POLARISATION

Content

- Introduction
- Importance of polarization in engineering and technology
- Representation
- Law of Malus (to be taught in the lab)
- Method of producing PPL
- Double refraction
- Huygens theory of double refraction
- Quarter Wave Plate
- Applications

The wave nature of light clearly explained by

Interference and Difraction Phenomenon

But These Phenomenan failed to explain
Whether the light waves are longitudinal or Tansverse?
Whether the light waves linear, circular or elliptical?

WKT, Depending on direction of vibration waves are classified as

Transverse and longitudinal

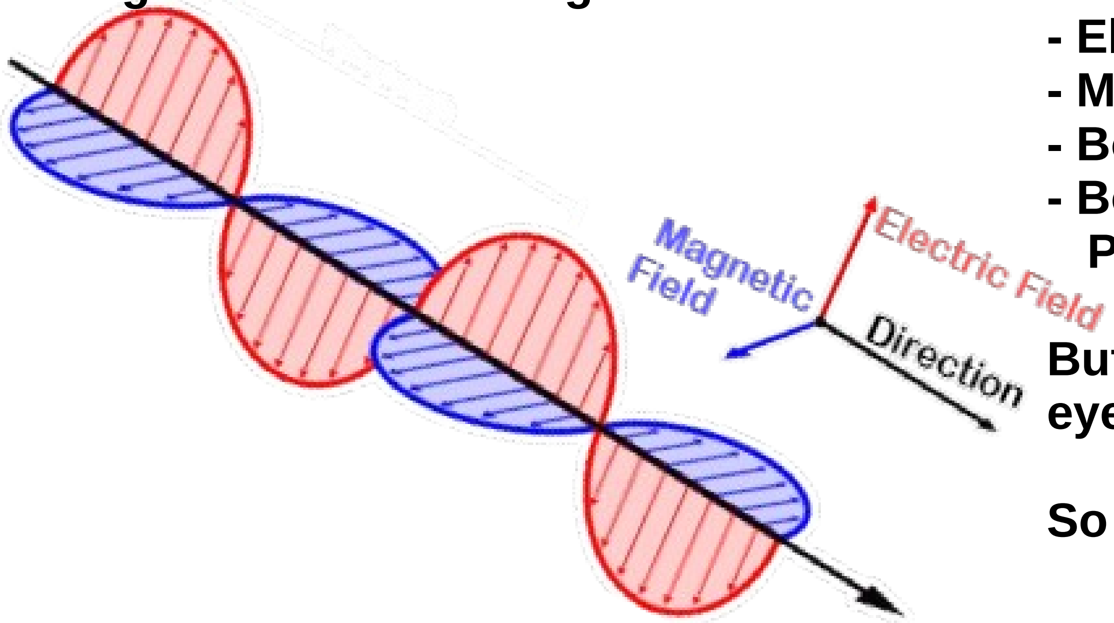
Phenomenon such as Reflection, Refraction, Interference, Difraction are common in both the types

But Polarisation is possible only in transverse waves

Polarisation is the charecteristics of the Transverse wave

Light?

Light is an Electromagnetic Wave

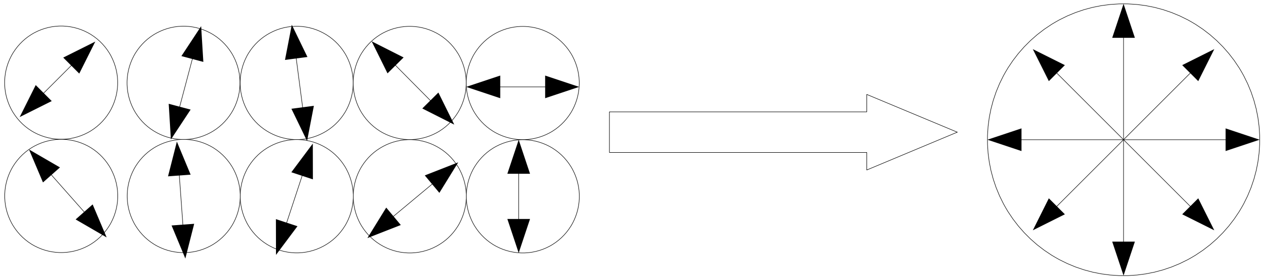


It contains:
- Electric Component
- Magnetic Component
- Both are perpendicular to each other
- Both are perpendicular to direction of Propogation

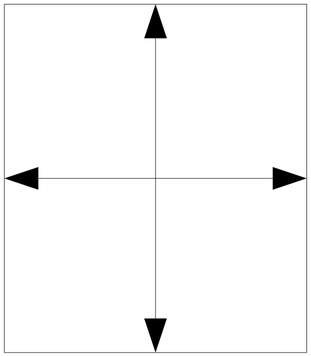
But Electric Component is sensitive to eye, so it is called as light vector

So one can neglect magnetic component

Source of light contains large number of atoms/molecules
Each atom produces its own wave independently
Each emission has its own electric component, orientation may be diffrent
What we se is resultant of each emission



