Date. No.

OPTICS:

Unit: 3: POLARIZATION

Polarization:

The phenomenon by which unpolarized light becomes polarized is called polarization.

Polarized and Unpolarized Light:

Unpolarized light has vibrations along all possible plane perpendicular to the direction of propagation of light.

Polarized light is the light having vibrations only along a single plane is called polarized light.

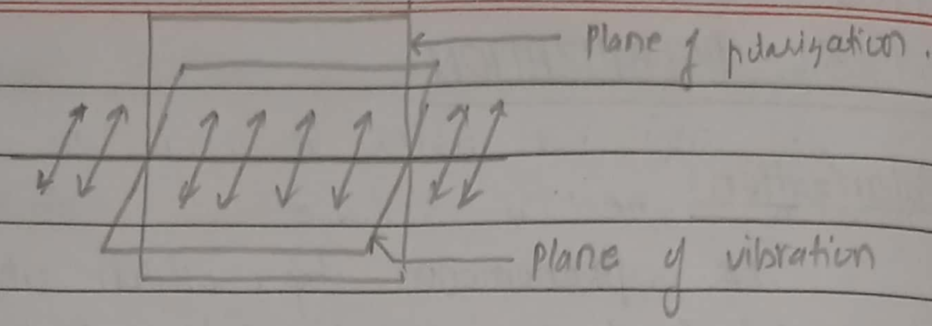
Introduction:

According to electromagnetic theory, light wave consists of mutually perpendicular electric field $\vec{E}$ and magnetic field $\vec{H}$.

So, in polarized light, $\vec{E}$ or $\vec{H}$ are confined to vibrate along a straight line perpendicular to the direction of propagation of light wave.

Experimentally, we know, light has transverse wave motion in which vibrations of particles are perpendicular to the direction of propagation of wave.

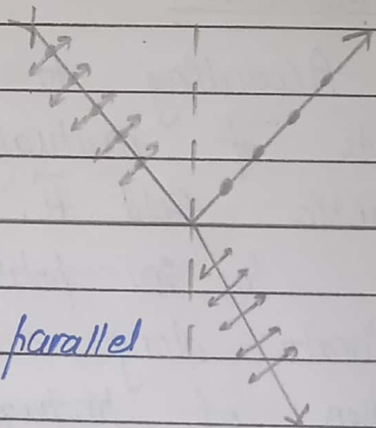
When unpolarized light passes through polarizing filters, it becomes polarized. Such polarizing filters are called polaroids. Eg: sunglasses, camera lens, etc.



The plane containing the direction of vibration and direction of propagation of light is called plane of vibration.

The plane perpendicular to the plane of vibration and containing the direction of propagation of light is called plane of polarization.

Polarization ~~of~~ By Reflection



When ordinary light is incident on any surface of transparent material, the reflected beam is partially ~~plt~~ plane polarized. These vibrations of reflected beam are parallel to the reflecting surface.

*) Polarizing angle (i_p):

The particular angle of incidence for which the reflected beam becomes completely plane polarized is called polarizing angle.

The vibration of incident unpolarized light may be resolved into two directions: parallel and perpendicular

Date. No.

to reflecting surface.

The reflected light is only due to the components parallel to reflecting surface and transmitted light is due to components perpendicular to it.

Double Refraction

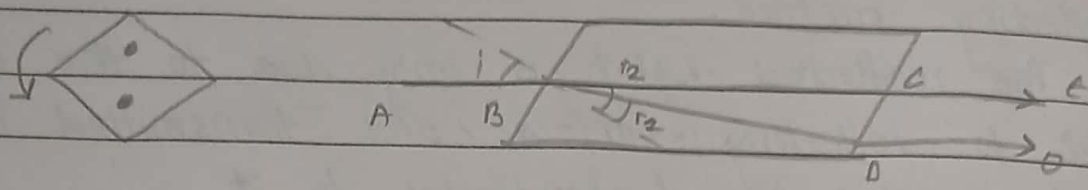
When a ray of ordinary unpolarized light is passed through some crystals like Calcite, it splits up into two refracted rays. This phenomenon is called double refraction.

One of the ray follows the ordinary laws of ~~reflection~~ refraction which is called ordinary ray (O-ray) whereas another ray of light doesn't follow the ordinary laws of refraction which is called extraordinary ray (E-ray).

Hence, if an object is viewed through such crystals two images of the object ~~is~~ are observed.

