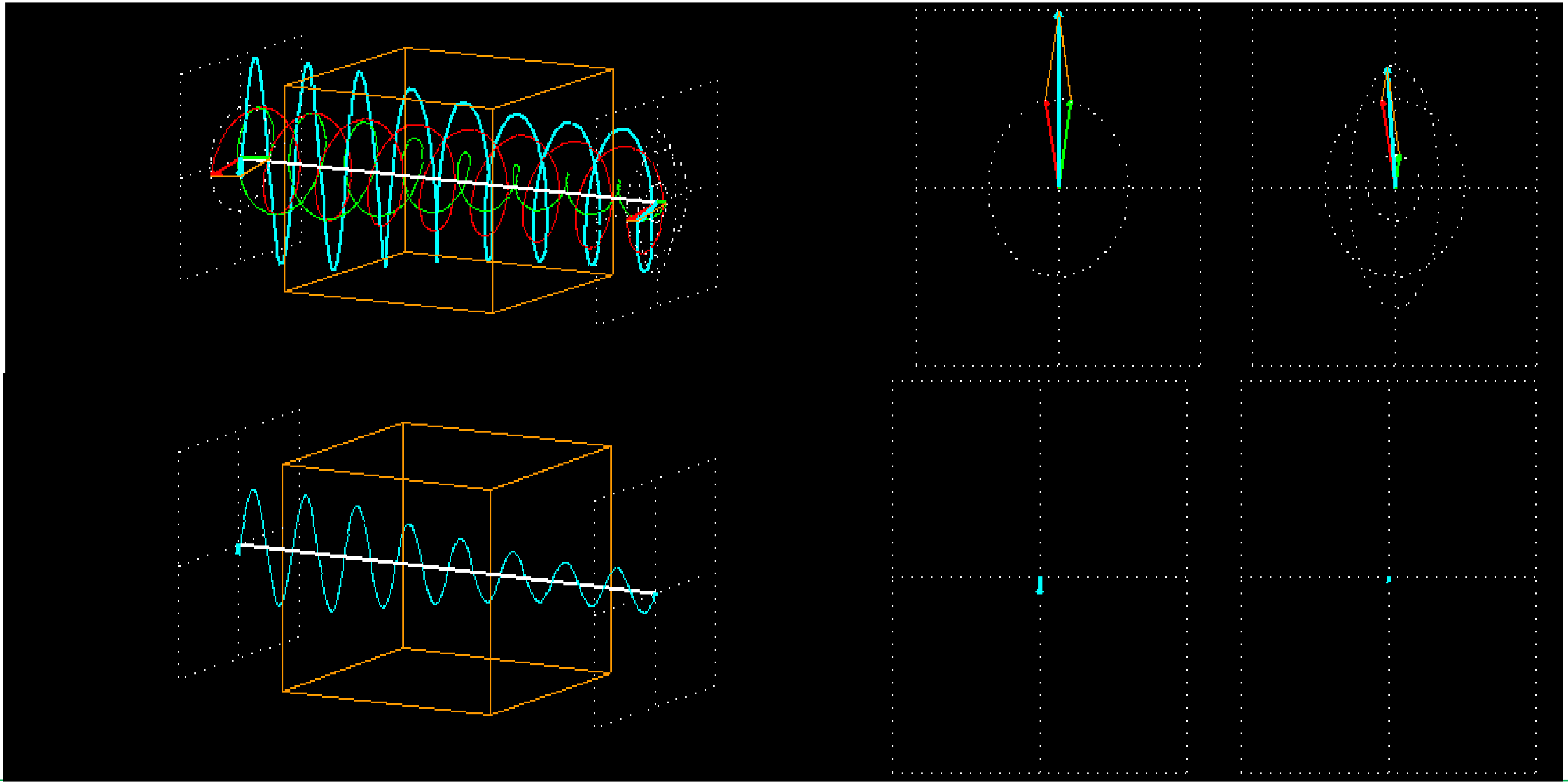
Polarization

UNIT III, Optics, Lecture-9

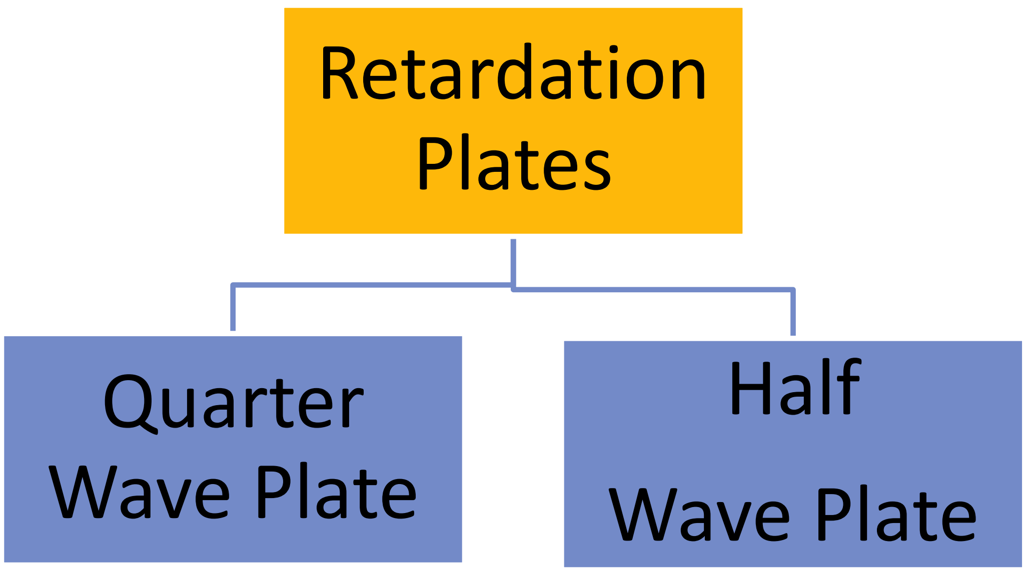


Content of Lecture

- RETARDATION PLATES HALF WAVE PLATE AND QUARTER WAVE PLATE.
- POLAROIDSPRODUCTION AND DETECTION OF PLANE, CIRCULARLY, AND ELLIPTICALLY POLARISED LIGHT
- OPTICAL ROTATION
- FRESNEL’S THEORY OF OPTICAL ROTATION
- SPECIFIC ROTATION
- HALF SHADE AND BIQUARTZ POLARIMETER

RETARDATION PLATES

As we have already discussed that when O-ray and E-ray are emerging from the crystals, they have a path difference between them due to variation in their velocities. These crystals are known as retardation plates. These are mainly of two types.

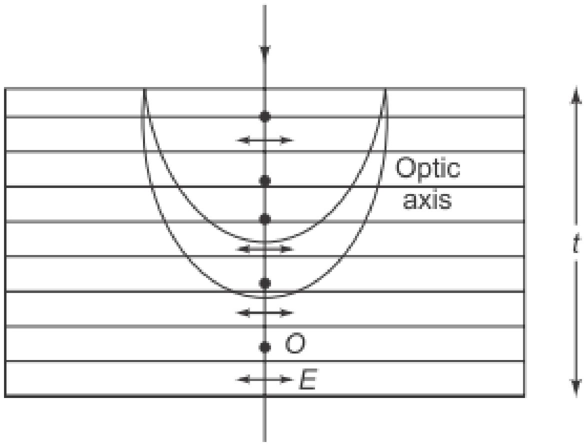


Quarter Wave Plate

