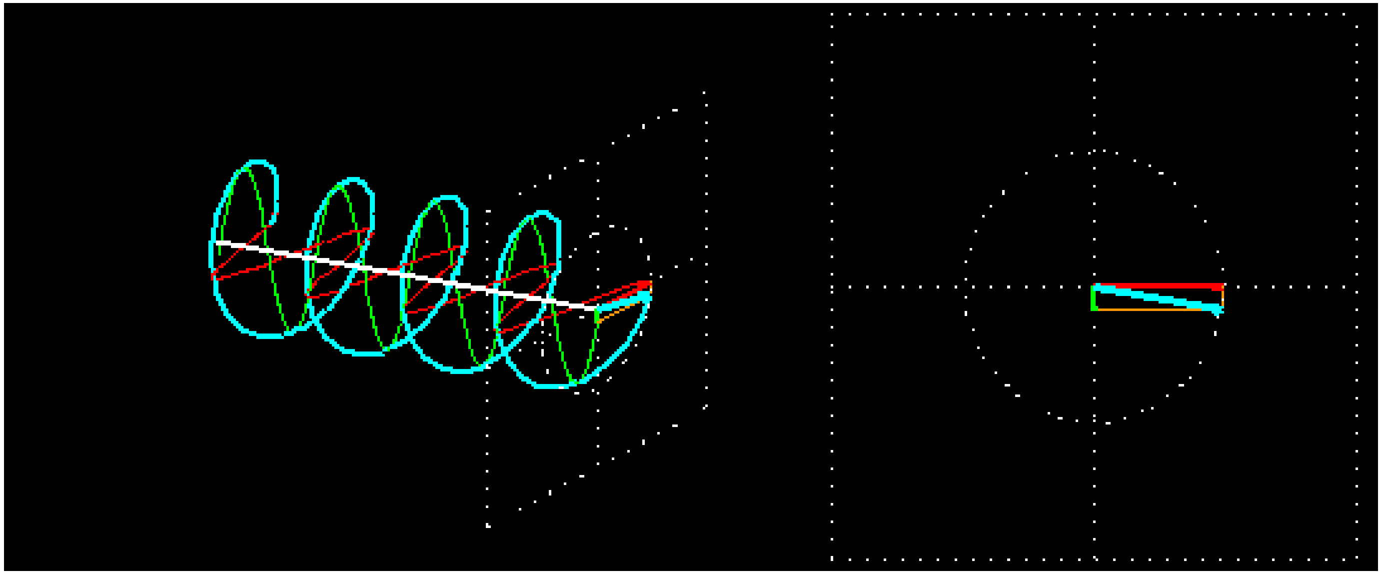
Polarization

UNIT III

Optics

Lecture-8



Content of Lecture

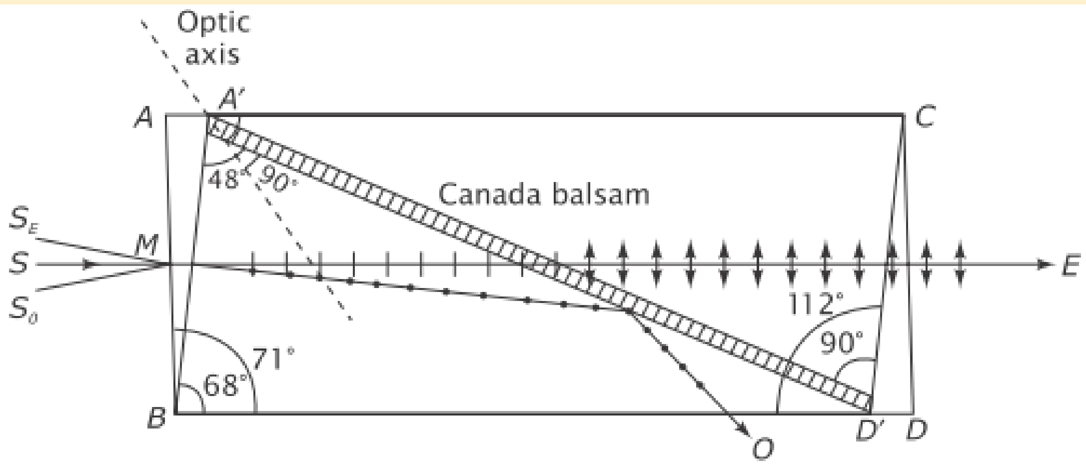
- NICOL PRISM
- NICOL PRISM AS A POLARISER AND AS AN ANALYSER
- POLAROIDS
- HUYGENS EXPLANATION OF DOUBLE REFRACTION
- PLANE, CIRCULARLY, AND ELLIPTICALLY POLARISED LIGHT
- SUPERPOSITION OF TWO PLANE POLARISED WAVES HAVING PERPENDICULAR VIBRATIONS

NICOL PRISM

- A Nicol prism is an optical device made from a calcite crystal for producing and analysing plane polarised light with the help of the phenomenon of total internal reflection.

