DEPARTMENT OF PHYSICS AND NANOTECHNOLOGY
SRM INSTITUTE OF SCIENCE AND TECHNOLOGY

18PYB101J -Electromagnetic Theory, Quantum Mechanics, Waves and Optics

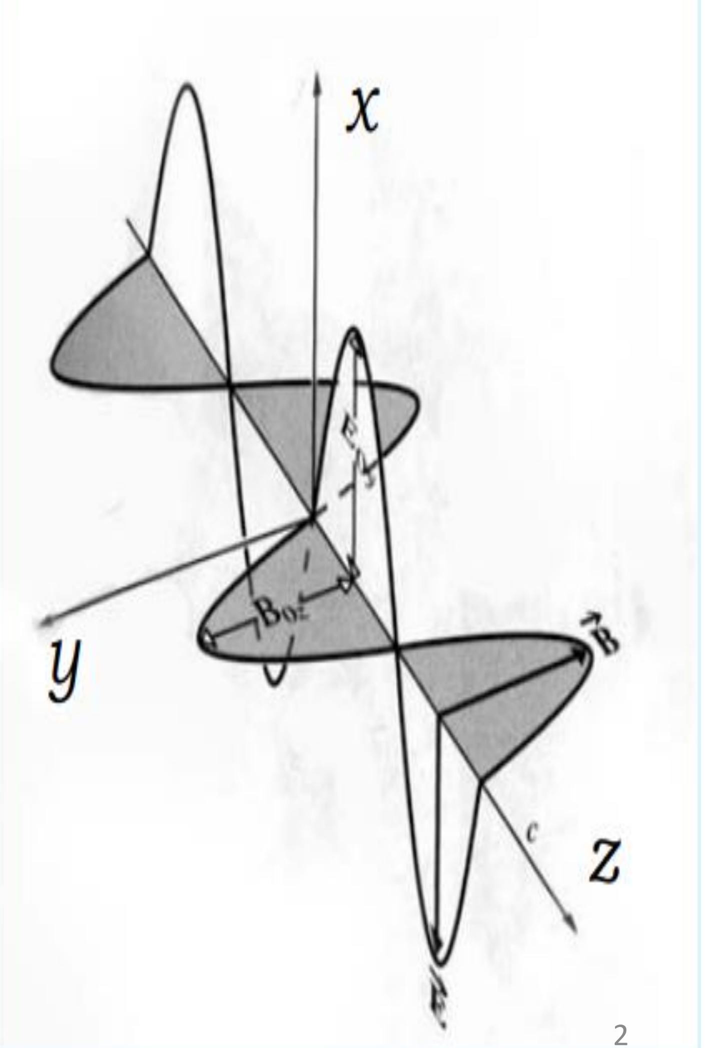
Module-IV (Waves and Optics) Lecture-9-15

