$$n = \frac{1}{N\lambda}$$

$n = 3.13$

$n \simeq 3$

Polarisation

Interference, Diffraction – Light has wave nature

Transverse wave :-

If the direction of vibration of particle is perpendicular to direction of the propagation of light, then the wave is called transverse.

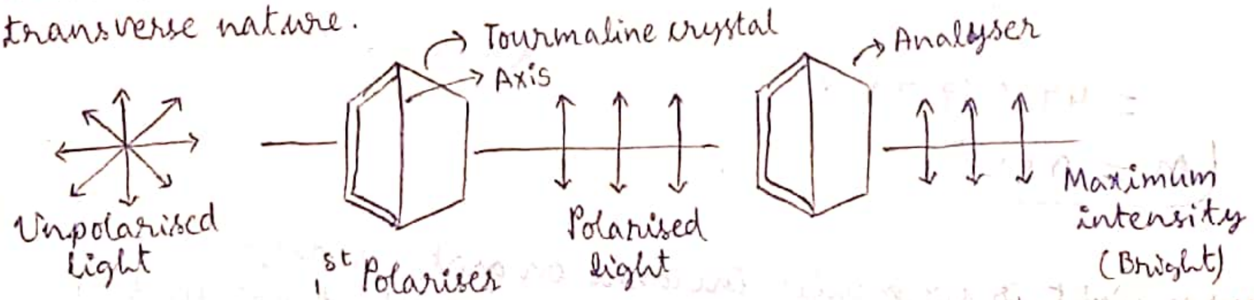
Ex:- Light waves

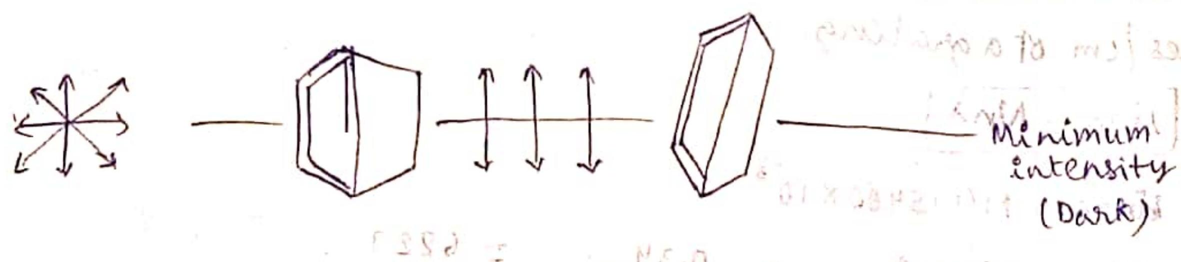
Longitudinal wave :-

If the direction of vibration of the particle is parallel to direction of propagation of light, the wave is called longitudinal.

Ex :- sound waves

Polarisation - From the phenomenon, the polarisation of light, light has transverse nature.





Tourmaline crystal :-

It has the property of allowing the components of light rays that are vibrating parallel to the axis

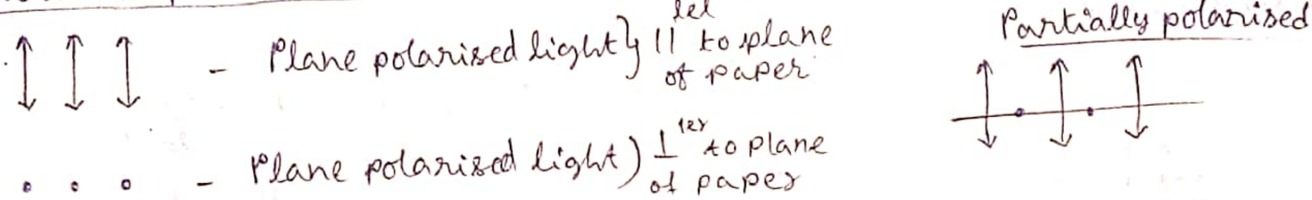
Polarised Light :- The light rays that are vibrating in one direction.

Polariser (crystal-1st) :- crystal which produces polarised light.

Analyser (crystal - 2nd) :- Crystal which analyze the polarised light.

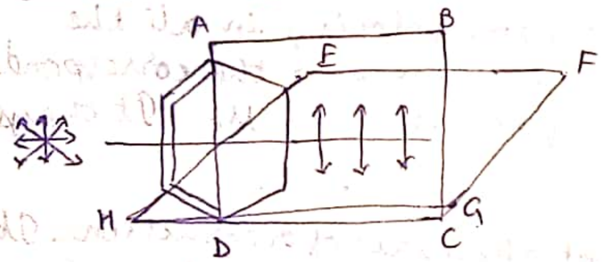
→ In one complete rotation of the analyzer (2nd crystal) we get two max. intensity and two min. intensity.

