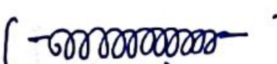
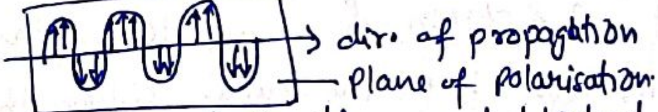
Polarisation of Light

Huygen's wave theory of light successfully explained the phenomenon of interference and diffraction. However it does not predict anything about the nature of light ie whether the light waves are longitudinal or transverse.

Longitudinal Wave : A wave in which the particles of the medium oscillate to and fro along the direction of propagation of wave is called Longitudinal wave. e.g. soundwave and wave produced on a spring []. The longitudinal wave consists of alternate compressions and rarefactions. In these waves, particle displacement (vibration) & wave propagation occurs in in the same direction.

Transverse wave : A wave in which every particle of the medium oscillate up & down at right angle to the direction of wave propagation is called transverse wave. e.g. ripples on the water surface. The wave propagation takes in the form of alternate crests and troughs. In these waves, the direction of particle displacement occurs ⊥ the wave propagation.



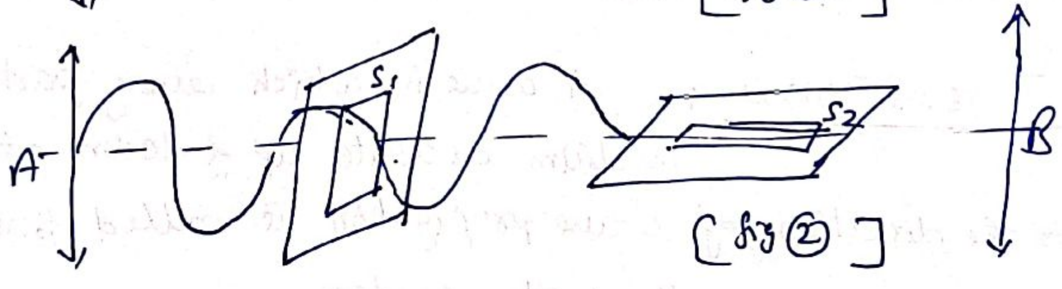
⇒ The phenomenon of polarization established the transverse nature of light.

Plane of Vibration : The plane having the direction of vibration & direction of propagation of light is called the plane of vibration. ie [the plane in which vibrations take place

Plane of Polarisation ; The plane containg the direction of propagation of light & ⊥ₒ the direction of vibrations is called the plane of polarisation. ie. [the plane at right angle to plane of vibration]

Concept of Polarisation

[fig ①]



[fig ②]

Let us consider a string AB, passing through two ∥ slits S_1 & S_2. Keeping the end B of the string fixed, a transverse wave in the string AB is produced by moving the end A up & down & ⊥ₒ AB. This transverse wave is passed through both the slits. When the slits S_1 & S_2 are ∥ & the string vibrate ∥ to S_1, then the wave travel towards the end B.

But when S_2 is ⊥ₒ S_1, it will not allow the transverse wave to pass through it (in fig ②). However if longitudinal vibrations are produced by moving the end A to & fro the vibrations are easily allowed to pass through S_2 in its all positions. →

So we conclude that the transverse waves can only pass through S_2; when it is $\parallel$ to S_1 & will be completely stoped if the direction of S_2 is $\perp$ to S_1.

Now in longitudinal mode of vibration there is only one possible direction of vibration of the particles is possible i.e along the direction of wave propagation.

But in case of transverse mode of vibration there are infinite directions of vibrations are possible for the particles which are perpendicular to the direction of wave propagation.

Now if a restriction is imposed on the different possible directions of vibration of the particles $\perp$ to the path of a wave propagation, so that their vibrations are confined only to a single plane i.e. only along one direction which is $\perp$ to dir. of wave propagation, then the outgoing wave is called polarised wave.

So the transverse wave can be polarised in an infinite wave.

Now when the vibration of the particles of the medium $\perp$ to the path of transverse wave propagation occurs in all possible directions with equal favour, then the outgoing wave is called unpolarised wave. If the vibration of particles occur in only one plane or direction which is $\perp$ to the wave propagation then the. the outgoing wave is called plane polarised wave or linearly polarised.

