Measurements of Retardation in Polarized Light

NYMS Workshop
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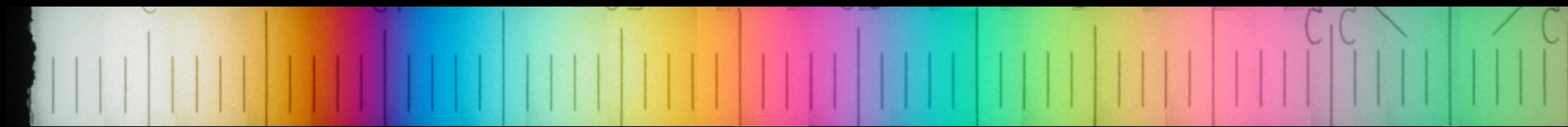
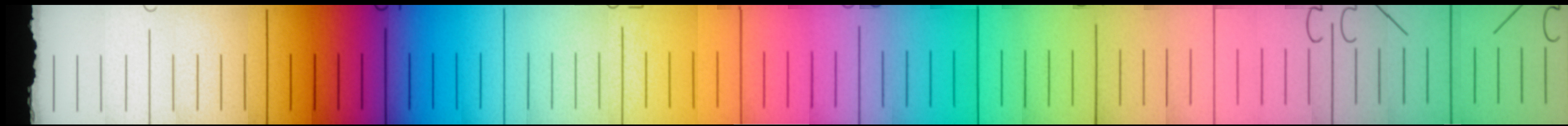
McCann Imaging

Interference Colors, a Key to Determining Retardation



The sequence of colors produced in the quartz wedge are the indication of the retardation introduced by the birefringence of the quartz crystal

