**Written as per the revised syllabus prescribed by the Maharashtra State Board of Secondary and Higher Secondary Education, Pune.**

# Perfect
# Physics – II
## STD. XII Sci.

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**Note: 1.** **** mark represents all Textual questions.***

**2.** ***# mark represents all Intext questions.***

# 10 Wave Theory of Light

## *Subtopics*



### 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.

**Note**

**Maxwell's electromagnetic theory:**

i. Maxwell postulated the existence of electromagnetic waves.

ii. 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.

iii. Thus, Maxwell established relationship between electricity and magnetism.

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

**Planck's quantum theory:**

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

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

iii. Each quantum of light (photon) has energy, $E = h\nu$

where, $h$ = Planck's constant $= 6.63 \times 10^{-34}$ Js

$\nu$ = frequency of light

## 10.1 Wave theory of light

***Q.3. Give a brief account of Huygens' wave theory of light. [Oct 01, 04]**

**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.

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.

**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 reach the 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'.

**Note**

Light waves are assumed to be transverse whose speed in a hypothetical medium is given by $v = \sqrt{\frac{E}{\rho}}$,

where E and $\rho$ are elasticity and density of the medium respectively.

**Q.4. State the merits of Huygens' wave theory of light.**

**Ans: Merits of Huygens' wave theory of light:**

i. It gives satisfactory explanation for laws 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 experimentally proved that velocity of light in rarer medium is greater than that in a denser medium.

**Q.5. State demerits of Huygens' wave theory of light. [Oct 01]**

**Ans: Demerits of Huygens' wave theory of light:**

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

ii. It could not explain polarisation of light, Compton effect, photoelectric 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**

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.6. Define the following terms.**

**i. Wavefront**

**ii. Wave normal**

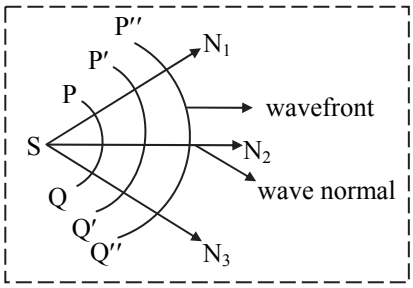
**iii. Wave surface**

**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.7. State the main characteristics of wave normal.**

**Ans: Characteristics of wave normal:**

i. It gives the direction of propagation of wave.

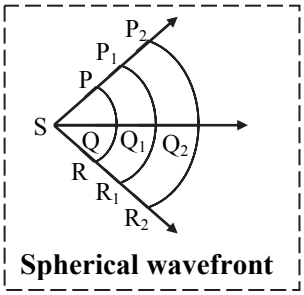
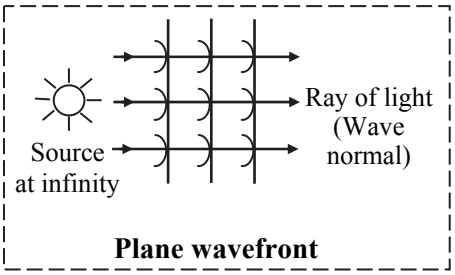
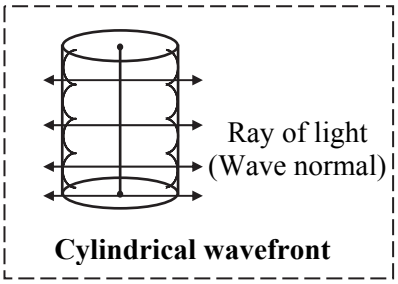
ii. It is perpendicular to wavefront.

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.

