Wave Optics

Dual Nature of Light

I Newton's Corpuscular

1. Light is emitted in the form of particles called as Corpuscles.
2. These particles are emitted by the source of light and they travel in straight line path with a speed of light.
3. When particles changes the medium, they change their directions.
4. When the light is incident on the retina of eyes we get sensation of vision.
5. Different colours of light are due to different masses and size of corpuscles.
6. Refraction and reflection of light is due to forces of attraction and repulsion acting on the corpusculs.
7. Application of Newton's corpuscular theoiry lead to consclusion that the velocity of light in denser medium is greater than the velocity of light in rarer medium.

Drawbacks :

1. If light consist of particles mass of sources of light must be decreased but as such no decrease in mass of sources of light in observed.
2. According to Newton's corpuscular theory velocity of light in denser medium is greater than the velocity of light in rare medium but it is observed that the velocity of light in rare medium is greater than the velocity of light in denser medium which is in contradiction with Newton's theory.
3. Phenomenon like interference of light defraction of light and polarisation of light could not be explained on the basis of Newton's corpuscular theory.
4. When light is incident on the surface of glass or water, it is partly reflected and partly refracted. This phenomenon of simultaneous reflection and refraction cannot be explain by Newton's Corpuscular theory of light.

II Huygen's Theory :

1. Light is emitted and propogated in the form of wave.
2. Light wave are emitted by the source and travels away from the source.
3. Medium required for propagation of light wave is called as luniniferous ether. Ethers is suppose to present in vacuume as well as in material medium.
4. Phenomenon like reflection, refraction could be explained on the basis of wave theory.
5. Different colours are due to different wavelength.
6. Intensity of light is directly proportional to square of amplitude.

Merits of Wave Theory :

1. The wave theory gives satisfactory explaination of reflection and refraction of light.
2. Application of wave theory to refraction of light leads to conclusion that velocity of light in rarer medium is grater than velocity of light in denser medium which agree with experiment observation.
3. Several phenomenon such as simultaneous reflection and refraction of light, interference, diffraction, polarisation of light etc. can be satisfactorily explained on the basis of wave theory of light.

Drawback OR Demerit of wave Theory :

Huygen wave theory of light suffered from the following drawbacks.

1. Huygen considered a presence of hypothetical medium, ether, experimentally it is proved that ether does not exist.

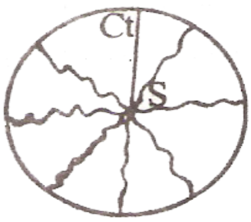
2. It cannot explain the phenomena like photoelectric effect, compoton effect etc,
3. Rectilinear propogation of light can not be explain on the basis of wave theory. The phenomenon like photoelectric effect and compoton effect etc. can be explained only by considering light as a particle nature. The phenonmenon like interference of light, polarisation of light etc. can be explained only by considering light as a wave nature. By considering above situation we can say that light has dual
nature namely

1. Wave nature 2. Particle nature

Maxvell proved that light has electromagnetic nature no medium is required for propogation of electromagnetic waves.

Q. Explain what you understand by a wavefront ?

Ans : Imagine a point source S of light placed in air. The source will emit waves of light in all possible directions. If the velocity of light in air is ‘c’, then in time ‘t’ each wave will cover distant ct. Therefore at the end of the time interval t, the light wave emitted by the source will reach the surface of a sphere with the centre S and radius equal to ct. Such a spherical surface is called a spherical wavefront.

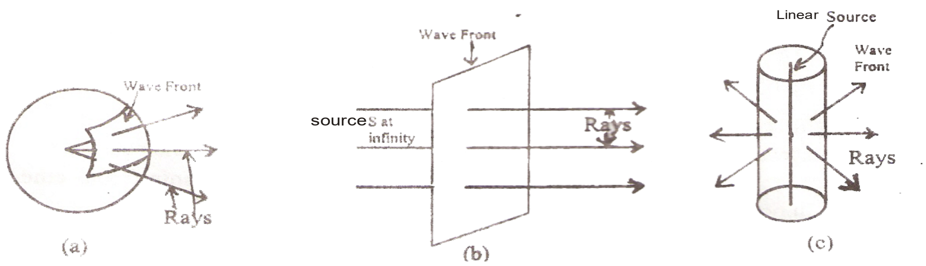


Def. : Locus of all such point of the medium to which wave reaches at the same instant and which are in the same phase i.e. in the same state of motion is called as **Wavefront**.

