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.
### Additional Information

**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, \( h = \text{Planck’s constant} = 6.63 \times 10^{-34} \text{ Js} \)

\( \nu = \text{frequency of light} \)

### 10.1 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.

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.

**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.

Additional Information

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

Concept Builder

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.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. SN₁, SN₂ and SN₃ 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 different types of wavefronts 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.
ii. Plane wavefront:

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

Q.8. 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 \(2\pi n\) 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.9. 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 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 wavefront).

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


Ans:

<table>
<thead>
<tr>
<th>No.</th>
<th>Primary source of light</th>
<th>Secondary source of light</th>
</tr>
</thead>
<tbody>
<tr>
<td>i.</td>
<td>It is a real source of light</td>
<td>It is a fictitious source of light</td>
</tr>
<tr>
<td>ii.</td>
<td>It sends out primary waves in all possible directions</td>
<td>It sends out secondary waves only in the forward direction</td>
</tr>
<tr>
<td>iii.</td>
<td>Primary wave is effective at every point on its surface</td>
<td>Secondary wave is effective only at the points where it touches the envelope</td>
</tr>
<tr>
<td>iv.</td>
<td>Primary source is situated in air</td>
<td>Secondary source is situated on a wavefront</td>
</tr>
</tbody>
</table>
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:**
- Diverging spherical wavefront

[Diagram of a diverging spherical wavefront with rays and point source]


**Ans:**
- A plane wavefront is formed when point of observation is very far away from the primary source.
- 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.
- Draw hemispheres with P, Q, R... as centres and ‘ct’ as radius. The surface tangential to all such hemispheres is P, Q, R... at instant ‘t’. It is a new wavefront at time ‘t’.
- The plane wavefronts is propagated as plane waves in homogeneous isotropic medium. They are parallel to each other.

[Diagram of plane wavefronts with wave normals PP₁N₁, QQ₁N₂, RR₁N₃ showing direction of propagation]


**Ans:**
- Spherical wavefront is formed when source of light is at a finite distance from point of observation.
- Let S be the point source of light in air. PQR represents spherical wavefront at any instant. The wavefront PQR acts as a

**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.

**Ans:**
- Diverging spherical wavefront
- Plane wavefront

[Diagrams of wavefronts with rays and wave normals]

---

**Q.13. Explain the Huygens’ construction of plane wavefront.**

**Ans:**

- The geometrical shape of the wavefront for the light diverging from a point source would be diverging spherical wavefront, as shown in figure (a).
- 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).
- 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.14. Explain the Huygens’ construction of spherical wavefront.**

**Ans:**
- Spherical wavefront is formed when source of light is at a finite distance from point of observation.
- 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.

\[ S \quad P \quad Q \quad R \]

\[ PQR : \text{Primary wavefront,} \]
\[ P_1Q_1R_1 : \text{Secondary wavefront after time } t, \]
\[ SPN_1, SQN_2, SRN_3 : \text{Wave normals at } P, Q, R \]

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.

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.15. With the help of a neat diagram, explain the 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:

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

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 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 $\angle A_1M = \angle BB_1N = i$ 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 $\triangle A_1RB_1$ and $\triangle A_1PB_1$

$\angle A_1RB_1 \equiv \angle A_1PB_1$

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

$A_1B_1 = A_1B_1$ (common side)

$\therefore \triangle A_1RB_1 \equiv \triangle A_1PB_1$

\[
\angle RA_1B_1 \equiv \angle PB_1A_1 \\
90 - r = 90 - i \quad \therefore \quad i = r
\]

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 $\pi$ radian.


[Mar 96, Oct 99, 04, 12]

Ans: Refer Q.15 (diagram)

10.6 Refraction of a plane wavefront at a plane surface

Q.17.*Explain refraction of light on the basis of wave theory. Hence prove laws of refraction.

[Mar 96, Mar 13 old course]

OR

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

[Mar 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.

\[
XY : \text{plane refracting surface} \\
AB : \text{incident plane wavefront} \\
B_1R : \text{refracted wavefront} \\
AA_1, BB_1 : \text{incident rays} \\
A_1R, B_1R_1 : \text{refracted rays} \\
\angle AA_1M = \angle BB_1M = \angle i : \text{angle of incidence} \\
\angle RA_1N = \angle R_1B_1N_1 = \angle r : \text{angle of refraction}
\]

[Diagram + labelling – 1 Mark]

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.

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, 
$$\angle AA_1M + \angle MA_1P = 90^\circ$$  \hspace{1cm} (1)
and
$$\angle MA_1P + \angle PA_1B_1 = 90^\circ$$  \hspace{1cm} (2)

From equations (1) and (2), 
$$\angle AA_1M = \angle PA_1B_1$$  \hspace{1cm} (1)

ii. Similarly,
$$\angle NA_1R = \angle N_1B_1R$$  \hspace{1cm} (3)

We have,
$$\angle N_1B_1R + \angle N_1B_1R = 90^\circ$$ \hspace{1cm} (3)
and
$$\angle N_1B_1R + \angle A_1B_1R = 90^\circ$$ \hspace{1cm} (4)

From equations (3) and (4), 
$$\angle N_1B_1R = \angle A_1B_1R = r$$  \hspace{1cm} (3)

v. Dividing equation (5) by (6), 
$$\frac{\sin i}{\sin r} = \frac{c_1}{c_2}$$  \hspace{1cm} (7)

$$\therefore \frac{\mu_2}{\mu_1} > 1$$ \hspace{1cm} (1)

ii. Since, \(\frac{c_1}{c_2} = \frac{\mu_2}{\mu_1}\) \hspace{1cm} (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.19. On the basis of Huygens’ wave theory of light, prove that velocity of light in a rarer medium is greater than velocity of light in a denser medium. \hspace{1cm} [Mar 13]

Ans: Refer Q. 17 & Q. 18

Ray diagram – 1 Mark, Description – \(\frac{1}{2}\) Mark, Proof of Snell’s law – 1 \(\frac{1}{2}\) Mark, Angle of incidence in rarer medium is greater than angle of refraction in denser medium – \(\frac{1}{2}\) Mark, Conclusion: \(c_1 > c_2 – \frac{1}{2}\) Mark

Q.20. Define wave number. Write down its unit and dimensions.

Ans: i. Definition:
Wave number is defined as number of waves per unit distance.

