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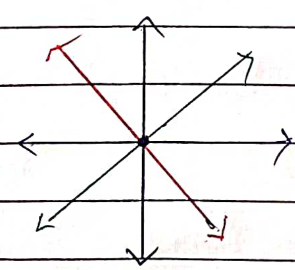
Polarization

Interference & Diffraction phenomena proved wave nature of light. But unable to explain/ give information regarding characteristics of waves i.e. whether light waves are longitudinal or transverse, what kind of vibrations in the wave etc.
Another phenomena i.e. Polarization proved that light is transverse wave. →
Light waves are transverse waves consisting of electric & magnetic fields vibrating perpendicular to each other & to the direction of propagation of wave which constitute a plane.
In unpolarized light there is infinite number of such planes around the direction of propagation.
In polar light these vibrations are confined to particular plane

* Unpolarized Light:
  - Direction of oscillation of electric field vectors in all possible planes perpendicular to direction of propagation of wave.

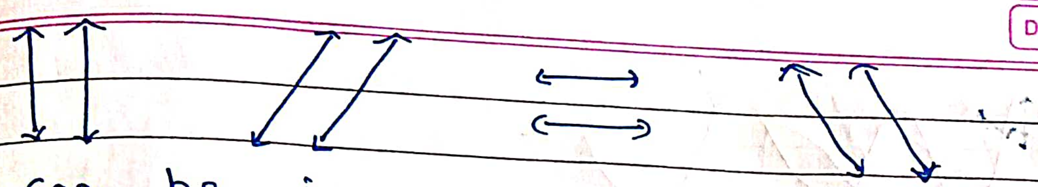
Ex - light emitted by conventional light sources.



*Electric field vector oscillates in more than one planes..

Unpolarized light.

* Polarized light:
  - Direction of oscillation of electric field vector in a particular plane



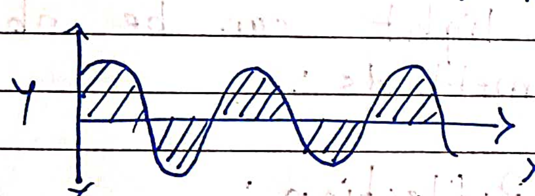
↳ can be in any particlar plane depending on polarizer & Analyzer's planes.

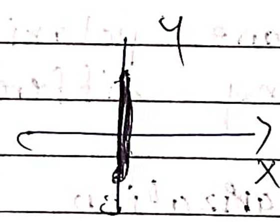
∴ Polarized light can not be produced naturally. Obtained by converting unpolarized light in polarized light using polarizer.

* Types of Polarization :

① Plane / Linear Polarization :

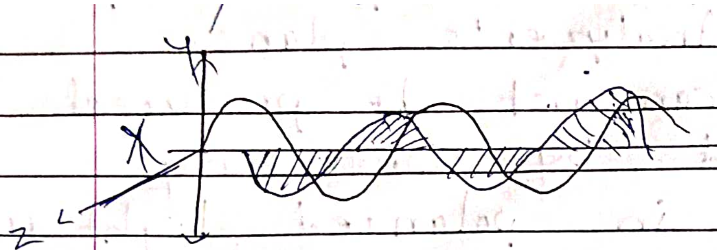
- Oscillations occur in a "single plane" Vibrations (of Electric field vector) are confined strictly to a plane perpendicular to direction of propagation.

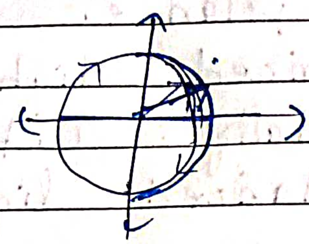




(ii) Circularly Polarized light :

- During wave propagation, magnitude of (vibrations) wave remains constant but it rotates at constant rate about direction of propagation & sweeps circular helix in space.
- We can say, circularly polarized light is regarded as resultant wave produced due to superposition of two coherent linerly polarized waves of equal amplitude amplitude oscillating in mutually perpendicular planes.





(III) Elliptically Polarized Light:

- Same as in case of circular polarized light only ~~there~~ magnitude of electric field vector is changing with time & hence instead of circle it will ~~spee~~ sweep out an ellipse.

* Production of Plane polarized light:
Plane polarized light can be obtained using different methods:

(1) Polarization by Reflection:
When a unpolarized light in reflected from a boundry of two ~~d~~ media, Reflected light is ~~pal~~ polarized to a very small extent.
We can get polarized light after reflection for a particular angle of incidence.
Condition is given by Brewster's law:

~~Brewter~~ Brewster's law:
He experimented polarization of light by reflection from different surfaces.
He found that polarizing angle depends upon refractive index of medium.