Construction

- To construct a Nicol prism, a calcite crystal ABCD about three times as long as it is wide is taken.
- Its end faces AB and CD are ground such that the angles in principal section becomes 68° and 112°, instead of 71° and 109°
- The crystal is then cut apart along the plane A'D perpendicular to the principal section as well as to the end faces A'B and CD.
- They are then cemented together by Canada balsum which is a transparent glue of refractive index 1.55 for sodium light. The crystal is then put inside a blackened tube.



Working

- When a ray SM of unpolarised light nearly parallel to BD' is incident on the face A'B, it splits up into two refracted rays, O and E-rays, both being plane polarised.

- The O-ray has vibrations perpendicular to the principal section of the crystal, while E-ray has vibration in the principal section.

- The refraction indices of Canada balsam, O-ray, and E-ray for calcite crystal are in order as μ_{CB} =1.55, μ_{o}= 1.658, and μ_{E} = 1.486.

- Therefore, when the O-ray reaches the layer of Canada balsam, the total internal reflection at calcite–balsam surface takes place and this ray is absorbed by the tube containing the crystal.

- However, E-ray on reaching at calcite–balsam layer is transmitted because it passes from a rarer medium to a denser medium.

- Since the E-ray is plane polarised, the light emerging from the Nicol prism is plane polarised with vibrations parallel to the principal section.

Nicol Prism As a Polariser and As an Analyser

The prism P is called the polariser, and the prism A is called the analyser.