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

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

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

iii. Dimensions: \([M^0L^{-1}T^0]\)

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.21. What do you mean by polarisation? \hspace{1cm} [Oct 09]

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 Builder**

**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, end $A$ of string 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 $S_2$ 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.

**Additional Information**

**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 light is polarised by crystal $C_1$. Hence $C_1$ 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).

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

---

**Concept Builder**

**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 \( \mathbf{E} \).

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

v. There are infinite number of directions perpendicular to the direction of propagation of light. So the electric field vector may be along any one of these 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 and at any instant, electric vector can be resolved into two mutually perpendicular components.

---

Q.23. How will you distinguish between polarised and unpolarised light?

Ans:

<table>
<thead>
<tr>
<th>No.</th>
<th>Polarised light</th>
<th>Unpolarised light</th>
</tr>
</thead>
<tbody>
<tr>
<td>i.</td>
<td>The light in which vibrations of the electric field vectors are confined only to one plane is called polarised light.</td>
<td>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.</td>
</tr>
<tr>
<td>ii.</td>
<td>Polarised light has the electric component only in one direction at a given time.</td>
<td>Unpolarised light has electrical component in every direction at any time.</td>
</tr>
</tbody>
</table>

---

Q.24. Explain the following terms with necessary diagram.

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.
Chapter 10: Wave Theory of Light

Q.25. Draw a neat labelled diagram showing the plane of vibration and plane of polarisation for polarised light. [Oct 14]
Ans: Refer Q.24 (only diagram)
[Diagram – 1 Mark, Labelling – 1 Mark]

Q.26. 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.27. 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.

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

Q.29. 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, \( \tan \theta_p = \mu \).

Q.30. Show that when light is incident at polarising angle \( \theta_p \), then \( \tan \theta_p = \mu \) where \( \mu \) is the R.I. of the medium.
Ans: i. Let XY be the interface of refracting media
Ordinary light

\[ \begin{align*}
A & : \text{incident ordinary light} \\
B & : \text{partially polarised or unpolarised light} \\
C & : \text{reflected plane polarised light} \\
\triangle ABN & : \text{incident unpolarised angle} \\
\triangle NBC & : \text{reflected polarised angle} \\
\triangle ABN & : \text{incident polarising angle}
\end{align*} \]
ii. From laws of reflection,
\[ \angle ABN = \angle NBC = i_p \]
Also, \[ \angle CBD = 90^\circ \]

iii. From figure,
\[ i_p + 90^\circ + r_p = 180^\circ \]
\[ \therefore r_p = 90^\circ - i_p \quad \ldots (1) \]

iv. From Snell’s law,
\[ \frac{\sin i_p}{\sin r_p} = \mu \]
\[ \therefore \frac{\sin i_p}{\sin(90^\circ - i_p)} = \mu \quad \text{[From equation (1)]} \]
\[ \therefore \frac{\sin i_p}{\cos i_p} = \mu \]
\[ \therefore \tan i_p = \mu \]
Hence proved.

Q.31. State and explain Brewster’s law. [Oct 09]
Ans: Refer Q.29 and Q.30

*Q.32. 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 \( \perp \) BC
i.e. \( \angle DBC = 90^\circ \)

\[ \therefore \sin i_p = \mu \quad \text{[From equation (1)]} \]
\[ \therefore \cos i_p = \mu \]
\[ \therefore \tan i_p = \mu \]
Hence proved.

**10.10 Polaroids**

Q.33. What is a polaroid?
Ans: 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 a polaroid.

Example: H-Polaroids, K-Polaroids etc.
Additional Information

In 1852, W.H. Herapath discovered a synthetic material, iodosulphate of quinine, known as Herapathite. Though it showed strong dichroism, these crystals were not stable and were affected by slight strain. Hence they were not of much use. In 1934, E.H. Lamb developed a new type of polarizer called as Polaroid. He arranged herapathite crystals side by side to form a single crystal of large dimensions. Crystals were arranged in such that their optic axes remained parallel.

**Polarising action of a polaroid:**

i. 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](image)

ii. When light is incident on $P_1$, the emergent light from $P_1$ is plane polarised. This is now transmitted through the second polaroid $P_2$.

iii. 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.

iv. 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).

![Figure (b) Transverse position of polaroid](image)

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

Q.34. State the main uses of polaroids.

**Ans:** Use 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.

Q.35. What is a polaroid? State its ‘two’ uses.

**Ans:** Refer Q.33, Q.34

**Explanation** - 1 Mark, Any two uses - $\frac{1}{2}$ Mark each

Q.36. What is dichroism?

**Ans:** 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.

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

ii. Dichroic substance produces linearly polarised light.

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

Example: Tourmaline crystal.

Q.37. Distinguish between ordinary and extra ordinary ray.

**Ans:**

<table>
<thead>
<tr>
<th>No.</th>
<th>Ordinary ray</th>
<th>Extra ordinary ray</th>
</tr>
</thead>
<tbody>
<tr>
<td>i.</td>
<td>The ray which obeys Snell’s law and laws of refraction is called ordinary ray.</td>
<td>The ray which does not obey the laws of refraction is called extra ordinary ray.</td>
</tr>
<tr>
<td>ii.</td>
<td>It is denoted by O.</td>
<td>It is denoted by E.</td>
</tr>
<tr>
<td>iii.</td>
<td>It passes undeviated through the crystal.</td>
<td>It deviates after refraction.</td>
</tr>
<tr>
<td>iv.</td>
<td>Inside the crystal, speed of O-ray is less than E-ray.</td>
<td>Inside the crystal, speed of E-ray is more than O-ray.</td>
</tr>
<tr>
<td>v.</td>
<td>The speed is constant in the medium.</td>
<td>The speed is not constant in the medium.</td>
</tr>
<tr>
<td>vi.</td>
<td>It gives spherical wavefront.</td>
<td>It gives ellipsoidal wavefront.</td>
</tr>
</tbody>
</table>
10.11 Doppler effect in light

*Q.38. 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 relative to observer 1 and 2.

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

\[ v = v_0 \left[ \frac{1 \pm \frac{v}{c}}{\sqrt{1 - \left(\frac{v}{c}\right)^2}} \right] = v_0 \frac{c \pm v}{c \mp v} \quad \ldots (1) \]

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

\( v \) = radial component of velocity of source relative to the observer.