A doubly refracting crystal plate having a thickness such as to produce a path difference of λ/4 or a phase difference of π/2 between the ordinary and extraordinary wave is called the quarter wave plate or λ /4 plate.

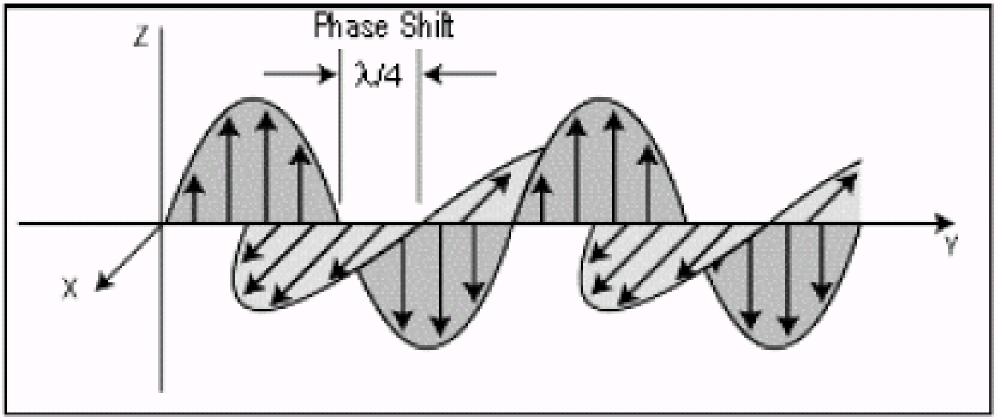
$$(\mu_O - \mu_E)t = \frac{\lambda}{4}$$

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



Quarter-Wave plate

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



C. Circularly Polarized Light

- Used to convert linear polarization to elliptical.

Half Wave Plate

A doubly refracting crystal plate having a thickness such as to produce a path difference of λ /2 or phase difference of π between O-ray and E-ray is called half wave plate or λ /2 plate.