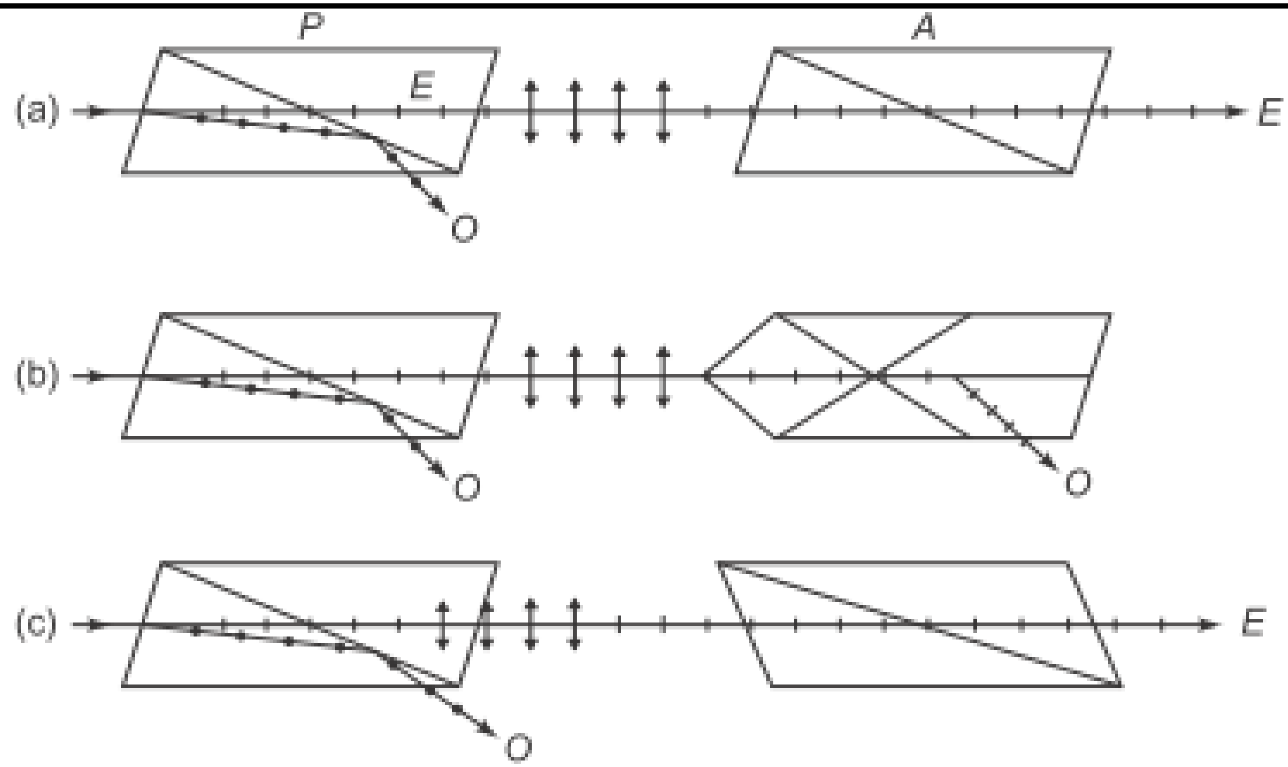
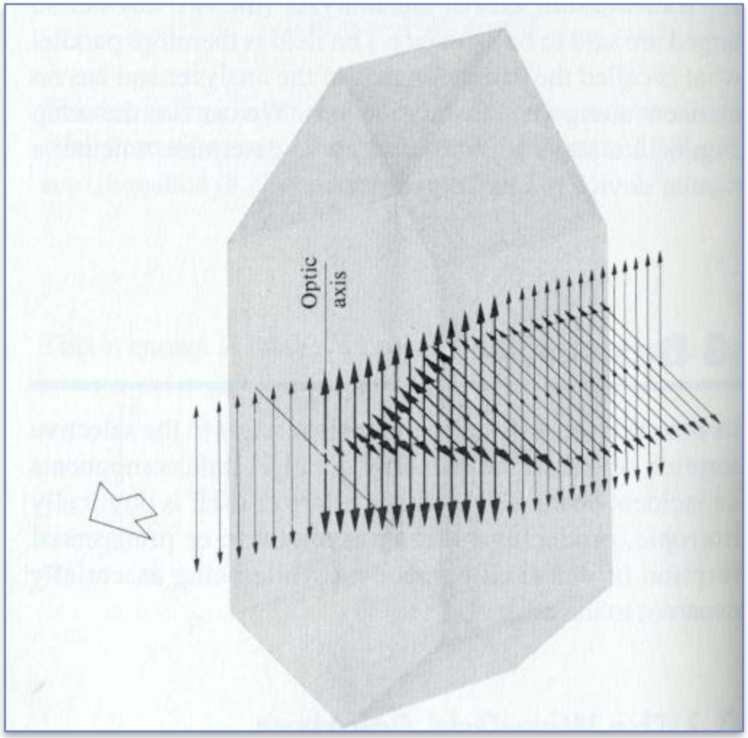


Fig. 14.15 Polariser and analyser with different positions

Dichroism

Dichroic crystals absorb one polarization state over the other one.

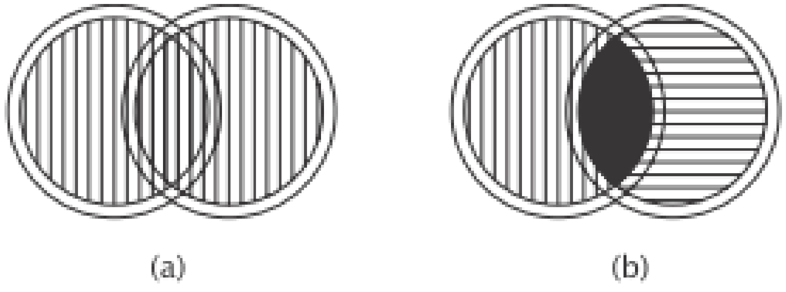
Example: tourmaline.



POLAROIDS

- When a ray of unpolarised light is sent through a tourmaline plate, it splits into O- and E-rays. The O-ray is completely absorbed, while the E-ray is transmitted and emerges as plane polarised. This is the basic principle of the commercial polarising devices known as polaroids.

- Polaroid can also be developed by stretching a film of polyvinyl alcohol. The stretching orients complex molecules with their long axes in the direction of stress and make them doubly refracting. To make this film dichroic, it is impregnated with iodine. These are called polaroid.



