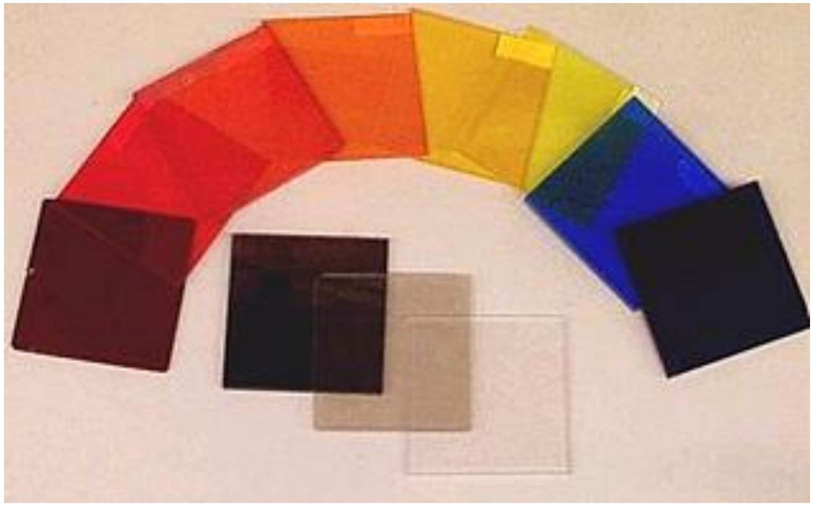
PH 301

ENGINEERING OPTICS

Lecture_Optical Components_11

Filters

Optical filters are devices that selectively transmit light of different wavelengths, usually implemented as plane glass or plastic devices in the optical path which are either dyed in bulk or have interference coatings.



- **Optical filters selectively transmit light in a particular range of wavelengths, while blocking remainder.**
- **They can usually pass long wavelengths only (longpass), short wavelengths only (shortpass), or a band of wavelengths, blocking both longer & shorter wavelengths (bandpass).**
- **Passband may be narrower or wider; transition or cutoff between maximal & minimal transmission can be sharp or gradual.**

Types of Filters

- **Absorptive filter: Usually made from glass to which various inorganic or organic compounds are added. These compounds absorb some wavelengths of light while transmitting others. Compounds can also be added to plastic (often polycarbonate or acrylic) to produce gel filters, which are lighter & cheaper than glass-based filters.**

- **Dichroic filter: Also called ‘reflective’ or ‘thin film’ or ‘interference’ filter. Made by coating a glass substrate with a series of optical coatings. Dichroic filters usually reflect unwanted portion of light & transmit remainder.**

- **Monochromatic filter: Allow a narrow range of wavelengths (essentially a single color) to pass.**

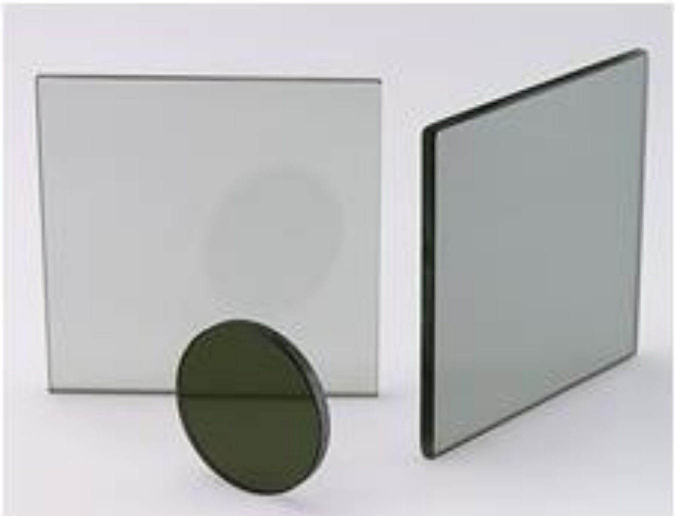
- **Infrared filter: To pass infrared (blocking other wavelengths) or to block infrared (only).**