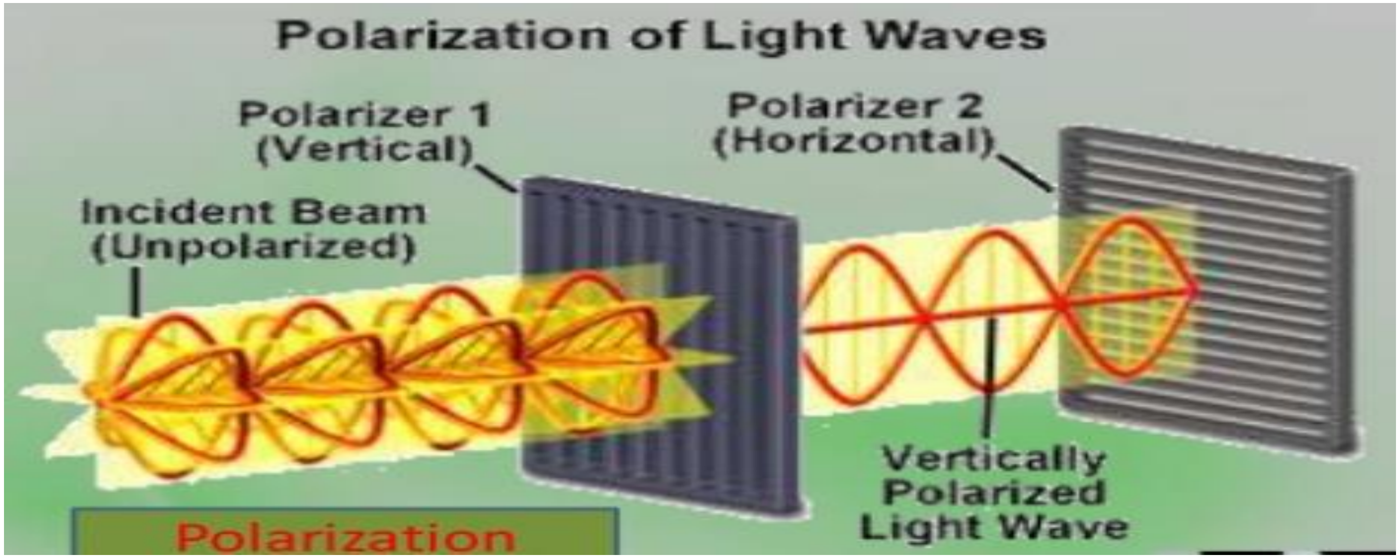
Polarization

Polarization of Light

Ordinary Light:

- Electromagnetic Wave
- Electric field E & Magnetic field B
- Both E & B Perpendicular to each other, also perpendicular to direction of propagation
- In Phase
- Unpolarized in nature





POLARIZATION

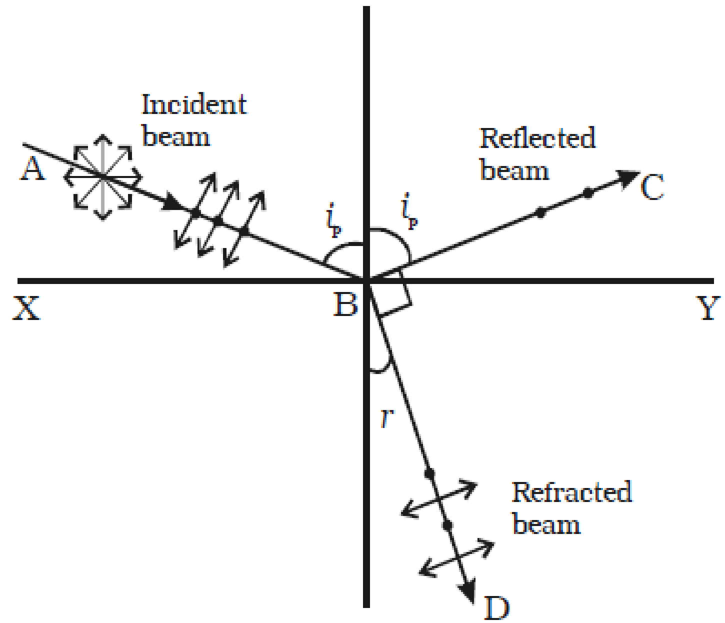
- Transforming unpolarized light into polarized light
- Restriction of electric field vector E in a particular plane so that vibration occurs in a single plane
- Characteristic of transverse wave
- Longitudinal waves can't be polarized; direction of their oscillation is along the direction of propagation

Polarization by reflection

- The simplest method of producing plane polarized light is by reflection.

- Malus, discovered that when a beam of ordinary light is reflected from the surface of transparent medium like glass or water, it gets polarized.

- The degree of polarization varies with angle of incidence.



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➢When the light is allowed to be incident at a particular angle, (for glass it is 57.5°) the reflected beam is completely plane polarized.

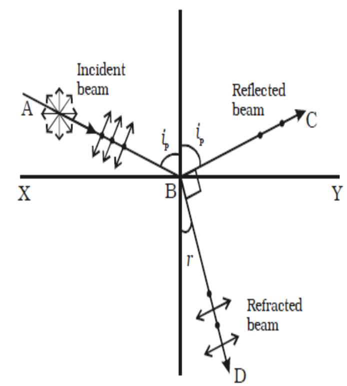
➢ The angle of incidence at which the reflected beam is completely plane polarized is called the **polarizing angle** (i_p). This is called **Brewster's Law**

From Fig $\quad i_p + 90^0 + r = 180^0$

$$r = 90^0 - i_p$$

From Snell's law, $\dfrac{\sin i_p}{\sin r} = \mu$

where μ is the refractive index of the medium (glass)



Substituting for r, we get

$$\frac{\sin i_p}{\sin(90 - i_p)} = \mu \quad ; \quad \frac{\sin i_p}{\cos i_p} = \mu$$

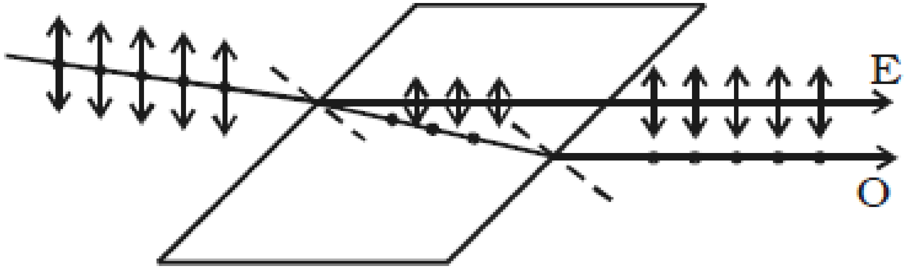
$$\therefore \quad \tan i_p = \mu$$

The tangent of the polarising angle is numerically equal to the refractive index of the medium.

