10.0 : Introduction

Q.1. State the postulates of Newton's corpuscular theory.

Ans: Postulates of Newton's corpuscular theory:

i. Every source of light emits large number of tiny particles known as 'corpuscles' in a medium surrounding the source.
ii. These corpuscles are perfectly elastic, rigid and weightless.
iii. The corpuscles travel in a straight line with very high speeds which are different in different media.
iv. One gets a sensation Of light when the, corpuscles fall on the retina.
v. Different colours of light are due to different sizes of corpuscles.

Q.2. State ,the drawbacks of Newton's corpuscular theory.

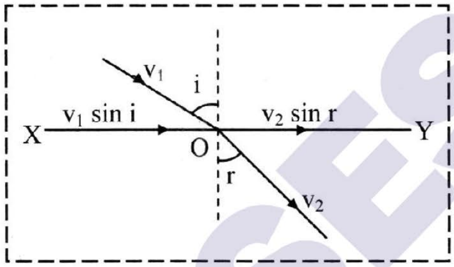
Ans: Drawbacks of Newton's corpuscular theory:

i. It could not explain partial reflection and refraction at the surface of a transparent medium.
ii. It was unable to explain phenomenon such as interference, diffraction, polarisation etc.
iii. This theory predicted that speed of light in a denser medium is more than the speed of light in a rarer medium which was experimentally proved wrong by Focault. Hence Newton's corpuscular theory was rejected.
iv. When particles are emitted from the source of light, the mass of the source of light must decrease but several experiments showed that there is no change in the mass of the source of light.

Q.3. Explain how Newton's corpuscular theory predicts the speed of light in' a medium, say water, to be greater than the speed of light in vacuum. Is the prediction confirmed by the experimental determination of speed of light in water? If not, which alternative picture of light is consistent with experiment?

(NCERT)

Ans:



As per Newton's corpuscular theory of light, when corpuscles of light strike the interface XY separating a denser medium from a rarer medium, the component of their velocity along XY remains the same (see figure).

If v_1 is velocity oflight in rarer medium (air), v_2 is velocity oflight in denser medium (water), i is angle of incidence and r is angle of refraction, then

component of v_1 along XY = v_1 sin i and

component of v_2 along XY = v_2 sin r

As $v_1 \sin i = v_2 \sin \Rightarrow \frac{v_2}{v_1} = \frac{\sin i}{\sin r} = \mu$

As $\mu > 1 \Rightarrow v_2 > v_1$

i.e. light should travel faster in water than in air. This prediction of Newton's theory is contrary to the experimental result.

Q.4. Explain

i. Maxwell's electromagnetic theory

ii. Planck's quantum theory.

Ans: i. Maxwell's electromagnetic theory:

a. Maxwell postulated the existence of electromagnetic waves.
b. According to Maxwell, light waves are electromagnetic waves which require no material medium for their propagation. So light can travel through a medium where there is no atmosphere i.e. in vacuum.
c. Thus, Maxwell established relationship between electricity and magnetism.

ii. Planck's quantum theory:

a. Max planck proposed quantum theory in order to explain black body radiation.

b. According to Planck's quantum theory, light is propagated in the form of packets of light energy called quanta.

c. Each quantum of light (photon) has energy, E = hv
where, h = Planck's constant
= 6.63×10^{-34} Js
V = frequency of light

10.1 : Wave theory of Light

Q.5. Give a brief account of Huygen's wave theory of light.

Ans: Huygens' wave theory of light:

In 1678, Dutch physicist Christian Huygens proposed a theory to explain the wave nature of light. This theory is called Huygens' wave theory of light.

Main postulates of Huygens' wave theory:

i. Light energy from a source is propagated in the form of waves: The particles of the medium vibrate about their mean positions in the form of simple harmonic motion. Thus, the particles transfer energy from one particle to its neighbouring particle and reachthe observer.

ii. In homogeneous isotropic medium, the velocity of wave remains constant: Speed of the wave is not affected because density and temperature of isotropic medium are same throughout.

iii. Different colours of light waves are due to different wavelengths of light waves: Each wave has its own wavelength. As the wavelength changes, its colour and frequency also changes. This is indicated by change in the colour.

iv. The material medium is necessary for 'the propagation of wave: Periodic disturbance is created in the medium at one place which is propagated from that place to another place. The medium only carries disturbance and hand it over to the next particle. To explain the propagation of light waves through vacuum, Huygens suggested the existence of a hypothetical medium called 'luminiferous ether'.

Q.6. State the merits of Huygens' wave theory of light.

Ans: Merits of Huygens' wave theory of light:

i. It gives satisfactory explanation for laws C of reflection, refraction and double refraction of light assuming transverse nature of the light waves.

ii. It also explains the theory of interference and diffraction.

iii. It explains the phenomenon of polarisation of light.

iv. It experimentally proved that velocity of light in rarer medium is greater than that in a denser medium.

Q.7. State demerits of Huygens' wave theory of light.

Ans: Demerits of Huygens' wave theory of light:

i. This theory could not explain rectilinear propagation of light.

ii. It could not explain Compton effect, photoelectric effect, Raman effect etc.

iii. It could not explain properly the propagation of light through vacuum. This is because ether has high elastic constant and zero density which gives contradictory results.

iv. According to Huygens' wave theory, luminiferous ether medium exists everywhere in the universe even in vacuum which is treated as material medium for propagation of light waves. However, Michelson's and Morley's theory disapproved the existence of ether medium.

Note:

1. According to wave theory of light, a source of light sends out disturbance in all directions. When these waves carrying energy reach the eye, they excite the optic nerves and the sensation of vision is produced.

2. Electromagnetic nature of light was experimentally proved by Maxwell in 1873.

3. Light waves are assumed to be transverse whose speed in a hypothetical medium is given by $v = \sqrt{\frac{E}{\rho}}$, where E and pare elasticity and density of the medium respectively.

4. Huygens' theory was not accepted immediately due to following reasons:
   i. If light were waves, they should bend around the sharp corners in the same manner as the sound waves.

ii. If light were waves, they could not travel through vacuum. This difficulty was overcome by assuming the existence of a hypothetical medium (ether) which was assumed to fill the whole space.

10.2 : Wavefront and wave normal

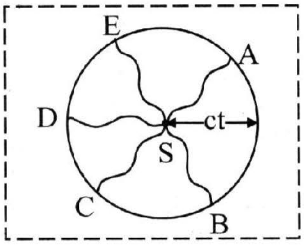
Q.8. Explain the concept of wavefront.

Ans: Concept of wavefront:

i. According to Huygens' theory, light travels in the form of waves which are emitted from the source.

ii. Consider a point source S of light situated in air or vacuum. Light waves spread out in all possible directions from the 'source of light with same speed c.

iii. After time t seconds, each light wave covers a distance equal to ct.



iv. Draw a spherical surface by considering radius ct and S as its centre. This surface cuts waves of light at different points A, B, C, D, E etc.

v. All the points on this surface are in the same phase. It is an equiphase surface. Such a surface is called spherical wave surface or a spherical wavefront.

Q.9. Define the following terms.

i. Wavefront

ii. Wave normal

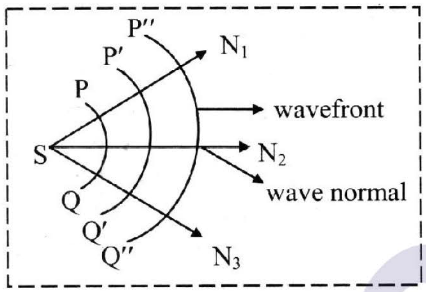
iii. Wave surface

Ans: i. Wavefront:

A locus of all the points of the medium to which waves reach simultaneously so that all the points are in the same phase is called wavefront.

ii. Wave normal:

A perpendicular drawn to the surface of a wavefront at any point of a wavefront in the direction of propagation of light waves is called a wave normal.



In the figure curve PQ, P'Q' and P" Q" represent wavefronts at different instants of time. SN_1, SN_2 and SN_3 represent wave normals.

iii. Wave surface:

The surface of sphere with source as centre and distance travelled by light wave as radius where each wave arrives simultaneously is called wave surface.

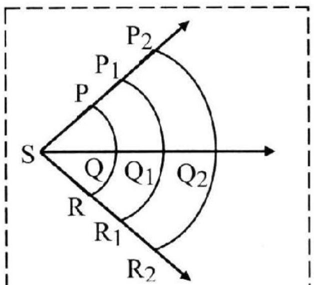
Q.10. State different types of wave fronts with examples.

Ans: Depending upon the source of light, wavefronts are classified into three types.

i. Spherical wavefront:

A wavefront originating from a point source of light at finite distance is called spherical wavefront.

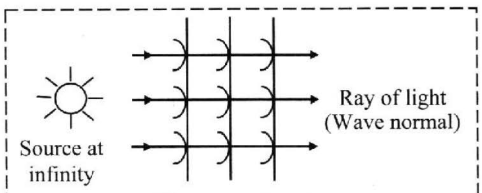
Example: Candle flame produces spherical wavefront



Spherical wavefront

ii. Plane wavefront:

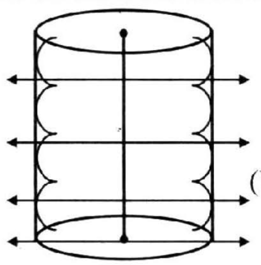
A wavefront originating from a point source of light at infinite distance is called plane wavefront.



Plane wavefront

Example: The light from the Sun reaches the surface of the Earth in the form of plane wavefront.

iii. Cylindrical wavefront:
A wavefront originating from a linear source (slit) of light at a finite distance is called cylindrical wavefront.
Example: A tube light emits cylindrical wavefront.



Cylindrical wavefront

Q.11. State the main characteristics of wavefront.
Ans: Characteristics of wavefront:

i. Wavefronts travel with the speed of light in all directions in an isotropic medium.
ii. The phase difference between any two points in the same phase on the two consecutive wavefronts is 2π. So, if the phase at a crest is 2π, then phase at next consecutive crest = 4π and so on. Hence at any crest, the phase is $2n\pi$ and phase at any trough is $(2n + 1)\pi$, where n is an integer.
iii. It always travels In the forward direction. During the propagation of spherical wavefront from a source, wave becomes weaker. It is so because same energy is distributed over circumference of larger circles of increasing radii.
iv. In anisotropic medium, it travels with different velocities in different directions due to variation in densities of the medium.

Q.12. State the main characteristics of wave normal.
Ans: Characteristics of wave normal:

i. It gives the direction of propagation of wave.
ii. It is perpendicular to wavefront.
iii. In a homogeneous isotropic medium, wave normal is same as direction of ray of light.
iv. It is drawn from the point of generation of wavefront.

10.3 : Huygen's principle

Q.13. State Huygens' principle. [Oct 99, 04]
Ans: It is the geometrical construction to determine new position of a wavefront at any later instant from its position at any earlier instant.
Statement:

i. Every point on the primary wavefront acts as a secondary source of light and sends out secondary waves (wavelets) in all possible directions.
ii. The new secondary wavelets are more effective in the forward direction only (i.e. direction of propagation of wavefront).
iii. The resultant wavefront at any position is given by the tangent to all the secondary wavelets at that instant.

Q.14. Distinguish between primary source of light and secondary source of light.
Ans:

No.	Primary source of light	Secondary source of light
i.	It is a real source of light.	It is a fictitious source of light.
ii.	It sends out primary waves in all possible directions.	It sends out secondary waves only in the forward direction.
iii.	Primary wave is effective at every point on its surface.	Secondary wave is effective only at the points where it touches the envelope.
iv.	Primary source is situated in air.	Secondary source is situated on a wavefront.

10.4 : Construction of plane & spherical wavefront

Q.15. What is the shape of the wavefront in each of the following cases?
i. Light diverging from a point source.
ii. Light emerging out of a convex lens when a point source is placed at its focus.
iii. The portion of the wavefront of light from a distant star intercepted by the earth.

(NCERT)

Ans:

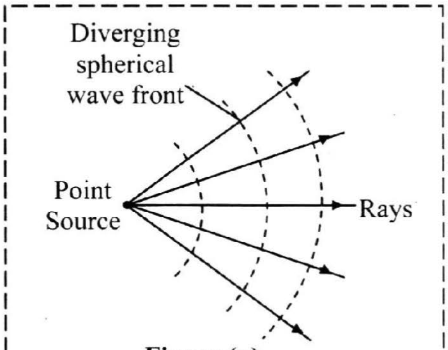


Figure (a)

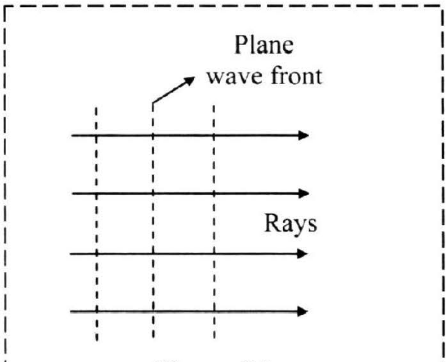


Figure (b)

i. The geometrical shape of the wavefront for the light diverging from a point source would be diverging spherical wavefront, as shown in figure (a).

ii. For a point source placed at the focus of a convex lens, the rays emerging from the lens are parallel. Hence the wavefront is a plane wavefront as shown in figure (b).

iii. As the star (i.e. source of light) is very far i.e. at infinity, the wavefront of the light coming from it which is intercepted by earth is a plane wavefront as shown in figure (b).

Q.16. Explain the Huygens' construction of plane wavefront. [Oct 99]

OR

Using Huygens' principle explain the propagation of a plane wavefront. [Feb 06]

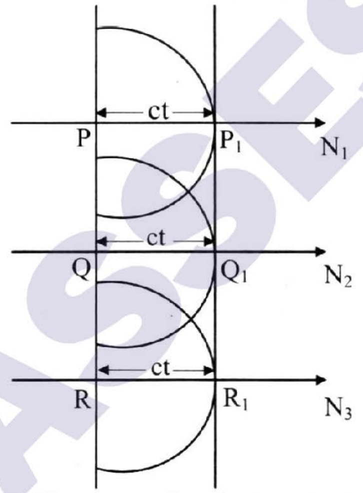
Ans: Huygens' construction of plane wavefront:

i. A plane wavefront is formed when point of observation is very far away from the primary source.

ii. Let PQR represent a plane wavefront at any instant. According to Huygens' principle, all the points on this wavefront will act as secondary sources of light sending out secondary wavelets in the forward direction.

iii. Draw hemispheres with P, Q, R .... as centres and, 'ct' as radius. The surface tangential to all such hemispheres is $P_1Q_1R_1$ .... at instant 't'. It is a new wavefront at time 't'.

iv. The plane wave fronts is propagated as plane waves in homogeneous isotropic medium. They are parallel to each other.



