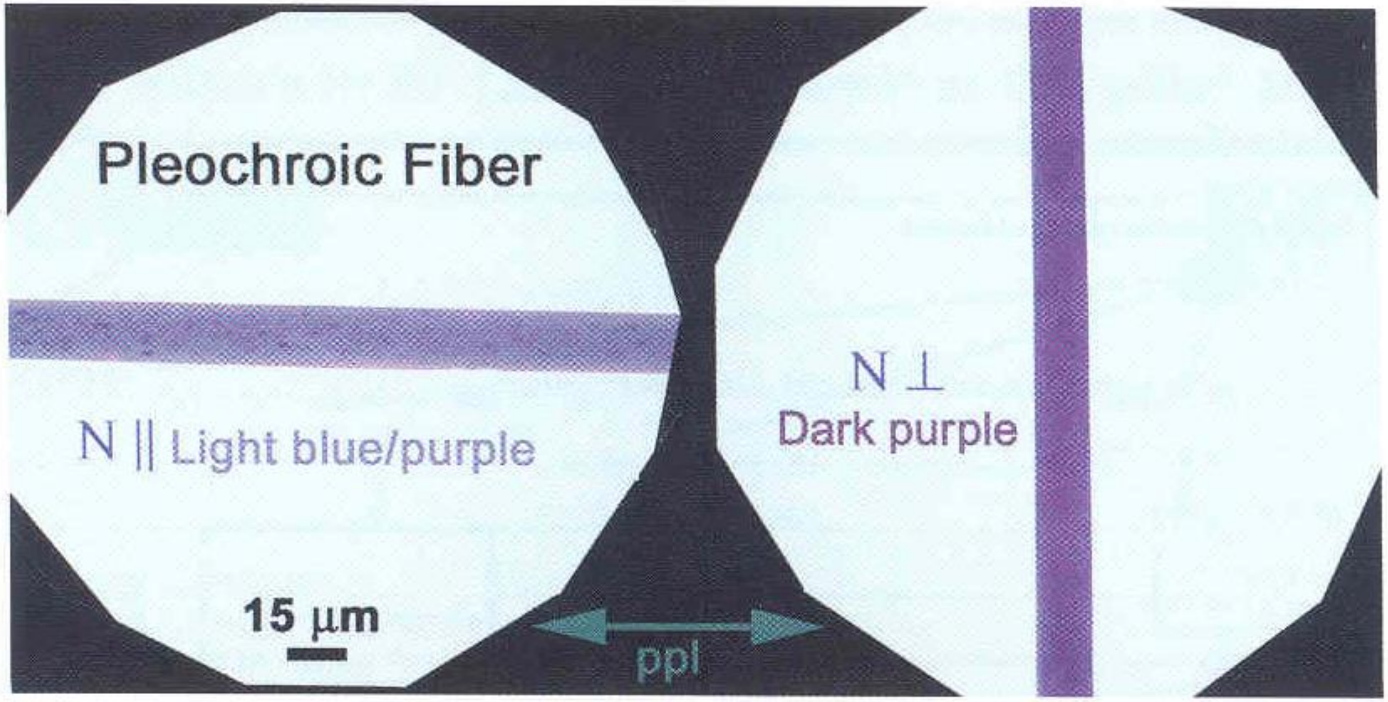
Pleochroism: Change in Colors of Crystal Particles



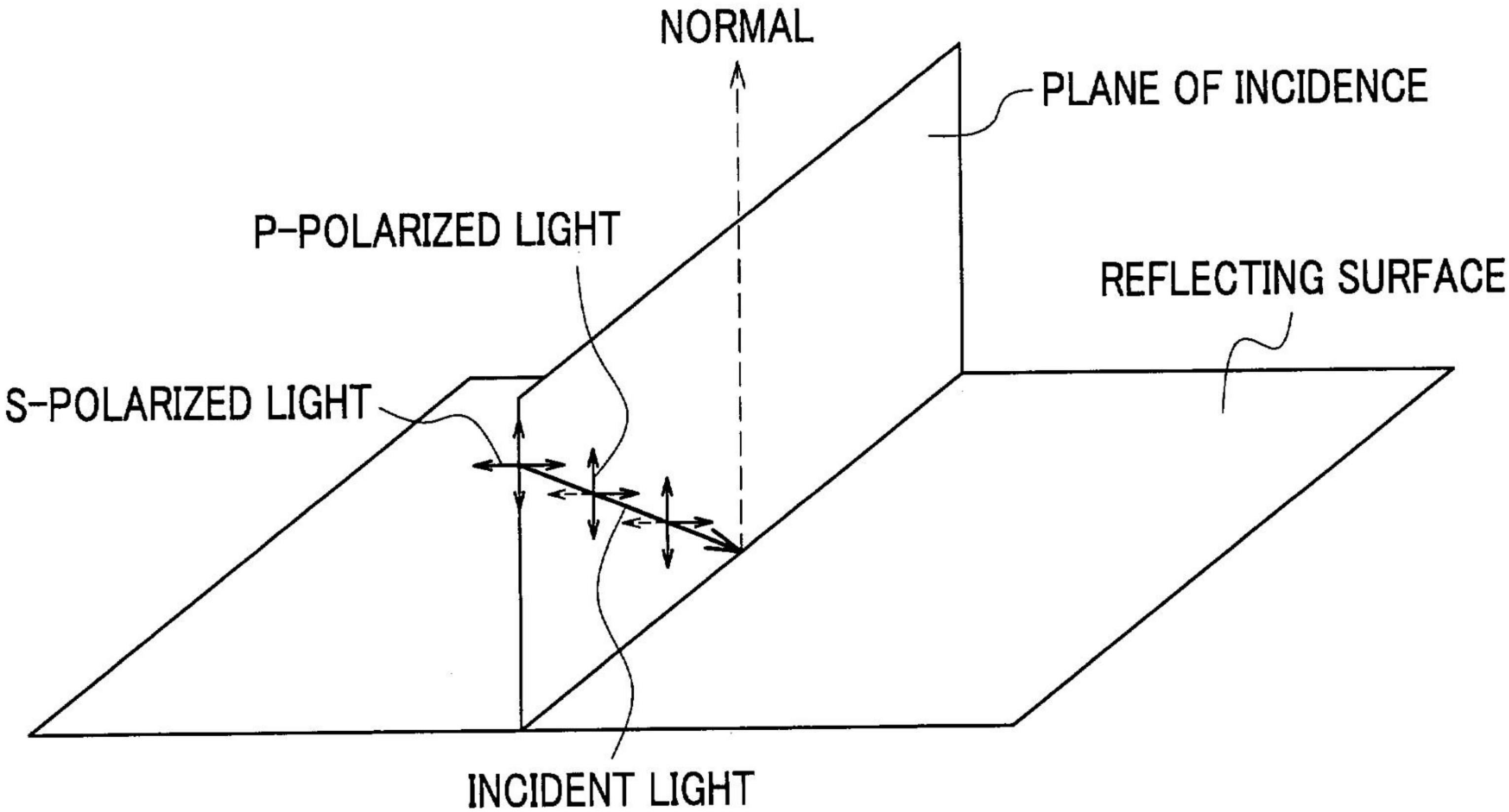
Change in Contrast of Crystal Particles



Pleochroism: Change in Contrast

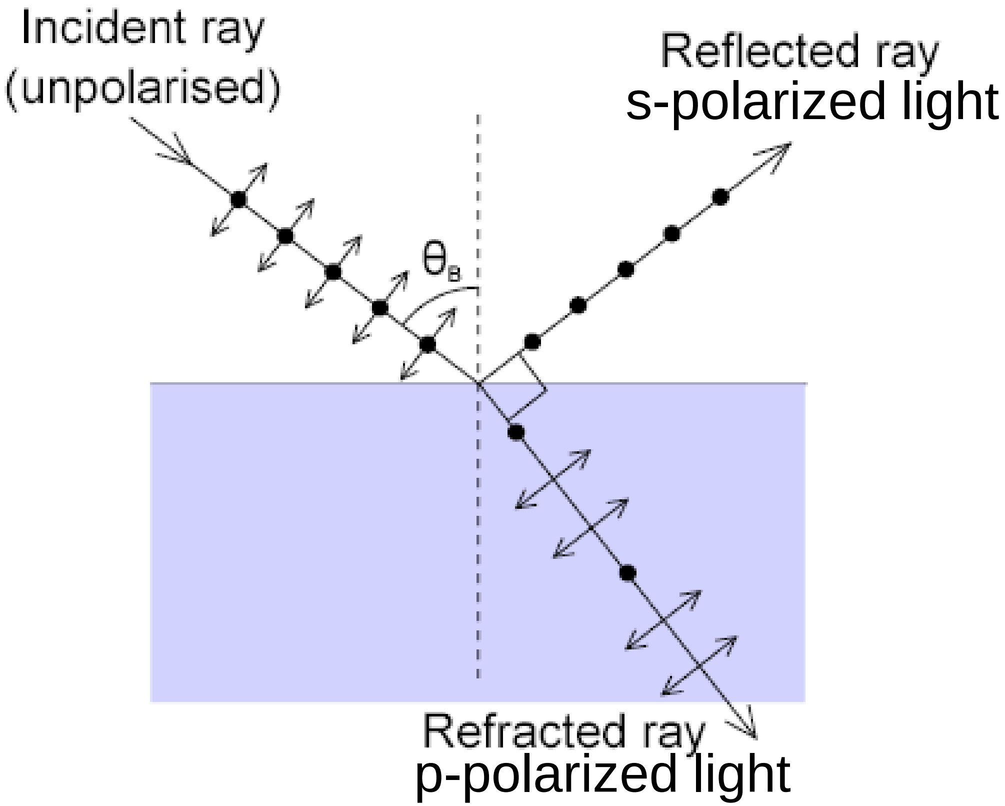


s- and p-Polarized Lights



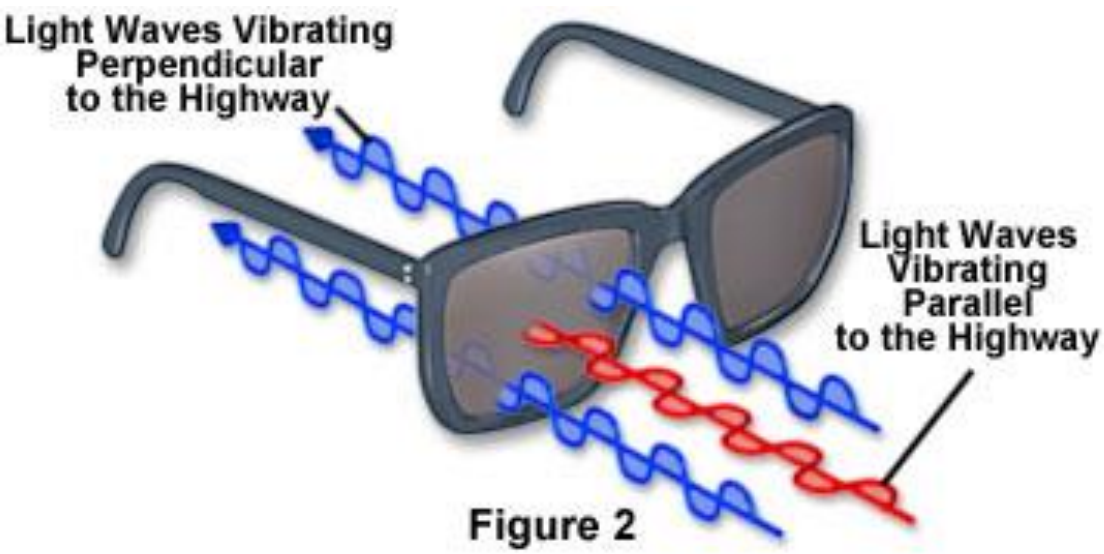
s: oscillating parallel to the reflection surface
p: oscillating perpendicular to the reflection surface

Reflection of Polarized Light

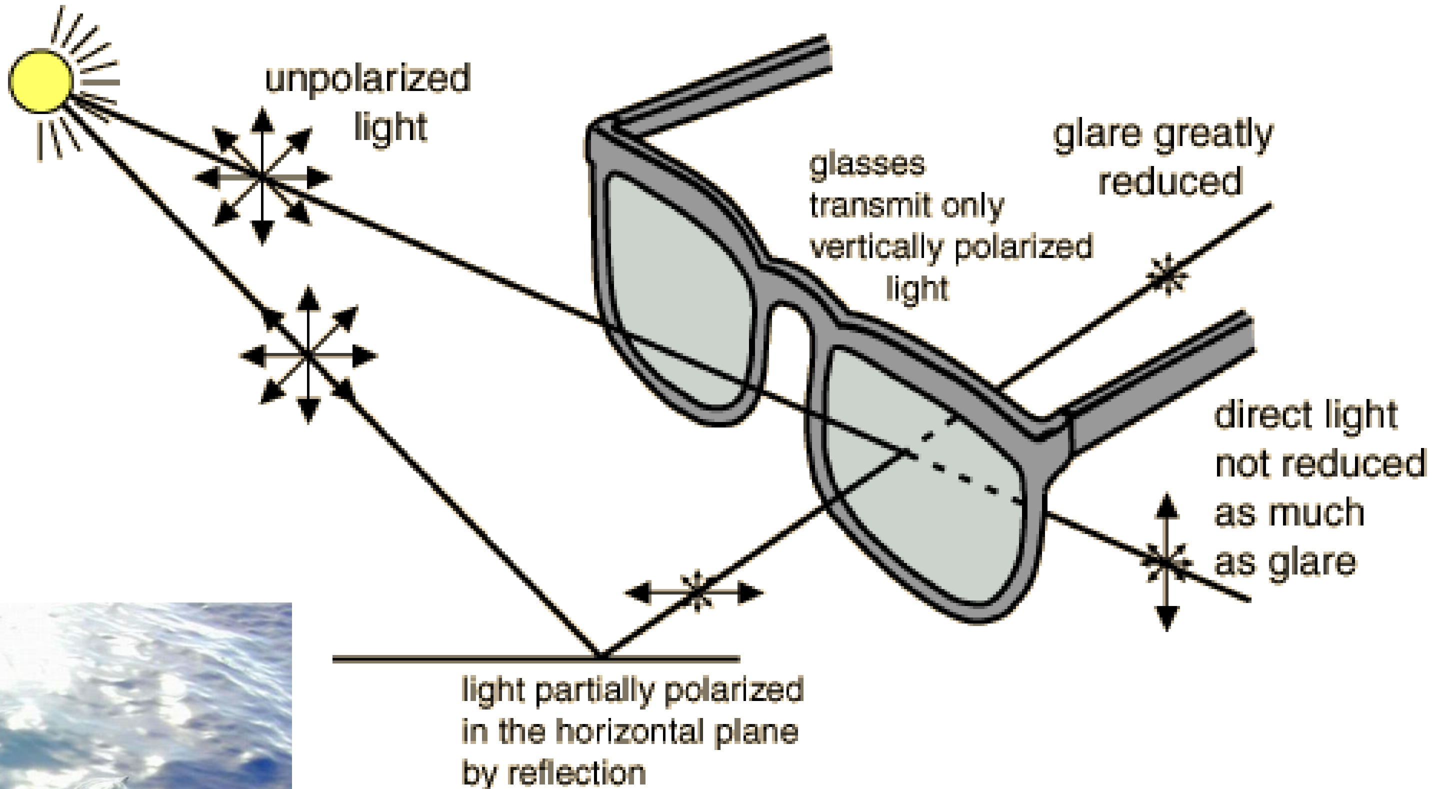


- More s-polarized light is reflected (30 degree)
- More p-polarized light is refracted
- 100 % s-polarized is reflected at Brewster angle (θ_B)
- glass (~56°), water (~55°),