Spherical Wavefront : A spherical surface on which all the point of medium are in the same phase i.e. In the same phase i.e. in the same state of motion is called as **Spherical wavefront.**

Plane Wavefront : A section of spherical wavefront when the point source is at infinity on which all the particles of medium are in the phase is called as **Plane wavefront.**

Cylinderical Wavefront : If the source of light is linear i.e. a slit then it produces a cylinderical wavefront. In this case rays are radially diverging.



a) Spherical wavefront and radial rays,
b) Plane wave front and parallel rays
c) Cylinderical wave front and radial rays.

Huygen's Principle :

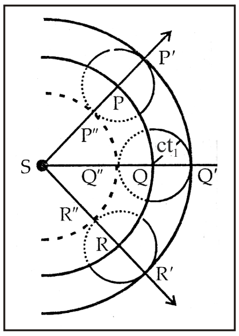
1. Every particle of the medium to which wave reaches acts as a secondary source and emit secondary wavelets in all direction.
2. Secondary source sends out secondary wavelets in only forword direction i.e. backward wavefornt do not exist.
3. The envelope of all secondary wavelets or common tangent to all secondary wavelets the position of new wavefront at that instant.

1) Construction of Spherical Wavefront :

S is a source of light situated in air. In time 't' the wave of light emitted by sources (S) will cover a distance 'ct' where c is the velocity of light in air.

Draw a sphere with 'ct' as a radius ans S as a centre. According to Huygen's principle point PQR on the sphere acts as a secondary source and emits secondary wavelets in all directions. To find new wavefront after a time 't_1' draw hemispohere around PQR as centre with ct_1, as a radius. The invelope P\`QR\` represents new wavefront after a time 't_1'.

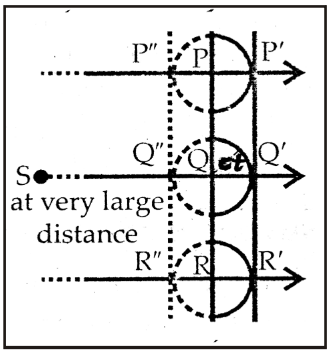
Note that secondary wavefront in backward direction do not exit.



Hygen's Construction of Spherical Wavefront

2) Construction of Plane Wavefront :

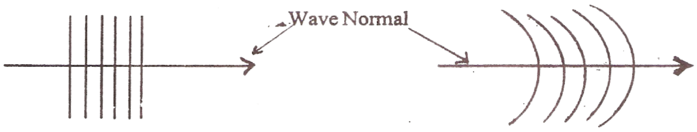
PQR is a plane wavefront. The point PQR on the wavefront acts as a secondary source and emits secondary wavelets in all direction (forward) according to Huygen Principles. To find new wavefront after a time 't' draw hemisphere with PQR as a centre and 'ct' as a radius. The envelope P'Q'R' represents new wavefront after a time 't'. Note that secondary wavefront in backward direction do not exist.



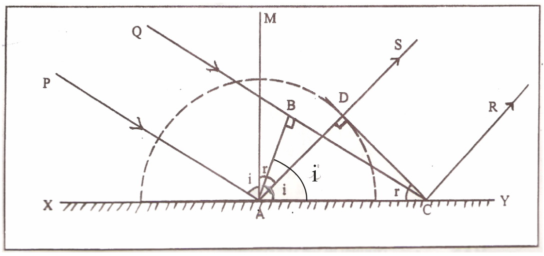
Hygen's Construction of Plane Wavefront

Defination

WaveNormal : Direction normal to the wavefront along which light energy is carried is called as wave normal. The direction in which light energy is propagated is called ray of light. Hence wave normal is same is ray of light.