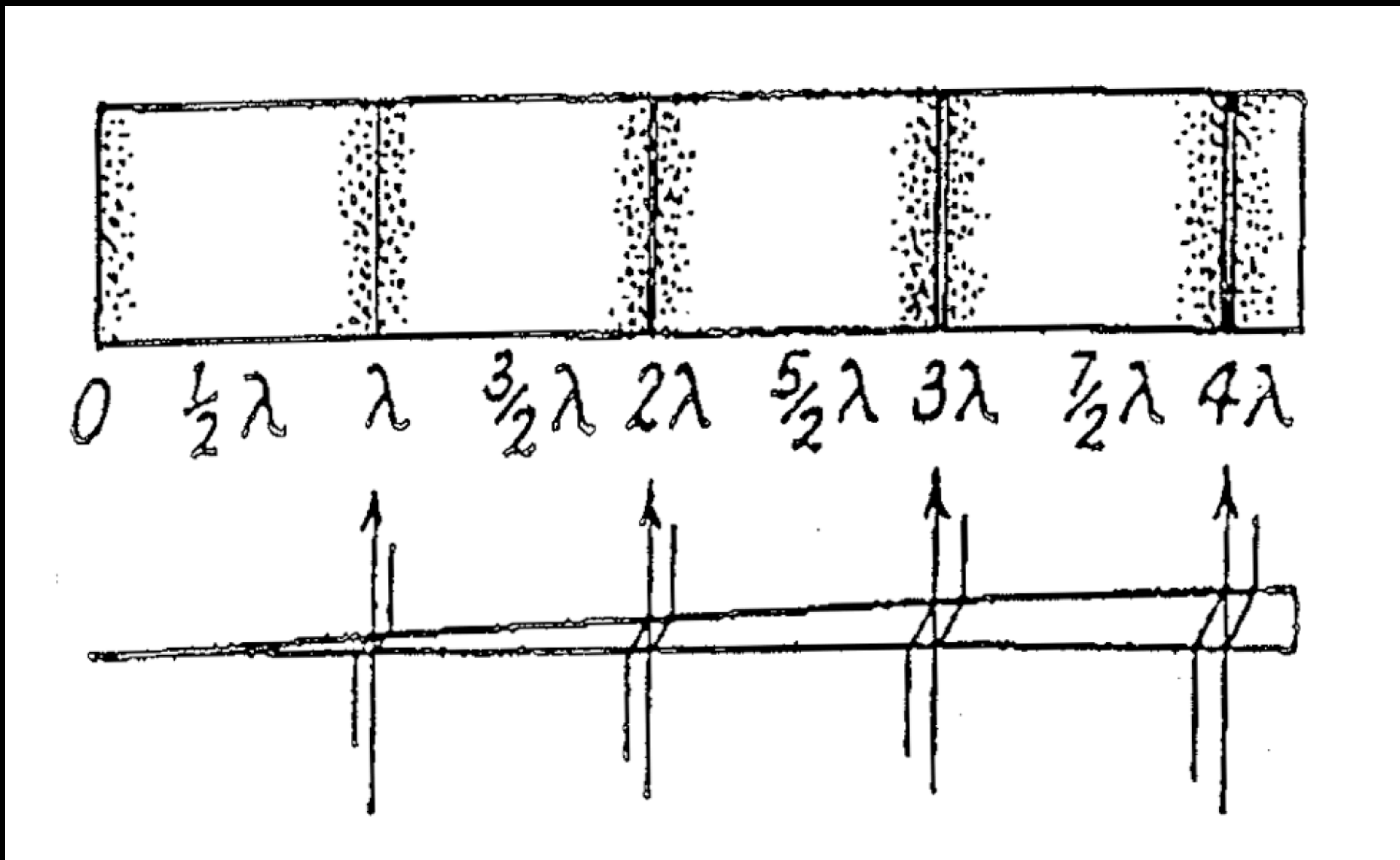
The Quartz Wedge



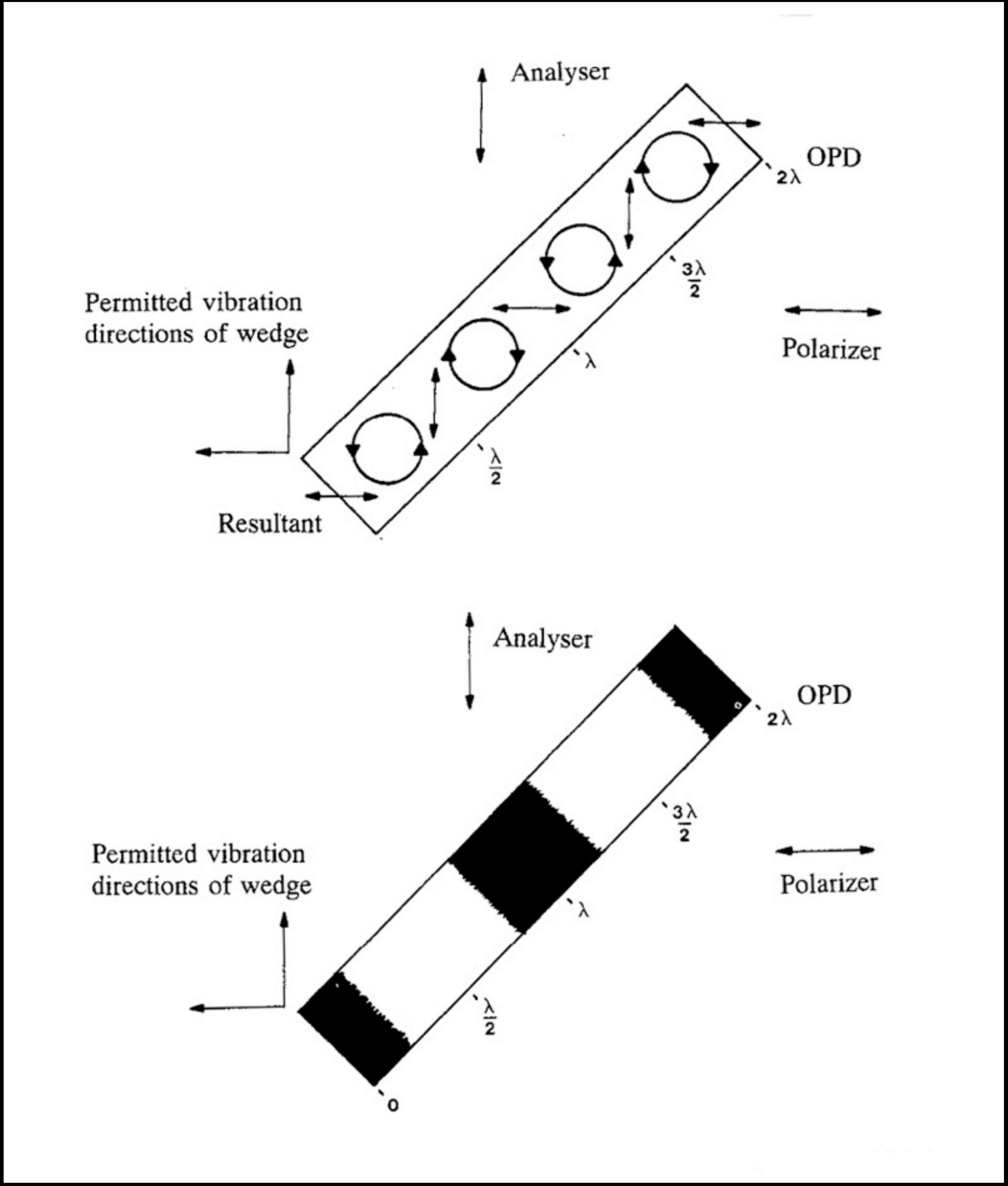
- A single crystal of quartz with gradually increasing thickness
- It is cut normal to the optic axis so light traversing it encounters two refractive indices
- When it is viewed in white light with crossed polarizers, a range of colors are visible -- the result of interference