- **Ultraviolet filter: To block UV radiation but let visible light through.**

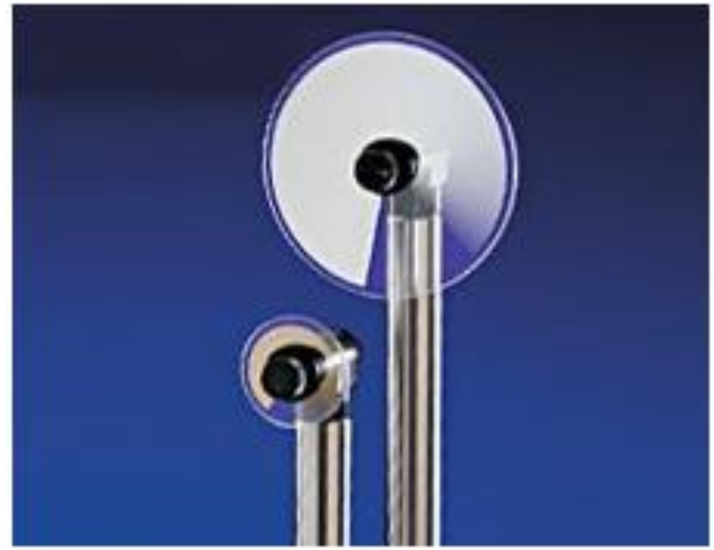

Regular Lenses
UV Protection Lenses

Types of Filters

- **Neutral density filter**: **Constant attenuation across range of visible wavelengths. Reduces intensity of light by reflecting or absorbing a portion of it.**
- **Longpass filter**: **It is an optical interference or coloured glass filter that attenuates shorter wavelengths & transmits (passes) longer wavelengths over the active range of the target spectrum (UV, visible, or IR).**
- **Bandpass filter**: **Transmit a certain wavelength band & block others.**
- **Shortpass filter**: **It is an optical interference or coloured glass filter that attenuates longer wavelengths & transmits (passes) shorter wavelengths over the active range of the target spectrum (usually UV & visible region).**
- **Polarization filter**: **Blocks/transmits light according to its polarization.**



Absorptive neutral density filter



Mounted circular neutral density filter

Optical density **of a material is a logarithmic ratio of incident radiation to transmitted radiation through a material. It is also referred to as a fraction of absorbed radiation at a particular wavelength.**

Interference filter

When a Fabry–Perot interferometer is illuminated by a monochromatic (uncollimated) beam, we get a spectrum consisting of different intensity maxima which satisfy the relation,

$$2nh\cos\theta_r = m\lambda$$

If a Fabry-Perot interferometer is illuminated by a collimated white light incident normally (θ_r = 0), maxima of different orders are formed in transmitted light corresponding to wavelengths,

$$\lambda = \frac{2nh}{m}$$

If *h* is very large, a large no. of maxima will be observed in visible region; for ex., about 23,000 maxima are observed if *h* = 1 cm. But if we go on reducing *h*, we reach a situation in which one or two maxima are obtained in visible region.

Ex.