Brewster proved ~~that~~ that: " Tangent of the angle at which polarization is obtained by reflection is numerically equal to Refractive index of the medium "

Let, $\theta_B \rightarrow$ Brewster's angle

$\mu \rightarrow$ R.I. of medium

$$\therefore \boxed{\mu = \tan\theta_B} \leftarrow \text{Brewster's Law.}$$

* Brewster also found that maximum polarization of reflected ray occurs when it is at right angles to the ~~reflected~~ (refracted) ray.

$$\Rightarrow \theta_B + r = 90^\circ$$

$$\therefore \cancel{\theta_r}\ r = 90^\circ - \theta_B$$

r: Angle of Refraction

According to Snell's law:

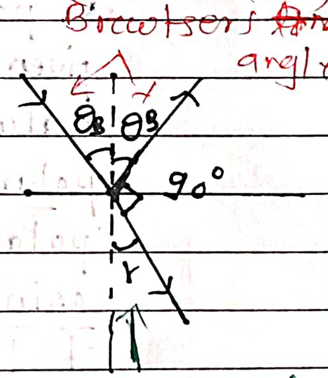
$$\frac{\sin\theta_B}{\sin r} = \frac{\mu_2}{\mu_1}$$

$\mu_2 \rightarrow$ R.I of reflecting surface &

$\mu_1 \rightarrow$ R.I of ~~sou~~ sorrounding medium.

(∵ Snell's law)

$$\therefore \frac{\sin\theta_B}{\sin(90^\circ - \theta_B)} = \frac{\mu_2}{\mu_1}$$



Angle of Refraction

$$\therefore \frac{\sin\theta_B}{\cos\theta_B} = \frac{\mu_2}{\mu_1}$$

$$\Rightarrow \boxed{\tan\theta_B = \frac{\mu_2}{\mu_1}}$$

* Applications of Brewster's law:
- Used to find R.I of medium
- To calculate polarizing angle required for total polarization of reflected light if R.I is known.
- Brewster's angle is used while manufacturing optical fibers (for reducing reflection losses)

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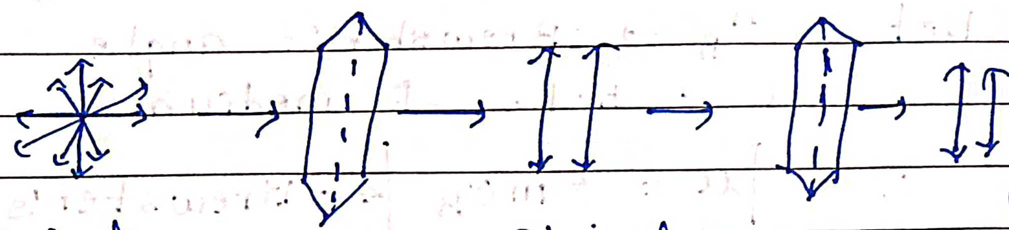
* Polarizer & Analyzer:

A polarizer is an optical element, which transforms unpolarized light into polarized light.



Analyzer is an optical element which is used to identify plane of vibration of plane polarized light & intensity of light.
Structure of analyzer is same as polarizer, only working is different.

* Malus Law:

- Amount of light transmitted through a polarizer at an arbitary angle is given by malus' law.
- Malus found that "The intensity of polarized light transmitted through a polarizer is proportional to square of cosine of angle between plane of polarization of light & transmission axis of polarizer"

If unpolarized light of intensity I_0 is incident on a polarizer, plane polarized light of intensity $\frac{I_0}{2}$ is transmitted by it.

& let $I_1 = \frac{I_0}{2}$

∴ Intensity of light transmitted through polarizer is

$$I = I_1 \cos^2\theta = \frac{I_0}{2}\cos^2\theta$$

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

Light transmitted through analyzer at specific settings are:

(i) $\theta = 0^\circ \Rightarrow$ axes parallel $\Rightarrow I = \frac{I_0}{2}$

max. intensity

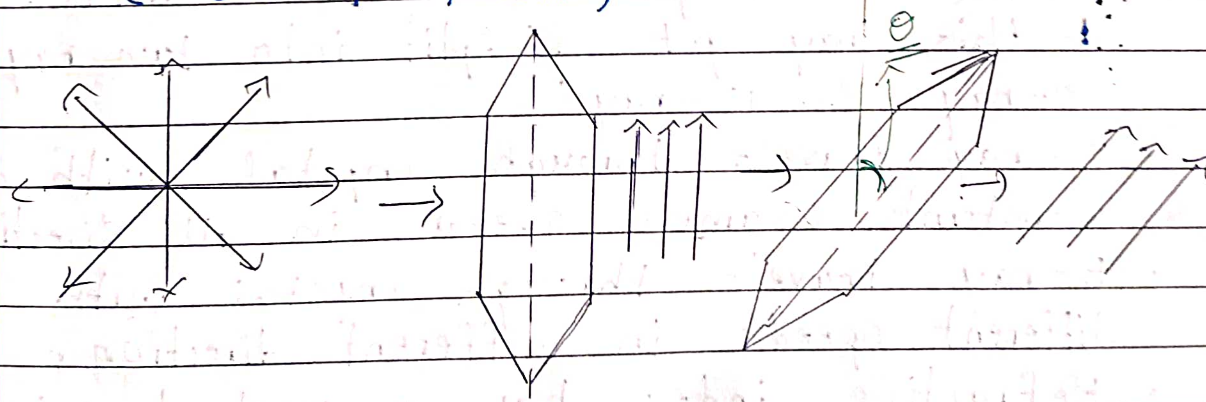
(ii) $\theta = 90^\circ \Rightarrow$ axes perpendicular $\Rightarrow I = 0$

(iii) $\theta = 180^\circ \Rightarrow$ axes parallel $\Rightarrow I = \frac{I_0}{2}$

(iv) $\theta = 270^\circ \Rightarrow$ axes perpendicular $\Rightarrow I = 0$

minimum intensity

* We obtain maximum intensity at two positions ($\theta = 0^\circ$ & 180°) & minimum intensity at two positions ($\theta = 90^\circ, 270^\circ$)



polarizer

Analyzer

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* Anisotropic media:

For istropic media like water, air, glass the atoms / molecules are arranged in particular periodic manner in all directions hence ~~the~~ such materials will have same properties in any direction for ex R.I.

But if arrangement of atoms differe in different directions within crystal, physical properties vary with direction.

Such media / materials are anisotropic.

Anisotropic crystals are divided into:

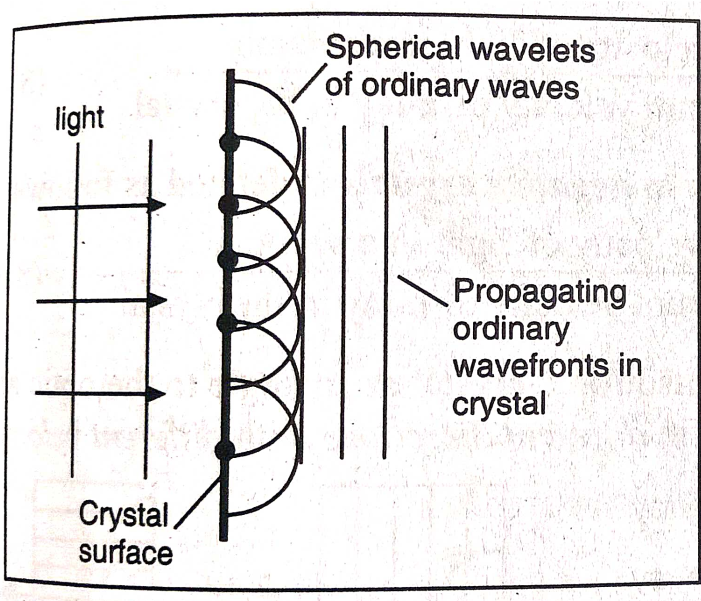
① Uniaxial crystals:
Refracted rays are (i) ordinary ray & other (ii) Extra-ordinary ray