Q. Law of Reflection on the basis of Huygens's principles



AB = Incident plane wavefront
XY = Plane reflecting surface
MA = Normal to the plane reflecting surface.
CD = Reflected wave front.

AB is a plane wavefront bounded by the rays PA and QB incident obliquely on plane reflecting surface XY. As soon as wavefront reaches the point A. Point A becomes secondary source and give rise to secondary waves in the same medium. Draw a hemisphere with A as a centre and 'ct' as a radius CD is tangent to it C and D are in the same phase. CD represents reflected wavefront bounded by the ray 'AS' and CR.

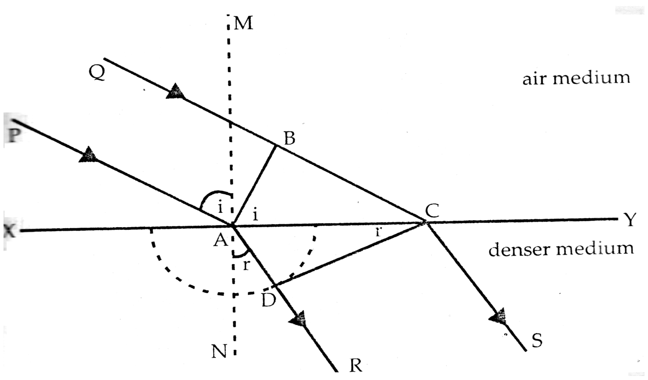
In time 't' if B reaches to C than d(BC) = ct ....(1)
The point D is on the sphere d(AD) = ct ....(2)
From (1) and (2) d(BC) = d(AD)

MA is the normal to reflecting surface then,
m$\angle$PAM = i (angle of incident)
m$\angle$MAS = r (angle of reflection)
In Δ ABC and in Δ ADC
AC is common
d(BC) = d(AD)
$\therefore$ m $\angle$ABC = m$\angle$ADC = 90^0
Δ 's are congruents
By the property of the congruent Ds we can write,
m$\angle$BAC = m$\angle$DCA ....(3)
from the geomentry of the fig. it can be prove that
m$\angle$PAM = m$\angle$BAC = $\angle$i
m$\angle$MAS = m$\angle$DCA = $\angle$r
Putting this values in (3)
$\angle$i = $\angle$r

$$m\angle PAM + m\angle MAB = 90^0$$
$$m\angle BAC + m\angle MAB = 90^0$$
$$m\angle PAM = m\angle BAC = \angle i$$
$$m\angle MAD + m\angle DAC = 90^0$$
$$m\angle DCA + m\angle DAC = 90^0$$
$$\Rightarrow m\angle MAD + m\angle DCA = \angle R$$

Then angle of incident is equal to the angle of reflection. Moreover incident ray, normal and reflected ray are in the same plane. Hence laws of reflection is varified. From fig. incident ray and reflected ray lie on two opposite side of normal.

Q. Phenomenon of Refraction on the basis of Huygen's Principle.



AB	-	Incident plane wavefront
XY	-	Plane refracting surface
MAN	-	Normal to the refracting surface
CD	-	Refracted wavefront

XY is a plane refracting surface seperating air and the denser medium. AB is a plane wavefront incident at 'A' on the refracting surface XY. As soon as wavefront reaches point A. Point A will acts as a secondary source and gives rise to the secondary wave in the denser medium. Let v_1 be the velocity of light in air and v_2 be the velocity of light in denser medium let in time 't' wavefront moves from 'B' to C then,

$d(BC) = v_1t$ ....(1)

In the same time 't' secondary waves cover a distance of v_2t in denser medium with A as a centre and v_2t as a radius. Draw a hemisphere CD is a tangent to it. CD represents refracted wavefromt bounded by the rays AR and CS. Point D is on the surface of sphere hence.