Polarizer in Daily Life



Direct and Reflected Light



Images after Polarizer

http://www.cs.mtu.edu/~shene/DigiCam/User-Guide/filter/polarizer.html

LCD and Polarizer

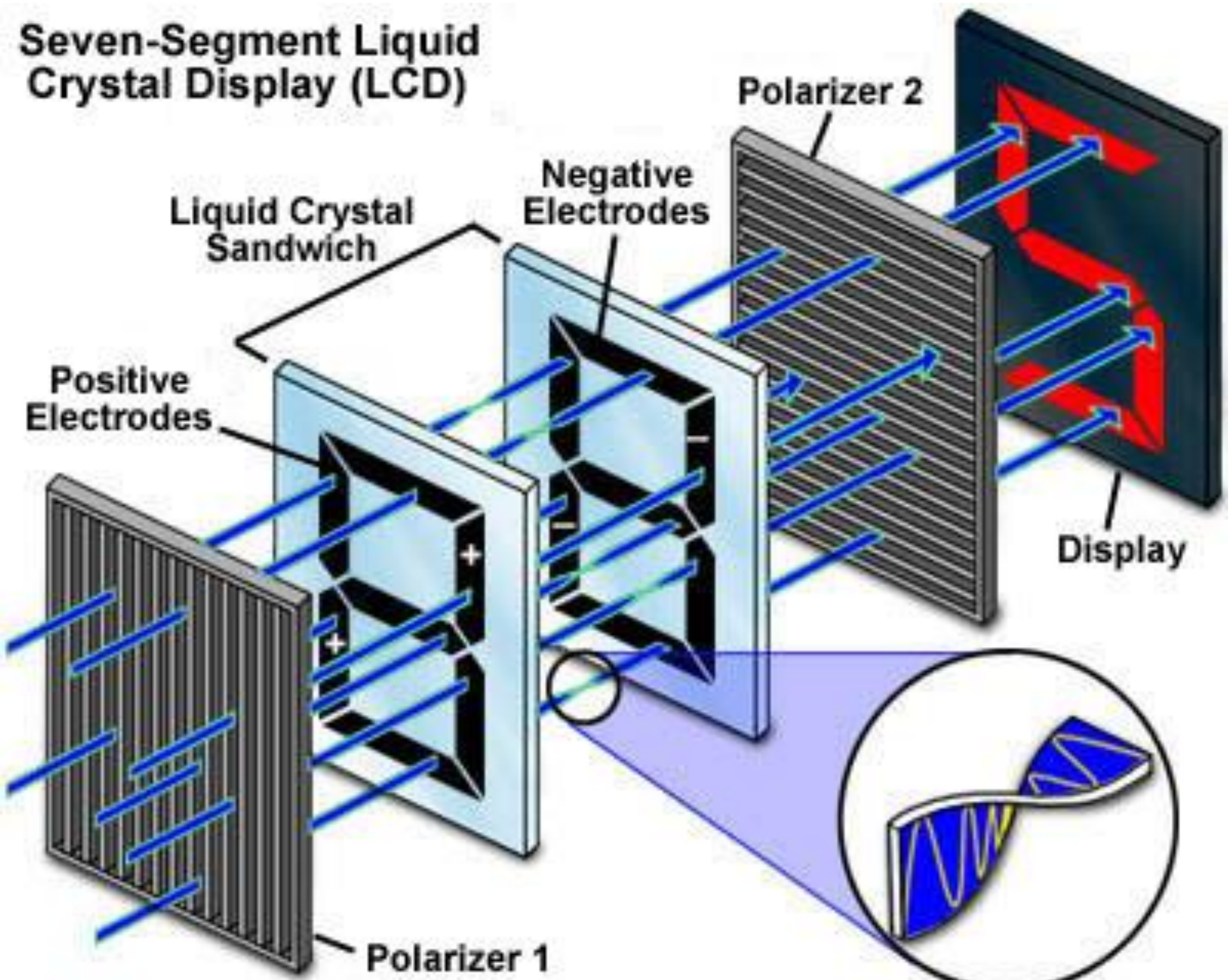
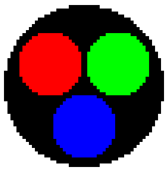
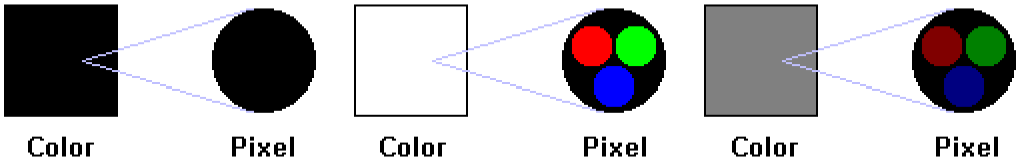


Figure 3

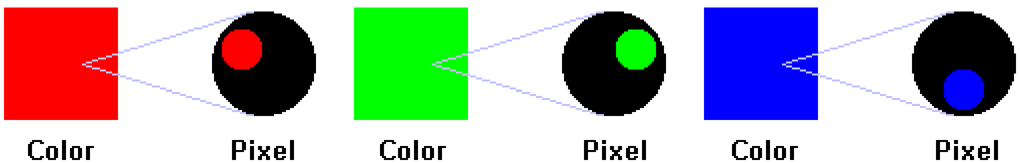
More about LCD: Color and Contrast



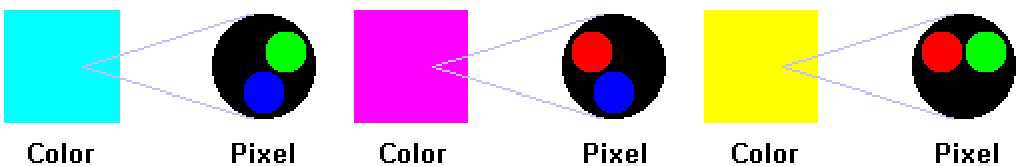
a pixel consisting of the red, green and blue color



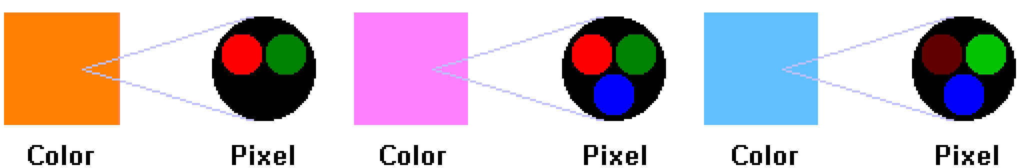
Black, White, and Gray: Nothing, All, or Some



Red, Green and Blue: Pure Colors



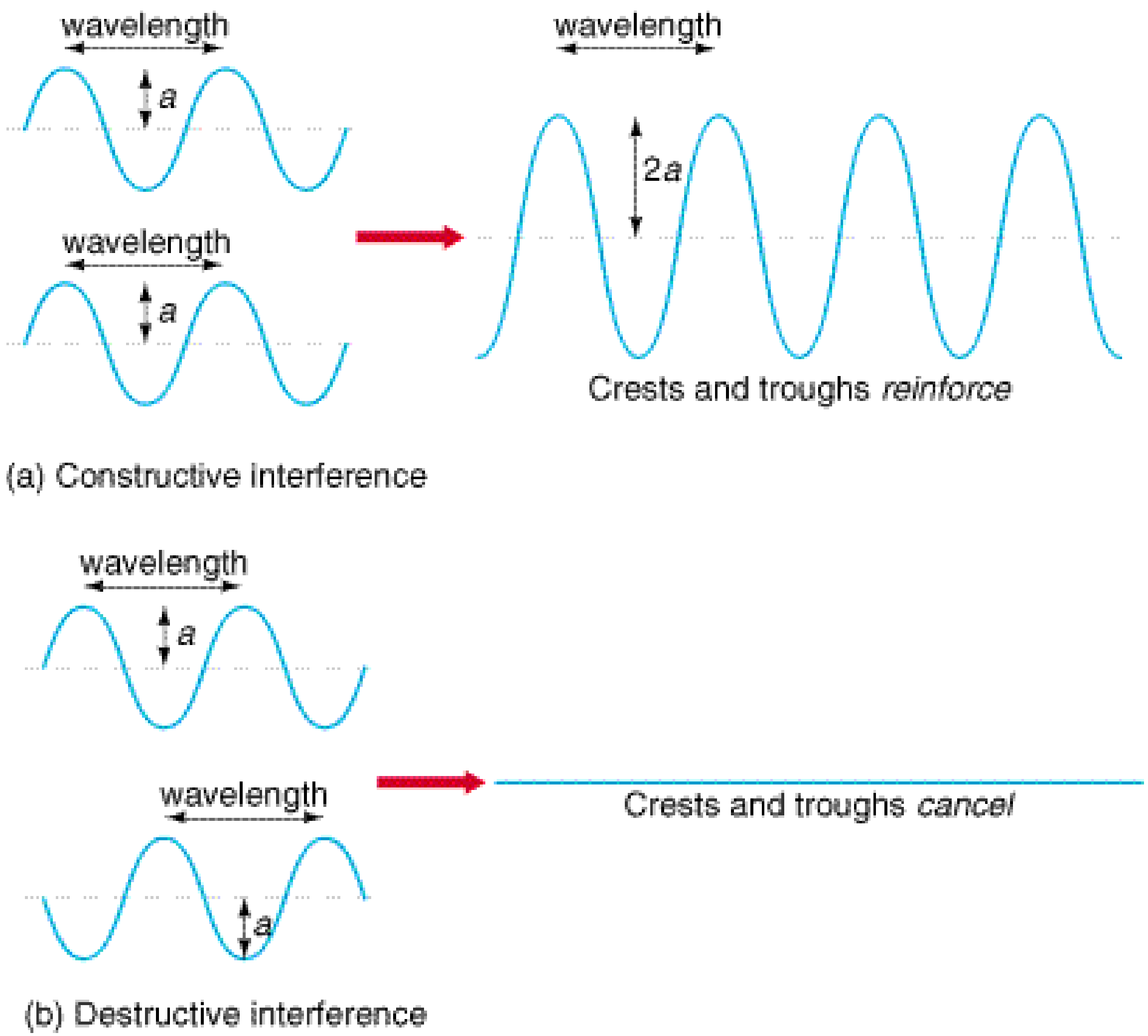
Cyan, Purple, and Yellow: Combinations of Two Colors



Mixtures of Three Colors

http://www.chem.purdue.edu/gchelp/cchem/RGBColors/body_rgbcolors.html

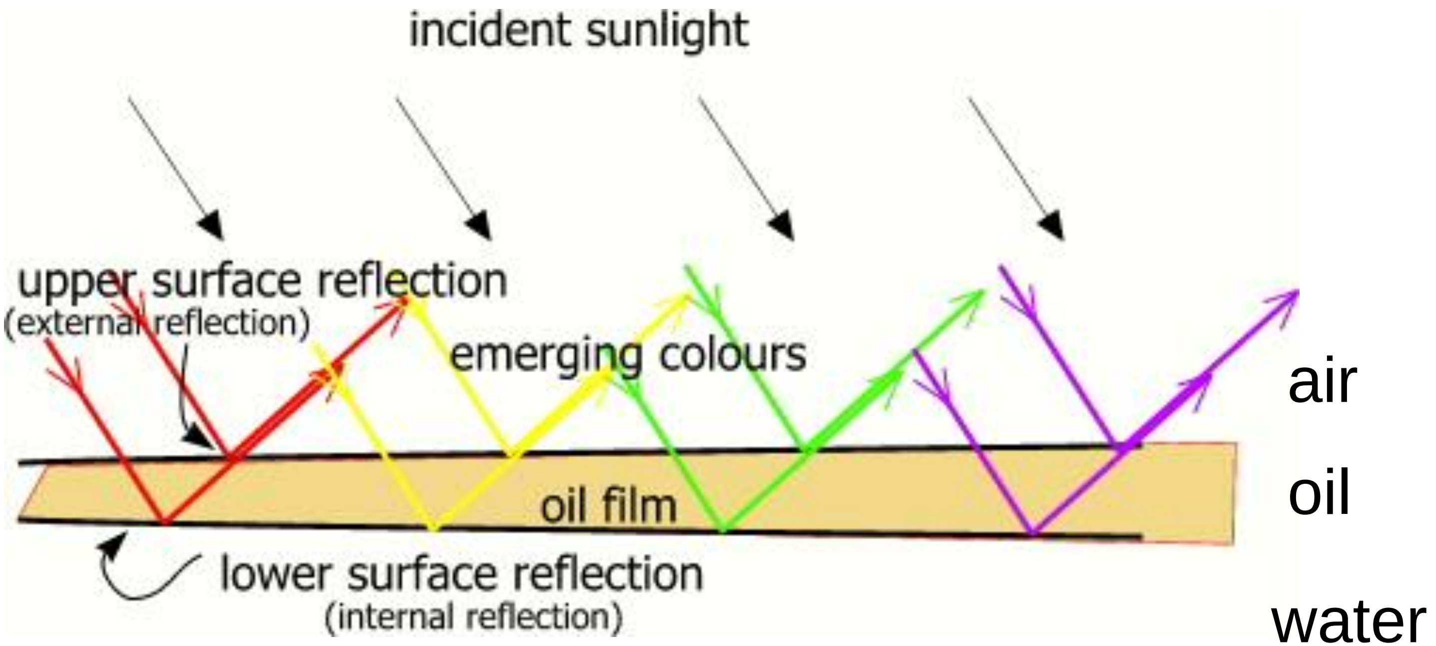
Interference of Light

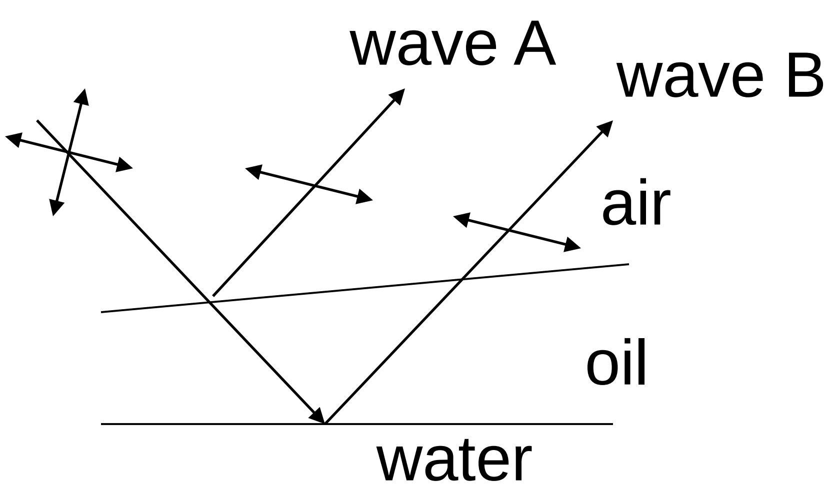


- Same directions
- Constant phase relationship (coherent)