Un-Polarised Light Electric field component Vibrates in all direction

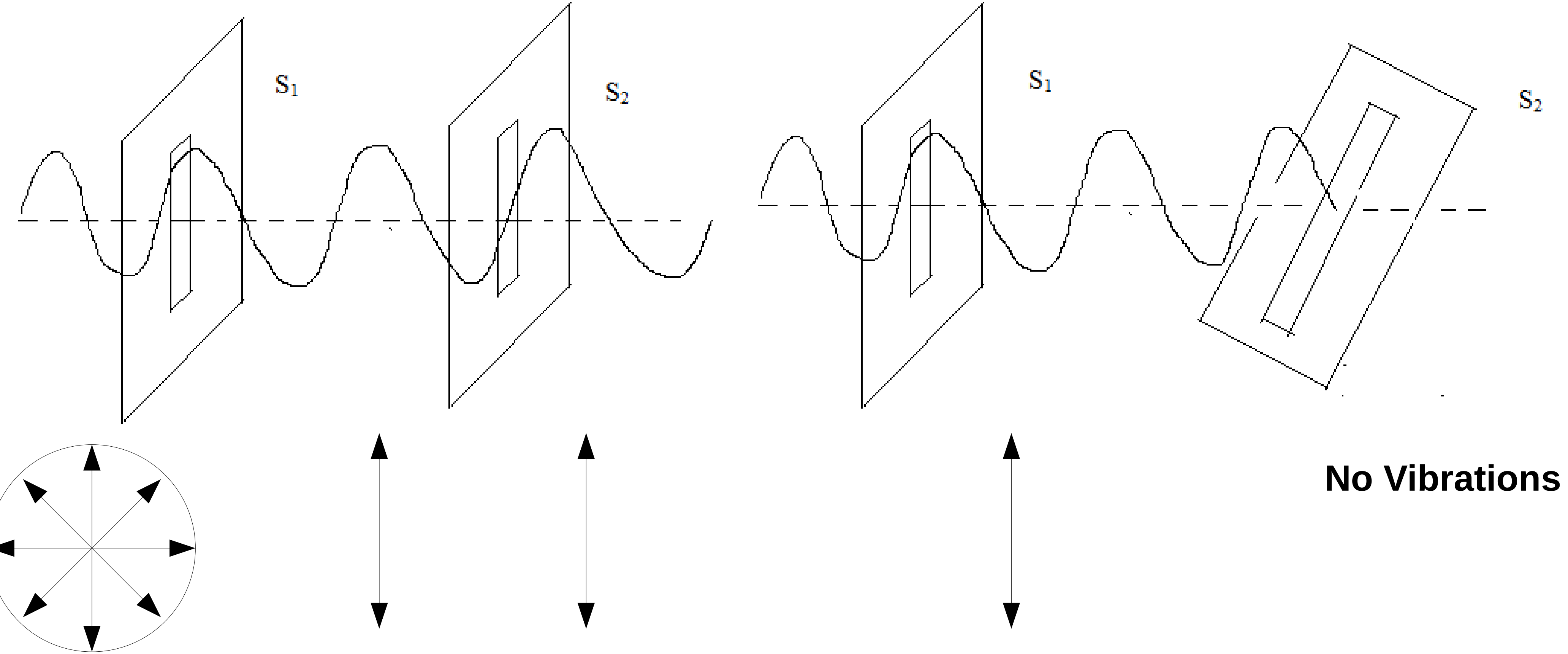


Electric field is a vector quantity, So one can resolve the vector

Polarisation

“Restricting vibrations or oscillations of a wave in a plane perpendicular to the wave propogation in only one direction”

Mechanical Analogy



Optical Analogy

Consider an ordinary light instead of a string
a Polaroid (or a tourmaline crystal) instead of a slit.
If the Polaroid S_1 is rotated then the intensity of the light will not vary proving that it is unpolarized.

However, the case will be different if light is passed through two Polaroids instead of one.

If the second Polaroid S_2 is rotated across the first one,

Intensity of the light Varies
at **90^o** and **270^o** intensity is **minimum**

At **0^o**, **180^o** and **360^o** intensity is **maximum**
Ordinary light contains vibrations in all possible directions perpendicular to the direction of propagation.

When such light passes through a polarizer, it contains vibrations only in a particular direction decided by polarizing direction (optic axis) of the polarizer.

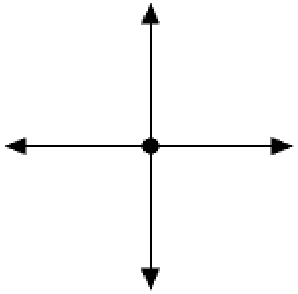
This experiment conclusively proves that light is a transverse wave

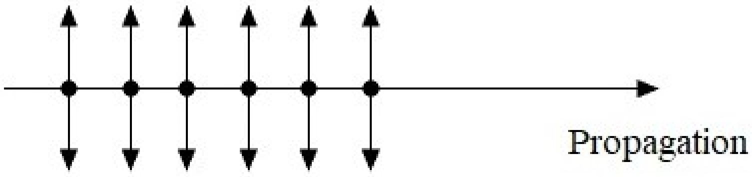
Types of Polarisation and Representations

1. Un Polarised Light (UPL)
2. Linearly/Plane Polarised Light (PPL)
3. Circularly Polarised Light (CPL)
4. Elliptically Polarised Light (EPL)
5. Partially Polarised Light (PRPL)

Unpolarized light:

The vibrations are symmetrically distributed in all the directions perpendicular to the direction of propagation

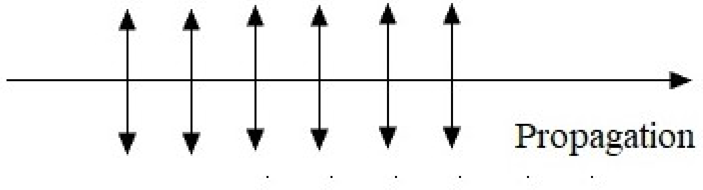




Plane Polarized Light (PPL)

UPL is allowed to pass through a polarizer, then it vibrates only in one direction parallel to its optic axis. Such light which vibrates only in a particular plane.

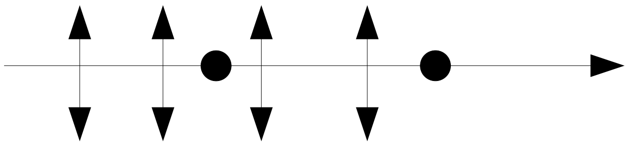
PPL (Vertically polarized)



PPL (Horizontally polarized)

Partially Polarised Light (PRPL)

Neither fully polarized nor fully unpolarized

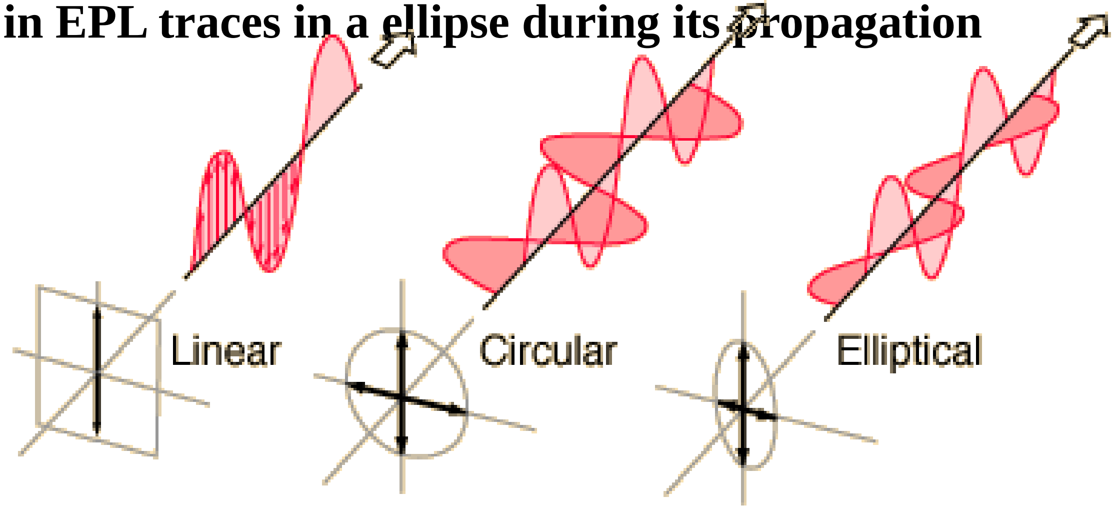


Circularly Polarised Light

Two plane polarised light of Equal amplitude are superimposed with a path difference λ/4 polarized electric vector in CPL rotates in a circle during its propagation