**Q.8. State different types of wavefronts with examples.**

**Ans:**

| Types of wavefronts | | |
|---|---|---|
| **Spherical wavefront** | **Plane wavefront** | **Cylindrical wavefront** |
| *A wavefront originating from a point source of light at finite distance is called spherical wavefront.* | *A wavefront originating from a point source of light at infinite distance is called plane wavefront.* | *A wavefront originating from a linear source (slit) of light at a finite distance is called cylindrical wavefront.* |
|   **Spherical wavefront** |   **Plane wavefront** |   **Cylindrical wavefront** |
| Example: Candle flame produces spherical wavefront. | Example: The light from the Sun reaches the surface of the Earth in the form of plane wavefront. | Example: A tube light emits cylindrical wavefront. |

**Q.9. 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 $2\pi$. So, if the phase at a crest is $2\pi$, then phase at next consecutive crest = $4\pi$ 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.

## 10.3 Huygens' principle

***Q.10.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 wave-front).*

iii. *The resultant wavefront at any position is given by the tangent to all the secondary wavelets at that instant.*

**Q.11. 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 and spherical wavefront

**Brain Teaser**

**Q.12.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:**

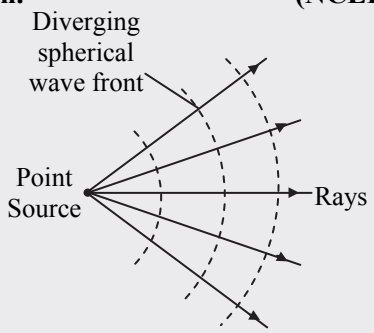



**Figure (a)**

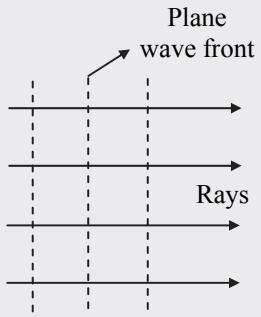



**Figure (b)**

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.13.Explain the Huygens' construction of plane wavefront. [Oct 99]**

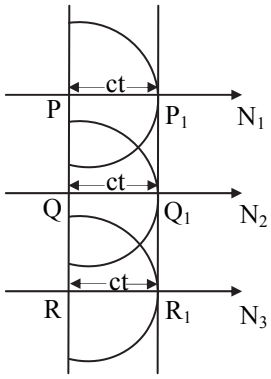
**Ans:**

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 wavefronts 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.14.Explain the Huygens' construction of spherical wavefront. [Mar 12]**

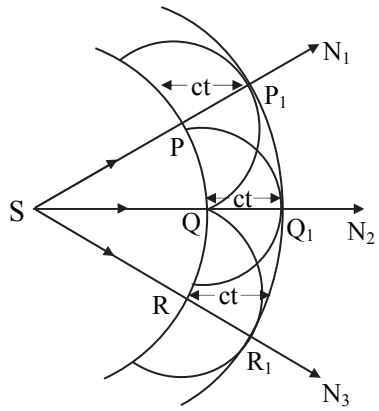
**Ans:**

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 and refraction of a plane wavefront at a plane surface

***Q.15. With the help of a neat diagram, explain reflection of light from a plane reflecting surface on the basis of wave theory of light.**

**Ans:**

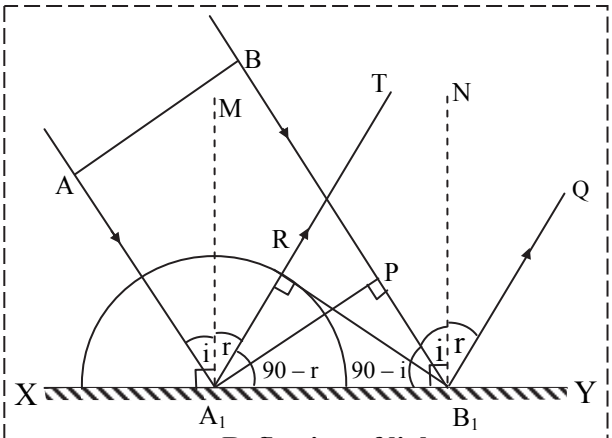
**Laws of reflection:**

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., $\angle i = \angle r$.

**Diagram**




**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**

**Explanation**

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 $A_1R = PB_1 = ct$.