Thin Film Interference of Light: Reflection Angle Dependence

Why and How: Thin Film Interference



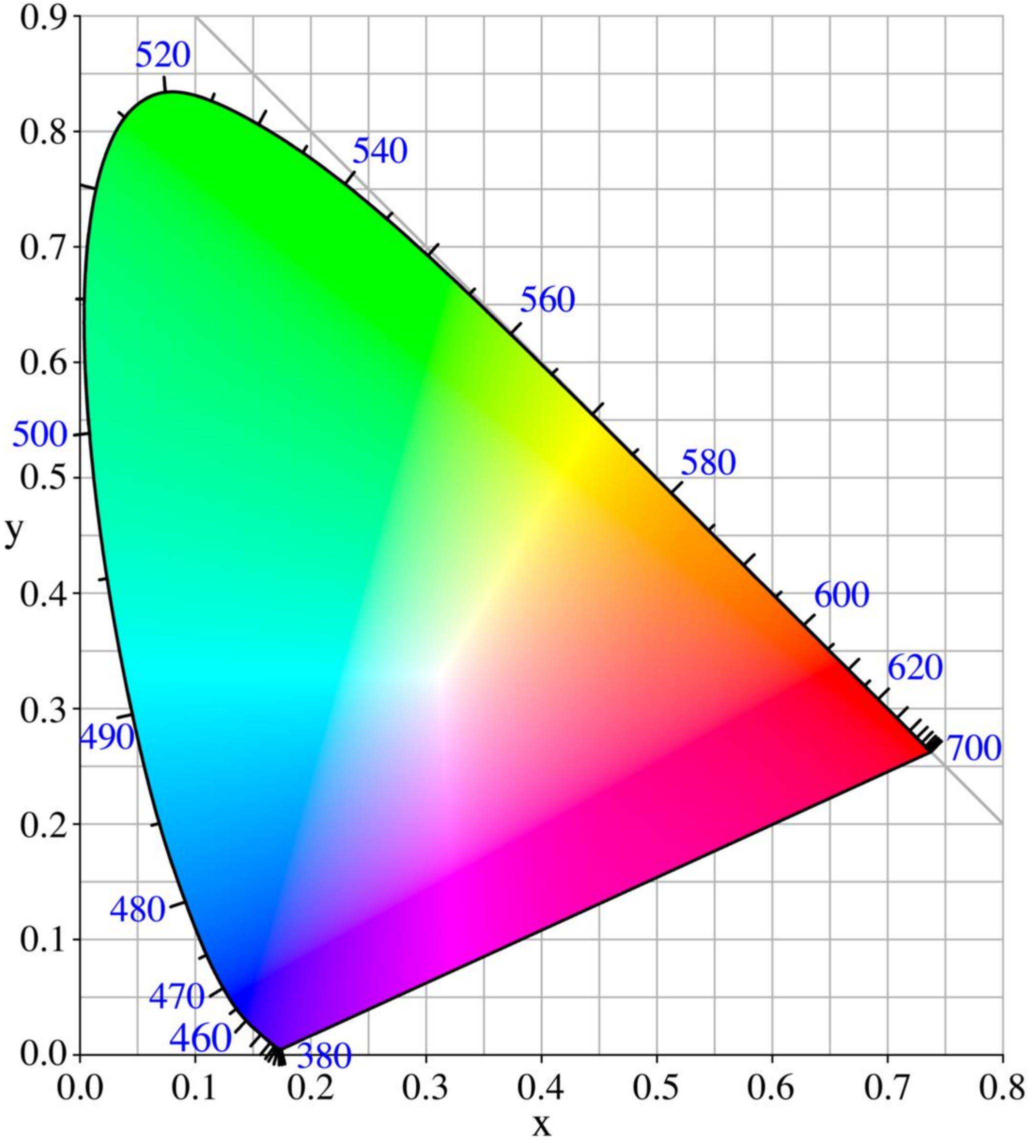


Red (λ) = 720 nm

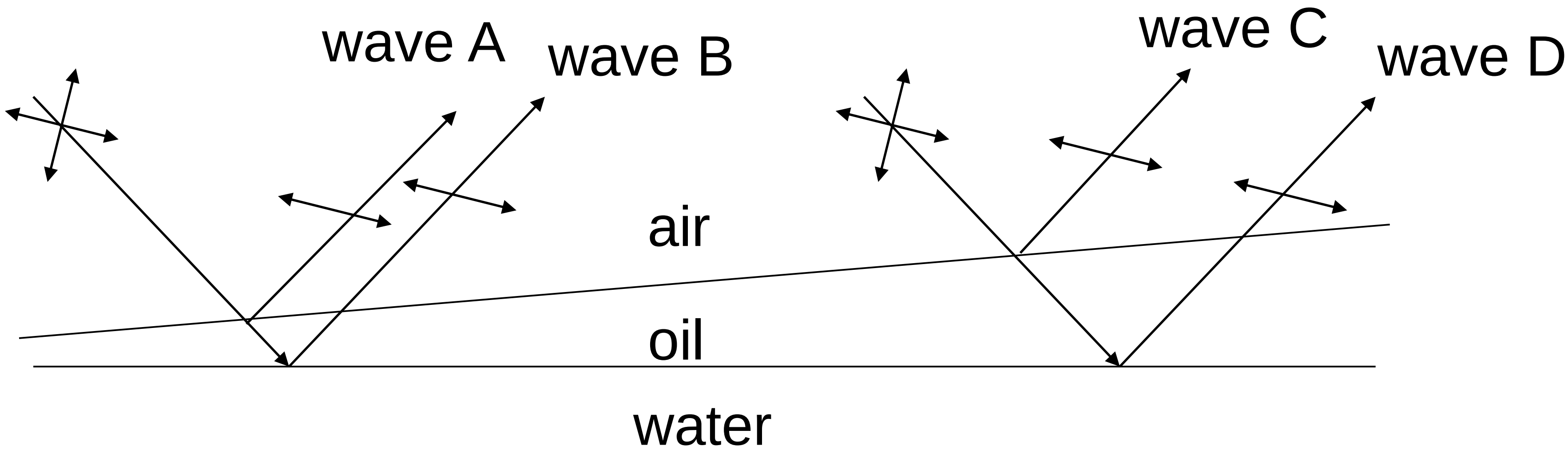
If wave B travels extra 360 nm, then red is gone, you can see ________ color.

Complementary Color

CIE *xy* Chromaticity Diagram



Color Depends on Thickness



Red (λ) = 720 nm

If wave B and D travels extra 360 nm (½λ) and 1080 nm (3/2λ), then red is gone, you can see same cyan color.

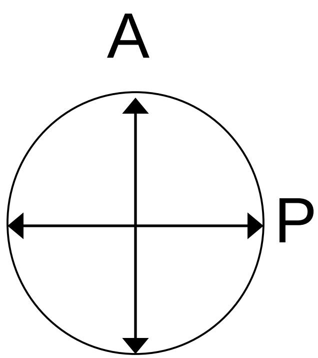
Lecture 11

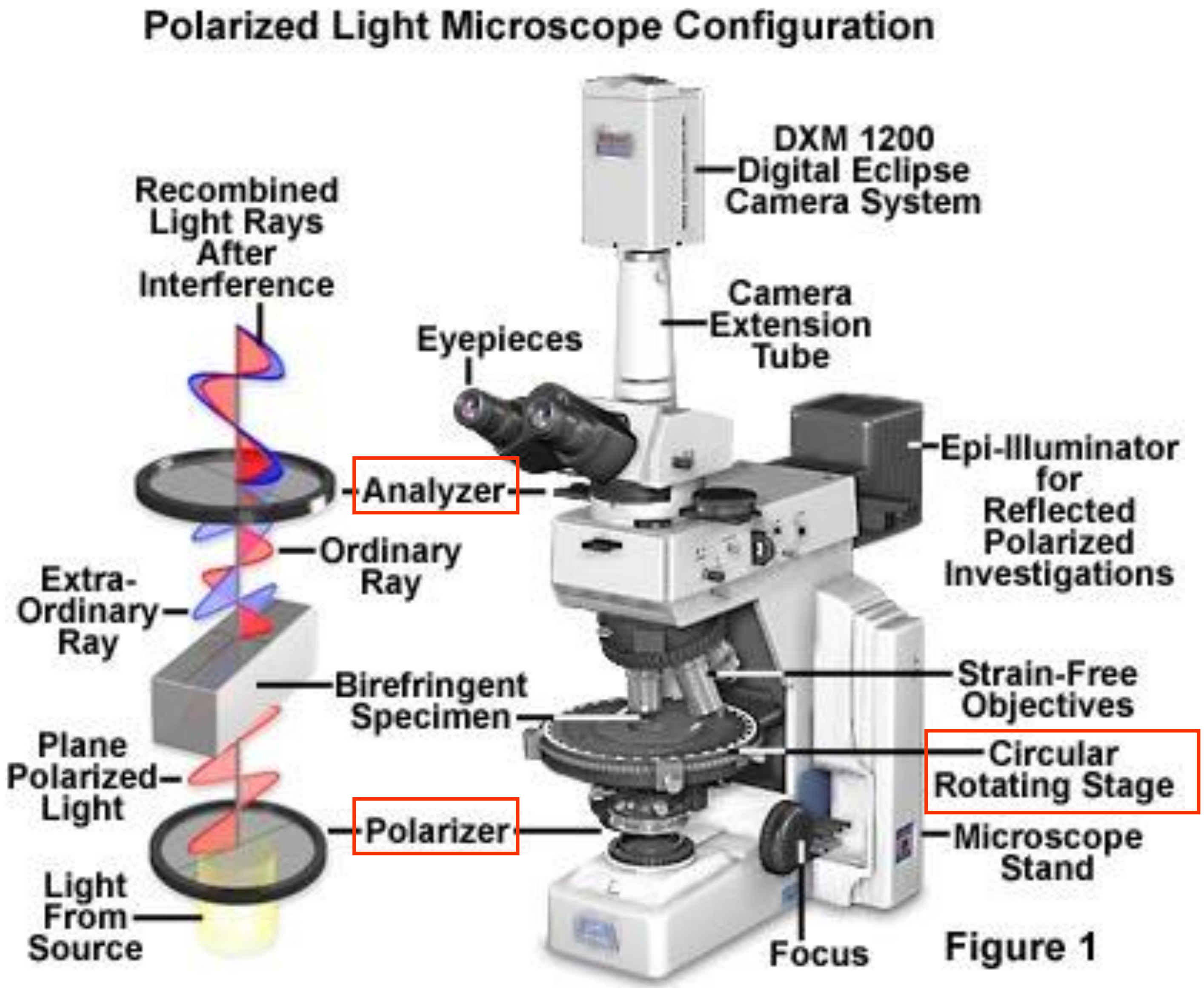
PLM and Interference

http://www.brocku.ca/earthsciences/people/gfinn/optical/222lect.htm

http://edafologia.ugr.es/optmine/indexw.htm

Polarized Light Microscope





What’s More in Polarized Light Microscope

- Specialized Stage - a 360-degree circular rotating specimen stage
- Eyepieces with a cross wire reticle (or graticule) to mark the center of the field of view.
- Strain Free Objectives - P, PO, or Pol on the barrel.
- Centerable Revolving Nosepiece
- Strain Free Condenser
- Bertrand Lens
- Compensator and Retardation Plates

Strain Free Objectives

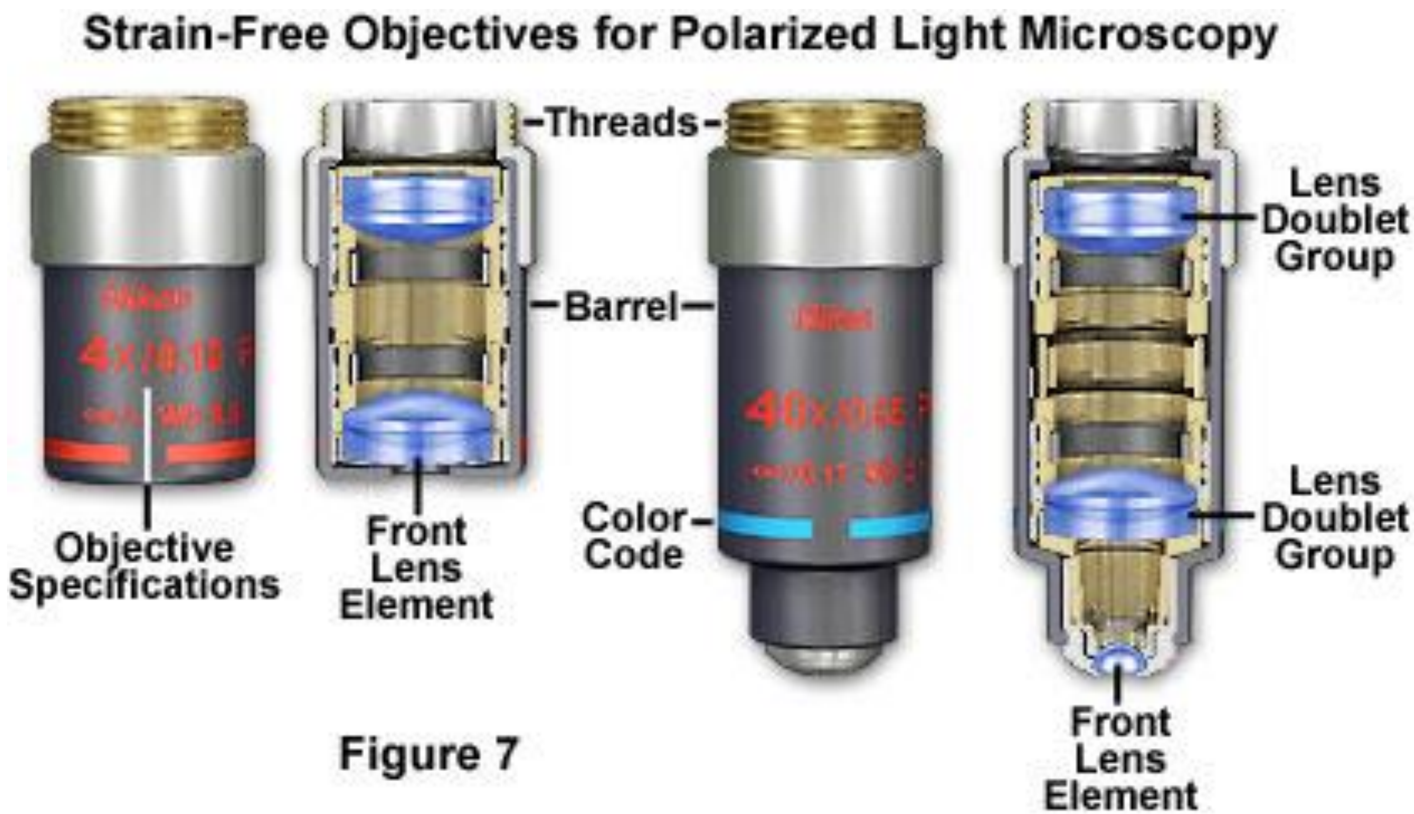
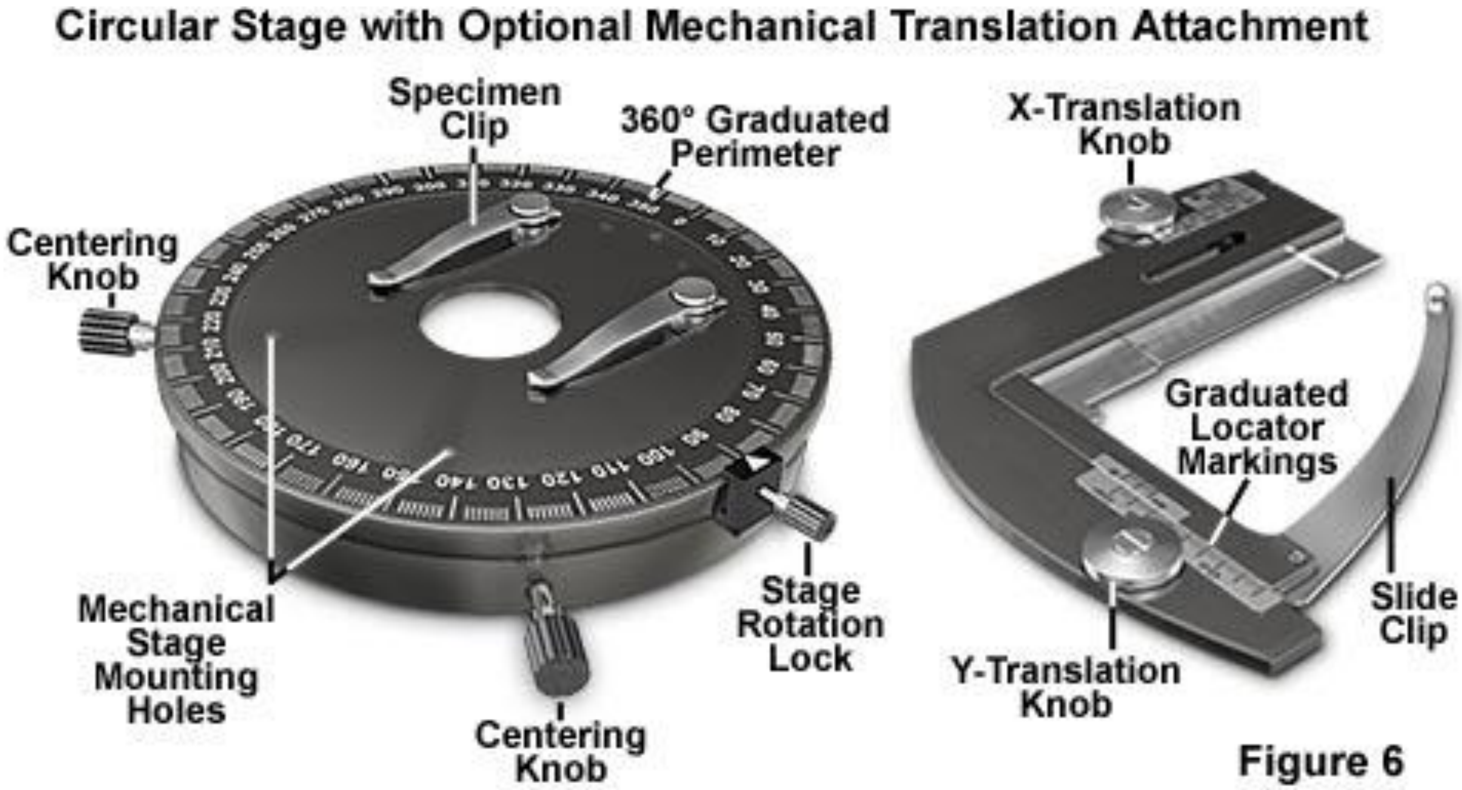