Polarization by double refraction

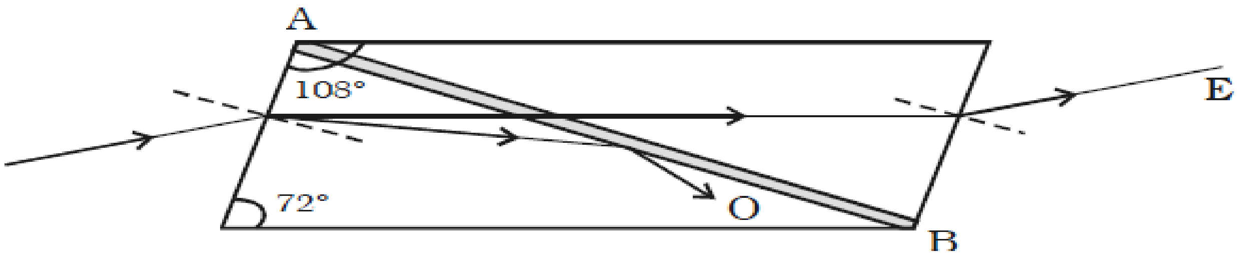
Double Refraction:

- When a ray of unpolarised light is incident on a calcite crystal, two refracted rays are produced, this phenomenon is called **double refraction**.
- Two images of a single object are formed. This phenomenon is exhibited by several other crystals like quartz, mica etc.
- **Ordinary ray** (O) and **Extraordinary ray** (E)



- **Ordinary Ray** (O), obey the laws of reflection & refraction.
- **Extraordinary Ray** (E), do not obey the laws of reflection and refraction.
- Inside a double refracting crystal the ordinary ray travels with same velocity in all directions and the extra ordinary ray travels with different velocities along different directions.
- Inside the crystal there is a particular direction in which both the rays travel with same velocity is called **optic axis**.
- The refractive index is same for both rays and there is no double refraction along optic axis.

Nicol prism



- Nicol prism was designed by William Nicol.
- It is cut into two halves along the diagonal so that their face angles are 72° and 108°.
- The two halves are joined together by a layer of Canada balsam, a transparent cement.
- For sodium light, the refractive index for ordinary light is 1.658 and for extraordinary light is 1.486. The refractive index for Canada balsam is 1.550 for both rays.

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- A monochromatic beam of unpolarised light is incident on the face of the nicol prism. It splits up into two rays as ordinary ray (O) and extraordinary ray (E) inside the nicol prism.

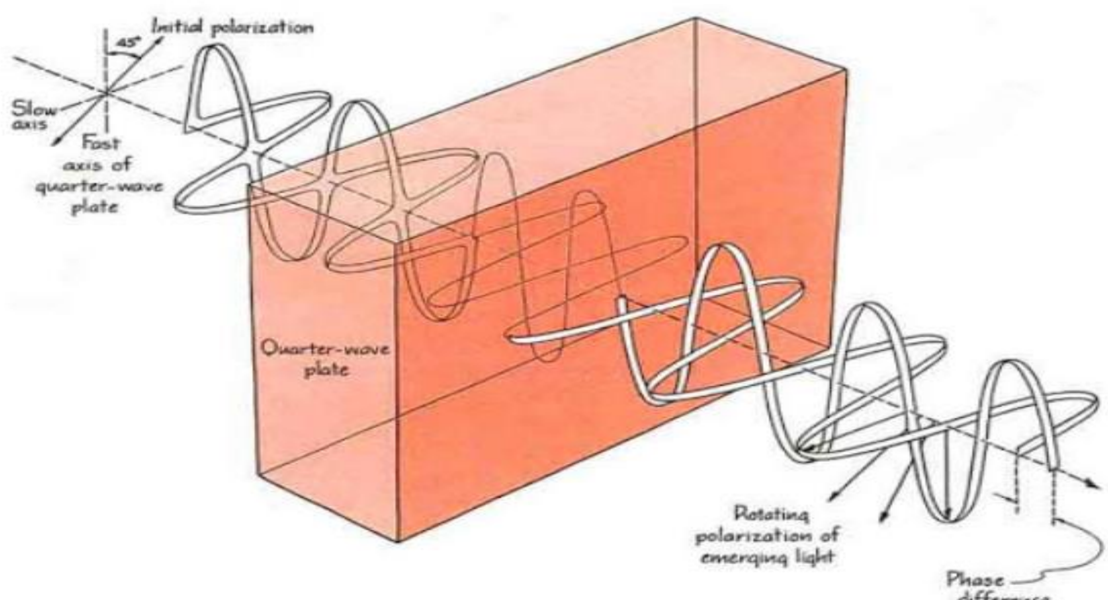
- The ordinary ray is totally internally reflected at the layer of Canada balsam and is prevented from emerging from the other face.