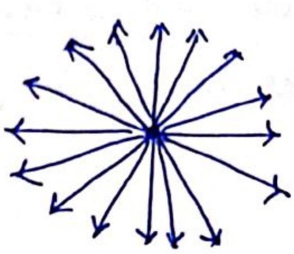
Que:- Define Polarised and unpolarised light, also draw their pictorial representations.

Sol:- **Unpolarised Light :**

An ordinary light having vibrations along all possible directions ⊥ to the direction of propagation of light is called an unpolarised light.

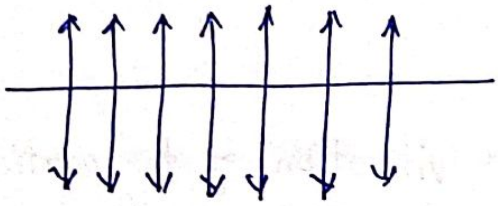
It consists of an infinite no. of plane polarised lights, each having its own direction of vibration.

e.g. white light or ordinary light

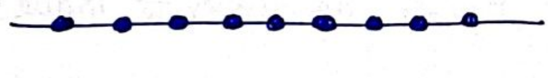


Plane Polarised Light :

The light having vibrations only along a single direction ⊥ to the direction of propagation of light is called polarised light.



[fig ①]



[fig. ②]

When vibrations are in the plane of paper they are represented by by st. arrows [in fig ①]

When vibrations lie in a direction ⊥ to the plane of paper, then the polarised light is represend by dots. [in fig ②]

★★ The phenomenon in which the wave vibrations are restricted to a particular direction in a plane is called polarization.

Production of Linearly Polarised Light

Plane polarised can be produced by different methods & a few methods are as under.

1) Polarisation by reflection
2) Polarisation by refraction
3) Polarisation by double refraction
4) Polarisation by scattering

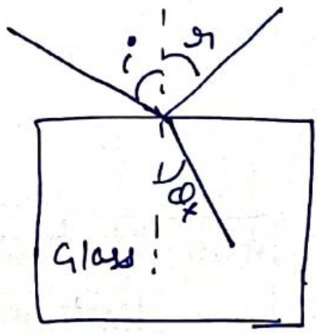
etc.

Brewster's law

Sir David Brewester performed a series of experiments on the polarization of light by reflection at a no. of surfaces. He found that polarising angle depends upon the refractive index of the medium.

statement: It states that when a ray of light reflected from a surface is polarised, then the tangent of polarising angle is equal to refractive index of the medium.

i.e $\boxed{\tan\theta_p = \mu}$ → Brewester's law



i.e θ_p = polarising angle

& angle of incidence $\Rightarrow \theta_i = \frac{\pi}{2} - \theta_p$

also $\frac{\sin\theta_i}{\sin\theta_p} = \frac{n_2}{n_1}$

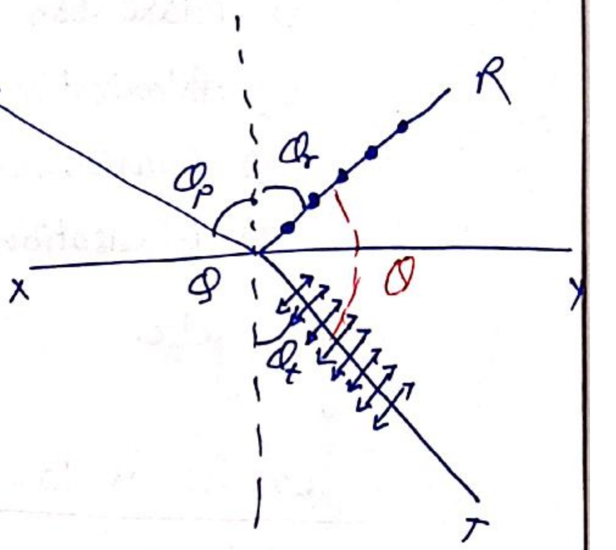
$$\frac{\sin\theta_p}{\sin(\frac{\pi}{2}-\theta_p)} = \frac{n_2}{n_1}$$

$$\boxed{\tan\theta_p = \frac{n_2}{n_1} = \mu}$$

for alternatively P.T.O

30. let a beam PQ of unpolarised light be incident on the surface XY of a transparent medium having refractive index μ. QR is the reflected light & QT is refracted light, θ_p is the angle of incidence (ie polarising angle) & θ_t angle of refraction.

