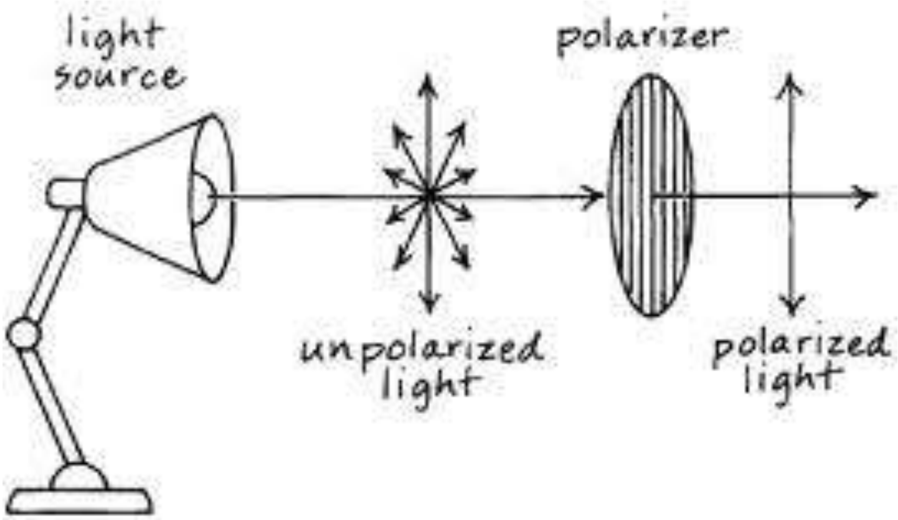
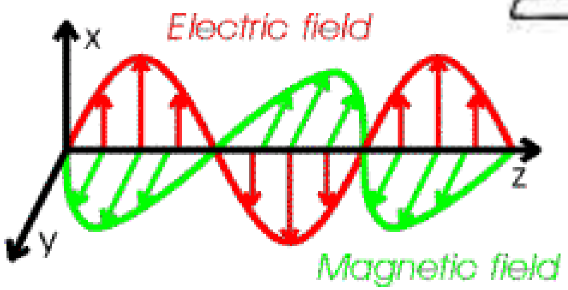
Polarization of Light:- The phenomena is which vibration of electric field vector of light are confined is a definite direction by any mean is known as polarization of light and this type of light is called polarized light

Or

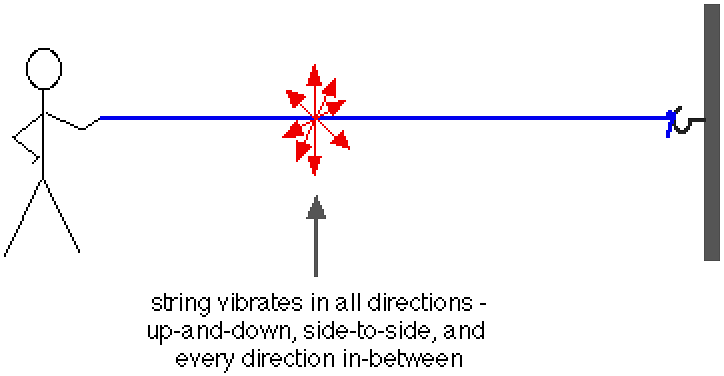
"The process of transfer unpolarized light into polarized light is called polarization"

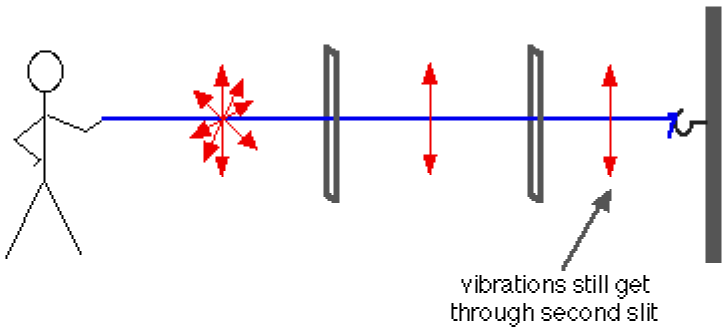


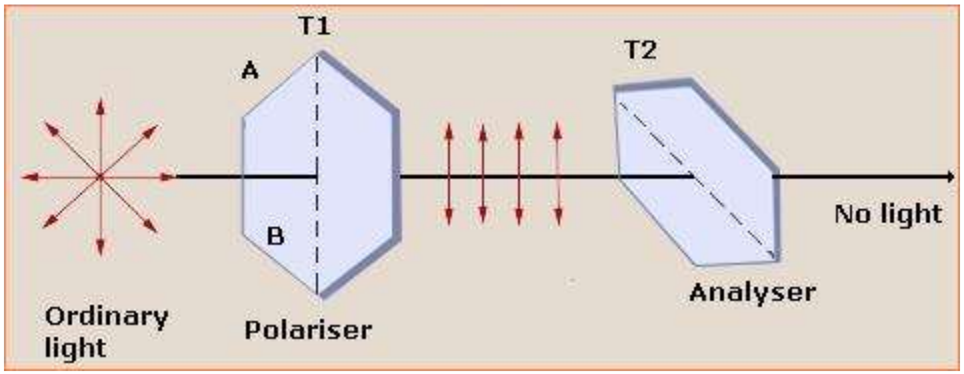


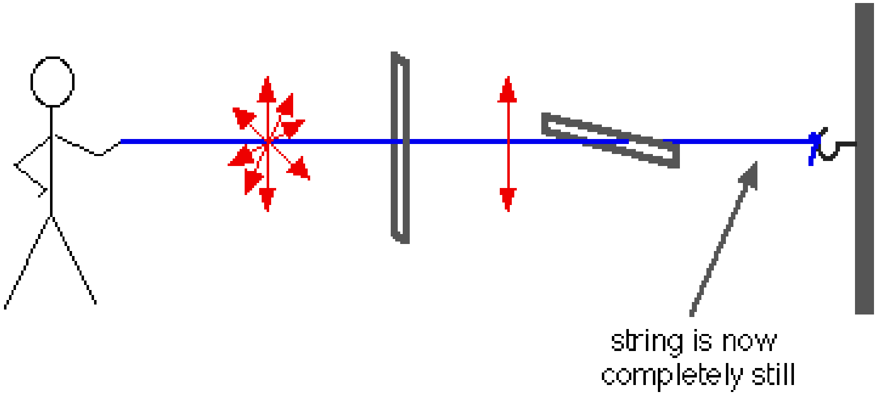
Light is a transverse wave,
an electromagnetic wave