$n = 1.5$

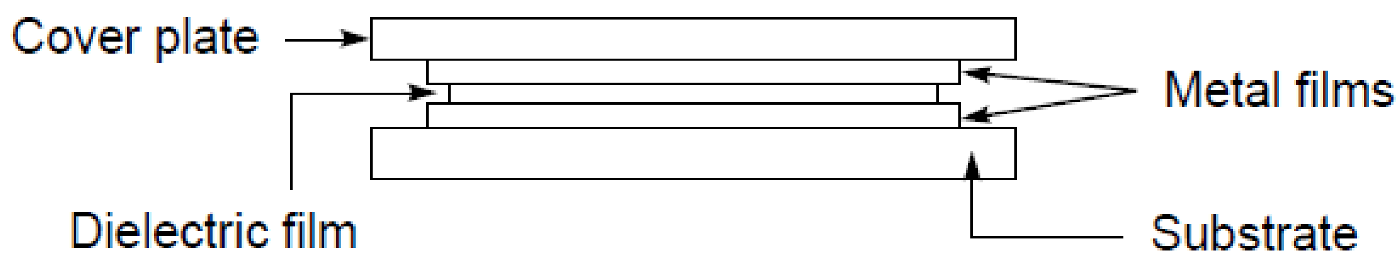
$h = 6 \times 10^{-5}$ cm

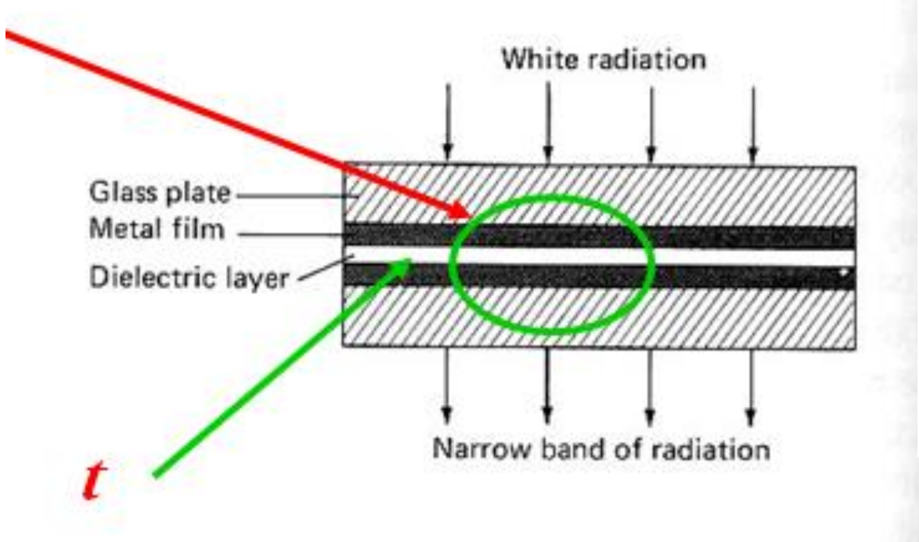
$\lambda = 6000$ Å ($m = 3$)

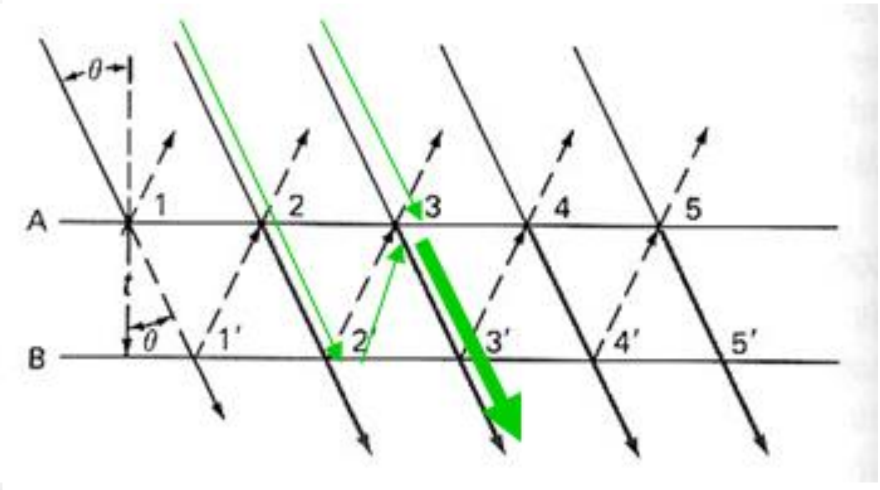
$\lambda = 4500$ Å ($m = 4$)

In this case, maxima are widely separated, & one of them can be masked so as to transmit only one wavelength. In this way, it is possible to filter a particular wavelength out of a white light beam. Such a structure is known as an interference filter.