PQR: Plane wavefront at any instant, $P_1Q_1R_1$: Plane wavefront after time 't', PP_1N_1, QQ_1N_2, RR_1N_3 : wave normals at PQR

v. PP_1N_1, QQ_1N_2, RR_1N_3 are the wave normals at P, Q, R respectively. These wave normals show the direction of propagation of plane wavefront.

vi. The new wavefront $P_1Q_1R_1$ is parallel to primary wavefront PQR.

Q.17. Explain the Huygens' construction of spherical wavefront. [Mar 12]

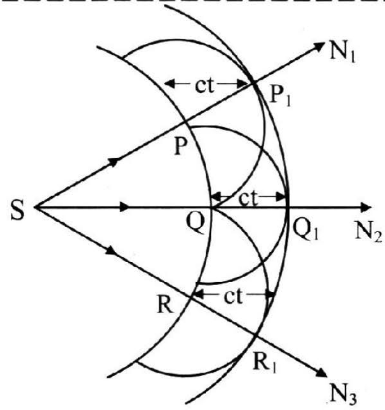
Ans: Huygens' construction of spherical wavefront:

i. Spherical wavefront is formed when source of light is at a finite distance from point of observation .

ii. Let S be the point source of light in air. PQR represents spherical wavefront at any instant. The wavefront PQR acts as a primary wave which is propagated through air.

iii. According to Huygens' principle, all the points on PQR will act as secondary sources 'of light and send secondary wavelets with same velocity 'c' in air.

iv. To find out new wavefront at a later instant 't', draw hemispheres with P, Q, R .... as centres and 'ct' as radius in the forward direction.



PQR : Primary wavefront,
$P_1Q_1R_1$: Secondary wavefront after time t,
SPN_1, SQN_2, SRN_3 : Wave normals at P, Q, R

v. The surface tangential to all such hemispheres is an envelope at that instant 't'. Such a surface is passing through the points P_1, Q_1, R_1 .... on the hemispheres and touching all the hemispheres. This surface is the new wavefront at that instant 't'.

vi. SPN_1 SQN_2, SRN_3 are the wave normals at P, Q, R respectively.

vii. These wave normals show the direction of propagation of spherical wavefront.

viii. The new wavefront $P_1Q_1R_1$ is parallel to PQR at every instant.

Note:

The intensity of secondary waves varies from maximum in forward direction to zero in backward direction. This indicates that secondary waves are effective only in forward direction.

10.5 : Reflection at a plane surface

Q.18. With the help of a neat diagram, explain tile reflection of light from a plane reflecting surface on the basis of wave theory of light.

OR

On the basis of wave theory of light explain 'the laws of reflection. [Oct 96]

Ans: Reflection of plane wavefront from plane reflecting surface:

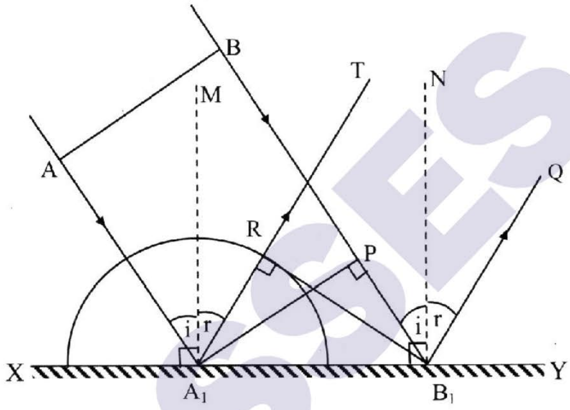
According to laws of reflection:

i. The incident rays, reflected rays and normal to the reflecting surface at the point of incidence, all lie in the same plane.

ii. The incident rays and the reflected rays lie 'on the opposite sides of the normal.

iii. The angle of incidence is equal to angle of reflection. i.e. $\angle i = \angle r$.

Explanation:



Reflection of light

XY : Plane reflecting surface
AB : Plane wavefront
RB_1 : Reflecting wavefront
A_1M, B_1N : Normal to the plane
$\angle AA_1M = \angle BB_1N = \angle i$ = Angle of incidence
$\angle TA_1M = \angle QB_1N = \angle r$ = Angle of reflection

i. A plane wavefront AB is advancing obliquely towards plane reflecting surface XY. AA_1 and BB_1 are incident rays.

ii. When 'A' reaches XY at A_1, then ray at 'B' reaches point 'P' and it has to cover distance PB_1 to reach the reflecting surface XY.

iii. Let 't' be the time required to cover distance PB_1. During this time interval, secondary wavelets are emitted from A_1 and will spread over a hemisphere of radius A_1R, in the same medium.

Distance covered by secondary wavelets to reach from A_1 to R in time t is same as the distance covered by primary waves to reach from P to B_1.

Thus $A_1R = PB_1 = ct$.

iv. All other rays between AA_1 and BB_1 will reach XY after A_1 and before B_1. Hence they also emit secondary wavelets of decreasing radii.

v. The surface touching all such hemispheres is RB_1 which is reflected wavefront bounded by reflected rays A_1R and B_1Q.

vi. Draw $A_1M \perp XY$ and $B_1N \perp XY$.

Thus, angle of incidence is $\angle AA_1M = \angle BB_1N = i$ and angle of reflection is $\angle MA_1R = \angle NB_1Q = r$.

$\angle RB_1A_1 = 90 - r$

$\angle PB_1A_1 = 90 - i$

vii. In ΔA_1RB_1 and ΔA_1PB_1

In $\angle A_1RB_1 \cong \angle A_1PB_1$

$A_1R = PB_1$ (Reflected waves travel equal distance in same medium in equal time).

$A_1B_1 = A_1B_1$ (common side)

$\therefore$ $\Delta A_1RB_1 \cong \Delta A_1PB_1$

$\therefore$ $\angle RA_1B_1 = \angle PB_1A_1$

$\therefore$ $90 - r = 90 - i$

$\therefore$ $i = r$

viii. Also from the figure, it is clear that incident ray, reflected ray and normal lie in the same plane.

ix. This explains laws of reflection of light from plane reflecting surface on the basis of Huygens' wave theory.

Note:

1. Frequency, wavelength and speed of light do not change after reflection.
2. If reflection takes place from a denser medium, then phase changes by π radian.

Q.19. Draw neat and labelled ray diagram of reflection of light from a plane reflecting surface using plane wavefront.

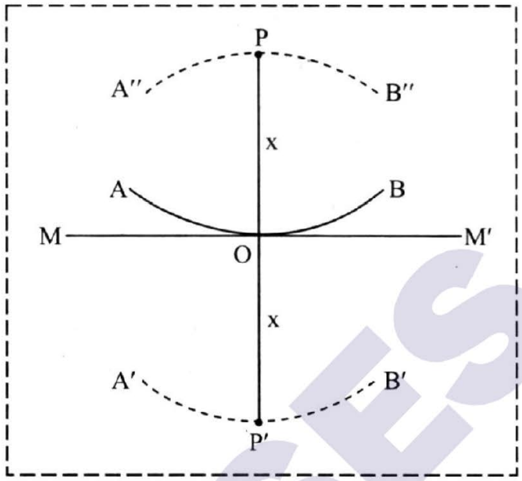
[Mar 96, Oct 99, 04, 12]

Ans: Refer Q.18 (diagram)

Q.20. You have learnt in the text how Huygens principle leads to the laws of reflection and refraction. Use the same principle to deduce directly that a point object placed in front of a plane mirror produces a virtual image whose distance from the mirror is equal to the distance of the object from the mirror.

(NCERT)

Ans:



In the abvove figure, consider a point object P placed at a distance x from a plane mirror MM'. With P as centre and PO = x as radius, draw a spherical arc; AB. This represents the spherical wavefront from the object incident on MM'.

In the absence of mirror, the position of wave front AB would be A'P'B' where PP' = 2x. In the presence of the mirror, wavefront AB would appear as A"PB", according to Huygens' construction. As is clear from the figure, A'B' and A"B" are two spherical arcs located symmetrically on either sides of MM'. Therefore, A'P'B' can be treated as reflected image of A"PB". From ordinary geometry, we get OP = OP'.

10.6 : Refraction of a plane wavefront at a plane surface

Q.21. Explain refraction of light on the basis of wave theory. Hence prove laws of refraction.

[Mar 96, Feb 13 old course]

OR

Prove the laws of refraction on the basis of wave theory of light.

[Feb 02, 03, 05, Oct 03, 05, 06]

Ans: Laws of refraction:

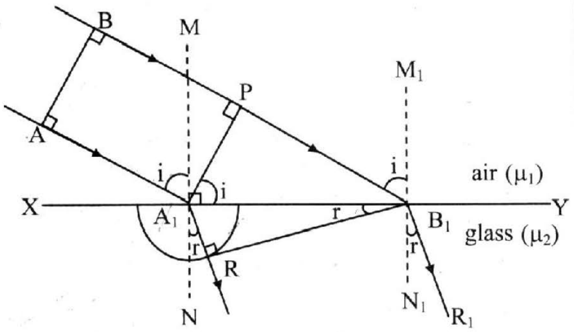
i. Ratio of velocity of light in rarer medium to velocity of light in denser medium is a constant called refractive index of denser medium w.r.t. rarer medium.

ii. The incident rays, refracted rays and normal lie in the same plane.

iii. Incident ray and refracted ray lie on opposite sides of normal.

Explanation:

Phenomenon of refraction can be explained on the basis of wave theory of light.



Refraction of light

XY : plane refracting surface
AB : incident plane wavefront
B_1R : refracted wavefront
AA_1, BB_1 : incident rays
A_1R, B_1R_1 : refracted rays
$\angle AA_1M = \angle BB_1M_1 = \angle i$: angle of incidence
$\angle RA_1N = \angle R_1B_1N_1 = \angle r$: angle of refraction

i. Let XY be the plane refracting surface separating two media air and glass of refractive indices μ_1 and μ_2 respectively.
ii. A plane wavefront AB is advancing obliquely towards XY from air. It is bounded by rays AA_1 and BB_1 which are incident rays.
iii. When 'A' reaches 'A_1', then 'B' will be at 'P'. It still has to cover distance PB_1 to reachXY.
iv. According to Huygens' principle, secondary wavelets will originate from A_1 and will spread over a hemisphere in glass.
v. All the rays between AA_1 and BB_1 will reach XY and spread over the hemispheres of increasing radii in glass. The surface of tangency of all such hemispheres is RB_1. This gives rise to refracted wavefront B_1R in glass.
vi. A_1R and B_1R_1 are refracted rays.
vii. Let c_1 and c_2 be the velocities of light in air and glass respectively.
viii. At any instant of time 't' , distance coyered by incident wavefront from P to $B_1 = PB_1 =$ c.t
Distance covered by secondary wave from A_1 to $R = A_1R = c_2t$.

Proof of laws of refraction:

i. From figure,

$\angle AA_1M + \angle MA_1P = 90°$ .... (i)

and

$\angle MA_1P + \angle PA_1B_1 = 90°$ .... (ii)

From equations (i) and (ii), we have,

$\angle AA_1M = \angle PA_1B_1 = i$

ii. Similarly,

$\angle NA_1R = \angle N_1B_1R_1 = r$

We have,

$\angle N_1B_1R_1 + \angle N_1B_1R = 90°$ .... (iii)

and

$\angle N_1B_1R + \angle A_1B_1R = 90°$ .... (iv)

From equations (iii) and (iv), we have,

$\angle N_1B_1R_1 = \angle A_1B_1R = r$

iii. In ΔA_1PB_1

$$\sin i = \frac{PB_1}{A_1B_1} = \frac{c_1t}{A_1B_1} \quad .... (v)$$

iv. In ΔA_1RB_1

$$\sin r = \frac{A_1R}{A_1B_1} = \frac{c_2t}{A_1B_1} \quad .... (vi)$$

v. Dividing equation (v) by (vi), we have

$$\frac{\sin i}{\sin r} = \frac{c_1t/A_1B_1}{c_2t/A_1B_1} = \frac{c_1t}{c_2t}$$

$$\therefore \quad \frac{\sin i}{\sin r} = \frac{c_1}{c_2} \quad ....(vii)$$

$$\text{Also } \frac{c_1}{c_2} = \frac{\mu_1}{\mu_2} = {}_1\mu_2 \quad ....(viii)$$

where ${}_1\mu_2$ = R.I. of glass w.r.t air.

vi. From the explanation, it is clear that incident rays AA_1, BB_1, refracted rays A_1R, B_1R_1 and normal MN and M_1N_1 lie on the same plane XY. Also incident ray AA_1 and refracted ray A_1R lie on opposite sides of normal MN. Hence, laws of refraction can be explained.

Q.22. Show that velocity of light in rarer medium is greater than velocity in denser mediuni. [Oct 08]

Ans: i. To show velocity of light in rarer medium is greater than velocity in denser medium, we haveto prove, $c_1 > c_2$.
From figure,
(Refer fig. of Q. 21 Refraction of light)

$\angle i > \angle r \quad \Rightarrow \quad \sin i > \sin r$

$$\therefore \quad \frac{\sin i}{\sin r} > 1 \quad \Rightarrow \quad \frac{\mu_2}{\mu_1} > 1 \quad .... (1)$$

ii. Since , $\frac{c_1}{c_2} = \frac{\mu_2}{\mu_1}$ .... [From 1]

$\therefore \frac{c_1}{c_2} > 1 \Rightarrow c_1 > c_2$

Hence, velocity of light in rarer medium is greater than velocity in denser medium.

Q.23. On the basis of Huygens' wave theory of light, prove that velocity of light in a rarer medium is greater that velocity of light in a denser medium. [Feb 13]

Ans: Refer Q. 21 & Q. 22

Q.24. Defirre wave number. Write down its unit and dimensions.

Ans: i. Definition:

Wave number is defined as number of waves per unir distance.

OR

Reciprocal of wavelength of the light is called'wave number.

