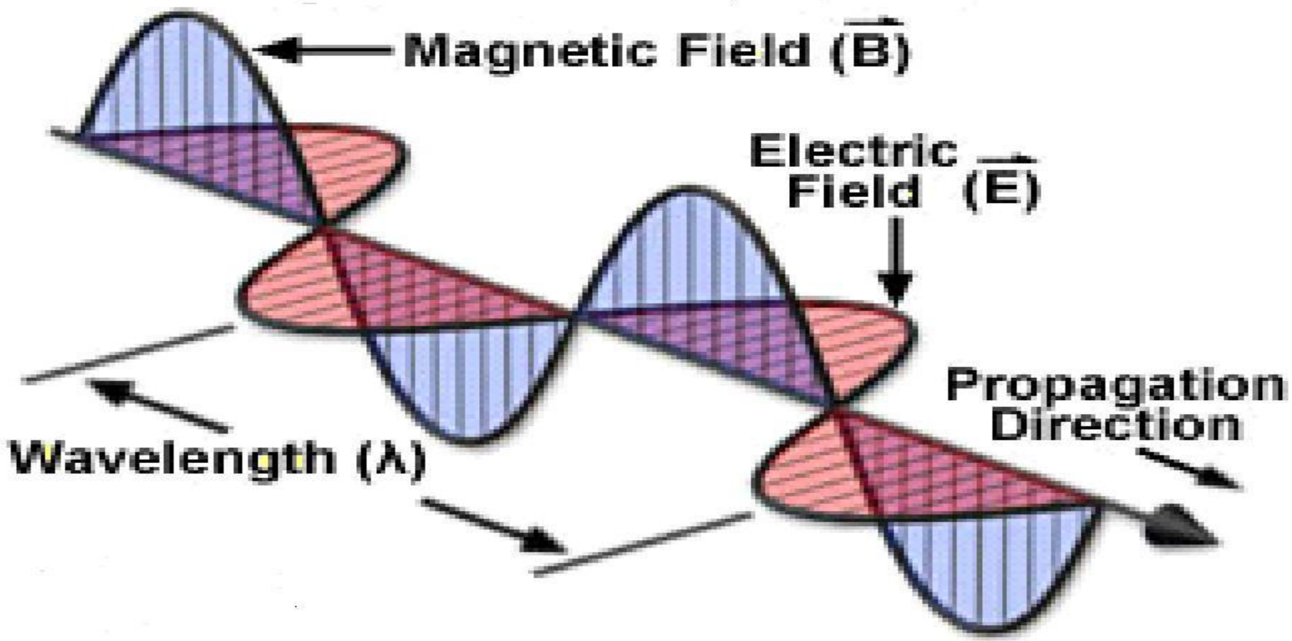
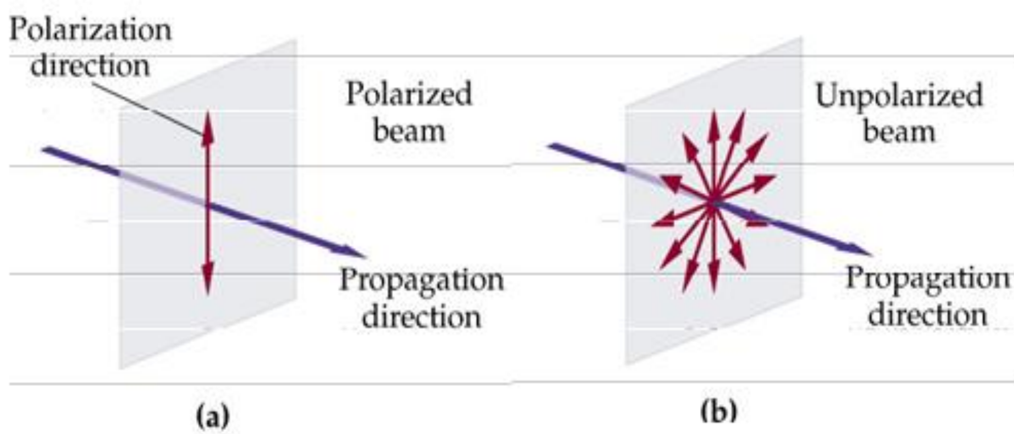
POLARIZATION

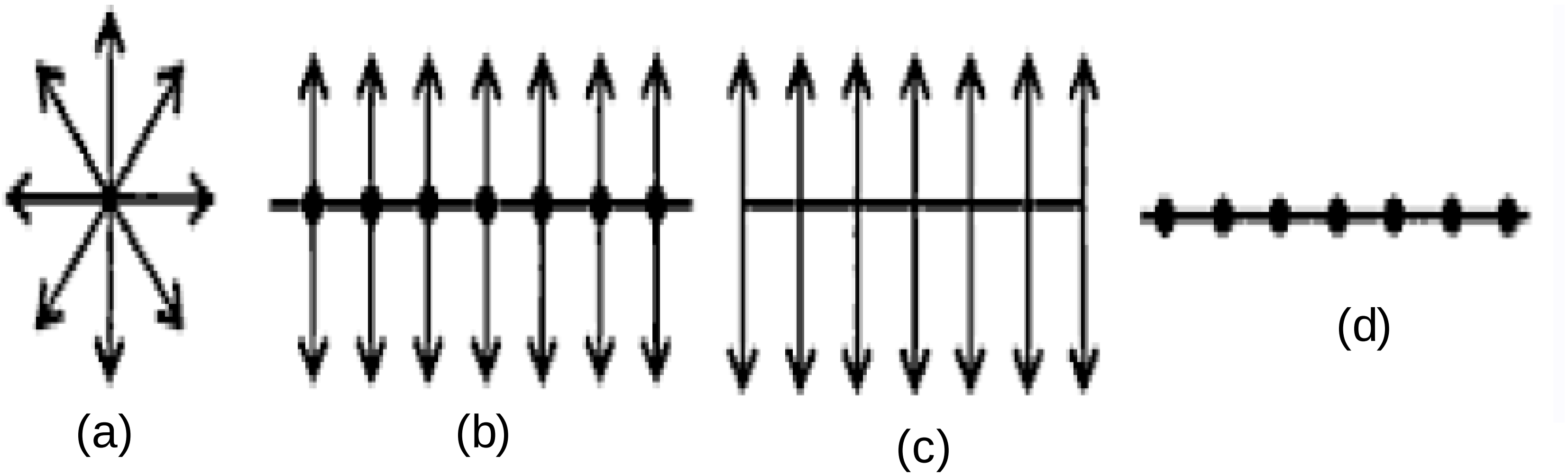
Polarization of Light

- According to Maxwell, light waves are transverse in nature ie electric & magnetic field vector vibrate mutually perpendicular & also perpendicular to the direction of propagation of propagation of waves.
- The electric field vector E is called light vector ie it produces all the observed effects of light.
- Light is emitted by excited atoms & molecules. So in a ray of light millions of waves follow each other in rapid succession at random. Hence, the vibrations are possible in all directions.
- So an ordinary light beam is unpolarised. In this electric vector keeps on changing its direction in a random manner.
- If electric vector oscillates in a particular direction then light is said to be linearly polarized.