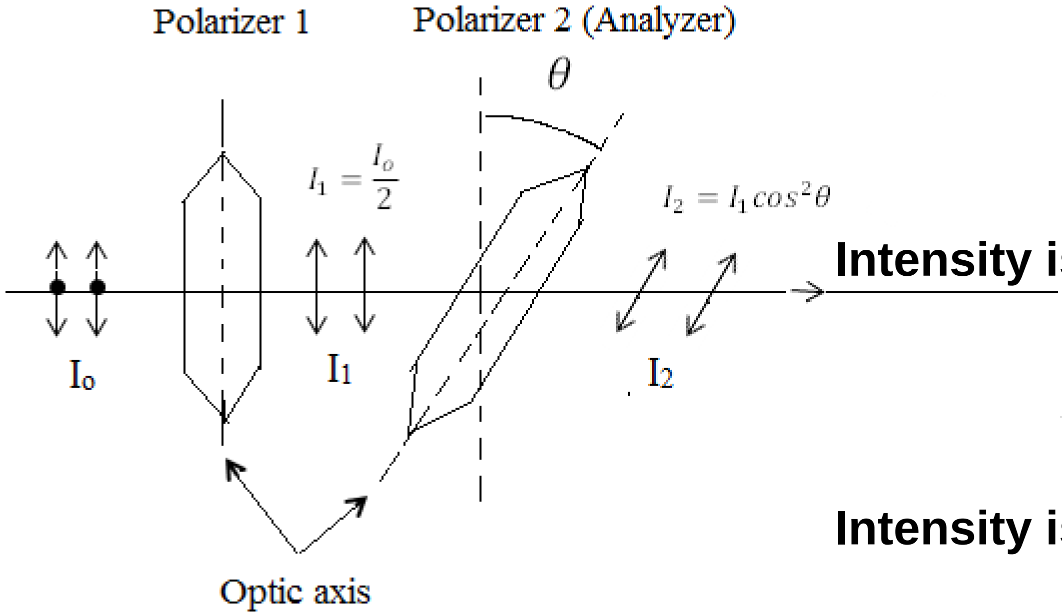
Elliptically Polarised Light

Two plane polarised light of unequal amplitude are superimposed with a path difference λ/4 polarized electric vector in EPL traces in a ellipse during its propagation



LAW OF MALUS

If the light is passed through two polarizers then the **intensity of light** passing through second polarizer **is a cosine square function** of the **angle** between their optic axis**.**



$$I_\theta = I_m cos^2\theta$$

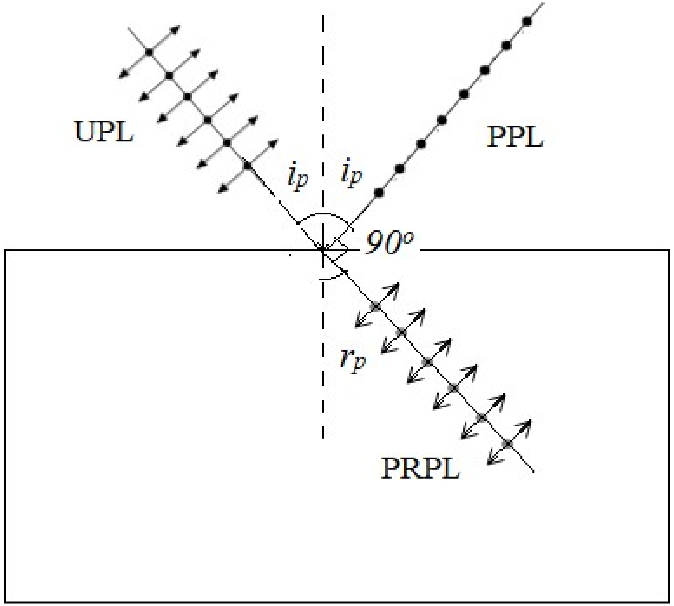
Intensity is Maximum at 0°, 180°, 360°

$$I_1 = I_o\overline{cos^2\theta} = \frac{I_o}{2}$$

Intensity is Minimum at 90°, 270°

If the light is polarized once, its intensity falls by 50%

PRODUCTION



Polarization by reflection: Brewster's law

When an ordinary light is incident on a transparent material at a perticular angle, then the reflected beam is polarised

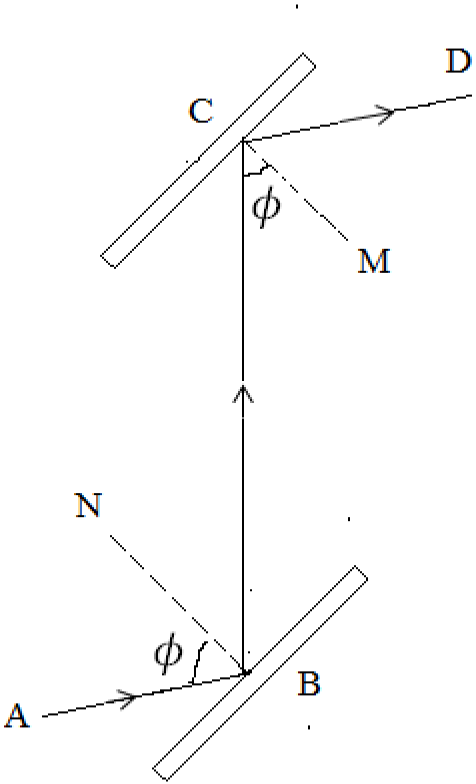
The degree of polarisation is depend on angle of incidence

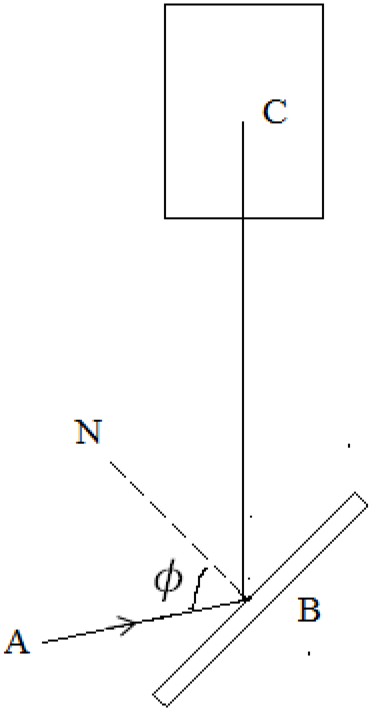
The reflected beam is completely polarised when the angle between the reflected and the refracted beam is 90^o.

$$i_p + r_p = 90^o \qquad \mu = \tan i_p$$

Biot’s polariscope

A system of glass plates obeys law of Malus. This system of two paarallel glass plates is called

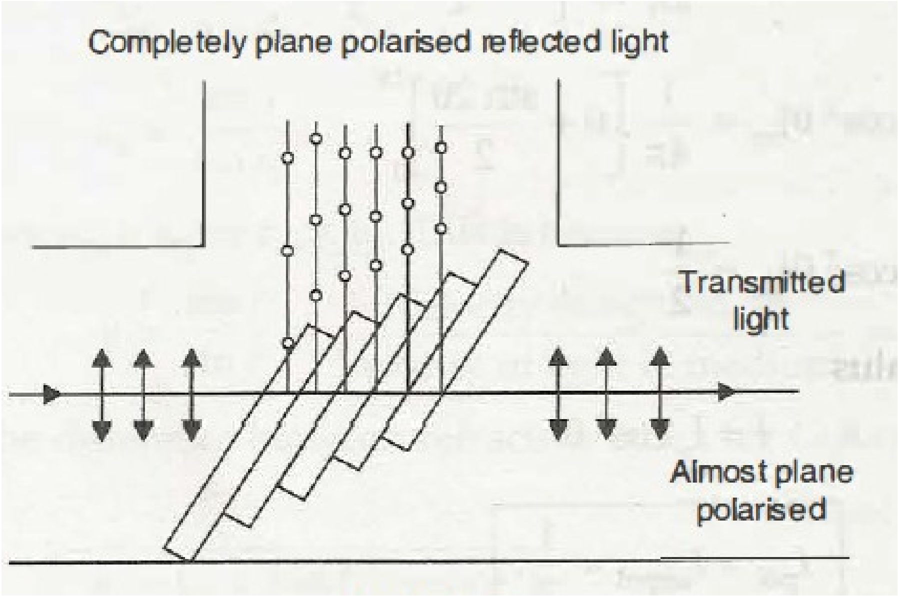




Polarization by pile of plates

Glass plates arranged parallel to each other.