- The extraordinary ray alone is transmitted through the crystal which is plane polarized. The nicol prism serves as a polarizer and also an analyser.

Quarter Wave And Half Wave Plates

Quarter Wave Plate:

A quarter wave plate is a thin plate of birefringent crystal having the optic axis parallel to its refracting faces and its thickness adjusted such that it introduces a quarter wave of Path difference λ/4 and phase difference π/2 between the extra ordinary ray and ordinary ray propagating through it.



- When a plane polarized light wave is incident on a birefringent crystal having the optic axis parallel to its refracting surface, the wave split into O ray and E ray.

- As a result, when they emerge from the rear face of the crystal an optical path difference (λ/4) would be developed between them.

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

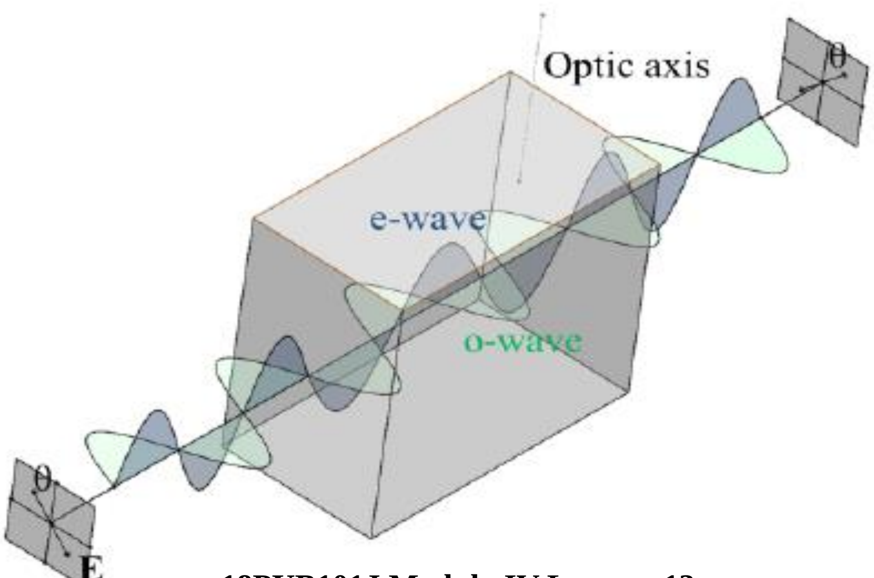
$$d = \frac{\lambda}{4[\mu_e - \mu_o]}$$

- **Phase difference δ = 90°**

- A quarter wave plate is used in producing **circularly** or **elliptically** polarized light.

Half Wave Plate

A Half wave plate is a thin plate of birefringent crystal having the optic axis parallel to its refracting faces and its thickness adjusted such that it introduces a half wave of path difference λ/2 and phase difference π between the extra ordinary ray and ordinary ray propagating through it.



- When a plane polarized light wave is incident on a birefringent crystal having the optic axis parallel to its refracting surface, the wave split into E-wave and O-wave.

- As a result, when they emerge from the rear face of the crystal an optical path difference ($\lambda/2$) would be developed between them.