$d(AD) = v_2t$ ....(2)

MAN is a normal to the refracting surface XY

m $\angle PAM = \angle i$ (Angle of incident)

m $\angle DAN = \angle r$ (Angle of Refraction)

From the geometry of the fig. it can be seen that

m $\angle PAM$ = m $\angle BAC = \angle i$ and

m $\angle DAN$ = m $\angle DCA = \angle r$

From fig.

In Δ BAC, $\text{Sin i} = \frac{l(BC)}{l(AC)}$

In ΔDCA, $\text{Sin r} = \frac{l(AD)}{l(AC)}$

$$\frac{\text{Sin i}}{\text{Sin r}} = \frac{l(BC)/l(AC)}{l(AD)/l(AC)}$$

$$\frac{\text{Sin i}}{\text{Sin r}} = \frac{l(BC)}{l(AD)}$$

$$\frac{\text{Sin i}}{\text{Sin r}} = \frac{v_1t}{v_2t}$$

$$\frac{\text{Sin i}}{\text{Sin r}} = \frac{v_1}{v_2}$$

By Snell's Law : $\frac{\text{Sin i}}{\text{Sin r}} = Constant\ (\mu)$,

This constant quantity is called as Refractive Index of medium (μ).

μ - Refractive Index of medium.

Refractive Index = v_1/v_2

Since, Refractive index of denser medium is greater then one i.e., μ >1, i.e. $v_1 > v_2$

Moreover incident ray normal and refracted ray are in the same plane.

From fig the incident ray and refracted ray lie on two opposite sides of normal.

This is a phenomenon of refraction on the basis of Huygen Principle.

Ex. 1 Speed of light in air is 3×10^8 m/s & that in diamond is 1.4×10^8 m/s. Find refractive index of diamond.

Soln : Given :- $V_{air} = 3 \times 10^8$ m/s

$V_{diamond} = 1.4 \times 10^8$ m/s

To find :- ${}^a\mu_d$

We know that, the refractive index of diamond over air is -

$${}^a\mu_d = \frac{V_{air}}{V_{diamond}} \qquad \therefore \quad {}^a\mu_d = \frac{3 \times 10^8}{1.4 \times 10^8}$$

$${}^a\mu_d = \frac{3}{1.4} \qquad \therefore \quad {}^a\mu_d = 2.143$$

Ex. 2 Wavelength of beam of light in glass is 4400 A.U. What is its wavelength in air, if refractive index of glass is 1.5

Sol^n Given : $\lambda_{med} = 4400\text{AU}$, $\qquad \lambda_{med} = 4400 \times 10^{-10}\text{m} \qquad {}^a\mu_g = 1.5$

To find : λ_{air}, $\qquad {}^a\mu_g = \frac{\lambda_{air}}{\lambda_{med}} \qquad \therefore\ \lambda_{air} = {}^a\mu_g \times \lambda_{med} \qquad \therefore\ \lambda_{air} = 1.5 \times 4400 \times 10^{-10}$

$\boxed{\therefore\ \lambda_{air} = 6600 \times 10^{-10} m}$ OR $\boxed{\therefore\ \lambda_{air} = 6600\ \text{AU}}$

Ex. 3. Wavelength of certain light in air and in medium is 4560 A^0 and 3648A^0 respectively. Compare the speed of light in air with its speed in medium.

Soln: Given $\lambda_{air} = 4560\ A^0 \qquad \lambda_{med} = 3648\ A^0$

To, find - $\frac{V_{air}}{V_{mid}}$

Refractive index is given by air $\boxed{\mu_{med} = \frac{\lambda_{air}}{\lambda_{medium}}}$ ....(I)

$\therefore\ {}^{air}\mu_{med} = \frac{4560}{3648}$ $\qquad$ Also $\boxed{{}^{air}\mu_{med} = \frac{V_{air}}{V_{med}}}$ ....(II)

Equating (I) and (II), we get, $\frac{V_{air}}{V_{med}} = \frac{V_{air}}{V_{med}}$ $\qquad$ But, $\frac{V_{air}}{V_{med}} = \frac{4560}{3648}$ $\qquad \therefore \boxed{\frac{V_{air}}{V_{med}} = 1.25}$