Image corresponding to o-ray is called original image while another image corresponding to e-ray is called extraordinary image.

If the crystal is rotated, the image corresponding to E-ray ~~ro~~ only rotates.



Let ray AB be incident on calcite crystal at angle of incidence 'i'.

Here, ray AB splits up inside the crystal into two refracted rays along BC and BD such that angle of refractions are 'r_2' and 'r_1' respectively.

The rays emerging from crystals along CE and DO which are parallel.

Now,

Refractive index for:

ordinary ray $(\mu_o) = \frac{\sin i}{\sin r_1}$ extraordinary ray $(\mu_e) = \frac{\sin i}{\sin r_2}$

Here, μ_o is constant

whereas, μ_e depends on angle of incidence i.

*) Negative crystals:

In negative crystals,

$r_1 < r_2$ Hence, $\mu_o > \mu_e$.

So, $v_o < v_e$.

Eg: calcite, tourmaline, ruby.

*) Positive crystals

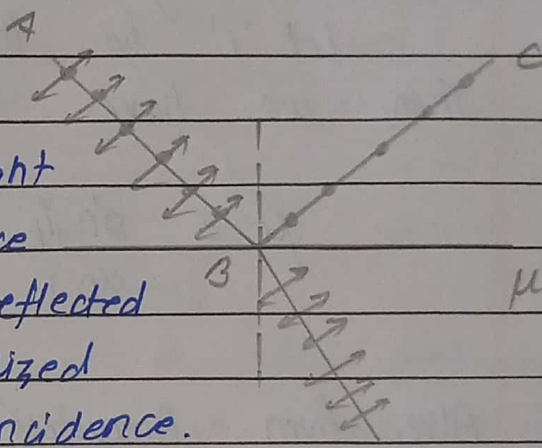
In positive crystals,

$r_2 < r_1$ Hence, $\mu_e > \mu_0$

So, $v_e < v_0$

Eg: quartz, iron oxide.

Brewster's law:



When ordinary beam of light is reflected from the surface of transparent medium, the reflected ray is completely plane polarized at some particular angle of incidence. This angle ~~is~~ of incidence is called polarizing angle.

Fig: Brewster's law.

If μ is refractive index of the medium, it is found that,

$$\mu = \tan(i_p)$$

i.e, ~~angle~~ tangent of angle of polarization for a given medium is numerically equal to refractive index of that medium.

and

at polarizing angle, the reflected ray and the refracted ray are perpendicular to each other.

This is Brewster's law.

Date. No.

Let a beam of unpolarized light AB be incident at an angle equal to polarizing angle i_p on surface of transparent medium.

The beam AB is reflected along BC and refracted along BD.

Let 'r' be the angle of refraction.

Then, we have.

$$\mu = \frac{\sin i_p}{\sin r} \quad \text{—— (i)}$$

Also, from Brewster's law,

$$\mu = \tan i_p = \frac{\sin i_p}{\cos i_p} \quad \text{—— (ii)}.$$

From (1) and (2),

$$\cos i_p = \sin r = \cos\left(\frac{\pi}{2} - r\right)$$

or, $$i_p = \frac{\pi}{2} - r$$

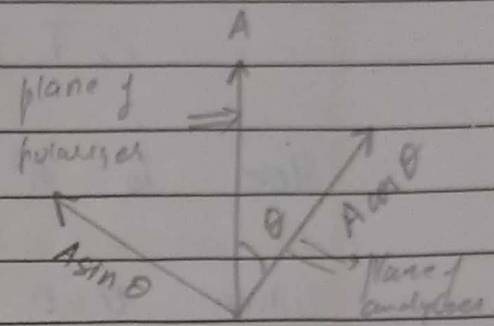
$$\therefore\ i_p + r = \frac{\pi}{2}$$

From figure, $\angle CBD = \pi - (i_p + r) = \pi - \frac{\pi}{2}$

$\therefore \angle CBD = \pi/2$.

Thus, the angle between refracted ray and reflected ray is $\pi/2$ i.e, perpendicular to each other.

Law of Mallus



When a beam of light polarized by reflection at one plane surface is allowed to fall on the second plane surface at the polarizing angle, the intensity of the final reflected beam varies as the square of the cosine of the angle between the two planes of incidence.

Mallus law can be stated as, "The intensity of light emerging from the analyzer is proportional to the square of the cosine of the angle between the plane of transmission of the analyzer and the polarizer."