(a) Polaroids placed parallel to each other and **(b)** polaroids placed perpedicular to each other

HUYGENS EXPLANATION OF DOUBLE REFRACTION

(i) When a light wave strikes the surface of a doubly refracting crystal, each point on the surface becomes the origin of two secondary wavelets corresponding to ordinary and extraordinary which spread out in the crystal.

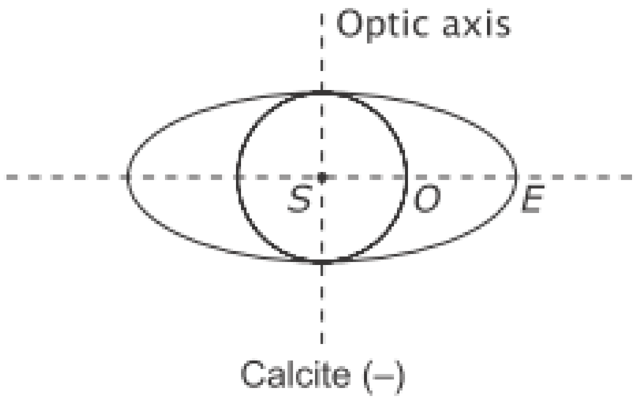
(ii) The wavefront corresponding to the ordinary wavelets which travel with the same velocity in all directions is spherical.

(iii) The wavefront corresponding to the extraordinary wavelets whose velocity varies with direction is an ellipsoid of revolution with optic axis as the axis of revolution.

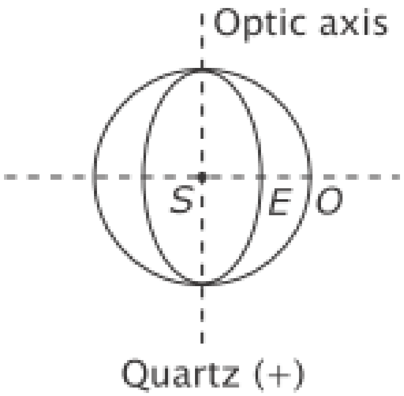
HUYGENS EXPLANATION OF DOUBLE REFRACTION

(iv) Since velocity of both the rays is same along the optic axis, therefore wavefront of each ray touches at a point which lies on the optic axis.

(v) In a negative crystal, the sphere lies inside the ellipsoid [Fig. (a)], while in a positive crystal, the ellipsoid lies inside the sphere [Fig. (b)].



(a)



(b)

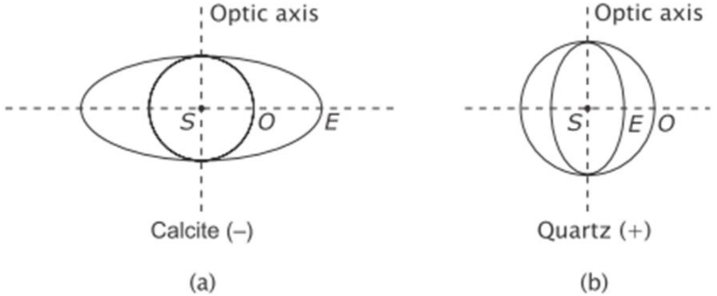
Negative and Positive Uniaxial Crystals

- In fact, uniaxial crystals are of two types: negative and positive.

- In a negative crystal such as calcite, the refractive index for E-ray is less than that for O-ray ($\mu_E < \mu_o$).

- In such a crystal, the velocity of the E-ray is the greatest in a direction perpendicular to the optic axis and is least along the direction of the optic axis equal to that of the O-ray.

- In a positive crystal such as quartz ($\mu_E > \mu_o$), the velocity of the E-ray is least in a direction perpendicular to the optic axis and the greatest along the direction of the optic axis.