Ex 4. When light of wavelength $5000 A^0$ is incident on a water surface of refractive index 4/3. Find wavelength & frequency of light in water if its frequency in air is 6×10^{14} Hz

Sol_n : Given : $\lambda_{air} = 5000 A^0$ $\lambda_{air} = 5000 \times 10^{-10}$ m ${}^a\mu_w = 4/3$

frequency $_{(air)} = 6 \times 10^{14}$ Hz

To find : λ_{water} & frequency $_{(water)}$ ${}^a\mu_w = \dfrac{\lambda_{air}}{\lambda_{water}}$

$$\therefore \lambda_{water} = \frac{\lambda_{air}}{{}^a\mu_w} \qquad \therefore \lambda_{water} = \frac{5000 \times 10^{-10}}{4/3} \qquad \boxed{\therefore \lambda_{water} = 3750 \times 10^{-10} m}$$

OR $\boxed{\therefore \lambda_{water} = 3750\ A^0}$

When light passes from one medium to another medium, there is no change in the frequency of light i.e. frequency of light in air is same as frequency of light in water

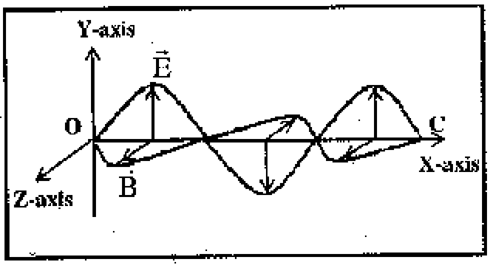
$$\boxed{\therefore \text{frequency of light in water} = 6 \times 10^{14} Hz}$$

1) Transverse Nature of light :

We know that the phenomenon of reflection, refraction, diffraction and interference of light is exhibited by longitudinal and transverse waves. But **polarisation of light** is exhibited by transverse waves and it can distinguish between two types of waves.

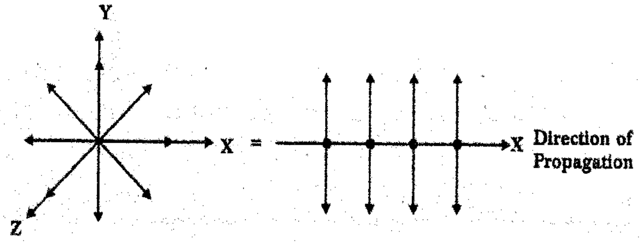
Q. Explain the concept of unpolarised light.

- According to Maxwell, light is an electromagnetic wave.
- Following fig. shows the propagation of a plane e.m. wave with velocity C along X-axis. The electric field vector is along Y-axis, with the magnetic field vector, is along Z-axis.



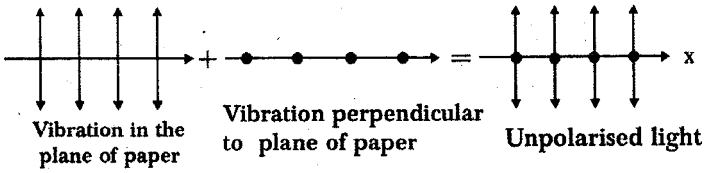
- Electromagnetic wave consist of electric and magnetic field vectors which vibrate perpendicular to each other and both are also perpendicular to the direction of propagation of the light wave.
- The contribution of magnetic field vector in light is small & is supposed to be neglected. Hence the phenomenon related with light are described by the electric field vector in e.m. waves. So the transverse wave nature of light may be attributed to vibrations of electric field vector in a direction perpendicular to the direction of propagation of a ray of light.
- The phenomenon concerning about light are described by only the electric vector i.e. light is representated by the electric field vector ($\vec{E}$).
- In an unpolarised light (or ordinary light) the electric field vector ($\vec{E}$) is always perpendicular to the direction of propagation of light.
- There are infinite number of directions perpendicular to the direction of propagation of light. So the electric field vector may be along any one of these direction.
- For example, if the light propagates along the X axis, the electric field vector may be along Y axis, or along Z axis or along any direction in Y-Z plane.