so by Brewster's law



$$\tan\theta_p = \mu \quad —(1)$$

also $$\frac{\sin\theta_p}{\sin\theta_t} = \mu \quad —(2) \text{ from Snell's law}$$

∴ from (1) & (2)

$$\frac{\sin\theta_p}{\cos\theta_p} = \frac{\sin\theta_p}{\sin\theta_t}$$

or $$\cos\theta_p = \sin\theta_t$$

$$\Rightarrow \sin(90° - \theta_p) = \sin\theta_t$$

or $$90° - \theta_p = \theta_t \Rightarrow \theta_p + \theta_t = 90° \quad —(3)$$

if θ is the angle b/w reflected & refracted light beam

the from fig.

$$\theta_p + \theta_t + \theta = 180°$$

$$\theta = 180° - (\theta_p + \theta_t) = 180° - 90°$$

$$\boxed{\theta = 90°}$$

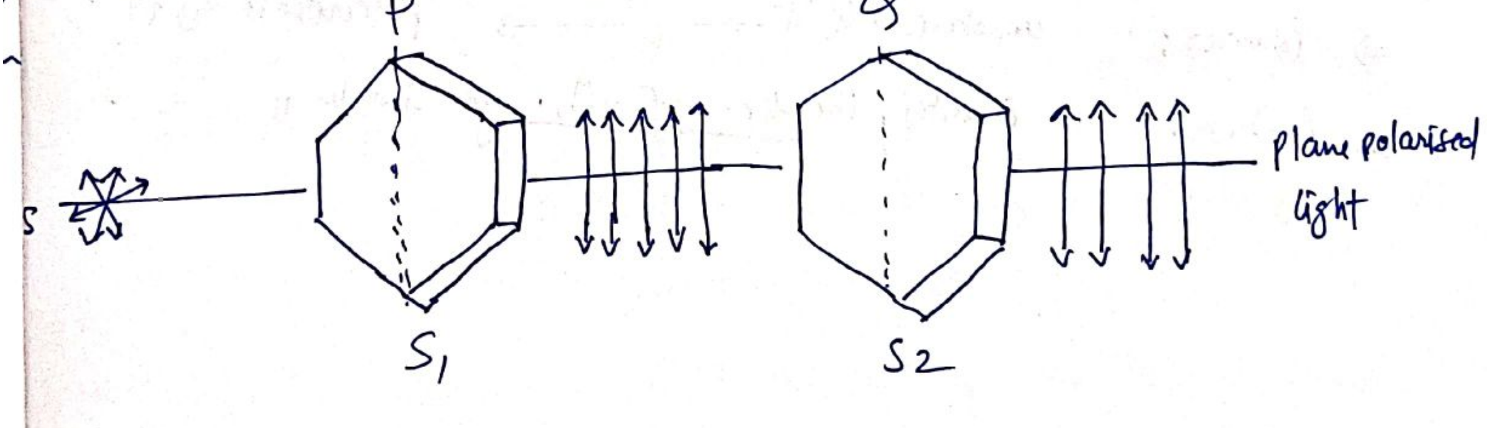
Also, it proves that the angle b/w reflected & refracted light beam is 90°