Pictorial representation :-



Plane polarised light :- After passing through the crystal, the vibration of the incident ray is confined only in a particular plane then the light is called plane polarised light.

Plane of vibration & Plane of polarisation :-

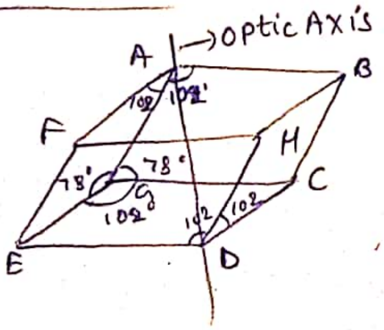


The plane in which vibration of polarised light takes place is called plane of vibration. (ABCD)

→ The plane perpendicular to plane of vibration is called plane of polarisation (EFGH).

Double refraction (Birefringence)

Calcite crystal :-



Calcite crystal → colourless transparent material
↓
$CaCO_3$
↓
Rhomohedron
↓
each face - parallelogram

Blunt corners :-
The corners having 3 obtuse angles

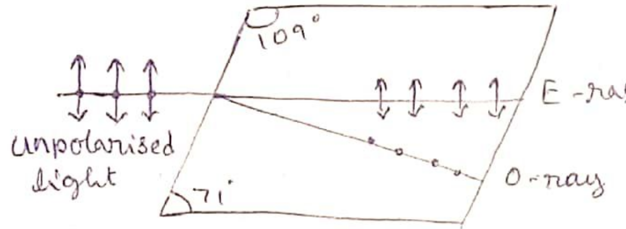
Optic axis :- The line joining the blunt corners is called optic axis. Optic axis is not an axis but it represents direction in the crystal.

Principal section :-

A plane containing optic axis and perpendicular to two opposite faces is called principal section.

*

⇒ Double refraction



$r_1 < r_2$

$\mu_o > \mu_e$

$\mu_o = \frac{\sin i}{\sin r_1}$

$\mu_e = \frac{\sin i}{\sin r_2}$

$\mu_o = 1.6584$

$\mu_e = 1.4864 - 1.6584$

When unpolarised light is passed through the unisotropic crystal (→ exhibit different properties in different directions), calcite, quartz then it splits up into two refracted rays (plane polarised lights). This phenomenon is called double refraction

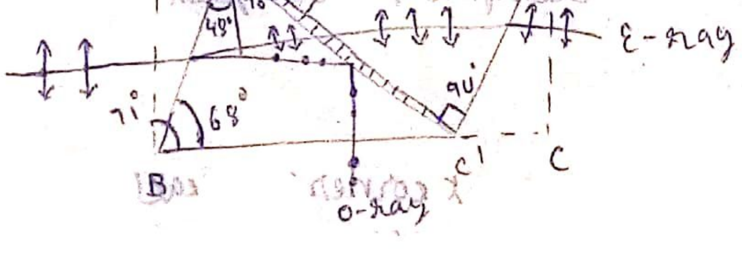
Ordinary ray (O-Ray) :- It travels with same velocity in all the directions, hence the refractive index is same and the corresponding refractive index is called ordinary refractive index μ_o. It obeys law of refraction.

Extraordinary ray (E-Ray) :- It does not obey law of refraction. It travels with different velocity in different direction, hence the refractive index varies and the corresponding refractive index is called extra ordinary refractive index μ_e.

⇒ Along the optic axis, the velocities of O-ray and E-ray are same. And the velocity of E-ray is maximum along the direction $\perp^{ler}$ to the optic axis.

⇒ The vibration of E-ray & O-ray are $\perp^{ler}$ to each other.

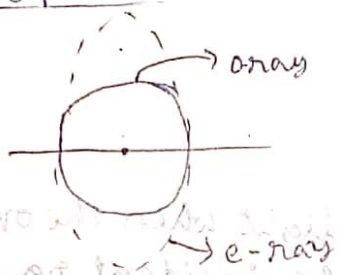
Nicol's Prism



Types of crystal

- Uniaxial → One optic axis
  - Positive → Quartz → $V_o > V_e$, $\mu_o < \mu_e$
  - Negative → Calcite crystal → $V_e > V_o$, $\mu_e < \mu_o$
- Biaxial → Two optic axis → Mica, Borax, Topaz