We know that, when the light falls on the glass at the polarizing angle, reflected light is completely polarized. As the glass plates are parallel, the light is incident on each glass plate at polarizing angle.

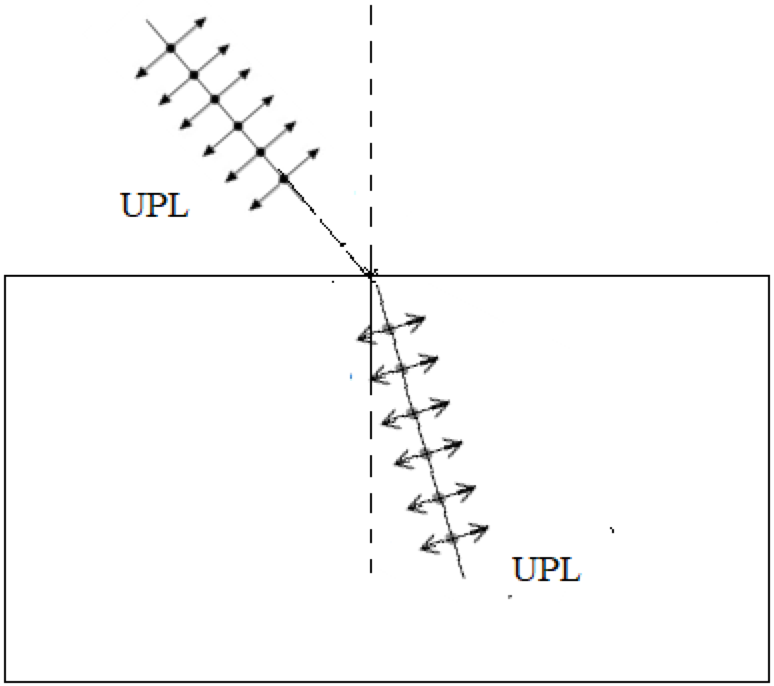


Thus in every reflection, 15 % of the 'dotted' vibrations are reflected.

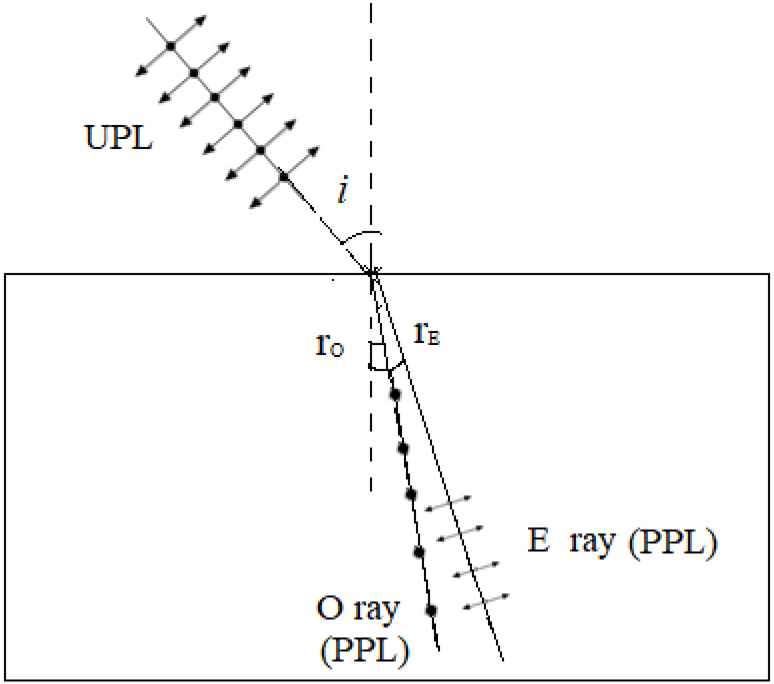
Thus the percentage of 'dot' in successive transmissions decreases and finally, the light transmitted through the last glass plate contains only 'lines' and is thus polarized

Double Refraction

The phenomenon of splitting of light in to two linearly polarised beams, whose plane of vibrations are mutually perpendicular

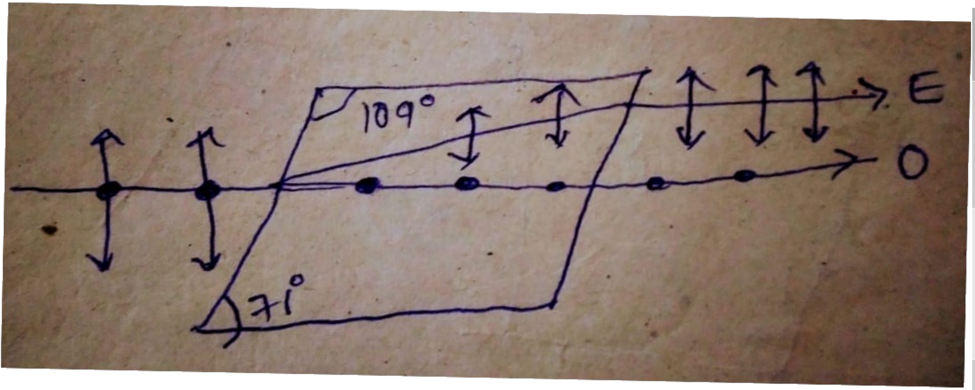


Glass (monorefringent)



Calcite (birefringent)

When unpolarised light pass through a calcite crystal, it splits in to Two rays called as O-Ray and E-Ray



Both the rays emerge out as parallel from the crystal due to the opposite faces of the calcite crystals are parallel to each other

Ordinary-Ray	Extraordinary-Ray
Passes without Deviation	Deviated from the incident direction
Obeys Snell’s law	Donot obey Snell’s law
Velocity remain same in all direction	Velocity is diffrent in diffrent directions
Vibrations perpendicular to the optic axis	Vibrations parallel to the optic axis
Refractive index is same	Refractive index is diffrent
Wavefronts are Spherical	Wavefronts are ellipsoid

Biaxial Crystal
There are two optic axes, these two axes make certain angle with each other, which is the charecterstics of the crystal
Ex: **Mica, Borax**

Uniaxial Crystal
Only one optic axis
Ex: **Calcite, Quartz, Tourmaline**

Two Types

Negative Crystal

Positive Crystal

The quantity $\Delta\mu = \mu_O - \mu_E$ is called birefringence

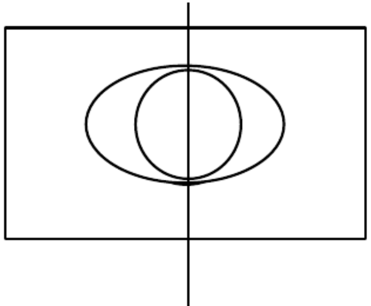
Negative Crystal

Δμ is –ve

Velocity of E-ray > Velocity of O-ray
Velocity of E-ray is diffrent in diffrent direction
Maximum at perpendicular to the optic axis
Minimum along the optic axis
Velocity of O-ray is same in all direction