Interference filter

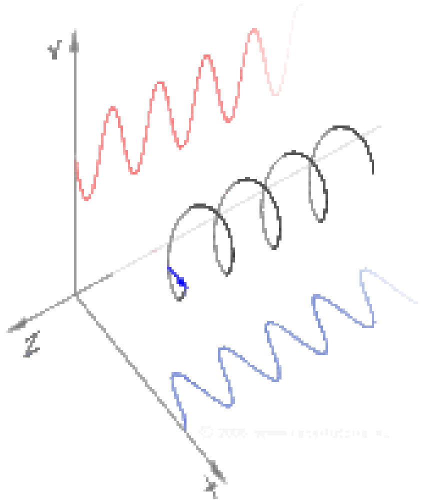




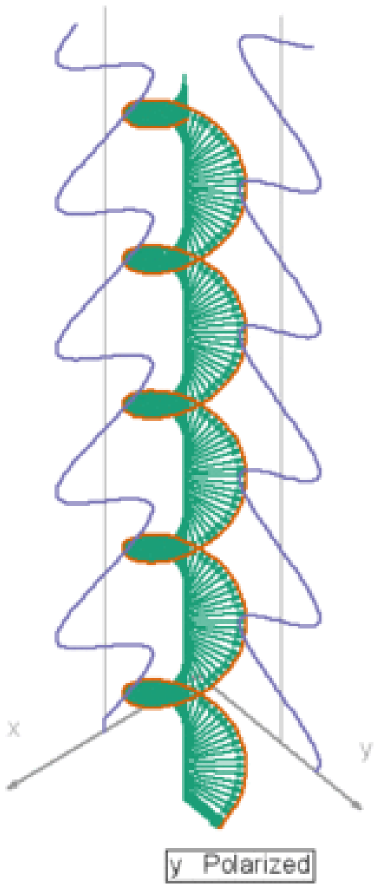


Polarizing components

Wave plates



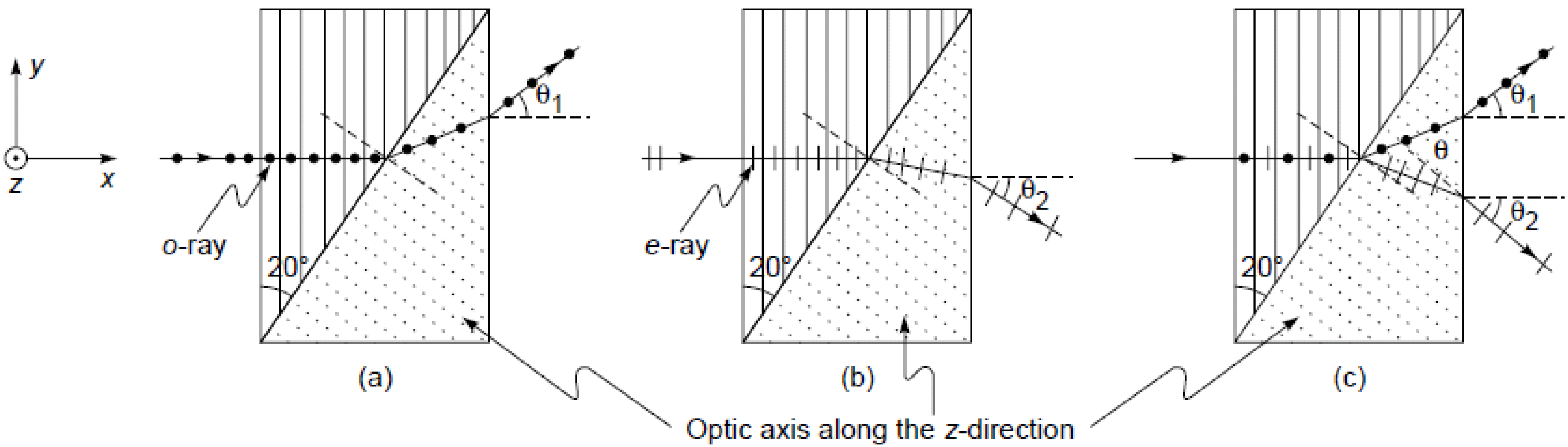
Circularly polarized wave as a sum of two linearly polarized components 90° out of phase.



Four different polarization states & two orthogonal projections.

Wollaston prism

Optic axis of 1st prism is along *y*-axis & optic axis of 2nd prism is along *x*-axis.