Magnetic Field ($\vec{B}$)
Electric Field ($\vec{E}$)
Propagation Direction
Wavelength (λ)

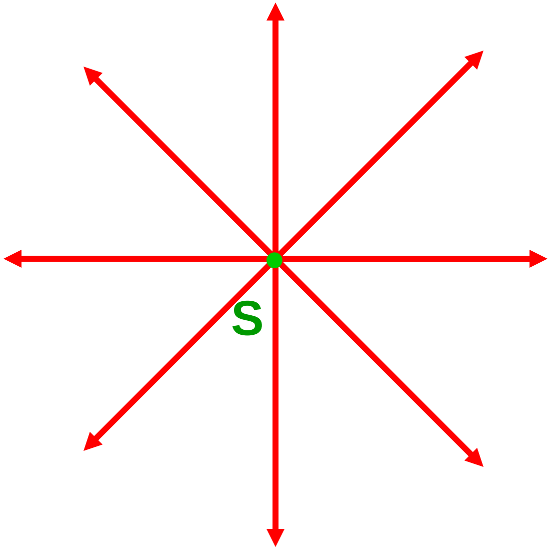

Polarization direction
Polarized beam
Propagation direction
Unpolarized beam
Propagation direction
(a)
(b)

Representation of Polarized light

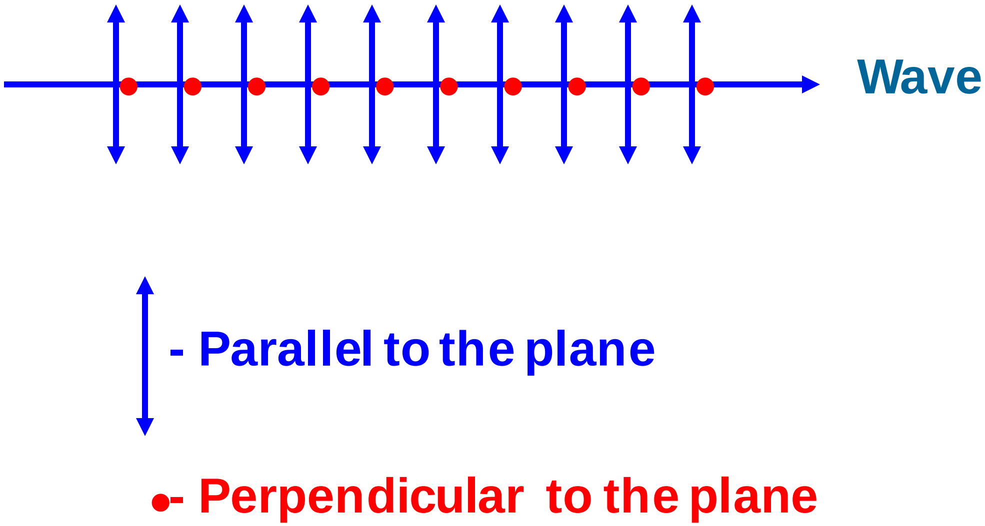


(a, b) ordinary light or unpolarized light (c) Plane Polarized light with vibration along the plane of paper (d) Plane Polarized light with vibration perpendicular the plane of paper.

Polarization of Light Waves:



Natural Light



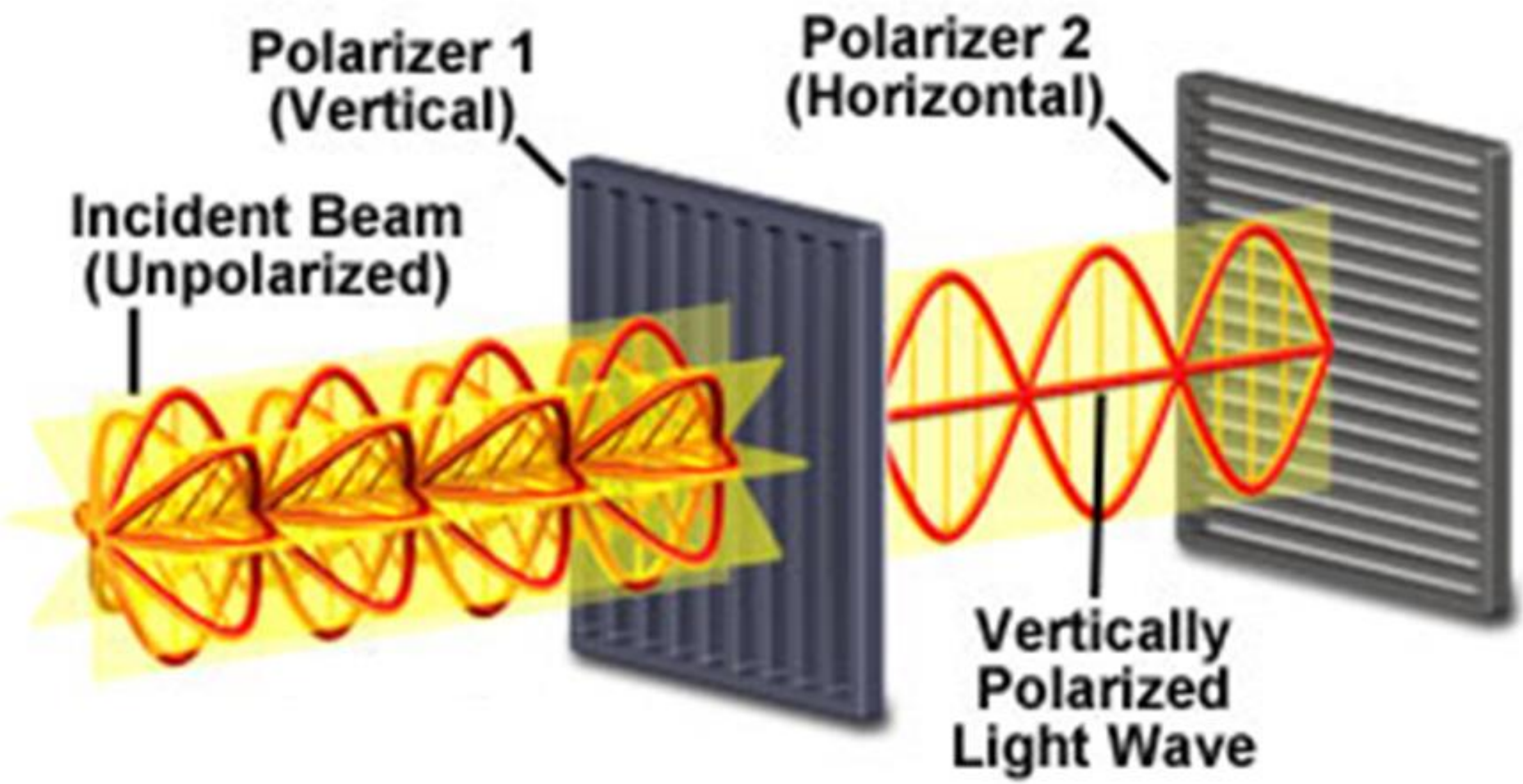
Representation of Natural Light

In natural light, millions of transverse vibrations occur in all the directions perpendicular to the direction of propagation of wave.