Quartz Wedge in Monochromatic Light

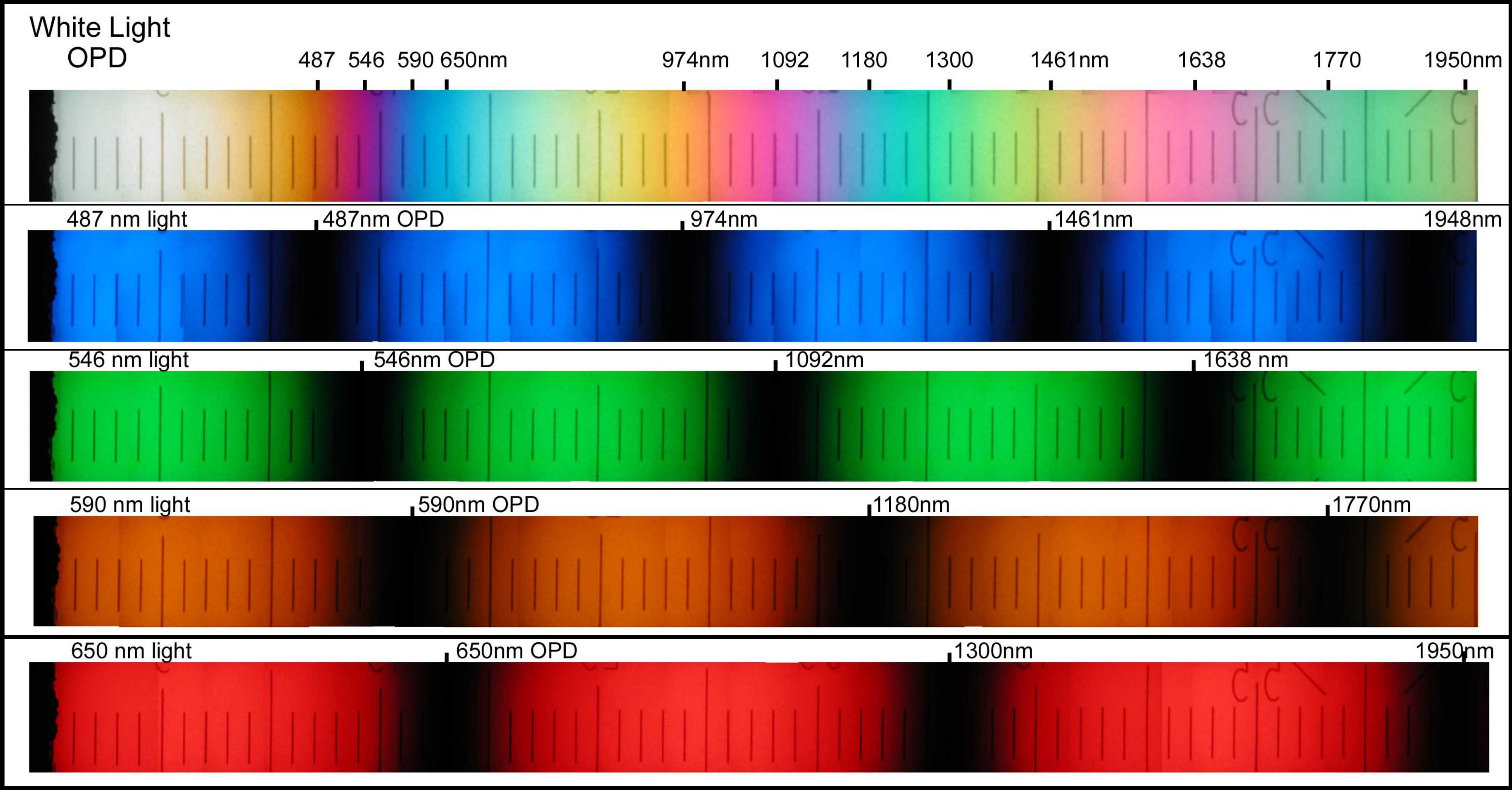
OPD



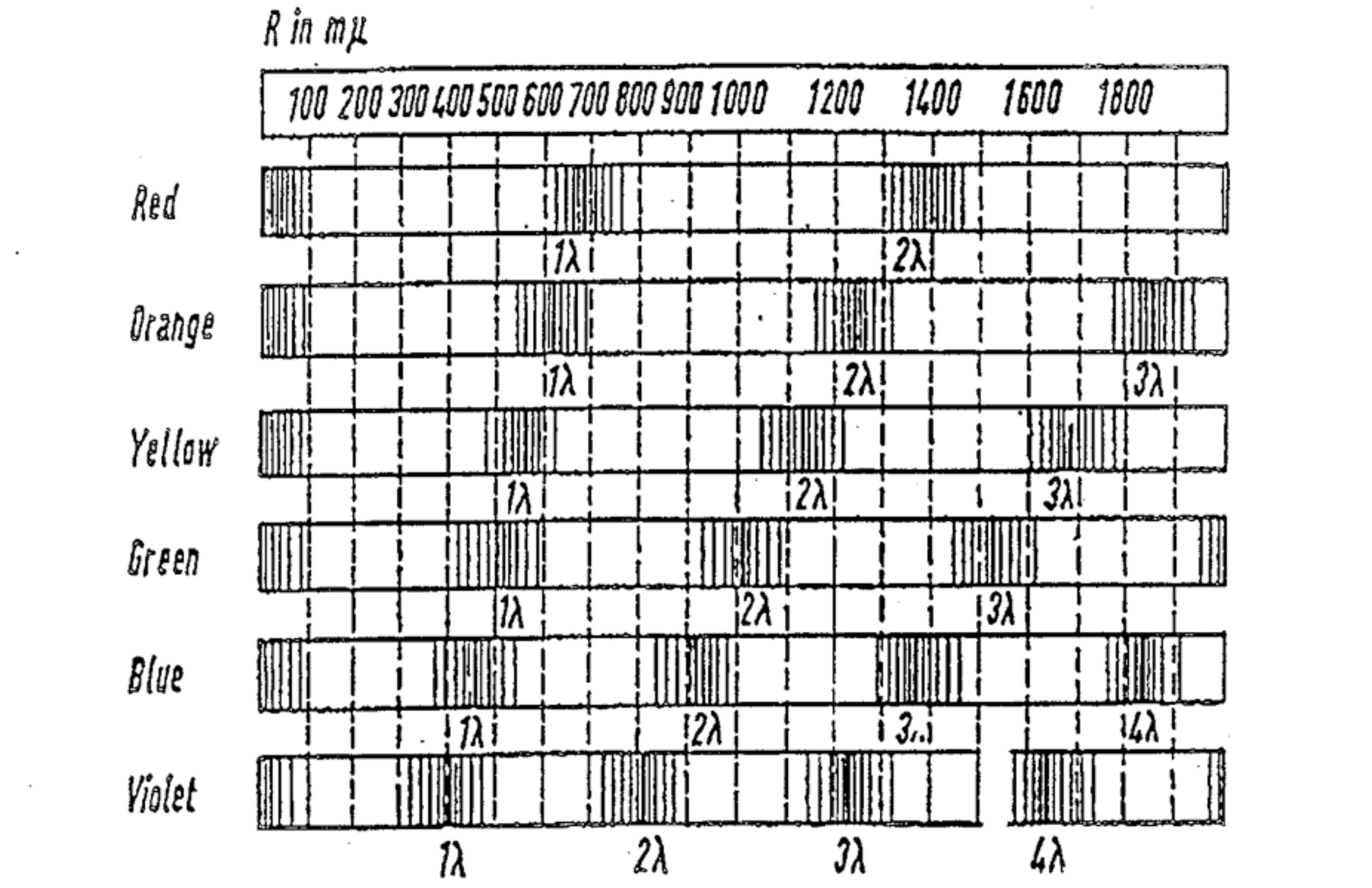
Resultant Vibration Directions in Wedge



Quartz Wedge in White and Monochromatic Light



Quartz Wedge in Monochromatic Light



Compensators

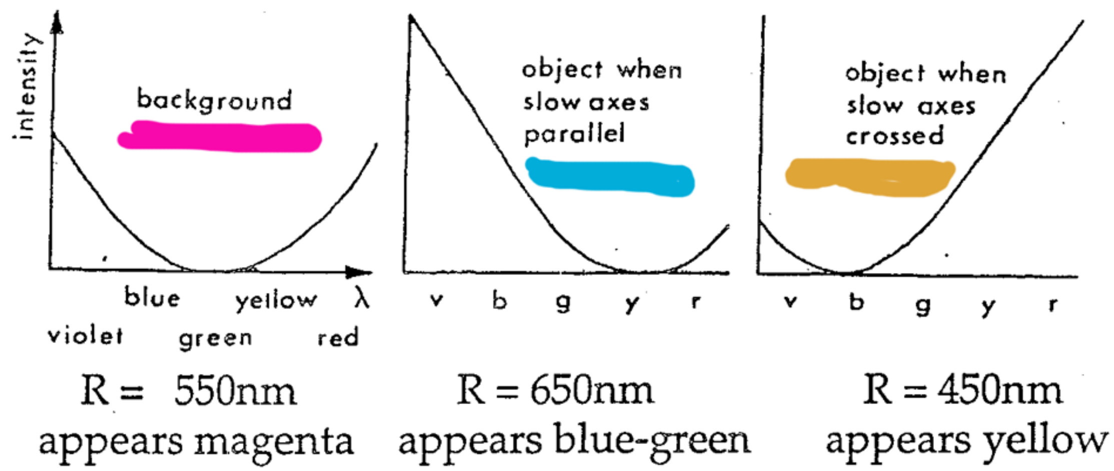
- Fixed and variable compensators are used as reference objects with known orientation of their fast and slow directions, and known amount of retardation introduced.
- The compensators are introduced on the diagonal in the tube slot of the microscope. (fast and slow directions are at 45degrees to polarization directions) The vibration direction of the slow ray, gamma, is engraved

Fixed Compensators

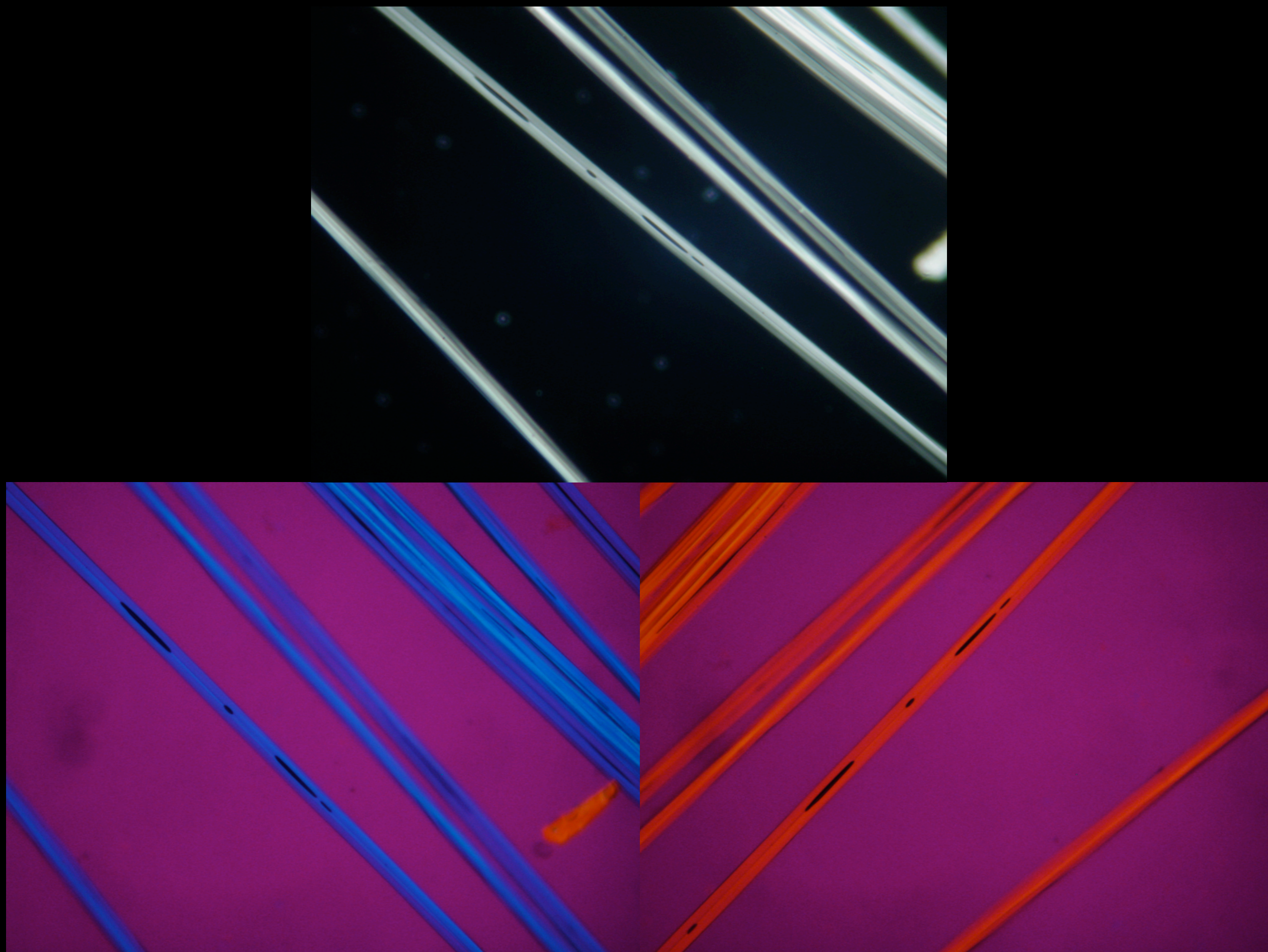
- Full Wave Plate, also called Red 1 plate, λ Plate, Sensitive Tint Plate, or Quartz or Gypsum plate introduces a phase difference of ~550nm.
- It is called "sensitive tint" because the addition or subtraction of very small phase differences, its magenta interference color changes toward blue or yellow respectively

