POLARIZATION OF LIGHT & ITS APPLICATION

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PRESENTATION LAYOUT

- Concept of Polarization
- Types of Polarization
- Methods of achieving Polarization
- Applications of Polarization

ORDINARY LIGHT

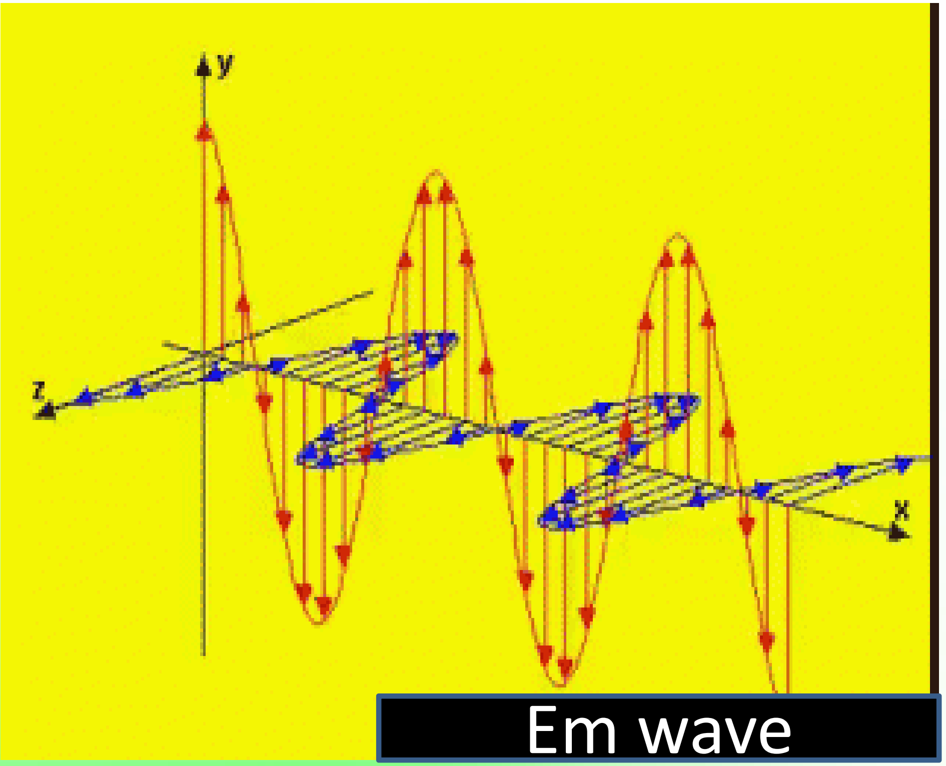
- Electromagnetic wave

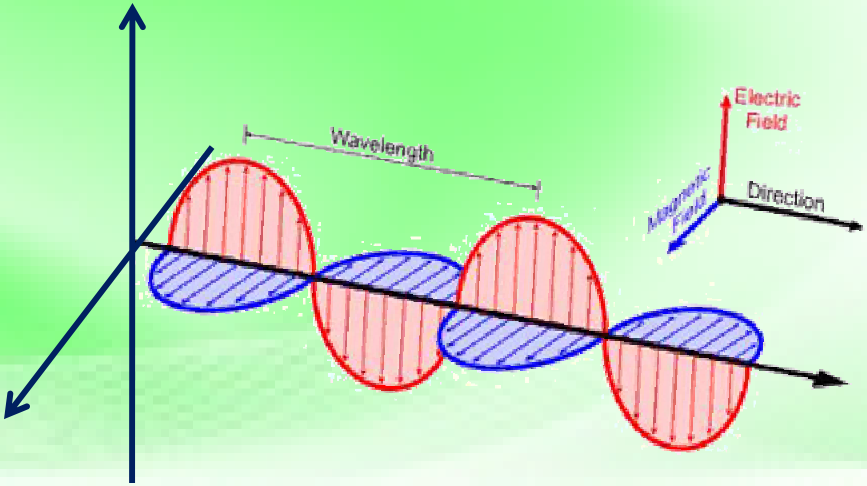
  Electric field E and magnetic field B are:

  - Perpendicular to each other
  - In phase
  - Also perpendicular to the direction of propagation

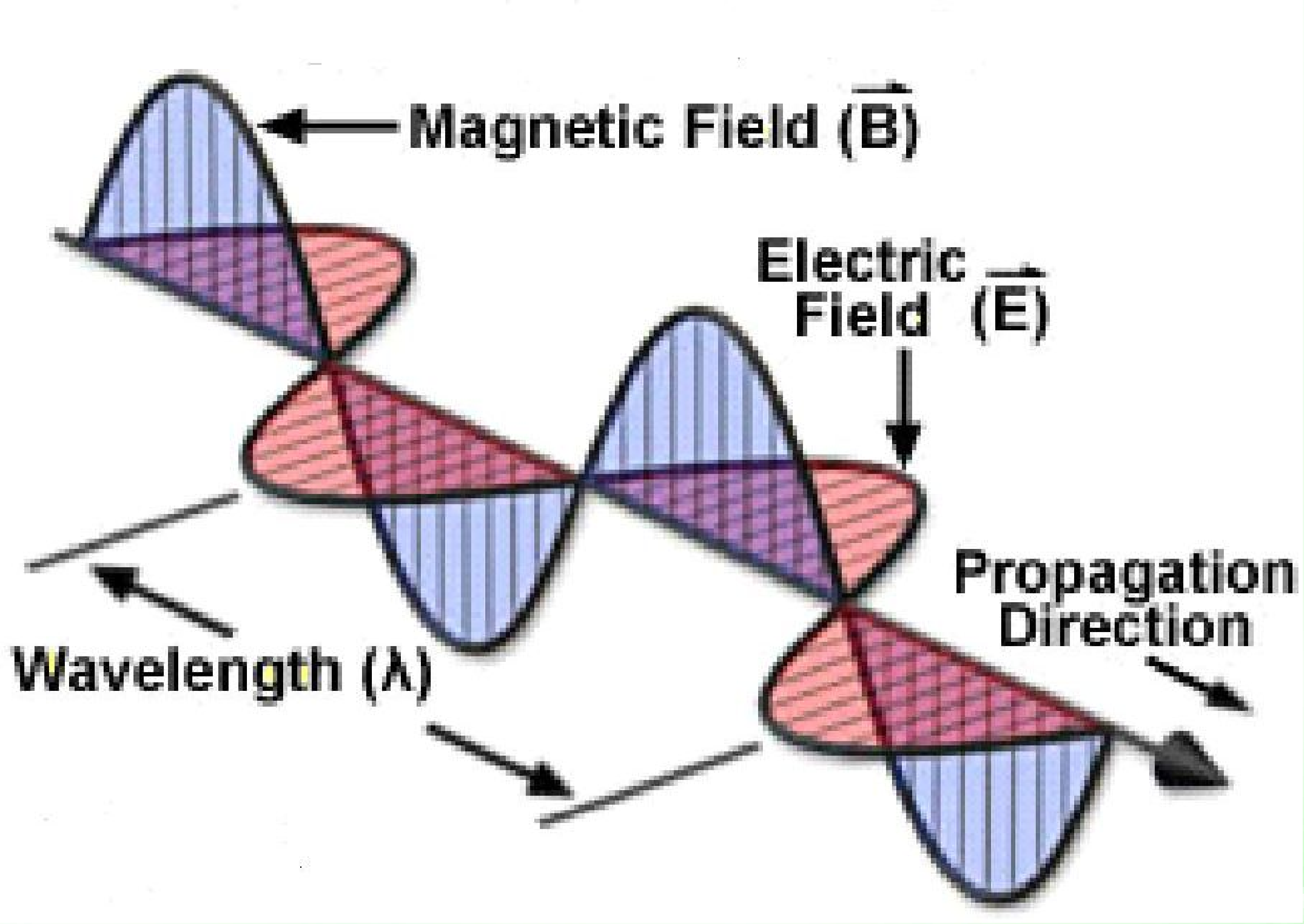
Electric field vector

Magnetic field vector





Electromagnetic Wave

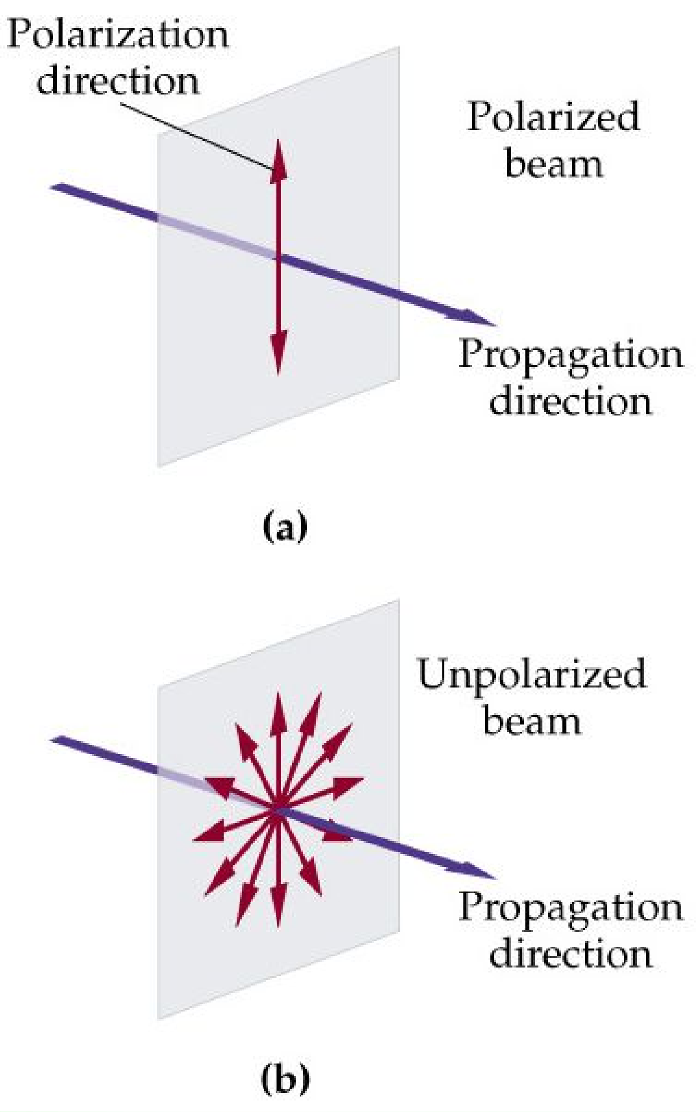


ORDINARY LIGHT

❑Unpolarized Light

- Contains large no.of atoms producing waves with particular orientation of electric vector E
- Resultant wave:unpolarized wave:superposition of waves vibrating in all possible directions

Polarized Light



Polarized Light

Vibrations lie on one single plane only.

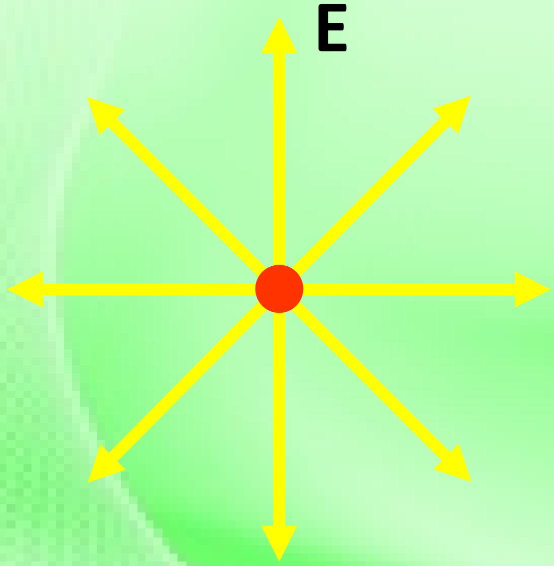
Unpolarized Light

Superposition of many beams, in the same direction of propagation, but each with random polarization.

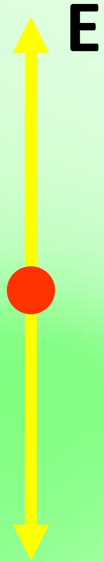
POLARIZATION

- Transforming unpolarized light into polarized light
- Restriction of electric field vector E in a particular plane so that vibration occurs in a single plane
- Characteristic of transverse wave
- Longitudinal waves can’t be polarized; direction of their oscillation is along the direction of propagation

Representation . . .

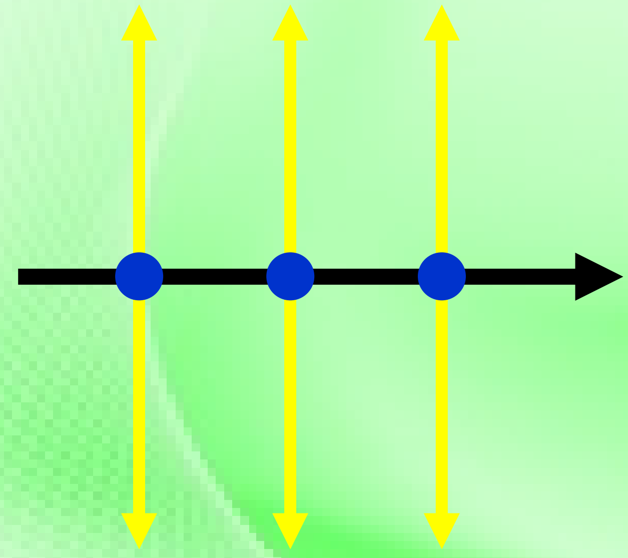


Unpolarized

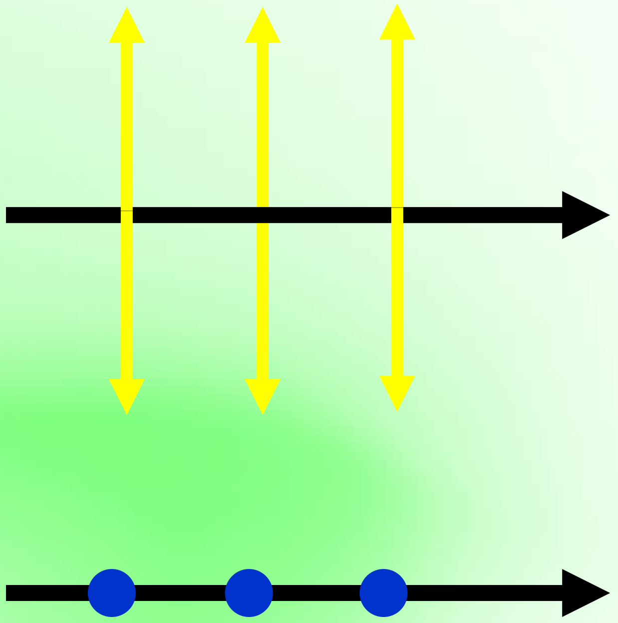


Polarized

Representation . . .



Unpolarized



Polarized

Mathematical description of the EM wave

Light wave that propagates in the z direction:

$$\boxed{\begin{aligned}\vec{E}_x(z,t) &= E_{0x}\cos(kz-\omega t)\,\hat{x}\\ \vec{E}_y(z,t) &= E_{0y}\cos(kz-\omega t+\varepsilon)\,\hat{y}\end{aligned}}$$

Graphical representation of the EM wave (I)

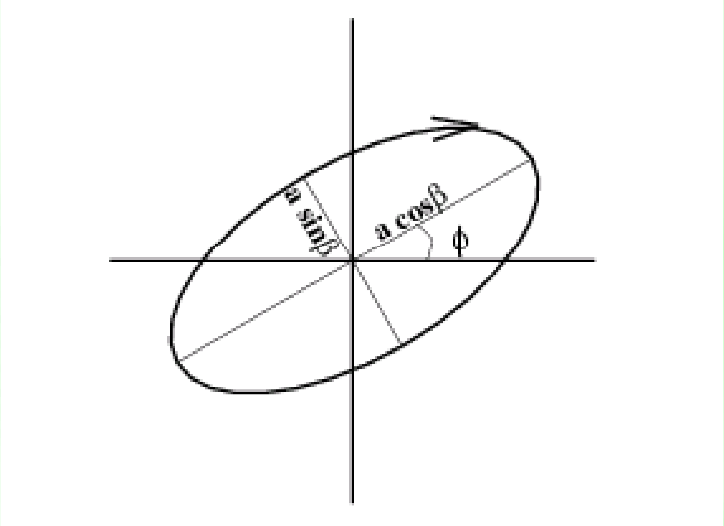
One can go from:

$$\vec{E}_x(z,t) = E_{0x}\cos(kz - \omega t)\,\hat{x}$$
$$\vec{E}_y(z,t) = E_{0y}\cos(kz - \omega t + \varepsilon)\,\hat{y}$$

to the equation of a… c identities, squaring, adding):

$$\left(\frac{E_x}{E_{0x}}\right)^2 + \left(\frac{E_y}{E_{0y}}\right)^2 - 2\frac{E_x}{E_{0x}}\frac{E_y}{E_{0y}}\cos\varepsilon = \sin^2\varepsilon$$

Graphical representation of the EM wave (II)



An ellipse can be represented by 4 quantities:

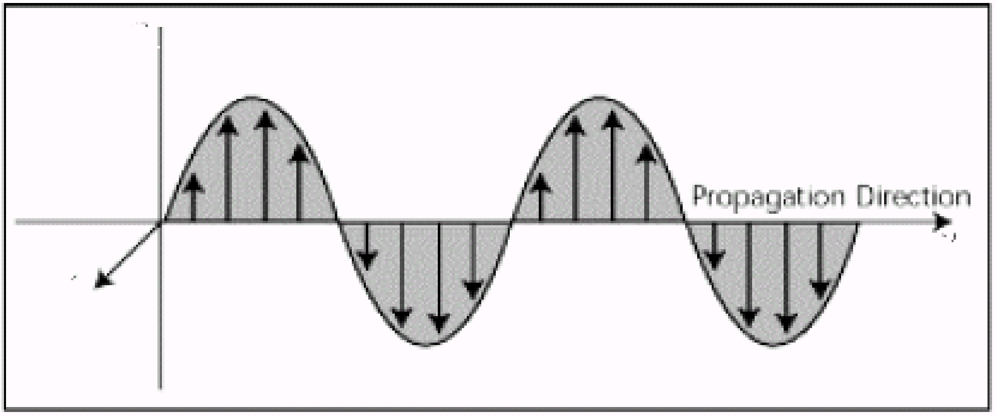
1. size of minor axis
2. size of major axis
3. orientation (angle)
4. sense (CW, CCW) (Clock Wise, Counter clock wise)

Light can be represented by 4 quantities...

Vertically polarized light

$$\vec{E}_x(z,t) = E_{0x}\cos(kz - \omega t)\,\hat{x}$$
$$\vec{E}_y(z,t) = E_{0y}\cos(kz - \omega t + \varepsilon)\,\hat{y}$$

If there is no amplitude in x (E_{0x} = 0), there is only one component, in y (vertical).