If t is the thickness of such a plate, then for a negative crystal such as calcite, we have

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

or

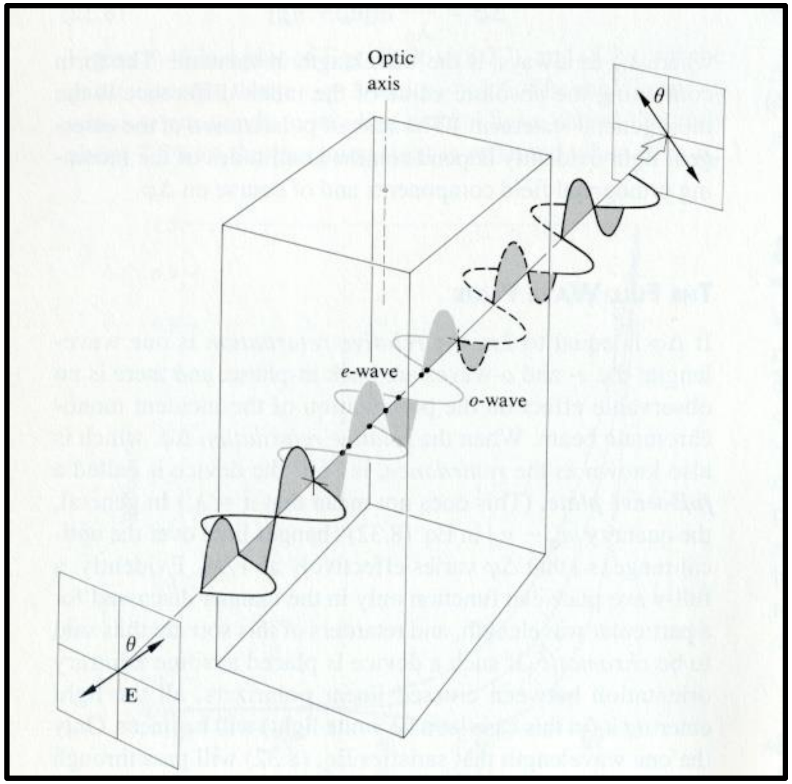
$$t = \frac{\lambda}{2(\mu_O - \mu_E)}$$

Similarly, for a positive crystal (quartz),

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

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

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

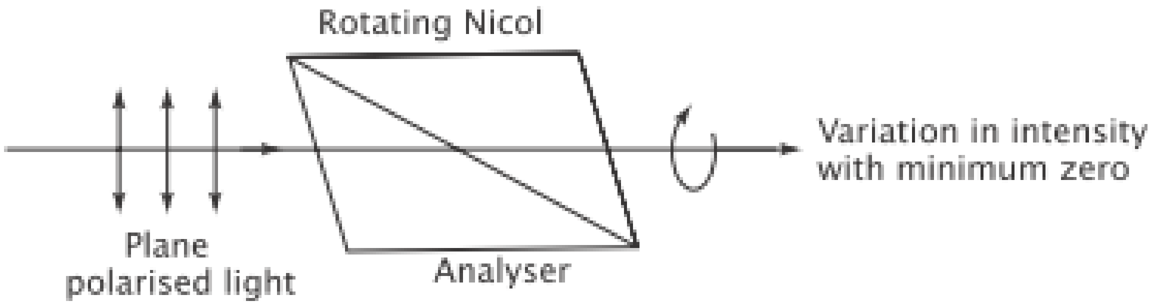


PRODUCTION AND DETECTION OF PLANE, CIRCULARLY, AND ELLIPTICALLY POLARISED LIGHT

Plane Polarised Light

Production: When a beam of unpolarised light is passed through a Nicol prism, then its output is linearly polarised light.

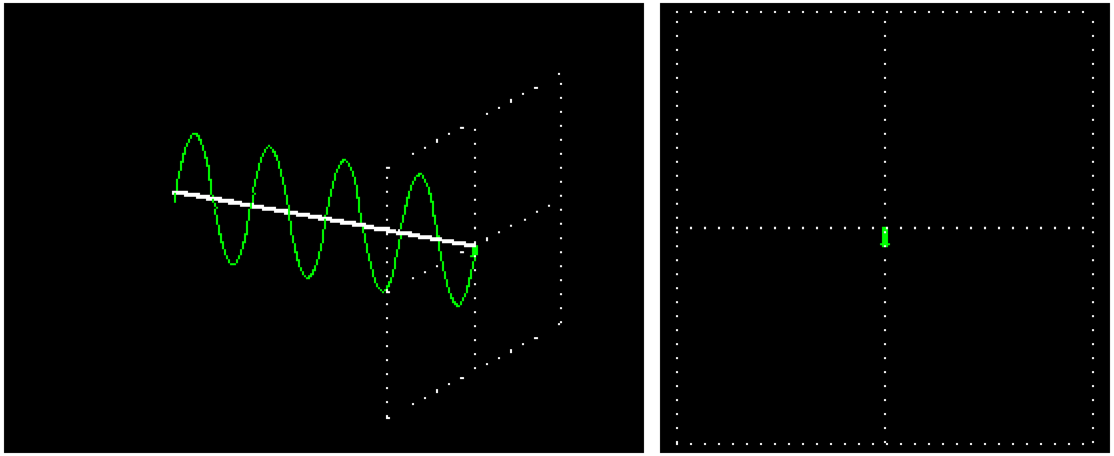
Detection: To detect plane polarised light, the emergent light is passed through another Nicol prism which is rotated gradually about the direction of propagation of light. If the intensity of the light emerging from rotating Nicol prism varies with zero minimum, the light is plane polarised. The detection of linearly plane polarised light is shown in Fig.