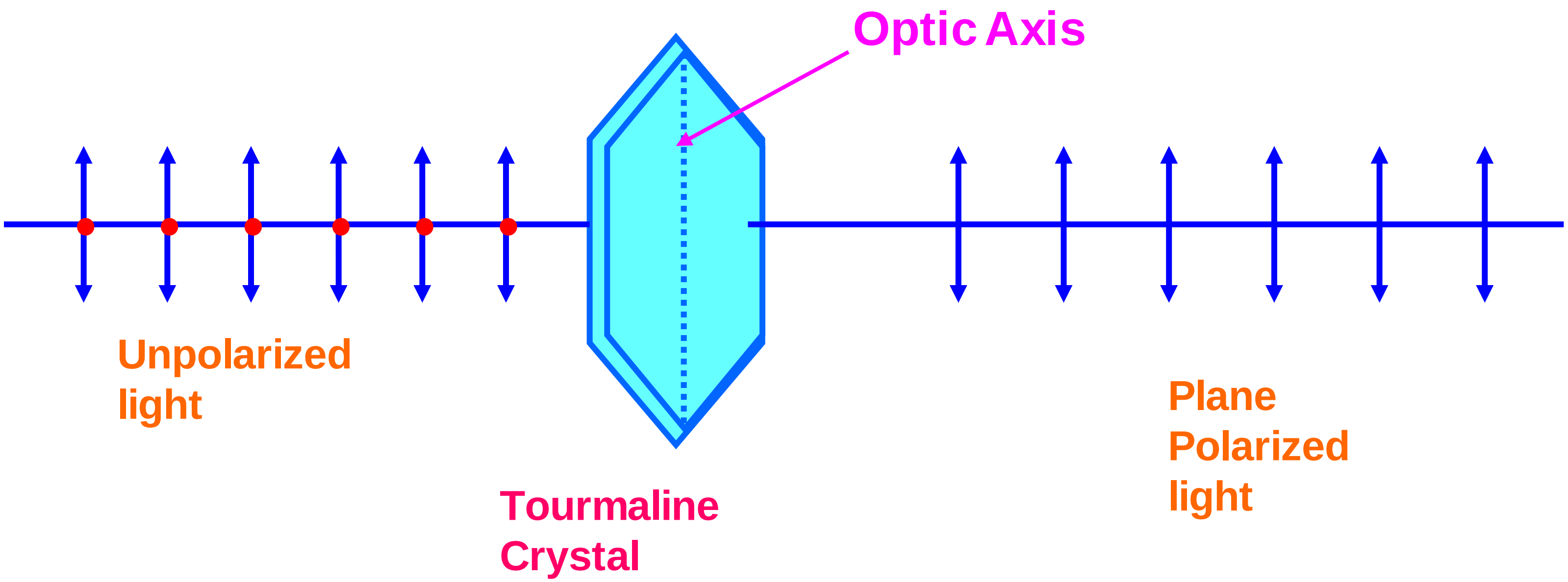
But for convenience, we can assume the rectangular components of the vibrations with one component lying on the plane of the diagram and the other perpendicular to the plane of the diagram.

PRODUCTION OF PLANE POLARIZED LIGHT

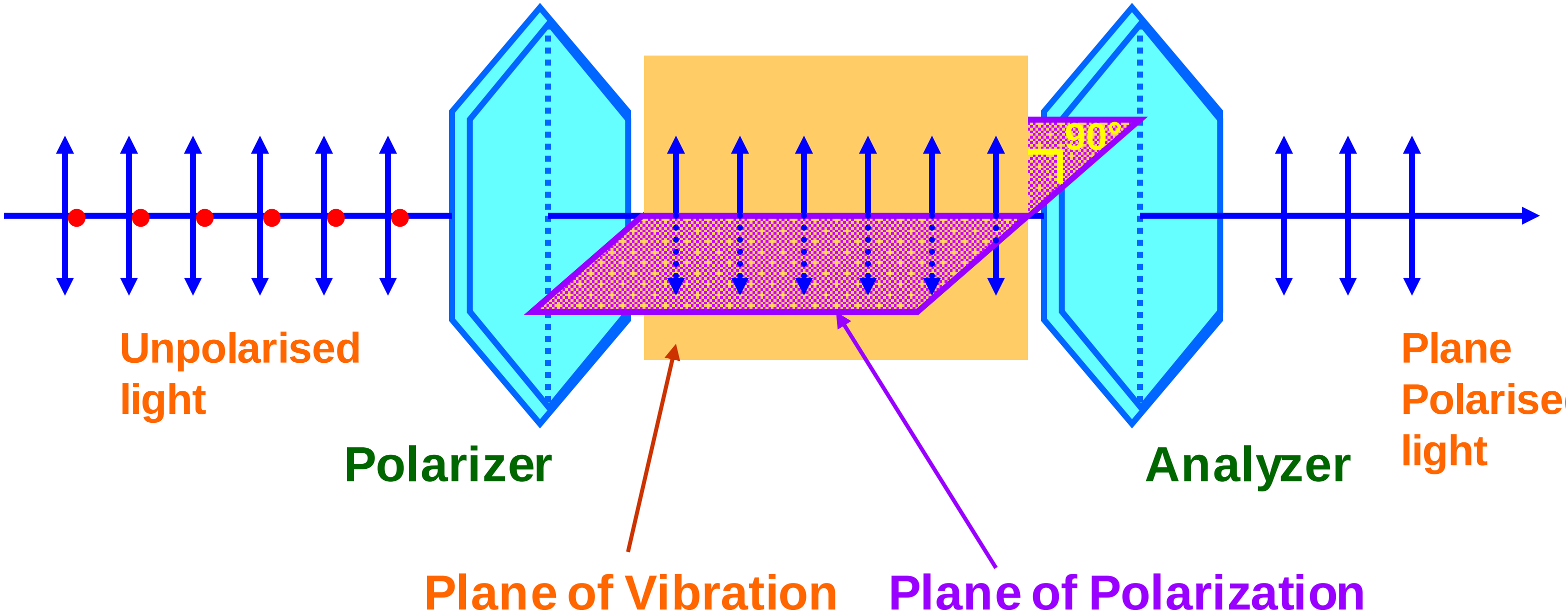
Polarization of Light



Polarization of Light Waves:



Light waves are electromagnetic waves with electric and magnetic fields oscillating at right angles to each other and also to the direction of propagation of wave. Therefore, the light waves can be polarized.