- The Gypsum or Quartz Red I Plate is cut to a thickness to give a retardation of ~550nm It is most useful with crystals showing first order retardation or less.

Colors produced by a Red I plate and a sample giving ~100nm retardation.

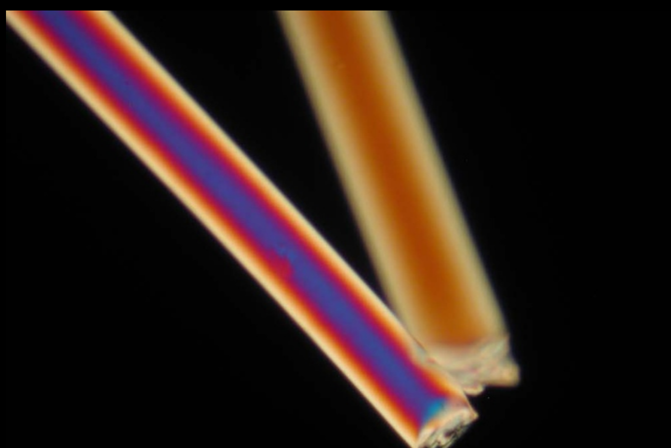


Low Birefringence Fiber and Full Wave Plate



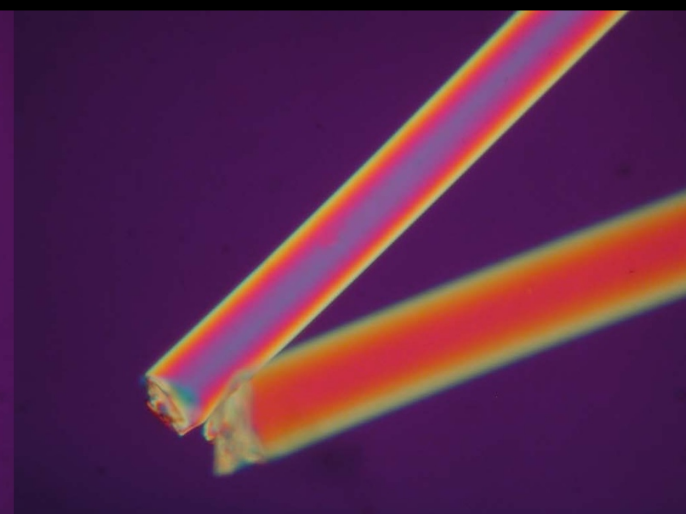
Red I Plate Added to Fiber Exhibiting ~ Full Wave Retardation

Crossed Polarizers



Slow Directions Subtract

Slow Directions Add



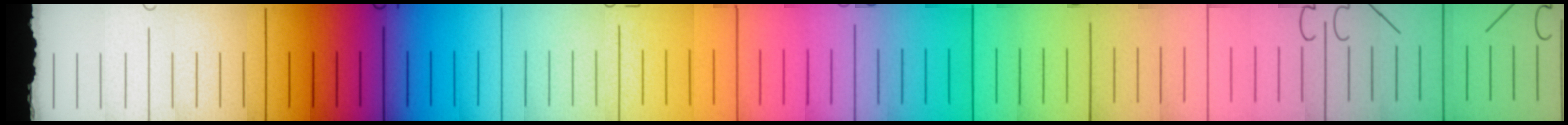
Fixed Compensator

- The Quarter Wave Plate has a phase difference of ~140nm. It produces a first-order grey. It may be useful in determining the retardation of colors higher than first order. --- Requires careful comparison of color sequence.

Quarter Wave Plate with Fibers Showing Higher Order Retardation

Variable Compensators

- The quartz wedge produces interference colors up to about fourth order. By adjustment of the wedge in the tube slot of the microscope differences of 0 to 4 orders can be determined.
- More accuracy is possible if used with a slotted ocular and a wedge marked with a graduated scale. Retardation at exact compensation can be determined.
- For this wedge, First order interference for 546nm occurs at 14.5 and retardation increases at 29.7nm per division.
- The slow direction is along the length of the wedge.



Brace-Koehler Rotary Mica Compensators

- The Brace-Koehler Compensators are used for measuring specimens with extremely small path differences, $\lambda/10$, (55nm), $\lambda/20$ (27nm), or $\lambda/30$ (18nm)
- Compensator plate is a thin mica plate.
- It is rotated around the microscope axis until compensation of the crystal occurs.

Elliptic Rotary Mica Compensator

Rotating Elliptic Compensator.
(By Cooke, Troughton and Simms)

Brace-Koehler Rotary Mica Compensators

Sample is rotated to brightest position
Compensator is rotated until extinction is obtained

$R = R_0 \sin 2\psi$

R is relative retardation of crystal,

R_0 is that of compensator

ψ is angle compensator has been rotated.

de-Senarmont Compensator

- Quarter wave plate for specific wavelength, of either 589nm or 546nm.
- Used for determining path differences, up to one wavelength.
- Use monochromatic light, specific for your quarter wave plate.
- Orient the sample to a position of maximum brightness, 45 degrees from extinction.

de-Senarmont Compensation continued

- The plate is inserted into the accessory slot; it is oriented so that the *vibration directions are parallel and perpendicular to that of the polarizer* . You will see no apparent change in the image.
- Rotate the analyzer to bring extinction to the required part of the specimen. (This is usually accomplished with the field aperture stopped down to illuminate only the area of interest.)

de-Senarmont Compensation continued

- Rotate the specimen through exactly 90˚
- Find the corresponding extinction position by rotating the analyzer in the opposite direction from zero.
- Half the sum of the two angles is used to calculate the OPD from the following equation:
- OPD= λ, nm ∗ analyzer rotating angle/180