Plane-polarized light

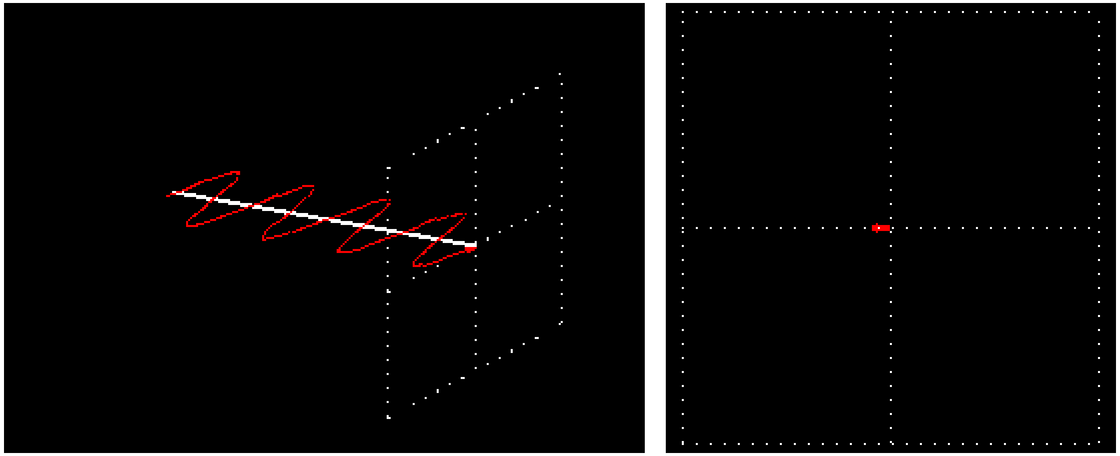
Vertical

$$E_y = A\sin(x/\lambda - \omega t)$$



Horizontal

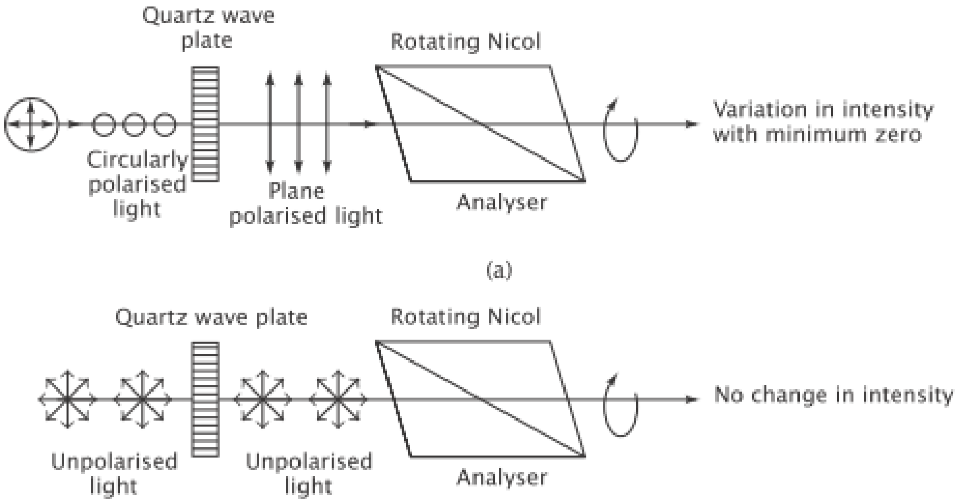
$$E_z = A\sin(x/\lambda - \omega t)$$



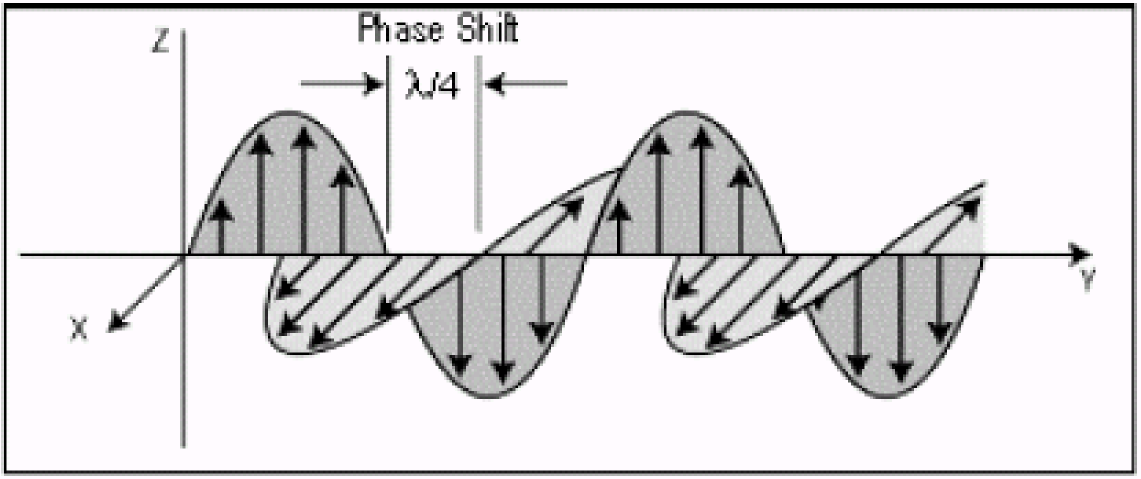
Circularly Polarised Light

Production: Circularly polarised light is produced if the amplitudes of O and E components are equal and have a phase difference of $\pi/2$ between them.

Detection: When a beam of circularly polarised light is observed through a rotating Nicol prism, no variations in intensity are observed, as it is in the case of unpolarised light. Hence, to detect, it is first passed through a quarter wave plate which converts circularly polarised light into plane polarised light