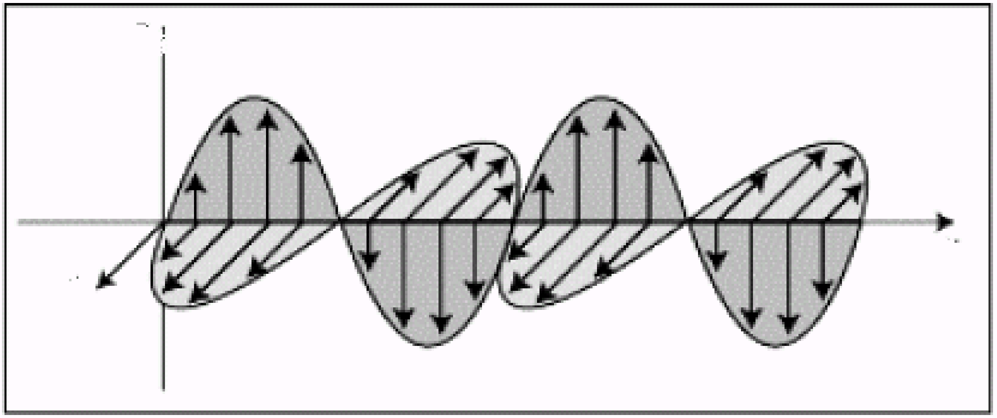
A. Linearly Polarized Light in the Vertical Direction

Polarization at 45º (I)

$$\vec{E}_x(z,t) = E_{0x}\cos(kz - \omega t)\,\hat{x}$$
$$\vec{E}_y(z,t) = E_{0y}\cos(kz - \omega t + \varepsilon)\,\hat{y}$$

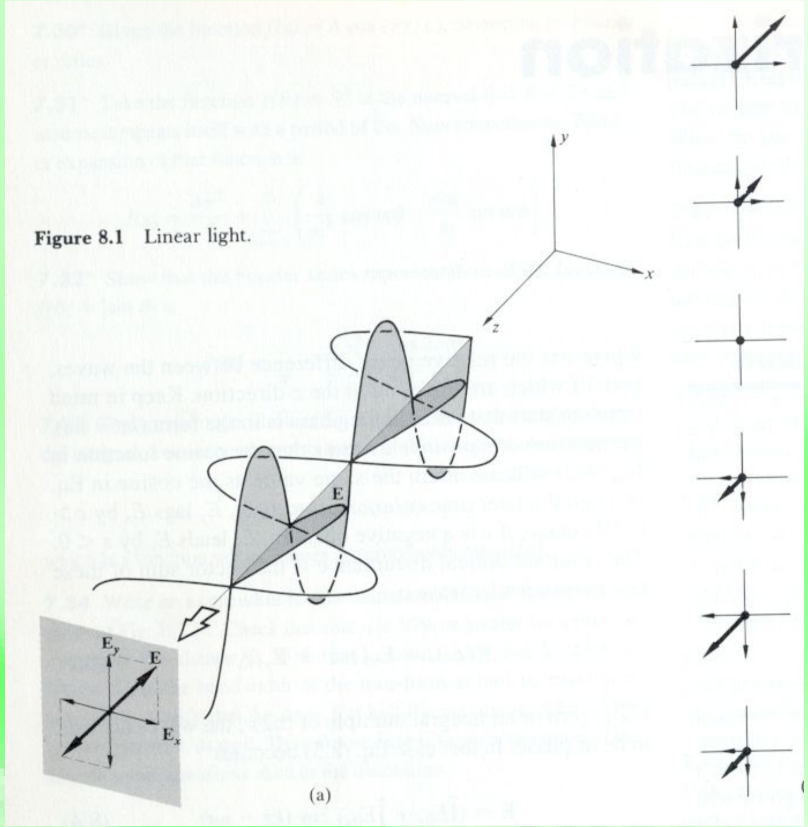
If there is no phase difference (ε=0) and

$E_{0x} = E_{0y}$, then $\mathbf{E}_x = \mathbf{E}_y$



B. Linearly Polarized Light at 45 Degrees

Polarization at 45º (II)



Circular polarization (I)

$$\boxed{\begin{aligned}\vec{E}_x(z,t) &= E_{0x}\cos(kz-\omega t)\,\hat{x}\\ \vec{E}_y(z,t) &= E_{0y}\cos(kz-\omega t+\varepsilon)\,\hat{y}\end{aligned}}$$

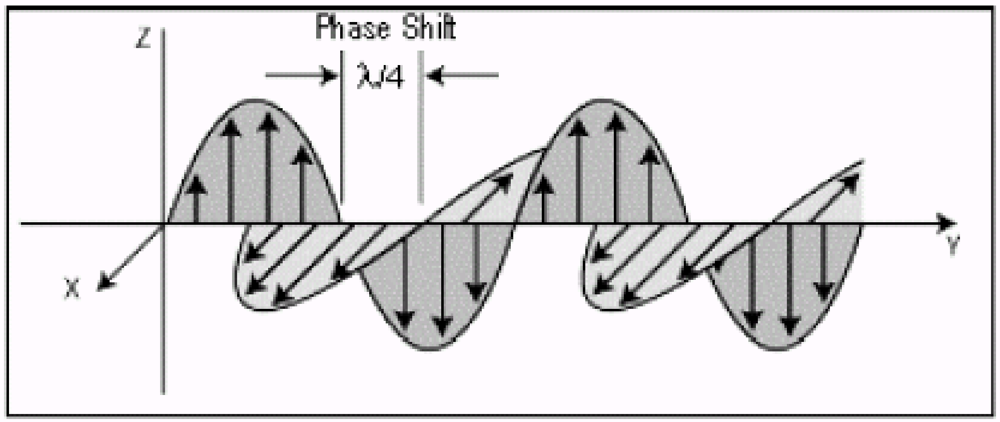
If the phase difference is $\varepsilon = 90º$ and $E_{0x} = E_{0y}$

then: $\mathbf{E_x} / \mathbf{E_{0x}} = \cos\Theta$, $\mathbf{E_y} / \mathbf{E_{0y}} = \sin\Theta$

and we get the equation of a circle:

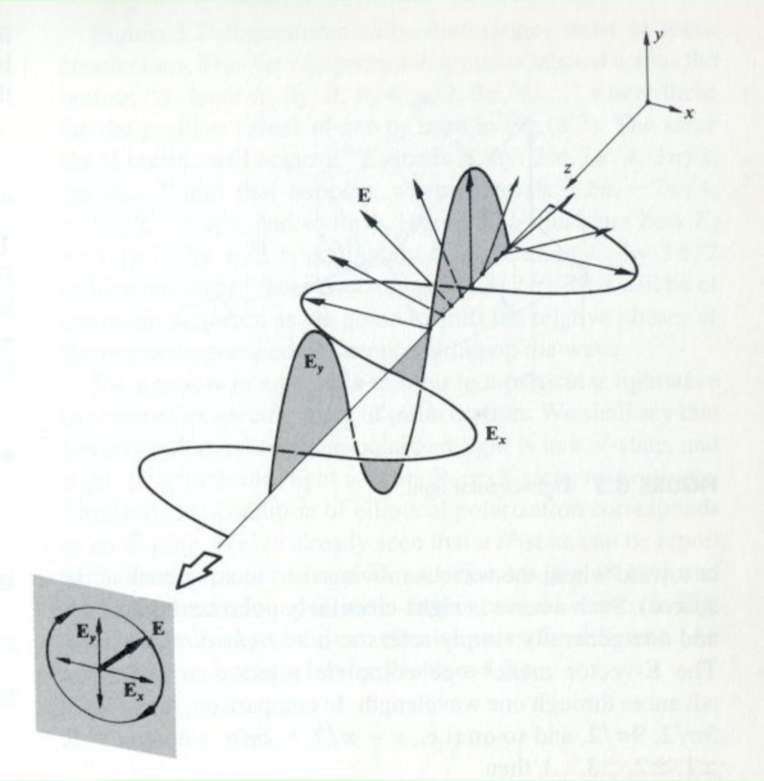
$$\left(\frac{E_x}{E_{0x}}\right)^2 + \left(\frac{E_y}{E_{0y}}\right)^2 = \cos^2\Theta + \sin^2\Theta = 1$$

Circular polarization (II)

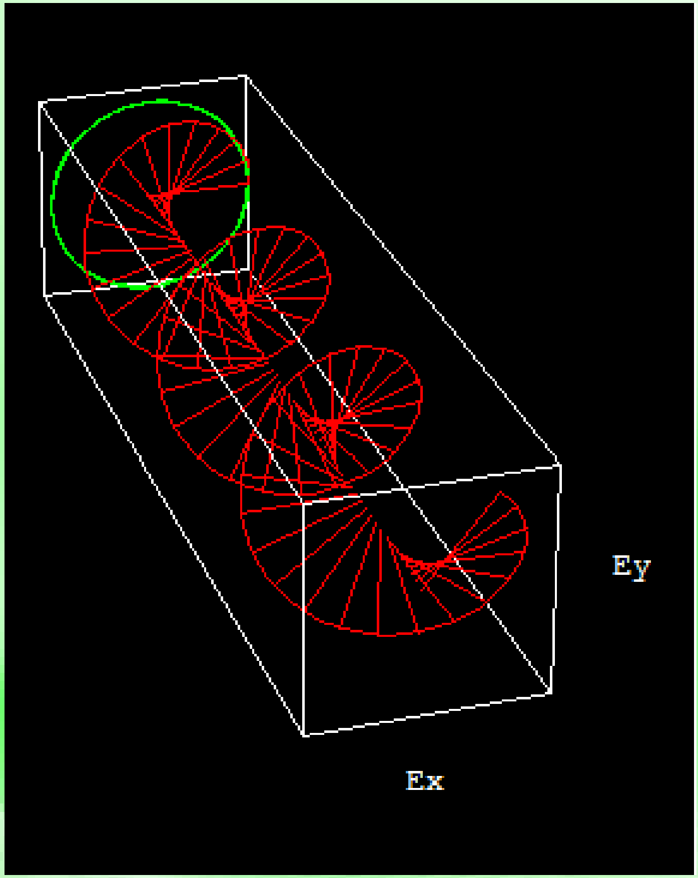


C. Circularly Polarized Light

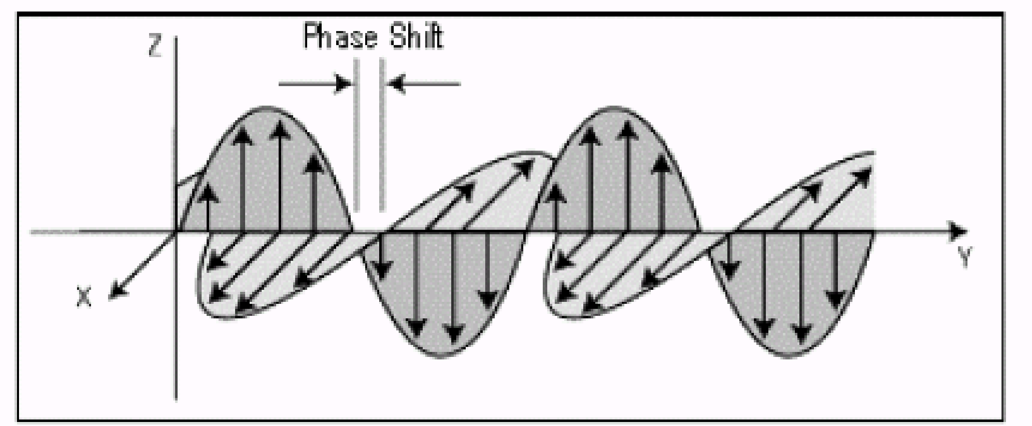
Circular polarization (III)



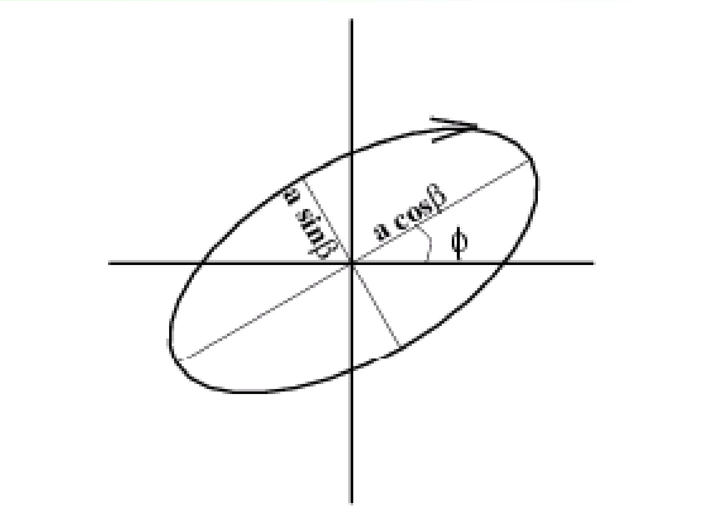
Circular polarization (IV)



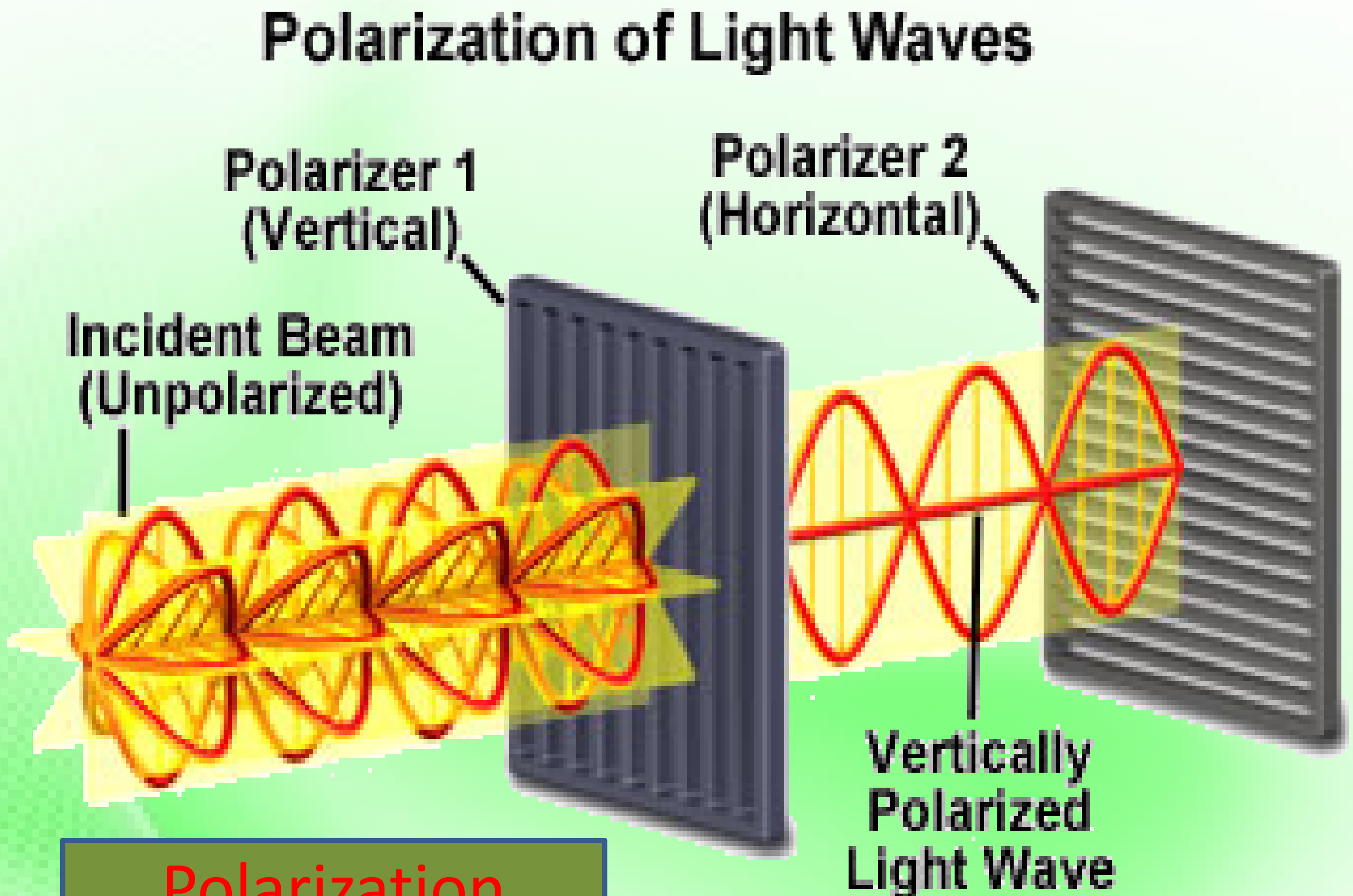
Elliptical polarization



D. Elliptically Polarized Light



- Linear + circular polarization = elliptical polarization



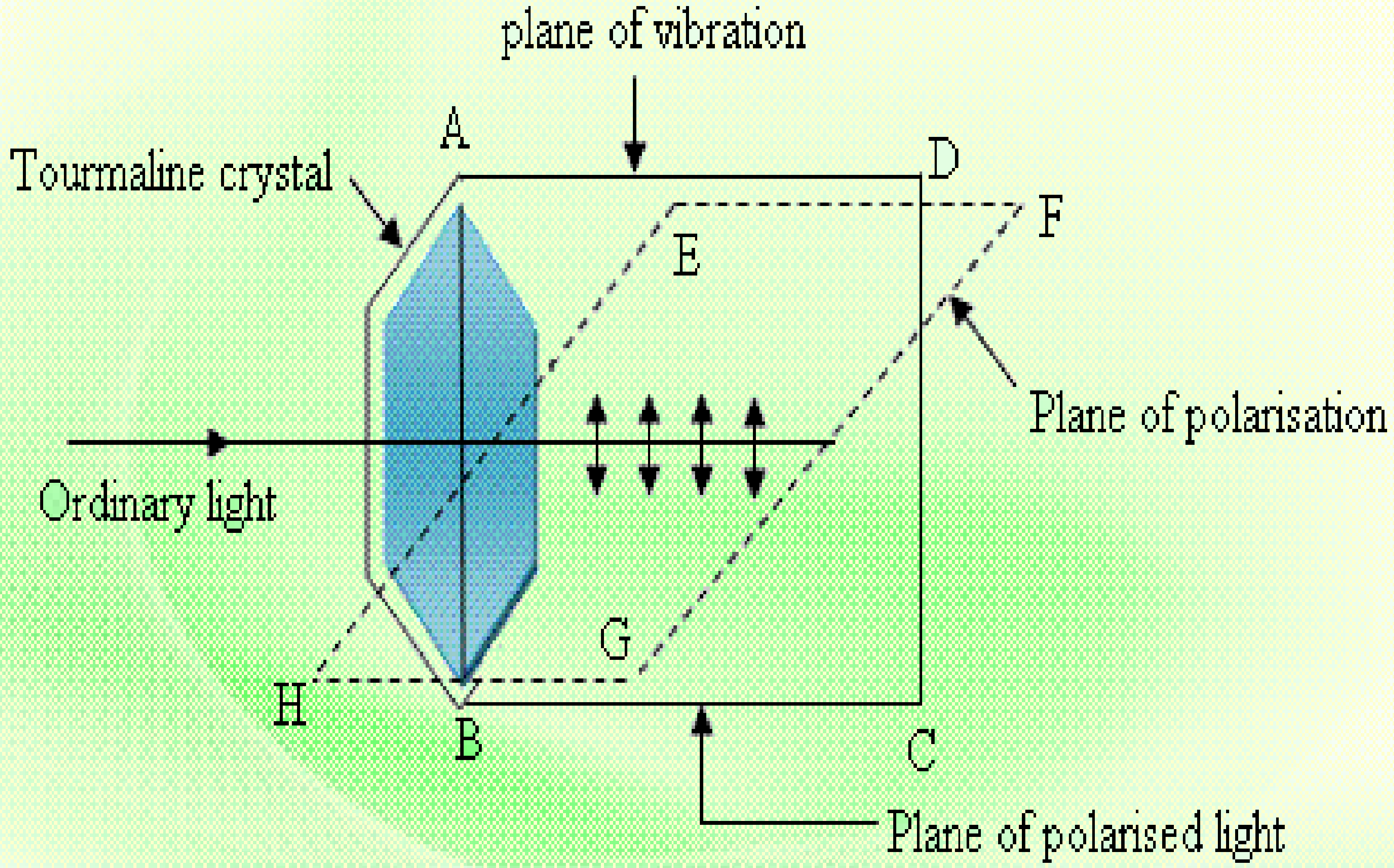
Polarization

Plane of vibration

A plane including the direction of light propagation and the direction of electric field

Plane of polarization

The plane perpendicular to the plane of vibration


plane of vibration
A
D
Tourmaline crystal
F
E
Plane of polarisation
Ordinary light
G
H
B
C
Plane of polarised light

Why only electric field vector is considered in polarization and not magnetic field vector?