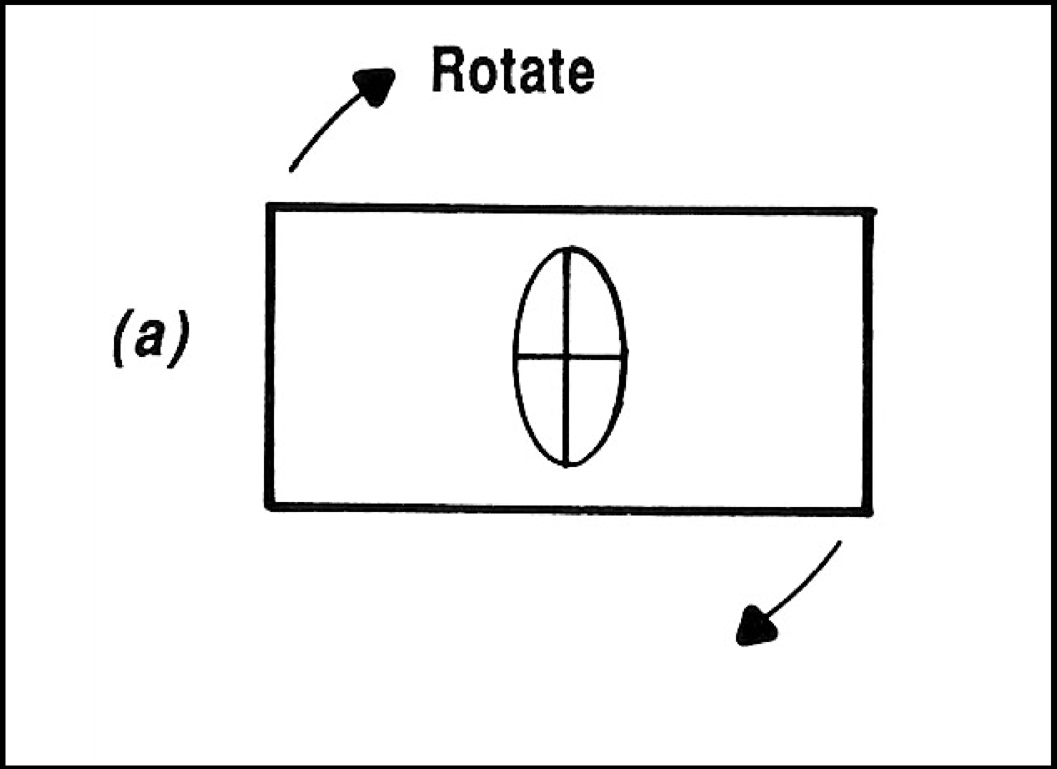
de-Senarmont Compensation continued

- While this method measures only the phase difference up to one order, it can be used to measure larger OPD if interference colors and Michel Levy chart or tilting compensators are used to determine the whole orders.

Berek Compensator

- Berek compensator consists of a piece of uniaxial birefringent material that can be tilted about an axis parallel to the specimen stage.
- The slow direction is labeled on the holder.
- The tilt increases both thickness and the orientation of the optical indicatrix of the plate.
- The compensator is calibrated in the factory for the C, D, e and F lines

Berek Compensator

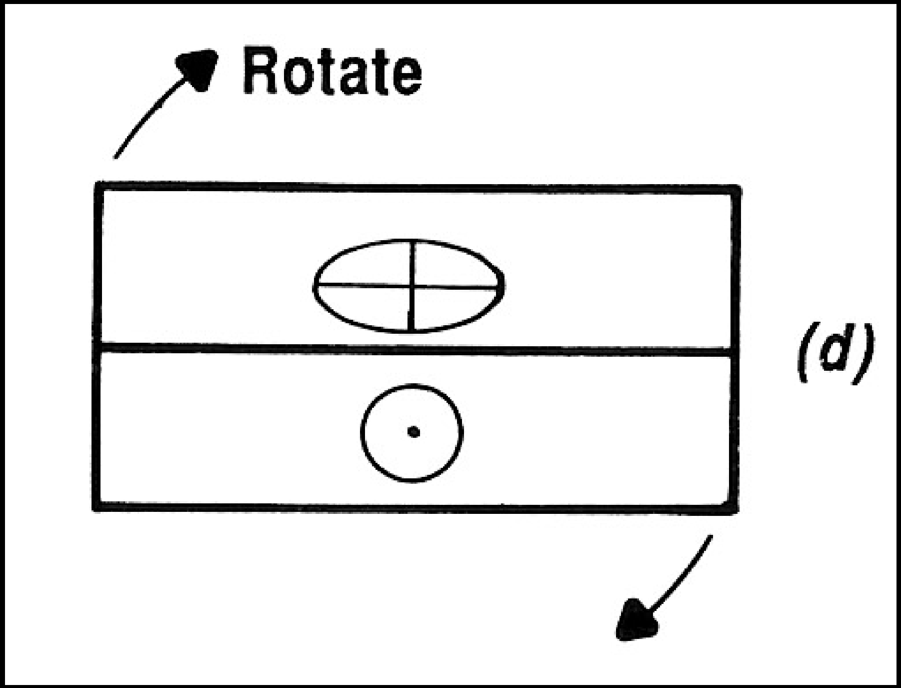


Schematic of tilting crystal

Ehringhaus Tilting Compensator

- The Ehringhaus Compensator consists of two parallel-sided birefringent plates cut parallel to the optic axis and superimposed with their slow and fast vibration directions crossed.
- The Ehringhaus compensator is popular because the material for the two plates can be selected to give low overall dispersion.