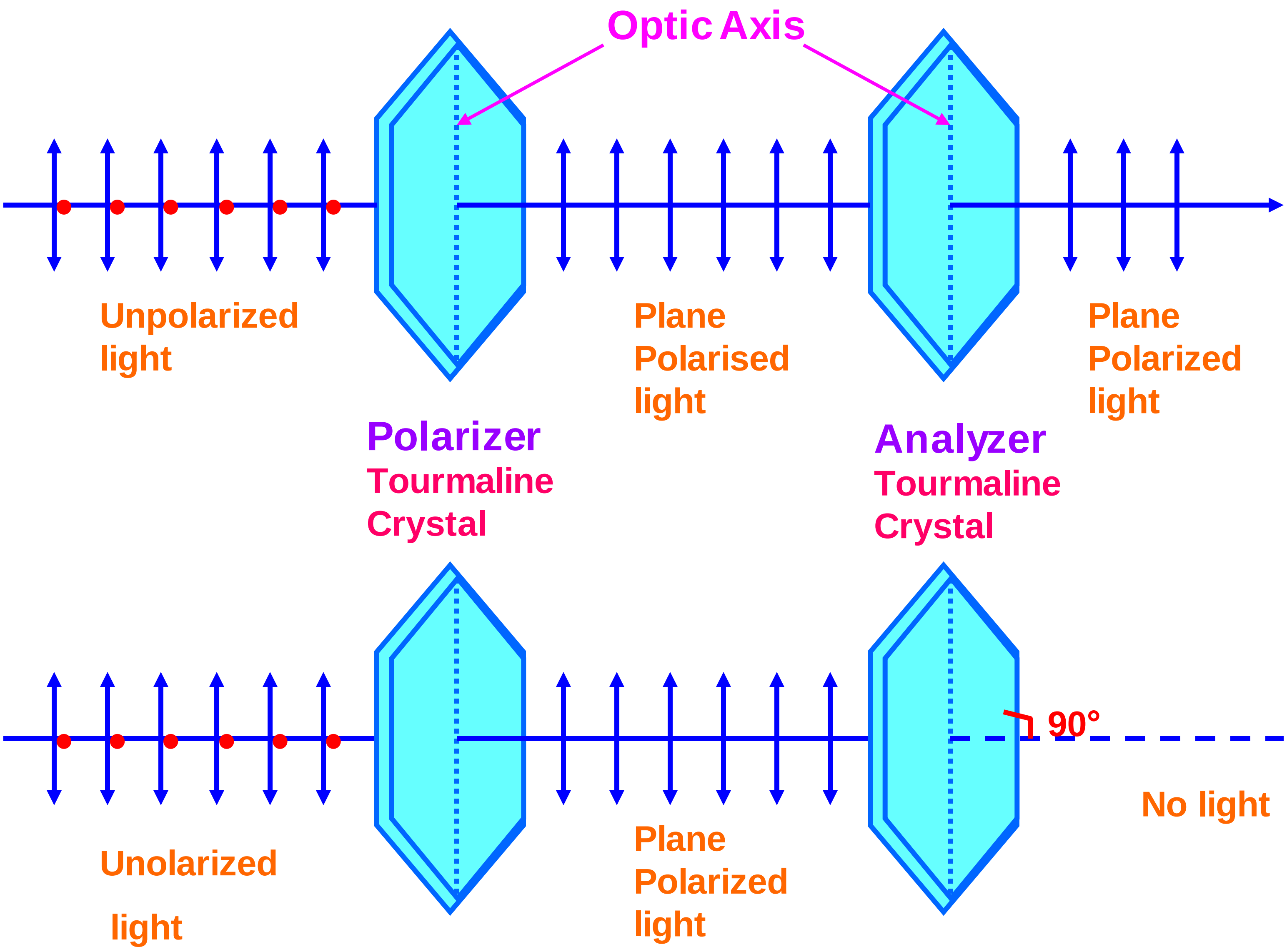


When unpolarized light is incident on the polarizer, the vibrations parallel to the crystallographic axis are transmitted and those perpendicular to the axis are absorbed. Therefore the transmitted light is plane (linearly) polarized.

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 polarization.

Light waves are electromagnetic waves with electric and magnetic fields oscillating at right angles to each other and also to the direction of propagation of wave. Therefore, the light waves can be polarized.



Malus' Law:

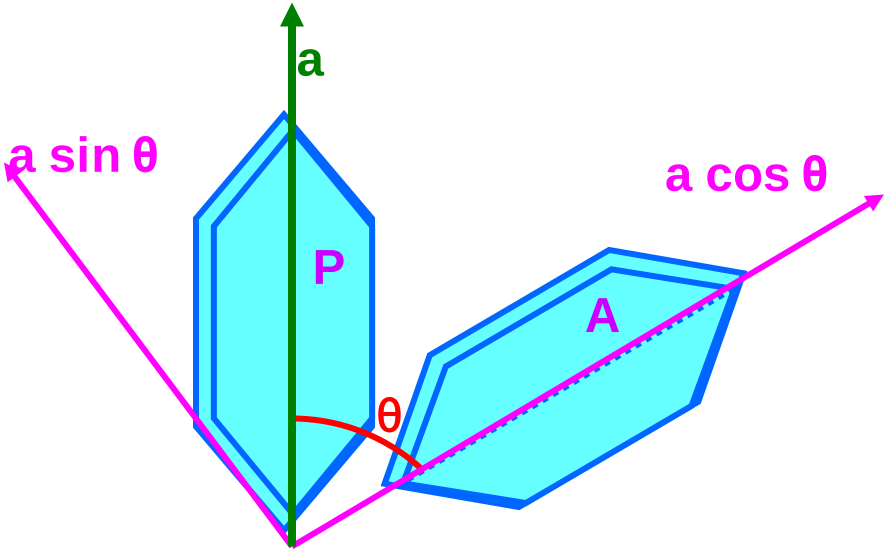
When a beam of plane polarized light is incident on an analyzer, the intensity I of light transmitted from the analyzer varies directly as the square of the cosine of the angle θ between the planes of transmission of analyzer and polarizer.

$$\boxed{I \propto \cos^2 \theta}$$

If a be the amplitude of the electric vector transmitted by the polarizer, then only the

component a cos θ will be

transmitted by the analyzer.



Intensity of transmitted light from the analyzer is

$$I = k\,(a \cos \theta)^2$$

or $$I = k\,a^2 \cos^2 \theta$$

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

(where $I_0 = k\,a^2$ is the intensity of light transmitted from the polariser)

Case I : When $\theta = 0°$ or $180°$, $I = I_0$

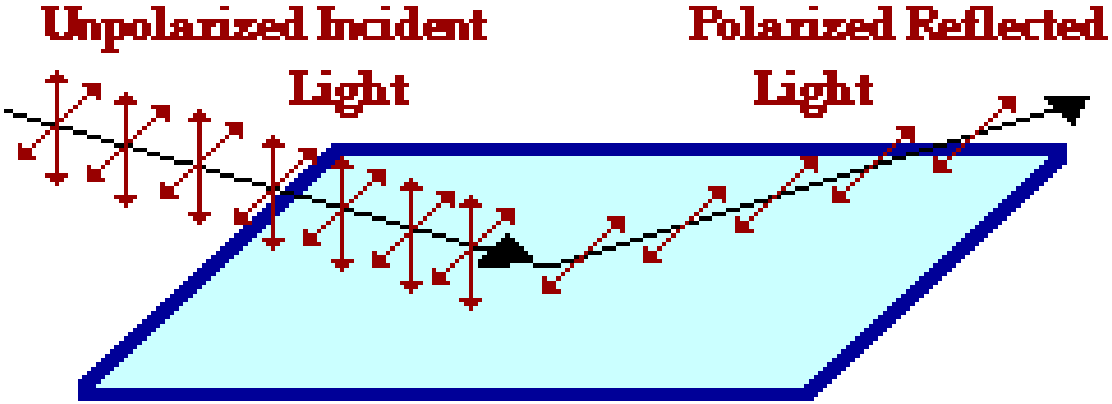
Case II : When $\theta = 90°$, $I = 0$

Case III: When unpolarized light is incident on the analyzer the intensity of the transmitted light is one-half of the intensity of incident light. (Since average value of $\cos^2\theta$ is ½)

POLARIZATION BY REFLECTION

Unpolarized light can be polarized, either partially or completely, by reflection.