Demonstration of polarized light

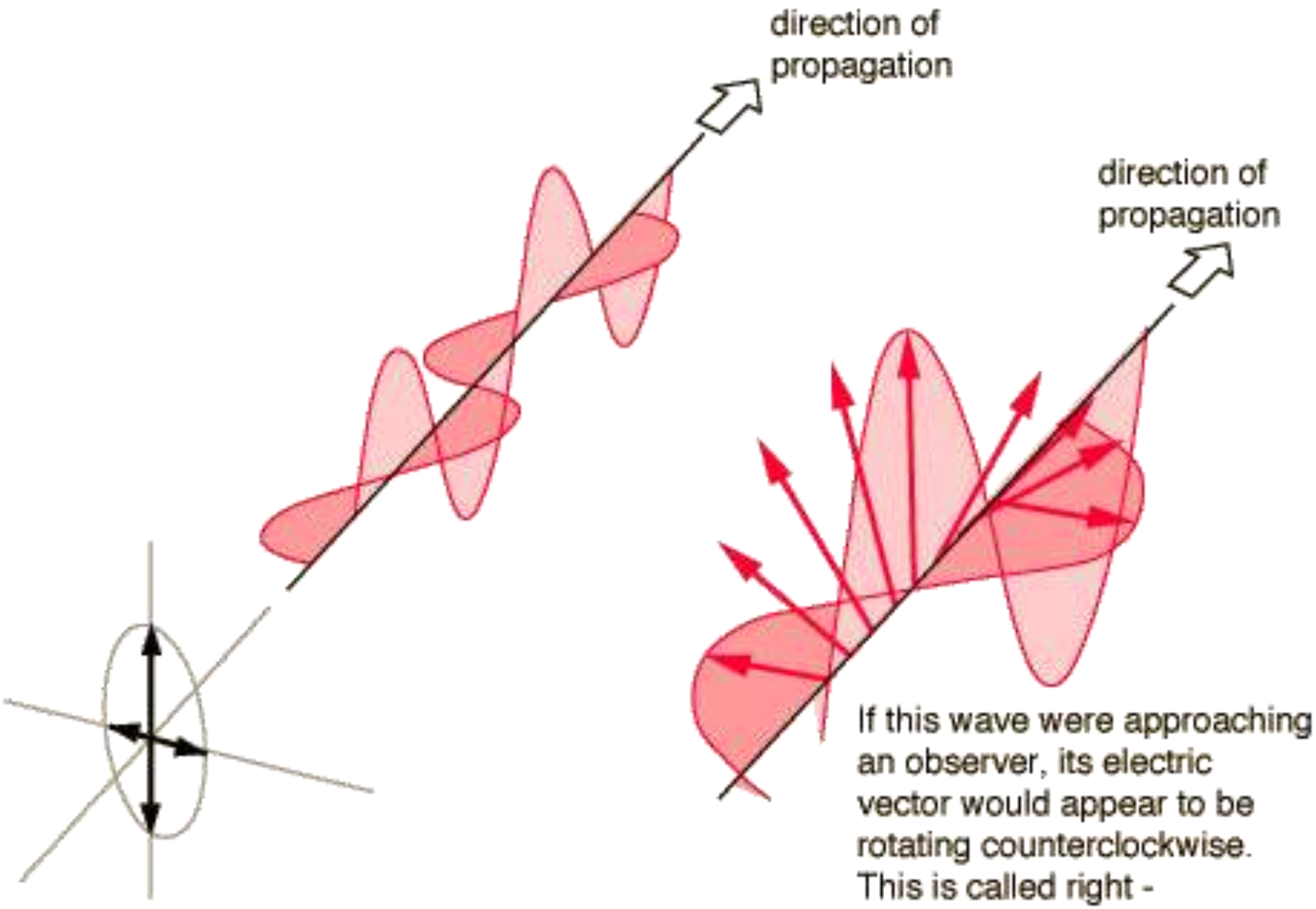




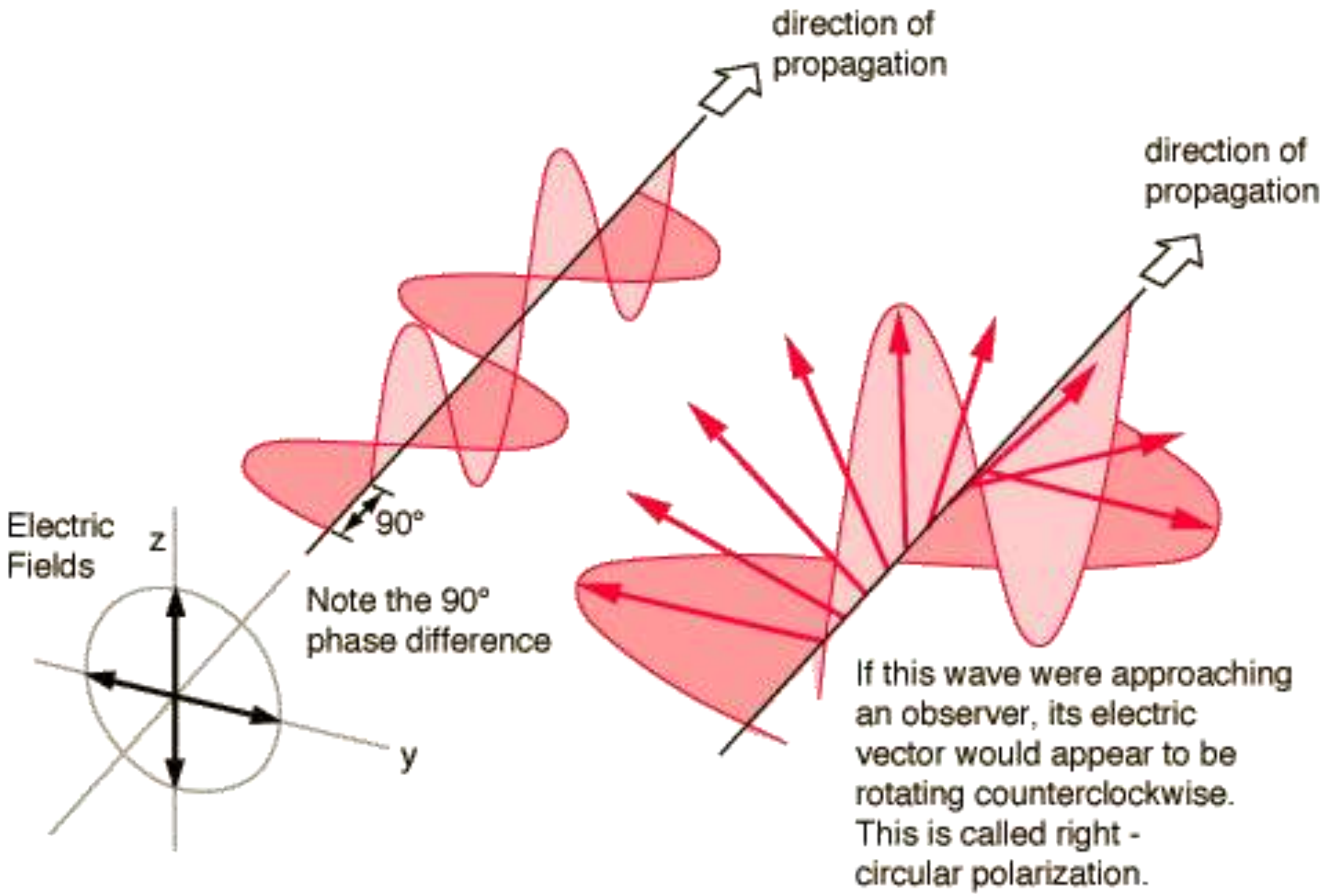


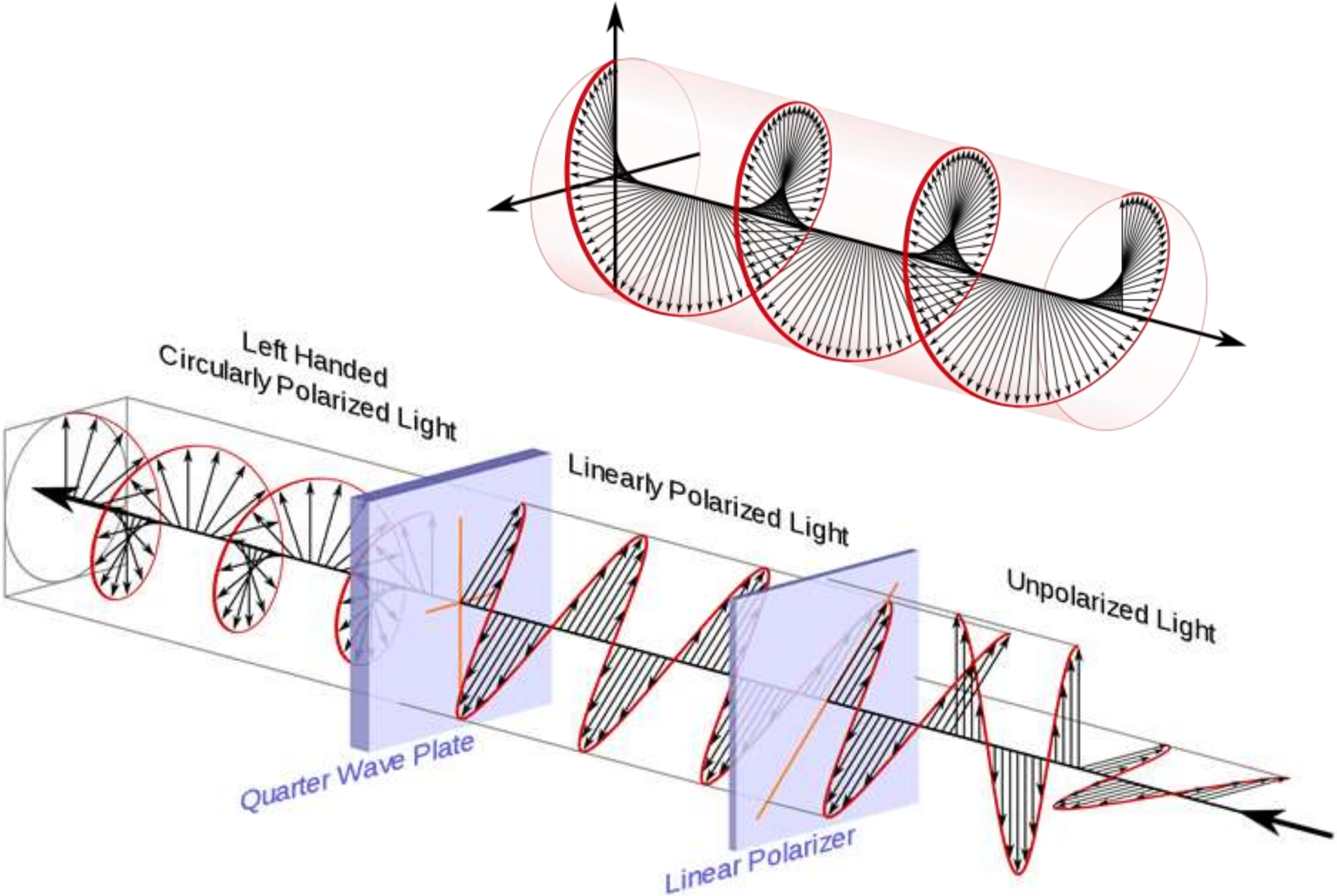


[Elliptical polarization] means the electric field vector is rotating in a plane perpendicular to the direction of propagation as it travels. Also the magnitude of the electric field vector changes as it rotates



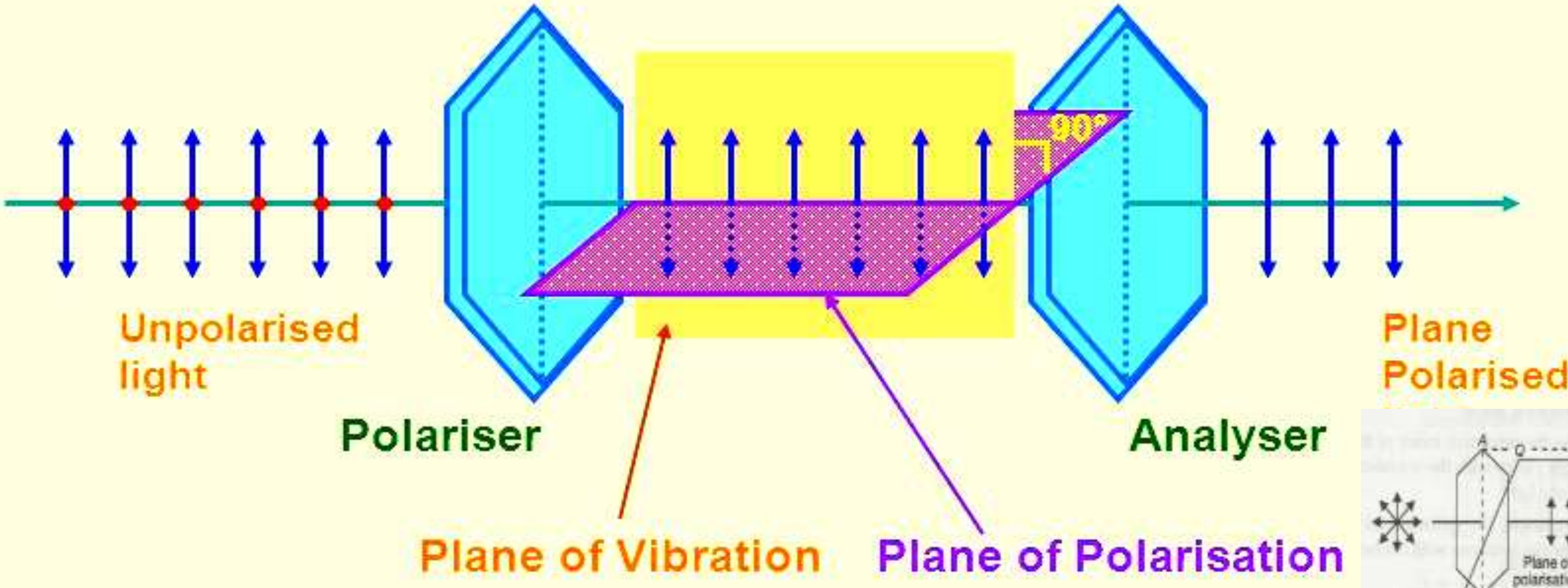
Circular polarization means the electric field vector rotates as it travels but the magnitude of electric field vector remains constant.

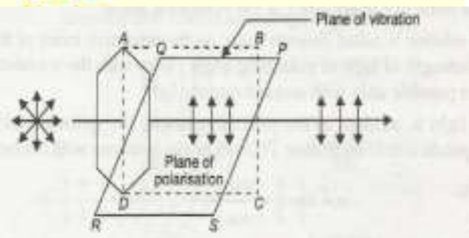