\( c \) = speed of light in vacuum.

iv. When \( v \ll c \), then equation (1) can be written as,

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

[From binomial expansion]

\[ \therefore v - v_0 = \pm \frac{v}{c} v_0 \]

\[ \therefore v - v_0 = \pm \frac{v}{c} \frac{v_0}{v_0} \]

\[ \therefore \Delta v = \pm \frac{v}{c} \quad \ldots (2) \]

[were, \( \Delta v = v - v_0 \)]

v. The negative sign is used in equation (2) 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,

\[ \frac{\Delta \lambda}{\lambda_0} = \pm \frac{v}{c} \quad \ldots (3) \]

In equation (3), 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.39. 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.40. Explain the applications of Doppler effect of light in astronomical physics.

Ans: i. Doppler effect of light is used to determine the radial velocities of distant galaxies.

ii. It is used to measure the speed of rotation of the sun.

a. 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.

b. 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.

c. 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.41. Explain the Doppler effect in measurement of plasma temperature.

Ans: i. In thermonuclear fusion experiments, scientists 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. Due to Doppler effect, the wavelength \( \lambda \) of a particular spectral line is apparently changed.

iv. One edge of the line now corresponds to an apparently increased wavelength \( \lambda \) due to molecules moving directly towards the observer and the other edge to an apparently decreased wavelength \( \lambda_2 \) 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 \( \lambda \) and \( c \) are known, the velocity \( v \) can be calculated using the formula,

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

Note: 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.

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, every point on the wavefront acts as secondary source. At any later instant, these sources give rise to new wavefronts 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:

\[
\mu_2 = \frac{\sin i_1}{\sin r_1} = \frac{c_1}{c_2}
\]

8. The reciprocal of wavelength is called the wave number (\( \nu \)). It is given by,

\[
\nu = \frac{1}{\lambda}
\]

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.

\[
\mu = \frac{c_1}{c_2} = \frac{\lambda_2}{\lambda_1} = \frac{\sin i_1}{\sin r_1}
\]

10. The wavelength range of visible light is from 4000 Å to 8000 Å. The corresponding frequency range is from \( 0.75 \times 10^{15} \) Hz to \( 3.75 \times 10^{14} \) 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., \( \tan \theta = \mu \).

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: \( c = \nu \lambda \).
2. Snell’s law: \( \mu = \frac{\mu_2}{\mu_1} = \frac{\lambda_1}{\lambda_2} \).
3. Velocity of light in a medium: \( v = \frac{c}{\mu} \).
4. Wavelength of light in a medium: \( \lambda_m = \frac{\lambda}{\mu} \).
5. Relation between R.I of different medium:
   i. \( a \mu_b \times b \mu_c \times c \mu_a = 1 \)
   ii. \( a \mu_b = \frac{1}{b \mu_c \times c \mu_a} \)
   iii. \( a \mu_c = \frac{1}{a \mu_b} \)
   iv. \( a \mu_b \times b \mu_c = a \mu_c \)
6. Wave number: \( \nu = \frac{1}{\lambda} \).
7. Critical angle: \( i_c = \sin^{-1}\left(\frac{1}{\mu}\right) \).
8. Brewster’s law: \( \mu = \tan i_p \).
9. Doppler’s shift: \( \frac{\Delta \lambda}{\lambda_0} = \pm \frac{v}{c} = \frac{\Delta \nu}{\nu_0} \).

**Solved Examples**

**Example 1**
What is the wave number of a beam of light in air if its frequency is \( 9 \times 10^{14} \) Hz?

**Solution:**
Given: \( \nu = 9 \times 10^{14} \) Hz, \( c = 3 \times 10^8 \) m/s
To find: Wave number \( (\nu) \)
Formula: \( \nu = \frac{c}{\lambda} \)
Calculation: From formula,
\[ \lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{9 \times 10^{14}} \]
\[ \therefore \nu = 3 \times 10^6 \text{ m}^{-1} \]
Ans: The wave number of the beam is \( 3 \times 10^6 \text{ m}^{-1} \).

**Example 2**
The refractive index of glass is 1.5. What is the speed of light in glass? [Speed of light in vacuum is \( 3 \times 10^8 \) ms^{-1}]

**Solution:**
Given: \( \mu = 1.5, c = 3 \times 10^8 \) m/s
To find: The speed of light in glass \( (v_g) \)
Formula: \( \mu = \frac{c}{v_g} \)
Calculation: From formula,
\[ v_g = \frac{c}{\mu} = \frac{3 \times 10^8}{1.5} = 2 \times 10^8 \text{ m/s} \]
Ans: The speed of light in glass is \( 2 \times 10^8 \) m/s.

**Example 3**
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,
\[ w \mu_g = \frac{4500}{4000} = \frac{9}{8} \]
\[ \therefore w \mu_g = 1.125 \]
Ans: The refractive index of glass w.r.t. water is 1.125.

**Example 4**
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 \( x \).

**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. \( \nu = \frac{1}{\lambda} \)
   ii. \( \frac{\lambda_{vac}}{\lambda_{med}} = \frac{\mu_{med}}{\lambda_{med}} \)

[Oct 10]
Chapter 10: Wave Theory of Light

**Example 5**
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:**
- \( \lambda_1 = 589 \text{ nm} = 589 \times 10^{-9} \text{ m}, \)
- \( c = 3 \times 10^8 \text{ m/s}, \) \( n_w = 1.33 \)

**To find:**
- i. Wavelength \( (\lambda_1) \), frequency \( (v_1) \) and speed \( (v_1) \) of reflected light
- ii. Wavelength \( (\lambda_2) \), frequency \( (v_2) \) and speed \( (v_2) \) of refracted light

**Formulae:**

i. \( c = \nu \lambda \)  
ii. \( n_w = \frac{\lambda_2}{\lambda_1} = \frac{v_1}{v_2} \)  
iii. \( \nu = \frac{1}{\lambda} \)

**Calculation:**

i. For reflected light,  
\( \lambda_1 = 589 \times 10^{-9} \text{ m} \)  
Using formula (i), we get  
\[ v_1 = \frac{c}{\lambda_1} = \frac{3 \times 10^8}{589 \times 10^{-9}} \]  
\[ = \frac{3000}{589} \times 10^{14} \]  
\[ \therefore \]  
\[ v_1 = 5.09 \times 10^{14} \text{ Hz} \]  

ii. Frequency remains unchanged on entering another medium.  
\( \therefore \)  
\[ v_2 = 5.09 \times 10^{14} \text{ Hz} \]  
For refracted light,  
Using formula (ii),  
\[ n_w = \frac{\lambda_1}{\lambda_2} \]  
\[ = \frac{589 \times 10^{-9}}{1.33} \]  
\[ = 4.43 \times 10^{-7} \text{ m} \]  
Using formula (ii),  
\[ \frac{c}{\nu_2} = \frac{v_2}{v_1} \]  
\[ = \frac{3 \times 10^8}{1.33} \]  
\[ \therefore \]  
\[ v_2 = 2.26 \times 10^8 \text{ m/s} \]  