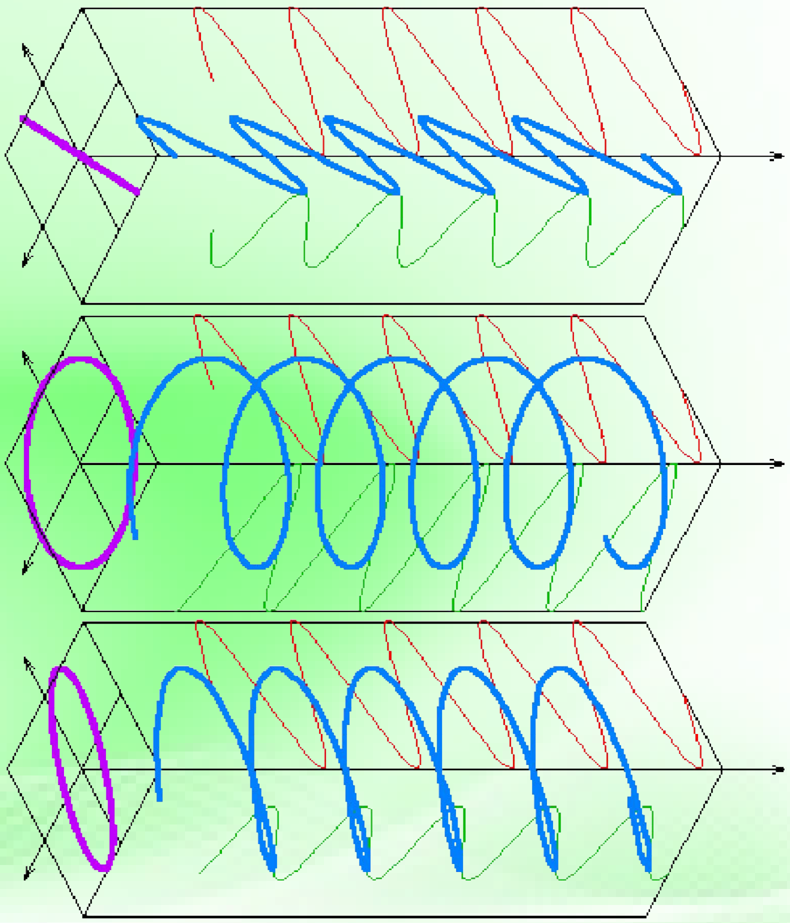
- Maxwell's Equation

  $E = c \times B$

- c is velocity of light($c=3 \times 10^{8}$ m/s),very large value
- E>>>B i.e. Em wave is predominantly an electric wave
- To change any characteristics of Em wave, including polarization,E should be affected

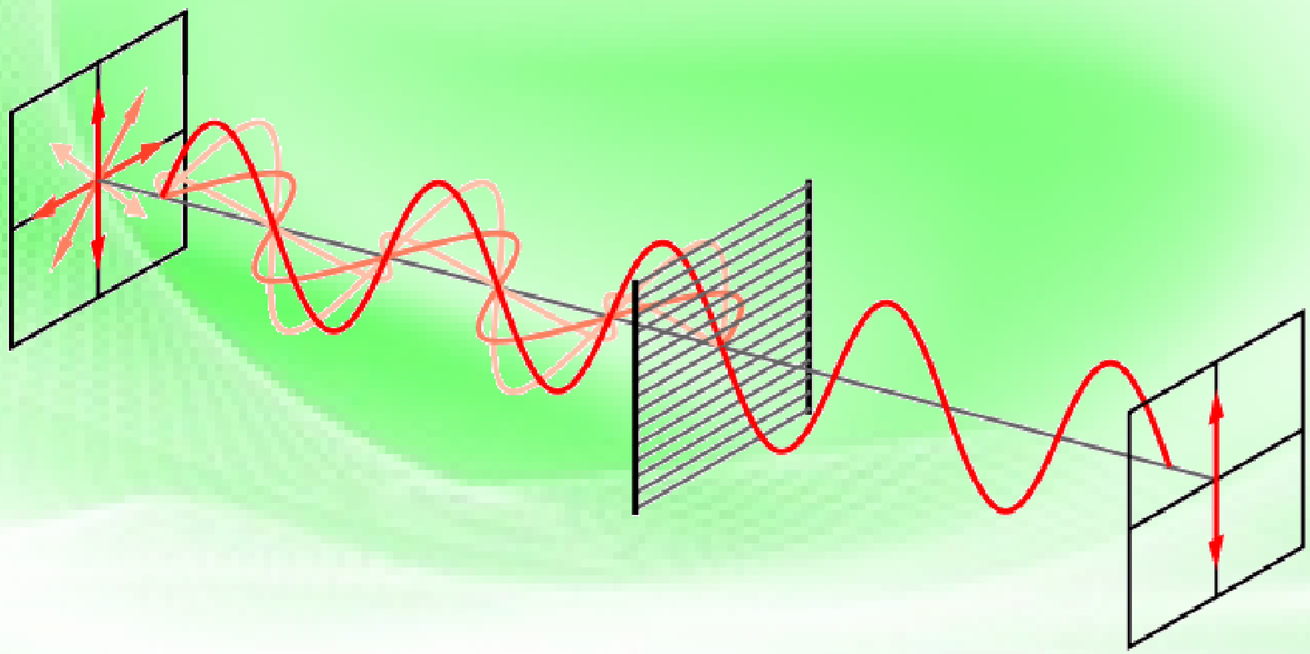
TYPES OF POLARIZATION

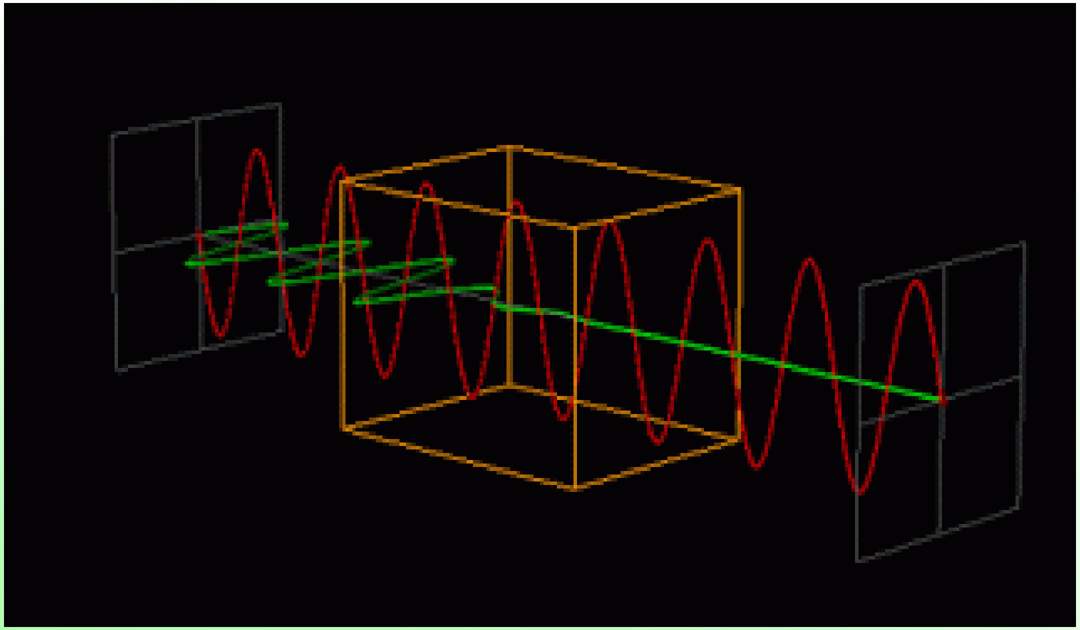
1. Linear Polarization
2. Circular Polarization
3. Elliptical Polarization



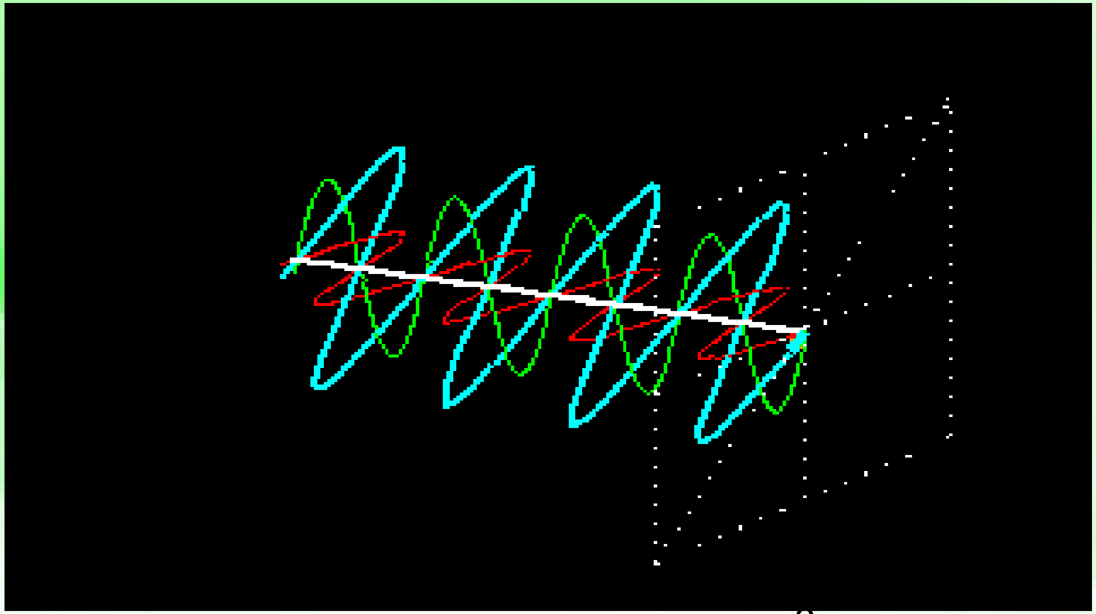
LINEAR POLARIZATION

- Plane polarized wave
- Electric field vector oscillates along a straight line in one plane





Resultant wave is linear in vertical plane



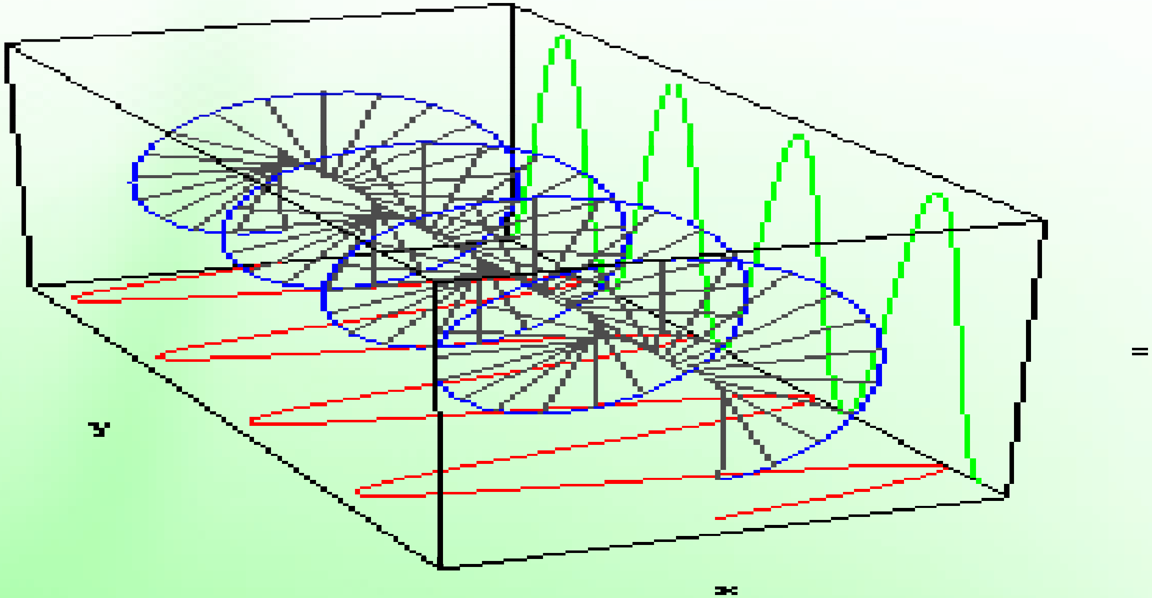
Resultant wave is linear in 45^0 plane

Superposition of plane polarized wave

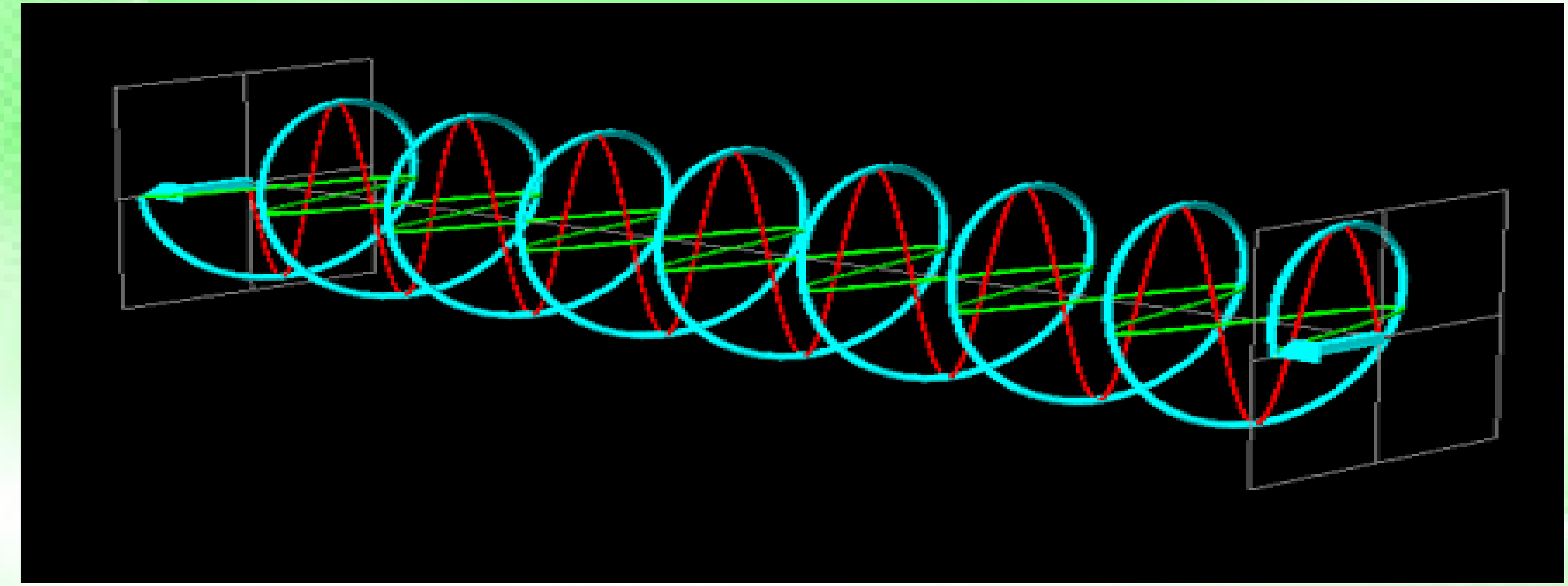
- Two plane polarized waves are added according to the rules of vector addition
- Results in a linear,elliptical or circular polarized wave depending on the amplitude and the phase shift between two waves

CIRCULAR POLARIZATION

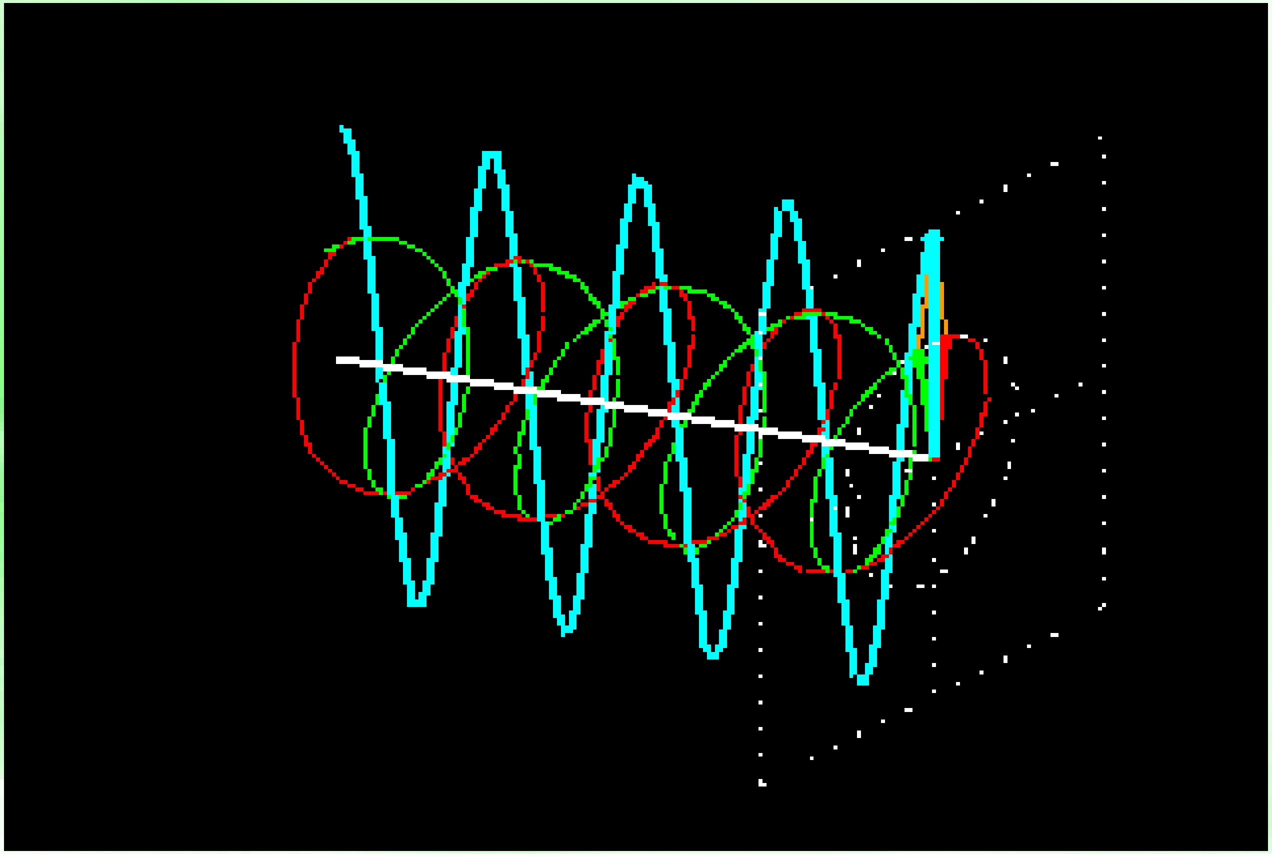
- Consists of two perpendicular plane Em waves with *equal amplitude* and 90^0 phase difference
- Plane of oscillation rotates around the propagation axis
- May be right circularly polarized(clockwise) or left circularly polarized(counterclockwise)