Left Handed
Circularly Polarized Light
Linearly Polarized Light
Unpolarized Light
Quarter Wave Plate
Linear Polarizer

Plane of polarization/Plane of vibration





When unpolarised light is incident on the polariser, the vibrations parallel to the crystallographic axis are transmitted and those perpendicular to the axis are absorbed. Therefore the transmitted light is plane (linearly) polarised.

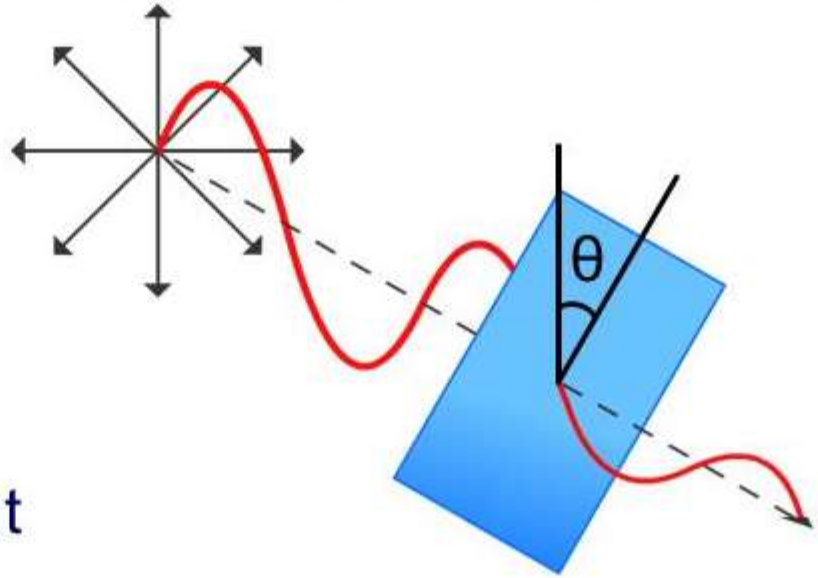
The plane which contains the crystallographic axis and vibrations transmitted from the polariser is called plane of vibration.