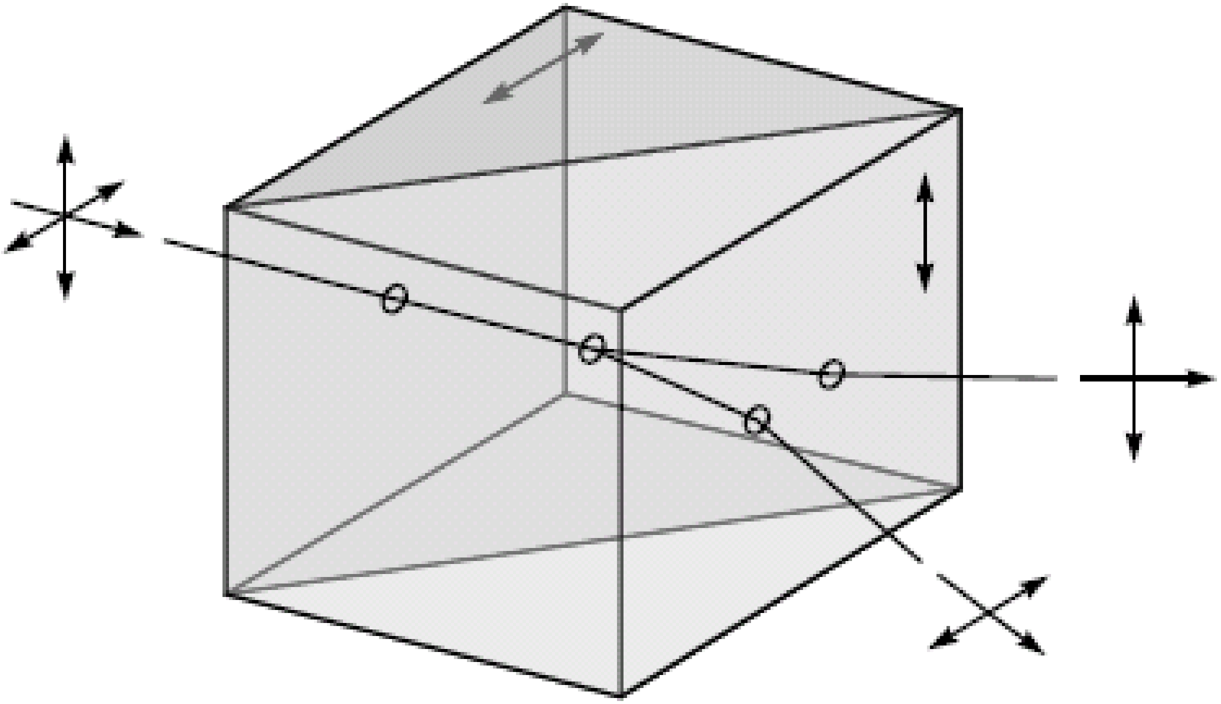


(a) If incident beam is *z*-polarized, it will propagate as an *o*-wave in 1st prism & an e-wave in 2nd prism.

(b) If incident beam is *y*-polarized, it will propagate as an *e*-wave in 1st prism & an o-wave in 2nd prism.

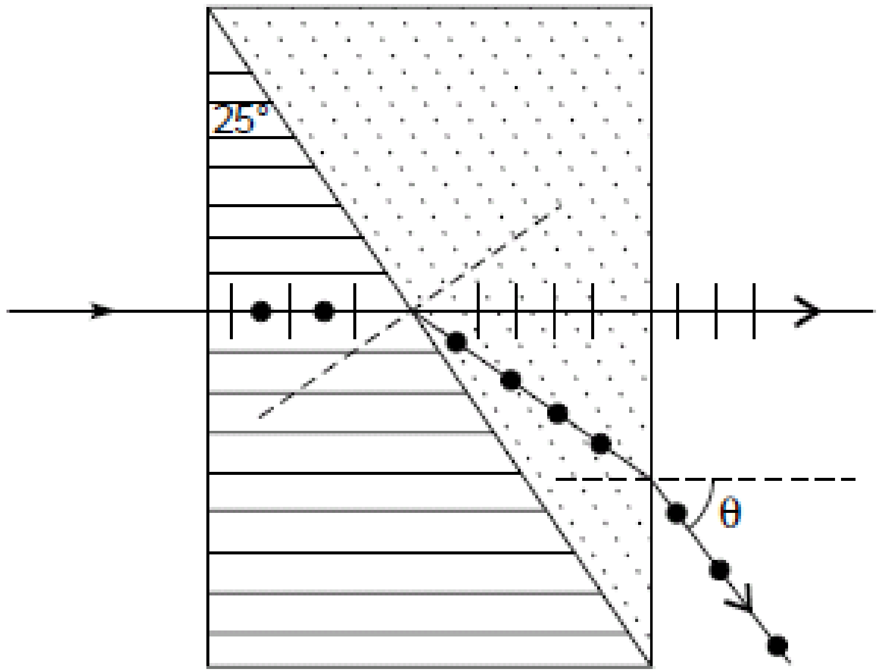
(c) For an unpolarized beam incident normally, there will be two linearly polarized beams propagating in different directions.