Figure 7

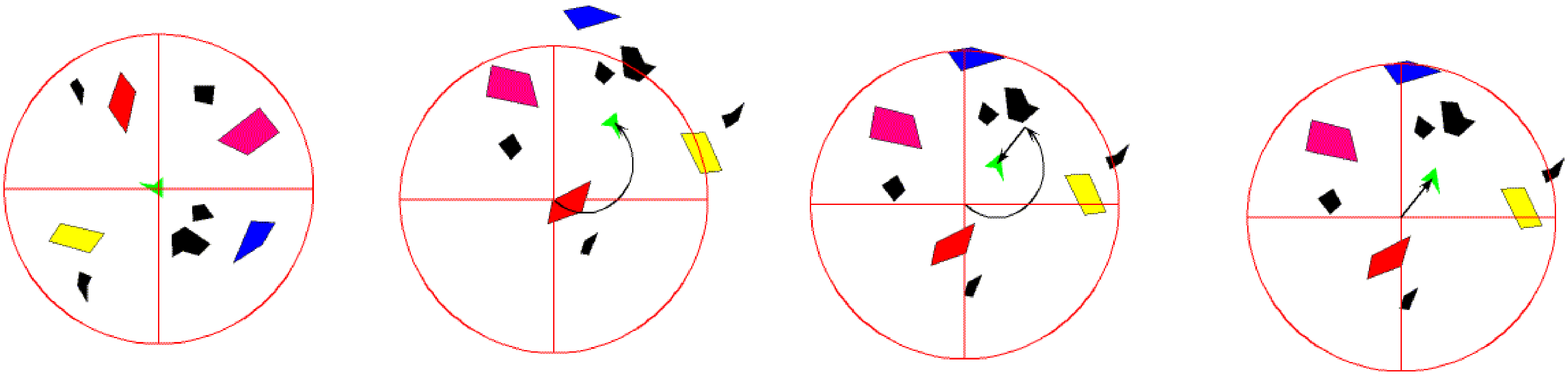
- Strain (or stress): a source of distorted of images
- Use homogenous (isotropic) glasses, crystals and other materials used to make the lenses
- Avoid multiple lenses which are cemented together and mounted in close proximity with tightly fitting frames.

Circular Stage



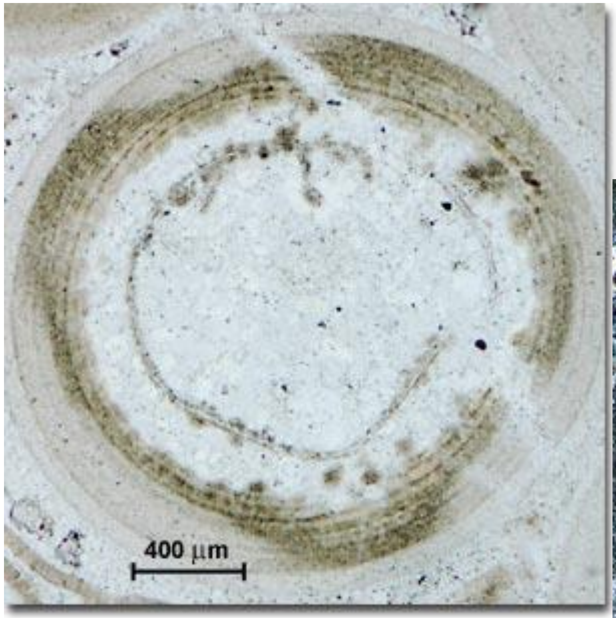
Centering Circular Stage

Can be centered via either circular stage or objectives
Depends on manufacturer of microscopes

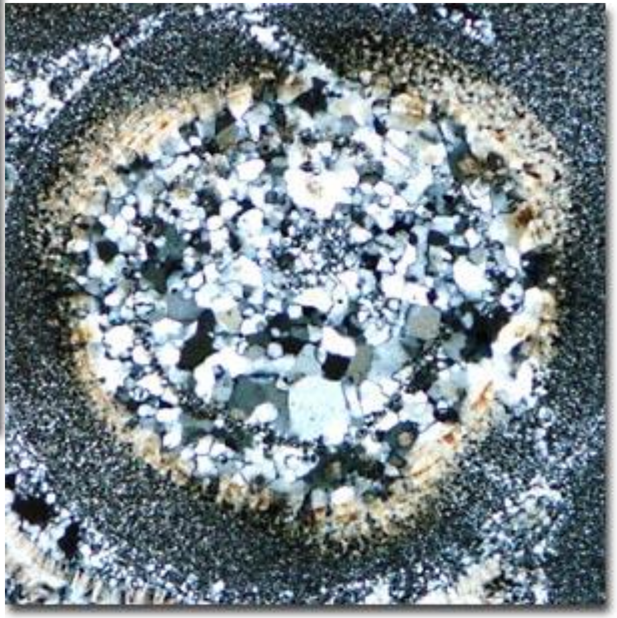


1. Put a recognizable speck of something exactly under the crosshair intersection.
2. Rotate the stage until the speck is as far from the intersection as possible.
3. Turn the stage (or objective) centering screws to move the speck half way back to the crosshair intersection
4. Move the thin section to bring the speck back to the crosshair intersection.

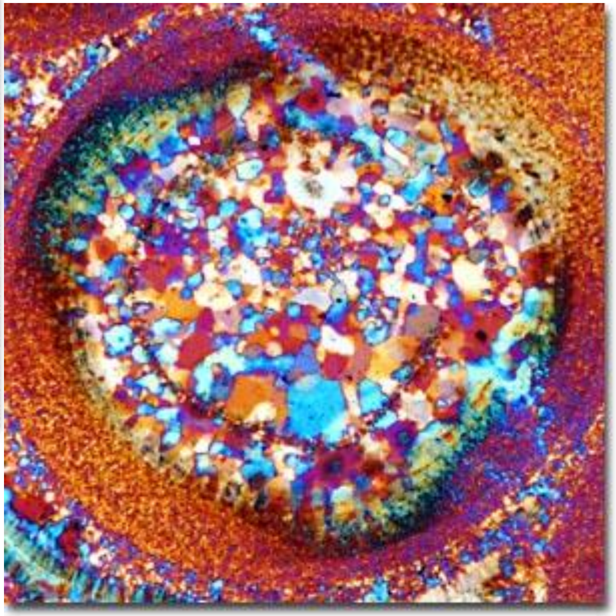
Microscopic Images with Different Polarizer Setup