Let A = amplitude of plane polarized light
θ = angle between planes of polarizer and analyzer

Resolving A into $A\cos\theta$ parallel to plane of analyzer.
into $A\sin\theta$ perpendicular to plane of analyzer.

Date. No.

Only the ~~f~~ component $A\cos\theta$ is transmitted to analyzer. So, intensity of transmitted beam is,

$$I = (A\cos\theta)^2 = A^2\cos^2\theta = I_0\cos^2\theta$$

$$\therefore I \propto \cos^2\theta.$$

Here $I_0 = A^2$ = intensity of incident plane polarized light.

When $\theta = 0$, $I = I_0$ (maximum)
$\theta = \pi/2$, $I = 0$ (minimum)

So, intensity of light transmitted from analyzer is maximum when the planes are parallel and minimum when they are perpendicular to each other.

Nicol Prism as Analyzer and Polarizer

Nicol prism is an optical device used to produce and analyze plane polarized light.
When ordinary ray passed through calcite crystal, it splits into O-ray and E-ray.
Nicol prism is made in such a way that it eliminates one of the two rays by total internal reflection.
We find that O-ray is eliminated and only E-ray is transmitted.

A calcite crystal is suitably cut into two pieces and cemented by optically transparent material called Canada ~~Bt~~ Balsam. ~~The~~ It's refractive index lies between μ_o and μ_e.

Numerically,

$\mu_o = 1.66$

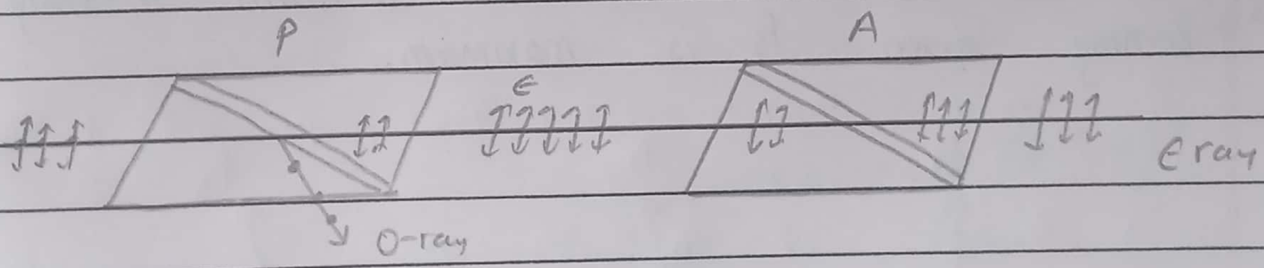
$\mu_B = 1.55$

$\mu_e = 1.49.$

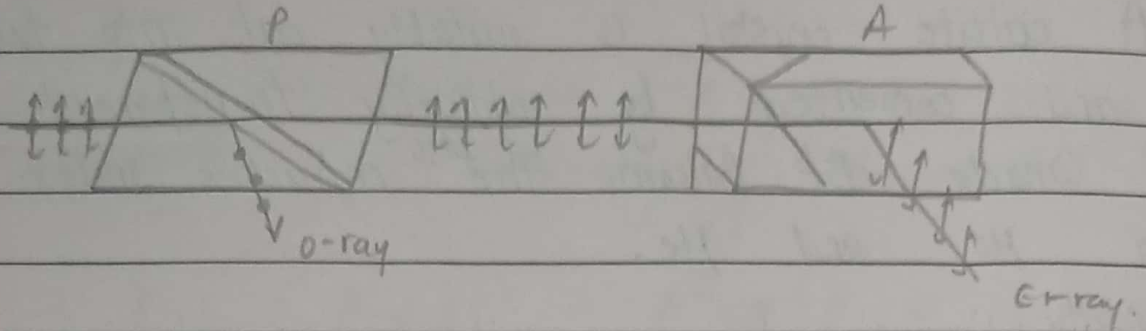
Here, canada ~~bta~~ Balsam is optically denser than calcite for E-ray and rarer for O-ray.

Hence, O-ray is totally internal reflected and only E-ray is transmitted through prism which is plane polarized light. Hence, nicol prism acts as polarizer.

To analyze polarized ray, second nicol prism is placed adjacent to the first.