Refractive index varies for E-Ray
Maximum along the optic axis
Minimum at perpendicular to the optic axis
Refractive index of O-ray > Refractive index of E-ray
Wave front of O-Ray is inside the Wave front of E-Ray

Ex: calcite, Tourmaline,



Positive Crystal

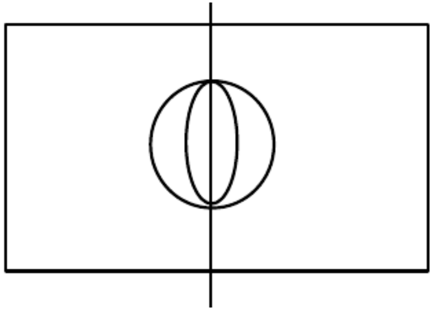
Δμ is +ve

Velocity of O-ray > Velocity of E-ray
Velocity of E-ray is diffrent in diffrent direction
Maximum along the optic axis
Minimum at perpendicular to the optic axis
Velocity of O-ray is same in all direction

Refractive index varies for E-Ray
Maximum at perpendicular to the optic axis
Minimum along the optic axis

Refractive index of E-ray > Refractive index of O-ray
Wave front of E-Ray is inside the Wave front of O-Ray

Ex: Quartz, Aragonite



Crystal	Formula	M_E	μ_O	Birefringence $\Delta\mu = \mu_E - \mu_O$	Type of crystal
Calcite	$CaCO_3$	1.486	1.658	-0.172	-ve
Ice	H_2O	1.313	1.309	+0.004	+ve
Quartz	SiO_2	1.553	1.544	+0.009	+ve
Siderite	$Feo.CO_2$	1.635	1.875	-0.240	-ve
Sodium Nitrate	$NaNO_3$	1.336	1.587	-0.251	-ve

The crystals with large Δμ are strongly birefringent (sodium nitrate), while the crystals, such as ice have a very low value of Δμ and are termed weakly birefringent.

Calcite is widely used : naturally occuring, colorless, low cost, ease to cut, rhombohedral breaks: pieces also rhombohedral

Polariser and Analyser

Polariser:

optic used to polarise the light

Nicol Prism: O-Ray is eliminated using concept of Total Internal Reflection and only E-ray is perfectly polarised and transmitted

Polaroids: O-Ray is eliminated using “ selective absorption”

Tourmaline Crystal and doped **PVA** is also used for Dichroism

Analyser:

Polariser used to detect or analyse polarised light

Huygen’s Theory of Double Refraction

“Light Energy propagates interms of wavefront”

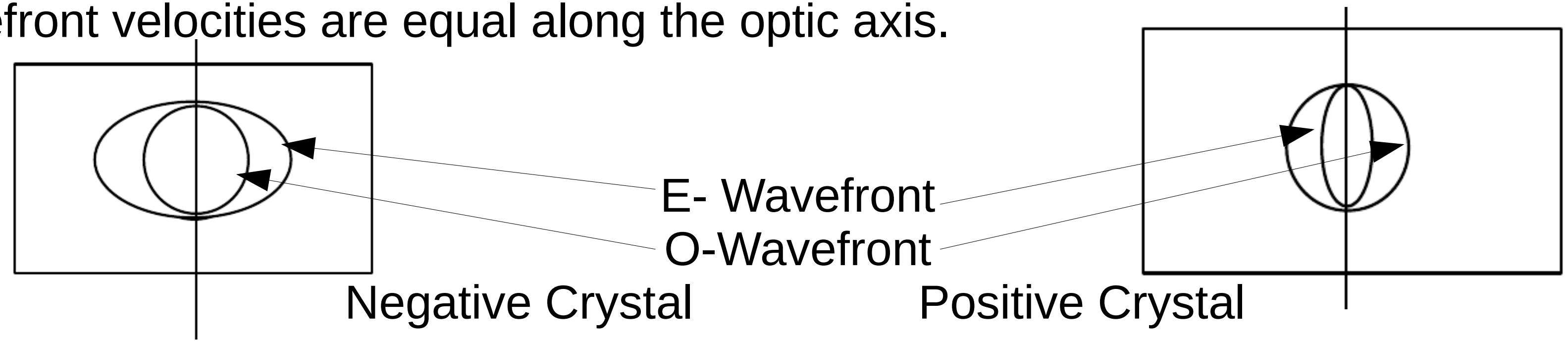
Assumptions:

1. when beam of light strikes a double refacting crystal each point on the refracting surface acts as a source for two secondary wavefronts, which spread out in to the crystal

2. One wavefront obeys the ordinary laws of refraction which travels with the same speed in all the directions. Hence corresponding wave surface is spheroid and called as O-wavefront

3. Second wave front travelswith a diffrent velocities in diffrent directions. Hence wave surface is ellipsoid called E-wavefront. They donot obey Snell’s law

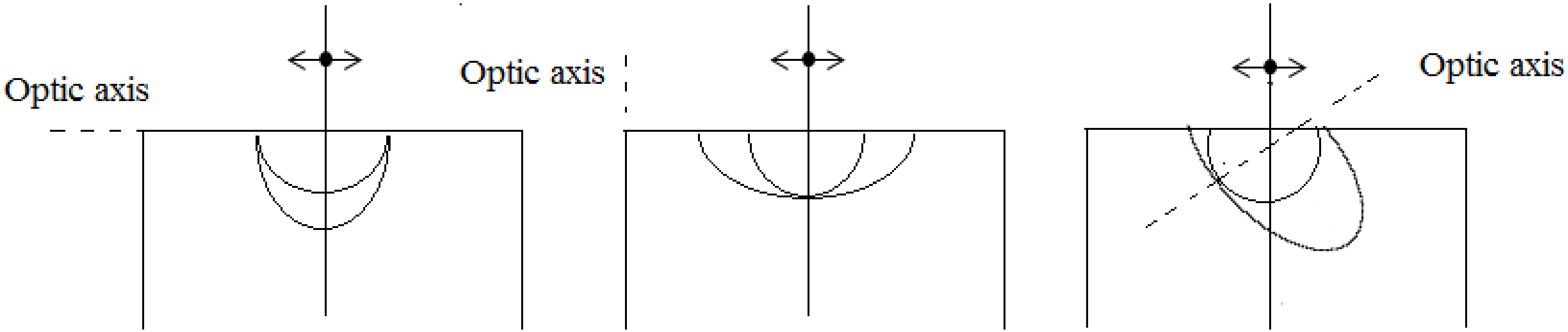
4. The rays corresponding to the two wavefronts merge along the optic axis. The O- and E-Wavefront velocities are equal along the optic axis.