- At any instant this electric vector can be resolved into two mutually perpendicular components **(i)** One vibrates in the plane of paper represented by ($\updownarrow$) and **(ii)** other vibrates perpendicular to the plane of paper represented by ($\bullet$).
- Symbolic representation of unpolarised light is



This representation shows a component of light vector ($\updownarrow$) in plane of paper and also other component of light vector ($\bullet$) perpendicular to plane of paper.

- Superposition of plane polarised light, one with vibration in the plane of paper and other with vibration perpendicular to the plane of paper gives an unpolarised light.



- **Unpolarised light :** The light waves consisting of vibration of electric field vectors in all possible planes are called unpolarised light. (ordinary light)

Q. Mechanical experiment to understand polarisation of wave on rope.

- Consider two slits S_1 and S_2 which are parallel to each other. A rope AB is passed through both the slits. One end of the rope (A) is in our hand and other end (B) is fixed to a rigid support as shown in fig. (a)
- Now, move the end A, up and down so that transverse wave is formed in the rope. It is observed that, transverse wave passes through both the slit upto the end B as shown in fig. (b)
- Now keep the slit S_2 perpendicular to slit S_1. In this case transverse wave travels up to slit S_2 and after slit S_2 there are no vibrations in the rope as shown in fig. (c). This means slit S_2 does not allows the transverse wave to pass through it.
- If longitudinal waves are set up on the rope at end A, then in any position of slit S_1 and S_2 this vibration can pass through both the slits as shown in fig. (d).

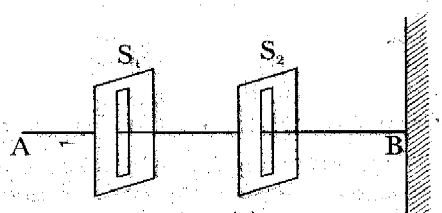


fig.(a)

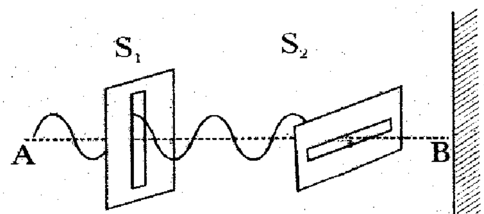


fig.(c)

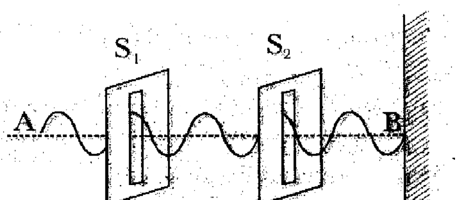


fig.(b)

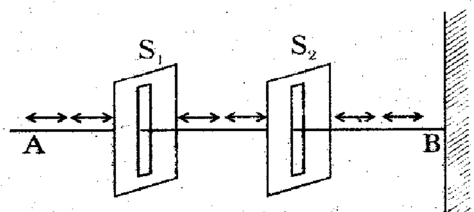


fig.(d)

- Above experiment shows that the slit allows the vibrations to pass through it only if, the vibrations are in particular plane. After passing through the slit the vibrations are confiend to only in one plane. This wave is called **as plane polarised wave**. This process is called as **polarisation.**
- There is no effect of position of slit on the propagation of longitudinal waves. This means **longitudinal waves can not be polarised.**
- There is effect of position of slit on the propagation of transverse waves. This means transverse waves can be polarised. So, **polarisation is the property of transverse wave only.**

Q. Define polarisation of light. Explain light waves are transverse in nature.

Polarisation of light : Restricting the vibrations of an unpolarised light only in one plane and removing the vibrations in other planes is called polarisation of light.