The plane which is perpendicular to the plane of vibration is called plane of polarisation.

Malus's Law

If a beam of plane-polarized light is shone through a polarizer, its subsequent intensity, I, is calculated as follows:

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



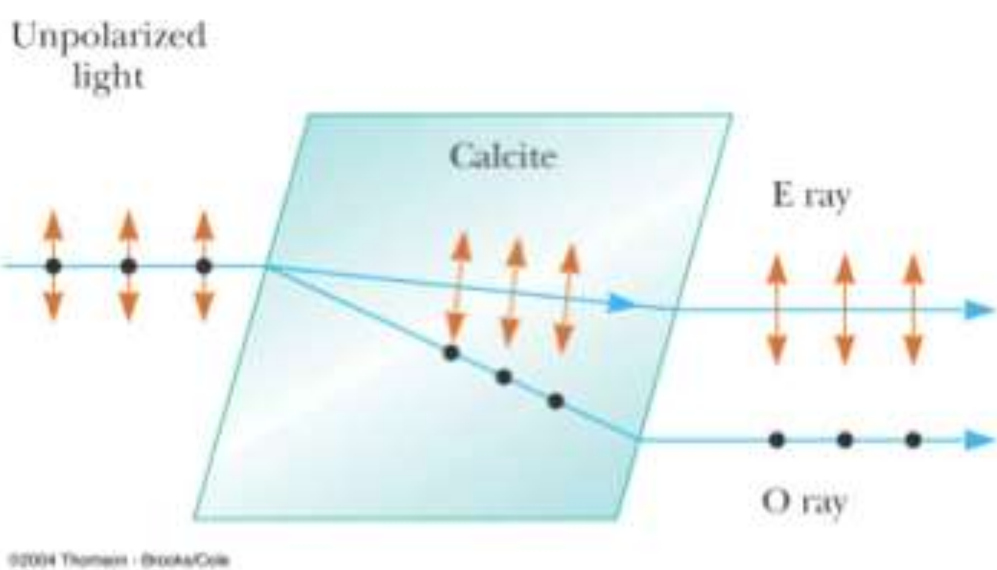
where:

- I_0 = initial intensity of light
- θ = angle of polarizer relative to position of initial polarized light

This is **Malus's law**, named after Étienne-Louis Malus, a French physicist, mathematician and officer.

DOUBLE REFRACTION

Double refraction, also called birefringence, an optical property in which a single ray of unpolarized light entering an anisotropic medium is split into two rays, each traveling in a different direction. One ray (called the extraordinary ray) is bent, or refracted, at an angle as it travels through the medium; the other ray (called the ordinary ray) passes through the medium unchanged



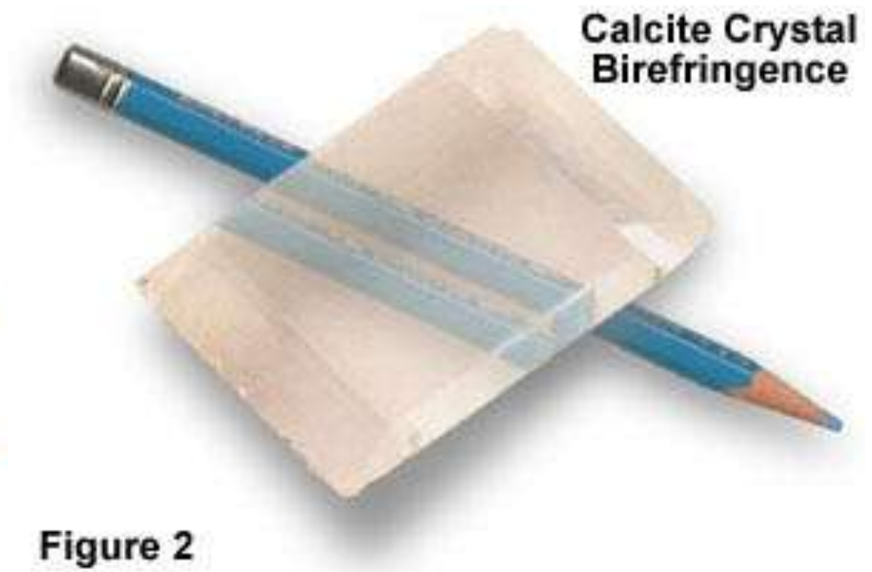
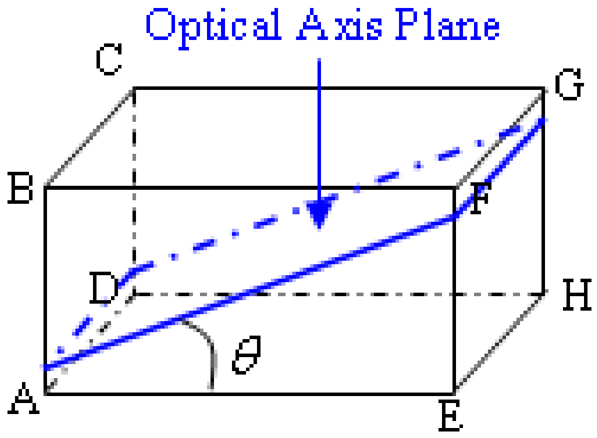
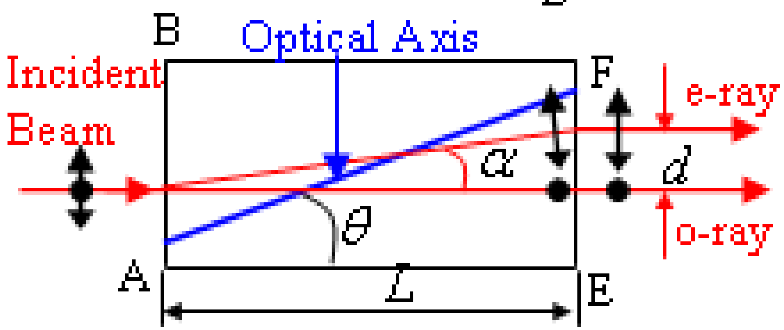


Figure 2

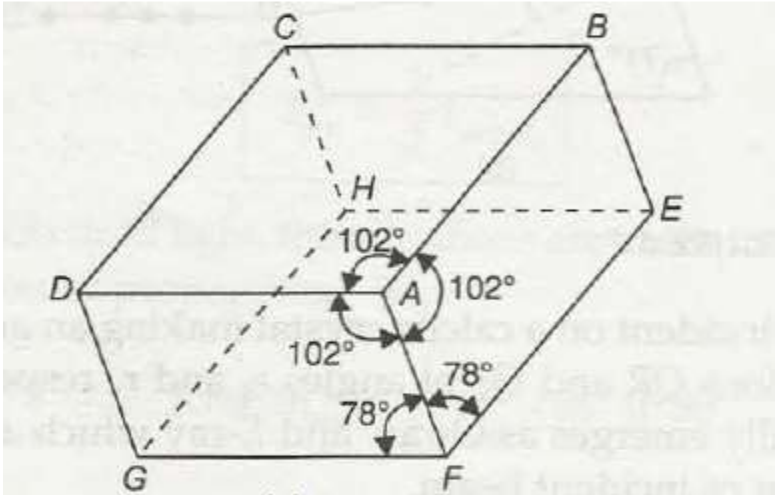
Optic Axis and Calcite Crystal





The calcite crystal and quartz crystal has an important characteristic i.e. there is only one direction through the calcite crystal along which no double refraction take place. This particular axis is called optic axis. ADGF