Circular polarization



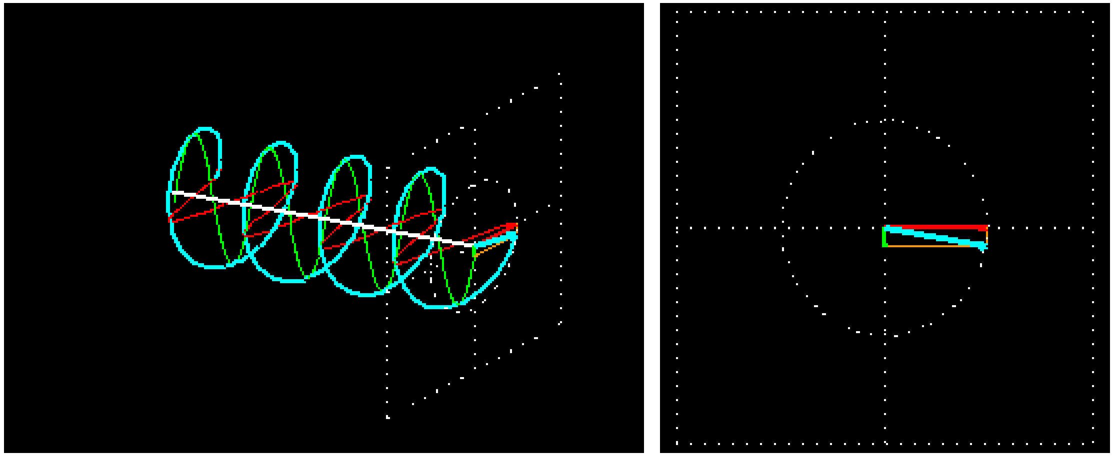
C. Circularly Polarized Light

Circularly polarized light

Right circular

$$E_y = A\sin(x/\lambda - \omega t + 90°)$$

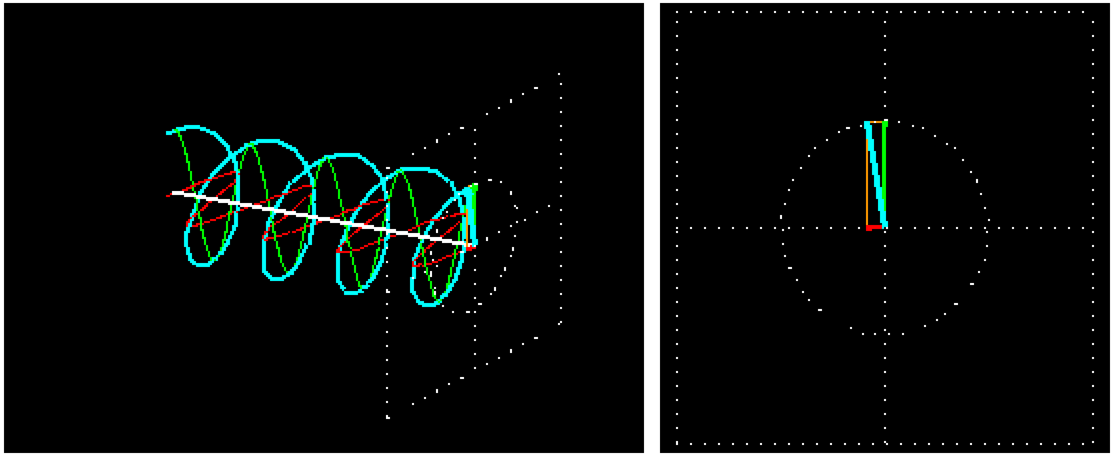
$$E_z = A\sin(x/\lambda - \omega t)$$



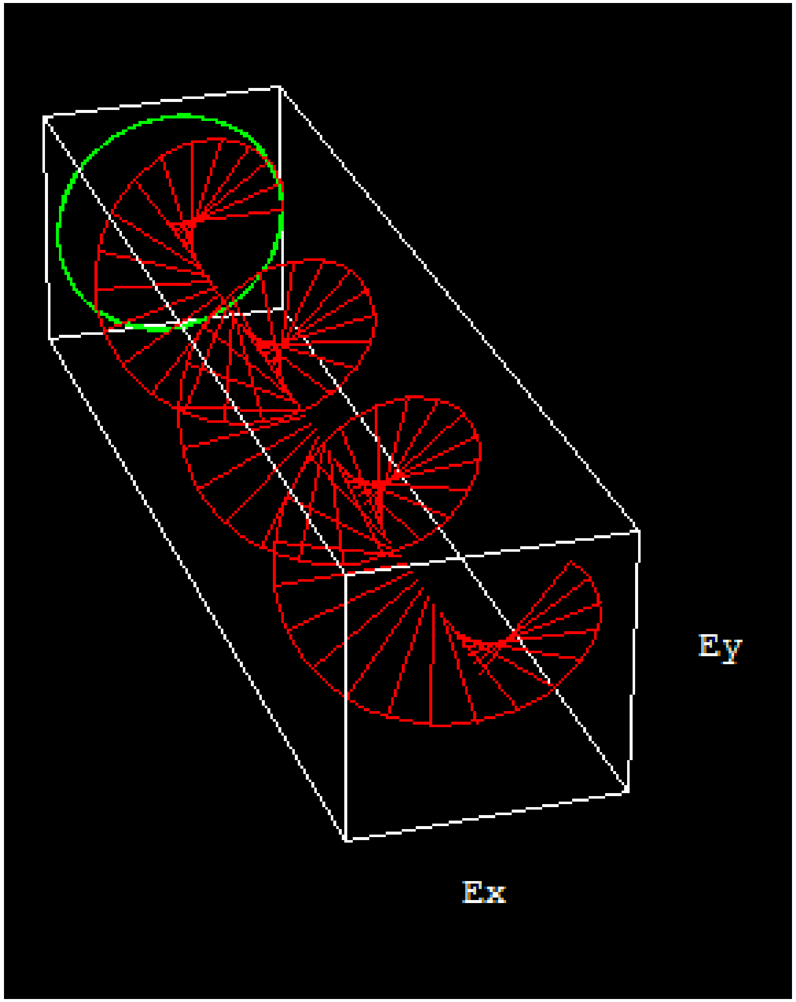
Left circular

$$E_y = A\sin(x/\lambda - \omega t - 90°)$$

$$E_z = A\sin(x/\lambda - \omega t)$$



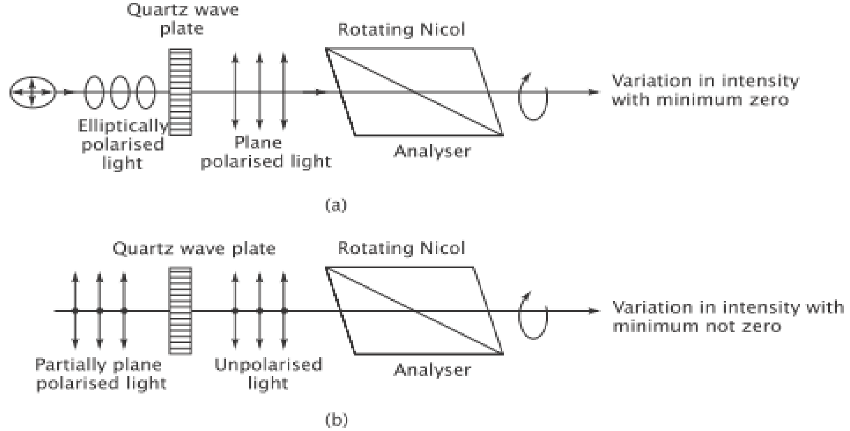
Circular polarization