plane-polarized light

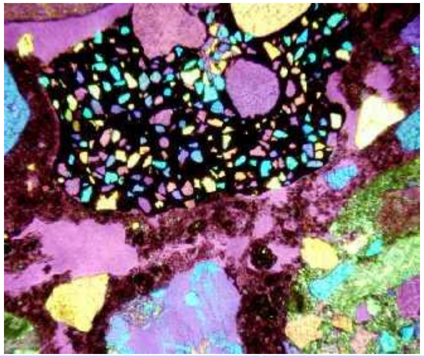


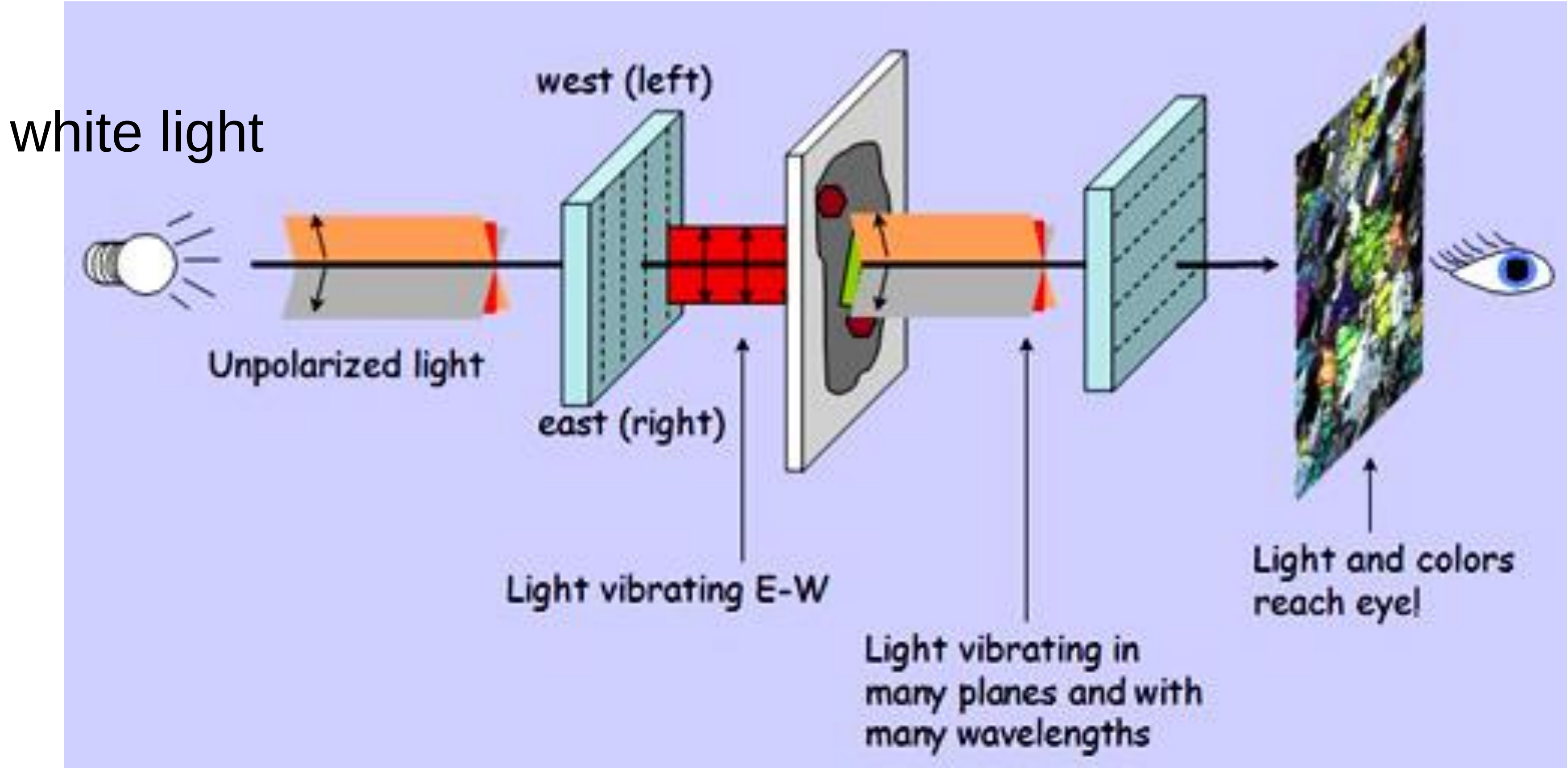
crossed polarizers



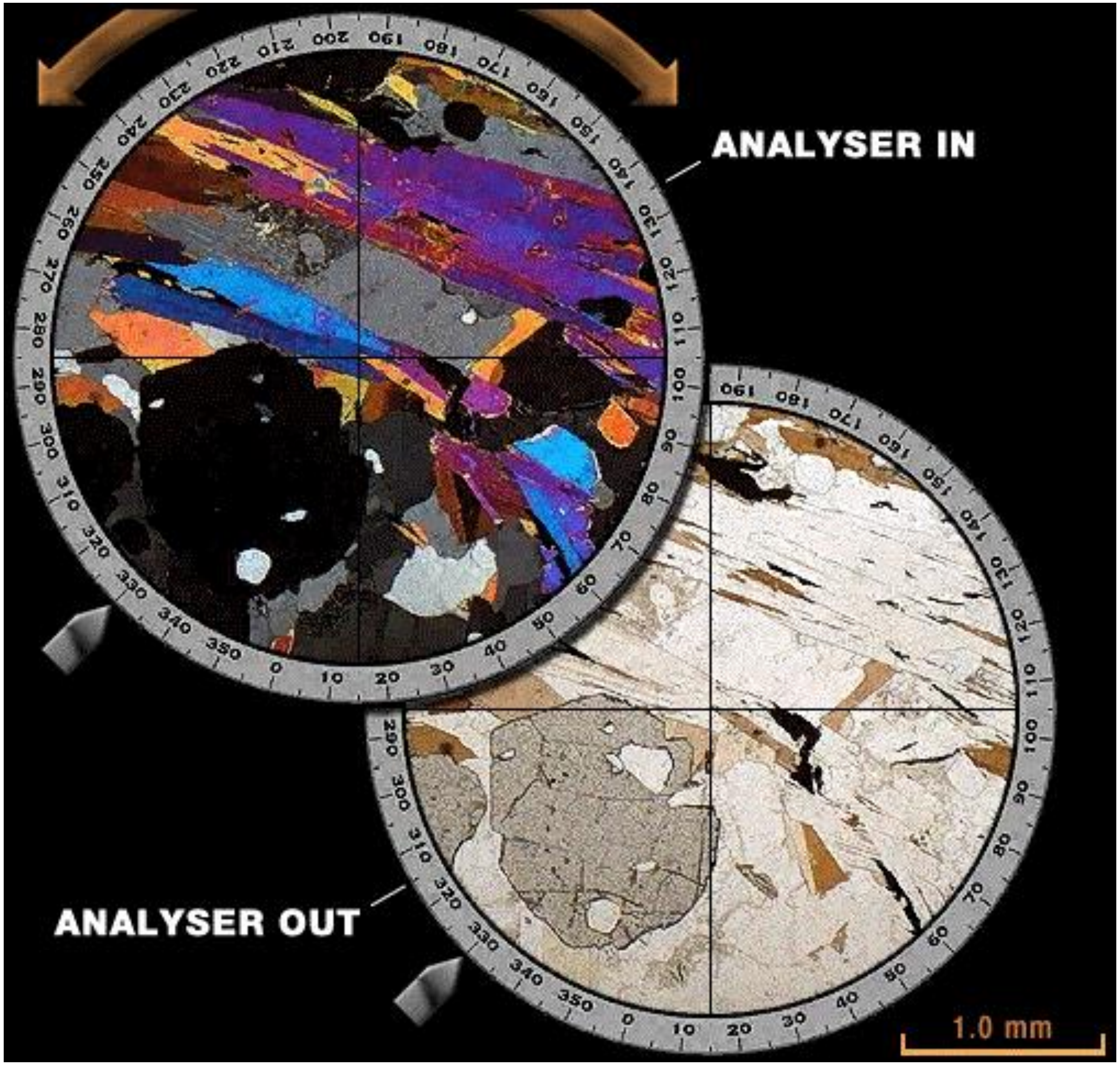
crossed polarizers and a full-wave retardation plate

How Polarized Light Microscope Works

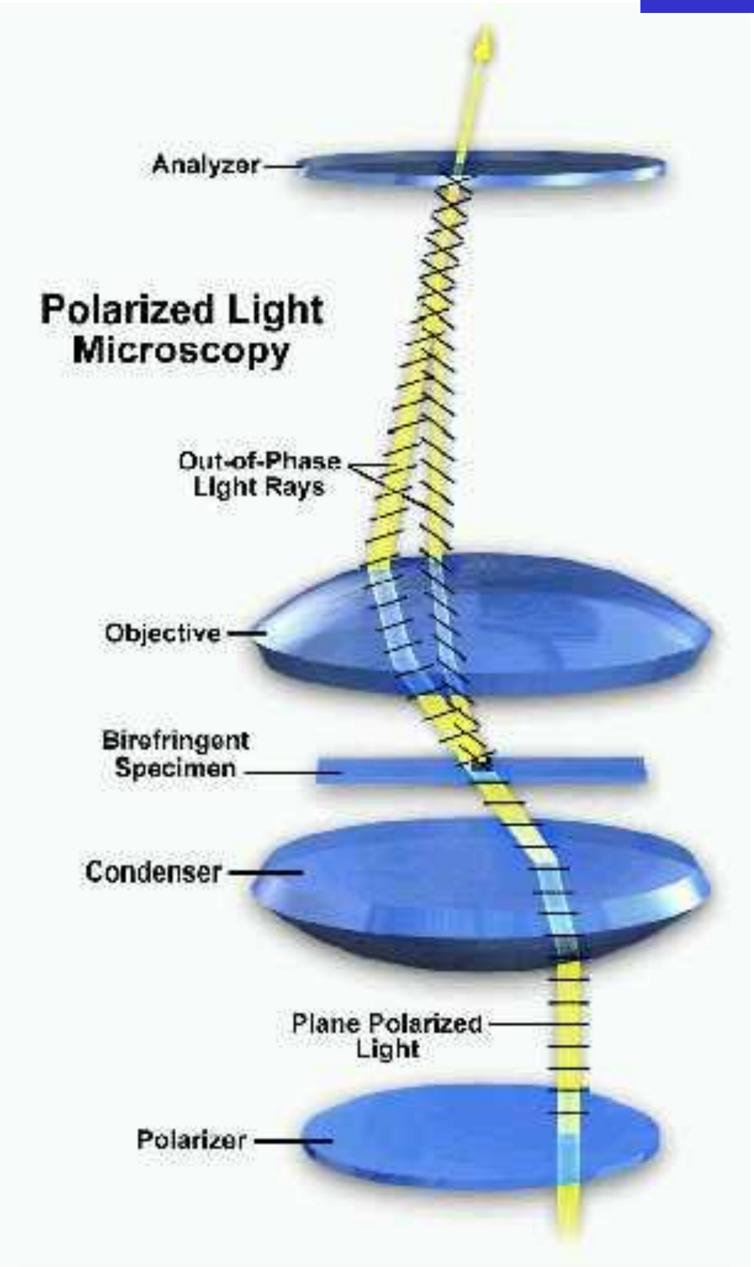




Views With and Without Analyzer

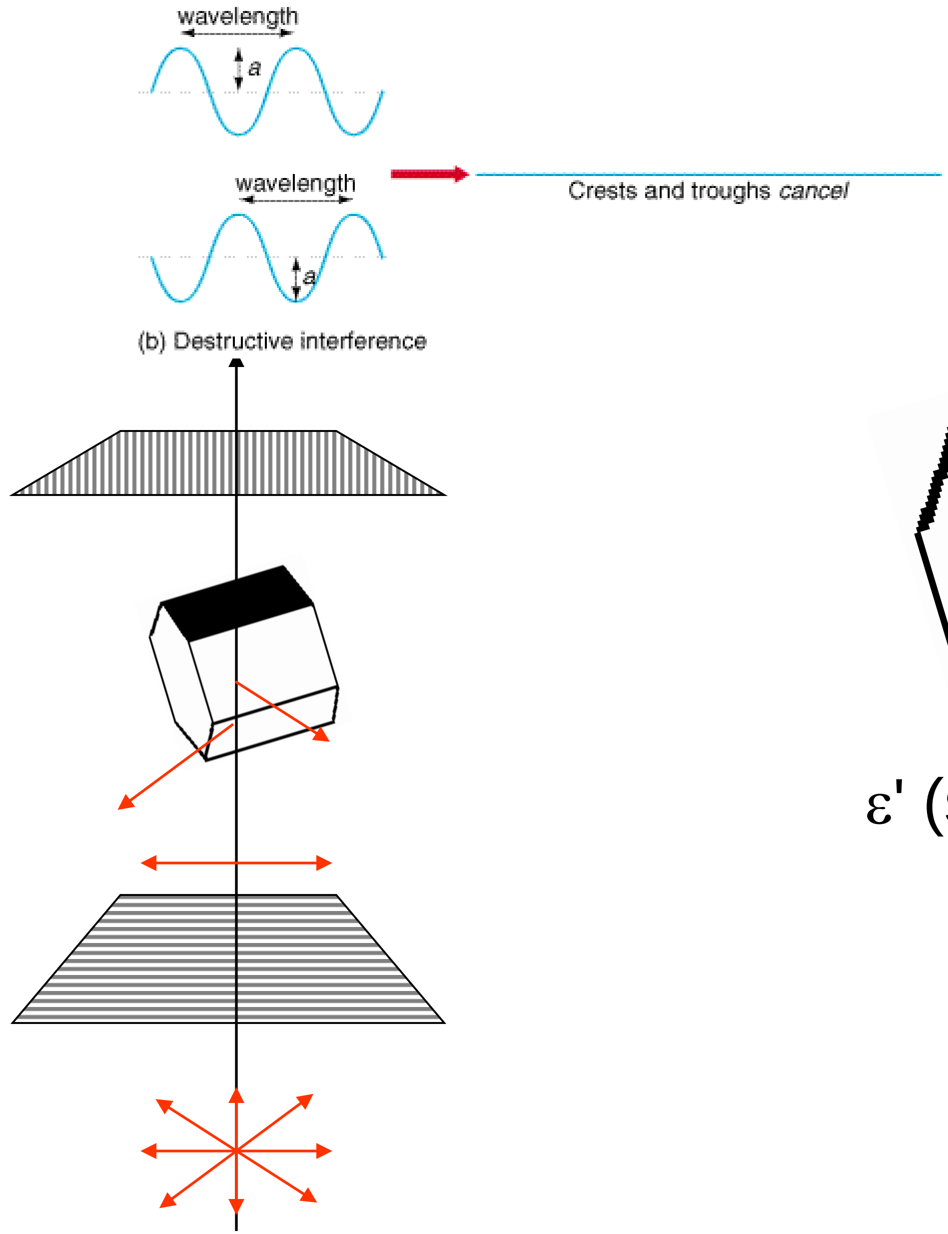


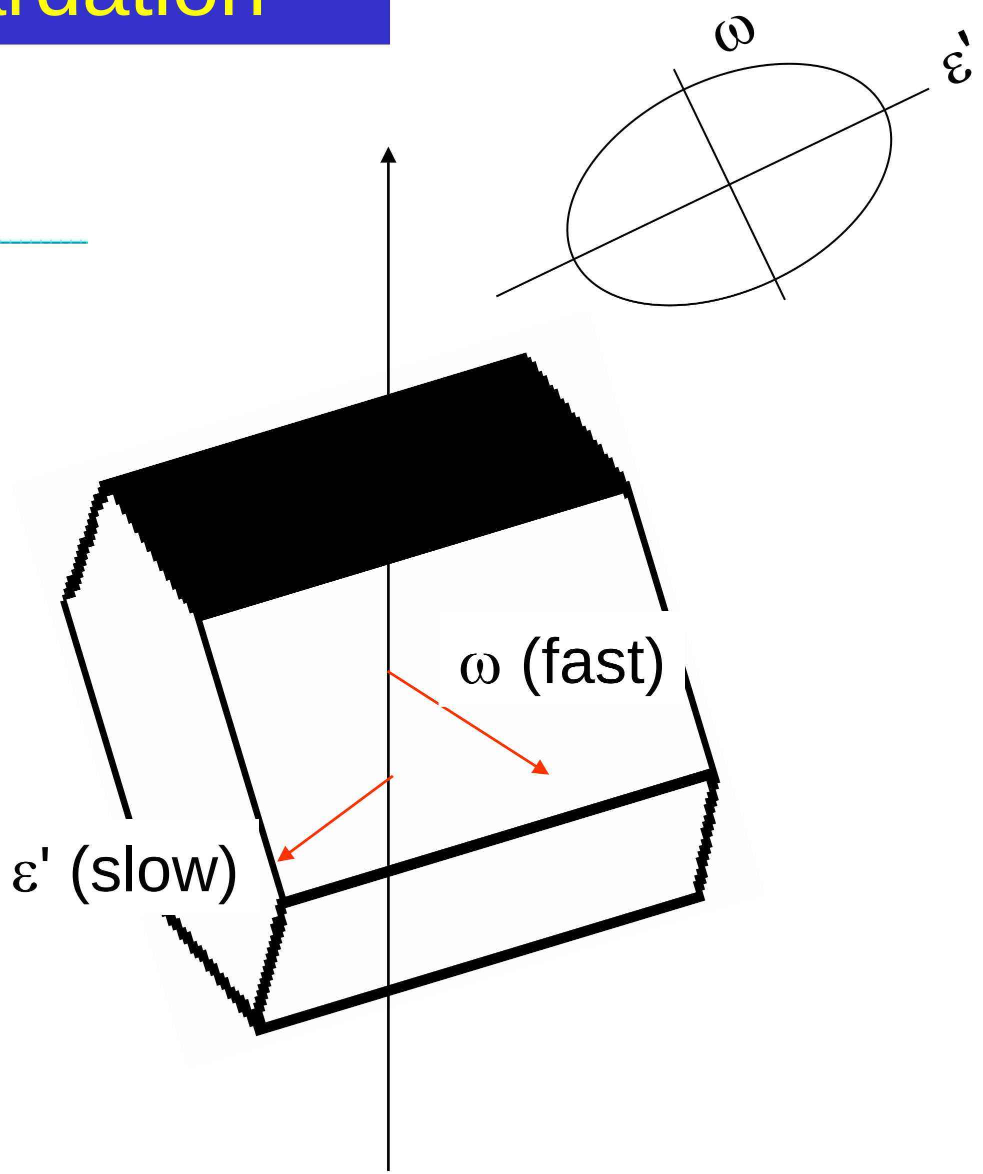
Origin of Colors



- Polarizer
- Polarized light > minerals (uniaxial or biaxial)
- Splits two components with different speeds
- Retardation (R)
- Analyzer > combine
- Destructive interference
- You can see complementary color

Retardation





Uniaxial crystal

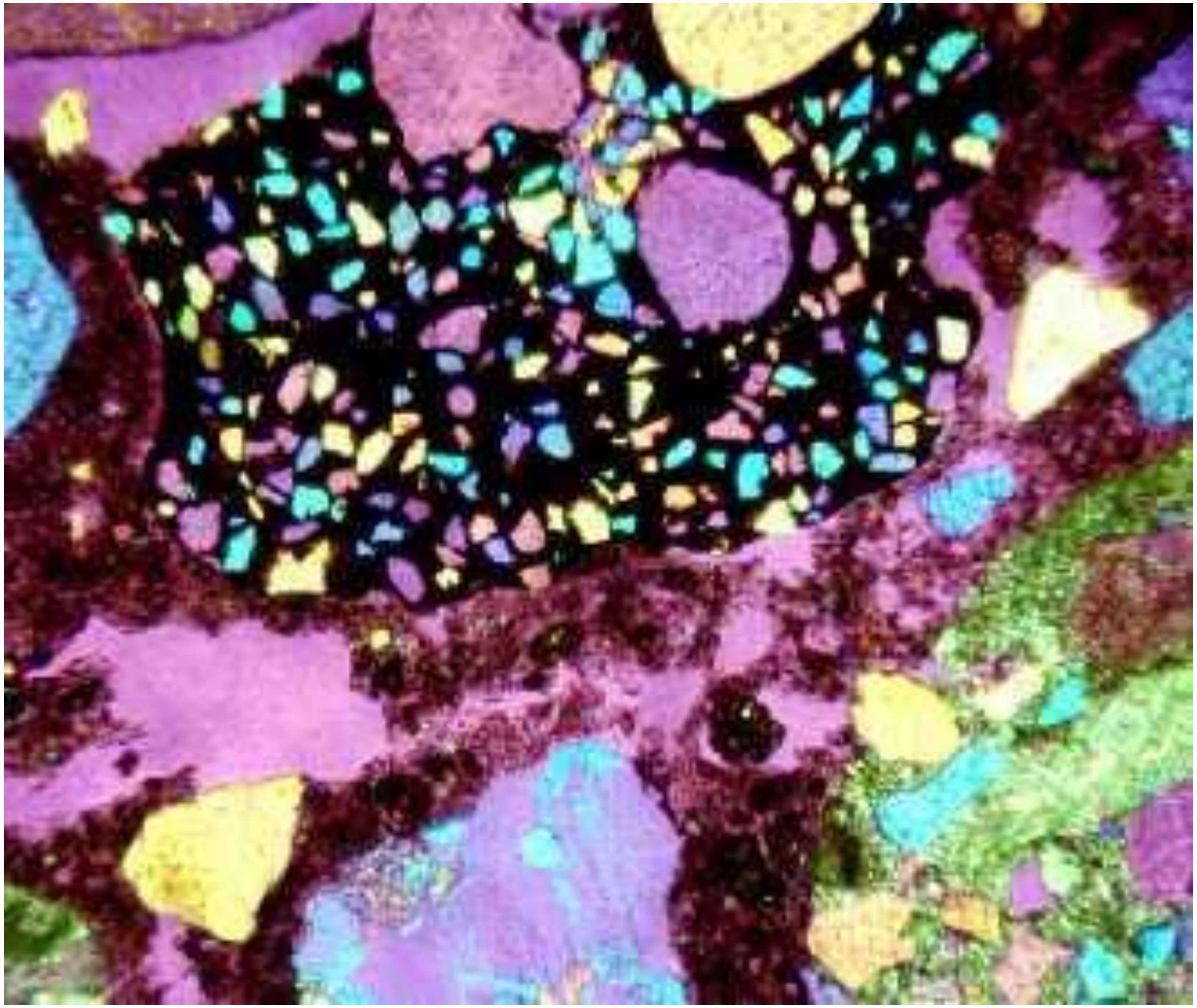
Retardation (R)