Ehringhaus Tilting Compensator

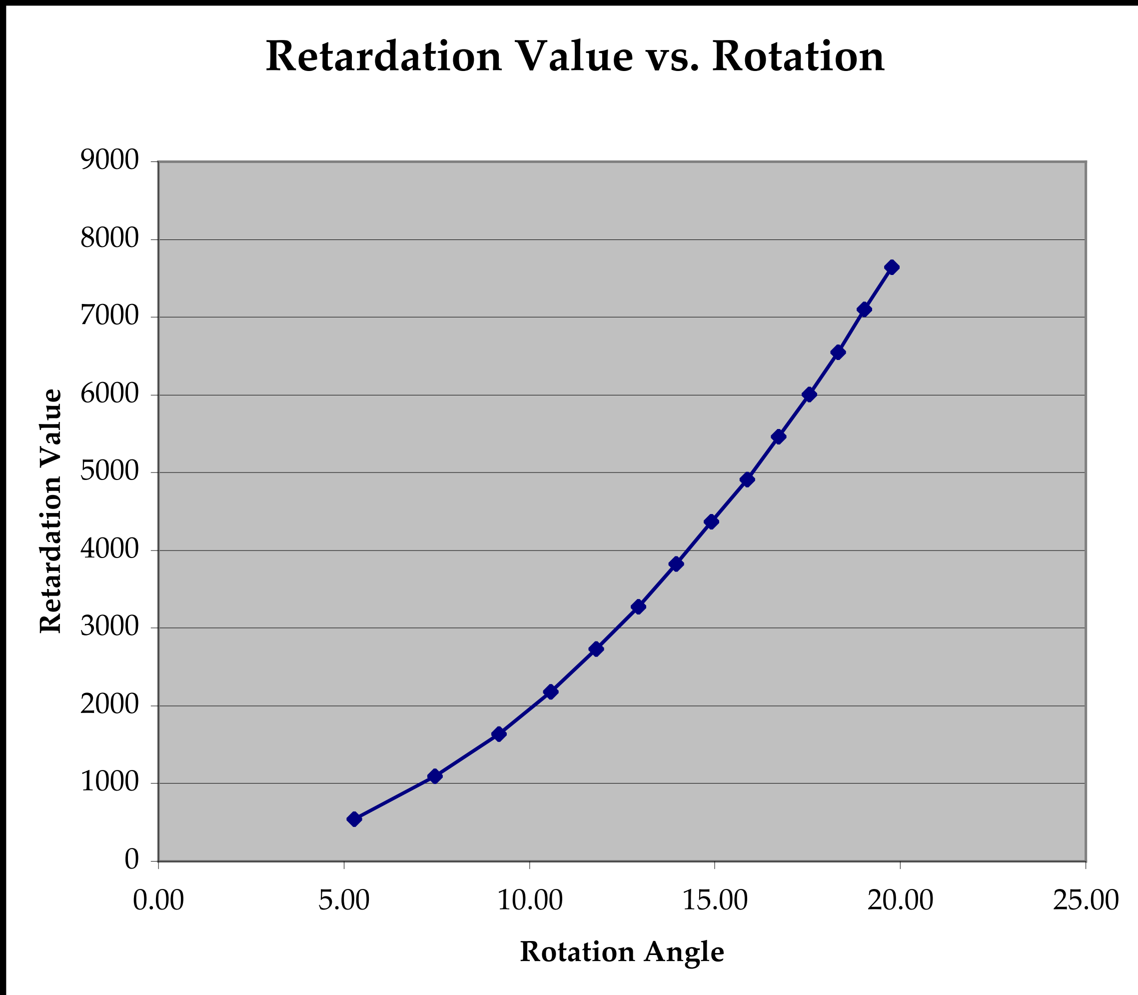


Schematic showing two plates with opposite orientations

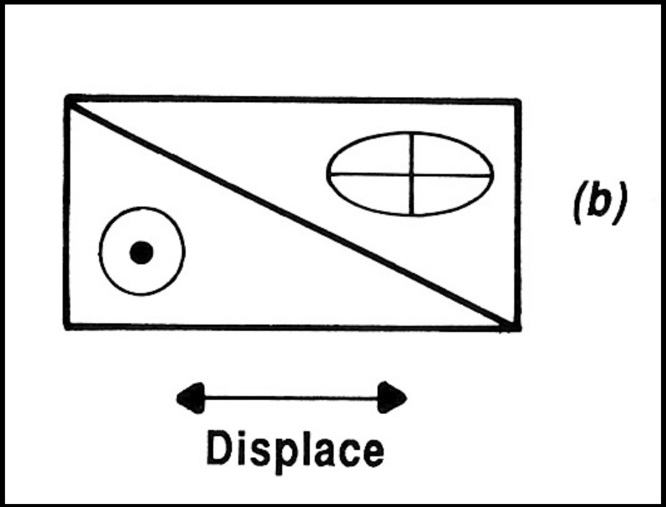
Ehringhaus Compensator

- Ehringhaus Compensator is calibrated at the factory for C, D, e and F lines.
- However, DIY calibration can keep it useful
- Readings should be taken in each direction for greater accuracy

Ehringhaus Compensator

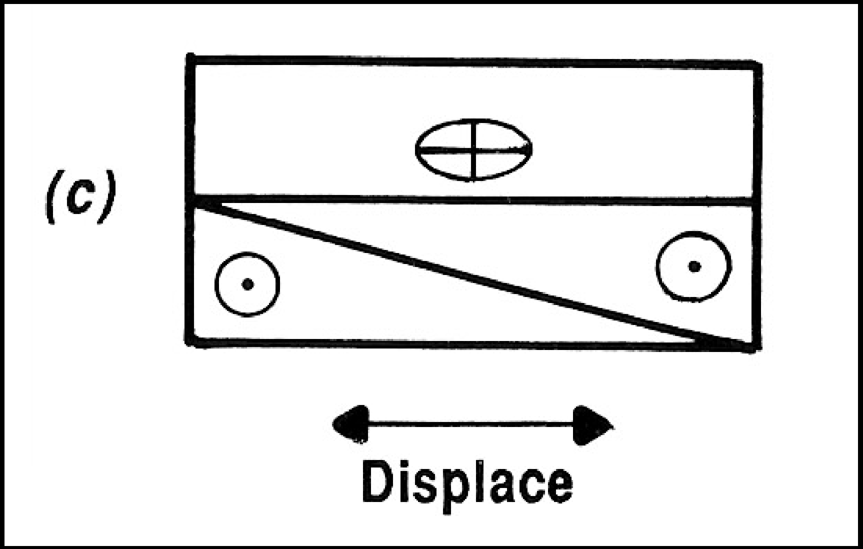


Babinet Compensator



Consists of two quartz wedges, with their optic axes crossed.
One wedge can be moved by means of a calibrated micrometer screw.

Soleil Compensator



The Soleil compensator consists of two quartz wedges and a parallel sided quartz plate.
It gives a uniform phase difference across the field of view
The phase difference is controlled by changing the relative displacement of the wedges.

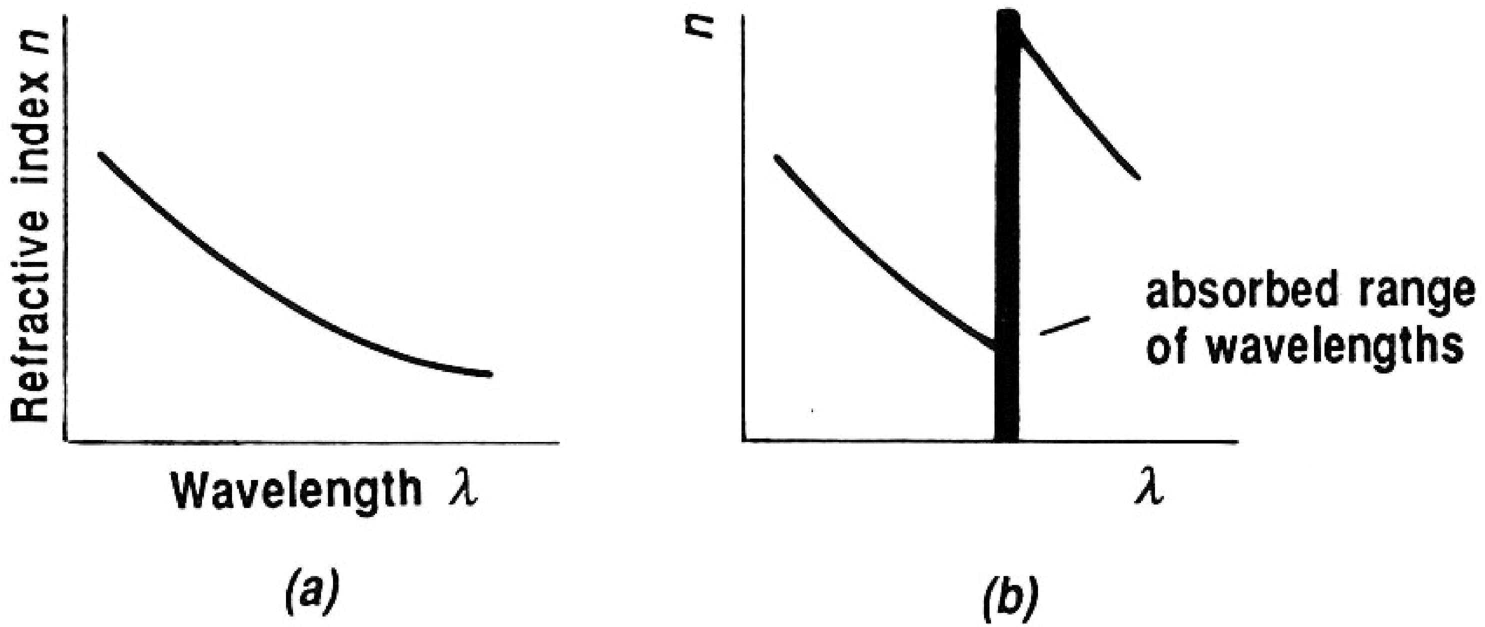
Wright Eyepiece

- Permits very accurate setting of extinction
- Must be used in a straight tube so that no depolarization occurs with prisms.
- Wright Eyepiece has a rotating top analyser.
- Half-shadow plates and wedges can be inserted in the intermediate-image plane of the eyepiece.