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

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

**Example 6**
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 is \( 4 \times 10^{14} \text{ Hz} \). Find the wave number of light in glass. [Velocity of light in air = \( 3 \times 10^8 \text{ m/s} \)]. [Mar 08]

**Solution:**

**Given:**
- \( n_g = 1.5, \) \( \nu = 4 \times 10^{14} \text{ Hz}, \)
- \( c = 3 \times 10^8 \text{ m/s} \)

**To find:**
- i. Change in wavelength of light \( (\Delta \lambda) \)
- ii. Wave number of light in glass \( (\bar{\nu}) \)

**Formulae:**

i. \( c = \nu \lambda \)  
ii. \( n = \frac{\lambda}{\lambda_g} = \frac{v_1}{v_2} \)  
iii. \( \bar{\nu} = \frac{1}{\lambda} \)

**Calculation:**

i. Using formula (i),  
\[ \lambda_g = \frac{c}{\nu} = \frac{3 \times 10^8}{4 \times 10^{14}} = 0.75 \times 10^{-6} \]  
\[ \therefore \]  
\[ \lambda_g = 7500 \text{ Å} \]
Using formula (ii),
\[ \lambda_g = \frac{\lambda_a}{\mu_g} = \frac{7500 \text{ Å}}{1.5} \]
\[ \therefore \lambda_g = 5000 \text{ Å} \]
\[ \therefore \Delta \lambda = \lambda_a - \lambda_g = 7500 - 5000 \]
\[ \therefore \Delta \lambda = 2500 \text{ Å} \]

Using formula (iii),
\[ \nu_g = \frac{1}{c} \times \frac{1.5}{5.714 \times 10^{-7}} = 1.75 \times 10^6 \text{ m}^{-1} \]

Ans: i. The change in wavelength of light is 2500 Å.
ii. The wave number of light in glass is 1.75 \times 10^6 \text{ m}^{-1}.

Example 8
Determine the change in wavelength of light during its passage from air to glass, if the refractive index of glass with respect to air is 1.5 and the frequency of light is 5 \times 10^{14} \text{ Hz}. Find the wave number of light in glass (velocity of light in air \( c = 3 \times 10^8 \text{ m/s} \)). [July 16]

Solution:
Given: \( \mu_g = 1.5, \nu = 5 \times 10^{14} \text{ Hz} \)
To find:
i. Change in wavelength (\( \Delta \lambda \))
ii. Wave number of light in glass (\( \nu_g \))

Formulae:
\[ i. \lambda = \frac{c}{\nu} \]
\[ ii. \mu_g = \frac{\lambda_a}{\lambda_g} \]
\[ iii. \nu_g = \frac{1}{\lambda_g} \]

Calculation:
Using formula (i),
\[ \lambda_a = \frac{c}{\nu} = \frac{3 \times 10^8}{5 \times 10^{14}} = 6 \times 10^{-6} \text{ m} \]
\[ \therefore \lambda_a = 6000 \text{ Å} \]
From formula (ii),
\[ \lambda_g = \frac{\lambda_a}{\mu_g} = \frac{6000}{1.5} = 4000 \text{ Å} \]
\[ \therefore \Delta \lambda = \lambda_a - \lambda_g = 6000 - 4000 = 2000 \text{ Å} \]

Using formula (iii),
\[ \nu_g = \frac{1}{\lambda_g} \]
\[ \therefore \nu_g = \frac{1}{4000 \times 10^{-10}} = 2.5 \times 10^6 \text{ m}^{-1} \]

Ans: i. Change in wavelength is 2000 Å.
ii. Wave number of light in glass is 2.5 \times 10^6 \text{ m}^{-1}.
Example 9
The wavelength of monochromatic light is 5000 Å in air. What will be its wave number in air?

Solution:
Given: \( \lambda = 5000 \ \text{Å} = 5 \times 10^{-7} \ \text{m} \)
To find: Wave number (\( \nu \))
Formula: \( \nu = \frac{1}{\lambda} \) [½ Mark]
Calculation: From formula,
\[ \nu = \frac{1}{5 \times 10^{-7}} \]
\[ \therefore \nu = 2 \times 10^6 \ \text{m}^{-1} \]
Ans: The wave number of monochromatic light is \( 2 \times 10^6 \ \text{m}^{-1} \).

Example 10
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: \( \angle i = 61^\circ, \angle r = 34^\circ \)
To find: Refractive index of the medium (\( \mu_m \))
Formula: \( \mu_m = \sin i \sin r \) [½ Mark]
Calculation: From formula,
\[ \mu_m = \frac{\sin 61^\circ}{\sin 34^\circ} \]
\[ = \frac{0.8746}{0.5592} \]
\[ \therefore \mu_m = 1.564 \]
Ans: The refractive index of the medium is 1.564.

Example 11
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.

Solution:
Given: \( i = 50^\circ, \mu_w = \frac{4}{3} \)
To find: Angle of refraction (\( r \))
Formula: \( \mu_w = \frac{\sin i}{\sin r} \)
Calculation: Using formula,
\[ \sin r = \frac{\sin i}{\mu} = \frac{\sin 50^\circ}{\frac{4}{3}} \]
\[ = \frac{3}{4} \times 0.7660 \]
\[ = 0.5745 \]
\[ \therefore r = \sin^{-1}(0.5745) \]
\[ = 35^\circ 41' \]
Ans: The angle of refraction of the ray of light is 35° 41'.

Example 12
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: \( \mu = \tan i_p \) [½ Mark]
Calculation: From formula,
\[ i_p = \tan^{-1}(1.5) \]
\[ \therefore i_p = 56.3^\circ = 56^\circ 18' \]
Ans: Brewster angle for air to glass transition is 56.3° or 56° 18'.

Example 13
For a glass plate as a polariser with refractive index 1.633, calculate the angle of incidence at which light is polarised.