- Thickness of crystal (T)
- Δn (n_1-n_2)
- Birefringence (B): $\Delta n = n_1 - n_2$
- B: Highest – lowest refractive index in a material
- Retardation $\propto T \cdot \Delta n$

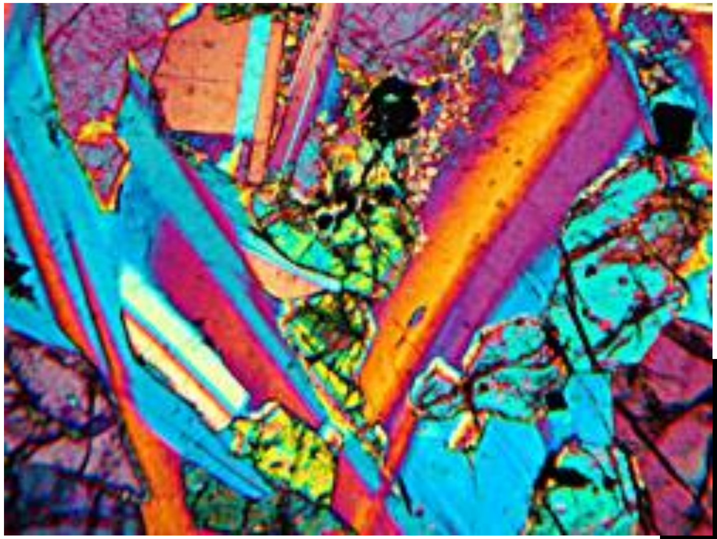
$B = R(nm)/[T(\mu m) \cdot 1000]$

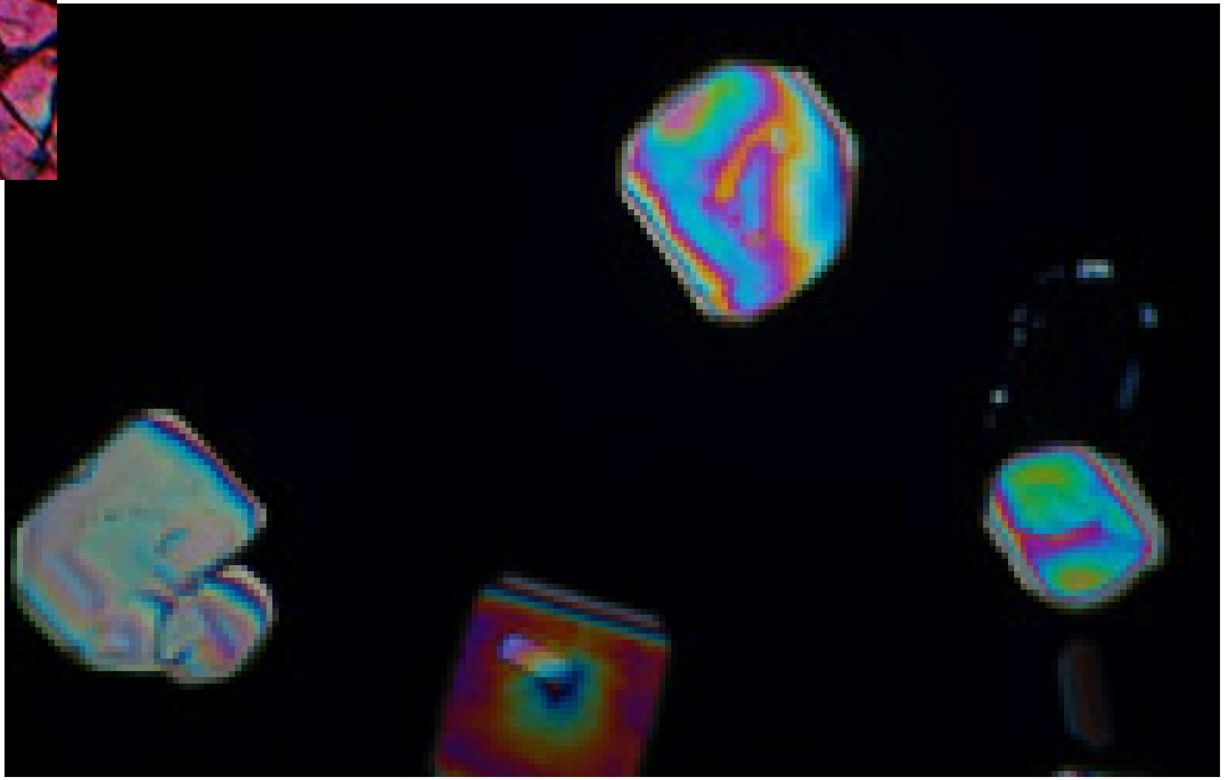
Substance	B
Isotropic (n)	0
Uniaxial (2n)	$\lvert \varepsilon - \omega \rvert$
Biaxial (3n)	$\gamma - \alpha$
Fibers	$\lvert n_{\parallel} - n_{\perp} \rvert$

Rock Thin Section: Retardation Depends on Birefringence



Why Repeating Colors



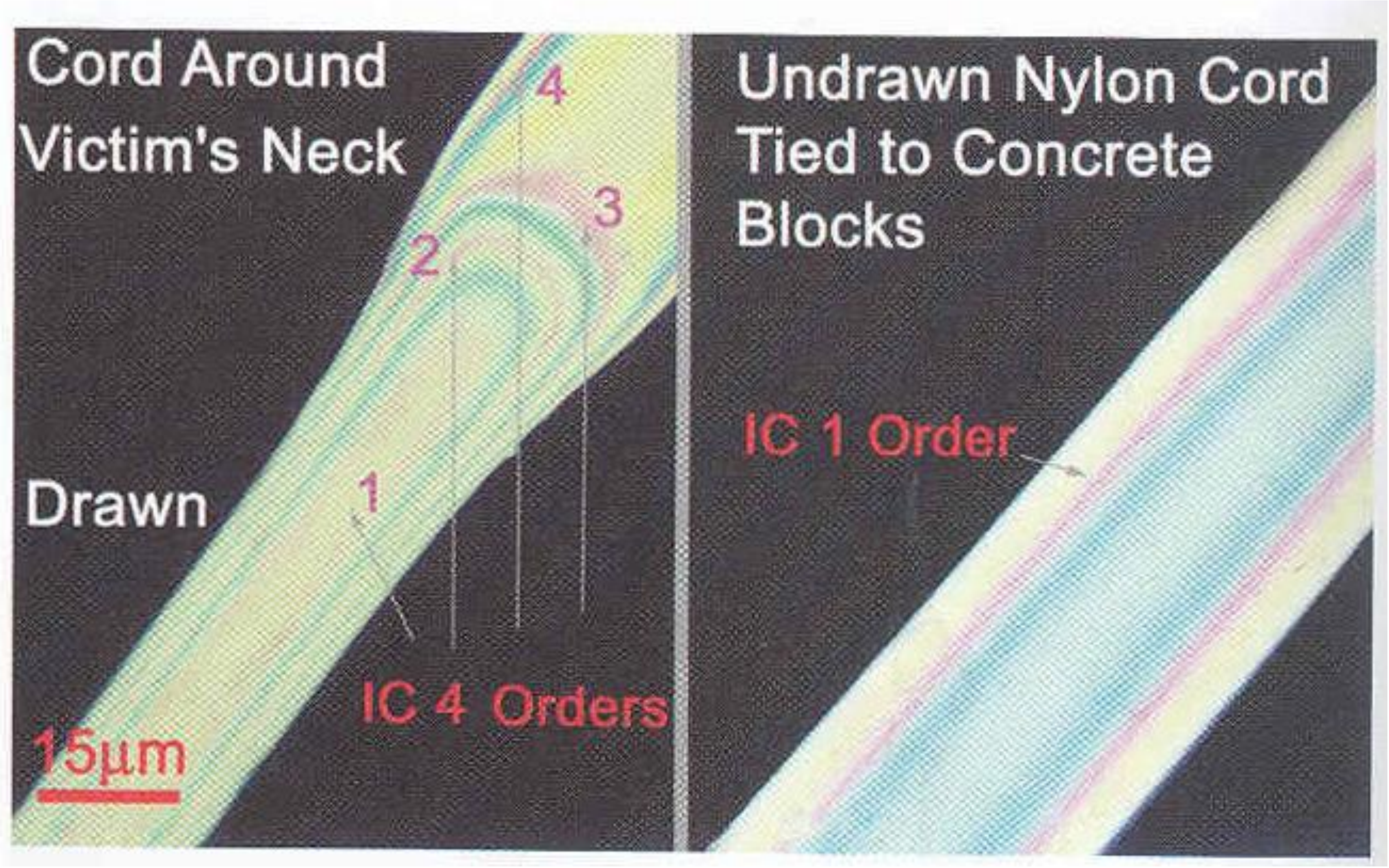


Orders of Colors

- Most consistently repeating color is red ~560 nm
- 0 – 550 nm: 1st
- 550 – 1100 nm: 2nd
- 1100 – 1650 nm: 3rd

Retardation	Color
0 nm (isotropic)	Black (~gray)
1st – 3rd	Vibrant colors of variety of colors
4th – 8th	Pale repeating (pink & green)
Above 8th	White (washed out)

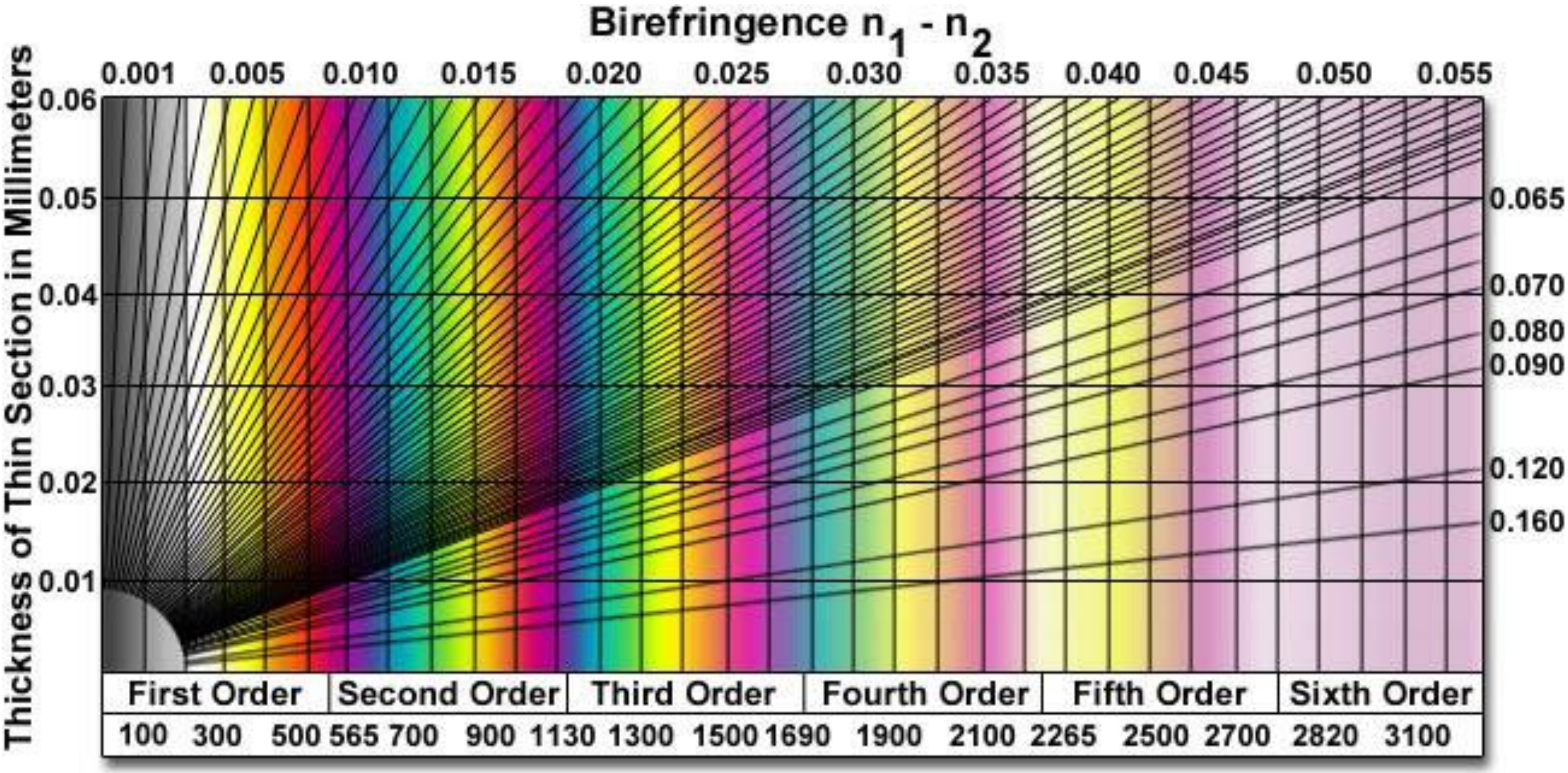
Orders of Colors: Fibers



Birefringence (B)