Nakamura Plate

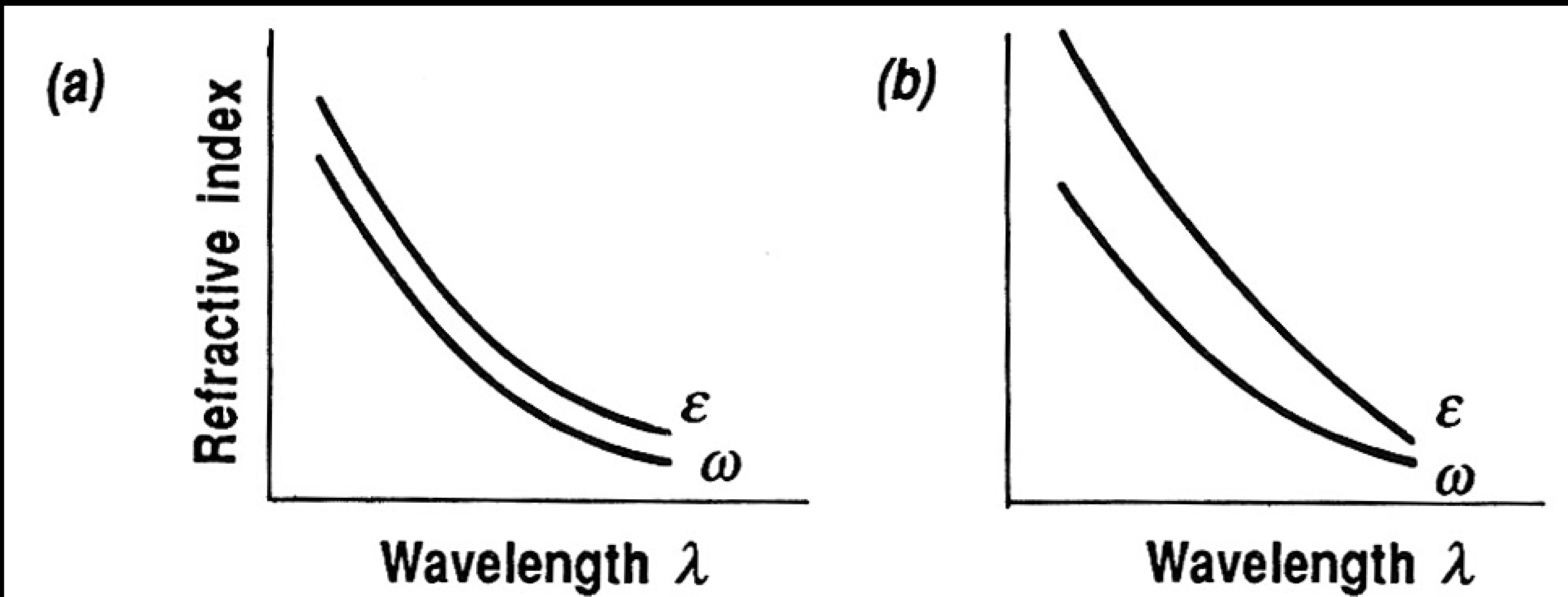
- The two plates are thin and rotation is almost identical for all wavelengths.
- At precisely crossed polarizers or accurately set compensation position the two halves of the field appear in a grey tone.

Dispersion of Refractive Index



Form of dispersion curves for optically isotropic material:
(a) normal; (b) anomalous.