***Q.16.Explain refraction of light on the basis of wave theory. Hence prove laws of refraction. [Mar 96, Mar 13 old course]**

**Ans:**

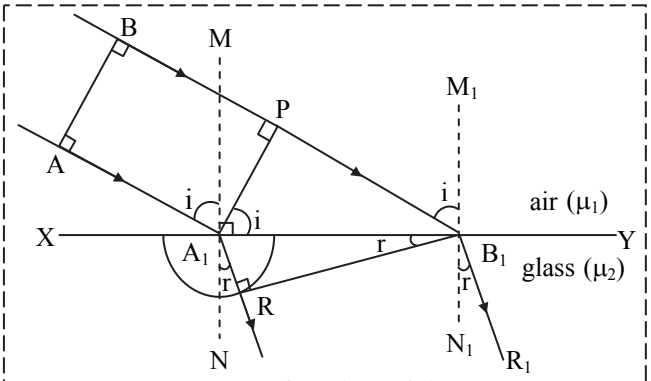
**Laws of refraction:**

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

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

iii. 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.

**Diagram**




**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**

*[Diagram + labelling – **1 Mark**]*

**Explanation**

i. Let XY be the plane refracting surface separating two media air and glass of refractive indices $\mu_1$ and $\mu_2$ 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 reach XY.

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.

iv. All other rays between $AA_1$ and $BB_1$ will reach XY after $A_1$ and before $B_1$. Hence they will 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 $\angle MA_1R = \angle NB_1Q = r$.
$\angle RA_1B_1 = 90 - r$
$\angle PB_1A_1 = 90 - i$

vii. In $\Delta A_1RB_1$ and $\Delta A_1PB_1$
$\angle A_1RB_1 \cong \angle A_1PB_1$
$A_1R = PB_1$ (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.

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 covered by incident wavefront from P to $B_1 = PB_1 = c_1t$
Distance covered by secondary wave from $A_1$ to $R = A_1R = c_2t$. ***[½ Mark]***

**Proof of laws of refraction:**

i. From figure,
$\angle AA_1M + \angle MA_1P = 90°$ ….(1)
and $\angle MA_1P + \angle PA_1B_1 = 90°$ ….(2)
From equations (1) and (2),
$\angle AA_1M = \angle PA_1B_1 = i$

ii. Similarly, $\angle NA_1R = \angle N_1B_1R_1 = r$
We have, $\angle N_1B_1R_1 + \angle N_1B_1R = 90°$ ….(3)
and $\angle N_1B_1R + \angle A_1B_1R = 90°$ ….(4)
From equations (3) and (4),
$\angle N_1B_1R_1 = \angle A_1B_1R = r$ ***[½ Mark]***

iii. In $\Delta A_1PB_1$, $\sin i = \frac{PB_1}{A_1B_1} = \frac{c_1t}{A_1B_1}$ ….(5)

iv. In $\Delta A_1RB_1$, $\sin r = \frac{A_1R}{A_1B_1} = \frac{c_2t}{A_1B_1}$ ….(6)

v. Dividing equation (5) by (6),
$$\frac{\sin i}{\sin r} = \frac{c_1t / A_1B_1}{c_2t / A_1B_1} = \frac{c_1t}{c_2t}$$
$$\therefore \quad \frac{\sin i}{\sin r} = \frac{c_1}{c_2} \quad \text{….(7)}$$ ***[½ Mark]***
Also $\frac{c_1}{c_2} = \frac{\mu_2}{\mu_1} = {}_1\mu_2$ ….(8)
where ${}_1\mu_2$ = R.I. of glass w.r.t air.
$$\frac{\sin i}{\sin r} = \frac{\mu_2}{\mu_1}$$ ***[½ Mark]***

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.

## NCERT Corner

- **Refraction at a rarer medium:**

**Refraction of a plane wave incident on a rarer medium for which $v_2 > v_1$. The plane wave bends away from the normal.**