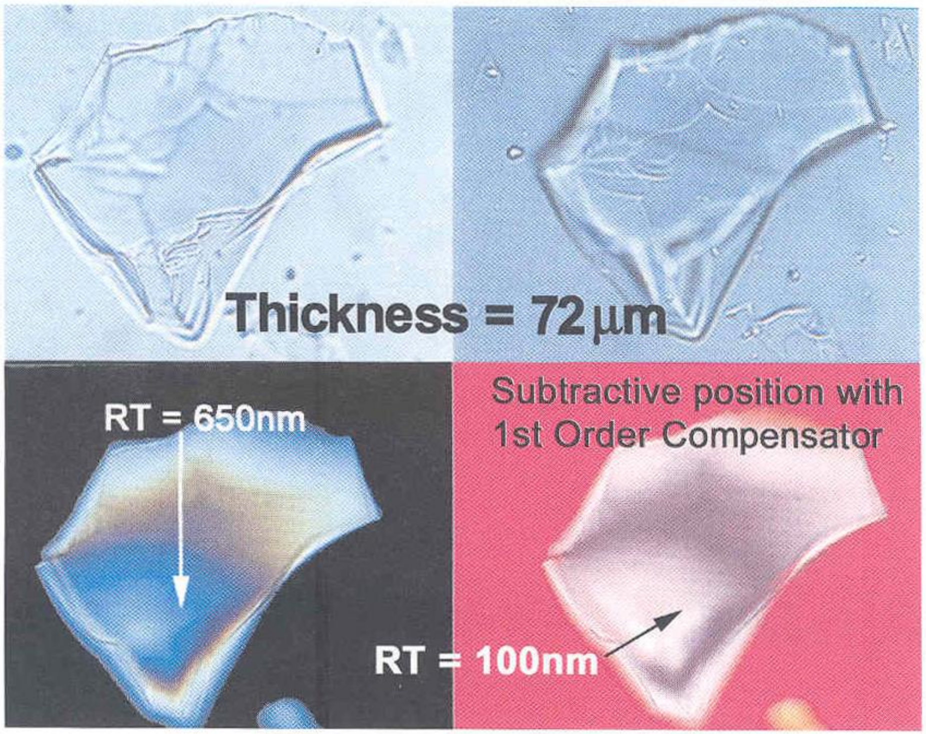
Qualitative Term	B
Isotropic	0
Low	$B < 0.01$
Moderate	$0.01 < B < 0.05$
High	$0.05 < B$

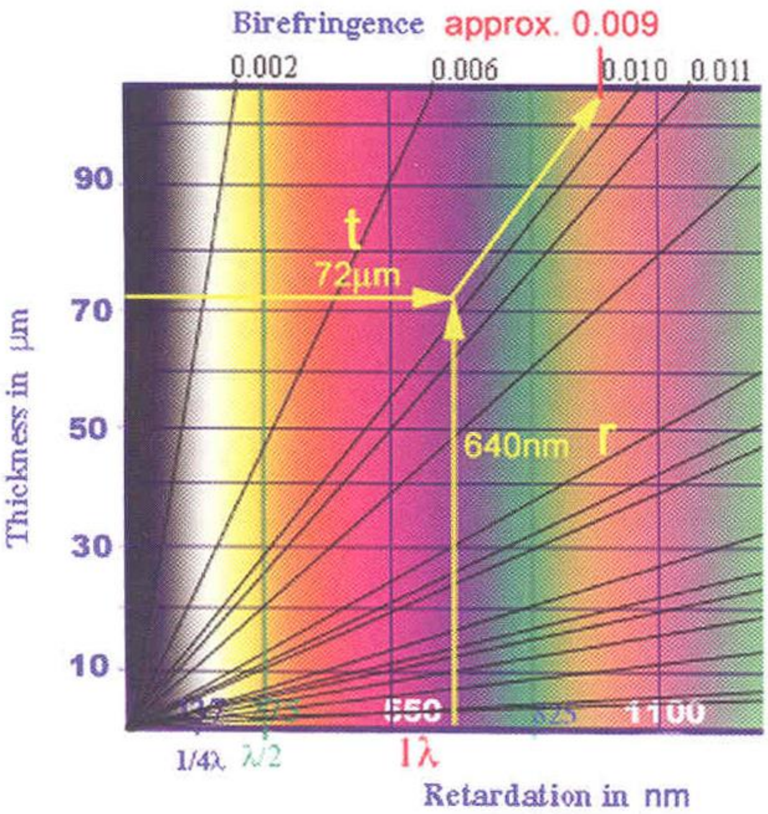
Michel Lévy Color Chart



Measure thickness > color > birefringence

How to Calculate Birefringence

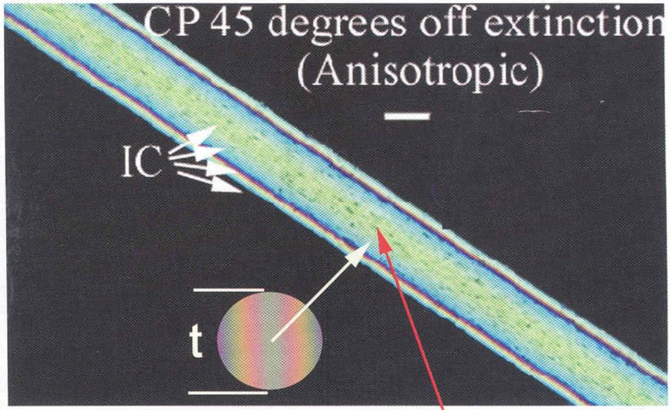


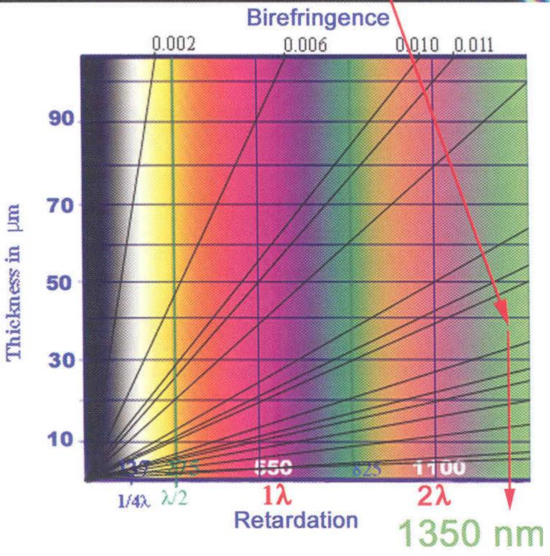


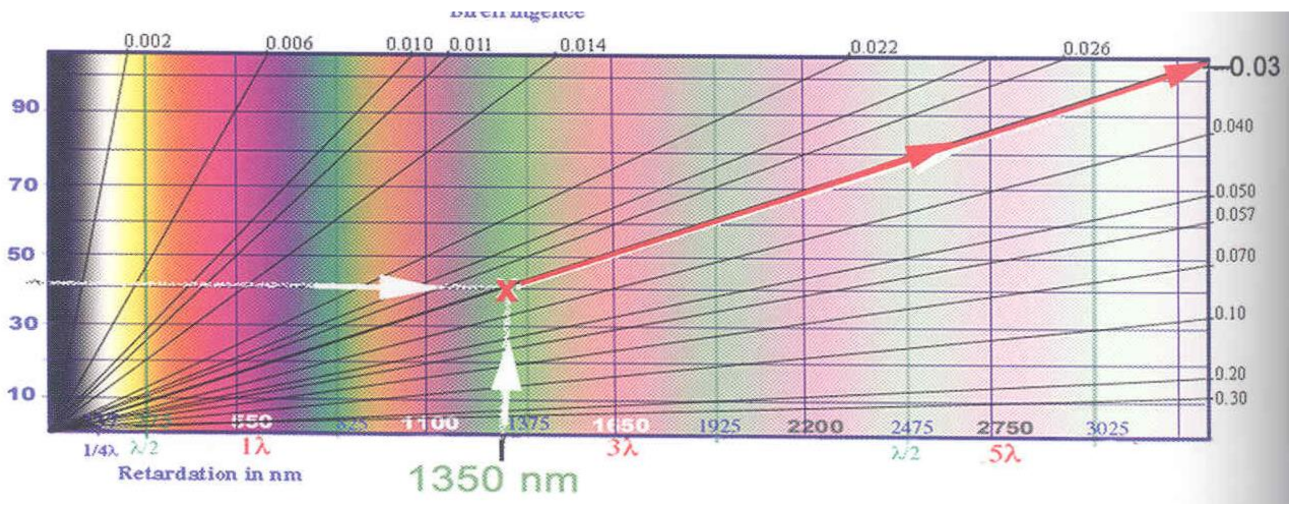
$B = R(nm)/[T(\mu m)\cdot 1000]$
$=(640\ nm/[72\ \mu m\cdot 1000]$
$=0.009$

From ML Chart

How to Calculate Birefringence

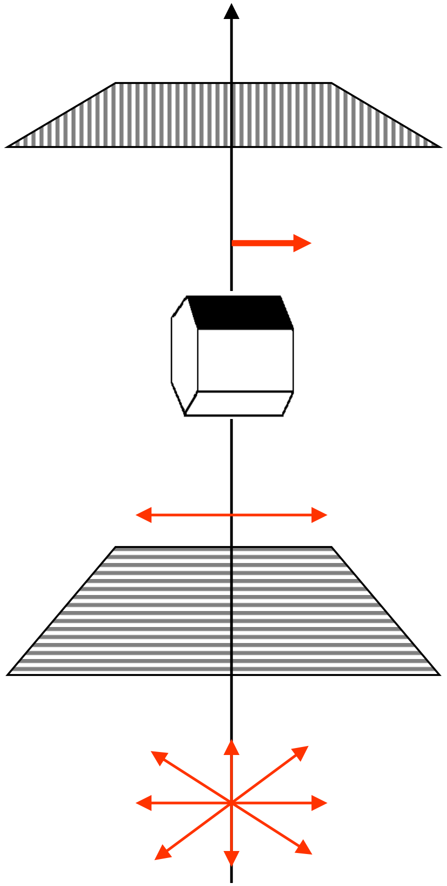


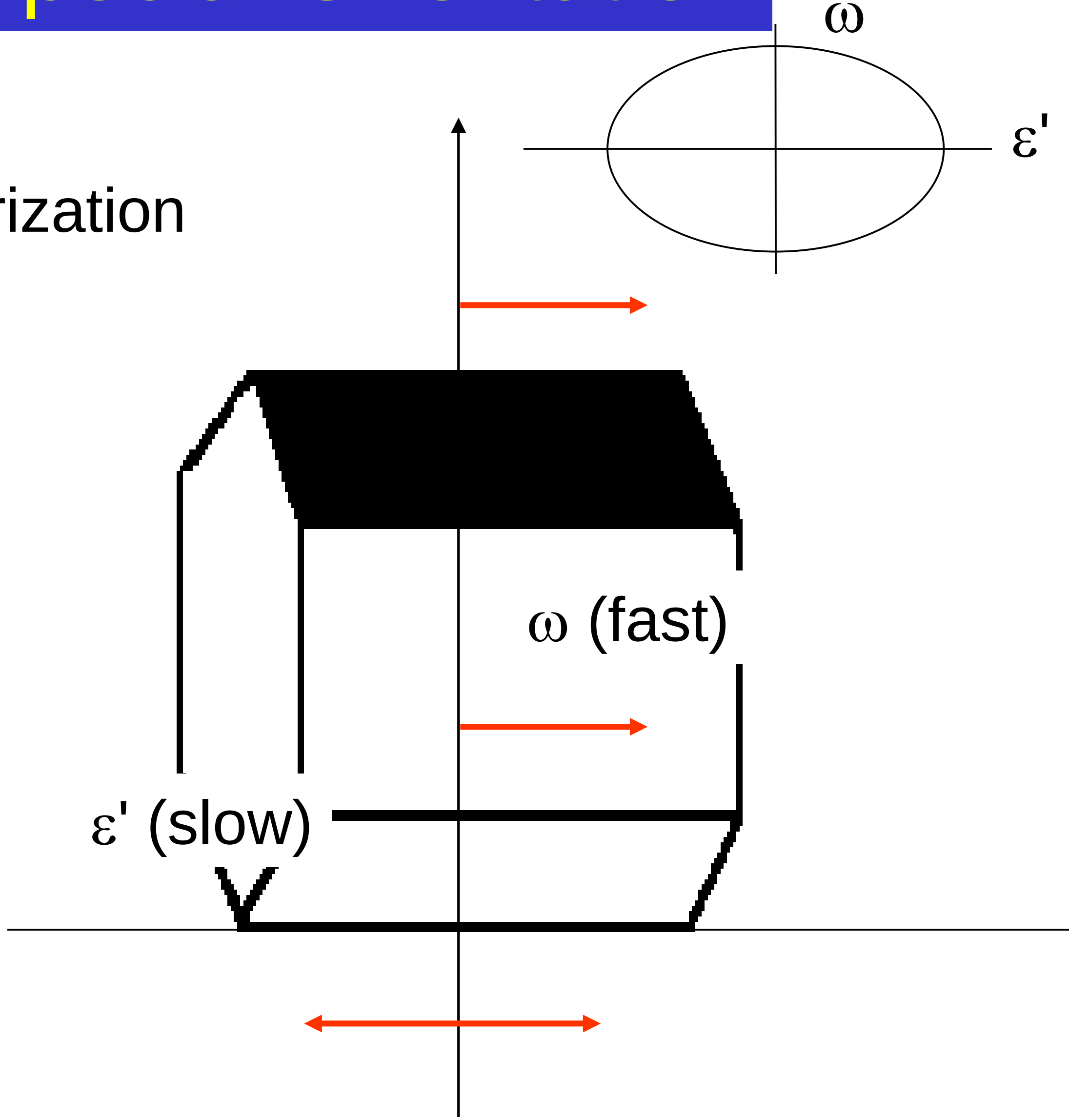




Extinction: Special Orientation

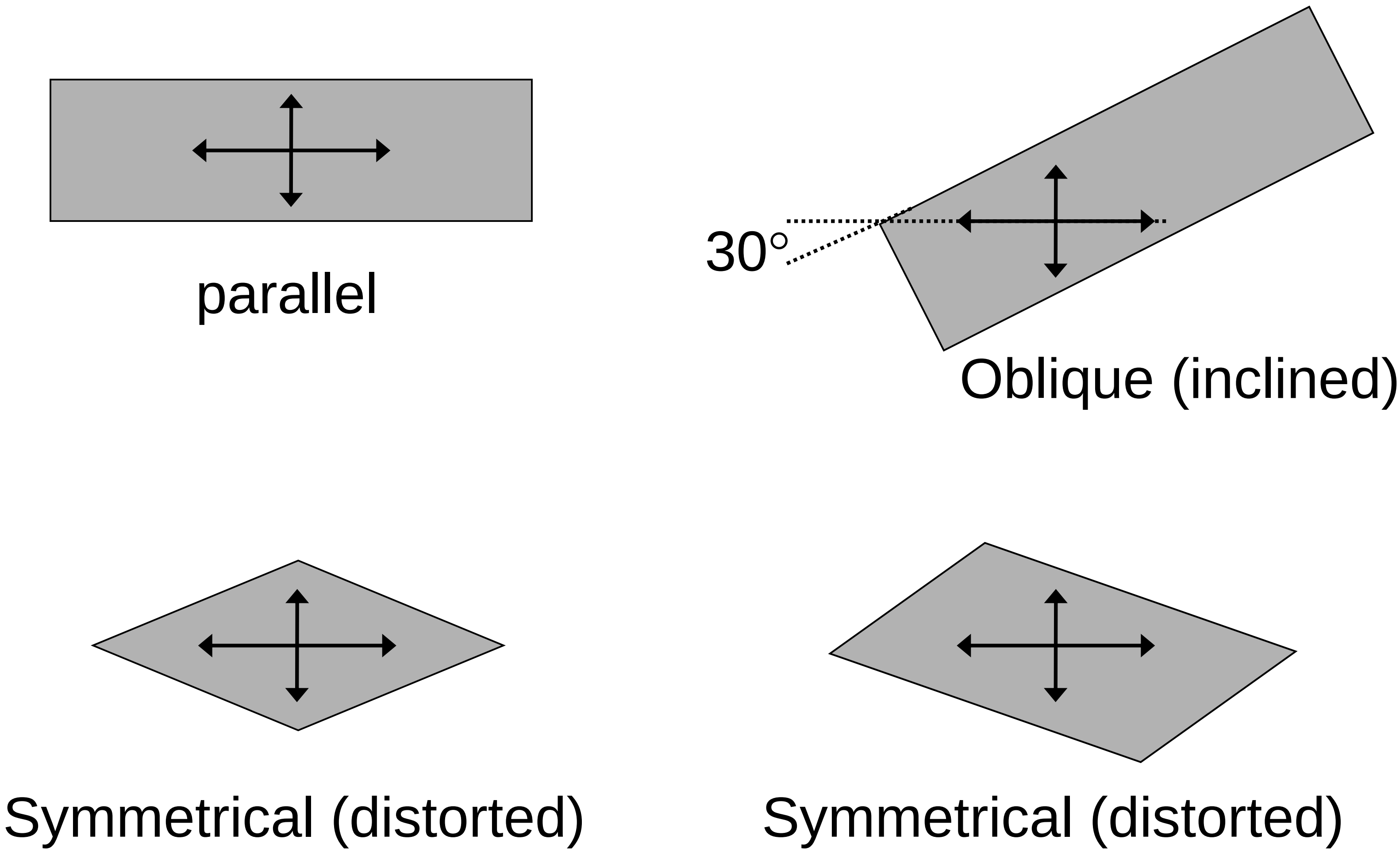
Optical axis is parallel (or perpendicular) to the polarization