Calcite crystal also known as Iceland spar, chemically known as Calcium Carbonate $CaCo_3$ that have rhombohedra structure



(a)

Phase Retardation Plates

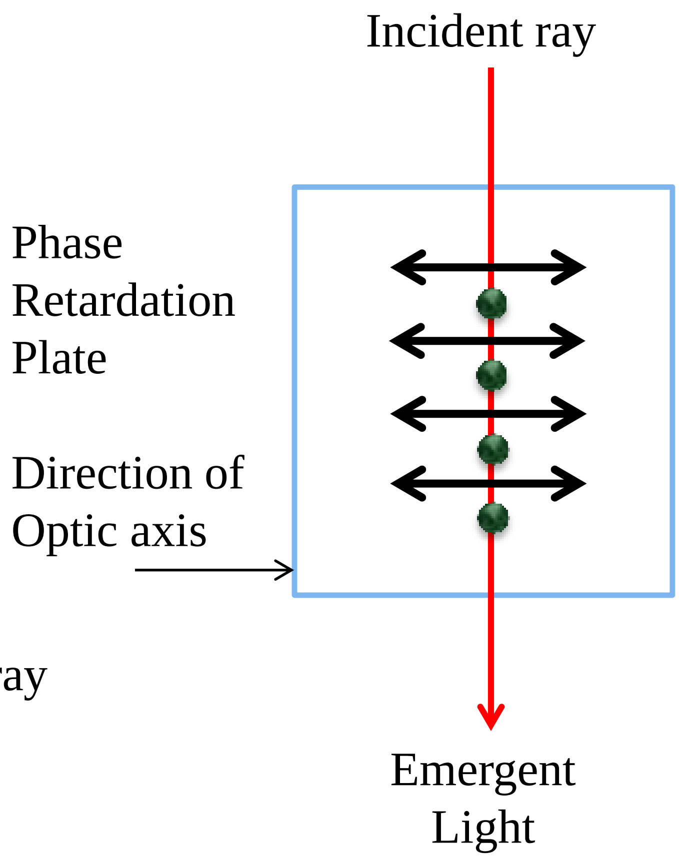
A doubly refracting uniaxial crystal *plate* of uniform thickness having refracting surface parallel to direction of optic axis and capable of producing a definite phase difference between the ordinary and the extraordinary ray,is called *phase retardation plate*.

In calcite crystal the velocity of E-ray V_E is greater than that of O-ray V_O so that the difference in time taken by these waves to cross the plate of thickness d can be given as

$$\Delta t = t_o - t_e \qquad \text{-------------eq 1}$$

Here t_O and t_E ate the time taken by O-ray and E-ray

$$t_o = \frac{d}{V_O}, t_e = \frac{d}{V_E} \qquad \text{-------------eq 2}$$



Putting the values in equation 1

$$\Delta t = \frac{d}{V_O} - \frac{d}{V_E} \qquad \text{--------------eq 3}$$

So that the path difference occurs between E-ray and O-ray on passing the plate thickness d can be given as

$$\Delta = c\Delta t = c\left(\frac{d}{V_O} - \frac{d}{V_E}\right) = d\left(\frac{c}{V_O} - \frac{c}{V_E}\right) \qquad \text{--------------eq 4}$$

Since $\mu_O = \frac{c}{V_O}, \mu_E = \frac{c}{V_E}$ --------------eq 5

$$\Delta = d(\mu_O - \mu_E) \qquad \text{--------------eq 6}$$

Here μ and μ are the refractive indices of calcite crystal plate for O-ray and E-ray respectively and Δ is the path difference Hence the phase difference between O-Ray and E-ray is given by

$$\delta = \frac{2\pi}{\lambda}(\Delta) = \frac{2\pi}{\lambda}(\mu_O - \mu_E)d \qquad \text{--------------eq 7}$$

For quartz crystal (positive crystal E-ray velocity is higher then O-ray so the path difference and phase difference given by $\delta = \frac{2\pi}{\lambda}(\Delta) = \frac{2\pi}{\lambda}(\mu_E - \mu_O)d$

$$\Delta = d(\mu_E - \mu_O)$$

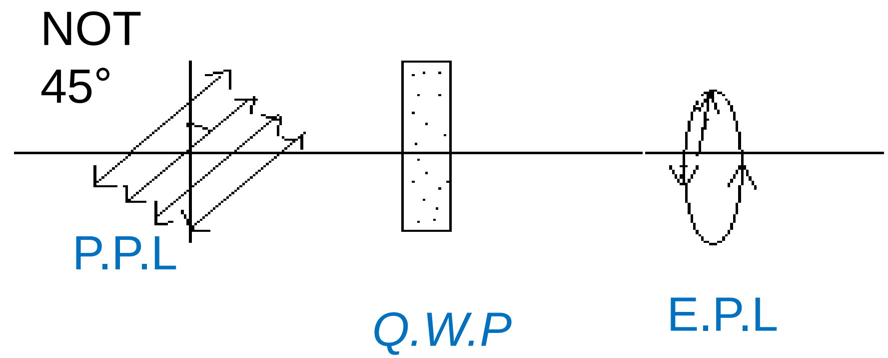
QUARTER WAVE **PLATE**

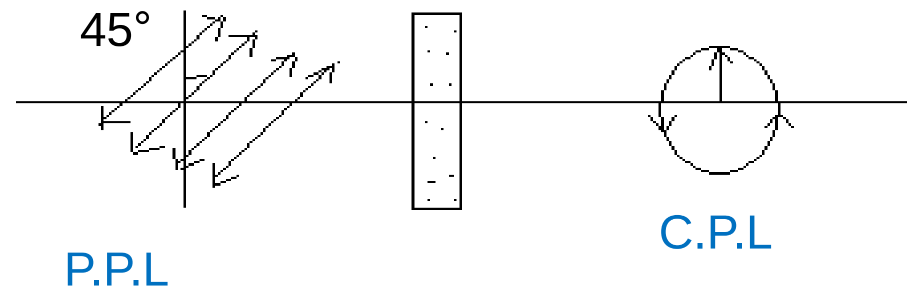
A doubly refracting uniaxial crystal plate having refracting faces parallel to the direction of the optic axis, having a thickness such as to create a path difference of λ /4 or a phase difference of π/2 between the O-ray and the E-ray , is called *Quarter wave plate. For* quarter wave plate :

$$\Delta = d(\mu_E - \mu_O) = \frac{\lambda}{4}$$

where λ is the wavelength of the incident light.