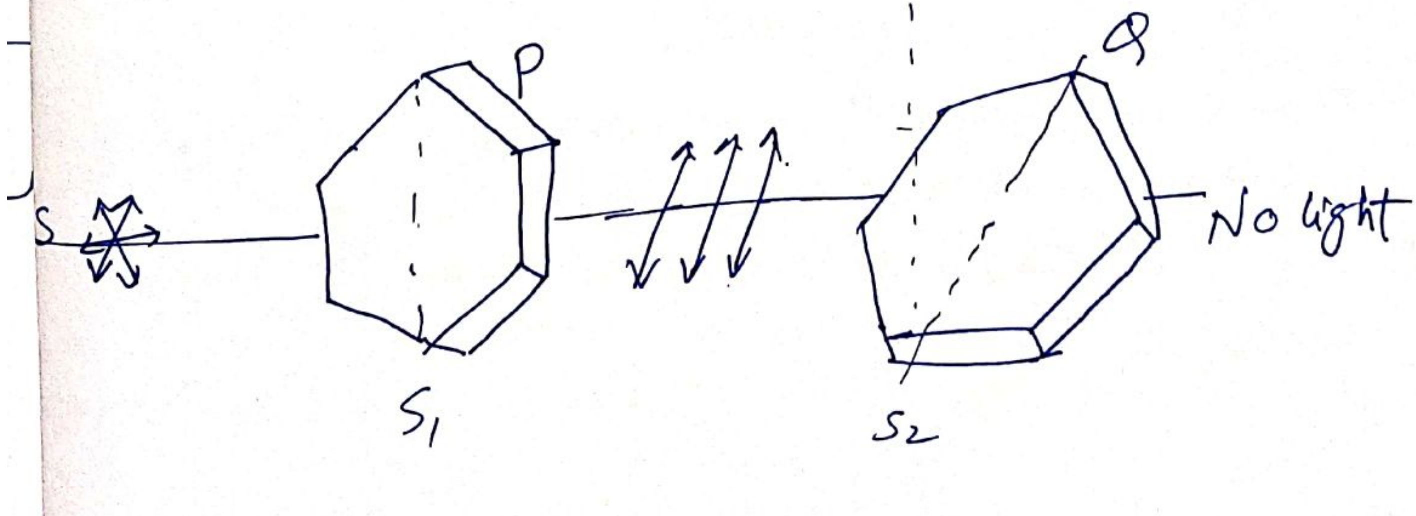
Polariser & Analyser

When a beam of ordinary light is allowed to passes through a pair of tourmaline crystals [see fig.] . S is a source of light and P & Q are two tourmaline crystals. It is observed that when the optic axis of the crystal P & Q are ∥ light passes out through Q. However when Q is rotated, the intensity of light decreases & becomes zero. when the optic axis of Q is ⊥ to optic axis of P.

The light wave incident on P is unpolarised & when pass through the optic axis S_1 of P it becomes polarised. The crystal P is thus acts as a polariser.

The polarised light comes out of the crystal Q, when its optic axis S_2 is ∥ to the optic axis S_1 of crystal P. This crystal Q is called analyser.





Defn:

Polariser : A polariser is an optical device that transforms unpolarised light into polarised light. If it produces linear polarised light, it is called linear ~~polari~~ polariser. A linear polariser is associated with a specific direction called the transmission axis of the polariser.

Analyser : An ~~Analy~~ analyser is a device, which is used to identify the direction of vibration of linearly polarised light. A polariser and an analyser are fabricated in the same way & have the same effect on the incident light.

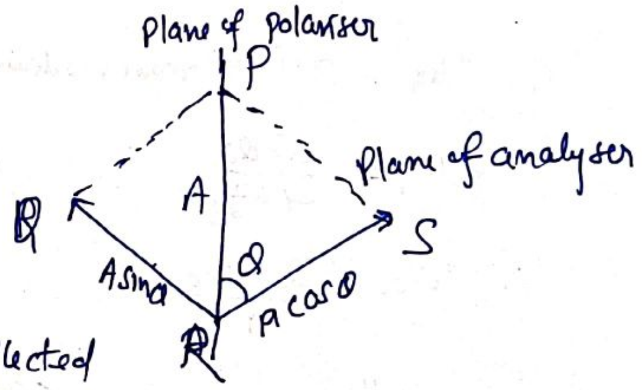
⇒ Polariser ; unpolarised light —transform into→ polarised light.

⇒ Analyser : identify the dir. of vib. of linearly " " .

Law of Malus ;

When a completely plane polarised light is incident on a polariser, the intensity of the transmitted light varies as the square of the cosine of the angle b/w the planes of transmission of analyser & polariser.

Let A be the amplitude of plane polarised light & θ is the angle b/w the planes of transmission of analyser and polariser [see fig.]
The amplitude may be resolved in two components along & ⊥ to the plane of transmission of analyser. Hence.