Solution:
Given: \( \mu = 1.633 \)
To find: Polarising angle (\( i_p \))
Formula: \( \mu = \tan i_p \) [½ Mark]
Calculation: From formula we get,
\[ i_p = \tan^{-1}(1.633) \]
\[ \therefore i_p = 58^\circ 31' \]
Ans: The angle of incidence at which light is polarised is 58° 31'.

Example 14
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,
\[ \tan i_p = 1.55 \]
\[ \therefore i_p = \tan^{-1}(1.55) = 57^\circ 10' \]
Since \( i_p + r = 90^\circ \),
\[ r = 90^\circ - i_p = 90^\circ - (57^\circ 10') \]
\[ r = 32^\circ 50' \]
Ans: The angle of refraction of the ray of light is \( 32^\circ 50' \).

**Example 15**
For a given medium, the polarising angle is \( 60^\circ \). What will be the critical angle for the medium?

**Solution:**
Given: \( i_p = 60^\circ \)
To find: Critical angle \( (i_c) \)

Formulae: i. \( \mu = \tan i_p \) ii. \( \mu = \frac{1}{\sin i_c} \)

Calculation: Using formula (i) we get,
\[ \mu = \tan 60^\circ = \sqrt{3} \]
Using formula (ii) we get,
\[ \sin i_c = \frac{1}{\mu} = \frac{1}{\sqrt{3}} = 0.5774 \]
\[ i_c = \sin^{-1}(0.5774) \]
\[ i_c = 35^\circ 16' \]
Ans: The critical angle for the medium is \( 35^\circ 16' \).

*Example 16*
If the critical angle of a medium is \( \sin^{-1} (3/5) \), find the polarising angle. [Mar 15]

**Solution:**
Given: \( i_c = \sin^{-1} \left( \frac{3}{5} \right) \)
To find: Polarising angle \( (i_p) \)

Formula: \( \mu = \tan i_p \) [½ Mark]

Calculation: \( \sin i_c = \frac{3}{5} \) (from given data)
But, \( \mu = \frac{1}{\sin i_c} \) [½ Mark]
\[ \frac{1}{\left( \frac{3}{5} \right)} = \frac{5}{3} = 1.667 \] [½ Mark]

From formula, \( i_p = \tan^{-1} (\mu) \)
\[ i_p = \tan^{-1}(1.667) \]
\[ i_p = 59^\circ 2' \]
Ans: The polarising angle of the medium is \( 59^\circ 2' \). [½ Mark]

*Example 17*
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 \( \mu_g \approx \mu_a \)) [Mar 2000, Oct 14]

**Solution:**
Given: \( \lambda_a = 6400 \text{ Å} \), \( \lambda_g = 4000 \text{ Å} \), 
\( (\lambda_a)_{air} = 4400 \text{ Å} \)
To find: Wavelength \( (\lambda_g)_{glass} \)

Formula: \( \frac{\lambda_g}{\lambda_a} = \frac{\lambda_{air}}{\lambda_{glass}} \) [½ Mark]

Calculation: From formula,
\[ \frac{4000}{4400} = \frac{\lambda_{air}}{\lambda_{glass}} \]
\[ \frac{4000}{4400} = \frac{4400}{\lambda_{glass}} \]
\[ \lambda_{glass} = \frac{4400 \times 4000}{6400} \]
\[ \lambda_{glass} = 2750 \text{ Å} \]
Ans: The wavelength of violet light in glass is 2750 Å. [½ Mark]

**Example 18**
The speed of light in air is \( 3 \times 10^8 \text{ m/s} \). 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: \( c = 3 \times 10^8 \text{ m/s}, \mu_g = 1.5 \), 
\( d_g = 20 \text{ cm} = 0.2 \text{ m} \)
To find: Time of travel \( (t) \)

Formula: \( \frac{c}{\mu_g} \)

Calculation: From formula,
\[ v_g = \frac{c}{\mu_g} = \frac{3 \times 10^8}{1.5} = \frac{30}{15} \times 10^8 \text{ m/s} \]
\[ v_g = 2 \times 10^8 \text{ m/s} \]
The time taken by light to travel a distance of \( 2 \times 10^{-2} \text{ m} \) in glass is given by,
\[ t = \frac{d_g}{v_g} = \frac{0.2}{2 \times 10^8} = 1 \times 10^{-9} \text{ s} \]
Ans: The time of travel of light is \( 10^{-9} \text{ s} \).

**Example 19**
The velocity of light in air is \( 3 \times 10^8 \text{ m/s} \). Find the frequency and wavelength of a beam of light in diamond whose wavelength in air is \( 4800 \text{ Å} \). [Given: R.I. of diamond is 2.4]

**Solution:**
Given: \( c = 3 \times 10^8 \text{ m/s}, \mu_d = 2.4 \)
\( \lambda_a = 4800 = 48 \times 10^{-3} \text{ m} \)
To find: i. Wavelength in diamond \( (\lambda_d) \) ii. Frequency in diamond \( (\nu_d) \)

Formulae: i. \( \frac{\lambda_d}{\lambda_a} = \frac{\mu_a}{\mu_d} \) ii. \( c = \nu \lambda \)
Chapter 10: Wave Theory of Light

**Example 20**
The velocity of light in air is $3 \times 10^8$ 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,
- $\mu_d = 2.4$

*To find:*
- i. Frequency in diamond ($v_d$)
- ii. Wavelength in diamond ($\lambda_d$)

**Formulae:**
- i. $v_a = \frac{c}{\lambda_a}$
- ii. $\lambda_a = \frac{\lambda_d}{\mu_d}$

**Calculation:**

- $v_a = \frac{c}{\lambda_a} = \frac{3 \times 10^8}{4.5 \times 10^{-7}} = 6.67 \times 10^{14}$ Hz

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

- $v_a = v_d = 6.67 \times 10^{14}$ Hz

From formula (ii),

- $\lambda_d = \frac{\lambda_a}{\mu_d} = \frac{4.5 \times 10^{-7}}{2.4} = 1.875 \times 10^{-7}$ m

- $\therefore \lambda_d = 1875$ Å

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

**Example 21**
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: $c = 3 \times 10^8$ m/s]

**Solution:**

*Given:*
- $a_{alc} = 1.35$
- $a_g = 1.5$
- $\lambda_{alc} - \lambda_g = 440$ Å

*To find:*
- Frequency ($v_a$)

**Formula:**
- $\frac{1}{a_{alc}} - \frac{1}{a_g}$

**Calculation:**

- $\lambda_{alc} - \lambda_g = \frac{\lambda_a}{a_{alc}} - \frac{\lambda_a}{a_g}$