It is given by $\overline{v} = \frac{1}{\lambda}$

ii. Unit : m^{-1} in SI system and cm^{-1} in CGS system.

iii. Dimensions: $[L^{-1}M^0T^0]$

Note:

1. During refraction, speed and wavelength of light change but frequency remains the same.
2. Change in wavelength is due to change in speed of light as it travels from one medium to another.
3. More dense is the medium, smaller is the wavelength.
4. Phase of light does not change during refraction.

10.7 : Polarisation

Q.25. What do you mean by polarisation? [Oct 09]

Explain the concept of polarisation by considering transverse wave on a rope.

Ans: Polarisation:

The phenomenon of restriction of the vibration of light waves in a particular plane perpendicular to direction of wave motion is called polarisation of light.

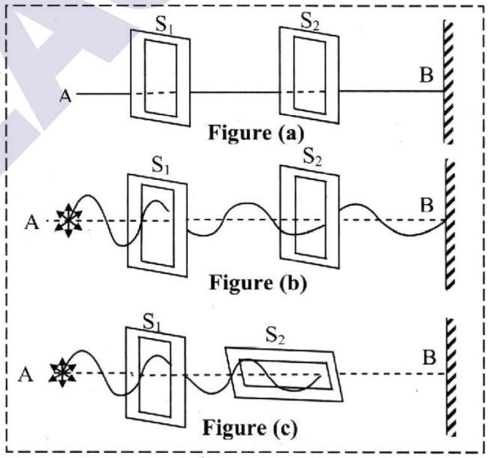
Concept of Polarisation:

i. Consider two slits S_1 and S_2 which are kept parallel to each other. A string AB is passed through both the slits. One end of the string A is in our hand and the other end B is fixed to a rigid support as shown in figure (a).

ii. Now, A is given a jerk up and down so that transverse wave is formed in the string. It is observed that, transverse wave passes through both the parallel slits without loss in amplitude of vibrations as shown in figure (b).

iii. Now the slit S_2 is kept perpendicular to slit S_1. In this case, transverse wave travels up to slit S_2 but there are no vibrations in the string through S_2 as shown in figure (c). This means slit S2 does not allow the transverse wave to pass through it.

In this case, amplitude of vibration reduces to zero.



iv. Instead of transverse vibration, if we produce longitudinal vibration then it will pass through the slit without any change in amplitude of vibration even though the slits may be parallel or at right angles to each other.

v. From the above experiment, it is concluded that transverse vibrations can pass through the slits only in certain conditions, i.e., vibrations are restricted in certain plane. This phenomenon is called polarisation.

Note:

1. There is no effect of position of slit on the propagation of longitudinal waves. This means, longitudinal waves cannot be polarised.
2. 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 waves only.

Q.26. Explain in brief the transverse nature of light.

Ans: Explanation of transverse nature of light:

i. Consider a tourmaline crystal C_1 with its crystallographic axis perpendicular to the direction of propagation of light.

ii. Ordinary light (unpolarised light) is made incident on crystal C_1 as shown in figure (a).

iii. The components of electric field vector which are in the plane of paper pass through the crystal and the components of electric field vector which are perpendicular to the plane of paper are blocked.

iv. Light transmitted through the crystal C_1 has only one component of electric vector. Thus, crystal C_1 has restricted the vibration of light in one direction. Thus "Iight is polarised by crystal C_1. Hen'ce C_1 is called polariser and the light transmitted by it is called linearly polarised light.

v. Now, another tourmaline crystal C_2 with its axis parallel to crystal C_1 is placed in the path of linearly polarised light. In this case, polarised light is fully transmitted through crystal C_2.

vi. When the crystal C_2 is rotated with respect to crystal C_1, the intensity of light transmitted by crystal C_2 decreases.

vii. When axis of crystal C_2 is perpendicular to crystal C_1, then no light is transmitted through the crystal C_2 as shown in figure (b).

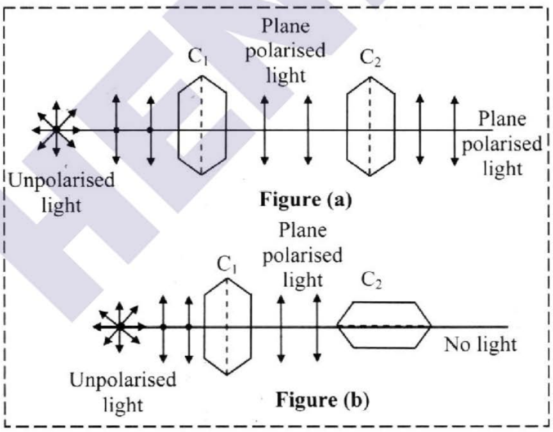


Figure (a)
Figure (b)

viii. From the above explanation, it is observed that there is restriction of vibration of light in the plane of propagation, hence light is polarised.

ix. Crystal C_1 polarised the ordinary light i.e. unpolarised light, so it is called polariser while crystal C_2 detects the polarising nature of light hence it is called analyser or detector.

x. Since polarisation takes place only in case of transverse waves, hence light is a transverse wave.

Q.27. What is unpolarised light? Explain the concept of unpolarised light.

Ans: Unpolarised light:

A light in which the vibrations of the electric vectors are in all possible directions, which are perpendicular to the directions of propagation is called as unpolarised light.

Concept of unpolarised light:

i. According to Maxwell, light is an electromagnetic wave.

ii. Electromagnetic wave consists 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.

iii. The phenomenon concerning light are described by only the electric vector i.e., light is represented by the electric field vector $(\vec{E})$.

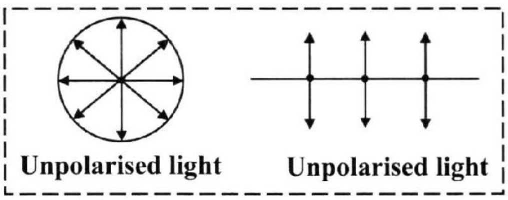
iv. In an unpolarised or ordinary light, the electric field vector $\vec{E}$ is always perpendicular to the direction of propagation of light.

There are infinite number of directions perpendicular to the direction of propagation of light. So the electric field vector may be along anyone of these directions.

vi. 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.

vii. At any instant, electric vector can be resolved into two mutually perpendicular components.

viii. Symbolic representation of unpolarised light is as shown in figure.



This representation shows a component of light vector (↕) in plane of paper and also other component of light vector (•) perpendicular to plane of paper.

ix. 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.

Q.28. How will you distinguish between polarised and unpolarised light?

Ans:

No.	Polarised light	Unpolarised light
i.	The light in which vibrations of the electric field vectors are confined only to one plane is called polarised light.	The light in which the vibrations of the electric vectors are in all possible directions, which are perpendicular to the directions of propagation, is called as unpolarised light.
ii.	Polarised light has the electric component only in one direction at a given time.	Unpolarised light has electrical component in every direction at any time.

10.8 : Plane polarised light

Q.29. Explain the following terms with necessary diagram.

i. Plane polarised light

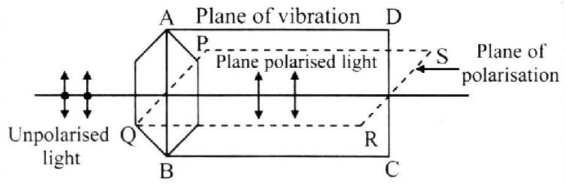
ii. Plane of vibration

iii. Plane of polarisation

Ans: i. Plane polarised light: The light waves in which vibrations of the electric field vectors are confined only to one plane are called plane polarised light.

ii. Plane of vibration: The plane in which the vibrations of polarised light take place is called as plane of vibration.

iii. Plane of polarisation: The plane perpendicular to the plane of vibration in which there are no vibrations of polarised light is called as plane of polarisation.



ABCD is plane of vibration, PQRS is plane of polarisation

Q.30. Draw a neat labelled diagram showing the plane of vibration and plane of polarisation for polarised light. [Oct 14]

Ans: Refer Q.29 (only diagram)

Q.31. State any four methods to produce plane polarised light.

Ans: Plane polarised light can be produced by:

i. reflection
ii. scattering
iii. refraction
iv. property of dichroism in calcite or quartz materials
v. polaroids.

Q.32. Explain a method to detect plane polarised light.

Ans: Detection of plane polarised light:

i. Naked eyes or the polariser alone cannot make distinction between unpolarised light and plane polarised light. To analyse the nature of light, another crystal (analyser) is used.

ii. The tourmaline crystal is used to produce plane polarised light.

iii. If the polariser is rotated in the path of ordinary light, the intensity of the light transmitted from the polariser remains unchanged. It is because in each orientation of the polariser, the plane polarised light is obtained which has vibrations in a direction parallel to the axis of the crystal in that orientation.

iv. If the analyser is rotated in the path of the light transmitted from the polariser, so that the axis of the polariser and the analyser are parallel to each other, then the intensity of light is found to remain unaffected. [see figure (a)]

v. If the axis of the polariser and the analyser are perpendicular to each other as shown in figure (b), then the intensity of light becomes minimum.

In this position, the polariser and the analyser are said to be in crossed position.

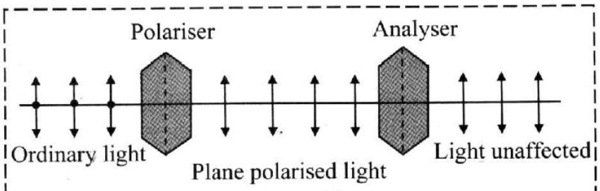


Figure (a)

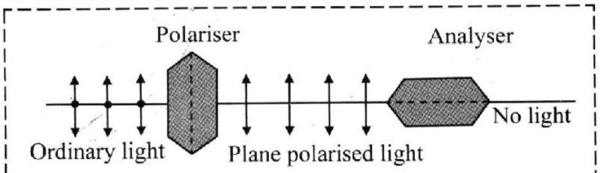


Figure (b)

10.9 : Brewster's law

Q.33. What is polarlslng angle?

Ans: The angle of incidence of ordinary light at which reflected light from transparent medium is completely plane polarised is called polarising angle.

Q.34. State Brewster's law.

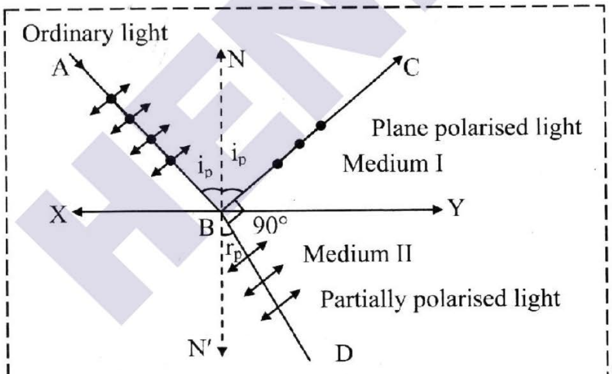
Ans: Statement:

The tangent of the polarising angle is equal to the refractive index of the refracting medium at which partial reflection takes place.

According to Brewster's law, $\tan i_p = \mu$.

Q.35. Show that when light is incident at polarising angle ip, then $\tan i_p = \mu$ where μ is the R.I. of the medium.

Ans: i. Let XY be the interface of refracting media



AB : incident ordinary light
BD : partially polarised or unpolarised light
BC : reflected plane polarised light
∠ABN : incident unpolarised angle
∠NBC : reflected polarised angle
∠ABN : incident polarising angle

ii. From laws of reflection,

$\angle LABN = \angle NBC = i_p$

Also, $\angle CBD = 90°$

iii. From figure,

$i_p + 90° + r_p = 180°$

$r_p = 90° - i_p$

iv. From Snell's law, $\frac{\sin i_p}{\sin r_p} = \mu$

$\therefore \quad \frac{\sin i_p}{\sin(90° - i_p)} = \mu$ [From equation (iii)]

$\therefore \quad \frac{\sin i_p}{\cos i_p} = \mu$

$\therefore \quad \tan i_p = \mu$

Hence proved.

Q.36. State and explain Brewster's law. [Oct 09]

Ans: Refer Q.34 and Q.35

Q.37. Show that when the light is incident at polarising angle, the reflected and refracted rays are mutually perpendicular to each other.

Ans: i. In the figure,

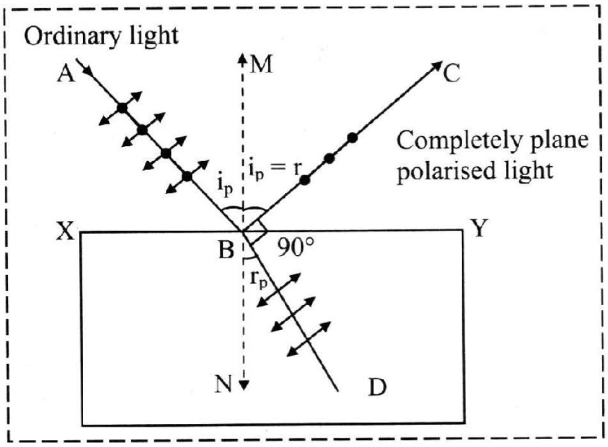
AB = incident ray

BD = refracted ray

BC = reflected ray

We have to show BD ⊥ BC

i.e. $\angle DBC = 90°$



ii. From Snell's law,

$\frac{\sin i_p}{\sin r_p} = \mu \quad .... (i)$

From Brewster's law,

$\tan i_p = \mu$

iii. From equations (i) and (ii),

$$\frac{\sin i_p}{\sin r_p} = \tan i_p$$

$$\frac{\sin i_p}{\sin r_p} = \frac{\sin i_p}{\cos i_p}$$

$\sin r_p = \cos i_p$

$\cos(90° - r_p) = \cos i_p$

$90° - r_p = i_p$

$i_p + r_p = 90°$ .... (iii)

iv. In the figure, $i_p = r$ [from laws of reflection]

But $i_p + r_p + \angle DBC = 180°$

$90° + \angle DBC = 180°$ [From equation (iii)]

$\angle DBC = 90°$

$BD \perp BC$

Hence reflected and refracted rays are perpendicular at polarising angle.

Note:

1. When rays 'of light are allowed to fall on a transparent or translucent object, then some part of light gets reflected and remaining part gets refracted. This phenomenon is called partial reflection.
2. In 1808, Malus discovered the phenomenon of polarisation by reflection.
3. When a beam of unpolarised monochromatic light is incident on a plane glass plate, some part of light is reflected while the rest is transmitted. The reflected light is partially polarised. At certain angle of incidence, reflected ray is completely polarised.