The amount of polarization in the reflected beam depends on the angle of incidence.

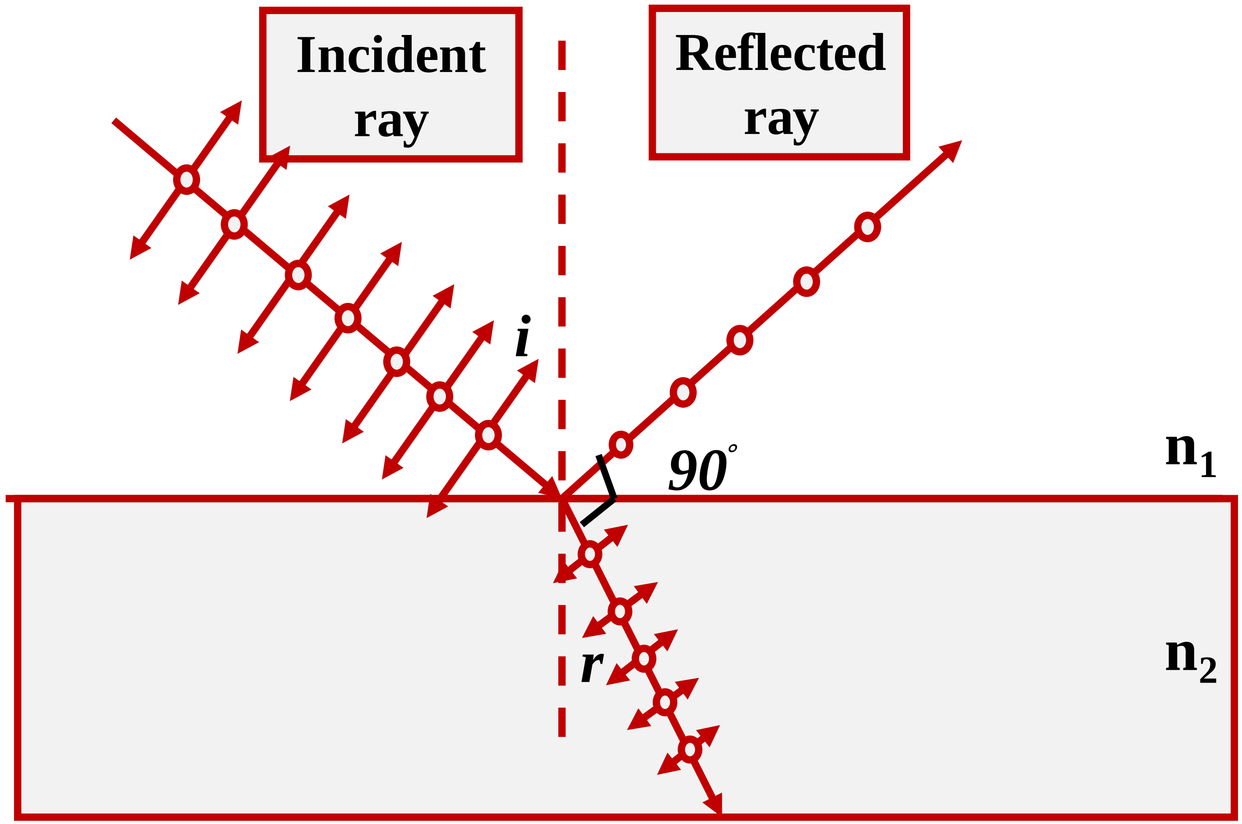


Reflection of light off of non-metallic surfaces results in some degree of polarization parallel to the surface.

BREWSTER'S LAW

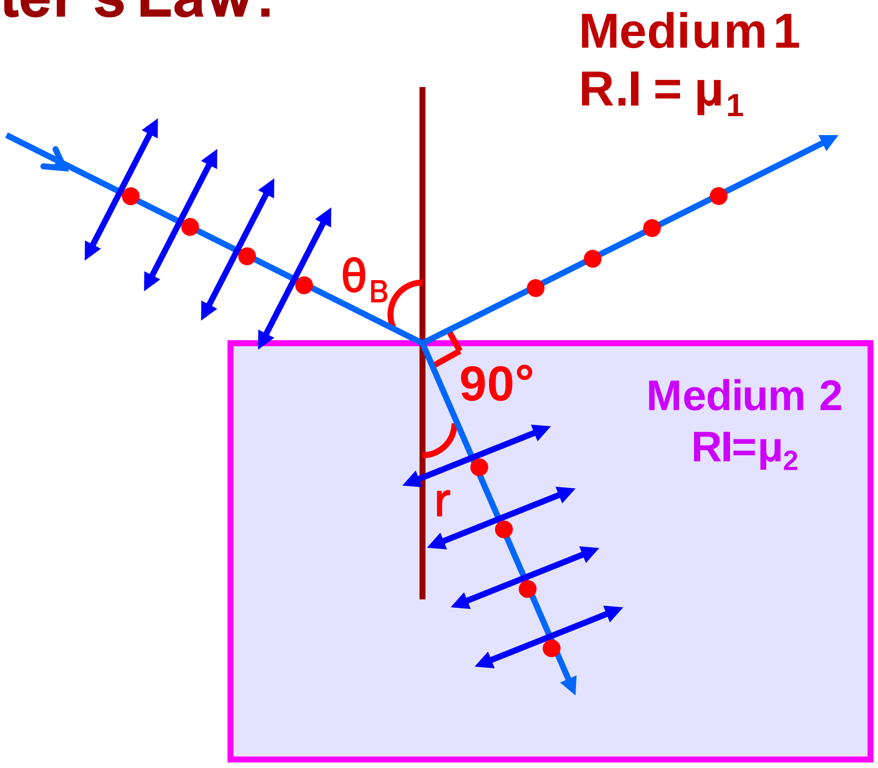
It is found that when light is incident at polarizing angle than the reflected light will be completely plane-polarized.

The reflected and refracted rays are perpendicular to each other.



Polarization by Reflection: Brewster's Law:

The incident light wave is made of parallel vibrations on the plane of incidence and perpendicular vibrations : perpendicular to plane of incidence).



At a particular angle θ_B, the parallel components completely refracted whereas the perpendicular components partially get refracted and partially get reflected.

i.e. the reflected components are all in perpendicular plane of vibration and hence plane polarized.

The intensity of transmitted light through the medium is greater than that of plane polarized (reflected) light.