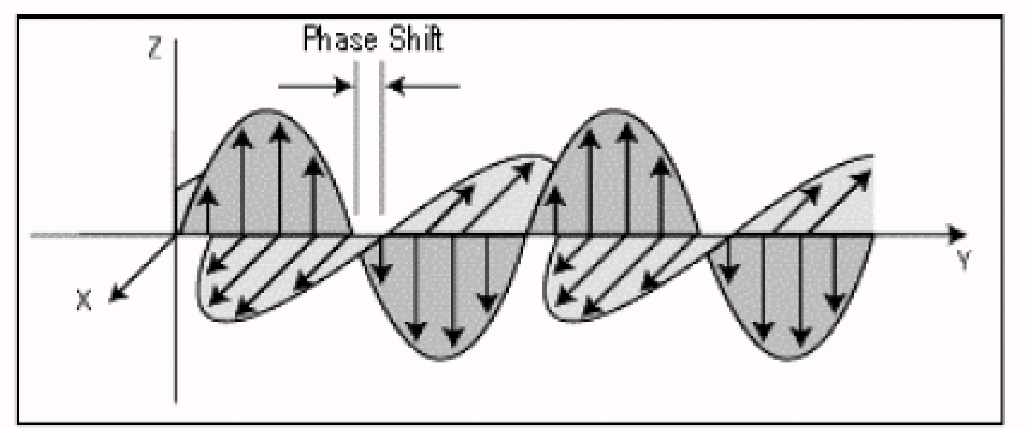
Elliptically Polarised Light

Production: The only difference between circularly and elliptically polarised light is that in the later, the amplitudes are not equal. To produce elliptically polarised light, the plane polarised light from Nicol is allowed to fall normally on a quarter wave plate such that the vibrations in the plane polarised incident light make an angle ɵ [ɵ≠ 0, 45°, 90°] with the optic axis of the plate.