Blue wave is resultant circular polarized wave

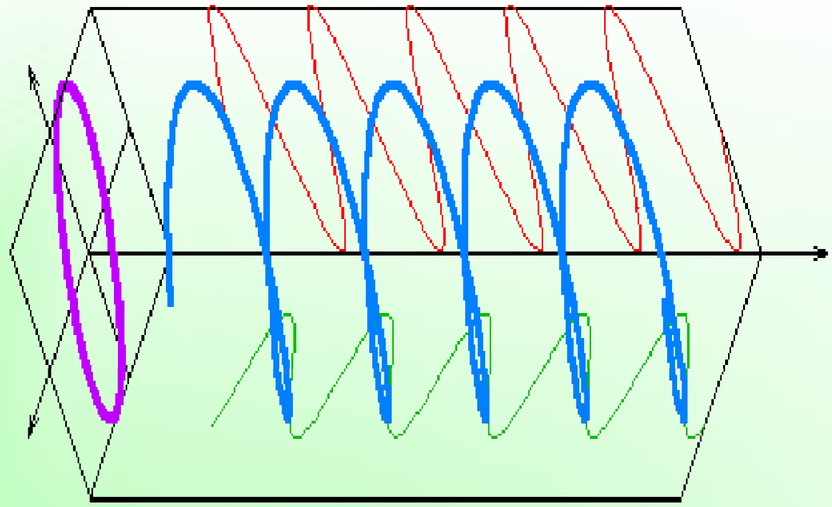


Superposition of oppositely polarized waves results in to plane polarized wave

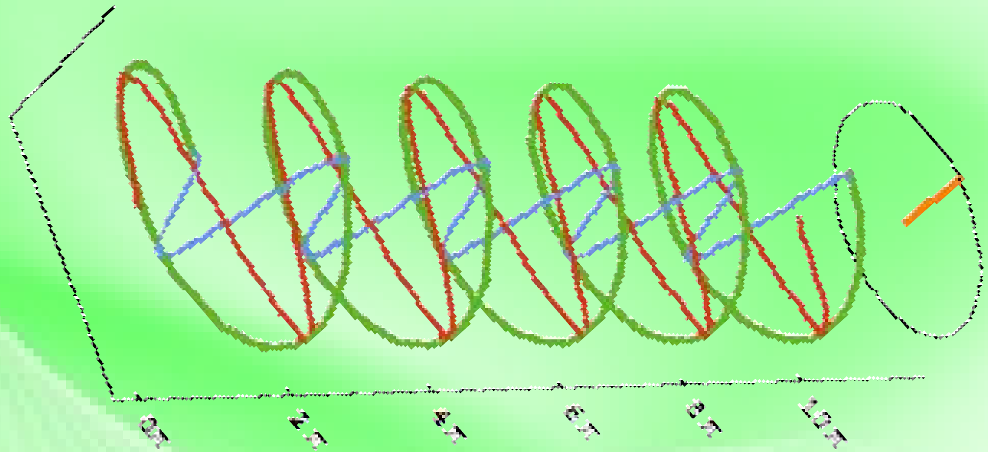


ELLIPTICAL POLARIZATION

- Consists of two perpendicular waves of *unequal amplitude* that differ in phase by 90^0
- The tip of the resultant electric field vector describes an ellipse in any fixed plane intersecting and normal to the direction of propagation
- Circular and linear polarization:special cases of elliptical polarization



Blue wave is resultant elliptical polarized wave



Green wave is resultant elliptical polarized wave

METHODS OF ACHIEVING POLARIZATION

1. Reflection
2. Scattering
3. Dichroism
4. Birefringence

POLARIZATION BY REFLECTION

- Unpolarized light can undergo polarization by reflection off of non metallic surfaces like snow, glass
- Incident angle is such that angle between reflected and refracted ray is 90^0
- Such incident angle is k/a polarizing angle or Brewster's angle
- Reflected ray is linearly polarized parallel to the reflecting surface

BREWSTER'S LAW

- When light is incident at polarizing angle:

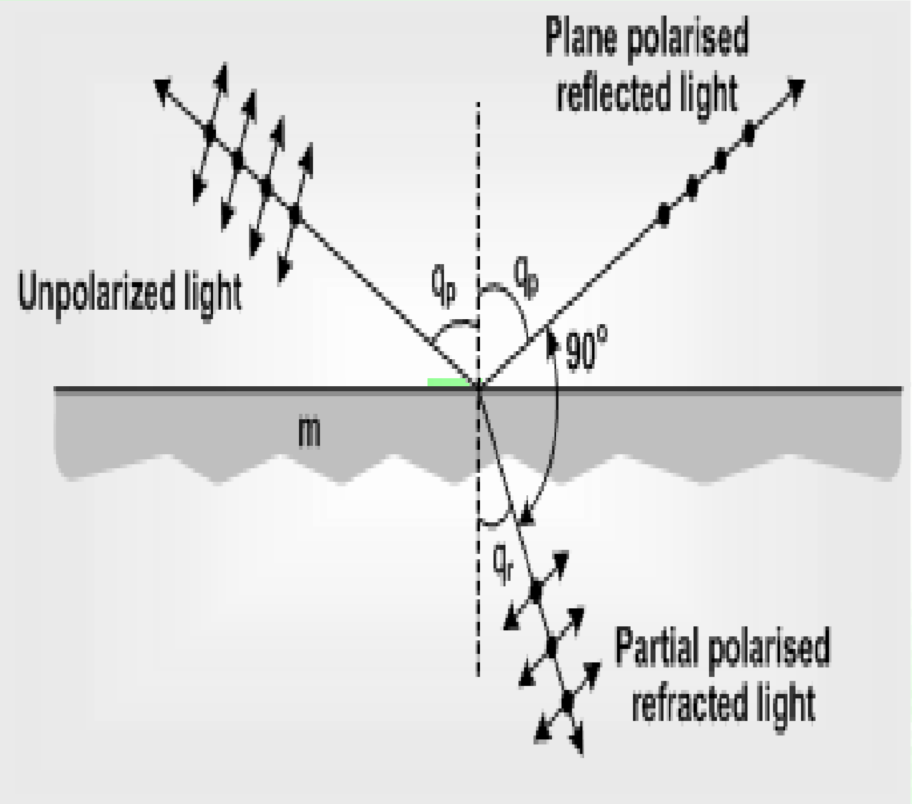
  The tangent of polarizing angle=Refractive index of material (Brewster's law)

  i.e, $\tan\theta = \mu$

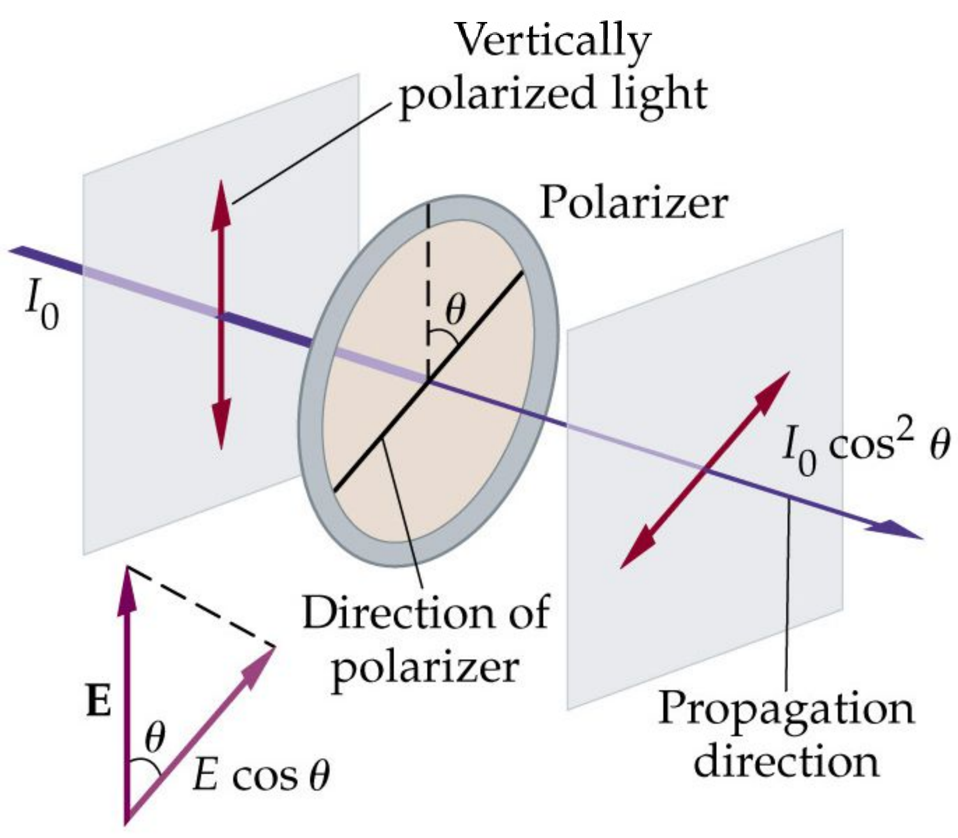
  For Sapphire, $\mu=1.77$

  So, $\theta=\tan^{-1}(1.77)=60.535^0$

- If the angle of incidence is not exactly the Brewster's angle the reflected ray will only be partially polarized



Polarizing Material

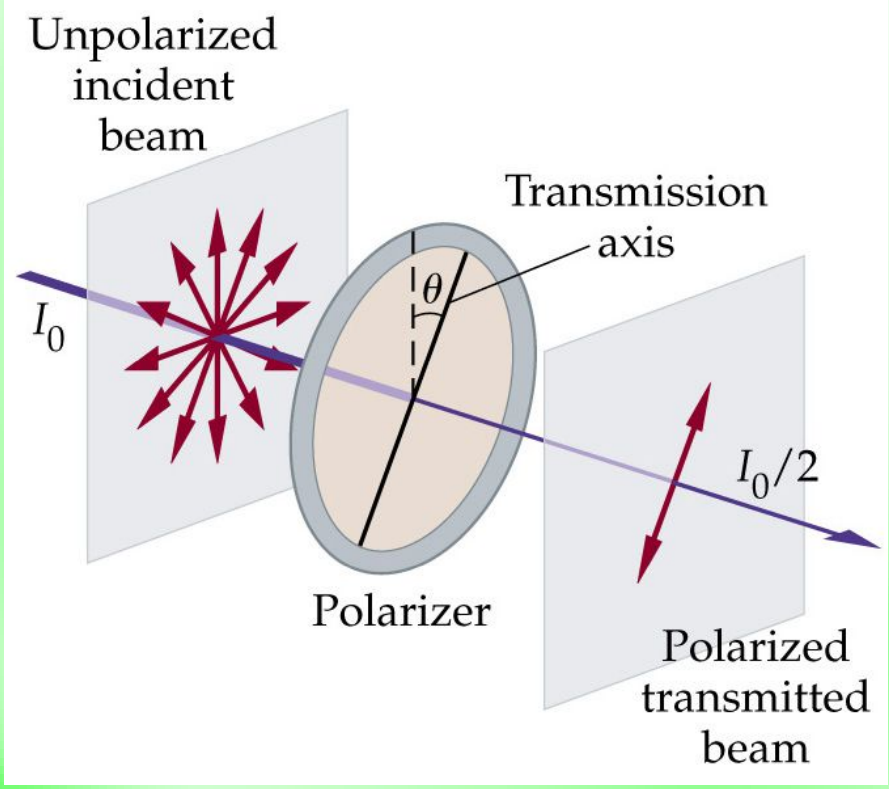


A Polarizing material will only allow the passage of that component of the electric field parallel to the polarization direction of the material

Malus Law

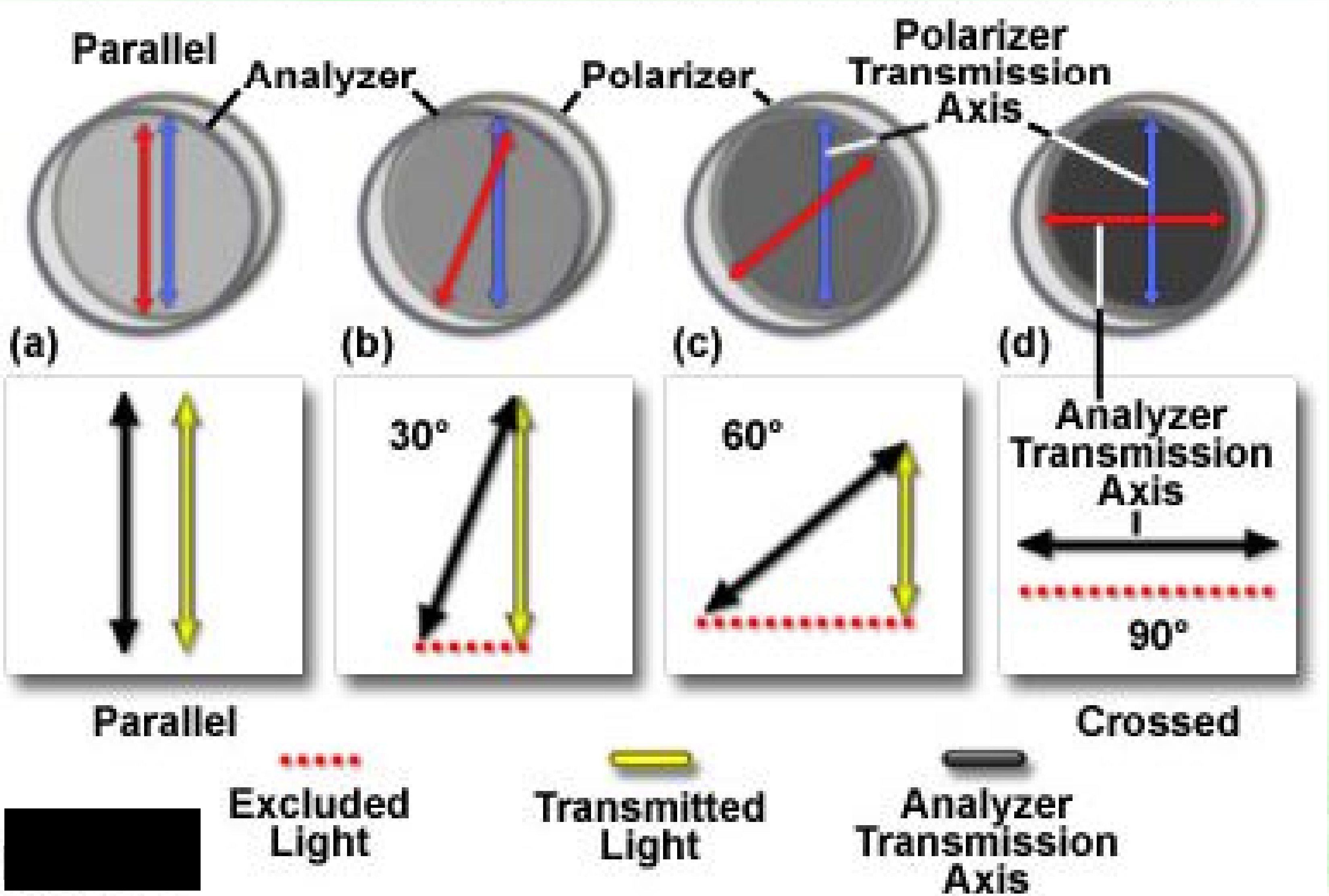
$$\boxed{I = I_0 \cos^2\theta}$$

Polarizer & Unpolarized Light



- Each wave is attenuated by factor $\cos^2\theta$.
- Average attenuation is $< \cos^2\theta > = 1/2$

Crossed at different angles . . .



Part II: Stokes parameters and Mueller matrices

- Stokes parameters, Stokes vector
- Stokes parameters for linear and circular polarization
- Stokes parameters and polarization P
- Mueller matrices, Mueller calculus
- Jones formalism

Stokes parameters

A little bit of history...

- 1669: Bartholinus discovers double refraction in calcite
- 17^{th} – 19^{th} centuries: Huygens, Malus, Brewster, Biot, Fresnel and Arago, Nicol...
- 19^{th} century: unsuccessful attempts to describe unpolarized light in terms of amplitudes
- 1852: Sir George Gabriel Stokes took a **very different approach** and discovered that polarization can be described in terms of **observables** using an **experimental definition**

Stokes parameters (I)

The polarization ellipse is only valid at a given instant of time (function of time):

$$\left(\frac{E_x(t)}{E_{0x}(t)}\right)^2 + \left(\frac{E_y(t)}{E_{0y}(t)}\right)^2 - 2\frac{E_x(t)}{E_{0x}(t)}\frac{E_y(t)}{E_{0y}(t)}\cos\varepsilon = \sin^2\varepsilon$$

To get the Stokes parameters, do a time average (integral over time) and a little bit of algebra...