$\theta_B + r = 90°$ or $r = 90° - \theta_B$

$$_1\mu_2 = \frac{\sin \theta_B}{\sin r}$$

$$_1\mu_2 = \frac{\sin \theta_B}{\sin 90° - \theta_B}$$

$$\boxed{_1\mu_2 = \tan \theta_p}$$

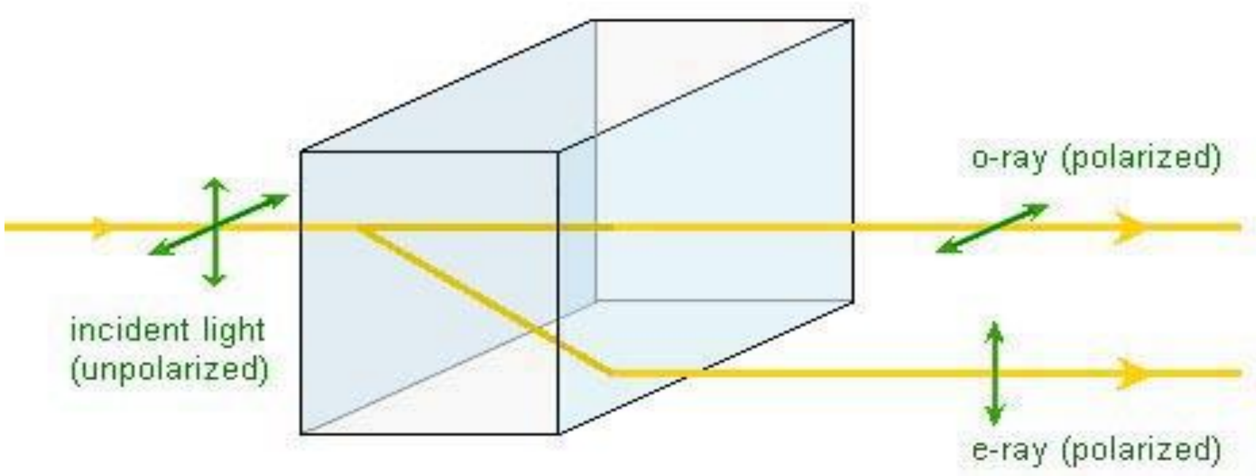
DOUBLE REFRACTION

- Some crystals in nature have different index of refraction in different directions.
- The index of refraction depends on the direction of polarization of the light entering the crystal.
- Since the index of refraction determines the speed of light in the medium (c/n), thus different indices of refraction for different polarizations creates phase difference between different polarization.
- Thus, the material split the incident light into two separate polarized beams, which are at right angle to each other. The two beams are known as:

Ordinary Beam - A beam that pass through the material in a path determined by Snell's law of refraction.

Extraordinary Beam - A beam that does not oblige to Snell law and have a deviation to the side.

Practically, the material have different indexes of refraction for the ordinary beam and the extraordinary beam. Such material is said to have **Birefringence (Double Refraction).**



Two types of doubly refracting crystals:

Uniaxial: There is only one direction (optic axis) along which the two refracted rays travel with the same velocity. Eg. Tourmaline, calcite and quartz crystal.

Biaxial: There are two such directions along which the velocities are same. Eg. Topaz, Aragonite.

Optic axis and Principal axis

Optic Axis: The direction of optic axis is a line passing through any one of the blunt corners and equally inclined to the three edges meeting there. Along optic axis, there is no double refraction as the structure is symmetric in that direction.

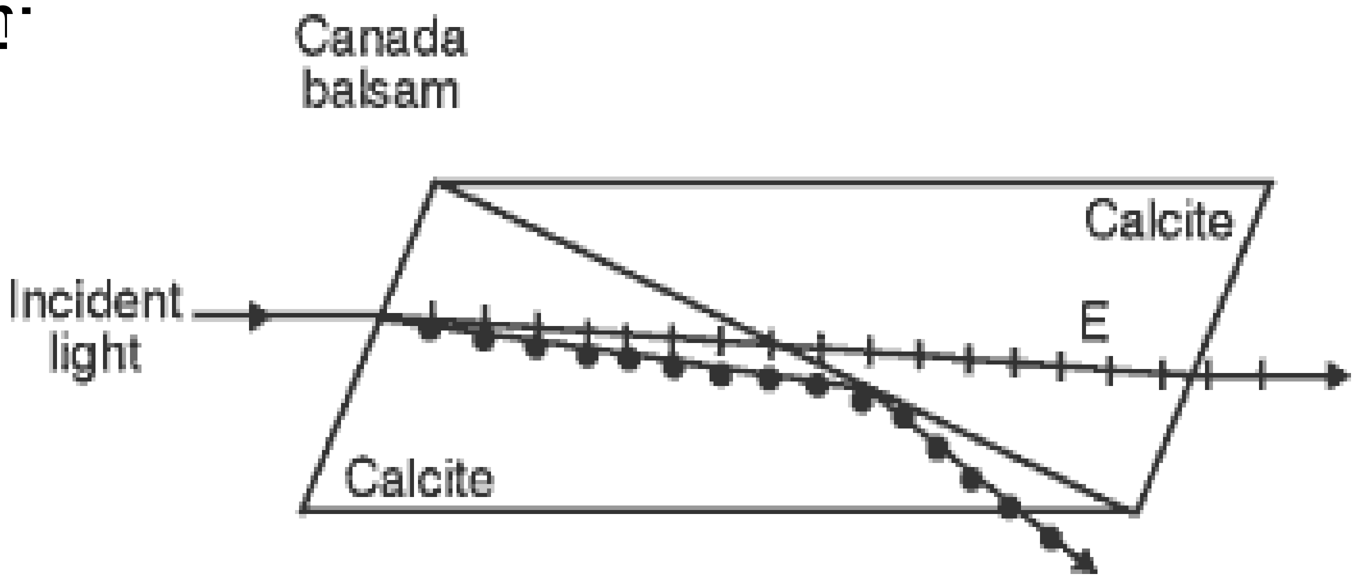
Principal Section: A plane containing the optic axis and perpendicular to a pair of opposite faces of the crystal is called principal section of the crystal for that pair of faces. A principal section, always cuts the surfaces of the calcite crystal in a parallelogram having angles 71° & 109°.

NICOL PRISM

It is an optical device made from calcite crystal and is used in many optical instrument for producing and analyzing plane polarized light. It is constructed in such a way that the O-ray get totally reflected and E-ray get transmitted. It gives an instance beam of plane polarized light.

Principle: It depends on the phenomenon of double refraction. i.e. ordinary and extra ordinary rays in calcite possess unequal refractive index.

Construction:



In a Nicol prism, we want total internal reflection of ordinary ray and transmission of Eextraordinary ray at calcite – Canada balsam interface.