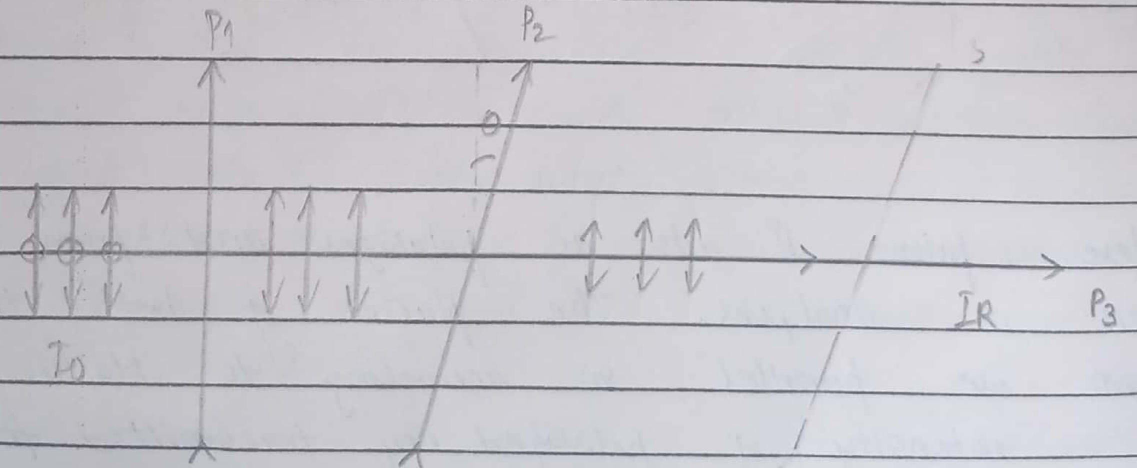
Here, prism P acts as polarizer and prism A acts as analyzer. The planes of both the prism are parallel, so according to Mallus law, intensity of polarized ray transmitted from analyzer ~~to polarizer.~~ is maximum.



Now, prism A is gradually rotated, the intensity of ~~po~~ transmitted ~~IF~~ E-ray decreases in accordance to Mallus ~~ray~~ law. and when planes of these prisms are crossed, the intensity of light transmitted from analyser is zero.
ie, E-ray is totally internally reflected.

Thus, nicol prism can be both used as polarizer and analyzer.
The combination of two nicol prisms is called a polarimeter.

<Q>: Calculate 'θ' such that resultant intensity coming from P_3 is maximum.



Soln:

Let the intensity of unpolarized light be I_0.

The Intensity of light passing through P_1 $(I_1) = \frac{I_0}{2}$

Here, ~~the~~ θ be the angle betn P_1 and P_2.

So,
intensity of light passing through P_2 $(I_2) = \frac{I_0}{2}\cos^2\theta$

Again, angle betn P_2 and P_3 $(\theta_2) = 90^\circ - \theta$

So, intensity of light passing through P_3 $(I_R) = \frac{I_0}{2}\cos^2\theta \cdot \cos^2\theta_2$

$$= \frac{I_0}{2}\cos^2\theta \cdot \cos^2(90^\circ - \theta)$$

$$= \frac{I_0}{8}\, 4\sin^2\theta\cos^2\theta$$

$$= \frac{I_0}{8}(\sin^2 2\theta)^2$$

For I_R ~~to~~ to be maximum,

~~I_R~~ $\sin 2\theta = 1$

or, $\sin 2\theta = \sin\frac{\pi}{2}$

$\therefore \theta = \frac{\pi}{4}.$

Optically Active substance

Some substance can rotate plane of vibration or plane of polarization when plane polarized light passes through them.

This property of rotation of plane of polarization is called optical activity and the substance is called optically active substance.

*) **Dextrorotatory:** If the plane of polarization is rotated towards right, substance is right handed or dextrorotatory.

*) **Laevorotatory:** If the plane of polarization is rotated towards left, substance is left handed or Laevorotatory.

Optically active substance can rotate the plane of polarization of plane polarized light. The angle through which the plane of polarization is rotated depends upon.

i) thickness of the medium
ii) concentration of solution or density of substance.
iii) wavelength of light
iv) temperature.

Date. No.

*) Specific Rotation:

Specific rotation is defined as the rotation ~~throu~~. produced by a decimeter (10cm long) column of the liquid containing 1 gm of active substance in 1 cc of solution.

Therefore,

$$S_\lambda^t = \frac{10\,\theta}{l\,c}$$

Here,

S_λ^t = specific rotation at temperature $t°c$ for λ wavelength.

θ = angle of rotation.

l = length in cm

c = concentration in gm/cc.

Polarimeter is used to determine specific rotation and its study helps us to find amount of active substance in sample of optically active solution.