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

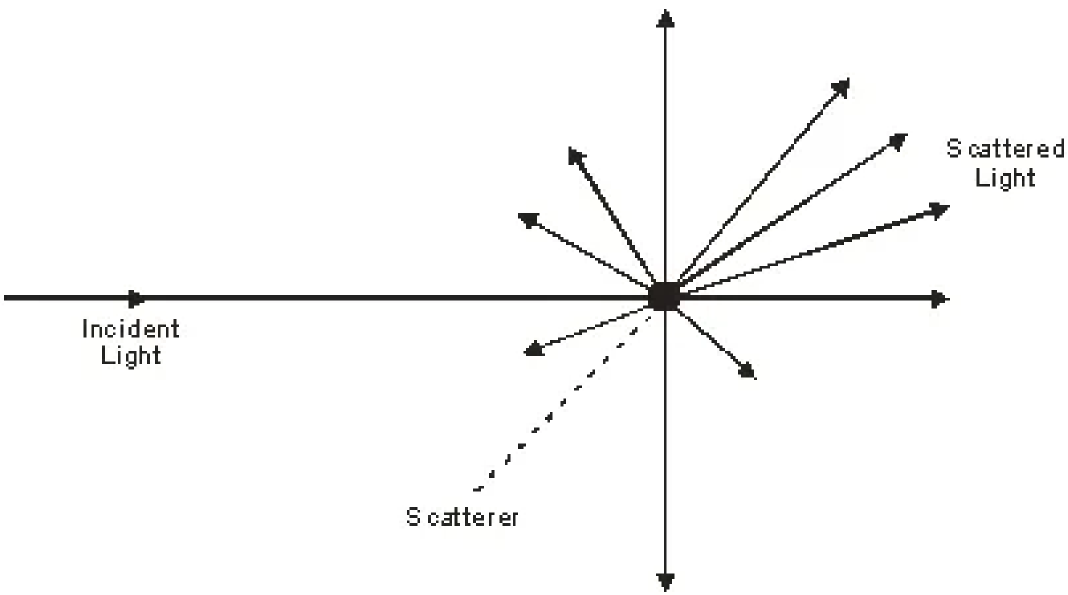
$$\boxed{d = \frac{\lambda}{2(\mu_e - \mu_o)}}$$

- **Phase difference δ = 180^o**

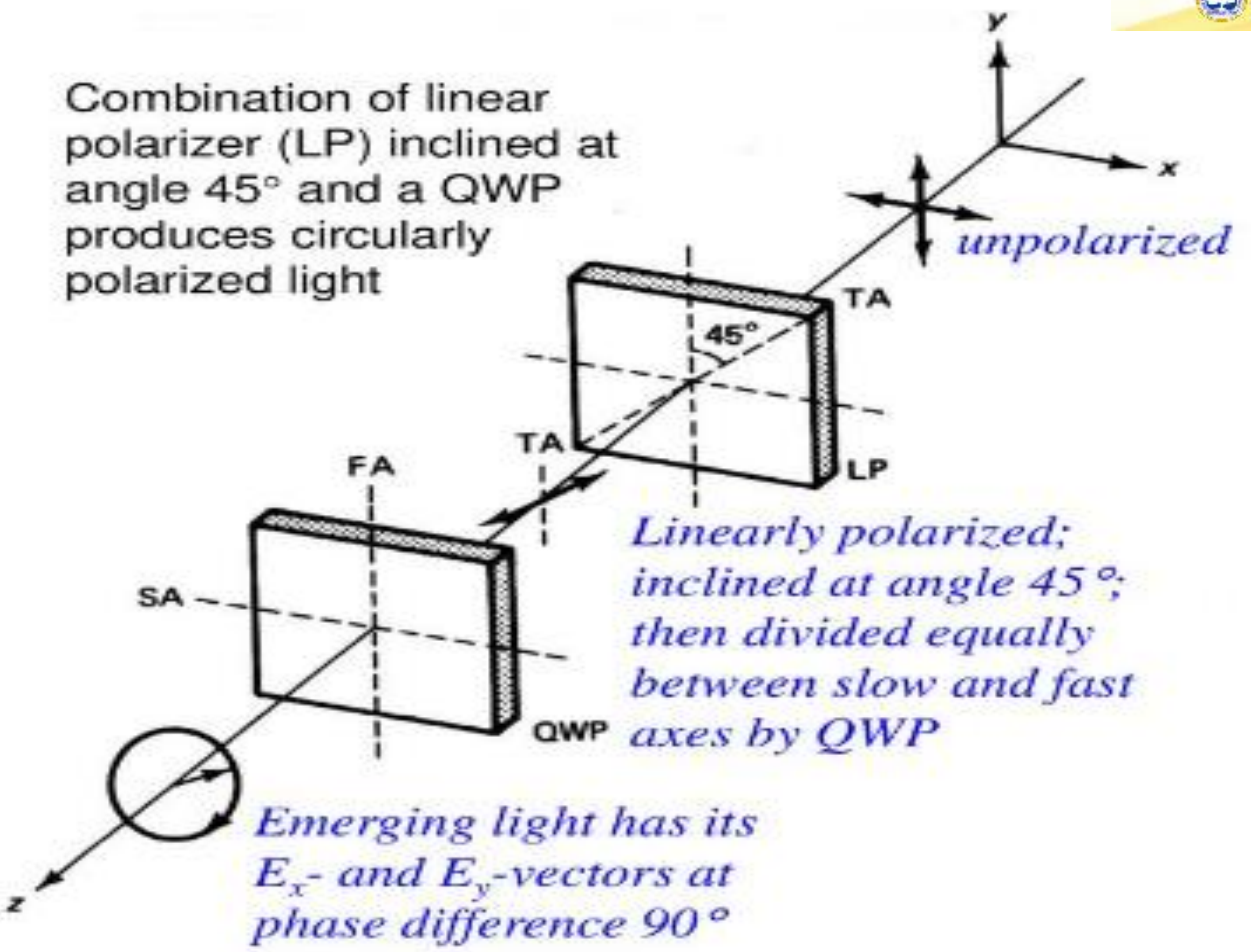
- A half wave plate is used in producing **circularly** or **elliptically** polarized light.