10.1 : Polaroid

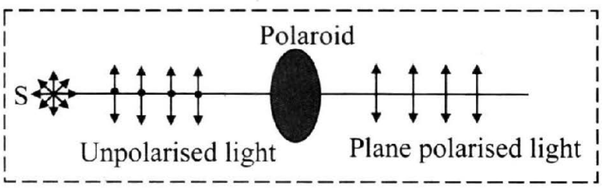
Q.38. What is a polaroid?

Ans: i. A large sheet of synthetic material packed with tiny crystals of a dichroic substance oriented parallel to one another so that it transmits light only in one direction of the electric vector is called a polaroid.

OR

A thin and large sheet of synthetic material capable of producing plane polarised beams of large cross-section is called polaroid.

Example: H-Polaroids, K-Polaroids etc.



ii. In 1852, W.H. Herapath discovered a synthetic material, iodosulphate of quinine, known as Herapathite.

iii. Though it shows strong dichroism, these crystals are not stable and are affected by slight strain. Hence they were not of much use.

Q.39. What is dichroism?

Ans: i. The property by which some doubly refracting crystals absorb the ordinary rays (O-rays) completely and extraordinary rays whose direction is parallel to the optic axis passing through the crystal, is called dichroism.

ii. The crystal possessing dichroism property is called dichroic crystal.

iii. Dichroic substance produces linearly polarised light.

iv. This property of substance is used to construct a polaroid.

Example: Tourmaline crystal.

Q.40. Distinguish between ordinary and extra ordinary ray.

Ans:

No.	Ordinary ray	Extra ordinary ray
i.	The ray which obeys Snell's law and laws of refraction is called ordinary ray.	The ray which does not obey the laws of refraction is called extra ordinary ray.
ii.	It is denoted by O.	It is denoted by E.
iii.	It passes undeviated through the crystal.	It deviates after refraction.
iv.	Inside the crystal, speed of O-ray is less than E-ray.	Inside the crystal, speed of E-ray is more than O-ray.
v.	The speed is constant in the medium.	The speed is not constant in the medium.
vi.	It gives spherical wavefront.	It gives ellipsoidal wavefront.

Q.41. Explain the polarising action of a polaroid.

Ans: i. In 1934, E.H. Lamb developed a new type of polaroid to explain polarising action.

ii. To understand this, herapathite crystals are arranged side by side to form a single crystal of large dimensions. For this, crystals are arranged in such a way that their optic axes remain parallel.

iii. To understand polarising action of polaroids, two polaroids P_1 and P_2 are kept in such a way that their axes are parallel as,shown in figure(a).

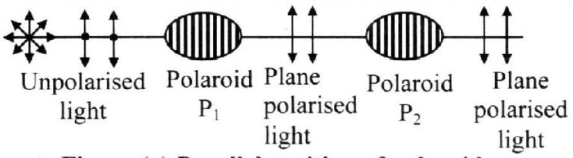


Figure (a) Parallel position of polaroid

Figure (b) Transverse position of polaroid

iv. When light is incident on P_1, the emetgent light from P_1 is plane polarised. This is now transmitted through the second polaroid P_2.

v. When one polaroid P_1 is fixed and the second polaroid P_2 is rotated about its axis, the intensity of transmitted light gradually decreases.

vi. When axis of P_2 is perpendicular to the axis of P_1, i.e., crossed to each other, the intensity becomes zero as shown in figure (b).

vii. The intensity of the transmitted light being twice maximum (bright) and twice minimum (dark) when polaroid P_2 completes a full rotation.

Q.42. State the main uses of polaroids.

Ans: Uses of Polaroids:

i. Polaroids are used in motor car head lights to remove head light glare.

ii. Used in three dimensional movie cameras.

iii. They are used to produce and analyse polarised light.

iv. They are used as filter in photography.

v. They are used in window of aeroplanes to control amount of light.

vi. Used in polarising sunglasses (goggles) to protect the eyes from glare of sunlight.

vii. They are used to improve colour contrast in old oil paintings.

viii. They are used in calculators, watches, monitors of laptops which have LCD screens.

10.1 : Dopper effect in light

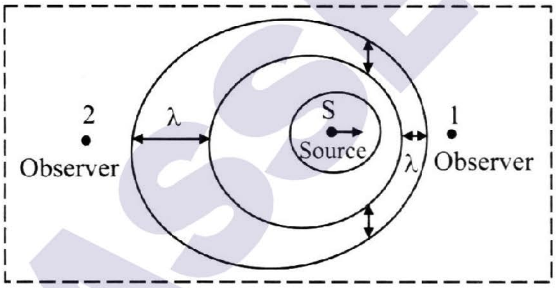
Q.43. Explain the Doppler effect in light.

Ans: Statement:

The frequency change of light waves when there is relative motion between the source of light and observer is called Doppler effect in light.

Explanation:

i. Consider a source of light 'S' moving towards or away from observer 1 and 2 as shown in figure.



ii. When the source of light 'S' moves towards observer 1 and away from observer 2, the wavelength of light appears to be less to observer 1 and more to the observer 2.

iii. The apparent frequency of light as perceived by an observer is given by

$$v = v_0\sqrt{\frac{c \pm v}{c \mp v}} \quad \text{.... (i)}$$

where v_0 is the actual frequency of light, v is the frequency of light as measured by the observer.

v = component of velocity of source along the line joining the source and the observer.

c = speed of light in vacuum.

iv. When $v << c$, then equation (i) can be written as,

$$v = v_0\left[1 \pm \frac{v}{c}\right]$$

[From binomial expansion]

$$\therefore \quad v - v_0 = \pm \frac{v}{c} v_0$$

$$\therefore \quad \frac{v - v_0}{v_0} = \pm \frac{v}{c}$$

$$\therefore \quad \frac{\Delta v}{v_0} = \pm \frac{v}{c} \quad \text{...(ii)}$$

[where, $\Delta v = v - v_0$]

v. The negative sign is used in equation (ii) when the source moves away from the observer and we substitute the magnitude of v. Similarly, (+) sign is used when the source moves towards the observer and we substitute the magnitude of v.

vi. The, equation in terms of wavelength is given by,

$$\frac{\Delta\lambda}{\lambda_0} = \pm\frac{v}{c} \quad \text{.... (iii)}$$

In equation (iii), we use the positive sign when the source moves away from the observer and we put the magnitude of v, Similarly, when the source moves towards the observer, (–) sign and magnitude of v is used.

Q.44. Explain red and blue shift.

Ans: i. Red shift:

When the source is receding away from the observer, then the frequency of light appears to be decreasing or the wavelength of light appears to be increasing to the observer. Therefore, the spectral line gets displaced towards red end, hence it is known as the red shift.

ii. Blue shift:

When the source is approaching the observer, then the frequency of light appears to be increasing or wavelength appears to be decreasing, i.e. the spectral line in electromagnetic spectrum gets displaced towards violet end, hence it is known as blue shift.

Q.45. Explain the Doppler effect of light to measure rotational speed of sun.

Ans: i. The east and west edges of the sun are photographed. Each contains absorption lines due to elements such as iron vaporised in the sun and also some absorption lines due to oxygen in the earth's atmosphere.

ii. When the two photographs are put together so that the oxygen lines coincide, the iron lines in the two photographs are displaced relative to each other.

iii. In one case, the edge of the sun approaches the earth and in the other, the opposite edge recedes from the earth. Measurements show a rotational speed of nearly 2 km/s.

Q.46. Explain the Doppler effect in measurement of plasma temperature.

Ans: i. In thermonuclear fusion experiments, we come across extremely hot gases or plasma where the temperature is of the order of millions of degree celsius.

ii. At such high temperatures, molecules of glowing gas are moving away and towards the observer with high speeds.

iii. Owing to Doppler effect, the wavelength A of a particular spectral line is apparently changed.

iv. One edge of the line now corresponds to an apparently increased wavelength A due to molecules moving directly towards the observer and the other edge to an apparently decreased wavelength A_2 due to molecules moving directly away from the observer.

v. The line is thus observed to be broadened. The breadth of the line can be measured by using a diffraction grating.

vi. Since 'A' and 'c' are known, the velocity 'v' can be calculated using the formula,

$v = \sqrt{\frac{3RT}{M}}$, where 'R' is the molar gas constant, 'T' is absolute temperature and M is the mass of one mole.

Note:

1. Doppler effect in light is symmetric, i.e., it depends only on the relative velocity of the source and the observer. The difference occurs because light does not require a medium for propagation and the speed of light is same for any observer whether the observer and/or the source is moving.

2. According to theory of relativity, frequency of light is given by,

$$v' = \left(\frac{1 \pm \frac{v_r}{c}}{\sqrt{1-\left(\frac{v_r}{c}\right)^2}}\right)$$

where v, is the radial component. of the velocity of the source relative to the observer.

Summary :

1. Wave theory of light was first proposed by a Dutch physicist Christian Huygens' in 1678 assuming hypothetical ether medium everywhere in the space.
2. Huygens' wave theory explained various phenomena like reflection, refraction, interference, polarisation, diffraction, double refraction but it could not explain photoelectric effect, rectilinear propagation of light, Compton effect, Raman effect etc.
3. Wavefront is the locus of the points of medium at which waves reach simultaneously so that all the points are in the same phase.
4. According to Huygens' principle, each and every point on the wavefront acts as secondary source. At any later instant, these sources give rise to new wave fronts at that instant.
5. Huygens' principle is used to find new shape and position of wavefront at any later instant.
6. The shape of the wavefront depends on the nature of source. It is spherical for the point source at finite distance and cylindrical for a linear source.
7. The refractive index of medium 2 with respect to medium 1 for a pair of media is given by

   Snell's law : ${}_1\mu_2 = \frac{\sin i}{\sin r} = \frac{c_1}{c_2}$
8. The reciprocal of wavelength is called the wave number ($\bar{v}$). It is given by, $\bar{v} = \frac{1}{\lambda}$
9. Refractive index of a medium is the factor by which the velocity of light changes when light travels from one medium to another medium.

   $$\mu = \frac{c_a}{c_g} = \frac{\lambda_a}{\lambda_g} = \frac{\sin i}{\sin r}$$
10. The wavelength range of visible light is from 4000 Å to 8000 Å. The corresponding frequency range is from 0.75×10^{15} Hz to 3.75×10^{14} Hz.
11. Polarisation' is the phenomenon of the restriction of the vibrations of light waves to a particular direction in a medium. If vibration occurs in all possible planes passing through direction of propagation, then light waves are unpolarised. If vibrations occur only in a single plane, then light wave is plane polarised.
12. Light waves are transverse and it is possible to produce and detect polarised light.
13. According to Brewster's law, tangent of the angle of polarisation is numerically equal to the refractive index of the medium i.e., $\tan i_p = \mu$.
14. Polaroid is an artificially made material which only transmits light with a single plane of polarisation.
15. Doppler effect in light explains red shift and blue shift in wavelength of light.

Formulae :

1. **Velocity of light in vacuum:**

   $c = v\lambda$
2. **Snell's law :**

   $${}_1\mu_2 = \frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1} = \frac{c_1}{c_2} = \frac{\lambda_1}{\lambda_2}$$
3. **Velocity of light in a medium:**

   $$v = \frac{c_a}{\mu}$$
4. **Wavelength of light in a medium:**

   $$\lambda_m = \frac{\lambda_a}{\mu}$$
5. **Relation between R.I of different medium:**

   i. ${}_a\mu_b \times {}_b\mu_c \times {}_c\mu_a = 1$

   ii. ${}_a\mu_b = \frac{1}{{}_b\mu_c \cdot {}_c\mu_a}$

   iii. ${}_c\mu_a = \frac{1}{{}_a\mu_c}$

   iv. ${}_a\mu_b \cdot {}_b\mu_c = {}_a\mu_c$
6. **Wave number:**

   $$\bar{v} = \frac{1}{\lambda}$$
7. **Critical angle:**

   $$i_c = \sin^{-1}\left(\frac{1}{\mu}\right)$$
8. **Brewster's law:**

   $\mu = \tan i_p$

9. Doppler's shift in wavelength:

$$\frac{\Delta\lambda}{\lambda_0} = \pm\frac{v}{c} = \frac{\Delta v}{v_0}$$

Solved Problems :

Example 1

What is the wave number of a beam of light in air if its frequency is 9 × 10¹⁴ Hz? [Given: c_a = 3 × 10⁸ m/s]

Solution:

Given : $v_a = 9 \times 10^{14}$ Hz, $c_a = 3 \times 10^8$ m/s

To find : Wave number ($\overline{v}$)

Formula : $v = v\lambda$

Calculation : From formula,

$$\lambda = \frac{v}{v} = \frac{c}{v} \quad .... [\because v = c \text{ for air}]$$

$$\text{Now, } \overline{v} = \frac{1}{\lambda} = \frac{v}{c} = \frac{9\times10^{14}}{3\times10^{8}}$$

$\therefore$ $\overline{v}$ = **3 × 10⁶ m⁻¹**

Ans: The wave number of the beam is **3 × 10⁶ m⁻¹.**

Example 2

The number of waves in 6 cm of vacuum is same as the number of waves in x cm of a medium. If the refractive index of the medium is $\frac{3}{2}$, find x.

[Oct 10]

Solution:

Given : Number of waves in 6 cm of vacuum = Number of waves in x cm of medium,

$\mu = \frac{3}{2}$.

To find : Distance (x)

Formulae : i. $\overline{v} = \frac{1}{\lambda}$

ii. $_{vac}\mu_{med.} = \frac{\lambda_{vac.}}{\lambda_{med.}}$

Calculation: Using formula (i),

$$\overline{v}_{vac} = \frac{1}{\lambda_{vac}} \text{ and } \overline{v}_{mad} = \frac{1}{\lambda_{mad}}$$

$$\therefore \frac{1}{\lambda_{vac}} \times 6 = \frac{1}{\lambda_{mad}} \times x \quad ...[\text{Given}]$$

$$\therefore \frac{\lambda_{vac.}}{\lambda_{med.}} = \frac{6}{x} \quad ...(i)$$

Now, using formula (ii) we get,

$$_{vac}\mu_{med.} = \frac{\lambda_{vac.}}{\lambda_{med.}}$$

$$\therefore \frac{3}{2} = \frac{6}{x} \quad .... [\text{From (i)}]$$

$$\therefore x = \frac{12}{3}$$

$\therefore$ **x = 4 cm**

Ans: The distance x is **4 cm.**

Example 3

Monochromatic light of wavelength 589 nm is incident from air on a water surface. What are the wavelength, frequency and speed of (a) reflected and (b) refracted light? Refractive index of water is 1.33.