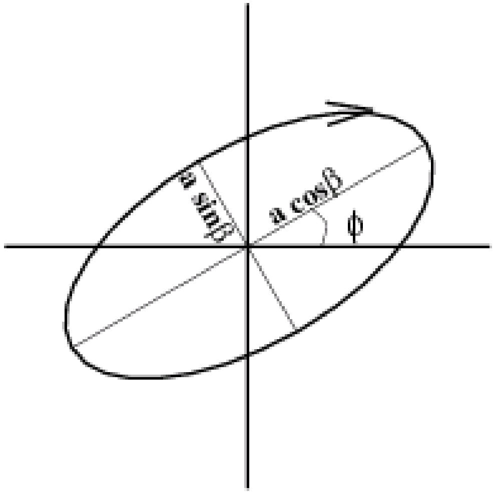
Detection: In order to detect elliptically polarised light, it is passed through a quarter wave plate, before passing through the analysing Nicol. The quarter wave plate converts the elliptically polarised



Elliptical polarization



D. Elliptically Polarized Light



- **Linear + circular polarization = elliptical polarization**

OPTICAL ROTATION (ROTATORY POLARISATION)

- When a plane polarised light passes through certain substances, the plane of polarisation of the light is rotated about the direction of propagation of light through a certain angle.

- This phenomenon is called optical rotation or rotating polarisation. The substances which rotate the plane of polarisation are said to be optically active, and the property is called optical activity.

OPTICAL ROTATION (ROTATORY POLARISATION)

- Biot (1815) gave the following laws about optical rotation:

- The angle of rotation of the plane of polarisation, for a given wavelength, is directly proportional to the length of the optically active substance traversed.

- For solutions and vapours, the angle of rotation for a given path length is proportional to the concentration of the solution or vapour.

- The rotation produced by a number of optically active solutions is equal to the algebraic sum of individual rotations. The anticlockwise and clockwise rotations are taken with opposite signs.

- The angle of rotation is approximately inversly proportional to the square of wavelength, e.g., for quartz, we have
- Angle of rotation $\theta = A + B/\lambda^2$

FRESNEL'S THEORY OF OPTICAL ROTATION

Fresnel made the following assumptions:

(i) The incident polarised light on entering a substance is broken up into two circularly polarised waves, one clockwise and the other anticlockwise.

(ii) In an optically inactive substance, the two waves travel with the same velocity. However, in an optically active substance, they travel with different velocities. In a dextrorotatory substance, the clockwise wave travels faster, while in the leavorotatory substance, the anticlockwise wave travels faster. Hence, a phase difference is developed between them as they traverse the substance.

FRESNEL'S THEORY OF OPTICAL ROTATION

(iii) On emergence, the two circular components recombine to form a plane polarised light whose plane of polarisation is rotated with respect to that of the incident light by an angle depending on the phase difference between them. Finally deduced the expression:

$$\delta = \frac{2\pi}{\lambda}(\mu_L - \mu_R)d$$

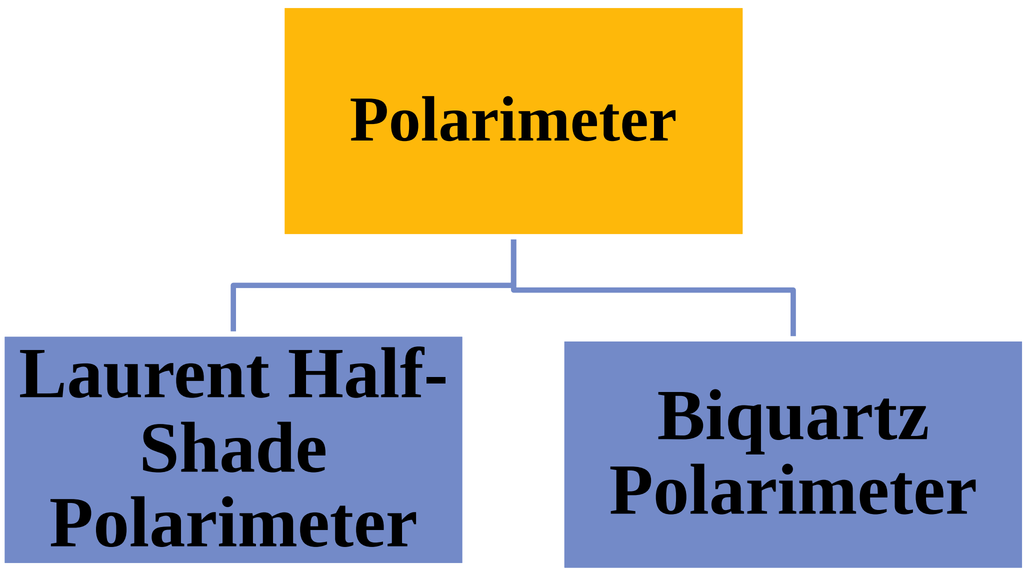
Hence, the rotation of the plane of vibration or of the plane of polarisation is