Stokes parameters (II)

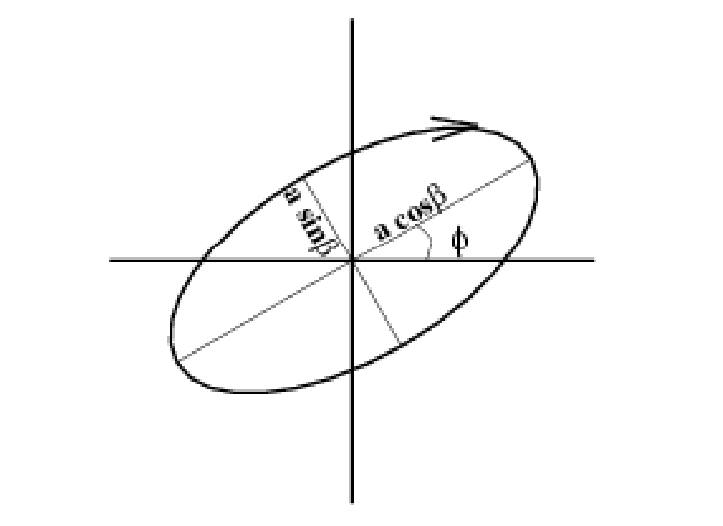
described in terms of the electric field

$$\left(E_{0x}^2 + E_{0y}^2\right)^2 - \left(E_{0x}^2 - E_{0y}^2\right)^2 - \left(2E_{0x}E_{0y}\cos\varepsilon\right)^2 = \left(2E_{0x}E_{0y}\sin\varepsilon\right)^2$$

The 4 Stokes parameters are:

$$\boxed{\begin{aligned} S_0 &= I = E_{0x}^2 + E_{0y}^2 \\ S_1 &= Q = E_{0x}^2 - E_{0y}^2 \\ S_2 &= U = 2E_{0x}E_{0y}\cos\varepsilon \\ S_3 &= V = 2E_{0x}E_{0y}\sin\varepsilon \end{aligned}}$$

Stokes parameters (III)
described in geometrical terms



$$\begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} = \begin{pmatrix} a^2 \\ a^2 \cos 2\beta \cos 2\phi \\ a^2 \cos 2\beta \sin 2\phi \\ a^2 \sin 2\beta \end{pmatrix}$$

Stokes vector

The Stokes parameters can be arranged in a Stokes vector:

$$\begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix} = \begin{pmatrix} E_{0x}^2 + E_{0y}^2 \\ E_{0x}^2 - E_{0y}^2 \\ 2E_{0x}E_{0y}\cos\varepsilon \\ 2E_{0x}E_{0y}\sin\varepsilon \end{pmatrix} = \begin{pmatrix} \text{intensity} \\ I(0°) - I(90°) \\ I(45°) - I(135°) \\ I(RCP) - I(LCP) \end{pmatrix}$$

- Linear polarization: $Q \neq 0, U \neq 0, V = 0$
- Circular polarization: $Q = 0, U = 0, V \neq 0$
- Fully polarized light: $I^2 = Q^2 + U^2 + V^2$
- Partially polarized light: $I^2 > Q^2 + U^2 + V^2$
- Unpolarized light: $Q = U = V = 0$

Pictorial representation of the Stokes parameters

$$\boxed{\frac{\Delta}{\Sigma}}$$

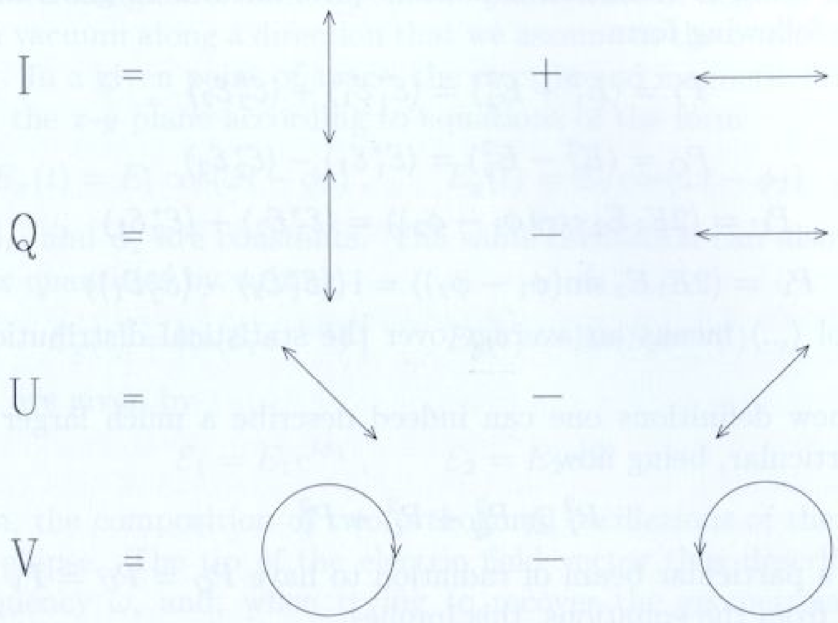


FIGURE 1. Pictorial representation of the Stokes parameters. The observer is supposed to face the radiation source.

Stokes vectors for linearly polarized light

LHP light

$$I_0\begin{pmatrix}1\\1\\0\\0\end{pmatrix}$$

LVP light

$$I_0\begin{pmatrix}1\\-1\\0\\0\end{pmatrix}$$

+45º light

$$I_0\begin{pmatrix}1\\0\\1\\0\end{pmatrix}$$

-45º light

$$I_0\begin{pmatrix}1\\0\\-1\\0\end{pmatrix}$$

Stokes vectors for circularly polarized light

RCP light

$$I_0\begin{pmatrix}1\\0\\0\\1\end{pmatrix}$$

LCP light

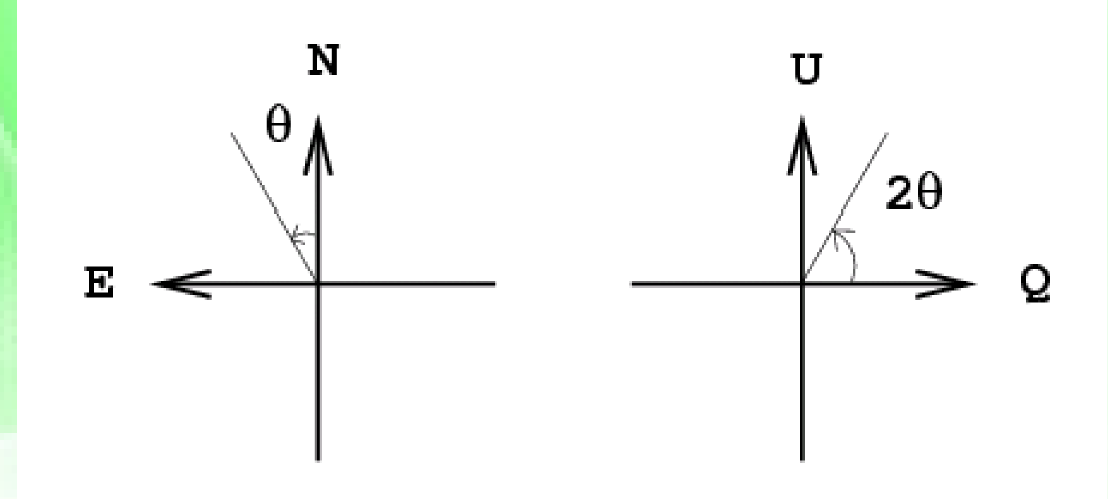
$$I_0\begin{pmatrix}1\\0\\0\\-1\end{pmatrix}$$

(Q,U) to (P,Θ)

In the case of linear polarization (V=0):

$$P = \frac{\sqrt{Q^2 + U^2}}{I} \qquad \Theta = \frac{1}{2}\arctan\left(\frac{U}{Q}\right)$$

$$Q = P\cos 2\Theta \qquad U = P\sin 2\Theta$$



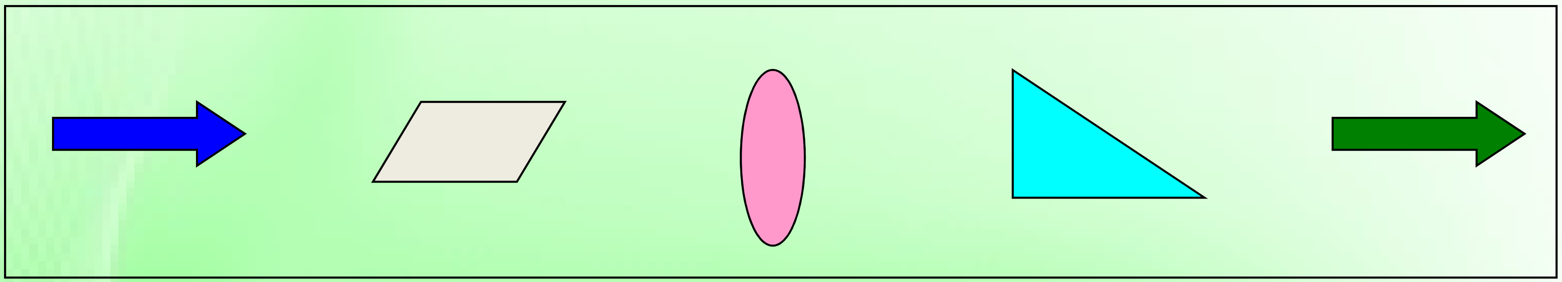
Mueller matrices

If light is represented by Stokes vectors, optical components are then described with Mueller matrices:

[output light] = [Muller matrix] [input light]

$$\begin{pmatrix} I' \\ Q' \\ U' \\ V' \end{pmatrix} = \begin{pmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \\ m_{41} & m_{42} & m_{43} & m_{44} \end{pmatrix} \begin{pmatrix} I \\ Q \\ U \\ V \end{pmatrix}$$

Mueller calculus (I)



Element 1 Element 2 Element 3

M_1 M_2 M_3

$$I' = M_3 M_2 M_1 I$$

Mueller calculus (II)

Mueller matrix **M’** of an optical component with Mueller matrix **M** rotated by an angle α:

M’ = R(- α**) M R(**α) with:

$$\mathrm{R}(\alpha)=\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & \cos 2\alpha & \sin 2\alpha & 0 \\ 0 & -\sin 2\alpha & \cos 2\alpha & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Jones formalism

Stokes vectors and Mueller matrices cannot describe interference effects. If the phase information is important (radio-astronomy, masers...), one has to use the Jones formalism, with complex vectors and Jones matrices:

• Jones vectors to describe the polarization of light:

$$\vec{J}(t) = \begin{pmatrix} \vec{E}_x(t) \\ \vec{E}_y(t) \end{pmatrix}$$

• Jones matrices to represent optical components:

$$J = \begin{pmatrix} j_{11} & j_{12} \\ j_{21} & j_{22} \end{pmatrix}$$

BUT: Jones formalism can only deal with 100% polarization...

DOUBLE REFRACTION

6.9. DOUBLE REFRACTION OR BIREFRINGENCE :

When a beam of unpolarized light is allowed to pass through a calcite (or quartz) crystal, it is split up into two refracted beams in place of the usual one as in glass. This phenomenon is known as *double refraction* and was first discovered by a Dutch philosopher *Erarmus Bartholinus* in the year 1669.

The phenomenon of double refraction can be illustrated in a simple manner. If an ink dot is made on a sheet of paper and is viewed through a calcite crystal, two images are observed. If now the crystal is rotated slowly as shown in Fig. (6.11*a*), one of the two images remains stationary while the second image rotates around the first. The image which remains stationary is known as the *ordinary image* and the refracted ray which produces this image is known as the *ordinary ray* (*O*–ray) as it obeys the ordinary laws of refraction. The second image which rotates round the first is known as the *extraordinary image* and the refracted ray which produces this image is known as the *extraordinary ray* (*E*–ray) as it does not obey the ordinary laws of refraction.

OPTIC AXIS

6.11. OPTIC AXIS :

A line passing through any of the blunt corners and equally inclined with the three faces, which meet there, *gives the direction of the optic axis of the crystal*. Any line parallel to this line is also an optic axis. If the rhombohedron is so cut that all its edges are equal as shown in Fig. (6.12), the line *CF* joining the opposite blunt corners or any line parallel to it gives the direction of the optic axis. The crystal is symmetrical about this axis. It may be noted that—

(i) Optic axis is a direction and not a particular line.

(ii) If a ray of light falls on the crystal along the optic axis or in a direction parallel to it, then it does not break up into ordinary (O) and extra ordinary (E) rays i.e., there is no double refraction along this direction. We may say that *E*-ray and *O*-ray travel with the same speed and in the same direction along the optic axis.

Crystals like calcite, quartz, tourmaline and nitre of soda have only one optic axis and, therefore, such crystals are called *uniaxial crystal*. There is another class of crystals such as borax, mica, argonite and selenite in which there are two directions of one uniform velocity and such crystals are known as *biaxial crystals*.

NICOL PRISM

6.14. NICOL PRISM :

It is *an ingenious optical device* made from calcite *for producing and analysing plane polarized light*. It was invented by William Nicol, in 1828, and is known as Nicol's prism or simply a Nicol after his name.

Nicol prism is *based for its action on the phenomenon of double refraction*. When light is passed through a double refracting crystal just as iceland spar (calcite), it is broken up into two refracted rays : (*i*) the ordinary ray with its vibrations perpendicular to the principal section of the crystal and (*ii*) the extra-ordinary ray with its vibrations parallel to the principal section. Both these rays are plane polarized but have their vibrations at right angles to each other. In order to get a beam of plane polarized light, one of these rays should be got rid off. The Nicol prism is designed in such a way so as to eliminate the ordinary ray by total internal reflection. Hence only the extra-ordinary ray is transmitted through the prism and we get plane polarized light with vibrations in the principal section of the crystal.

Construction. A calcite crystal with length DH three times the breadth DB is taken [Fig. (6.15)]. Its end faces are grounded in such a way that $\angle BDH$ and $\angle BFH$ become equal to 68° instead of $\angle B'DH'$ and $\angle BFH'$ which are 71° in the natural crystal. The crystal is then cut along BH perpendicular to the principal section of the crystal as well as the end faces BD and FH. These two pieces are grounded and polished optically flat and again cemented together by a layer of Canada balsam, which is a clear transparent substance whose refractive index lies midway between the refractive indices of calcite for the O-ray and E-ray. The values of these for sodium yellow light of mean wavelength $\lambda = 5893$ Å are :

Refractive index of calcite for O-rays $\mu_0 = 1{\cdot}658$

Refractive index of Canada balsam $\mu_0 = 1{\cdot}55$

Refractive index of calcite for E-ray $\mu_e = 1{\cdot}486$.

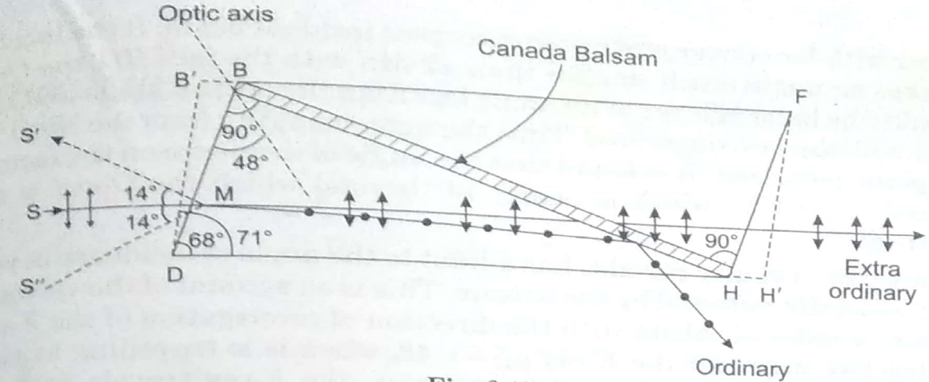


Fig. 6.15.

The action of Nicol prism.

When a ray of light is incident on this prism parallel to *DH*, it gives rise to ordinary and extra-ordinary rays. The Canada balsam, as explained above, is more dense than calcite for the *E*-ray while less dense for the *O*-ray. Hence when the *O*-ray reaches the layer of Canada balsam, it is travelling from an optically denser to a rarer medium and is, therefore, totally reflected when the angle of incidence is greater than a certain critical value (critical angle). This reflected ray is absorbed by the tube containing the crystal which is coated black. The extra-ordinary ray is not affected as it travels from an optically rarer medium to a denser medium and, therefore, *E*-ray is transmitted through the prism.

The angle of incidence on the Canada balsam layer depends upon the angle which the edge *BD* makes with the blunt edge *DH* and also on the breadth to length ratio of the crystal. It is for this reason that the *natural angle* 71° *is reduced to* 68° and a crystal with *length about three times its width is* chosen. *This enables the O-ray to fall at the Canada balsam layer at an angle greater than the critical angle*. If θ is the critical angle for the *O*-ray, then since refractive index of *O*-ray with respect to Canada balsam (μ) is equal to $\frac{1.658}{1.55}$, we have

$$\sin\ \theta = \frac{1}{\mu} = \frac{1.55}{1.658}$$

or

$$\theta = \sin^{-1} \frac{1.55}{1.658} = 69°.$$

Hence if the angle of incidence for the *O*-ray is greater than 69°, it is totally internally reflected and then absorbed. Thus only the *E*-ray is transmitted and *we are able to get a single beam of plane polarized light* with vibrations parallel to the principal section. Thus Nicol prism acts as a *polarizer*.

...ffective only with a

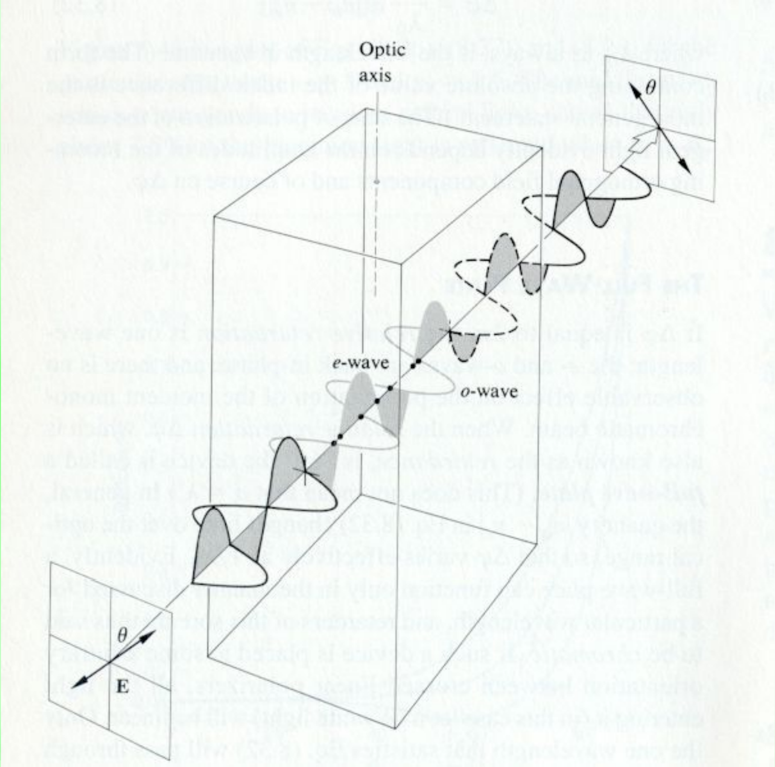
Retarders

- In retarders, one polarization gets 'retarded', or delayed, with respect to the other one. There is a final phase difference between the 2 components of the polarization. Therefore, the polarization is changed.
- Most retarders are based on birefringent materials (quartz, mica, polymers) that have different indices of refraction depending on the polarization of the incoming light.