Dispersion of Birefringence



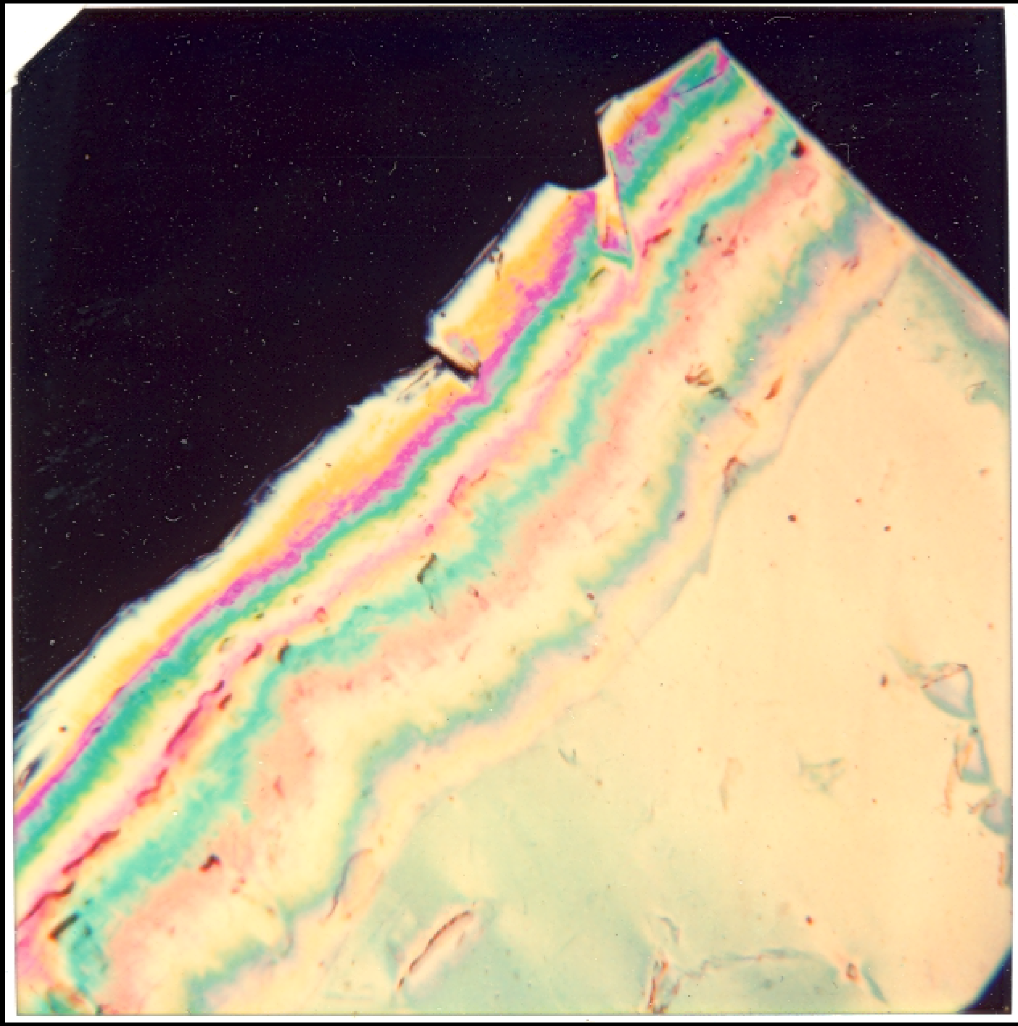
Normal

Anomalous

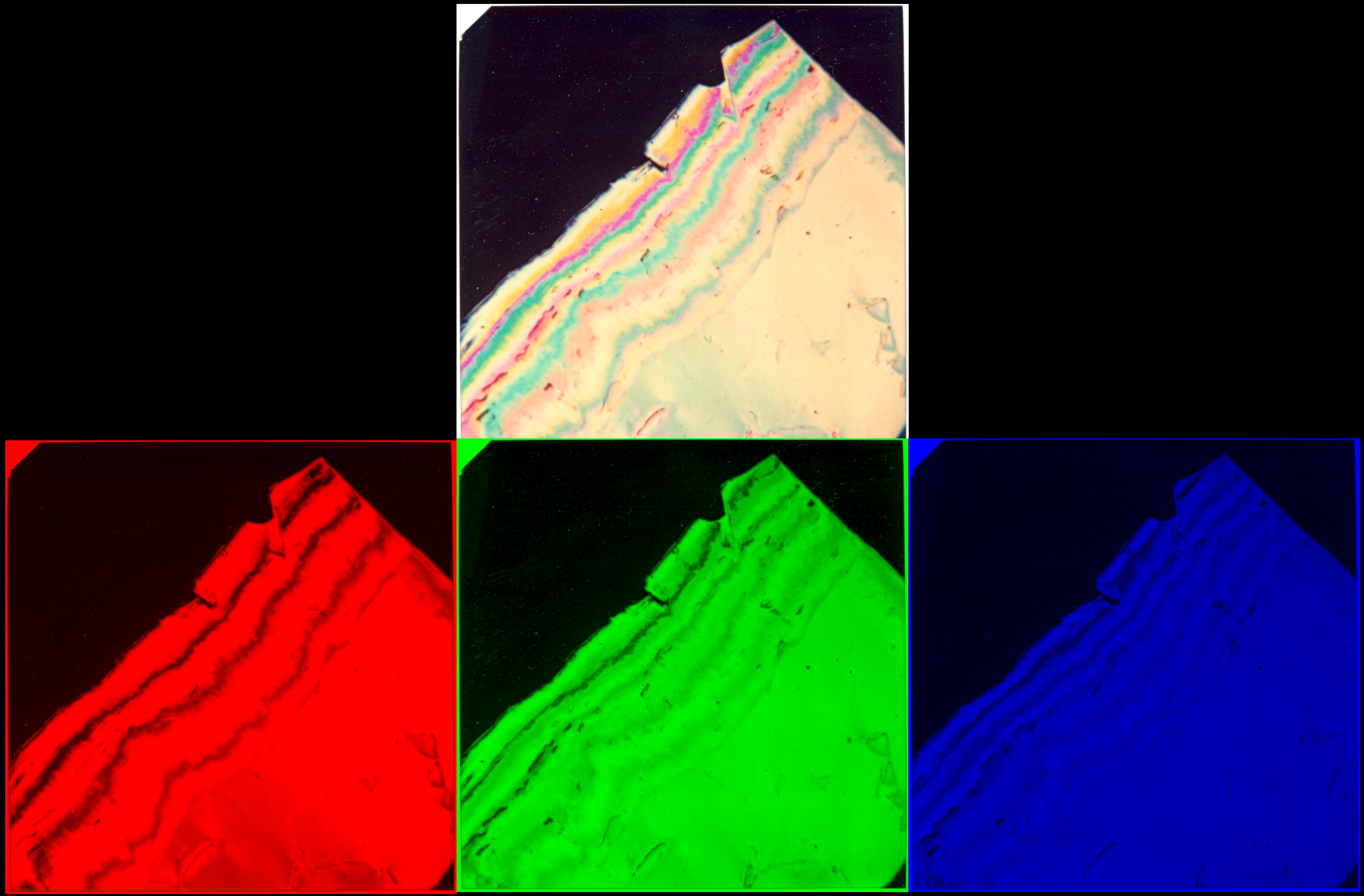
What to do with anomalous interference colors ?

- Cut a wedge - as uniform and as shallow as possible
- Use monochromatic light
- Count the fringes up the slope
- Repeat with different wavelength

Anomalous Dispersion



Anomalous Dispersion
Use Monochromatic Light



Refractive Index of Common Fibers

Table 2.4: RI of fibres

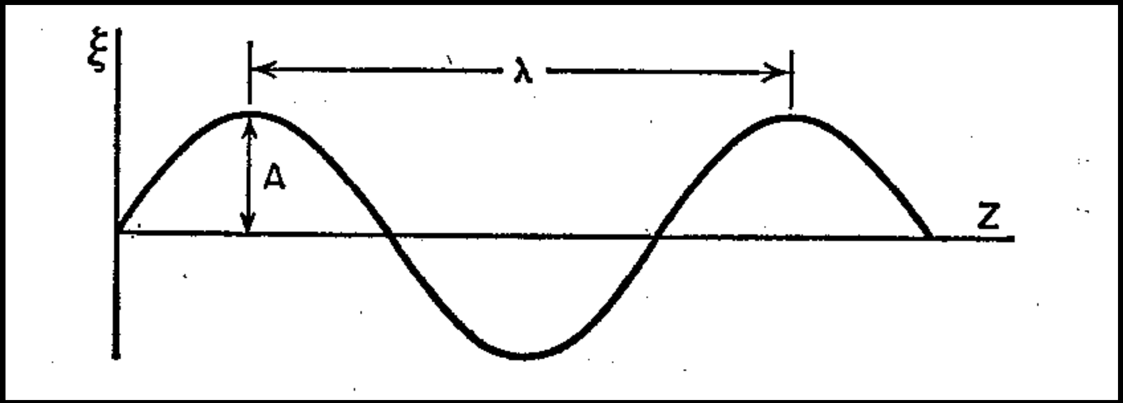
Fibre	$n\|\|$	$n\perp$	Birefringence
Acrylic	1.511	1.514	–0.003
Cellulose diacetate	1.477	1.472	0.005
Cellulose triacetate	1.469	1.469	0
Chlorofibre	1.541	1.536	0.005
Cotton	1.577	1.529	0.048
Flax	1.590	1.525	0.065
Modacrylic	1.520	1.516	0.004
Nylon 6	1.575	1.526	0.049
Nylon 6.6	1.578	1.522	0.056
Polyester	1.706	1.546	0.160
Polypropylene	1.530	1.496	0.034
Silk	1.591	1.538	0.053
Viscose (ordinary)	1.542	1.520	0.022
Wool	1.557	1.547	0.010

The values given are for guidance only and variations on these figures may be found in some cases.

References Describing Compensators

- The Polarizing Microscope, third edition, A. F. Halimond, Vickers Ltd., York England 1970
- Transmitted Polarised Light Microscopy, Christopher Viney, The Microscope Series, McCrone Research Institute, Chicago IL, 1990
- Polarized Light Microscopy, Principles, Instruments, applications, Walter J. Patzelt, Ernst Leitz Wetzlar, GMBH, Wetzlar

Wavelength and Frequency



$\xi = A \sin(\omega t - 2\pi z/\lambda)$
The equation describing ξ, the magnitude of the electric field at any given time t, and any given position z, in terms of ω, the angular frequency (2π times the frequency ν in cycles/unit time)

A is the amplitude of the electric field.
The wavelength, λ, indicates the distance between two identical points on the wave, usually measured in nanometers, nm.

Frequency = c/λ cycles/sec
c is the speed of light