The ⊥ component $A \sin\theta$ is reflected from the analyser while the component $A\cos\theta$ is transmitted through it.

$$\therefore \quad \boxed{I = A^2\cos^2\theta = I_0\cos^2\theta} \rightarrow \text{law of Malus}$$

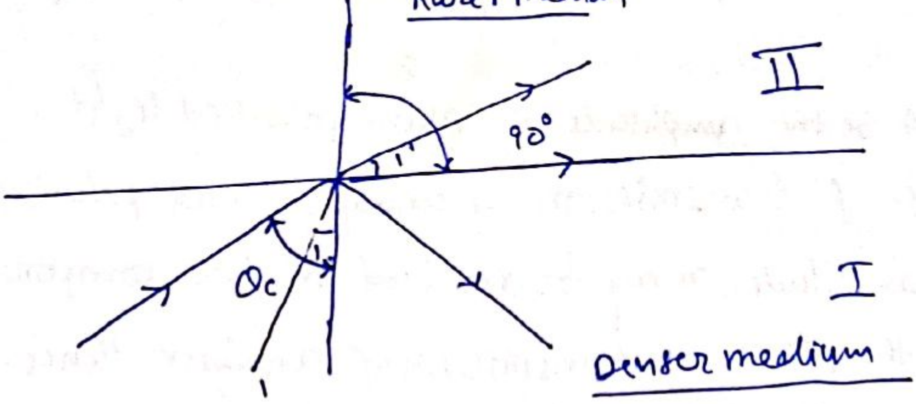
where I_0 is the intensity of completely plane polarised light.

OR

statement : The intensity of the polarised light emerging from the analyser is ∝ to the square of cosine of the angle (θ) b/w polariser & analyser. ie. $\boxed{I \propto \cos^2\theta}$

Critical Angle (θ_c):

When the angle of incidence in the denser medium for which the corresponding angle of refraction (in rarer medium) becomes 90° is called the Critical Angle (θ_c)



if ${}^{d}\mu_r$ = r.i. of rarer medium w.r.t denser medium then

$${}^{d}\mu_r = \frac{\sin\theta_i}{\sin\theta_t} \quad , \quad \theta_t = 90^\circ \text{ for } \theta_i = \theta_c$$

$$\therefore {}^{d}\mu_r = \frac{\sin\theta_c}{1}$$

$$\text{or } {}^{r}\mu_d = \frac{1}{\sin\theta_c} = \operatorname{cosec}\theta_c$$

{r.i. of denser w.r.t rarer

so if light is totally internally reflected on entering from liquid to air then the r.i (ref index) of the liquid w.r.t air is given by

$$\boxed{\mu = \operatorname{cosec}\theta_c}$$

where θ_c is the critical angle at which the total internal reflection (TIR) just starts.

TIR:

When a ray of light travels from a denser to a rarer medium and the angle of incidence is increased beyond the critical angle (θ_c); the incident ray doesn't pass into the IInd medium but reflected back into the Ist medium. This phenomenon is called TIR. {as the ray is completely reflected back into the same medium & no part of light is refracted into rarer medium.

* TIR not occurs from rarer to denser

Dispersive Power of a Grating : It is defined as the ratio of the difference in the angle of diffraction of any two neighbouring spectral line to the difference in the wavelength of b/w two spectral lines,

OR

It is also defined as the rate of change of angle of diffraction with the wavelength of light

$$(a+b)\sin\theta = n\lambda$$

$$(a+b)\cos\theta \cdot \frac{d\theta}{d\lambda} = n \quad \text{on differentiation}$$

$$\boxed{\frac{d\theta}{d\lambda} = \frac{n}{(a+b)\cos\theta}} \rightarrow \text{D.P.}$$

n = order of diffraction
θ = angle of diffraction
(a+b) = grating element

R.P of a grating → It is defined as its ability to show two neighbouring lines in a spectrum as separate

$$\boxed{R.P = \frac{\lambda}{d\lambda} = nN}$$

n = order of spectrum
N = total no. of the lines on the surface of grating.

OR

R.P of a diffⁿ grating may be defined as the ratio of the wavelength of any spectral line to its difference of wavelengths b/w this line & a neighbouring line s.t. two spectral lines can be just resolved.