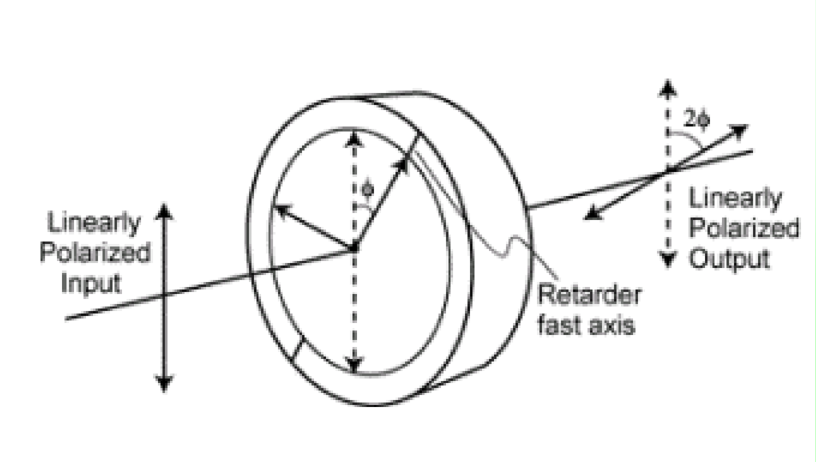
Half-Wave plate (I)

- Retardation of ½ wave or 180º for one of the polarizations.

- Used to flip the linear polarization or change the handedness of circular polarization.

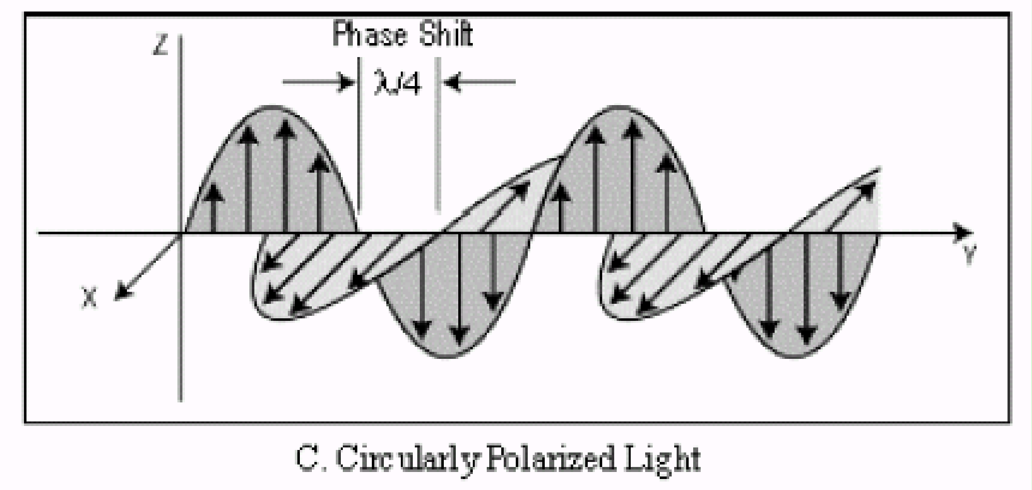


Half-Wave plate (II)



Quarter-Wave plate (I)

- Retardation of ¼ wave or 90º for one of the polarizations

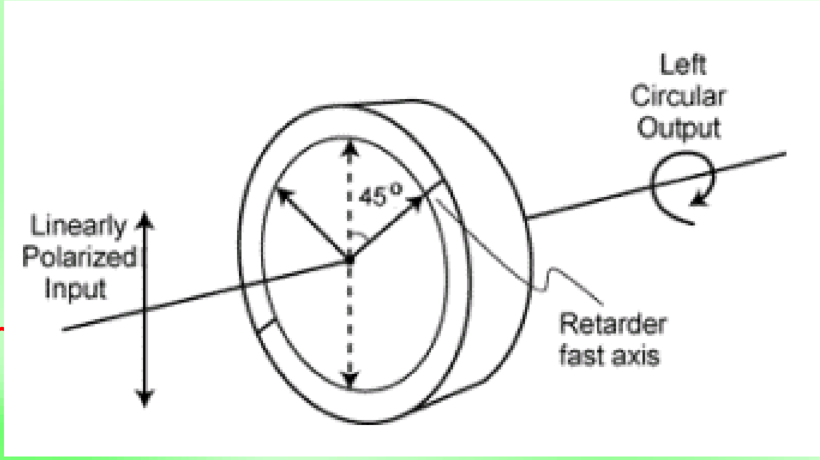


- Used to convert linear polarization to elliptical.

Quarter-Wave plate (II)

- Special case: incoming light polarized at 45º with respect to the retarder's axis

- Conversion from linear



Mueller matrix of retarders (I)

- Retarder of retardance τ and position angle ψ:

$$\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & G + H\cos 4\psi & H\sin 4\psi & -\sin\tau\sin 2\psi \\ 0 & H\sin 4\psi & G - H\cos 4\psi & \sin\tau\cos 2\psi \\ 0 & \sin\tau\sin 2\psi & -\sin\tau\cos 2\psi & \cos\tau \end{pmatrix}$$

$$\text{with}: G = \frac{1}{2}(1+\cos\tau) \quad \text{and} \quad H = \frac{1}{2}(1-\cos\tau)$$

Mueller matrix of retarders (II)

- Half-wave oriented at 0º or 90º

$$k\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

- Half-wave oriented at ± 45º

$$k\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & -1 \end{pmatrix}$$

Mueller matrix of retarders (III)

- Quarter-wave oriented at 0º

$$k\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & -1 & 0 \end{pmatrix}$$

- Quarter-wave oriented at ±45º

$$k\begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & \mu 1 \\ 0 & 0 & 1 & 0 \\ 0 & \pm 1 & 0 & 0 \end{pmatrix}$$

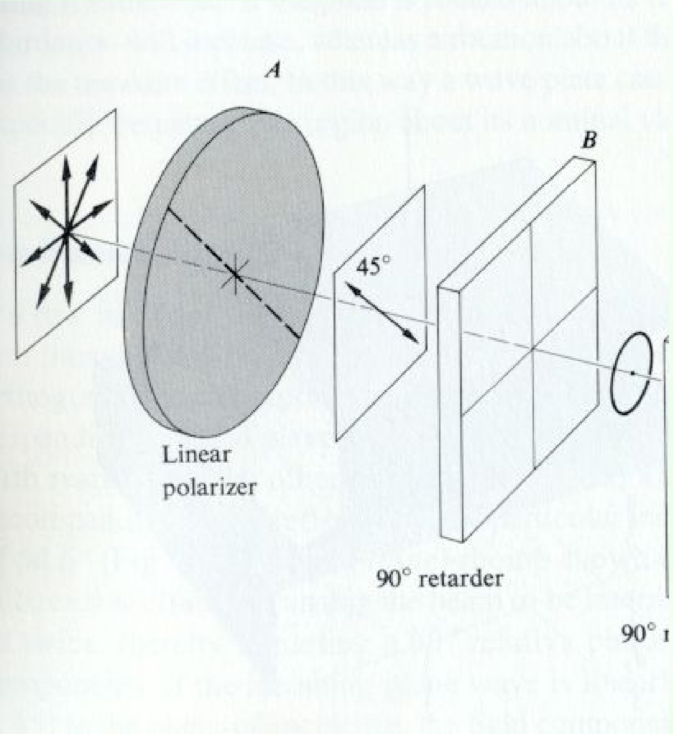
Mueller calculus with a retarder

- Input light linear polarized (Q=1)
- Quarter-wave at +45º
- Output light circularly polarized (V=1)

$$\begin{pmatrix} I' \\ Q' \\ U' \\ V' \end{pmatrix} = k \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -1 \\ 0 & 0 & 1 & 0 \\ 0 & +1 & 0 & 0 \end{pmatrix} \begin{pmatrix} 1 \\ 1 \\ 0 \\ 0 \end{pmatrix} = k \begin{pmatrix} 1 \\ 0 \\ 0 \\ 1 \end{pmatrix}$$

(Back to polarizers, briefly)
Circular polarizers

- Input light: unpolarized --- Output light: circularly polarized
- Made of a linear polarizer glued to a quarter-wave plate oriented at 45º with respect to one another.



Achromatic retarders (I)

- Retardation depends on wavelength
- Achromatic retarders: made of 2 different materials with opposite variations of index of refraction as a function of wavelength
- Pancharatnam achromatic retarders: made of 3 identical plates rotated w/r one another
- Superachromatic retarders: 3 pairs of quartz and MgF_2 plates

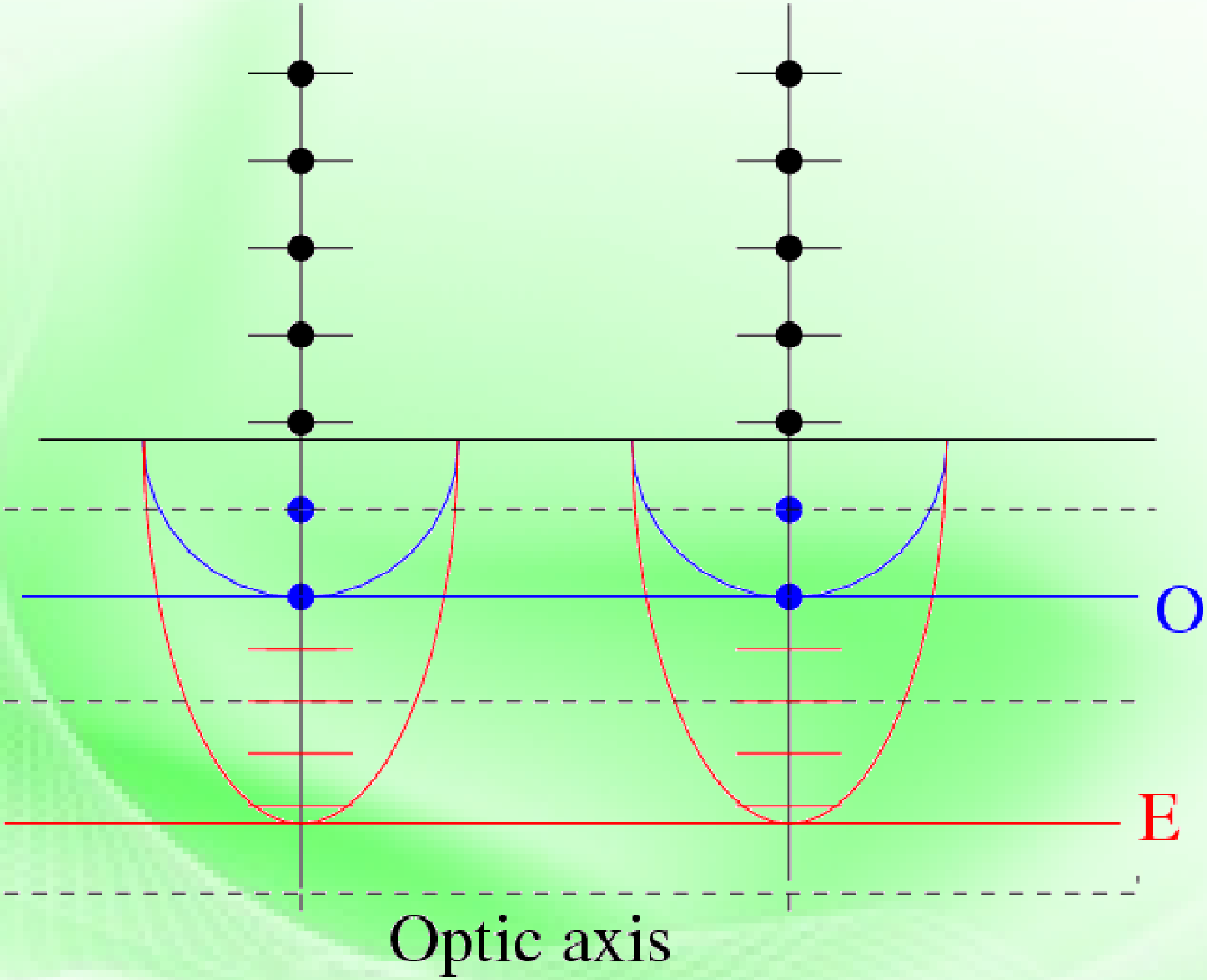
WAVEPLATES

PLATE RETARDERS

Waveplate (Retarders)

A **wave plate** or **retarder** is an optical device that alters the polarization state of a light wave traveling through it.

- Full Wave Plate
- Half Wave Plate
- Quarter Wave Plate


O
E
Optic axis

Optical path length

$$\Lambda = t\left|n_0 - n_e\right|$$

Phase difference

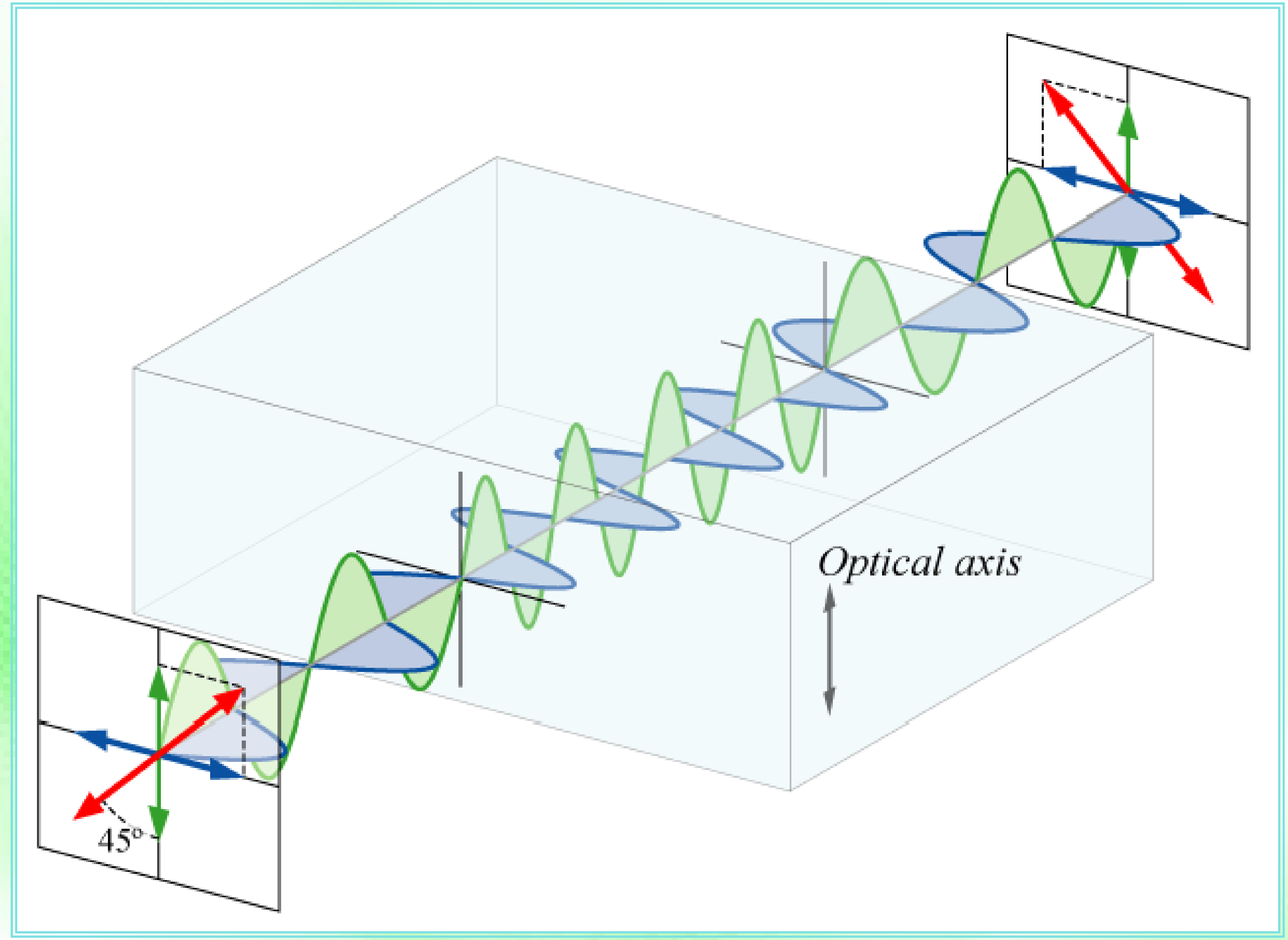
$$\Delta\phi = \frac{2\pi}{\lambda_0} t\left|n_0 - n_e\right|$$

Quarter wave, Half wave and Full wave

$$\Lambda = \quad \frac{\lambda}{4} \qquad \frac{\lambda}{2} \qquad \lambda$$

$$\delta = \quad \frac{\pi}{2} \qquad \pi \qquad 2\pi$$

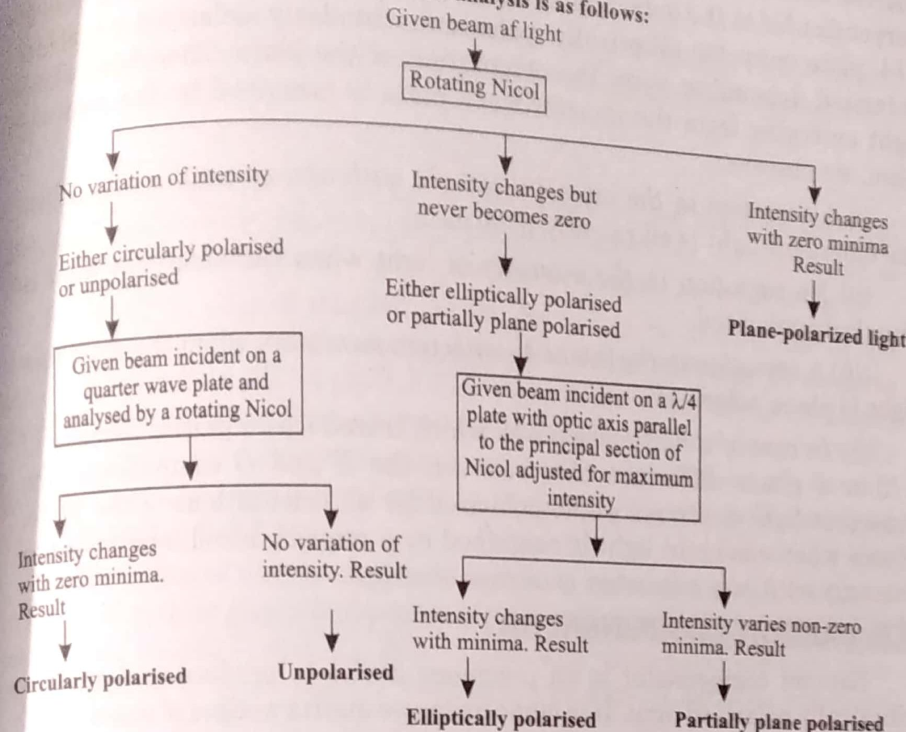
Half-Wave Plate



Desired Result	Method
Change linear polarization to circular polarization	Insert a λ/4 plate with axis at 45° to the input polarization
Change circular polarization to linear	Insert a λ/4 plate with axis at 45° to the desired output polarization.
Change the handedness of circular polarization	Insert a λ/2 plate – orientation unimportant.
Rotate linear polarization to a more desirable orientation	Insert a λ/2 plate with axis at ½ the desired rotation.