Solution :

Given : λ_1 = 589 nm = 589 × 10⁻⁹ m, c = 3 × 10⁸ m/s, $_a\mu_w$ = 1.33

To find : i. Wavelength (λ_1), frequency (v_1) and speed (v_1) of reflected light

ii. Wavelength (λ_2), frequency (v_2) and speed (v_2) of refracted light

Formulae: i. $v = v\lambda$

ii. $_a\mu_w = \frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2}$

Calculation :

i. For reflected light,

λ_1 = **589 × 10⁻⁹ m**

Using formula (i), we get

$v_1 = v_1\lambda$, or $c = v_1\lambda_1$

Now, for air,

v_1 = c = **3 × 108 m/s**

$$\therefore v_1 = \frac{c}{\lambda_1} = \frac{3\times10^8}{589\times10^{-9}}$$

$$= \frac{3000}{589}\times10^{14}$$

$\therefore$ v_1 = **5.09 × 10¹⁴ Hz**

ii. Frequency remains unchanged on entering another medium.

$\therefore$ v_2 = **5.09 × 10¹⁴ Hz**

For refracted light,
Using formula (ii) we get

$$\lambda_2 = \frac{\lambda_1}{{}_a\mu_w}$$

$$= \frac{589\times10^{-9}}{1.33}$$

$\lambda_2 =$ **4.43×10^{-7} m**

Using formula (ii),

$${}_a\mu_w = \frac{v_1}{v_2} = \frac{c}{v_2}$$

$$\therefore \quad v_2 = \frac{c}{{}_a\mu_w} = \frac{3\times10^8}{1.33}$$

$\therefore \quad v_2 = 2.26 \times 10^8$ m/s

Ans: i. For reflected light, wavelength is 589×10^{-9} m, frequency is 5.09×10^{14} Hz and speed is 3×10^8 m/s.

ii. For refracted light, wavelength is 4.43×10^{-7} m, frequency is 5.09×10^{14} Hz and speed is 2.26×10^8 m/s.

Example 4

Determine the change in wavelength of light during its passage from air to glass, if refractive index of glass with respect to air is 1.5 and frequency of light in 4 × 10¹⁴ Hz. Find the wave number of light in glass. [Velocity of light in air = 3 × 10⁸ m/s].

[Mar 08]

Solution:

Given : ${}_a\mu_g = 1.5$, $v = 4 \times 10^{14}$ Hz, $c = 3 \times 10^8$ m/s

To find : i. Change in wavelength of light ($\Delta\lambda$)

ii. Wave number of light ($\bar{v}$)

Formulae : i. $(\bar{v}) = \dfrac{1}{\lambda}$

ii. ${}_a\mu_g = \dfrac{\lambda_a}{\lambda_g}$

iii. $c = v\lambda$

Calculation:

i. Using formula (iii),

$$\lambda_a = \frac{c}{v} = \frac{3\times10^8}{4\times10^{14}} = 0.75 \times 10^{-6}$$

$\therefore \quad \lambda_a = 7500$ Å

Using formula (ii),

$$\lambda_g = \frac{\lambda_a}{{}_a\mu_g} = \frac{7500\text{Å}}{1.5}$$

$\therefore \quad \lambda_g = 5000$ Å

$\therefore \quad \Delta\lambda = \lambda_a - \lambda_g$

$= 7500 - 5000$

$\therefore \quad \Delta\lambda =$ **2500 Å**

ii. Now, using formula (i),

$$\bar{v} = \frac{1}{0.5\times10^{-6}} = \frac{10^6}{\frac{1}{2}}$$

$\bar{v} =$ **2×10^6 m⁻¹**

Ans: i. The change in wavelength of light is **2500 Å**.

ii. The wave number of light is 2×10^6 m⁻¹.

Example 5

The wavelength of monochromatic light is 5000 Å in air. What will be its wave number in air?

[Feb 13 old course]

Solution:

Given : $\lambda = 5000$ Å $= 5 \times 10^{-7}$ m

To find : Wave number ($\bar{v}$)

Formula : $\bar{v} = \dfrac{1}{\lambda}$

Calculation : From formula,

$$\bar{v} = \frac{1}{5\times10^{-7}}$$

$\therefore \quad \bar{v} =$ **2×10^6 m⁻¹**

Ans: The wave number of monochromatic light is **2×10^6 m⁻¹**

Example 6

A ray of light passes from air to a medium making an angle of incidence 61° and angle of refraction 34°. What is the refractive index of the medium?

Solution:

Given : $\angle i = 61°$, $\angle r = 34°$

To find : Refractive index of the medium (${}_a\mu_m$)

Formula : ${}_a\mu_m = \dfrac{\sin i}{\sin r}$

Calculation : From formula,

$$_a\mu_m = \frac{\sin 61^o}{\sin 34^o} = \frac{0.8746}{0.5592}$$

$$\therefore \quad _a\mu_m = \mathbf{1.564}$$

Ans: The refractive index of the medium is **1.564**.

Example 7

The refractive index of glass is 1.5. What is the speed of light in glass? [Speed of light in vacuum is 3 × 108 ms⁻¹] (NCERT)

Solution:

Given : $\mu = 1.5$, $c = 3 \times 10^8$ m s^{-1}

To find : The speed of light in glass (v_g)

Formula : $\mu = \frac{c}{v_g}$

Calculation : From formula,

$$v_g = \frac{c}{\mu}$$

$$= \frac{3\times10^8}{1.5}$$

$$\therefore \quad v_g = \mathbf{2 \times 10^8 \ m \ s^{-1}}$$

Ans: The speed of light in glass is 2×10^8 m s^{-1}.

Example 8

A ray of light is incident on a water surface of refractive index $\frac{4}{3}$ making an angle of 40° with the surface. Find the angle of refraction. [Mar 10]

Solution:

Given : $i = 50°$ $\mu_w = \frac{4}{3}$

To find: Angle of refraction (r)

Formula : $\mu_w = \frac{\sin i}{\sin r}$

Calculation: Using formula,

$$\sin r = \frac{\sin i}{\mu} = \frac{\sin 50^o}{\left(\frac{4}{3}\right)}$$

$$= \frac{3}{4} \times 0.7660$$

$$= 0.5745$$

$$\therefore \quad r = \sin^{-1}(0.5745)$$

$$= 35°4'$$

Ans: The angle of refraction of the ray of light is **35°4'**.

Example 9

Light of wavelength 4500 Å in water has a wavelength 4000 Å in glass. Find the R.I. of glass w.r.t. water.

Solution:

Given : $\lambda_w = 4500$ Å, $\lambda_g = 4000$ Å

To find : Refractive index ($_w\mu_g$)

Formula : $_w\mu_g \ \frac{\lambda_w}{\lambda_g}$

Calculation: From formula,

$$_w\mu_g = \frac{4500}{4000} = \frac{9}{8}$$

$$\therefore \quad _w\mu_g = \mathbf{1.125}$$

Ans: The refractive index of glass w.r.t. water is **1.125.**

Example 10

What is the Brewster angle for air to glass transition? [Refractive index of glass = 1.5] (NCERT)

Solution :

Given : $\mu = 1.5$

To find : Brewster angle (i_p)

Formula : $\mu = \tan i_p$

Calculation : From formula,

$$i_p = \tan^{-1}(\mu) = \tan^{-1}(1.5)$$

$$\therefore \quad i_p = \mathbf{56.3° = 56°18'}$$

Ans: Brewster angle for air to glass transition is **56.3° or 56°18'**.

Example 11

For a glass plate as a polariser with refractive index 1.633, calculate the angle of incidence at which light is polarised. [Mar 14]

Solution:

Given : $\mu = 1.633$

To find : Polarising angle (i_p)

Formula : $\mu = \tan i_p$

Calculation : From formula we get,

$$i_p = \tan^{-1}(1.633)$$

$$\therefore \quad i_p = \mathbf{58° \ 31'}$$

Ans: The angle of incidence at which light is polarised is **58° 31'.**

Example 12

A ray of light is incident on the surface of a glass plate of refractive index 1.55 at the polarising angle. Calculate the angle of refraction.

Solution:

Given : R.I. of glass, $\mu = 1.55$

To find : Angle of refraction (r)

Formula : $\tan i_p = \mu$

Calculation : From formula,

$\tan i_p = 1.55$

$\therefore i_p = \tan^{-1}(1.55) = 57° 10'$

Since $i_p + r = 90°$,

$\therefore r = 90° - i_p$

$= 90° - (57° 10')$

$= 32° 50'$

$\therefore r$ = **32° 50'**

Ans: The angle of refraction of the ray of light is **32°50'**.

Example 13

For a given medium, the polarising angle is 60°. What will be the critical angle for the medium?

Solution:

Given : $i_p = 60°$

To find : Critical angle (i_c)

Formulae : i. $\mu = \tan i_p$

ii. $\mu = \dfrac{1}{\sin i_c}$

Calculation: Using formula (i) we get,

$\mu = \tan 60° = \sqrt{3}$

Using formula (ii) we get,

$\therefore \sin i_c = \dfrac{1}{\mu} = \dfrac{1}{\sqrt{3}} = 0.5774$

$\therefore i_c = \sin^{-1}(0.5774)$

$\therefore i_c$ = **35°16'**

Ans: The critical angle for the medium is **35° 16'.**

Example 14 .

If the critical angle of a medium is sin⁻¹ (3/5), find the polarising angle.

Solution:

Given : $i_c = \sin^{-1}\left(\dfrac{3}{5}\right)$

To find: Polarising angle (ip)

Formula : $\mu = \tan i_p$

Calculation : $\sin i_c = \dfrac{3}{5}$ (from given data)

But $\mu = \dfrac{1}{\sin i_c} = \dfrac{1}{\left(\frac{3}{5}\right)} = \dfrac{5}{3} = 1.667$

From formula,

$i_p = \tan^{-1}(\mu)$

$\therefore i_p = \tan^{-1}(1.667)$

$\therefore i_p$ = **59° 2'**

Ans: The polarising angle ofthe medium is **59°2'**.

Example 15

Red light of wavelength 6400 Å in air has wavelength 4000 Å in glass. If the wavelength of violet light in air is 4400 Å, find its wavelength in glass.

(Assume that $\mu_r \approx \mu_v$) [Mar 2000, Oct 14]

Solution:

Given : $(\lambda_r)_{air} = 6400$Å, $(\lambda_r)_{glass} = 4000$ Å, $(\lambda_v)_{air} = 4400$ Å

To find : Wavelength $(\lambda_v)_{glass}$

Formula : $_a\mu_g = \dfrac{(\lambda_r)_{air}}{(\lambda_r)_{glass}} = \dfrac{(\lambda_v)_{air}}{(\lambda_v)_{glass}}$

Calculation : From formula,

$$(\lambda_v)_{glass} = (\lambda_v)_{air} \times \frac{(\lambda_r)_{glass}}{(\lambda_r)_{air}}$$

$$= \frac{4400 \times 4000}{6400}$$

$\therefore (\lambda_v)_{glass}$ = **2750 Å**

Ans: The wavelength of violet light in glass is **2750 Å**.

Example 16

The speed of light in air is 3 × 10⁸ m/s. If the R.I. of glass is 1.5, then find the time taken by light to travel a distance of 20 cm in glass.

Solution:

Given : $c_a = 3 \times 10^8$ m/s, $_a\mu_g = 1.5$, $d_g = 20$ cm $= 0.2$ m

To find : Time of travel (t)

Formula : $_a\mu_g = \dfrac{c_a}{c_g}$

Calculation : From formula,

$$c_g = \frac{c_a}{_a\mu_g} = \frac{3\times10^8}{1.5} = \frac{30}{15} \times 10^8$$

$\therefore c_g$ = **2 × 10⁸ m/s**

The time taken by light to travel a distance of 2×10^{-1} m in glass is given by,

$$t = \frac{d_g}{c_g} = \frac{0.2}{2\times10^8}$$

$\therefore$ $t = \mathbf{1 \times 10^{-9}}$ **s**

Ans: The time of travel of light is $\mathbf{1 \times 10^{-9}}$ **s**.

Example 17

The velocity of light in air is 3 × 10⁸ m/s. Find the frequency and wavelength of a beam of light in diamond whose wavelength in air is 4800 Å.
[Given: R.I. of diamond is 2.4]

Solution:

Given: $c_a = 3 \times 10^8$ m/s,
$\lambda_a = 4800 = 48 \times 10^{-8}$ m,
${}_a\mu_d = 2.4$

To find: i. Wavelength in diamond (λ_d)
ii. Frequency in diamond (v_d)

Formulae: i. ${}_a\mu_d = \frac{\lambda_a}{\lambda_d}$ ii. $c = v\lambda$

Calculation: Using formula (i) we get,

$$\lambda_d = \frac{\lambda_a}{{}_a\mu_d}$$

$$= \frac{4800}{2.4} = \frac{48000}{24} = 2000\ \text{Å}$$

$\therefore$ $\lambda_d = \mathbf{2000\ Å}$

Now using formula (ii),

$$c_a = v_a \lambda_a$$

$$\therefore\ v_a = \frac{c_a}{\lambda_a}$$

$$= \frac{3\times10^8}{48\times10^{-8}}$$

$$= \frac{3}{48} \times 10^{16}$$

$\therefore$ $v_a = 6.25 \times 10^{14}$ Hz

But, $v_d = v_a$

Frequency remains same

$\therefore$ $v_d = \mathbf{6.25 \times 10^{14}}$ **Hz**

Ans: i. The wavelength of light in diamond is **2000 Å**.
ii. The frequency of light in diamond is $\mathbf{6.25 \times 10^{14}}$ **Hz**.