$$d = \frac{\lambda}{4(\mu_E - \mu_O)}$$





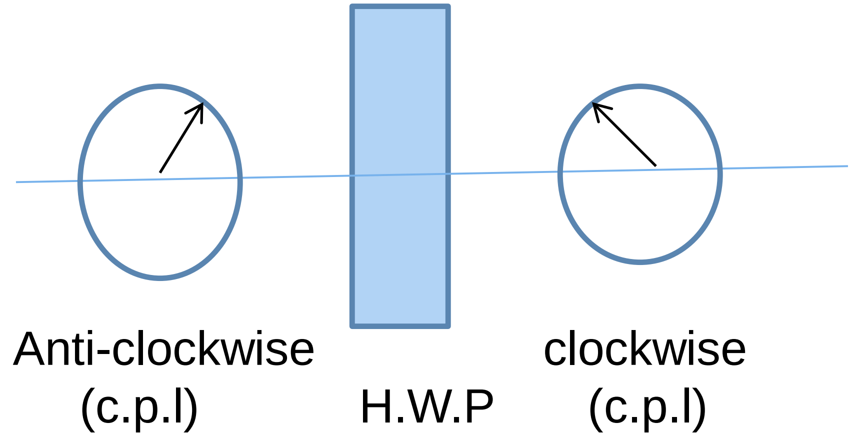
HAlF WAVE PLATE

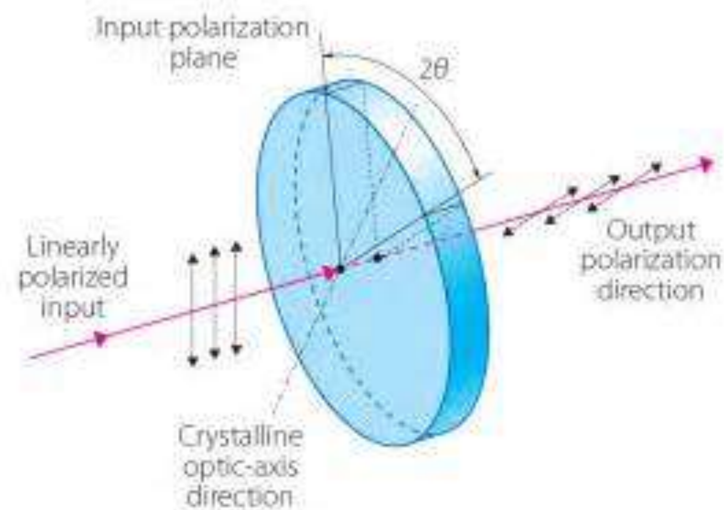
A doubly refracting uniaxial crystal plate having refracting faces parallel to the direction of the optic axis, having a thickness such as to create a path difference of λ /2 or a phase difference of π between the O-ray and the E-ray , is called *half wave plate*. *For* quarter wave plate :

$$\Delta = d(\mu_E - \mu_O) = \frac{\lambda}{2}$$

where λ is the wavelength of the incident light.

$$d = \frac{\lambda}{2(\mu_E - \mu_O)}$$



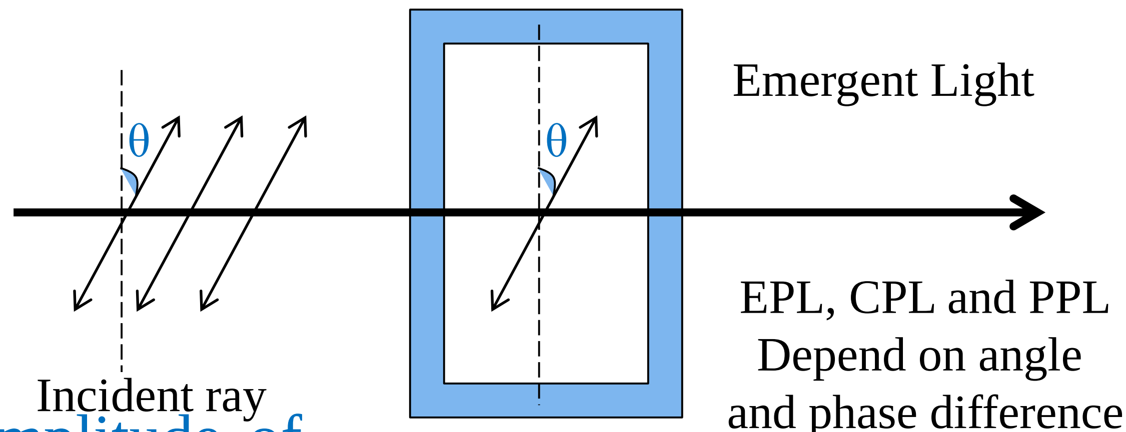


Performance of half (λ/2) waveplate

Production of PPL, EPL and CPL

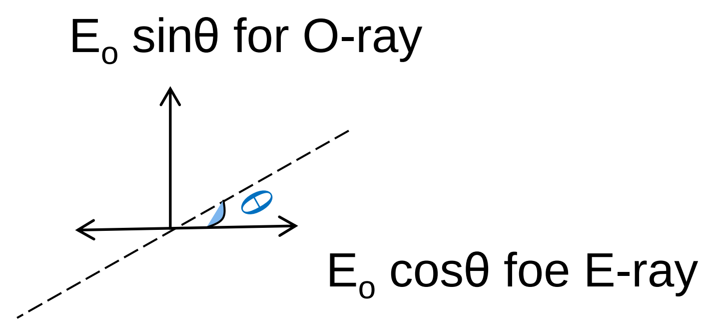
If a plane polarized light having an amplitude of E_o is incident on the face of calcite plate making an angle θ with its optic axis

Due to the double refraction its amplitude divided into two components $E_o cos\theta$ and $E_o sin\theta$



Let us assume $E_o$cosθ is amplitude of E-ray and $E_o$sinθ amplitude of O-ray

Now let us assume incident ray is represented by



$$E = E_O \sin wt$$ --------------eq 1

$$E_x = E_O \cos\theta \sin(wt + \delta)$$ --------------eq 2

$$E_y = E_O \sin\theta \sin wt$$ --------------eq 3

Here we put

$$E_x = x, E_O \cos\theta = a$$

$$E_y = y, E_O \sin\theta = b$$

So eq 2 and 3 rewritten as

$$x = a\sin(wt + \delta)$$ --------------eq 4

$$y = b\sin wt$$ --------------eq 5

$$\frac{x}{a} = \sin wt\cos\delta + \cos wt\sin\delta$$ --------------eq 6

$$\frac{y}{b} = \sin wt,$$ --------------eq 7

$$\cos wt = \sqrt{1-\sin^2 wt} = \sqrt{1-\frac{y^2}{b^2}}$$

$$\frac{x}{a} = \frac{y}{b}\cos\delta + \sqrt{1-\frac{y^2}{b^2}}\sin\delta$$ --------------eq 8

$$\frac{x}{a} - \frac{y}{b}\cos\delta = \sqrt{1-\frac{y^2}{b^2}}\sin\delta$$ --------------eq 9

$by, sqauring$

$$\left(\frac{x}{a} - \frac{y}{b}\cos\delta\right)^2 = \left(\sqrt{1-\frac{y^2}{b^2}}\sin\delta\right)^2$$

$$\frac{x^2}{a^2} + \frac{y^2}{b^2}\cos^2\delta - \frac{2xy}{ab}\cos\delta = 1 - \frac{y^2}{b^2}\sin^2\delta$$

$$\frac{x^2}{a^2} + \frac{y^2}{b^2}(\cos^2\delta + \sin^2\delta) - \frac{2xy}{ab}\cos\delta = \sin^2\delta$$

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} - \frac{2xy}{ab}\cos\delta = \sin^2\delta$$ --------------eq 10

Equation 10 represent an ellipse so the light emerge from calcite crystal is generally elliptical under certain condition it shows PPL, CPL