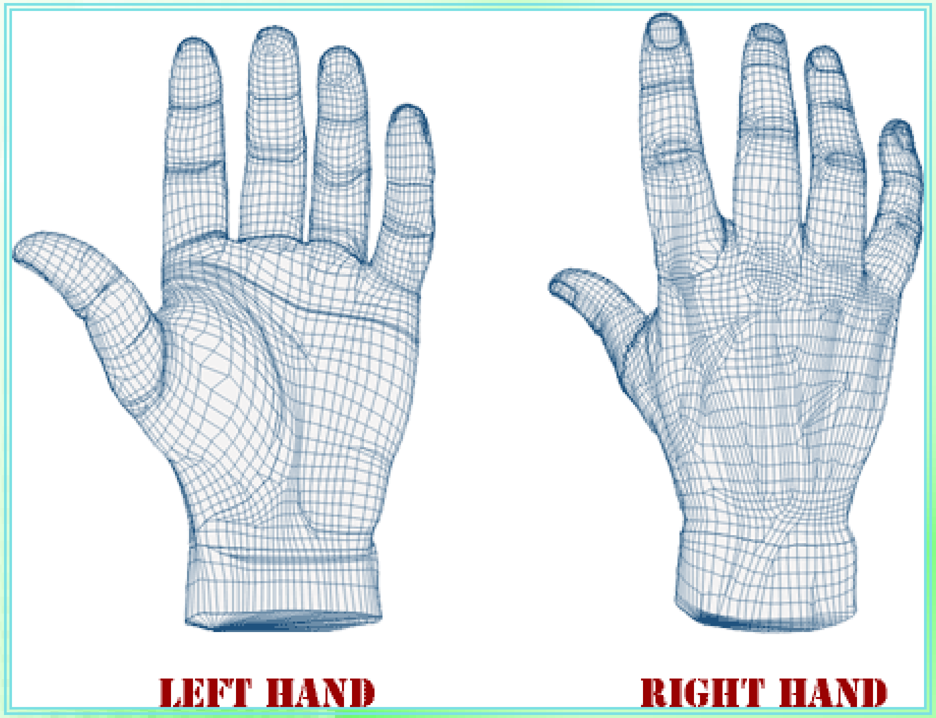
These results have been summarized :

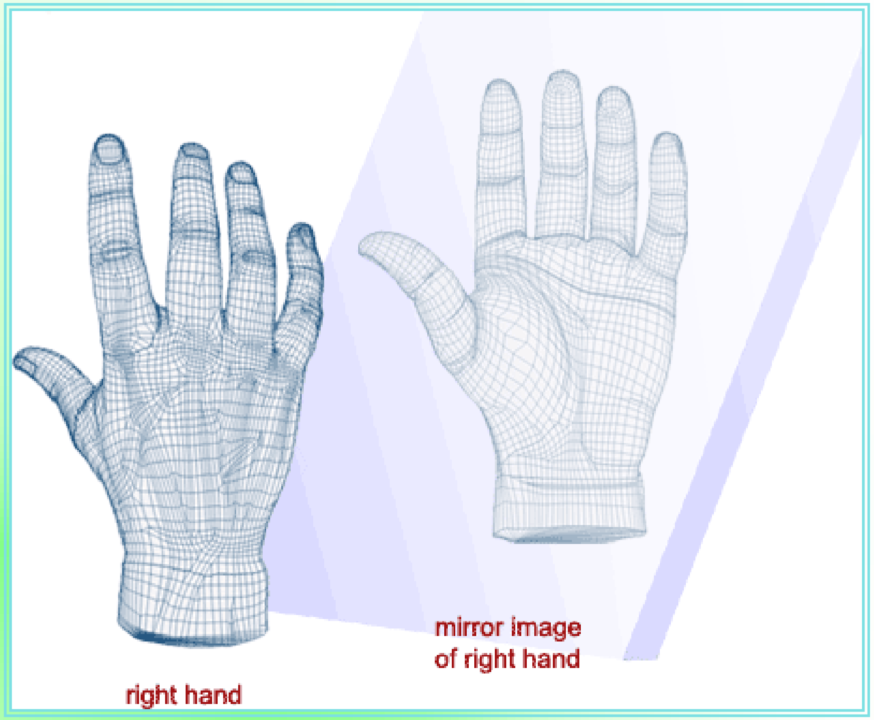
Summary of the analysis is as follows:



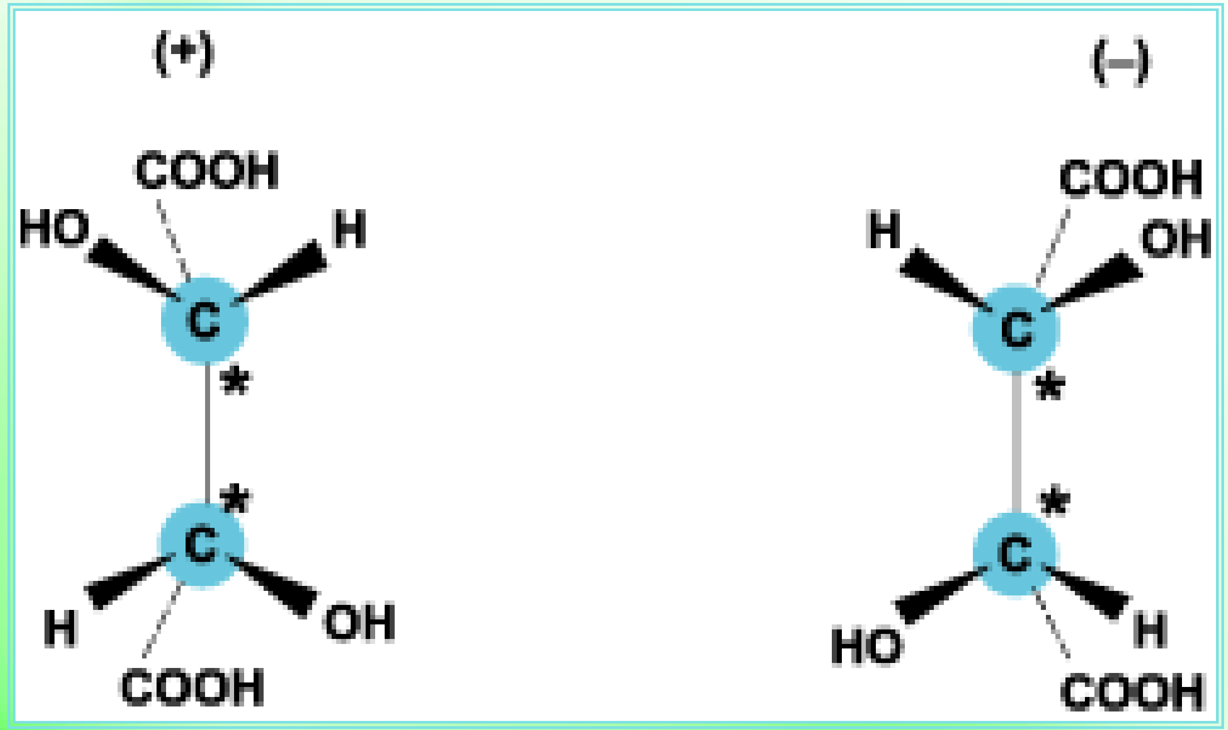
The described tests of analysis of polarised light, which have been summarised ahead in the form of a line sketch, are primarily based on the working of Nicol prism and quarter wave plate. However, the working of both, Nicol prism and $\frac{\lambda}{4}$ plate, is based on the phenomenon of *double refraction*. The phenomenon of *total internal reflection* is employed to make a Nicol prism to act as polariser and analyser; while the appropriate *orientation of optic axis* with the plane of $\frac{\lambda}{4}$ plate is employed as the basis to provide maximum birefringence $(\mu_0 \sim \mu_E)$. It shows that the basic principles involved are the foundation of all empirical and experimental measurements together with the allied analysis.

Optical Activity

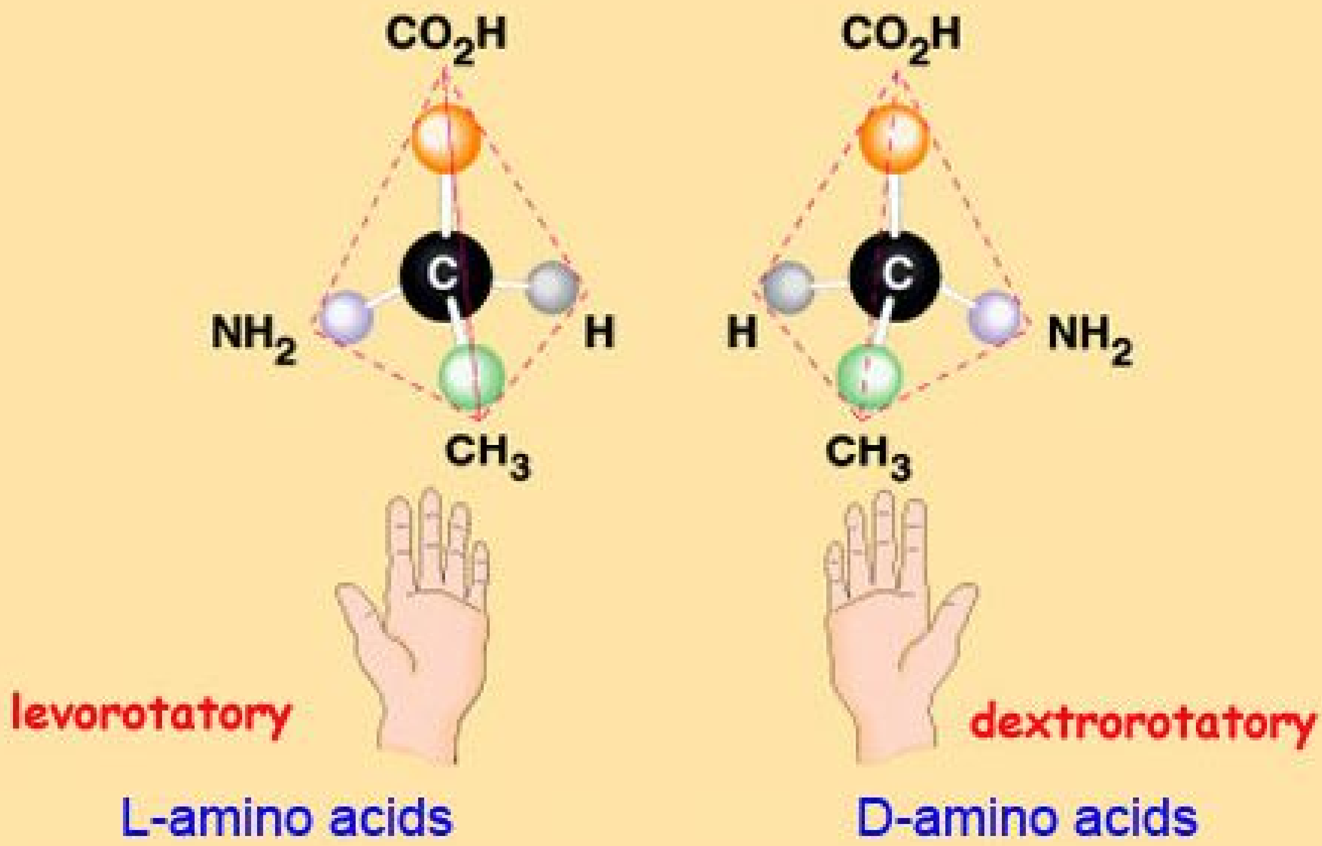




The two hands are "non-superimposable mirror images".

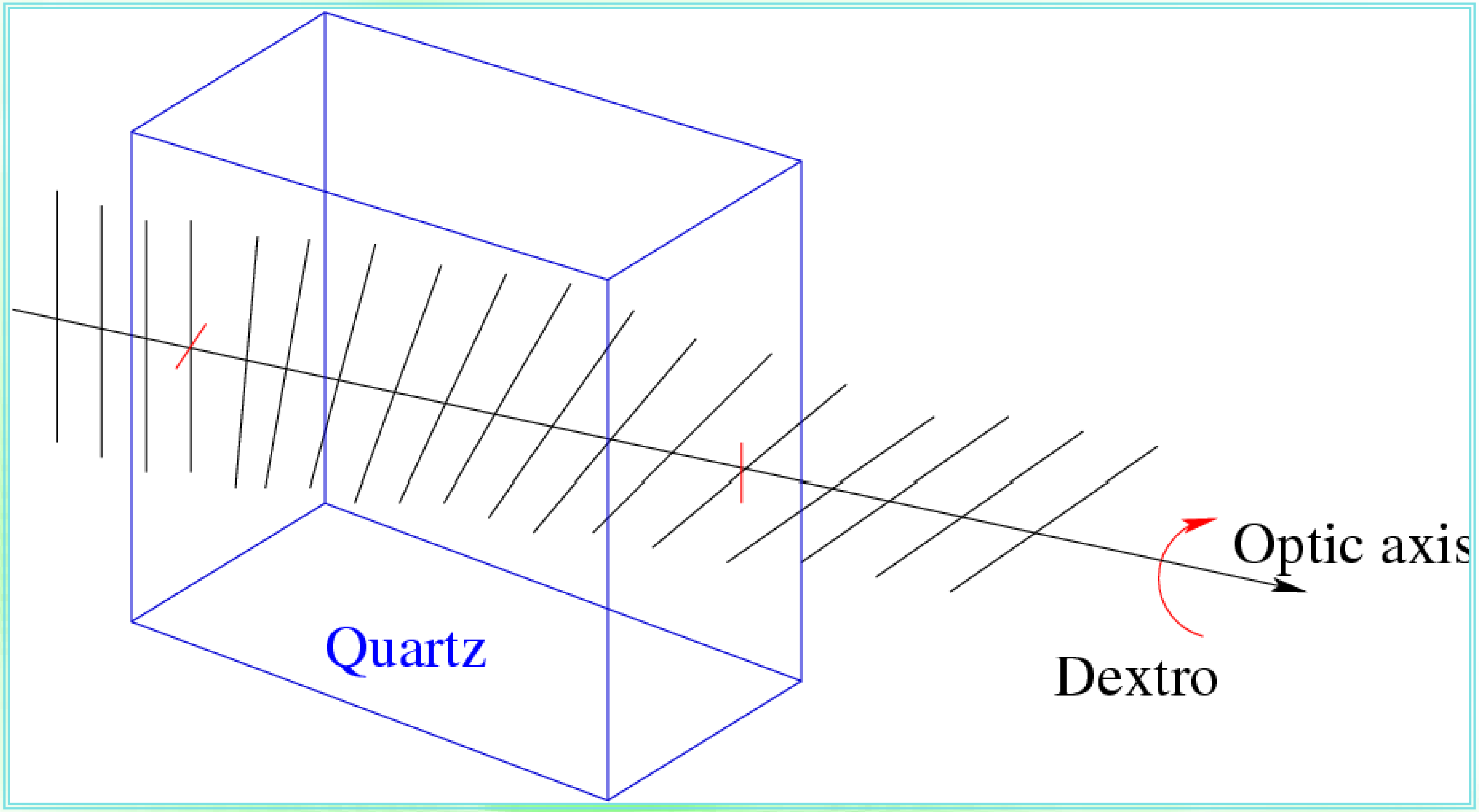


An optically active compound and its mirror image are called enantiomers or optical isomers

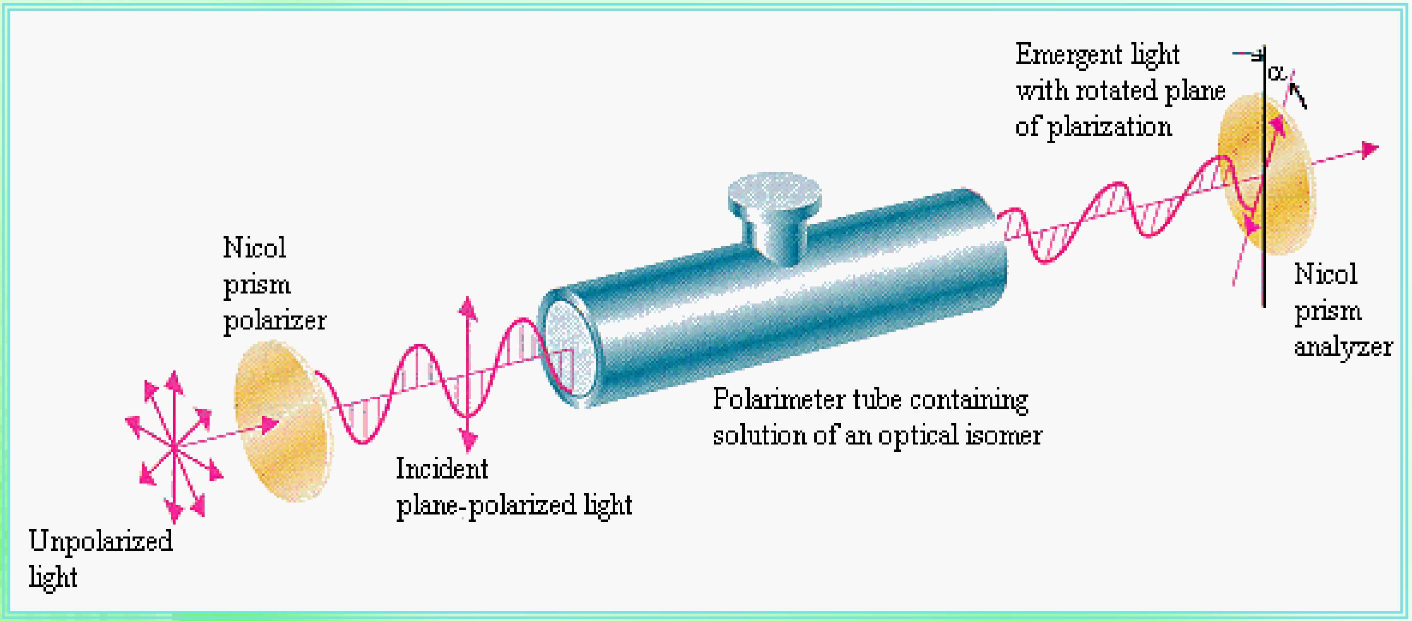


(c) Enantiomers: variation in spatial arrangement around an asymmetric carbon, resulting in molecules that are mirror images, like left and right hands. Enantiomers cannot be superimposed on each other.