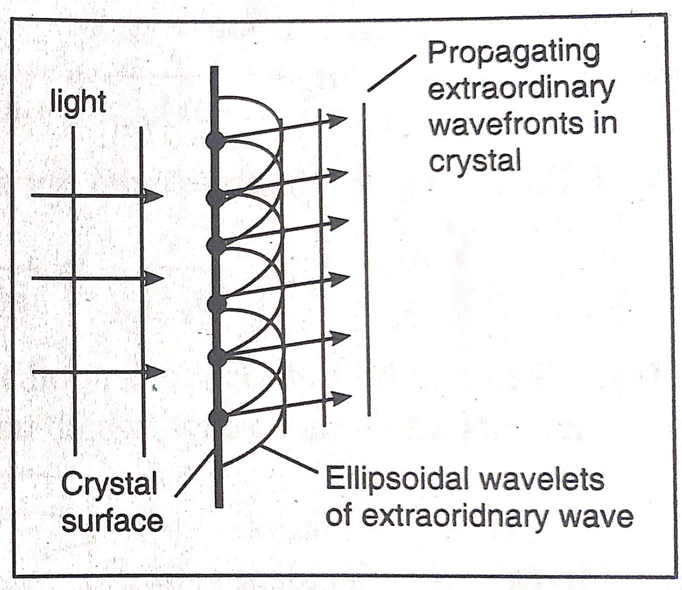
② Biaxial crystals:
Both refracted rays are extraordinary rays.

* Double Refraction:

When a ~~ry~~ ray of light incident on double refracting material like calcite. ~~&~~ this ray get ~~sp~~ split into two rays O-ray & E-ray

- O-ray travels through crystal with a constant (same) speed in all directions
- E-ray travels through crystal with different speeds in different directions.
- Refractive index has a constant value for ordinary ray & for E-ray R.I value will be different for different directions.
- Let Refractive index for O-ray be 'μ_o'


Spherical wavelets
of ordinary waves
light
Propagating
ordinary
wavefronts in
crystal
Crystal
surface


Propagating
extraordinary
wavefronts in
crystal
light
Crystal
surface
Ellipsoidal wavelets
of extraoridnary wave

R.I for E-ray be 'μ_e'

$\therefore$ Birefringence ($\Delta\mu$) is

$$\boxed{\Delta\mu = \mu_e - \mu_o}$$

* Huygen's Explanation of Double Refraction:

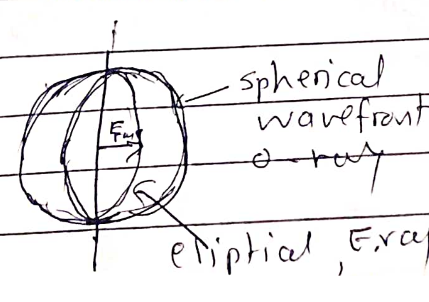
- When a ~~mo~~ light incident on double refracting material at a point.
- That light gives rise to two wavefronts
  (i) Ordinary ray wavefront which is a 'spherical wavefront' as speed of O-ray is constant in all directions within crystal.
  (ii) Extraordinary ray wavefront which is 'elliptical wavefront' as speed of E-ray is different for different directions ~~in~~ within the crystal.
- The speed of O-ray & E-ray is same along optic axis.

* Birefringence ($\Delta\mu$) →

Depending on value of $\Delta\mu$, two types of crystals:

(i) Positive crystals:
- $\Delta\mu$ is positive
- Speed of O-ray is more than speed of E-ray ($\mu_e > \mu_o$)
- Elliptical wavefront ~~for~~ of E-ray lies completely inside spherical wavefront of O-ray.

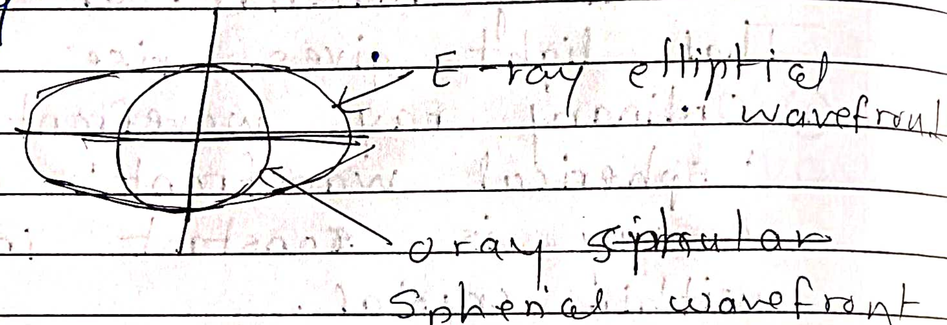
- ex -



② Negative crystals:

- $\Delta\mu$ is negative.
- Spee of E-ray is more than speed of o-ray inside the crystal (except along optics axis) $(\mu_o > \mu_e)$

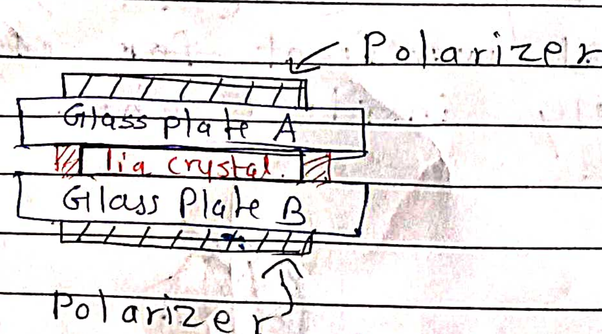
∴ Spherical wavefront of ~~or~~ O-ray lies completely inside elliptical wavefront of E-ray.