Scattering of light

Scattering of light results from the electric polarizability of the particles. The oscillating electric field of a light wave acts on the charges within a particle, causing them to move at the same frequency. The particle, therefore, becomes a small radiating dipole whose radiation we see as scattered light.



Production of Circularly polarized light



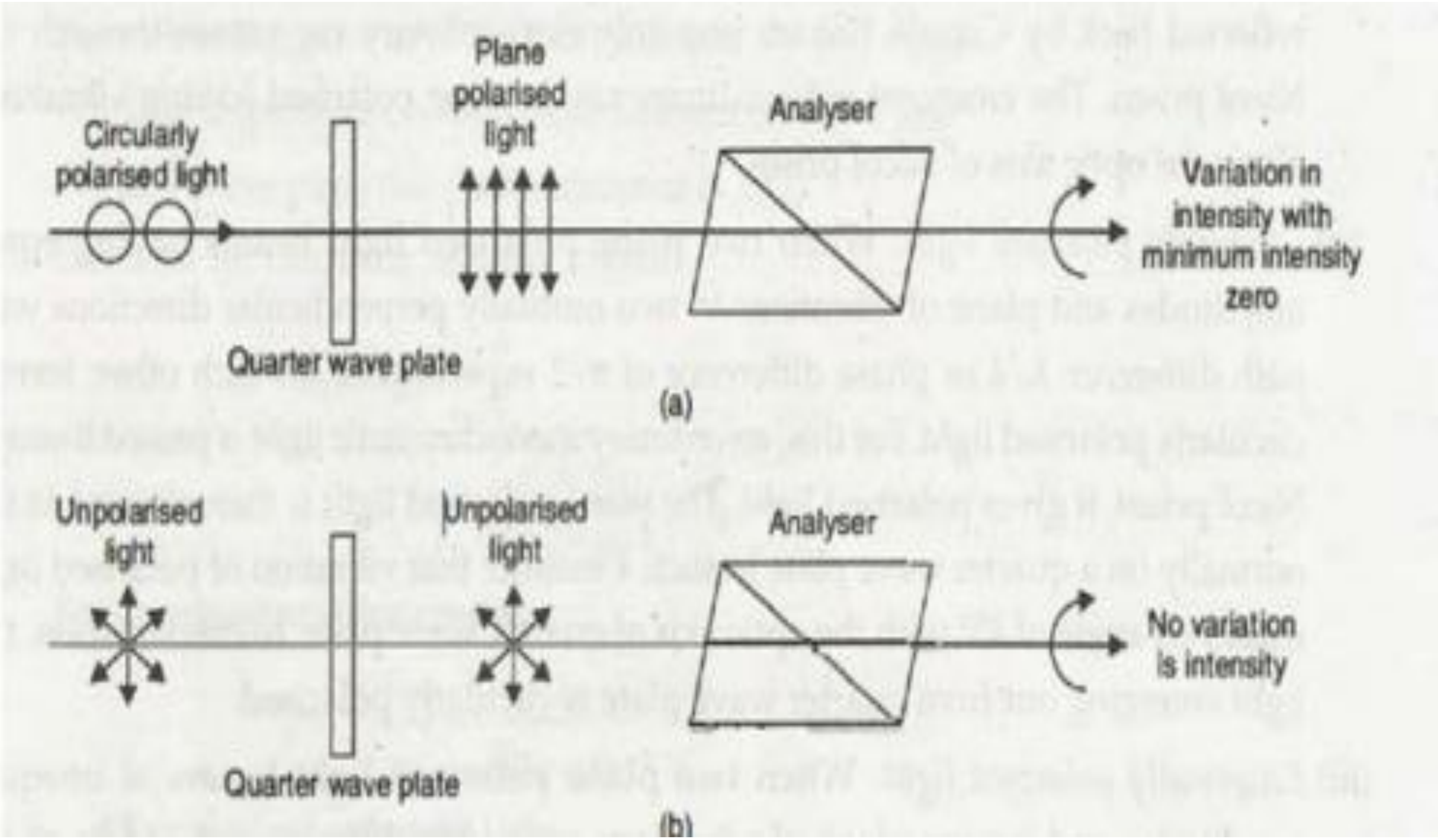
➢Unpolarized light is first converted to plane polarized light by allowing it to pass through a polarizer.