Explanation for light waves are transverse in nature :

- Consider a tourmaline crystal P with its crystallographic axis perpendicular to the direction of propagation of light.
- Consider ordinary light (unpolarised light) is incident on crystal P.
- The component of electric field vector which are in the plane of paper ($\updownarrow$) i.e. parallel to axis, passes through the crystal.
- The component of electric field vector which are perpendicular to plane of paper ($\bullet$) i.e. perpendicular to axis, is blocked.
- Light transmitted through the crystal P has only one component of electric vector. Thus, crystal P has restricted the vibration of light in one direction. This phenomenon is known as polarisation of light and crystal P is called **polariser.**
- The light which is transmitted by crystal P is known as **plane** (linear) **polarised light.**
- Place another tourmaline crystal A with its axis parallel to crystal P. Then plane polarised light is fully transmitted through crystal A as shown in fig.
- When the crystal A is rotated with respective crystal P, the intensity of light is transmitted by crystal A decreases.
- When axis of crystal A is perpendicular to crystal P, then no light is transmitted through the crystal A, as shown in fig

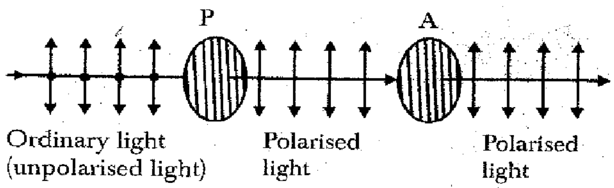


fig.(a)

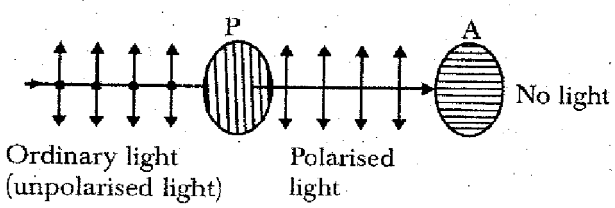
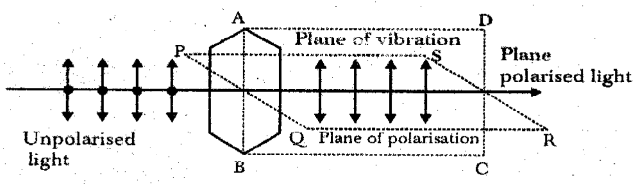


fig.(b)

- This experiment shows that light wave can be polarised. We know that only transverse wave can be polarised. Thus light waves are transverse in nature.

Note : The crystal A analyse (identifies) the polarisation of light hence it is known as **analyser.**

Q. Define (i) Plane of vibrations (ii) Plane of polarisation (iii) Plane polarised light.



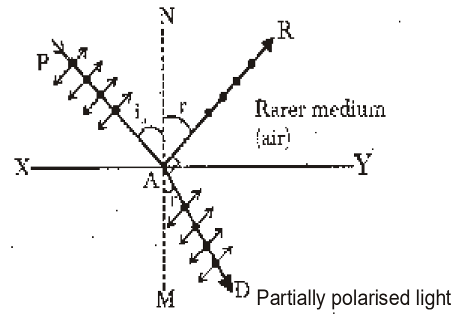
- **Plane of vibration :** The plane (ABCD) which contains the vibrations of plane polarised light is called plane of vibration.
- **Plane of polarisation :** The plane (PQRS) perpendicular to the plane of vibrations is called the plane of polarisation.
- **Plane polarised light :** The light wave consists of vibrations of the electric field vector only in one plane are called plane polarised light.

Q. Distiniguish between unpolarised light and polarised light.

Unpolarised light	Polarised light
• The light waves consisting of vibrations of electric field vectors in all possible planes are called unpolarised light (ordinary light)	• The light wave consists of vibrations of the electric field vector only in one plane are called plane polarised light.
• Intensity of unpolarised light is relatively high.	• On polarisation the intensity reduces to 50% of intensity of unpolarised light (50% is absrobed by polaroids)
• Ordinary light from any source is unpolarised.	• Ordinary light can be polarised by reflection.
• The sources of unpolarised light is electric bulb, Sun etc.	• The light emerging out of tourmaline crystal or polaroid is polarised light.