Wollaston prism



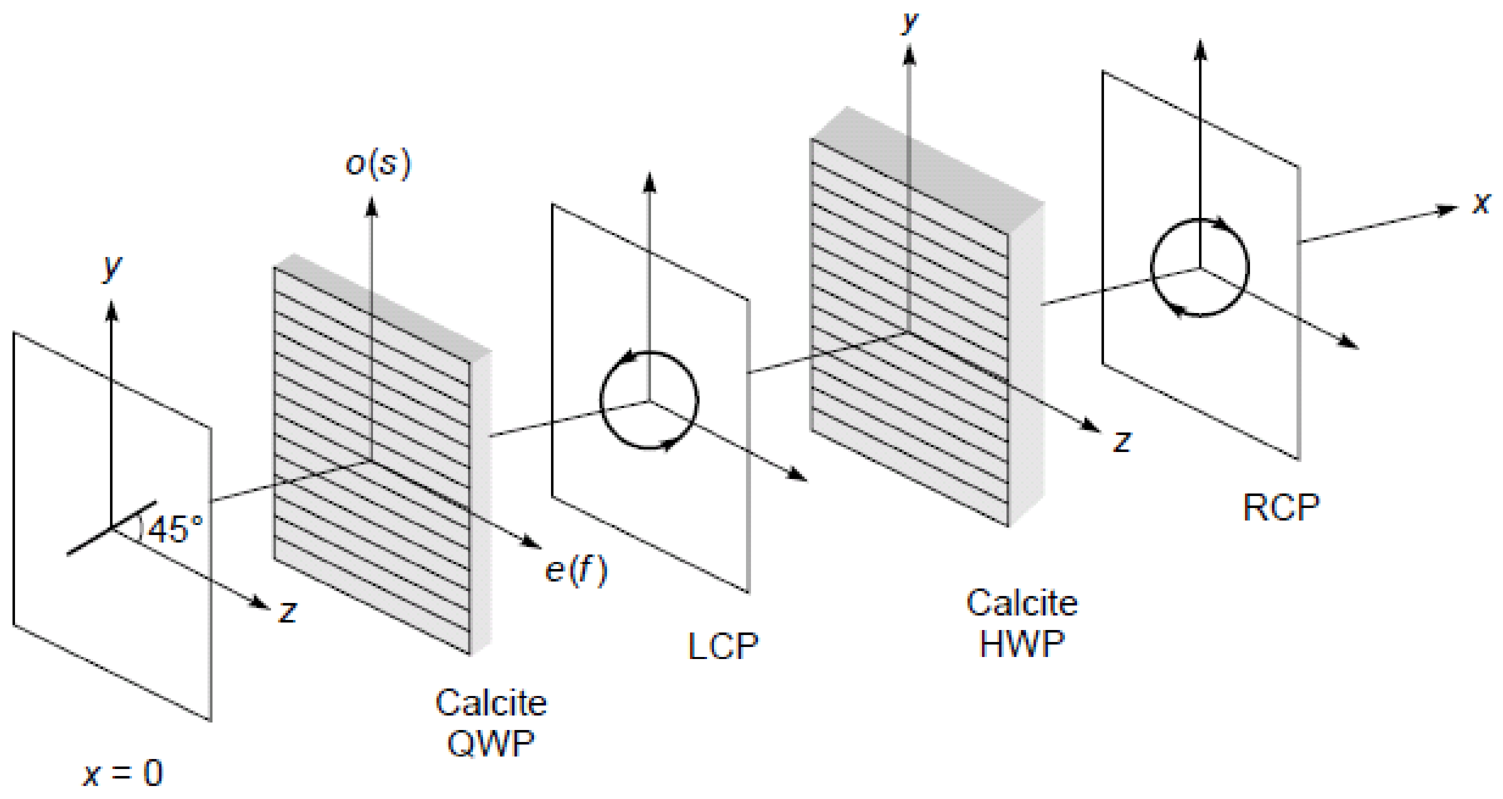
Prism separates an unpolarized light beam into two linearly polarized beams. It typically consists of two properly oriented calcite prisms (so that optic axes are perpendicular to each other), cemented together typically with Canada balsam. A commercially available Wollaston prism has divergence angles from 15° to about 45°.

Rochon Prism



Production of two orthogonally polarized light beams by a Rochon prism.

Wave plates; λ/4 & λ/2



A linearly polarized light making an angle 45º with *z* axis gets converted to a LCP after propagating through a calcite QWP; further, a LCP gets converted to a RCP after propagating through a calcite HWP. Optic axis in QWP & HWP is along *z* direction. [*s*-slow, *f*-fast]

- **If incident beam is *y*-polarized, beam will propagate as an *o*-wave & *e*-wave will be absent.**

- **If incident beam is *z*-polarized, beam will propagate as an *e*-wave & *o*-wave will be absent.**

- **For any other state of polarization of incident beam, both *e*- & *o*-components will be present.**

- **For a negative crystal such as calcite $n_e < n_o$, & *e*-wave will travel faster than *o*-wave.**