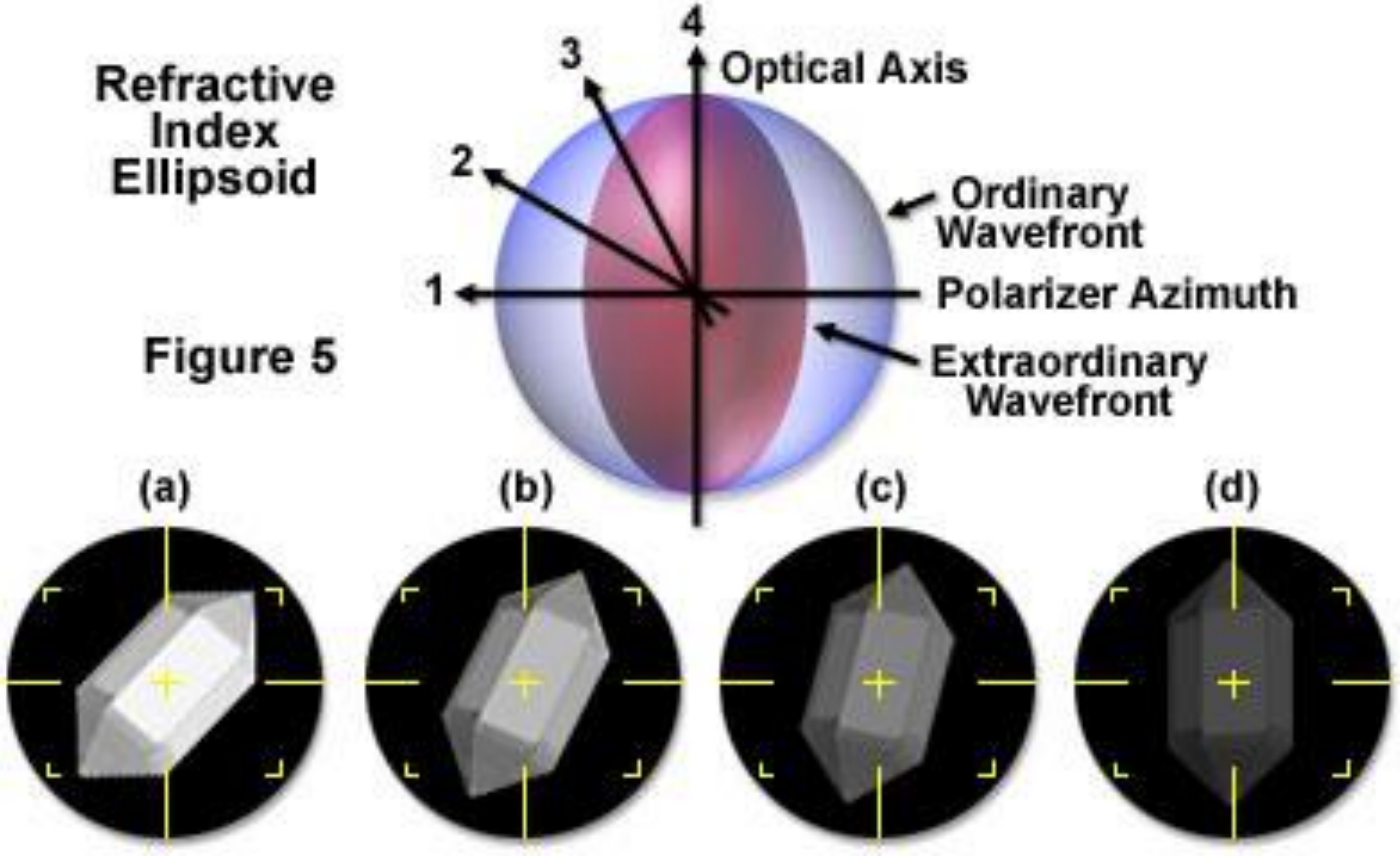


Uniaxial crystal

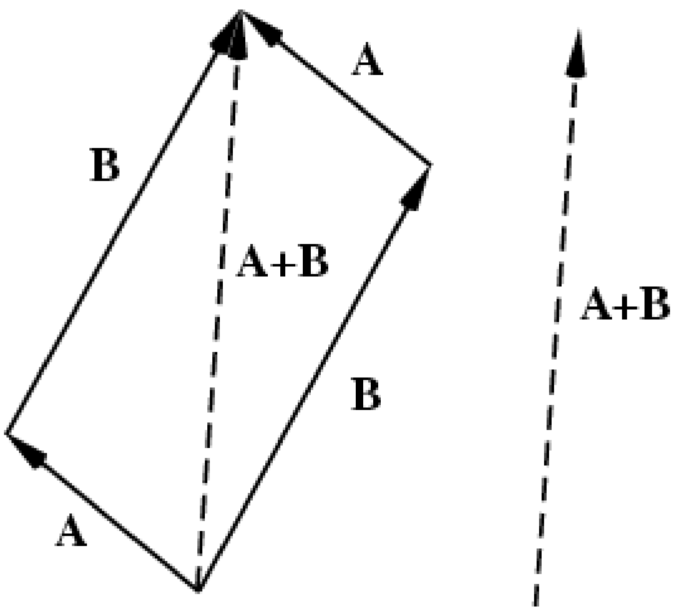
Types of Extinction

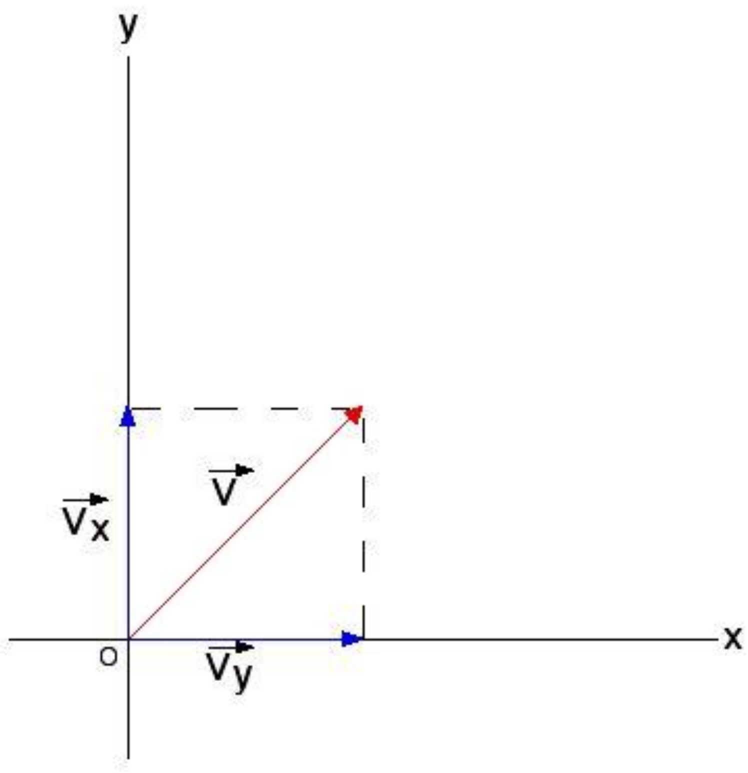


Symmetrical Extinction



Basic Vector Operation





$$\vec{A} + \vec{B} = \vec{C}$$

$\vec{V}$ has two components, $\vec{V}_x$ and $\vec{V}_y$

Symmetrical Extinction: Vector Analysis

What you can see is the magnitude of R
(Analyzer Component)

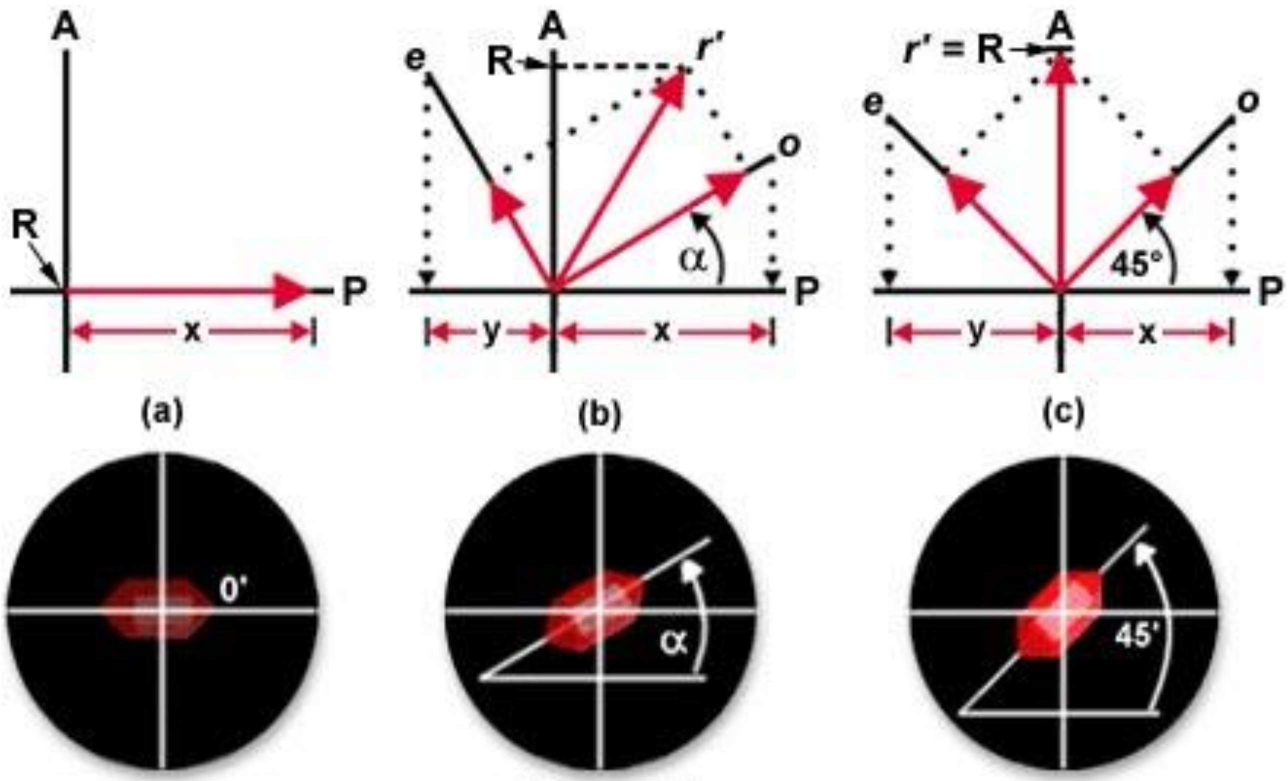
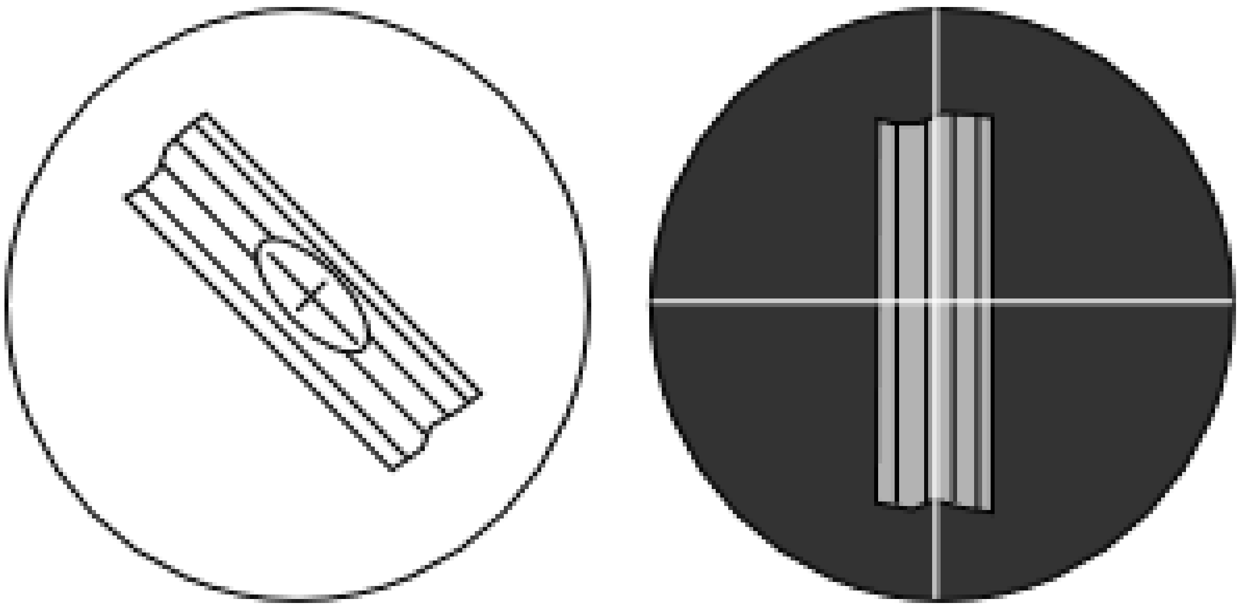


Figure 4

$R_a = 0$ $R_b < R_c$

Parallel Extinction: Fibers and Hairs

Cant' see hairs (or fibers) if they are aligned parallel (or perpendicular) to polarization



Parallel Extinction

Exercise

- Decide isotropic and anisotropic of five of your samples
- Check the extinction
- Measure the size of any of anisotropic mineral sample
- Calculate birefringence of your anisotropic mineral sample