Example 18

The velocity of light in air is 3 × 10⁸ m/s. Find the frequency and wavelength of a beam of light in diamond whose wavelength in air is 4500 Å. [Given: R.I. of diamond = 2.4]

Solution:

Given: $c = 3 \times 10^8$ m/s,
$\lambda_a = 4500$ Å
$= 4.5 \times 10^{-7}$ m,
${}_a\mu_d = 2.4$

To find: i. Frequency in diamond (v_d)
ii. Wavelength in diamond (λ_d)

Formula: i. $v_a = \frac{c}{\lambda_a}$ ii. ${}_a\mu_d = \frac{\lambda_a}{\lambda_d}$

Calculation: From formula (i),

$$v_a = \frac{c}{\lambda_a}$$

$$= \frac{3\times10^8}{4.5\times10^{-7}}$$

$$= 6.67 \times 10^{14}\ \text{Hz}$$

Since frequency of a given colour of light remains same in any medium,

$\therefore$ $v_a = v_d = \mathbf{6.67 \times 10^{14}}$ **Hz**

From formula (ii),

$$\lambda_d = \frac{\lambda_a}{{}_a\mu_d}$$

$$= \frac{4.5\times10^{-7}}{2.4}$$

$$= 1.875 \times 10^{-7}\ \text{m}$$

$\therefore$ $\lambda_d = \mathbf{1875\ Å}$

Ans: i. The frequency of light in diamond is $\mathbf{6.67 \times 10^{14}}$ **Hz**.
ii. The wavelength of light in diamond is **1875 Å**.

Example 19

For a light wave of certain frequency, the difference in the wavelength in alcohol of R.I. 1.35 and glass of R.I. 1.5. is 440 Å. Find the frequency of light wave.
[Given: c_a = 3 × 10⁸ m/s]

Solution: .

Given: ${}_a\mu_{alc} = 1.35$,
${}_a\mu_g = 1.5$, $\lambda_{alc} - \lambda_g$
$= 440$ Å

To find: Frequency (v_a)

Formula : $_1\mu_2 = \frac{\lambda_1}{\lambda_2}$

Calculation : From formula,

$$_a\mu_{alc} = \frac{\lambda_a}{\lambda_{alc}}$$

$$\therefore \quad \lambda_{alc} = \frac{\lambda_a}{_a\mu_{alc}} \quad ....(i)$$

Now, $_a\mu_g = \frac{\lambda_a}{\lambda_g}$

$$\therefore \quad \lambda_g = \frac{\lambda_a}{_a\mu_g} \quad ....(ii)$$

Subtracting equation (ii) from equation (i) we get,

$$\lambda_{alc} - \lambda_g = \frac{\lambda_a}{_a\mu_{alc}} - \frac{\lambda_a}{_a\mu_g}$$

$$= \lambda_a \left[\frac{1}{_a\mu_{alc}} - \frac{1}{_a\mu_g}\right]$$

$$\therefore \quad 440 = \lambda_a \left[\frac{1}{1.35} - \frac{1}{1.5}\right]$$

$$440 = \lambda_a \left[\frac{1.5 - 1.35}{(1.5)\times(1.35)}\right]$$

$$440 = \lambda_a \left[\frac{0.15}{(1.5)\times(1.35)}\right]$$

$$440 = \lambda_a \left[\frac{1.5\times 10^{-1}}{(1.5)\times(1.35)}\right]$$

$$440 = \lambda_a \left[\frac{1.5}{(1.5)\times(1.35)\times(10)}\right]$$

$\lambda_a = 440 \times 1.35 \times 10$

$= 44 \times 135$

$\lambda_a = 5940$ Å

Now, we have

$c_a = v_a \lambda_a$

$$\therefore \quad v_a = \frac{c_a}{\lambda_a}$$

$$v_a = \frac{3\times 10^8}{5940 \times 10^{-10}}$$

$= 0.5051 \times 10^{-3} \times 10^{18}$

$= 0.5051 \times 10^{15}$

$\therefore \quad v_a =$ **5.051×10^{14} Hz**

Ans: The frequency of light wave is **5.051×10^{14} Hz**.

Example 20

The light of wavelength 6400 Å is incident normally, on a plane parallel glass slab of thickness 5 cm and μ = 1.6. The beam takes the same time to travel from the source to the incident surface as it takes to travel through the slab. Find the distance of the source from the incident surface. What is the frequency and wavelength of the light in glass?

[Given: $c_a = 3 \times 10^8$ m/s]

Solution:

Given : $\lambda_a = 6400$ Å $= 6.4 \times 10^{-7}$ m,
$d_g = 5 \times 10^{-2}$ m, $_a\mu_g = 1.6$,
$c_a = 3 \times 10^8$ m/s

To find : i. Distance of source (d_a)
ii. Frequency in glass (v_g)
iii. Wavelength in glass (λ_g)

Formula : i. $t = \frac{d}{c}$ ii. $_a\mu_g = \frac{\lambda_a}{\lambda_g}$

Calculation : $t_a = t_g$ (given)

From formula (i),

$$\frac{d_a}{c_a} = \frac{d_g}{c_g}$$

$$\therefore \quad \frac{c_a}{c_g} = \frac{d_a}{d_g}$$

But, $\frac{c_a}{c_g} = {_a\mu_g}$

$$\therefore \quad _a\mu_g = \frac{d_a}{d_g}$$

$\therefore \quad d_a = {_a\mu_g}\, d_g = 1.6 \times 5 \times 10^{-2}$

$\therefore \quad d_a =$ **8 cm**

From formula (ii),

$$_a\mu_g = \frac{\lambda_a}{\lambda_g}$$

$$\therefore \quad \lambda_g = \frac{\lambda_a}{_a\mu_g} = \frac{6400}{1.6} = \frac{64000}{16}$$

$\therefore \quad \lambda_g =$ **4000 Å**

Now $c_a = v_a \lambda_a$

$$\therefore \quad v_a = \frac{c_a}{\lambda_a} = \frac{3\times10^8}{6.4\times10^{-7}} = \frac{3}{3.4}\times10^{15}$$

$= 0.468 \times 10^{15}$

$v_a = 4.68 \times 10^{14}$ Hz

But, $v_a = v_g$

$\therefore$ v_g = **4.68×10^{14} Hz**

Ans: i. The distance of source from incident surface is **8 cm**.

ii. The frequency of light in glass is **4.68×10^{14} Hz.**

iii. The wavelength of light in glass is **4000 Å**.

Example 21

A parallel beam of monochromatic light is incident on glass slab at an angle of incidence 60°. Find the ratio of the widths of the beam in glass to that in air, if refractive index of glass is 1.5. [Feb 01]

Solution :

Given : $i = 60°$, $\mu_g = 1.5$,
Let d_g = width of beam in glass slab,
d_a = width of beam in air

To find : Ratio of widths $\left(\frac{d_g}{d_a}\right)$

Formulae : i. $\mu_g = \frac{\sin i}{\sin r}$ ii. $\frac{d_g}{d_a} = \frac{\cos r}{\cos i}$

Calculation : From formula (i),

$$\sin r = \frac{\sin i}{\mu_g}$$

$$\therefore \quad \sin r = \frac{\sin 60°}{1.5} = \frac{0.8660}{1.5} = 0.5773$$

$\therefore$ $r = \sin^{-1}(0.5773) = 35°\ 16'$

From formula (ii),

$$\frac{d_g}{d_a} = \frac{\cos r}{\cos i} = \frac{\cos 35°16'}{\cos 60°}$$

$$\therefore \quad \frac{d_g}{d_a} = \frac{0.8164}{0.5} = 1.6$$

$$\therefore \quad \frac{d_g}{d_a} = \frac{16}{10} = 8:5$$

$\therefore$ Ratio of the widths of beam = **8 : 5**

Ans: The ratio of widths of the beam in glass to that in air is **8 : 5.**

Example 22

The refractive indices of water for red and violet colours are 1.325 and 1.334 respectively. Find the difference between velocities of the rays for these two colours in water. [Oct 98, Oct 13]

Solution:

Given : $\mu_r = 1.325$, $\mu_v = 1.334$

To find : Difference between velocities $(v_r - v_v)$

Formula : $\mu = \frac{c}{v}$

Calculation : From formula,

$$v_r = \frac{c}{\mu_r} = \frac{3\times10^8}{1.325}$$

$= 2.264 \times 10^8$ m/s

Similarly,

$$v_v = \frac{c}{\mu_v} = \frac{3\times10^8}{1.334}$$

$= 2.249 \times 10^8$ m/s

Now,

$v_r - v_v = 2.264 \times 10^8 - 2.249 \times 10^8$

$= 0.015 \times 10^8$ m/s

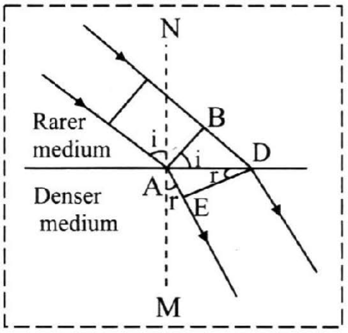
$\therefore$ $v_r - v_v$ = **1.5×10^6 m/s**

Ans: The difference between velocities of the rays for red and violet colours is **1.5×10^6 m/s**.

Example 23

The width of a plane incident wavefront is found to be doubled in a denser medium. If it makes an angle of 70° with the surface, calculate the refractive index for the rarer medium.

Solution:



From the figure,

$\angle ADE = \angle r, \angle DAB = \angle i = 70°$

$\therefore \quad \frac{ED}{AB} = \frac{\cos r}{\cos i} = 2$

$\therefore \quad \cos r = 2 \times \cos i$

$\cos r = 2 \times 0.3420$ [$\because \cos 70° = 0.3420$]

$= 0.684$

$\therefore \quad r = \cos^{-1}(0.684)$

$= 46.8°$

Now,

$$_{d}\mu_{a} = \frac{\sin r}{\sin i}$$

$$= \frac{\sin 46.8}{\sin 70^{o}}$$

$$= \frac{0.7289}{0.9396}$$

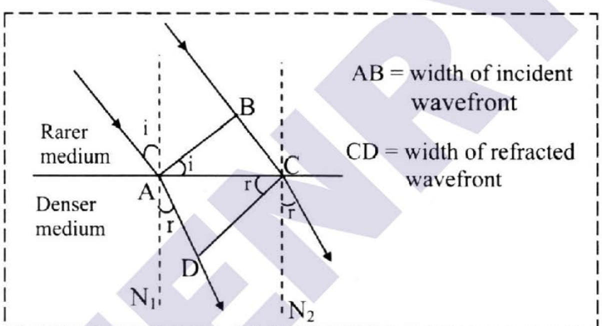
$$\therefore \quad _{d}\mu_{a} = \mathbf{0.78}$$

Ans: The refractive index for the rarer medium is **0.78**.

Example 24

The width of a plane incident wavefront is found to be doubled in a denser medium. If it makes an angle of 70° with surface, calculate the refractive index for the denser medium.

Solution:



Given : $i = 70°$, CD = 2AB

To find : Refractive index (μ)

Formulae : i. $\frac{\cos i}{\cos r} = \frac{AB}{CD}$

ii. $\mu = \frac{\sin i}{\sin r}$

Calculation : From formula (i),

$$\frac{\cos 70^{o}}{\cos r} = \frac{AB}{2AB}$$

$$\frac{0.3420}{\cos r} = \frac{1}{2}$$

$\cos r = 0.684$

$\therefore \quad r = 46° 50'$

From formula (ii),

$$\mu = \frac{\sin 70^{o}}{\sin(46^{o}48')} = \frac{0.9397}{0.7290}$$

$$\therefore \quad \mu = \mathbf{1.289}$$

Ans: The refractive index for the denser medium is **1.289.**

Example 25

If the difference in velocities of light in glass and water is 0.25 × 10⁸ m/s, find the velocity of light in air. [Given: $\mu_g = 1.5$, $\mu_w = 4/3$]

Solution:

Given : $\mu_g = 1.5$ and $\mu_w = \frac{4}{3}$

$v_w - v_g = 0.25 \times 10^8$ m/s

To find : Velocity of light in air (c)

Formula : $\mu = \frac{c}{v}$

Calculation : From formula,

$$\mu_g = \frac{c}{v_g} \text{ and } \mu_w = \frac{c}{v_w}$$

$$\therefore \quad v_g = \frac{c}{\mu_g} \text{ and } v_w = \frac{c}{\mu_w}$$

$$\therefore \quad v_w - v_g = \frac{c}{\mu_w} - \frac{c}{\mu_g} = c\left[\frac{1}{\mu_g} - \frac{c}{\mu_w}\right]$$

$$\therefore \quad 0.25 \times 10^8 = c\left[\frac{1}{4/3} - \frac{1}{1.5}\right]$$

$$= c\left[\frac{3}{4} - \frac{10}{15}\right] = c\left[\frac{3}{4} - \frac{2}{3}\right]$$

$$= c\left[\frac{9-8}{12}\right]$$

$$\therefore \quad 0.25 \times 10^8 = c\left[\frac{1}{12}\right]$$

$\therefore \quad c = 12 \times 0.25 \times 10^8$

$= 3.00 \times 10^8$ m/s

$\therefore \quad \mathbf{c = 3 \times 10^8\ m/s}$

Ans: The velocity of light in air is **3.00 × 10⁸ m/s.**

Example 26

If the difference in velocities of light in glass and wateris 2.7 × 10⁷ m/s, find the velocity of light in air.
(Refractive index of glass = 1.5, Refractive index of water = 1.333) [Mar 14]

Solution:

Given: $\mu_g = 1.5$, $\mu_w = 1.333$,
$v_w - v_g = 2.7 \times 10^7$ m/s

To find: Velocity of light in air (c)

Formula: $\mu = \frac{c}{v}$

Calculation: From formula we get,

$$\mu_g = \frac{c}{v_g} \text{ and } \mu_w = \frac{c}{v_w}$$

$$\therefore \quad v_g = \frac{c}{\mu_g} \text{ and } v_w = \frac{c}{\mu_w}$$

$$\therefore \quad v_w - v_g = \frac{c}{\mu_w} - \frac{c}{\mu_g}$$

$$\therefore \quad 2.7 \times 10^7 = c\left[\frac{1}{1.333} - \frac{1}{1.5}\right]$$

$$= c\left[\frac{1.5 - 1.333}{1.333 \times 1.5}\right]$$

$$\therefore \quad 2.7 \times 10^7 = c\left[\frac{0.167}{1.33 \times 1.5}\right]$$

$$\therefore \quad c = \frac{1.33 \times 1.5 \times 2.7 \times 10^7}{0.167}$$

$= 32.33 \times 10^7$

$c = 3.233 \times 10^8$ m/s

Ans: The velocity of light in air is **3.233×10^8 m/s.**

Example27

A ray of light travelling through air, falls on the surface of a glass slab at an angle ∠i. It is found that the angle between the reflected and refracted ray is 90°. If the speed of light in glass is 2 × 10⁸ m/s, find the angle of incidence. [c = 3 × 10⁸ m/s]