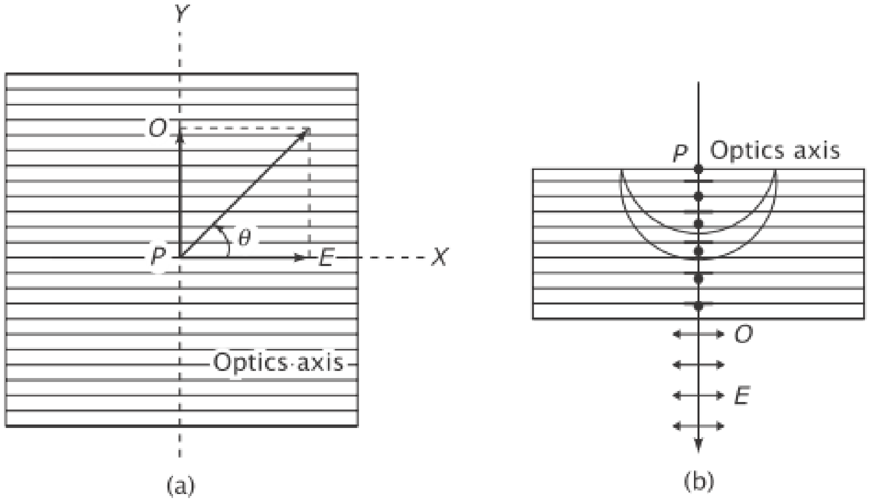


Superposition of two plane polarised waves having perpendicular vibrations

- Let a beam of plane polarised light be incident normally on a calcite plate cut with its optic axis parallel to its faces.

- Let the linear vibration in the incident light along PA be making an angle θ with the optic axis.

- Let A be the amplitude of vibration in the incident light.



Superposition of two plane polarised waves having perpendicular vibrations

- When plane polarised light is incident on the crystal, the light wave splits into two perpendicular directions PO and PE with amplitudes A sin θ and A cos θ , respectively.

- The component A cos θ having vibrations parallel to the optic axis forms E-ray, while the component A sin θ having vibrations perpendicular to the optic axis forms O-ray.

- According to Huygens' theory, the two waves travel with different velocities along the same path, the E-ray being faster [Fig.(b)].

- On emergence from the plate, a phase difference δ (say) is introduced between them. Thus, if the incident wave is A sin wt, the two components will be represented by

Superposition of two plane polarised waves having perpendicular vibrations

- $$x = A\cos\theta \sin(\omega t + \delta)$$
  $$y = A\sin\theta \sin(\omega t)$$

- Let $A\cos\theta = a$ and $A\sin\theta = b$.

- Then we have $x = a\sin(\omega t + \delta)$
- $$y = b\sin\omega t$$
- Now
- $$\frac{x}{a} = \sin\omega t\cos\delta + \cos\omega t\sin\delta$$

- $\frac{y}{b} = \sin\omega t$ and $\sqrt{1 - \frac{y^2}{b^2}} = \cos\omega t$

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

Superposition of two plane polarised waves having perpendicular vibrations

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

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

- This is an expression of an ellipse. Thus, the light emerging from the crystal plate is, in general, elliptically polarised.

Special Case-1:

- If the thickness of the plate is such that δ = 2nπ, n = 0, 1, 2, 3,…, then cos δ = 1, sin δ = 0. Under this condition, gives

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

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

or
$$\pm\left(\frac{x}{a} - \frac{y}{b}\right) = 0$$

or
$$\pm y = \pm \frac{b}{a}$$

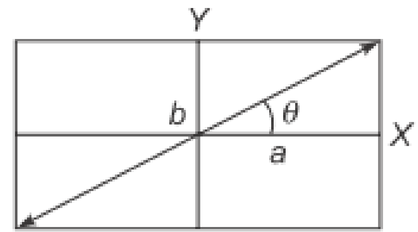


Fig. 14.19 Pair of linearly polarised light

- This represents a pair of coincident lines passing through the origin having slope b/a (Fig. 14.19). This means that emergent light is linearly polarised with the same direction of vibration as the incident light.

Special Case-2

If $\delta = (2n+1)\dfrac{\pi}{2}$, $\cos\delta = 0$, $\sin^2\delta = 1$, Eq. (14.7) will give

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

- This represents an ellipse with its axes along the x and directions and light emerging will be elliptically polarised. The axes of the ellipse being along and perpendicular to the optic axis.
- In this case, if θ = 45° , a = b and we will have
- $$x^2 + y^2 = a^2$$
- Hence, the emergent light is then circularly polarised.
- This case is the basis of quarter wave plate.

Assignment Based on this Lecture

- Explain the construction and working of Nicol Prism.
- What are the polaroids? How they can be constructed?
- Discuss the Huygens theory of Double refraction.
- Discuss the superposition of two plane polarized waves having perpendicular vibrations.
- Discuss the special cases which gives the conditions for linearly and elliptically polarized.