5. The direction of propogation of E- Wavefront depends on direction of optic axis relative to the refractive surfaces

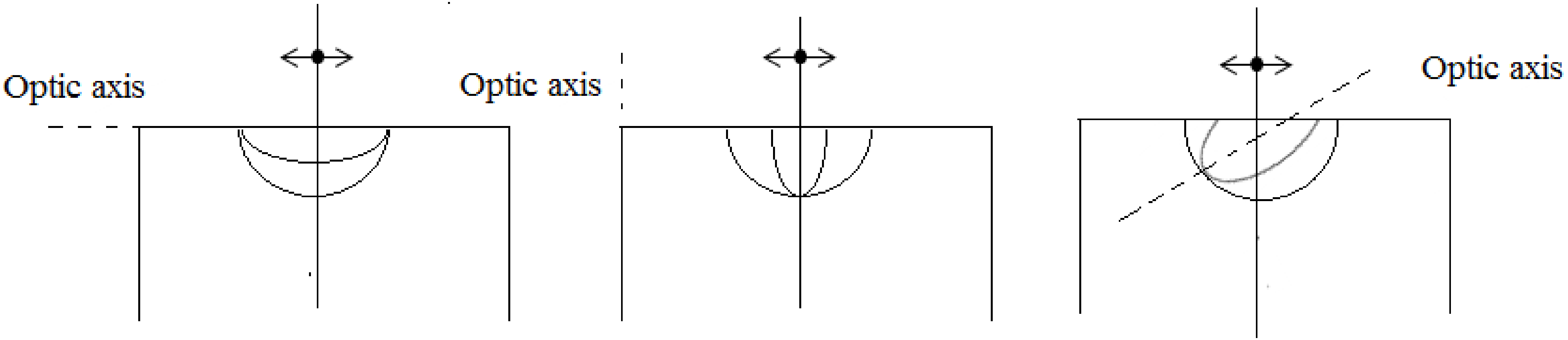
The wavefronts of E and O rays for different orientations of optic axis

For Negative Crystals



The wavefronts of E and O rays for different orientations of optic axis

For Positive Crystals



Theory of Circularly And Elliptically Polarized Light

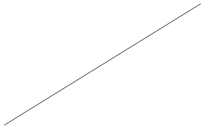
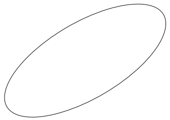
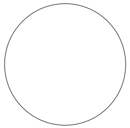
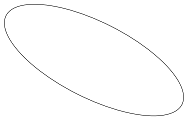
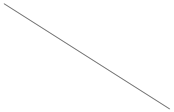
E ray and O ray vibrate in perpendicular directions with phase difference Φ
Then

$$x = a sin\omega t \qquad y = b sin(\omega t + \phi)$$

Superposition of E- Ray and O-Ray results

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

Equation of an Ellipse

Φ	**0°** **360°**	**180°-270°** **0°-90°**	**270°** **90°**	**270°-360°** **90°-180°**	**180°**
					

ϕ	Resulting eqn	Resulting vibration	Remark
0^o, 360^o	$y = \frac{b}{a}x$	Straight line	If two PPL is superimposed with zero phase difference then resulting vibration is PPL
180^o	$y = -\frac{b}{a}x$	Straight line	If two PPL is superimposed with zero phase difference hen resulting vibration is PPL
90^o, 270^o $a \neq b$	$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$	Ellipse	If two PPLs with unequal amplitudes are superimposed with a phase difference of 90^o, 270^o, the resulting vibration is EPL
90^o, 270^o $a = b$	$x^2 + y^2 = a^2$	Circle	If two PPLs with equal amplitudes are superimposed with a phase difference of 90^o, 270^o, the resulting vibration is CPL

Retardation Plates

When a light falls normally on a doubly refracting uniaxial crystal plate cut with optic axis parallel to the refracting surfaces, a phase diffrence between the O-ray and E-Ray is introduced. Then the crystal is called as Retardation Plate

The path difference between the two rays is given by

$$\Phi=(\mu_o-\mu_e)t$$

μ_o- Refractive index of O-Ray

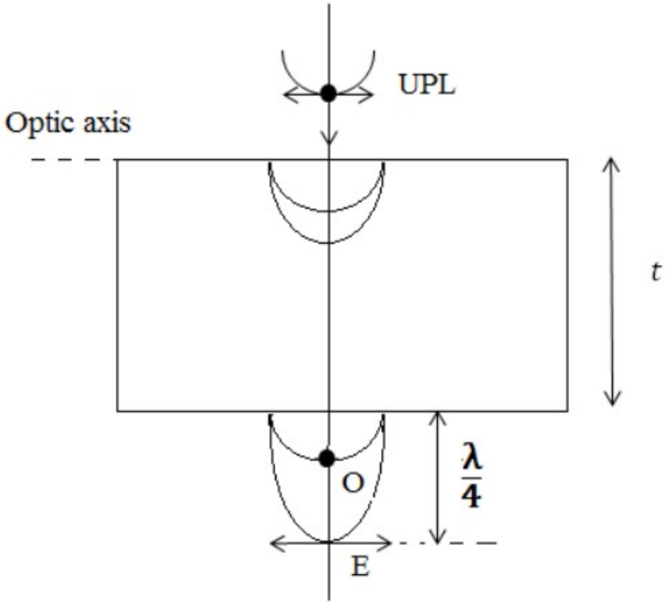
M_e -Refractive index of E-Ray

t- thickness of the plate

Ex: Quarter Wave Plate, Half Wave Plate

Quarter Wave Plate

It is doubly refracting uniaxial crystal plate that introduces a phase diffrence of π/2 or path diffrence of λ/4 between the O-Vibrations and E-vibrations, when light normally incident on it



For Negative Crystal

$$t = \frac{\lambda}{4(\mu_o - \mu_e)}$$

For Positive Crystal

$$t = \frac{\lambda}{4(\mu_e - \mu_o)}$$

Ex: **Mica, Quartz**

Converts PPL in to CPL (or EPL) and conversely it also converts CPL (or EPL) in to PPL

Half Wave Plate

It is doubly refracting uniaxial crystal plate that introduces a phase diffrence of π or path diffrence of λ/2 between the O-Vibrations and E-vibrations, when light normally incident on it