The refractive index of calcite

for O – Ray is μ_o = 1.658 for E – ray is μ_E = 1.486 & μ_{CB} = 1.55

Canada balsam is optically rarer for O – ray and optically denser for E – ray. The critical angle can be calculated as

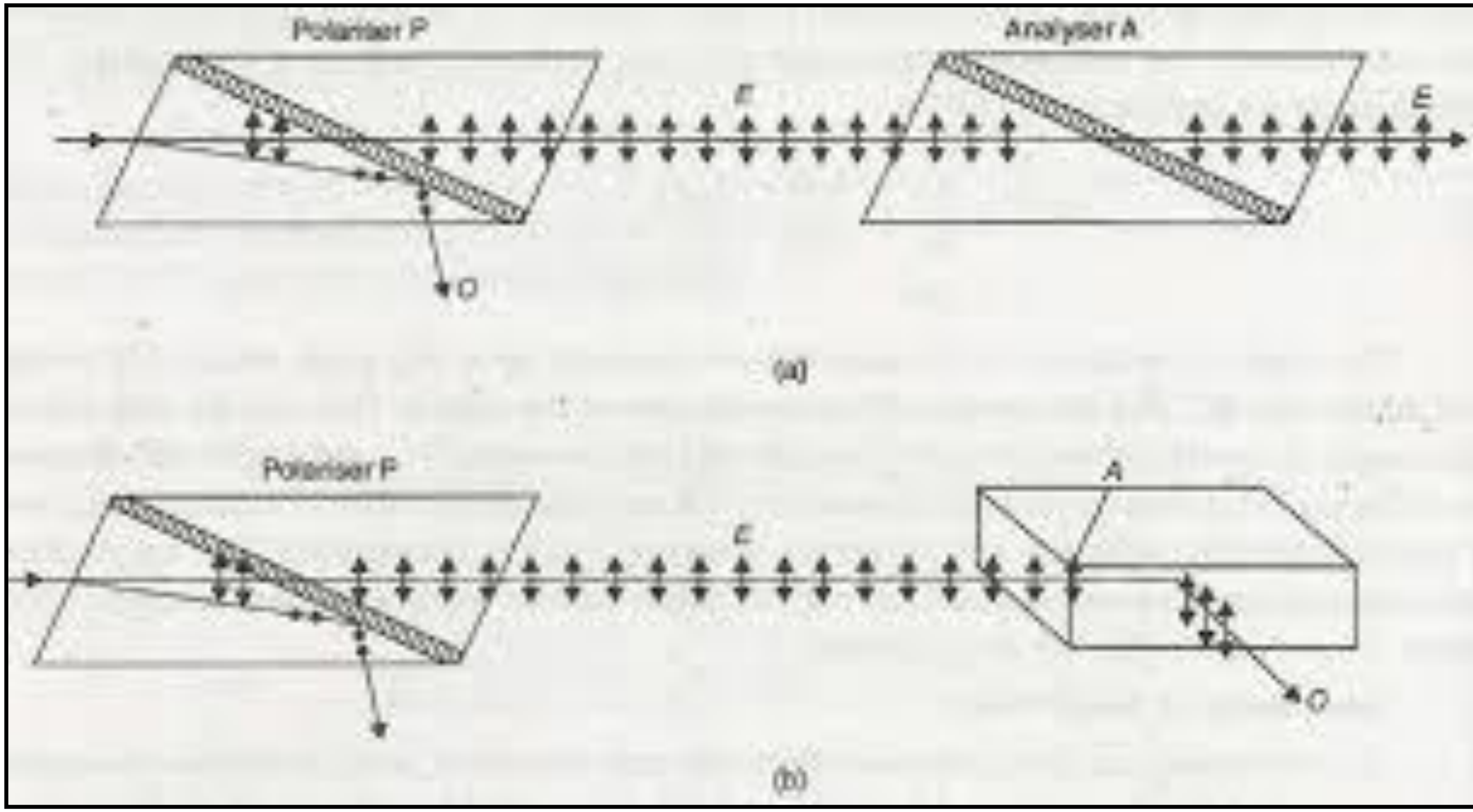
$\theta_c = \sin^{-1}(1.55/1.658) = 69.20°$

when angle of incidence at calcite- Canada balsam interface become greater than critical angle, then the conditions of total total internal reflection are satisfied , the O-ray get totally reflected. The E – ray get transmitted.

Limitation: Nicol prism can not be used for highly convergent and highly divergent beams. The angular limit is 14° on either side (28° in total in both sides between the extreme rays).

Uses of Nicol Prism

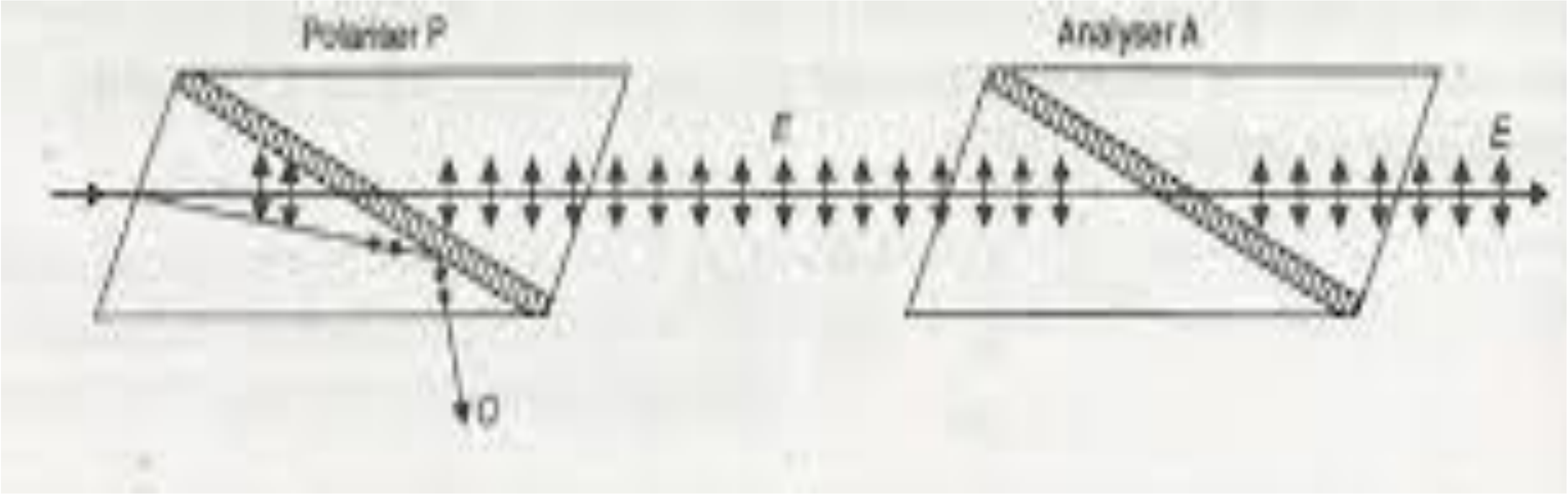
Nicol prism can be used as a Polarizer and as an Analyzer.



TYPES OF POLARIZED LIGHT

Elliptically and circularly Polarized Light

- When Linearly polarized monochromatic light is incident at an angle on a doubly refracting crystal with optic axis parallel to refracting face
- It splits up in to Ordinary and Extra-ordinary components.
- The two components travel in same direction with different velocities.
- On emergence, depending on the thickness of the crystal and angle of incidence, light may be elliptically or circularly or plane polarized as explained below.