Special Cases

Case 1 :- PPL if the thickness of the wave plate is such that

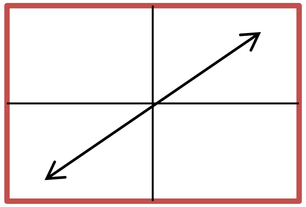
(a) From δ= 0, 2π, 4π, 6π……..2nπ

eq 10 sinδ =0 and cosδ=1 So

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}-\frac{2xy}{ab}=0$$

$$\left(\frac{x}{a}-\frac{y}{b}\right)^2=0,\ \frac{x}{a}+\frac{y}{b}=0$$

$$\frac{x}{a}=\frac{y}{b},\ y=\frac{b}{a}(x)$$



This represent a pair of straight line passing through the origin and having positive slope

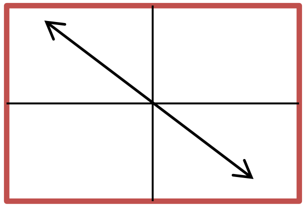
(b) From δ= π, 3π, 5π……..(2n+1)π

eq 10 sinδ =0 and cosδ= -1 So

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{2xy}{ab}=0$$

$$\left(\frac{x}{a}+\frac{y}{b}\right)^2=0,\ \frac{x}{a}+\frac{y}{b}=0$$

$$\frac{x}{a}=-\frac{y}{b},\ y=-\frac{b}{a}(x)$$



This represent a pair of straight line passing through the origin and having negative slope

Case 2 :- EPL/CPL if the thickness of the wave plate is such that

(a) From δ= π/2, 3π/2, 5π/2……..(2n+1)π/2

eq 10 sinδ =1 and cosδ=0 So

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}=1$$

This represent an ellipse so the emergent light is elliptical

(b) If a=b it means

$$E_O\cos\theta=1/\sqrt{2},$$

$$E_O\sin\theta=1/\sqrt{2}$$

means

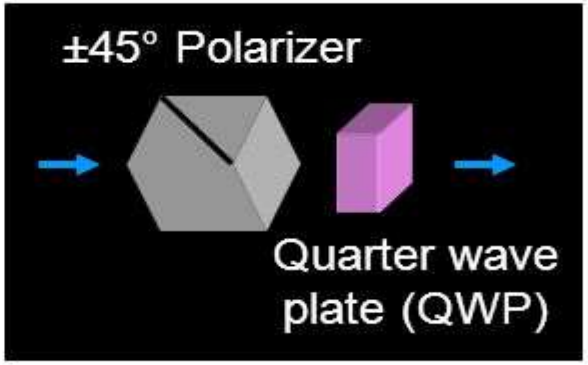
$$\theta=45^o \qquad x^2+y^2=1$$

This represent an circle so the emergent light is circular

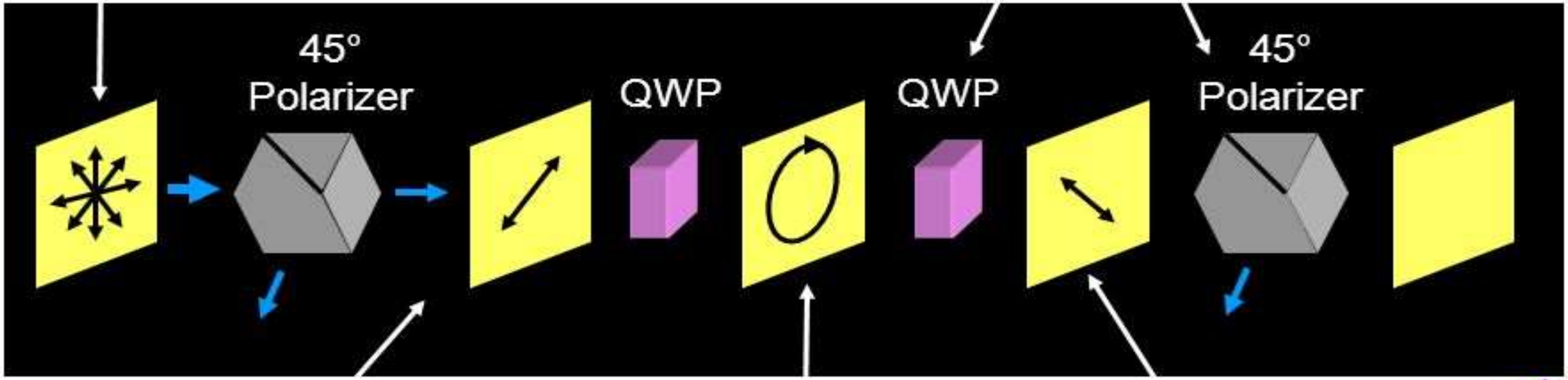
Experimental demonstration of production of PPL, EPL and CPL

Circular polarizers

A circular polarizer makes circularly polarized light by first linearly polarizing it and then rotating it to circular. This involves a linear polarizer followed by a quarter wave plate