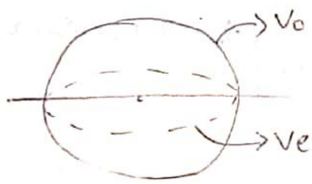
Wave plates



Negative

Calcite

$V_e > V_o$



Positive

Quartz

$V_o > V_e$

* Quarter wave plate

A double refracting uniaxial positive or negative crystal is cut in such a way that it produce a path difference of $\frac{\lambda}{4}$ or phase difference of $\frac{\pi}{2}$ b/w o-ray & E-ray is called Quarter wave plate

⇒ Optical path travelled by o-ray $= \mu_o t$

E-ray $= \mu_e t$

⇒

Path difference $= (\mu_o - \mu_e) t$ $\left(\because V_e > V_o,\ \mu_o > \mu_e \right)$

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

$$t = \frac{\lambda}{4(\mu_o - \mu_e)}$$ ⇒ For negative crystal

$$t = \frac{\lambda}{4(\mu_e - \mu_o)}$$ ⇒ For positive crystal

Half-Wave plate

A double refracting uniaxial positive or negative crystal is cut in such a way that it produce a path difference of $\boxed{\frac{\lambda}{2}}$ and phase difference of $\boxed{\pi}$ between o-ray and e-ray is called Half-wave plate.

⇒ Optic path travelled by o-ray $= \mu_o t$

⇒ " " e-ray $= \mu_e t$

Path difference $= (\mu_o - \mu_e)t$

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

$$\boxed{t = \frac{\lambda}{2(\mu_o - \mu_e)}}$$ ⇒ For negative crystal

$$\boxed{t = \frac{\lambda}{2(\mu_e - \mu_o)}}$$ ⇒ for positive crystal

Applications

⇒ QWP are used to produce circularly polarised light when the optic axis of the crystal makes an angle 45° with the incident ray.

⇒ QWP are used to produce ellipticaly polarised light when the optic axis of the crystal makes an angle other than 45° with the incident ray.

⇒ HWP are used to produce plane polarised light when the optic axis of the crystal makes an angle 45° with incident ray.

Limitations

⇒ QWP and HWP are designed only for particular wavelengths

Q) Calculate the thickness of HWP of quartz for a wavelength 500 nm the μ_e is 1.553, μ_o is 1.544

$$t = \frac{\lambda}{2(\mu_e - \mu_o)} = \frac{500 \times 10^{-9}}{2[1.553 - 1.544]} = \frac{5 \times 10^{-7}}{2 \times 9 \times 10^{-3}} = \frac{5 \times 10^{-4}}{18}$$

$$= 0.277 \times 10^{-4}$$

$$t = 2.77 \times 10^{-5} \text{ m}$$

Q) Calculate the thickness of QWP for sodium light of wavelength 589 nm given $\mu_e = 1.553$, $\mu_o = 1.544$

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

$$t = \frac{589 \times 10^{-9}}{4 \times 9 \times 10^{-3}} = \frac{589 \times 10^{-9}}{4 \times 9 \times 10^{-3}} = \frac{589 \times 10^{-6}}{36} = 16.36 \times 10^{-6} = 1.636 \times 10^{-5}\ m$$

Q) Find the minimum thickness of HWP & QWP for a light beam of $\lambda = 589.3$ nm, $\mu_o = 1.65833$, $\mu_e = 1.48640$

HWP

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

$$= \frac{589.3 \times 10^{-9}}{2(0.17193)}$$

$$= \frac{589.3 \times 10^{-9}}{0.34386}$$

$$= \frac{589.3 \times 10^{-9}}{343.86 \times 10^{-3}}$$

$$= 1.71377 \times 10^{-6}\ m$$

QWP

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

$$= \frac{589.3 \times 10^{-9}}{4(0.17193)}$$

$$= 8.56 \times 10^{-7}\ m$$

Q) The refractive index of calcite is 1.658 for ordinary ray & 1.486 for extra ordinary ray. A slice having thickness 0.9×10^{-4} cm is cut from the crystal for what wavelength this slice have Q.W & H.W

H.W

$$t = \frac{\lambda}{2(1.658 - 1.486)}$$

$$\lambda = 2 \times 0.172 \times 0.9 \times 10^{-6}$$

$$= 1.8 \times 0.172 \times 10^{-6}$$

$$= 0.3096 \times 10^{-6}\ m$$

Q.W

$$\lambda = 4 \times 0.172 \times 0.9 \times 10^{-6}$$

$$\lambda = 0.6192 \times 10^{-6}\ m$$