For Negative Crystal

$$t = \frac{\lambda}{2(\mu_o - \mu_e)}$$

For Positive Crystal

$$t = \frac{\lambda}{2(\mu_e - \mu_o)}$$

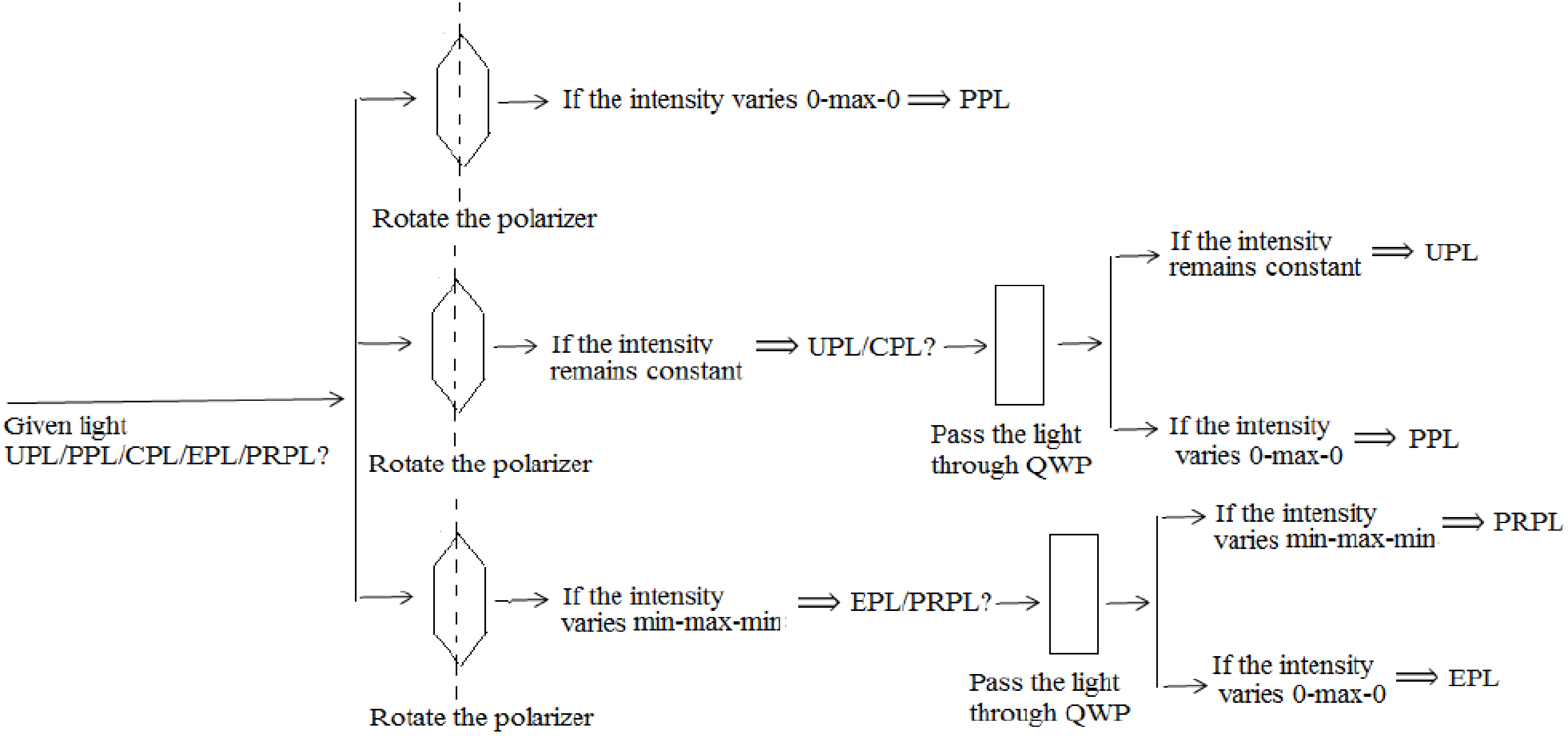
Made from doubly refracting uniaxial crystal, cut with refracting faces parallel to optic axes

Used to ulter the direction of vibration of the linearly polarized light by angle 2θ

θ--- angle between incident vibration and the optic axis

Detection

Allow the light to pass through the analyser



Application

Polarising Sunglass- cuts the glare of light

Without polarised lens With polarised lens

Optical Activity

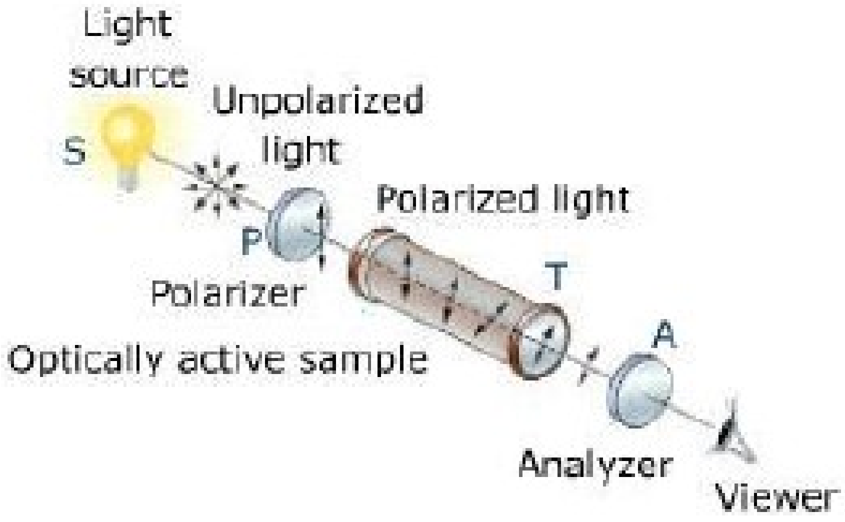
Certain Materials have an ability to rotate the plane of vibration of PPL

Ex: Sugar solution, Turpentine, Liquid Crystals, Tartaric acid, Camphor, Cholestrol