Theory

Let A = amplitude of the incident plane polarized light of wavelength λ

θ = angle made by linear vibrations with optic axes.

The component of A in *x*- direction = $A \cos \theta$

***The component of A* in *y*- direction = $A \sin \theta$**

On emerging from the crystal they have a phase difference δ.

So the equation for the two waves vibrating along perpendicular directions and having a phase difference δ.

<u>For E-rays</u>

$x = A \cos \theta \sin (\omega t + \delta)$ --------- (1) [let $A \cos \theta = a$]

Therefore, $x = a \sin (\omega t + \delta)$

<u>For O-rays</u>

$y = A \sin \theta \sin (\omega t)$ --------- (2) [$A \sin \theta = b$]

$y = b \sin (\omega t)$

On solving equation 1 & 2

$x^2/a^2 + y^2/b^2 - 2xy/(ab) \cos \delta = \sin^2\delta$ -------(3)

$$(x^2/a^2) + (y^2/b^2) - \{2xy/(ab)\cos\delta\} = \sin^2\delta \text{ -------(3)}$$

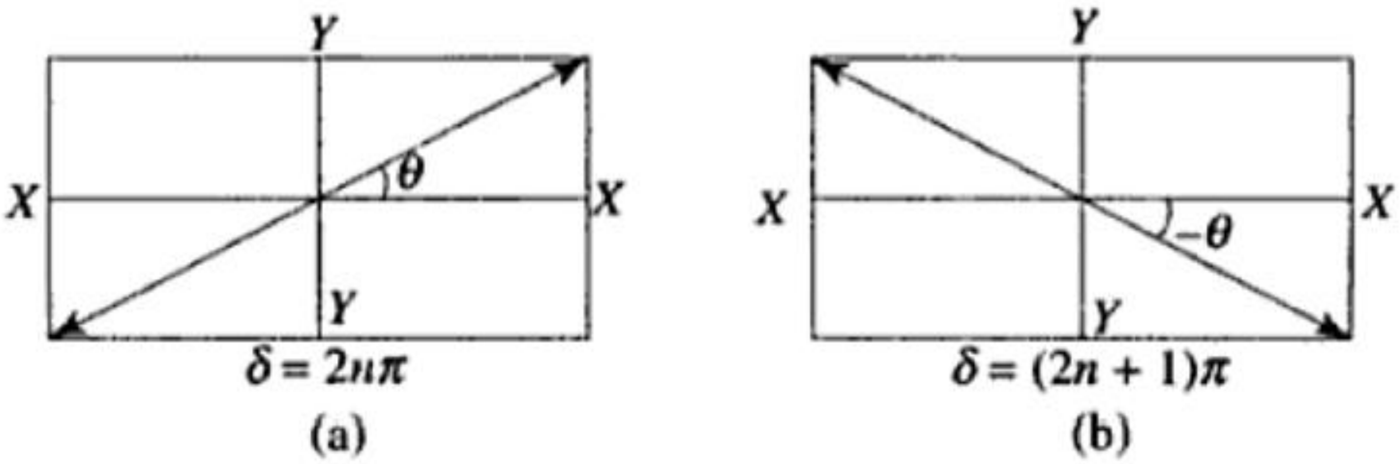
Special cases:

Case (i) If $\delta = 0$ or $2n\pi$ then $\sin\delta = 0$, $\cos\delta=1$.

Then from Equation gives $y = (b/a)x$

It is an equation of straight line with slope b/a.

So the emergent light is plane polarized.



Case (ii) If δ = (2n + 1) π/2

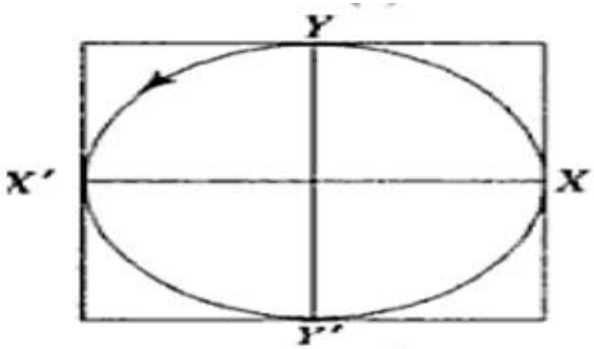
then from Equation (3) $(x^2/a^2)+(y^2/b^2)-\{2xy/(ab)\cos\delta\} = \sin^2\delta$ **-------(3)**

we get, $x^2/a^2 + y^2/b^2=1$

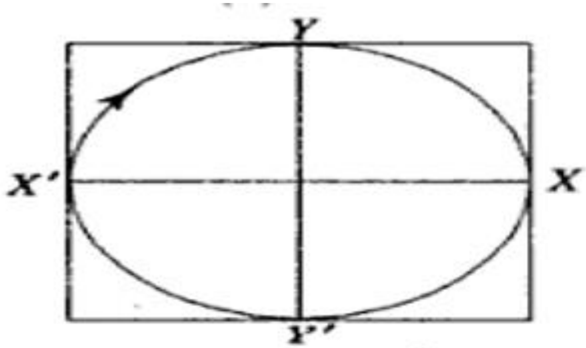
This represents the equation of an ellipse.

The emergent light will be elliptically polarized.

The magnitude of electric field vector E changes with time and vector E rotates about the direction of propagation and sweeps a flattened helix in space.



(a) $\delta = \frac{\pi}{2}$



(b) $\delta = \frac{3\pi}{2}$

Case (iii) If $\delta = \pi/2$

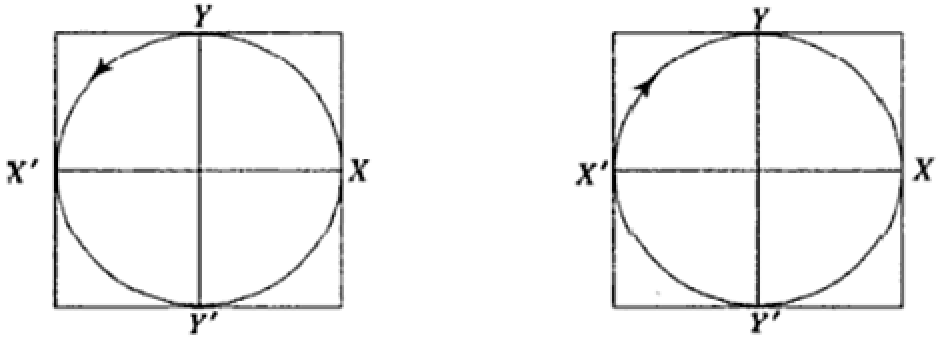
then from Equation (3) $(x^2/a^2) + (y^2/b^2) - \{2xy/(ab)\cos\delta\} = \sin^2\delta$ -------(3)

We get $x^2 + y^2 = 1$

It is an equation of a circle.

So the emergent light is circularly Polarized.

During the propagation of wave, the magnitude of the electric field vector E stays constant and also rotates at a constant rate about the direction of propagation and sweeps a circular helix in space.



(a) $\delta = \frac{\pi}{2}$ (b) $\delta = \frac{3\pi}{2}$