- **Let electric vector (of amplitude E_0) associated with incident polarized beam make an angle Φ (arbitrary angle) with *z* axis.**

- **Such a beam can be assumed to be a superposition of two linearly polarized beams (vibrating in phase), polarized along *y* & *z* directions with amplitudes; $E_0\sin\Phi$ & $E_0\cos\Phi$, respectively.**

- ***z* component (whose amplitude is $E_0\cos\Phi$) passes through as an *e*-beam propagating with wave velocity c/n_e.**

- ***y* component (whose amplitude is $E_0\sin\Phi$) passes through as an *o*-beam propagating with wave velocity c/n_o.**

- **Since $n_e \neq n_o$, two beams will propagate with different velocities; as such, when they come out of crystal, they will not be in phase. Consequently, emergent beam will be elliptically polarized.**

- **Let plane *x* = 0 represent surface of crystal on which beam is incident. *y* & *z* components of incident beam can be written as**

$$E_y = E_0 \sin\phi \cos(kx - \omega t)$$

$$E_z = E_0 \cos\phi \cos(kx - \omega t)$$

- **where *k* (= *ω*/*c*) represents free space wave number. Thus, at *x* = 0,**

$$E_y(x=0) = E_0 \sin\phi \cos\omega t$$

$$E_z(x=0) = E_0 \cos\phi \cos\omega t$$

- **Inside crystal, two components will be given by**

$$E_y = E_0 \sin\phi \cos(n_0 kx - \omega t) \qquad o - wave$$

$$E_z = E_0 \cos\phi \cos(n_e kx - \omega t) \qquad e - wave$$

- **If thickness of crystal is *d*, then at emerging surface, we have**

$$E_y = E_0 \sin\phi \cos(\omega t - \theta_o)$$

$$E_z = E_0 \cos\phi \cos(\omega t - \theta_e)$$

$$\theta_o = n_o kd, \quad \theta_e = n_e kd$$

- For instant $t = 0$,

$$E_y = E_0 \sin\phi \cos(\omega t - \theta)$$
$$E_z = E_0 \cos\phi \cos\omega t$$

$$\theta = \theta_o - \theta_e = kd(n_o - n_e) = \frac{\omega}{c}(n_o - n_e)d$$

represents phase difference between *o*- & *e*-beams.

- **If thickness *d* of crystal is such that $\theta = 2\pi, 4\pi, \ldots$ the emergent wave will have same state of polarization as incident beam.**

- **If thickness *d* of crystal is such that $\theta = \pi/2$, the crystal is said to be a quarter wave plate (QWP) – a phase difference of $\pi/2$ implies a path difference of $\lambda/4$.**

- **If thickness *d* of crystal is such that $\theta = \pi$, the crystal is said to be a half wave plate (HWP) – a phase difference of π implies a path difference of $\lambda/2$.**