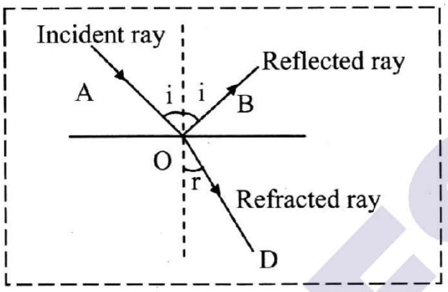
Solution:

Given: $c = 3 \times 10^8$ m/s, $v_g = 2 \times 10^8$ m/s
The angle between reflected refracted ray i.e. ∠BOD = 90° (in figure)

To find: Angle of incidence (i)

Formula: $\mu = \frac{\sin i}{\sin r}$

Calculation:



From the figure, $i + r + 90° = 180°$

$\therefore \quad i + r = 90°$

$\therefore \quad r = 90° - i$

$$\therefore \quad \mu = \frac{c}{v_g} = \frac{3 \times 10^8}{2 \times 10^8} = 1.5$$

From formula,

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin i}{\sin(90° - i)} = \frac{\sin i}{\cos i} = \tan i$$

$\therefore \quad i = \tan^{-1}(\mu) = \tan^{-1}(1.5)$

$\therefore \quad i \approx$ **56° 19'**

Ans: The angle of incidence of the ray is **56°19'.**

Example 28

Light of wavelength 5000 Å falls on a plane reflecting surface. What are the wavelength and frequency of the reflected light? For what angle of incidence is the reflected ray normal to the incident ray? (NCERT)

Solution:

$\lambda = 5000$ Å $= 5000 \times 10^{-10}$ m, $c = 3 \times 10^8$ m s^{-1}

Wavelength of reflected light = Wavelength of incident light = **5000 Å**

Also,

$$v = \frac{c}{\lambda} = \frac{3 \times 10^8}{5000 \times 10^{-10}} = \mathbf{6 \times 10^{14}\ Hz}$$

Now, i = r

Also, i + r = 90°

$\therefore \quad i + i = 90°$ or $2i = 90°$

$\therefore \quad i =$ **45°**

Ans: At **45°**, the reflected ray is normal to the incident ray.

Example 29

The earth is moving towards a fixed star with a velocity of 30 km s⁻¹. An observer on the earth observes a shift of 0.58 Å in the

wavelength of light coming from the star. Find the actual wavelength of light emitted by the star.

Solution:

Given : v = 30 km s^{-1} = 30 × 10^3 ms^{-1},

To find : $\Delta\lambda$ = 0.58 Å, c = 3 × 10^8 ms^{-1}

To find : Actual wavelength of light emitted (λ_0)

Formula : $\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$

Calculation : From formula,

$$\lambda_0 = \frac{c}{v}\Delta\lambda$$

$$\therefore \quad \lambda_0 = \frac{3\times10^8}{30\times10^3}\times 0.58Å$$

$$\therefore \quad \lambda_0 = \mathbf{5800\ Å}$$

Ans: Actual wavelength of light emitted by the star is **5800 Å.**

Example 30

6563 Å H_α line emitted by hydrogen in a star is found to be red-shifted by 15 Å. Estimate the speed with which the star is receding from the Earth. (NCERT)

Solution:

Given : λ_0 = 6563 Å = 6.563 × 10^{-7} m

To find : Speed (v)

Formula : $\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$

Calculation : From formula,

$$v = \left(\frac{\Delta\lambda}{\lambda_0}\right)c$$

$$= \frac{15\times10^{-10}}{6563\times10^{-10}} \times 3 \times 10^8$$

$$\therefore \quad v = \mathbf{6.86 \times 10^5\ m\ s^{-1}}$$

Ans: The speed with which the star is receding from earth is **6.86 × 10^5 m s^{-1}.**

Example 31

With what speed should a galaxy move with respect to us so that the sodium line at 589.0 nm is observed at 589.6 nm?

Solution:

Given : $\Delta\lambda$ = 589.6 – 589 = 0.6 nm

To find : Speed of the galaxy (v)

Formula : $\frac{\Delta\lambda}{\lambda_0} = \frac{v}{c}$

Calculation : From formula,

$$v = \left(\frac{\Delta\lambda}{\lambda_0}\right)c$$

$$= \left(\frac{0.6}{589}\right) \times 3 \times 10^8$$

$$= 3.06 \times 10^5\ m\ s^{-1}$$

$$\therefore \quad v = \mathbf{306\ km/s}$$

Ans: The galaxy should move with a speed of **306 km/s**.

Example 32

A light source approaches the observer with velocity 0.8 c. Find the Doppler shift for the light of wavelength 5500 Å.

Solution:

Given : λ = 5500 Å , v = 0.8 c

To find : Doppler shift ($\Delta\lambda$)

Formula : $\lambda' = \lambda\sqrt{\frac{1-(v/c)}{1+(v/c)}}$

Calculation : From formula,

$$\lambda' = 5500\sqrt{\frac{1-0.8}{1+0.8}}$$

$$= 1833.33$$

$\therefore$ Doppler Shift = 5500 – 1833.33 ≈ **3667 Å**

Ans: The doppler shift in wavelength is **3667 Å**.

Example 33

A characteristic wavelength of light from a galaxy is observed to' be increased in wavelength as compared with terrestrial sources, by about, 0.4%. What is the radial speed of the galaxy with respect to earth?

Solution:

Given : $\lambda = \frac{100.4}{100}\lambda_0$

To find : Radial speed (v)

Formula : $\frac{v}{c} = \frac{\Delta\lambda}{\lambda_0}$

Calculation : Since, $\lambda = \frac{100.4}{100}\lambda_0$

$$\therefore \quad \frac{\lambda}{\lambda_0} = \frac{100.4}{100}$$

On subtracting 1 from both sides, we get,

$$\frac{\lambda}{\lambda_0} - 1 = \frac{100.4}{100} - 1$$

$$\therefore \quad \frac{\lambda - \lambda_0}{\lambda_0} = \frac{100.4 - 100}{100}$$

$$\therefore \quad \frac{\lambda - \lambda_0}{\lambda_0} = \frac{0.4}{100}$$

$$\therefore \quad \frac{\Delta\lambda}{\lambda_0} = 0.004$$

From formula,

$$\frac{v}{c} = 0.004$$

$$\therefore \quad v = 0.004\ c$$

$$= 0.004 \times 3 \times 10^8$$

$$\therefore \quad v = \mathbf{1.2 \times 10^6\ m/s}$$

Ans: Radial speed of galaxy with respect to earth is **1.2×10^6 m/s**.

EXERCISE :

Section A: Practice Problems

1. What is the wave number of a beam of light in air if its frequency is 1.35×10^{14} Hz ?
   [$c = 3 \times 10^8$ m/s]
2. The velocity of light in a medium is 2×10^8 m/s and in air is 3×10^8 m/s. Find the R.I of the medium.
3. The R.I. of ice and diamond are 1.31 and 2.42 respectively. Find the R.I. of diamond w.r.t. ice.
4. A light wave has a wavelength 4100 Å in glass. If the R.I. of glass is 1.5, find the wavelength of light in air.
5. Calculate the polarising angle for water.
   [$\mu = 1.33$]
6. The critical angle for glass is 37°. What is the polarising angle for the specimen?
7. A ray of light is incident on a transparent plate of a material of refractive index $\sqrt{3}$ at the polarising angle. Find the angle of refraction.
8. A clear crystal has a critical angle of 24.4° for green light. What is the polarising angle of incidence?
9. A ray of light strikes a glass plate at an angle of incidence 57°. If the reflected and refracted rays are perpendicular to each other, find the index of refraction of glass.
10. A radar wave has frequency of 8.1×10^9 Hz. The reflected wave from an aeroplane shows a frequency difference of 2.7×10^3 Hz on the higher side. Deduce the velocity of aeroplane in the line of sight.
11. The velocity of light in vacuum is 3×10^8 m/s, in glass it is 1.8×10^8 m/s and in water it is 2.25×10^8 m/s. Calculate the R.I. of
    i. glass
    ii. water
    iii. glass w.r.t. water.
12. The wavelength of blue light in air is 4500 Å. What is its frequency? If the refractive index of glass is 1.55, find its wavelength in glass.
    [Given: $c = 3 \times 10^8$ m/s]
13. If the refractive indices of glass and water with respect to air are 3/2 and 4/3 respectively. Calculate the velocity of light in glass and water. From the result, calculate the refractive index of glass w.r.t. water.
    [velocity of light in air = 3×10^8 m/s]
14. The width of plane incident wavefront is found to be doubled in a denser medium. If it 'makes an angle of 71° with the interface, calculate the refractive index of the denser medium.
15. The reflected light is found to be completely plane polarised when sun light is incident on water surface at an angle of 37° with water surface. Determine angle of refraction and refractive index of water.
16. Given $v' = (1 - v/c)\ v$ and $v' = \dfrac{(1 - v/c)v}{\sqrt{1 - v^2/c^2}}$.
    For what value of v/c, these equations differ by 10%?

Section B: Theoretical Board Questions

1. State Huygens' principle and explain Huygens' construction of a spherical wavefront.
   [Oct 96, Feb 03,05]

2. Define a wavefront and explain Huygens' construction of a plane wavefront. **[Mar 98]**

3. Define:
   1. Wavefront ii. Wave normal

   [Mar 99, Oct 2000, 06]

4. State Huygens' principle of propagation of light and explain refraction of light on the basis of wave theory of light. **[Oct 2000]**

5. State Huygens' principle and prove Snell's law for refraction of light on the basis of Huygens' wave theory. **[Feb 04]**

6. State the laws of refraction. Derive the Snell's law on the basis of Huygens' wave theory of light. **[Feb 06]**

7. State Huygen's principle. Explain refraction of a plane wavefront at a plane surface on the basis of Huygen's wavetheory of light. **[Oct 08]**

8. Draw a neat labelled ray diagram of refraction of a plane wavefront at a plane surface. **[Oct 10, Oct 11]**

Section C: Numerical Board Questions

1. The refractive indices of glycerine and diamond with respect to air are 1.4 and 2.4 respectively. Calculate the speed of light in glycerine and in diamond. From these results calculate the refractive index of diamond w.r.t. glycerine. **[Oct 96]**

2. A ray of light is incident on a glass slab making an angle of 30° with the surface. Calculate the angle of refraction in glass and velocity of light in glass, if the refractive index of glass and velocity of light in air are 1.5 and 3×10^8 m/s respectively. **[Mar 98,05]**

3. A ray of light is incident on a glass slab making an angle of 25° with the surface. Calculate the angle of refraction in glass and velocity of light" in glass, if the refractive index of glass and velocity of light are 1.5 and 3×10^8 m/s respectively. **[Oct 01]**

4. The wave number of beam of light in air is 2.5×10^6 per metre. What is the wavelength in glass if refractive index of glass is 1.5? **[Oct 02]**

5. The refractive index of glass with respect to water is 1.125. If velocity and wavelength of light in a glass are 2×10^8 m/s and 4×10^{-7} m respectively. Find the velocity, wavelength and frequency of light in water. **[Oct 03]**

6. A ray of light travelling in air is incident on the glass making an angle of 30° with the surface. Calculate the angle by which the refracted ray in glass is deviated from its original path and velocity of light in glass

   [R. I of glass is 1.5] **[Oct 05]**

7. The wavelength of a beam of light in air is 3750 Å. Find the number of waves of the beam in 10 cm of glass. Also find the time required by the beam to pass through 10 cm of glass of refractive index 1.5.

   [Velocity of light in air = 3×10^8 m/s] **[Mar 11]**

8. If the difference in the velocities of light in glass and water in 0.25×10^8 m/s, find the velocity of light in glass.

   [Given $\mu_g = \frac{3}{2}$ and $\mu_w = \frac{4}{3}$] **[Oct 11]**

Multipal Choice Questions

1. The. nature of light waves is similar to
a) alpha rays b) gamma rays
c) cathode rays d) cosmic rays
2. Huygens' concept of secondary waves
a) allows us to find the focal length of a thick lens.
b) gives us the magnifying power of a microscope.
c) is a geometrical method to find a wavefront:
d) is used to determine the velocity of light.
3. According to Huygens' wave theory, every point on the wavefront behaves as a source of
a) secondary waves
b) stationary.waves
c) surface waves
d) beats
4. In isotropic medium,
a) speed oflight changes
b) speed of light remains constant
c) direction of propagation of light changes
d) wavelength of light changes
5. Luminiferous ether is a medium which is
a) actually present in atmospheric air.
b) actually present everywhere.
c) supposed to be present in atmospheric air according to Newton's corpuscular theory.
d) supposed to be present everywhere according to the Huygens' wave theory of light.
6. Which of the following properties is true in case of ether?
a) Very high elasticity of volume
b) Very high elasticity of shape
c) Very low elasticity of volume
d) Very low elasticity of shape
7. According to wave theory of light, velocity of light in rarer medium is
a) equal to velocity of light in denser medium,
b) greater than velocity of light in denser medium.
c) less than velocity of light in denser medium.
d) approximately equal to velocity of light in denser medium.
8. Huygens' wave Theory of light could not explain
a) reflection
b) refraction
c) interference
d) Photoelectric effect
9. Which of the following phenomenon is not explained by Huygens' construction of wavefront?
a) Refraction b) Reflection
c) Diffraction d) Origin of spectra
10. The wavefront originating from the point source of light at finite distance is _____ wavefront.
a) spherical b) plane
c) cylindrical d) circular
11. According to Huygens' construction, tangential envelope which touches all the secondary spheres is the position of
a) original wavefront
b) secondary wavefront
c) geometrical wavefront
d) extended wavefront
12. A wavefront is
a) a surface perpendicular to the direction of propagation of light.
b) a surface parallel to the direction of propagation of light.
c) a surface without any specific orientation to direction of propagation of light.
d) a surface which has nothing to do with intensity of light.
13. Spherical wavefront propagating in a homogeneous and isotropic medium gives rise to
a) plane wavefront
b) spherical wavefront
c) both spherical and plane wavefront
d) cylindrical wavefront
14. Cylindrical wavefront can be obtained from
a) point source of light
b) light source like slit
c) light source like circle
d) point source oflight at infinity
15. Plane wavefront can be obtained from
a) any point source of light
b) point source placed at focus of convex lens
c) linear source of light
d) co-axial source
16. A spherical wavefront propagating m a medium will change into
a) circular wavefront
b) cylindrical wavefront
c) plane wavefront
d) elliptical wavefront
17. As a plane wavefront propagates, its radius of curvature
a) decreases
b) increases
c) first increasesand then decreases
d) remains infinity

18. Light from star reaching on earth's surface is in the form of wavefront.
a) spherical b) plane
c) cylindrical d) elliptical

19. The wavefront obtained from a source of light is cylindrical at time t, the source of light is
a) a point source at finite distance.
b) a point source at infinite distance.
c) a thin linear source.
d) of a large size and of any shape.