- $\lambda_a \left( \frac{1}{a_{alc}} - \frac{1}{a_g} \right) = 440$

- $\lambda_a \left( \frac{1.35 - 1.5}{(1.35)(1.5)} \right)$
- $\lambda_a = \frac{440(1.5)(1.35)}{0.15}$
- $\lambda_a = 5940$ Å

- $\therefore \lambda_a = 5940$ Å

Now, $c = v_a \lambda_a$

- $v_a = \frac{c}{\lambda_a} = \frac{3 \times 10^8}{5940 \times 10^{-10}} = 0.5051 \times 10^{15}$

- $\therefore v_a = 5.051 \times 10^{14}$ Hz

**Ans:** The frequency of light wave is $5.051 \times 10^{14}$ Hz.
Example 22
The light of wavelength 6400 Å is incident normally on a plane parallel glass slab of thickness 5 cm and \( \mu = 1.6 \). 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: \( c = 3 \times 10^8 \text{ m/s} \)]

Solution:

Given:
- \( \lambda_a = 6400 \text{ Å} = 6.4 \times 10^{-7} \text{ m}, \)
- \( d_a = 5 \times 10^{-2} \text{ m}, \)
- \( c = 3 \times 10^8 \text{ m/s} \)

To find:
- i. Distance of source (\( d_s \))
- ii. Frequency in glass (\( \nu_g \))
- iii. Wavelength in glass (\( \lambda_g \))

Formulae:
- i. \( t = \frac{d}{c} \)
- ii. \( \mu_g = \frac{\sin i}{\sin r} \) [\( \frac{1}{2} \text{ Mark} \)]
- iii. \( \nu_g = \frac{\cos r}{\cos i} \) [\( \frac{1}{2} \text{ Mark} \)]

Calculation:
- From formula (i),
  \[ t_a = t_g \text{ (given)} \]
  \[ \therefore \frac{c}{v_g} = \frac{d_a}{d_g} \]
  \[ \therefore \frac{c}{v_g} = \frac{d_a}{d_g} \]
  \[ \therefore \mu_g = \frac{d_a}{d_g} \]
  \[ \therefore d_a = \mu_g d_g = 1.6 \times 5 \times 10^{-2} \]
  \[ \therefore d_a = 8 \text{ cm} \]

From formula (ii),
\[ \mu_g = \frac{\lambda_a}{\lambda_g} \]
\[ \therefore \lambda_g = \frac{\lambda_a}{\mu_g} = \frac{6400}{1.6} = 4000 \text{ Å} \]
\[ \therefore \lambda_g = 4000 \text{ Å} \]

Now \( c = v_a \lambda_a \)
\[ \therefore v_a = \frac{c}{\lambda_a} = \frac{3 \times 10^8}{6.4 \times 10^{-7}} = \frac{3}{6.4} \times 10^5 \]
\[ \therefore v_a = 4.68 \times 10^{14} \text{ Hz} \]

But, \( v_a = v_g \)
\[ \therefore v_g = 4.68 \times 10^{14} \text{ Hz} \]

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

Example 23
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.

[Mar 01, Oct 15]

Solution:

Given:
- \( i = 60^\circ, \mu_g = 1.5, \)
- 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. \( \mu_g = \frac{\sin i}{\sin r} \) [\( \frac{1}{2} \text{ Mark} \)]
- ii. \( \frac{d_g}{d_a} = \frac{\cos r}{\cos i} \) [\( \frac{1}{2} \text{ Mark} \)]

Calculation:
- From formula (i),
  \[ \sin r = \frac{\sin 60^\circ}{1.5} = 0.8660 \]
  \[ \therefore r = \sin^{-1} (0.5773) = 35^\circ 16' \] [\( \frac{1}{2} \text{ Mark} \)]

- From formula (ii),
  \[ \frac{d_g}{d_a} = \frac{\cos 35^\circ 16'}{\cos 60^\circ} \]
  \[ \therefore \frac{d_g}{d_a} = \frac{0.8164}{0.5} = 1.6 \]
  \[ \therefore \frac{d_g}{d_a} = \frac{16}{10} = 8 : 5 \]

Ans: The ratio of widths of the beam in glass to that in air is 8 : 5. [\( \frac{1}{2} \text{ Mark} \)]

*Example 24
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 \( (v_r - v_v) \)
Chapter 10: Wave Theory of Light

Formula: $\mu = \frac{c}{v}$ [½ Mark]

Calculation: From formula,

$$v_r = \frac{c}{\mu_r} = \frac{3 \times 10^8}{1.325} = 2.264 \times 10^8 \text{ m/s}$$ [½ Mark]

Similarly,

$$v_v = \frac{c}{\mu_v} = \frac{3 \times 10^8}{1.334} = 2.249 \times 10^8 \text{ m/s}$$ [½ Mark]

Now,

$$v_r - v_v = 2.264 \times 10^8 - 2.249 \times 10^8 = 0.015 \times 10^8 \text{ m/s}$$ [½ Mark]

∴ $v_r - v_v = 1.5 \times 10^6 \text{ m/s}$

Ans: The difference between velocities of the rays for red and violet colours is $1.5 \times 10^6 \text{ m/s}$.

Example 25

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,

$\angle ADE = \angle r, \angle DAB = \angle i = 70^\circ$

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

∴ $\cos r = 2 \times \cos i$

∴ $\cos r = 2 \times 0.3420 = 0.684$

∴ $r = \cos^{-1}(0.684) = 46.8^\circ$

Now,

$$\mu_a = \frac{\sin r}{\sin i} = \frac{\sin 46.8^\circ}{\sin 70^\circ} = 0.7289$$

∴ $\mu_a = 0.78$

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

Example 26

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: $i = 70^\circ$, $CD = 2AB$

To find: Refractive index ($\mu$)

Formulae:

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

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

Calculation: From formula (i),

$$\cos 70^\circ = \frac{AB}{2AB}$$

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

$$\cos r = 0.684$$

∴ $r = 46.51^\circ$

From formula (ii),

$$\mu = \frac{\sin 70^\circ}{\sin (46.51^\circ)} = 0.9397$$

∴ $\mu = 1.288$

Ans: The refractive index for the denser medium is 1.288.