$$\theta = \frac{\delta}{2} = \frac{\pi d}{\lambda}(\mu_L - \mu_R)^*$$

SPECIFIC ROTATION

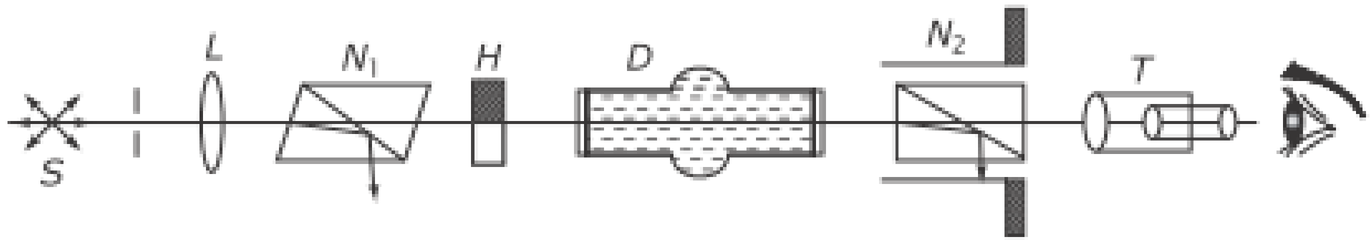
- The specific rotation S of a substance at a given temperature and for a given wavelength of light is defined as the rotation (in degrees) produced by 1 decimetre length of the substance in solution when its concentration is 1 g/cm^3 , i.e., for a solution

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



Laurent Half-Shade Polarimeter

- Laurent half-shade polarimeter is an instrument used for measuring the optical rotation of optically active substances. Its optical parts are shown in Fig.



- The difference between the two positions of N_2 gives the angle of rotation θ. The length l of the tube containing the solution is measured in decimetres. The specific rotation of the sugar solution is then calculated from

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

Biquartz Polarimeter

- It is a simple and accurate means of determining the optical rotation of optically active substances.

- It consists of a condensing lens, a polarising Nicol, biquartz plate, a tube for containing the optically active solution, an analysing Nicol, and a telescope arranged just as in a half-shade polarimeter except that the half-shade device is replaced by a biquartz plate.

- The sodium light is replaced by white light.

Example-1: The specific rotation of quartz at 5086 Å is 29.73 deg/mm. Calculate the difference in the refractive indices.

Solution

If μ_A and μ_C are, respectively, the refractive indices of quartz in the direction of the optic axis for anti-clockwise and clockwise circularly polarised light, and d is the thickness of the quartz plate, then the optical rotation produced is given by

$$\theta = \frac{\pi d}{\lambda}(\mu_A - \mu_C)$$

Thus, $$\mu_A - \mu_C = \frac{\lambda}{\pi}\frac{\theta}{d}$$

According to the question, $\frac{\theta}{d} = 29.73$ deg/mm and

$$\lambda = 5086 \text{ Å} = 5.086 \times 10^{-4} \text{ mm}$$

$\therefore$ $$\mu_A - \mu_C = \frac{5.086 \times 10^{-4}}{180^\circ} \times 29.73^\circ$$

$$= 8.4 \times 10^{-5}$$

Example-2: A sugar solution in a tube of length 20 cm produces optical rotation of 13° . The solution is diluted to one-third of its previous concentration. Find optical rotation produced by 30 cm long tube containing the diluted solution.

Solution

For two solutions, we have from $S = \dfrac{10\theta}{lc}$

$$\frac{10\theta_1}{l_1 c_1} = \frac{10\theta_2}{l_2 c_2}$$

$$\Rightarrow \qquad \theta_2 = \frac{\theta_1 . l_2 c_2}{l_1 c_1}$$

Here $l_1 = 20$ cm, $l_2 = 30$ cm, $c_2/c_1 = 1/3$, and $\theta = 13°$.

$$\theta_1 = \frac{30 \times 13}{20 \times 3} = 6.5°$$

Assignment Based on this Lecture

- What are the retardation Plates? Discuss the construction and working of half wave plate and quarter wave plate.
- Explain the production and detection of Plane, Circularly, and Elliptically Polarised Light.
- What do you mean by Optical Rotation?
- Explain the Fresnel's theory of optical rotation.
- What is Specific Rotation? Explain the construction and working of Half Shade and Biquartz Polarimeter.