Optically active medium



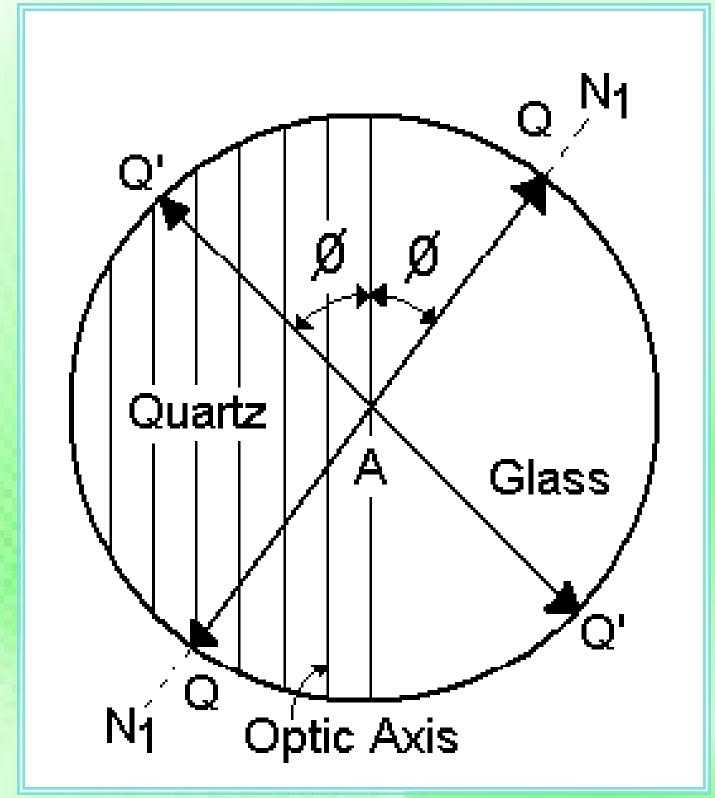
Polarimetry

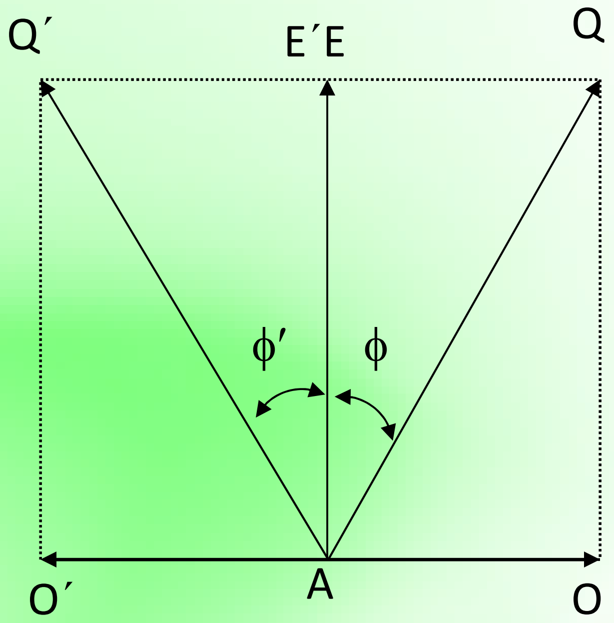


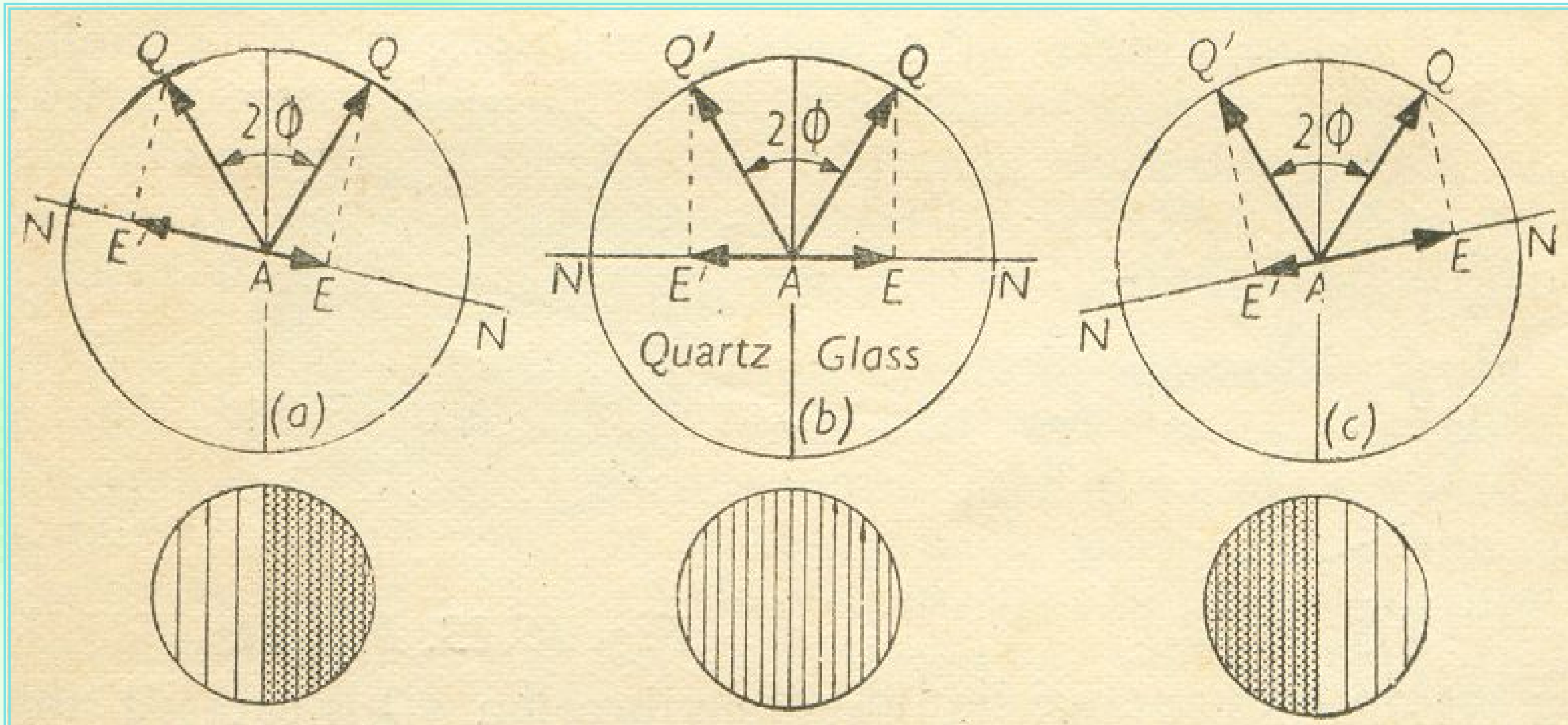
Sugar, Glucose and Fructose

		Specific rotation
Sugar (Sucrose or Cane sugar)	$C_{12}H_{22}O_{11}$	66.47^{o}
Glucose-D (Dextrose or Grape sugar)	$C_6H_{12}O_6$	52.7^{o}
Fructose (Levulose or Fruit sugar)	$C_6H_{12}O_6$	-92^{o}

Half Shade plate





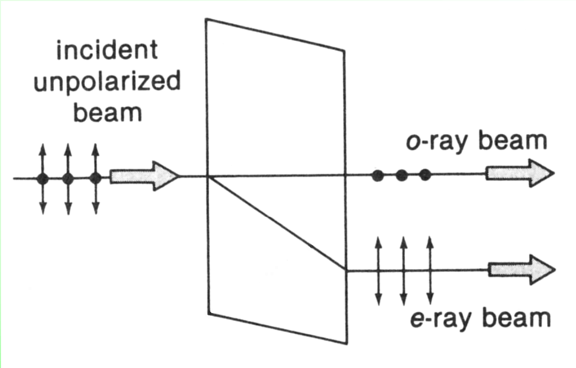


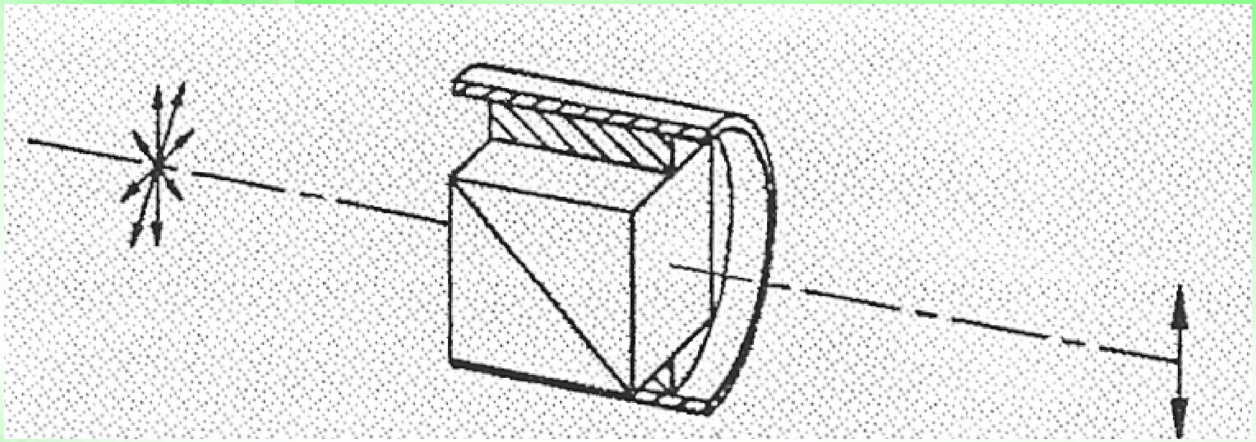
Q
Q
2Φ
N
E′
A
E
N
(a)
Q′
Q
2Φ
N
E′
A
E
N
Quartz
Glass
(b)
Q′
Q
2Φ
N
E
E′
A
N
(c)

Around 1830, scientists realized that the polarization state of light provided a *very sensitive* means for probing the nature of matter

Using an Iceland spar rhomb for such observations was sometimes inconvenient, due to image overlap

So in 1828, W. Nicol invented an Iceland spar prism where one image was *discarded.* Thousands of Nicol prisms have been made.





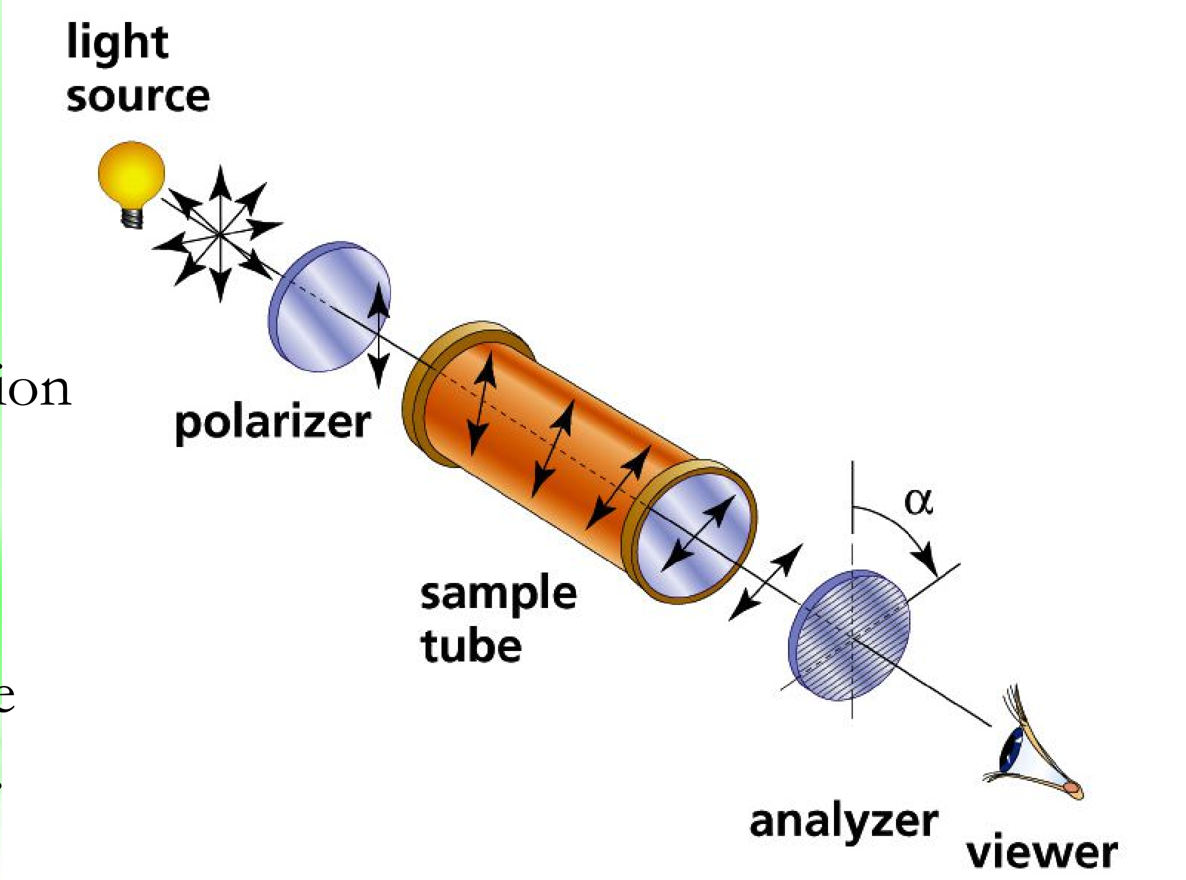
Nicol prisms are also valuable in *finding* the direction of vibration in polarized light.

Another important application of Nicol prisms from Iceland spar was in *polarimeters*, which measure *optical activity*

It occurs in some crystals and in various organic liquids and solutions.

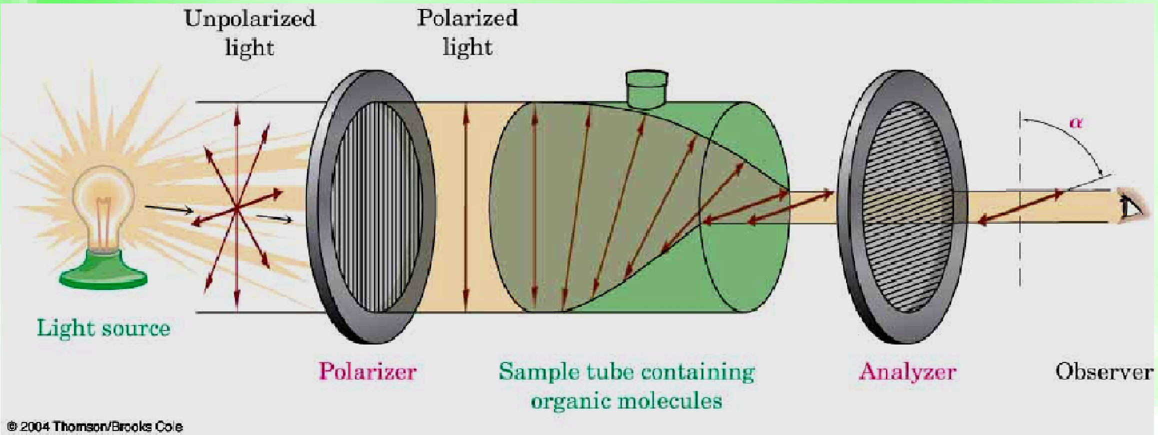
The direction of polarization of light *rotates* on passage through these substances.

Polarimeters were available commercially before 1850.



Optical Activity

- In 1815, Biot discovered that when a beam of plane polarized light is passed through solutions of certain organic molecules, such as sugar or camphor, the plane of polarization is rotated. We call molecules that exhibit this property <u>optically active</u>.
- A. The amount of rotation can be measured with an instrument known as polarimeter. In a polarimeter, plane polarized light is passed through a tube containing a solution of some optically active molecules and rotation occurs. The extent of rotation is determined by rotating a second polarized film until the light passes through it. The observed rotation is symbolized by the Greek letter α. In addition to determining the extent of rotation, the direction is also given.

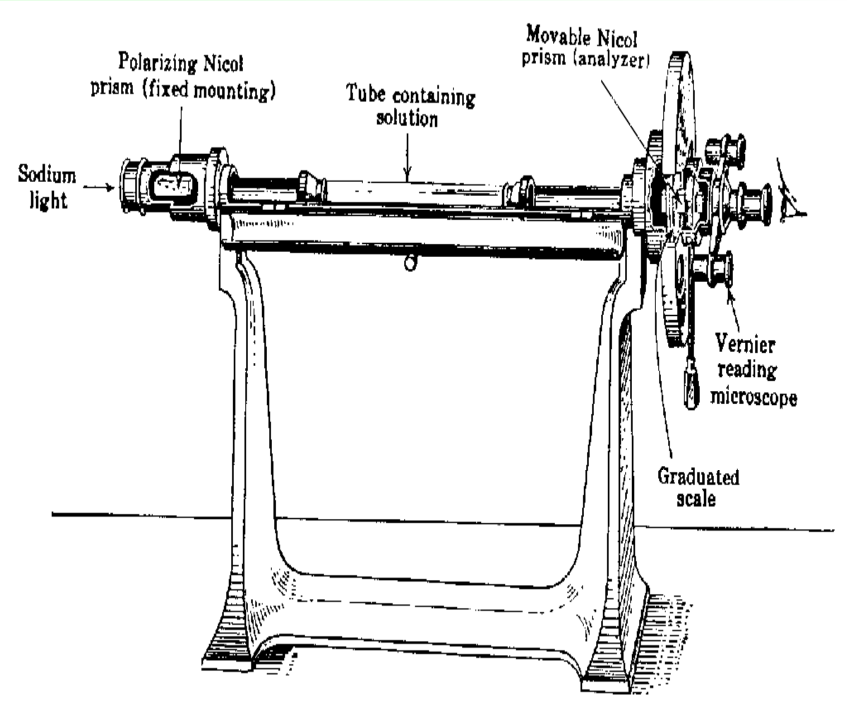


The Direction of Rotation in a Polarimeter

- Some optically active molecules rotate plane polarized light to the left (counter clockwise) and are said to be levoratatory.
- Others rotate polarized light to the right (clockwise), and are said to be dextrorotatory
- By convention rotation to the left is given a (-) minus sign, and rotation to the right is given a (+) positive sign

A Simple Polarimeter

- Measures extent of rotation of plane polarized light
- Operator lines up polarizing analyzer and measures angle between incoming and outgoing light



The Amount of Rotation

- The amount of rotation obtained from a polarimeter is dependent upon the number of optically active molecules the beam encounters and the nature of the light source. Consequently, the amount of rotation is dependent upon:
- **length of sample tube i. e. (θ) α l**
- **concentration of optically active molecules in solution**
- **i. e. (θ) α C**
- **the wavelength of the light used (θ) α 1/λ2**
- Because optical rotation is dependent upon these three variables,we must choose standard conditions so that comparisons can be made.

Specific Rotation

- To have a basis for comparison, define **specific rotation, $[\alpha]_D$** for an optically active compound
- $[\alpha]_D$ = ______observed rotation α_________________.   Path length l (dm) X concentration (g/ml)
- Specific rotation is that observed for 1 g/mL in solution in cell with a 10 cm path using light from sodium metal vapor (589 nanometers)

TABLE 9.1 Specific Rotation of Some Organic Molecules

Compound	$[\alpha]_D$ (degrees)	Compound	$[\alpha]_D$ (degrees)
Penicillin V	+233	Cholesterol	−31.5
Sucrose	+66.47	Morphine	−132
Camphor	+44.26	Acetic acid	0
Monosodium glutamate	+25.5	Benzene	0

THANK YOU