Q. Describe the method of producing plane polarised light by reflection.

Where, XY = plane refracting surface
NAM = normal drawn to XY
PA = incident ray of unpolarised light
$\angle PAN = \angle i_p$ = angle of incidence
= polarising angle or Brewster's angle
AR = reflected ray of plane polarised light
$\angle RAN = \angle r_1$ = angle of reflection
AD = refracted ray of unpolarised light
$\angle MAD = \angle r$ = angle of refraction.



Explanation of production of plane polarised light by reflection :

- Consider an unpolarised light PA is incident obliquely on surface XY in the air medium.
- When light reaches to point A, it is partially reflected and partially refracted.
- The refracted light travels along AD which is partially polarised.
- The polarisation of reflected light depends upon angle of incidence.
- If angle of incidence is in between 0^0 and 90^0 (except for one particular angle of incidence), the reflected ray is partially polarised.
- At a particular angle of incidence, the reflected light is completely plane polarised. This angle of incidence

is called polarising angle or Brewster's angle (i_p)

- The reflected light travels along AR which is completely plane polarised light.
- The plane polarised light has vibrations perpendicular to the plane of paper.
- The value of polarising angle depends on wavelength of light used and hence complete polarisation can be obtained with monochromatic light only.

At the polarising angle, **reflected and refracted rays are perpendicular to each other.**

Note : 1) This method was discovered by **Malus.**

2) Polarisation can also be obtain by scattering. Blue colour has more tendancy to scatter to smallar wavelength.

Q. Define polarising angle. Deduce Brewster's law. OR

Show that for any medium Refractive Index (μ) = + tan i_P where i_P = polarising angle or Brewster angle.

Polarising angle (Brewster's angle) (i_p) : The angle of incidence of ordinary light at which the reflected light from transparent medium is completely plane polarised is called polarising angle.

Ray Diagram :

Where,

XY = plane refracting surface

NAM = normal drawn to XY

PA = incident ray of unpolarised light

PAN = $\angle i_p$ = angle of incidence

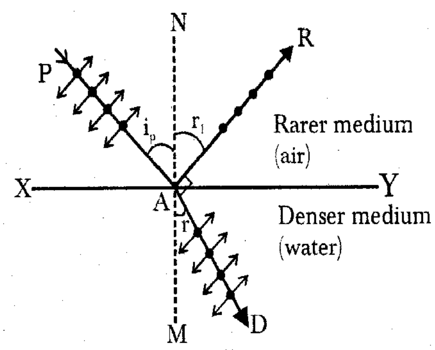
= polarising angle or Brewster's angle

AR = reflected ray of plane polarised light

$\angle$RAN = $\angle r_1$ = angle of reflection

AD = refracted ray of unpolarised light

$\angle$MAD = $\angle$r = angle of refraction.



Deduction of Brewster's law :

- At the polarising angle, the reflected and refracted rays are perpendicular to each other.
- From fig.

$r_1 + 90 + r = 180$

$r_1 + r = 90$

$\therefore \quad r = 90 - r_1$

According to first law of reflection

$r_1 = i_p \qquad \therefore \qquad r = 90^0 - i_p$

- From Snell's law, R.I. of transparent medium is

$$\mu = \frac{\sin i_p}{\sin r} \; ; \quad \mu = \frac{\sin i_p}{\sin (90 - i_p)} \; ; \quad \mu = \frac{\sin i_p}{\cos i_p}$$

$\therefore$ **μ = tan i_p**

This relation is called Brewster's law.

Brewster's Law : The tangent of the polarizing angle is equal to the refractive index of the refracting medium at which partial reflection takes place.

From Brewster's Law, it follows that the polarizing angle depends on wavelength and is different for different colours. However in most transparent media it is found that the dispersion is too small to affect the polarizing angle appreciably. Brtewster's law does not hold good for polished metallic surfaces.

Note : Polarising angle is 53^0 for airwater and 57^0 for air glass.