Angle of rotation (θ) depends on

1. Concerntration (c)
2. Length of the Cell (l)
3. Specific Rotation (S)

$$\theta = Slc$$

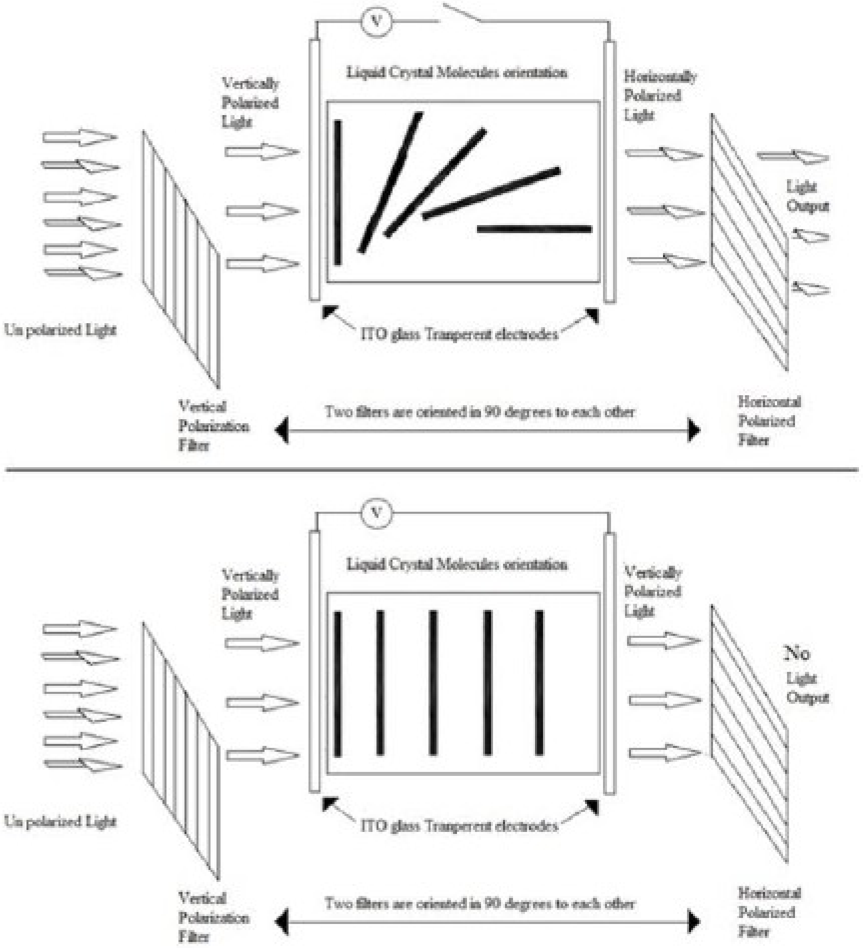


Saccharimeter

Instrument for measuring the concentration of sugar solutions

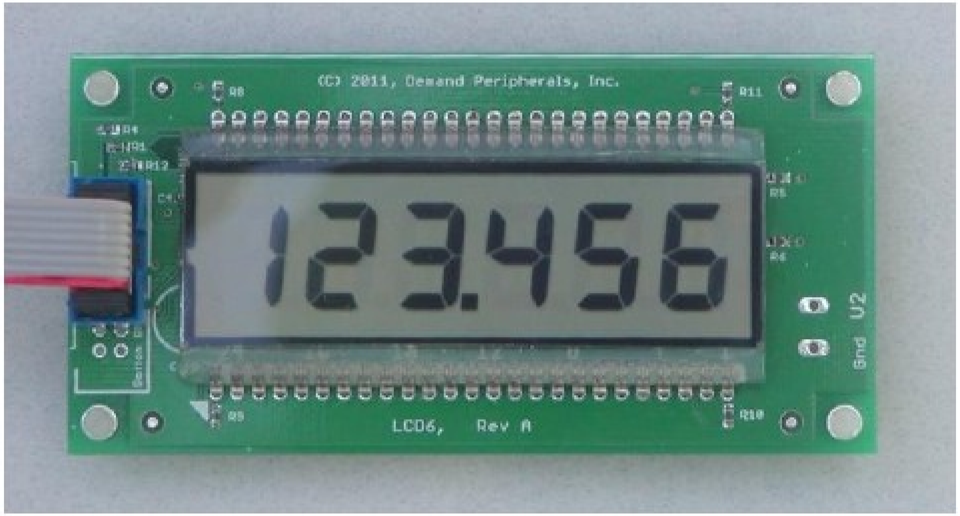
Liquid Crystal Display

- System of two crossed polarisors do not transmit the light
-Place optically active Liquid crystals between polarisors
- LC’s rotate the PPL by 90^o
-Now pass the UPL through the polarisor, it will allow vertical vibrations
-LC rotate the vertical vibrations into horrizontal vibrations
-These horizontal vibrations passed through the analyser
-keep mirror infront of analyser, so that horizontal vibrations reflect back to L.C.through the analyser, rotate again and comes out through the polariser
- **System appears bright**
- now apply small voltage to L.C., it looses optical activity, vertical components not rotatedin to horizontal, so PPL is blocked at the analyser
- System appears Dark



Using This Principle Seven segment displays were constructed

Similarly Combination of R.G.B LC’s used in Color displays



3-D Movies

- Shot twice through two lenses kept side by side
- These two movies are projected on the screen through two projectors mounted with two polarisers, vertical and horizontal
- Viewer looks movie with aspecial goggle mounted with two polarisers, horizontal for one eye and vertical from another
- Thus one eye sees only horizontally polarised movie and another see only vertically polarised movie
- Our brain mixes these two pictures and thus 3D stereo screen version is produced

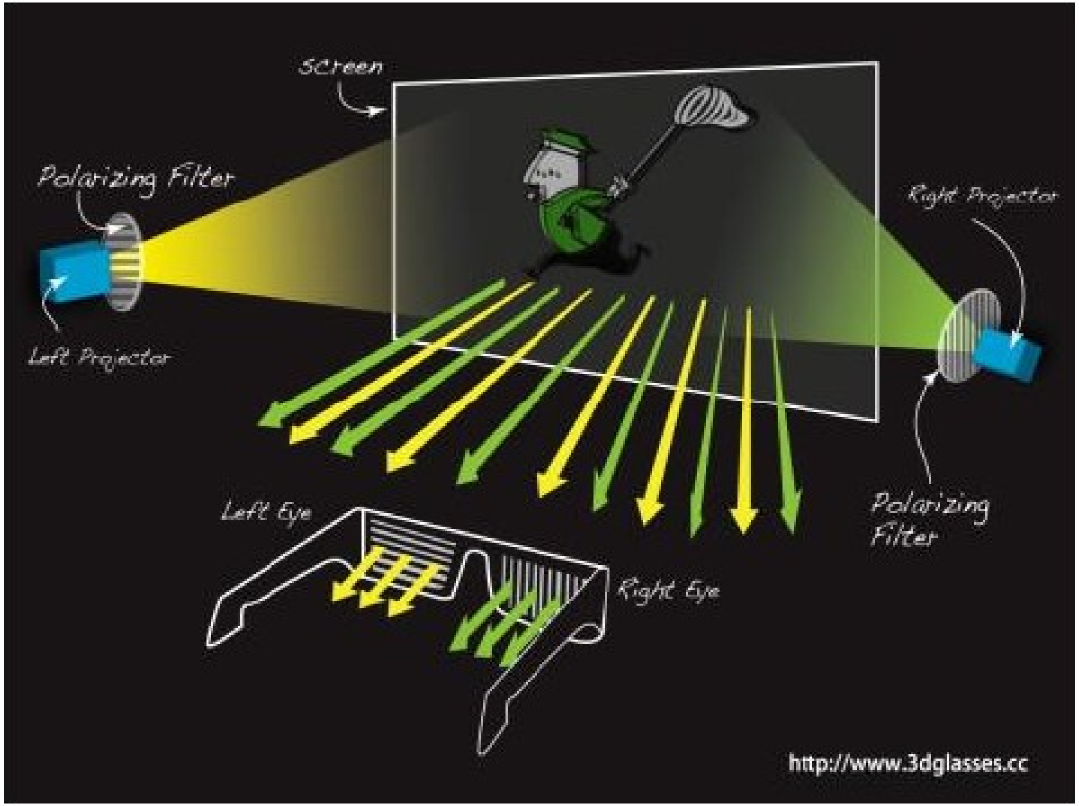
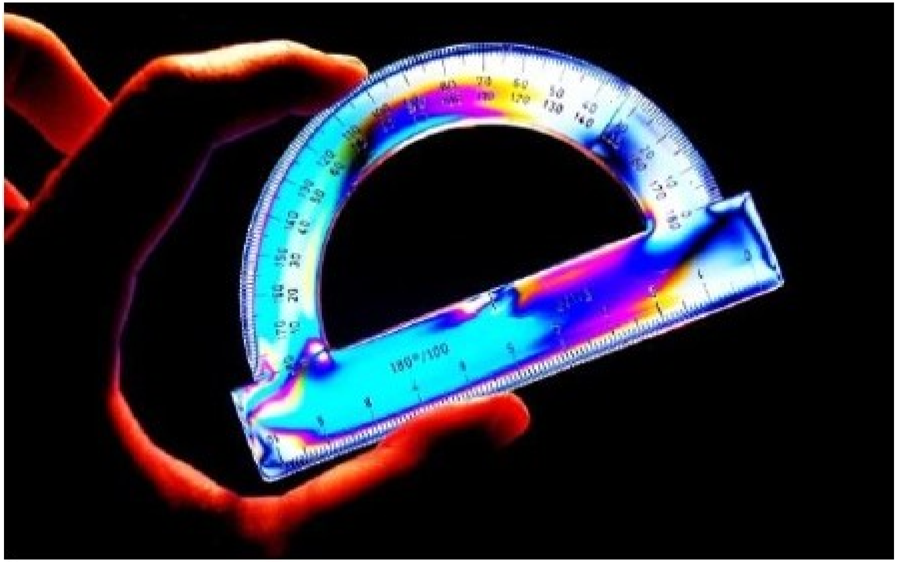


Photo-Elasticity

Due to force, defects or stressed Zones present in the components
These can be made visualised by polarisers
i.e. some material may become double refracting in stressed zone



Reference: Concepts of Engineering Physics, Dr. Narendra Mathakari, MITWPU

ಧನ್ಯವಾದ THANK YOU