20. When wavefront strikes a reflecting surface,
a) it comes to rest
b) it penetrates the reflecting surface
c) the surface bends
d) the points on the surface become source of secondary wavelets

21. During the refraction of a green light from denser medium to rarer medium, the property of light which always remains constant is its
a) speed b) frequency
c) wavelength d) direction

22. A parallel beam of light traveling in glass is incident obliquely oil water surface. After refraction, its width
a) decreases b) increases
c) remains same d) becomes zero

23. In case of refraction of light for normal incidence, there is no deviation because
a) i = 90° then r = 0°
b) i = 0° then r = 0°
c) i = 0° then r = 90°
d) i = 90° then r = 90°

24. A ray of light passes from vacuum to a medium of refractive index u. Angle of incidence is found to be twice the angle of refraction. The angle of incidence is given by
a) $\cos^{-1}\left(\frac{\mu}{2}\right)$ b) $\cos^{-1}(\mu)$
c) $2\cos^{-1}\left(\frac{\mu}{2}\right)$ d) $2\sin^{-1}\left(\frac{\mu}{2}\right)$

25. The absolute refractive index of air is
a) 0 b) 0.95
c) 1 d) ∞

26. The angle between the original direction of incident ray and reflected ray is
a) angle of deviation due to reflection
b) angle of emergence
c) angle of reflection
d) angle of refraction

27. A monochromatic beam of light is refracted into water and then into glass. If λ_a, λ_w and λ_g are its wavelengths in air, water and glass respectively, then
a) $\lambda_a = \lambda_w = \lambda_g$
b) $\lambda_a > \lambda_w > \lambda_g$
c) $\lambda_a < \lambda_w < \lambda_g$
d) $\lambda_a > \lambda_w$ or λ_g and $\lambda_w = \lambda_g$

28. Which of the following is correct?
a) ${}_1\mu_2 = \frac{\sin i}{\sin r}$ b) ${}_1\mu_2 = \frac{c_2}{c_1}$
c) ${}_1\mu_2 = \frac{\mu_1}{\mu_2}$ d) ${}_1\mu_2 = \frac{\sin r}{\sin i}$

29. The velocity of light in air is c. Its velocity in a medium of refractive index 1.4 will be
a) c b) $\frac{c}{1.4}$
c) c × 1.4 d) c + 1.4

30. The refractive index of glass is 1.68 and that of an oil is 1.2. When a light ray passes from oil to glass, its velocity will change by a factor
a) 1/1.2 b) 1.68 × 1.2
c) $\frac{1}{1.4}$ d) $\frac{1}{1.68 \times 1.2}$

31. A ray of light of frequency 4×10^{14} Hz is refracted through glass of R.I 1.5. If $c = 3 \times 10^8$ m/s in air, the percentage change in the wavelength from air to glass is
a) 50% b) 25%
c) 20% d) 33%

32. A light wave has a frequency of 4×10^{14} Hz and a wavelength of 5×10^{-7} m in a medium. The refractive index of the medium is
a) 1.5 b) 1.33
c) 1.0 d) 0.66

33. Time taken by the sunlight to pass through window of thickness 4 mm, whose refractive index is 1.5, is
a) 2×10^{-1} s b) 2×10^{8} s
c) 2×10^{-11} s d) 2×10^{11} s

34. The ratio of velocity of light in glass to water, if R.I of glass and water with respect to air are 3/2 and 4/3 respectively, will be
a) 9/8 b) 8/9
c) 3/4 d) 2/3

35. The velocity of light in vacuum is 3 × 108 m/s. Determine the velocity, wavelength and frequency of green light of wavelength 5270 Å in glass.

Refractive index of glass is 1.5.
a) 2×10^8 m/s, 3513Å, 5.7×10^{14} Hz
b) 3×10^8 m/s, 4513 Å, 6.7×10^{14} Hz
c) 4×10^8 m/s, 8900 Å, 7.7×10^{14} Hz
d) 5×10^8 m/s, 7000 Å, 8.7×10^{14} Hz

36. The refractive indices of glass and diamond with respect to air are 1.5 and 2.4 respectively. The refractive index of diamond with respect to glass is
a) 0.62 b) 0.9
c) 1.95 d) 1.6

37. Monochromatic light of wavelength 6870 Å is refracted through water surface. Determine its wavelength and frequency in water, if its frequency in air is 4.4×10^{14} Hz. Refractive index of water is 1.33.
a) 7100 Å, 3×10^{14} Hz
b) 4933 Å, 4×10^{14} Hz
c) 6565 Å, 6×10^{14} Hz
d) 5165 Å, 4.4×10^{14} Hz

38. A monochromatic light of wavelength 4310 Å is incident on the surface of a glass slab of R.I 1.6. Determine the wavelength and frequency of light in glass, if its frequency in air is 5.8×10^{14} Hz.
a) 5993 Å, 2×10^{14} Hz
b) 4693 Å, 4×10^{14} Hz
c) 3000 Å, 7×10^{14} Hz
d) 2694 Å, 5.8×10^{14} Hz

39. When light travels from air to water, its speed is retarded by [$\mu_w = 4/3$]
a) $\frac{3}{4} \times 10^7$ m/s b) $\frac{4}{3} \times 10^7$ m/s
c) 2.25×10^8 m/s d) 7.5×10^7 m/s

40. The refractive index of certain glass is 1.5 for yellow light of wavelength 591 nm in air. The wavelength of the light in the glass will be
a) 591 am b) 394 nm
c) 886.5 nm d) 295.5 nm

41. The number of waves of electromagnetic radiation of wavelengths 5000 Å in a path of 4 cm in vacuum is
a) 7.5×10^4 b) 8×10^4
c) 9×10^6 d) 10×10^6

42. The frequency of a beam of light in air is 8×10^{14} Hz. The wave number of the beam of light in air is
a) 1.67×10^6 m^{-1} b) 2.67×10^6 m^{-1}
c) 3.67×10^6 m^{-1} d) 4.67×10^6 m^{-1}

43. One cannot see through fog because
a) fog absorbs light.
b) light is scattered by the droplets in fog.
c) light suffers total reflection at the droplets in fog.
d) the refractive index of fog is infinity.

44. The transverse nature of light is shown by
a) interference of light
b) refraction of light
c) polarisation of light
d) dispersion of light

45. The polarisation of an electromagnetic wave is determined by
a) the electric field only.
b) the magnetic field only.
c) both the electric and magnetic fields.
d) the direction of propagation of electromagnetic waves.

46. The plane of vibration and the plane of polarisation of a beam of light
a) are identical to each other.
b) are orthogonal to each other.
c) make an angle, which depends on the colour of the light.
d) rotate with respect of each other along the path of the beam.

47. Which of the following phenomenon is used to test and measure the optical activity of crystal like quartz?
a) Interference b) Polarisation
c) Diffraction d) Refraction

48. Unpolarised light consists of electric field vectors in
a) anyone plane
b) plane of paper
c) perpendicular to plane of paper
d) all possible planes

49. Waves that cannot be polarised are
a) radio waves b) X-rays
c) visible light d) sound waves

50. When unpolarised light is passed through crossed polaroids, then light passing through first polaroid
a) also passes through second polaroid.
b) is blocked by second polaroid.
c) partially passes through second polaroid.
d) passes with greater intensity.

51. The critical angle does not depend upon
a) wavelength b) refractive index
c) temperature d) frequency

52. When unpolarised light is incident on a plane glass at Brewster's angle, then which of the following statements is correct?
a) Reflected and refracted rays are completely polarised with their planes of polarisation parallel to each other.

b) Reflected and refracted rays are completely' polarised with their planes of polarisation perpendicular to each other.

c) Reflected light is plane polarised but transmitted light is partially polarised.

d) Reflected light is partially polarised but refracted light is plane polarised.

53. An unpolarised beam of transverse waves is one whose vibrations

a) occur in all directions.

b) occur in all directions perpendicular to the direction of wave propagation.

c) occur in one direction.

d) occur in all directions parallel to the direction of wave propagation.

54. A ray of light strikes a glass plate at an angle of 60°. If reflected and refracted rays are perpendicular to each other, the R.I. of glass is

a) $\frac{1}{2}$ b) $\sqrt{\frac{3}{2}}$

c) 2/3 d) 1.732

55. Refractive index of material is equal to tangent of polarising angle. It is called

a) Lambert's law b) Bragg's law

c) Brewster's law d) Malus law

56. When a light wave suffers reflection at the interface from air to glass, the change in phase of reflected wave is equal to

a) 0 b) π

c) $\pi/2$ d) 2π

57. A ray of light incident on a glass slab gets completely polarised. If the angle of incidence is 8, then the angle of refraction is ______

a) θ b) $90^{o} - \theta$

c) $180° - \theta$ d) $90° + \theta$

58. According to Brewster's law, at polarising angle, the reflected and refracted rays are

a) parallel to each other

b) antiparallel to each other

c) perpendicular to each other

d) at 40° to each other

59. Angle of polarisation for a transparent medium

a) does not depend on wavelength oflight.

b) increases as wavelength increases.

c) decreases as wavelength increases.

d) changes irregularly with mcrease m wavelength.

60. If the polarizing angle for a given medium is 60°, then the refractive index of the medium is

a) $\frac{1}{\sqrt{3}}$ b) 1

c) $\frac{\sqrt{3}}{2}$ d) $\sqrt{3}$

61. For a given medium, the polarising angle is 60°. The critical angle for this medium

a) 47°23' b) 60°10'

c) 23°30' d) 35°16'

62. The angle of incidence at which the polarisation of light reflected from the surface of glass occurs is 58°. The refractive index of glass is

a) 1.9 b) 1.8

c) 1.7 d) 1.6

63. If the critical angle for total internal reflection from a medium to vacuum is 30°, then velocity of light in the medium is

a) 6×10^8 m/s b) 3×10^8 m/s

c) 2×10^8 m/s d) 1.5×10^8 m/s

64. The angle of-incidence is 60° and the angle of refraction is 30°. The polarising angle for the same medium is

a) 55° b) 45°

c) 30° d) 60°

65. In a doubly refracting crystal, optic axis is a direction along which

a) plane polarised light does not suffer deviation.

b) any beam of light does not suffer deviation.

c) double refraction does not take place.

d) O-ray and E-ray undergo maximum deviation.

66. Dichroism is the property where

a) unequal absorption of O-ray and B-ray takes place.

b) equal absorption of O-ray and E-ray takes place.

c) plane of polarisation rotates.

d) unequal reflection of O-ray and E-ray takes place.

67. If the shift of wavelength of light emitted by a star is towards violet, then this shows that star is

a) stationary

b) moving towards earth

c) moving away from earth

d) information is incomplete

68. If a star is moving towards the earth, then the lines are shifted towards

a) red b) infrared

c) blue d) green

69. It is believed that the universe is expanding and hence the distant stars are receding from us. Light from such a star will show

a) shift ill frequency towards longer wavelengths.
b) shift ill frequency towards shorter wavelength.
c) no shift in frequency but a decrease in intensity.
d) a shift in frequency sometimes towards longer and sometimes towards shorter wavelengths.

70. A rocket is going away from the earth at a speed 0.2c, where c = speed of light. It emits a signal of frequency 4×10^7 Hz. What will be the frequency as observed by an observer on the earth?
a) 4×10^6 Hz b) 3.2×10^7 Hz
c) 3×10^6 Hz d) 5×10^7 Hz

ANSWERS :

Section A

1. 4.5×10^5 m^{-1}
2. 1.5
3. 1.847
4. 6150 Å
5. 53° 3'
6. 58°57'
7. 30°
8. 67° 33'
9. 1.54
10. 180 kmh^{-1}
11. i. 1.67
    ii. 1.33
    iii. 1.25
12. 6.67×10^{14} Hz, 2903 Å
13. 2×10^8 m/s, 2.25×10^8 m/s, 1.125
14. 1.245
15. 37°, 1.327
16. 0.44

Section C

1. 2.143×10^8 m/s, 1.25×10^8 m/s, 1.714
2. 35° 16',2×10^8 m/s
3. 37° 9' , 2×10^8 m/s
4. 2667 Å
5. 2.25×10^8 m/s, 4500×10^{-10}m, 5×10^{14} Hz
6. 24° 44', 2×10^8 m/s
7. 4×10^5 m^{-1}, 5×10^{-10}s
8. 2×10^8 m/s

Answer Keys

1. b)	2. c)	3. a)	4. b)	5. d)	6. a)	7. b)	8. d)	9. d)	10. a)
11. b)	12. a)	13. b)	14. b)	15. b)	16. c)	17. d)	18. b)	19. c)	20. d)
21. b)	22. b)	23. b)	24. c)	25. c)	26. a)	27. b)	28. a)	29. b)	30. c)
31. d)	32. a)	33. c)	34. b)	35. a)	36. d)	37. d)	38. d)	39. d)	40. b)
41. b)	42. b)	43. b)	44. c)	45. a)	46. b)	47. b)	48. d)	49. d)	50. b)
51. d)	52. c)	53. b)	54. d)	55. c)	56. b)	57. b)	58. c)	59. c)	60. d)
61. d)	62. d)	63. d)	64. d)	65. c)	66. a)	67. b)	68. c)	69. a)	70. b)