Example 27

If the difference in velocities of light in glass and water is $0.25 \times 10^8 \text{ m/s}$, find the velocity of light in air. [Given : $\mu_g = 1.5$, $\mu_w = 4/3$]

Solution:

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

$$v_r - v_g = 0.25 \times 10^8 \text{ m/s}$$

To find: Velocity of light in air ($c$)

Formula: $\mu = \frac{c}{v}$
**Example 28**

If the difference in velocities of light in glass and water is $2.7 \times 10^7$ m/s, find the velocity of light in air.

(Refractive index of glass = 1.5, Refractive index of water = 1.333)

**Solution:**

Given:

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

To find: Velocity of light in air ($c$)

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

Calculation: From formula we get,

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

\[ \therefore v_g = \frac{c}{\mu_g} \text{ and } v_w = \frac{c}{\mu_w} \]

\[ v_w - v_g = \frac{c}{\mu_w} - \frac{c}{\mu_g} = \frac{c(\mu_g - \mu_w)}{\mu_g \mu_w} \]

\[ 0.25 \times 10^8 = c \left[ \frac{1}{1.5} - \frac{1}{1.33} \right] \]

\[ = c \left[ \frac{3}{4} \times 10^7 - \frac{4}{15} \right] = c \left[ \frac{3}{4} - \frac{2}{3} \right] \]

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

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

\[ \therefore c = 12 \times 0.25 \times 10^8 \]

\[ \therefore c = 3 \times 10^8 \text{ m/s} \]

**Ans:** The velocity of light in air is $3.00 \times 10^8$ m/s.

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**Example 29**

A ray of light travelling through air, falls on the surface of a glass slab at an angle $\angle i$. It is found that the angle between the reflected and refracted ray is $90^\circ$. If the speed of light in glass is $2 \times 10^8$ m/s, find the angle of incidence. \[c = 3 \times 10^8 \text{ m/s}\]

**Solution:**

Given: \[c = 3 \times 10^8 \text{ m/s}, v_g = 2 \times 10^8 \text{ m/s}\]

The angle between reflected and refracted ray i.e., $\angle BOD = 90^\circ$ (in figure)

To find: Angle of incidence ($i$)

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

Calculation:

From the figure, $i + r + 90^\circ = 180^\circ$

\[ \therefore i + r = 90^\circ \]

\[ \therefore r = 90^\circ - i \]

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

From formula,

\[ \mu = \frac{\sin i}{\sin r} = \frac{\sin i}{\sin(90^\circ - i)} = \frac{\sin i}{\cos i} \]

\[ \therefore i = \tan^{-1}(\mu) = \tan^{-1}(1.5) \]

\[ \therefore i \approx 56^\circ 19' \]

**Ans:** The angle of incidence of the ray is $56^\circ 19'$.

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**Example 30**

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:**

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

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

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

\[ \therefore \ c = 3.233 \times 10^8 \text{ m/s} \]

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

*Example 29*

A ray of light travelling through air, falls on the surface of a glass slab at an angle $\angle i$. It is found that the angle between the reflected and refracted ray is $90^\circ$. If the speed of light in glass is $2 \times 10^8$ m/s, find the angle of incidence. \[c = 3 \times 10^8 \text{ m/s}\]

**Solution:**

Given: \[c = 3 \times 10^8 \text{ m/s}, v_g = 2 \times 10^8 \text{ m/s}\]

The angle between reflected and refracted ray i.e., $\angle BOD = 90^\circ$ (in figure)

To find: Angle of incidence ($i$)

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

Calculation:

From the figure, $i + r + 90^\circ = 180^\circ$

\[ \therefore i + r = 90^\circ \]

\[ \therefore r = 90^\circ - i \]

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

From formula,

\[ \mu = \frac{\sin i}{\sin r} = \frac{\sin i}{\sin(90^\circ - i)} = \frac{\sin i}{\cos i} \]

\[ \therefore i = \tan^{-1}(\mu) = \tan^{-1}(1.5) \]

\[ \therefore i \approx 56^\circ 19' \]

**Ans:** The angle of incidence of the ray is $56^\circ 19'$.
Also, 
\[ v = \frac{c}{\lambda} = \frac{3 \times 10^8}{5000 \times 10^{-10}} = 6 \times 10^{14} \text{ Hz} \]
Now, \( i = r \)
Also, \( i + r = 90^\circ \)
\[ \therefore i + i = 90^\circ \text{ or } 2i = 90^\circ \]
\[ \therefore i = 45^\circ \]
Ans: i. The wavelength and frequency of light is 5000 Å and \( 6 \times 10^{14} \text{ Hz} \) respectively.
ii. At 45°, the reflected ray is normal to the incident ray.

Example 31
The earth is moving towards a fixed star with a velocity of 30 km \( \text{s}^{-1} \). 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: \( v = 30 \text{ km} \text{s}^{-1} = 30 \times 10^3 \text{ m} \text{s}^{-1} \), \( \Delta \lambda = 0.58 \text{ Å} \), \( c = 3 \times 10^8 \text{ ms}^{-1} \)
To find: Actual wavelength of light emitted \((\lambda_0)\)
Formula: \[ \frac{\Delta \lambda}{\lambda_0} = \frac{v}{c} \]
Calculation: From formula,
\[ \lambda_0 = \frac{c}{v} \Delta \lambda \]
\[ \therefore \lambda_0 = \frac{3 \times 10^8}{30 \times 10^3} \times 0.58 \text{ Å} \]
\[ \therefore \lambda_0 = 5800 \text{ Å} \]
Ans: Actual wavelength of light emitted by the star is 5800 Å.

Example 32
6563 Å \( \text{H}_\alpha \) 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: \( \lambda_0 = 6563 \text{ Å} = 6.563 \times 10^{-7} \text{ m} \)
To find: Speed (v)
Formula: \[ \frac{\Delta \lambda}{\lambda_0} = \frac{v}{c} \]
Calculation: From formula,
\[ v = \left( \frac{\Delta \lambda}{\lambda_0} \right) c \]
\[ = \frac{15 \times 10^{-10}}{6563 \times 10^{-10}} \times 3 \times 10^8 \]
\[ = 3.06 \times 10^5 \text{ ms}^{-1} \]
\[ \therefore v = 306 \text{ km/s} \]
Ans: The galaxy should move with a speed of 306 km/s.

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)

Example 34
A light source approaches the observer with velocity 0.8 c. Find the Doppler shift for the light of wavelength 5500 Å.