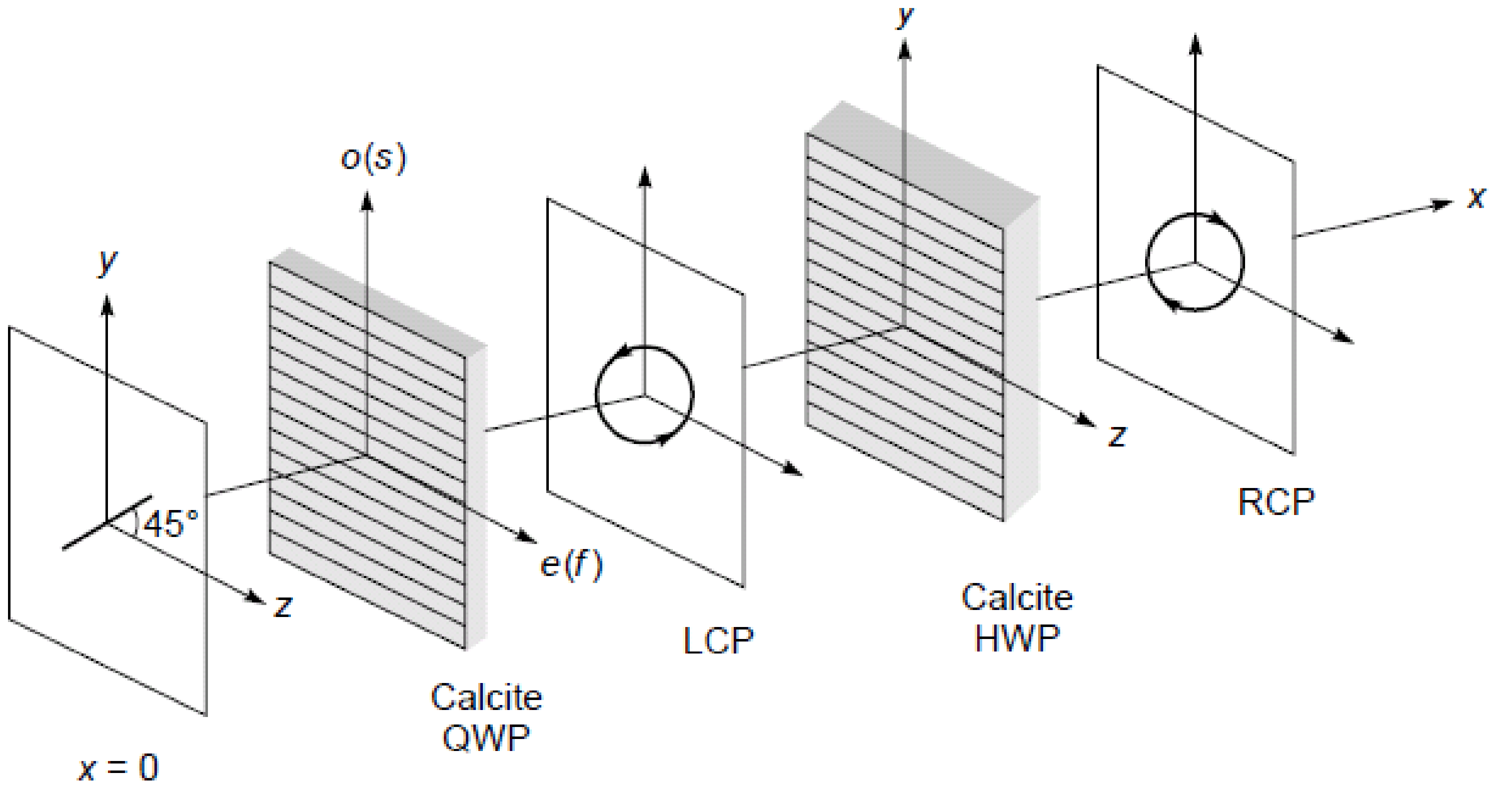
Ex.:

- **Consider *Φ* = *π*/4 & *θ* = *π*/2, i.e., *y* & *z* components of incident wave have equal amplitudes, & crystal introduces a phase difference of *π*/2. For emergent wave we have**

$$E_y = \frac{E_0}{\sqrt{2}} \sin \omega t \qquad\qquad E_z = \frac{E_0}{\sqrt{2}} \cos \omega t$$

which represents a circularly polarized wave because

$$E_y^2 + E_z^2 = \frac{E_0^2}{\sqrt{2}}$$



A linearly polarized light making an angle 45º with *z* axis gets converted to a LCP after propagating through a calcite QWP; further, a LCP gets converted to a RCP after propagating through a calcite HWP. Optic axis in QWP & HWP is along *z* direction. [*s*-slow, *f*-fast]

❖ To introduce a phase diff. of $\pi/2$, thickness of crystal should be

$$d = \frac{c}{\omega(n_o - n_e)} \frac{\pi}{2} = \frac{1}{4} \frac{\lambda_0}{n_o - n_e}$$

❖ For Calcite, n_0 = 1.65836, n_e = 1.48641, & λ_0 = 5893 Å.

$$d = \frac{5893 \times 10^{-8}}{4 \times 0.17195} cm \approx 0.000857 \ mm$$

❖ Thus, a Calcite QWP (at λ_0 = 5893 Å) will have a thickness of 0.000857 mm & will have its optic axis parallel to surface; such a QWP will introduce a phase difference of $\pi/2$ between *o*- & *e*-components.

- **If thickness is an odd multiple of above quantity,**

$$d = (2m+1)\frac{1}{4}\frac{\lambda_0}{n_o - n_e} \qquad m = 0,1,2....$$

then $\Phi = \pi/4$. It can be shown that emergent beam will be left circularly polarized for m = 0, 2, 4, … & right circularly polarized for m = 1, 3, 5, ….

***y*-polarized *o*-wave in Calcite has a smaller wave velocity (= c/n_o), & hence it is referred to as a slow wave *o*(*s*).**

Similarly, *e*-wave is fast wave (in Calcite).