➢The polarizer and QWP are rotated such that the electric vector E of the plane polarized wave makes an angle of 45^o with the optic axis of QWP, the plane polarized wave splits into two rays O-ray and E-ray of equal amplitude.

- The two rays are in phase at the front face of the crystal but progressively get out of phase as they travel through the crystal. As they emerge from the rear face of the crystal, they will have a path difference of $\lambda/4$ or phase difference of 90^o.

- The two rays are linearly polarized in mutually perpendicular directions. When they combine, they produce circularly polarized light.

Detection of Circularly polarized light



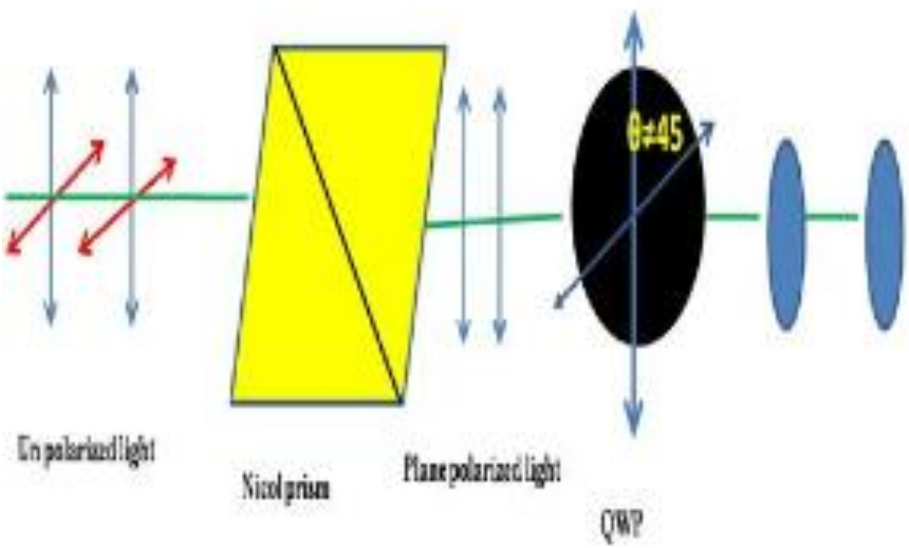
- The circularly polarized light beam is allowed to pass through the rotating analyzer, the intensity of the emerging beam remains uniform, then the incident is circularly polarized light. Similar result would be obtained if the incident light is unpolarized light.

- To distinguished between these two cases, by introducing the QWP in the path of light before it falls on the analyzer.

- If the light passes through the QWP, an additional path difference of 90^{o} is introduced between O-ray and E-ray. Therefore the total phase difference of 180^{o} between O-ray and E-ray. On emerging from the QWP, the O-ray and E-ray combine to produce plane polarized light.

- Therefore if light coming out of QWP is examined with an analyzer, light will be extinguished twice in one full rotation of the polarizer.

Production of Elliptically polarized light



- Unpolarised light ➡ Nicol prism ⬌ Plane polarized light
- vibration in the incident light making an angle, $\theta \neq 0, 45, 90$ degree with the optic axis of QWP.
- ➡ elliptically polarized light