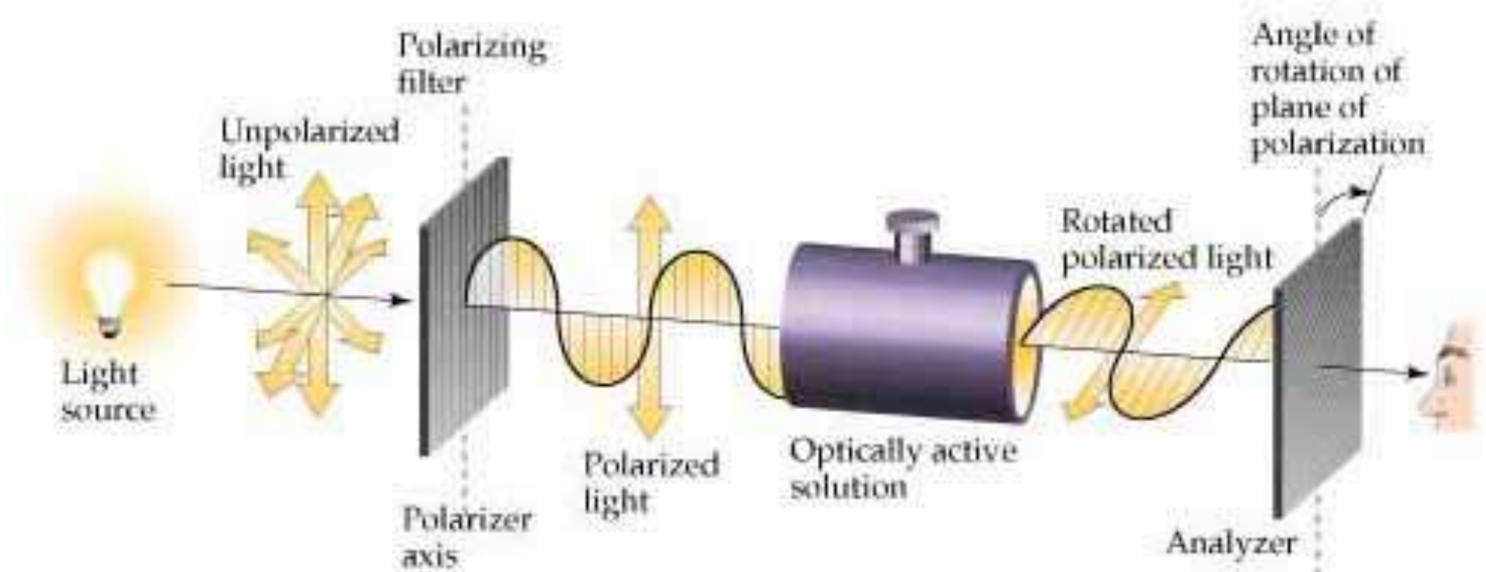


Unpolarized input light

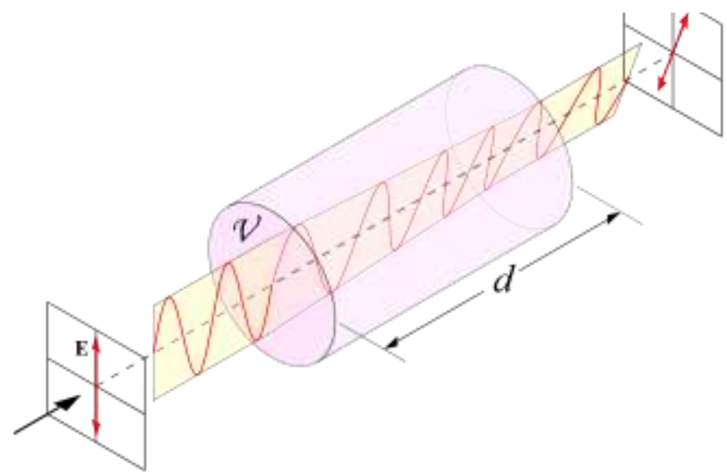


Optical Activity

When a plane polarized light is allowed to pas through certain substances, it is found that the plane of polarization of the emergent light is not the same as that of the incident light and it is rotated through a certain angle.



This property of rotating the plane of polarization of the emergent light is called optical activity or rotatory polarization, substances showing such property are known as optically active substances.



- The amount of optical rotation depends upon the thickness and density of the crystal or concentration in case of solution, the temperature and the wavelength of light used.
- There are two types of optically active substances:
- **<u>Righthanded or dextro-rotatory:-</u> the substances that rotate plane of vibration in the clockwise direction as seen by the observer facing the emergent light. Sodium chlorate,cane sugar.**
- **<u>Left handed or leavo rotatory:-</u> the substances that rotate plane of vibration in the anti-clockwise direction as seen by an observer facing the emergent light. Fruit sugar, turpentine.**

Biot's Law of Optical Rotation

- For a particular wavelength of light the angle of rotation of a plane of polarization is directly proportional to the length (l) of the optically active medium traversed. $\theta \propto l$
- In case of solution the angle of rotation for a given path length is directly proportional to the concentration (c) of the solution. $\theta \propto C$
- The angle of rotation is inversely proportional to the square of the wavelength for a given length of the optically active substance. $\theta \propto 1/\lambda^2$
- Optical rotation obeys the law of addition. The rotation produced by a number of optically active substances is equal to the algebraic sum of the indivudal rotations.

$$\theta = \theta_1 + \theta_2 + \theta_3 + \ldots.$$

$$\theta = \sum_i \theta_i$$

Specific Rotation

Specific rotation ([S]) is a property of a compound. It is defined as the change in orientation of plane polarized light per unit distance–concentration product, as the light passes through a sample of a compound in solution.

For Solid:- At a constant temperature for PPL of definite wavelength the angle of rotation θ of the plane of polarization is directly proportional to the length traversed by polarized light is the solid.

$$\theta \propto l, \theta = Sl$$

$$S = \frac{\theta}{l}$$

For Liquid :- At a constant temperature for PPL of definite wavelength the angle of rotation θ of the plane of polarization is directly proportional to the length traversed by polarized light is the liquid of density d.

$$\theta \propto ld, \theta = Sld$$

$$S = \frac{\theta}{ld}$$

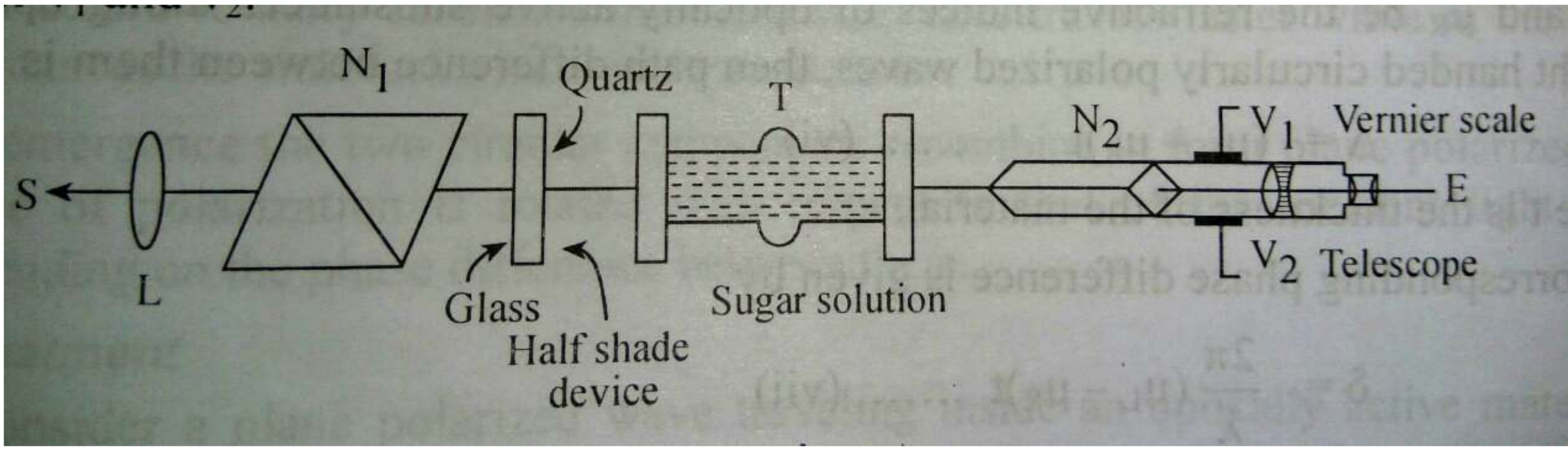
For Solution:- At a constant temperature for PPL of definite wavelength the angle of rotation θ of the plane of polarization is directly proportional to the length traversed by polarized light is the solutionof concentration c.

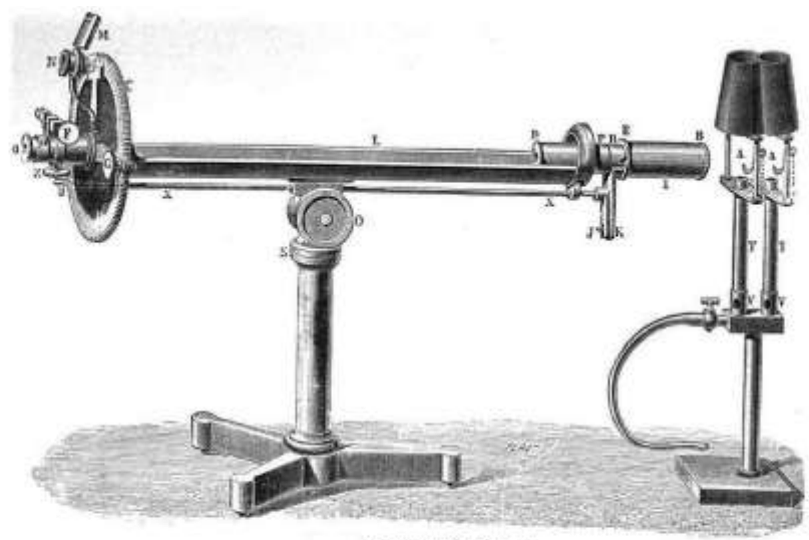
$$\theta \propto lc, \theta = Slc$$

$$S = \frac{\theta}{lc}$$

Lorentz Half Shade Polarimeter

It is used for the measurement of the angle of rotation of optically active substance in solution. That is, angle through which the plane of the polarized light is rotated on passing through a specific length of solution of known concentration.





A Laurent Polarimeter