* Applications of Polarized light:

Light reflected from nonmetallic surfaces like water, snow clad, mountains, etc is partially polarized which cause glare & ~~m~~ because of it image we see is not clear.
So to remove this glare & to get clear image we use polarizers in sunglasses & ~~ph~~ cameras.

LCDs:



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↳ Liquid crystal Display (LCD) are used in ~~different~~ wristwatches, computer screens, timers & clocks etc.

- These devices are based on interaction of rod-like liquid crystalline molecules with an electric field & polarized light waves.
- An LCD consists of a liquid crystal material which is a double refracting, of about 10 μm thick & it is supported by two thin glass plates having transparent conducting coating on their inner surfaces.
- This conducting coating is etched in the form of a digit or character

Assembly of glass plates with liquid crystal material in between is ~~an~~ sandwiched between two crossed-polarizer sheets.

- During fabrication of LCDs, Liquid crystal molecules are aligned in such a way that their long axes undergo a 90° rotation twisted molecular arrangement

When natural light incident, ~~on~~ front polarizer converts it into linearly polarized light.

As linearly polarized light propagates through the LCD, optical vector is rotated through 90° by twisted molecular arrangement.

Hence, it passes unhindered through rear polarizer whose transmission axis is perpendicular to that of front polarizer.

Reflecting coating at the back of rear polarizer sends back the light (reflects)

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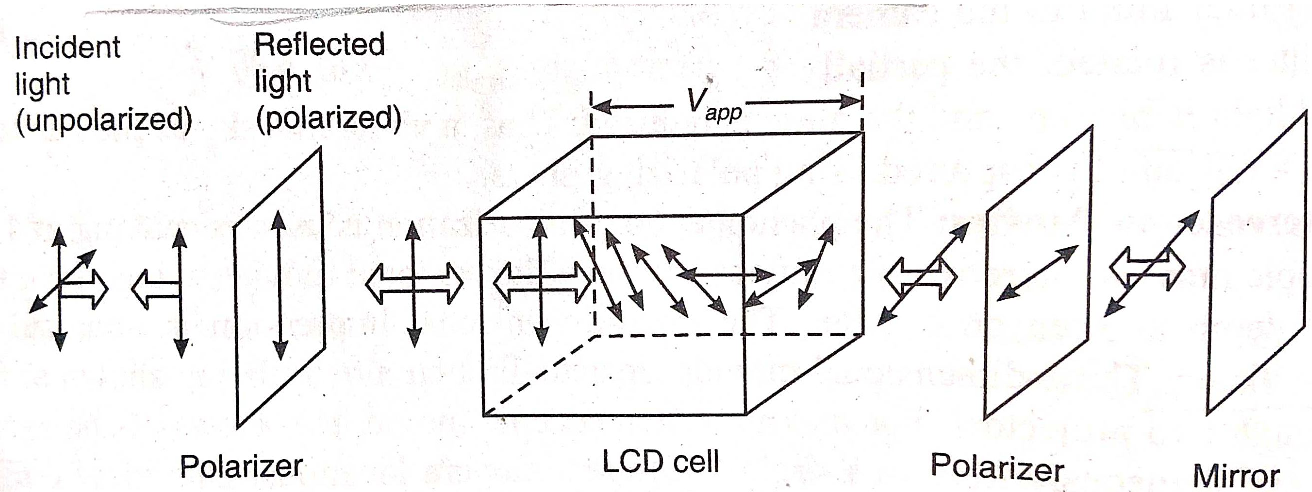
which emerges unobstructed by ~~Fr~~ front polarizer.

∴ Display appears uniformly illuminated

When voltage is applied to a device molecules between electrodes untwist & align along field direction.

As a result, optical vector doesn't undergo rotation as it passes through that region. The rear polarizer blocks the light & hence a dark digit or character is seen in that region.



Incident light (unpolarized)
Reflected light (polarized)
V_{app}
Polarizer
LCD cell
Polarizer
Mirror