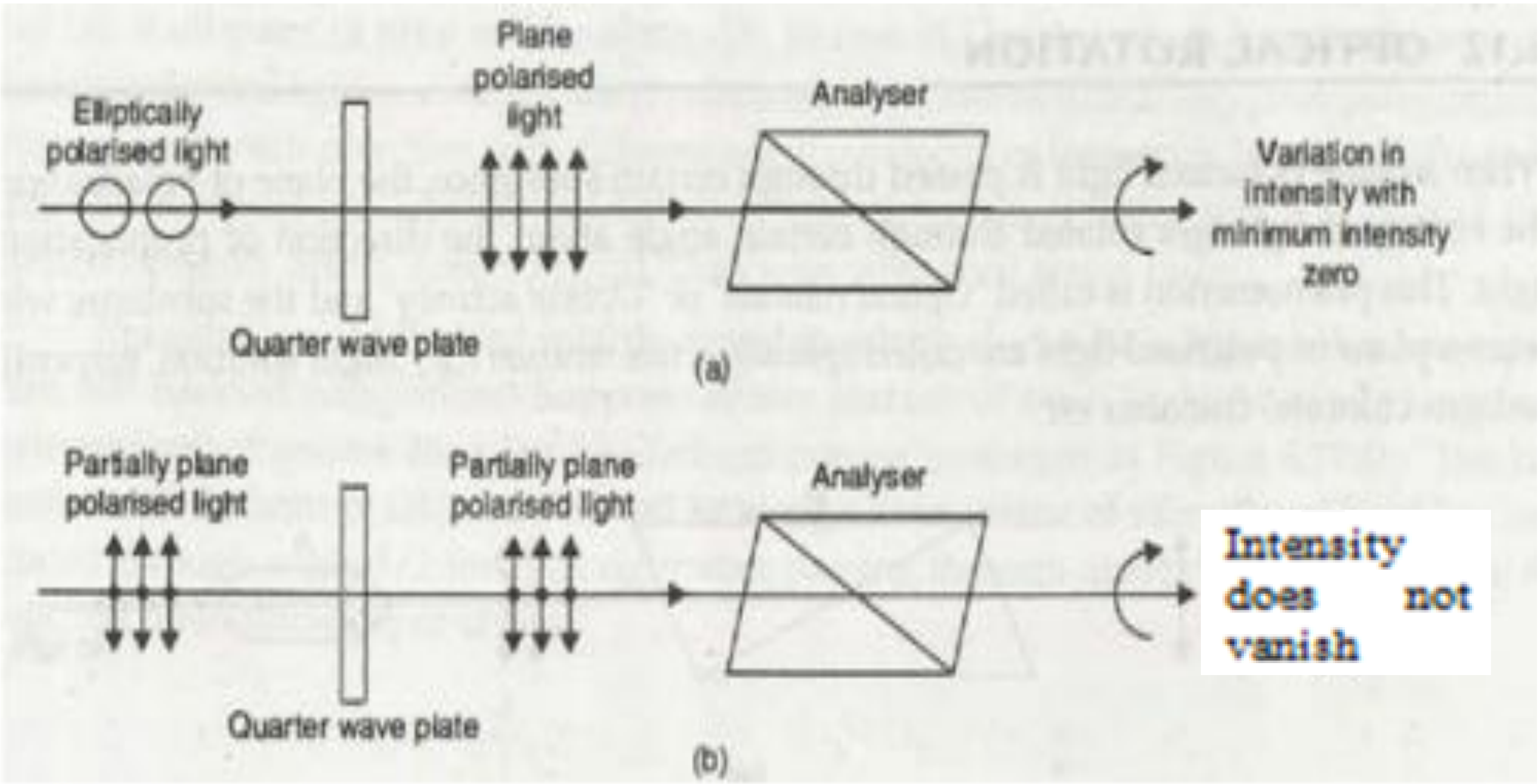
➢Unpolarized light is first converted to plane polarized light by allowing it to pass through a polarizer.

➢The polarizer and QWP are rotated such that the electric vector E of the plane polarized wave makes an angle of θ is not equal to 45^o with the optic axis of QWP, the plane polarized wave incident on QWP splits into two rays O-ray and E-ray of equal amplitude.

- The two rays are in phase at the front face of the crystal but progressively get out of phase as they travel through the crystal. As they emerge from the rear face of the crystal, they will have a path difference of $\lambda/4$ or phase difference of 90^{o}.

- The two rays are linearly polarized in mutually perpendicular directions. When they combine, they produce elliptically polarized light.

Detection of Elliptically polarized light



- The elliptically polarized light beam is allowed to pass through the rotating analyzer, the intensity of the emerging beam varies from maxima and minima, then the incident is elliptically polarized light. Similar result would be obtained if the incident light is unpolarized light.

- To distinguished between these two cases, by introducing the QWP in the path of light before it falls on the analyzer.

- If the light passes through the QWP, an additional path difference of 90^{o} is introduced between O-ray and E-ray. Therefore the total phase difference of 180^{o} between O-ray and E-ray. On emerging from the QWP, the O-ray and E-ray combine to produce plane polarized light.

- Therefore if light coming out of QWP is examined with an analyzer, light will be extinguished twice in one full rotation of the polarizer.