Solution:
Given: \( \lambda = 5500 \text{ Å} \), \( v = 0.8 \text{ c} \)
To find: Doppler shift (\( \Delta \lambda \))
Formula: \[ \lambda' = \lambda \sqrt{\frac{1-v/c}{1+v/c}} \]
Calculation: From formula,
\[ \lambda' = 5500 \sqrt{1-0.8} \sqrt{1+0.8} \]
\[ = 1833.33 \]
\[ \therefore \text{Doppler Shift} = 5500 - 1833.33 \approx 3667 \text{ Å} \]
Ans: The doppler shift in wavelength is 3667 Å.

Example 35
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: 
\[ \nu = \frac{\Delta \lambda}{c} \lambda_0 \]

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

\[ \frac{\lambda}{\lambda_0} = \frac{100.4}{100} \]

On subtracting 1 from both sides, we get,

\[ \frac{\lambda - \lambda_0}{\lambda_0} = \frac{100.4 - 100}{100} \]

\[ \frac{\lambda - \lambda_0}{\lambda_0} = 0.4 \]

\[ \Delta \lambda = 0.004 \lambda_0 \]

From formula,

\[ \frac{\nu}{c} = 0.004 \]

\[ \nu = 0.004 \times 3 \times 10^8 \]

\[ \nu = 1.2 \times 10^6 \text{ m/s} \]

Ans: Radial speed of galaxy with respect to earth is \( 1.2 \times 10^6 \text{ m/s} \).

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**EXERCISE**

**Section A: Practice Problems**

1. What is the wave number of a beam of light in air if its frequency is \( 1.35 \times 10^{14} \) Hz ? \( [c = 3 \times 10^8 \text{ m/s}] \)
2. The velocity of light in a medium is \( 2 \times 10^8 \) m/s and in air is \( 3 \times 10^8 \) 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 \( 8.1 \times 10^9 \) Hz. The reflected wave from an aeroplane shows a frequency difference of \( 2.7 \times 10^3 \) Hz on the higher side. Deduce the velocity of aeroplane in the line of sight.
11. The velocity of light in vacuum is \( 3 \times 10^8 \) m/s, in glass it is \( 1.8 \times 10^8 \) m/s and in water it is \( 2.25 \times 10^8 \) 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. \[ [\text{Given: } c = 3 \times 10^8 \text{ m/s}] \]
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 water.
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 \( v' = (1 - v/c) \nu \) and \( v' = \frac{(1-v/c)\nu}{\sqrt{1-v^2/c^2}} \).
   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. \[ [\text{Oct 96, Mar 03, 05}] \]
2. Define a wavefront and explain Huygens’ construction of a plane wavefront. \[ [\text{Mar 98}] \]
3. Define:
   i. Wavefront
   ii. Wave normal
   \[ [\text{Mar 99, Oct 2000, 06}] \]

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

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

7. State Huygen’s principle. Explain refraction of a plane wavefront at a plane surface on the basis of Huygen’s wave theory of light. [Oct 08]


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 \(3 \times 10^8\) 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 in air are 1.5 and \(3 \times 10^8\) m/s respectively. [Oct 01]

4. The wave number of beam of light in air is \(2.5 \times 10^6\) 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 \(2 \times 10^8\) m/s and \(4 \times 10^{-7}\) 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 = \(3 \times 10^8\) m/s] [Mar 11]

8. If the difference in the velocities of light in glass and water is \(0.25 \times 10^8\) m/s, find the velocity of light in glass. \[Given \mu_g = \frac{3}{2} \text{ and } \mu_w = \frac{4}{3}\] [Oct 11]

Section D: Multiple 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 of light 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 _______. [Mar 08]
   (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 of light 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 in 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 increases and 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 on water surface. After refraction, its width _______.
    (A) decreases
    (B) increases
    (C) remains same
    (D) becomes zero
23. A parallel beam of light travelling in water is incident obliquely on a glass surface. After refraction its width ______. [July 16]
   (A) decreases (B) increases (C) remains the same (D) becomes zero

24. In case of refraction of light for normal incidence, there is no deviation because
   (A) $i = 90^\circ$ then $r = 0^\circ$ 
   (B) $i = 0^\circ$ then $r = 0^\circ$
   (C) $i = 0^\circ$ then $r = 90^\circ$
   (D) $i = 90^\circ$ then $r = 90^\circ$

25. A ray of light passes from vacuum to a medium of refractive index $\mu$. Angle of incidence is found to be twice the angle of refraction. The angle of incidence is given by [Oct 13]
   (A) $\cos^{-1}\left(\frac{1}{\sqrt{2}}\mu\right)$
   (B) $\cos^{-1}(\mu)$
   (C) $2\cos^{-1}\left(\frac{1}{\sqrt{2}}\mu\right)$
   (D) $2\sin^{-1}\left(\frac{\mu}{2}\right)$

26. The absolute refractive index of air is ______. [Oct 09]
   (A) 0 (B) 0.95 (C) 1 (D) $\infty$

27. 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

28. A monochromatic beam of light is refracted into water and then into glass. If $\lambda_w$, $\lambda_a$ and $\lambda_g$ 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 $\lambda_g$ and $\lambda_w = \lambda_g$

29. Which of the following is correct?
   (A) $\mu_2 = \frac{\sin i}{\sin r}$
   (B) $\mu_2 = \frac{c_2}{c_1}$
   (C) $\mu_2 = \frac{\mu_1}{\mu_2}$
   (D) $\mu_2 = \frac{\sin r}{\sin i}$

30. 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) $c \times 1.4$ (D) $c + 1.4$

31. 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) $1.68 \times 1.2$
   (C) $\frac{1}{1.4}$ (D) $\frac{1}{1.68 \times 1.2}$

32. A ray of light of frequency $4 \times 10^{14}$ 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%

33. A light wave has a frequency of $4 \times 10^{14}$ Hz and a wavelength of $5 \times 10^{-7}$ m in a medium. The refractive index of the medium is
   (A) 1.5 (B) 1.33 (C) 1.0 (D) 0.66

34. Time taken by the sunlight to pass through window of thickness 4 mm, whose refractive index is 1.5, is
   (A) $2 \times 10^{-1}$ s
   (B) $2 \times 10^8$ s
   (C) $2 \times 10^{-11}$ s
   (D) $2 \times 10^{11}$ s

35. 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) $2/3$

36. The velocity of light in vacuum is $3 \times 10^8$ 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) $2 \times 10^8$ m/s, 3513 Å, $5.7 \times 10^{14}$ Hz
   (B) $3 \times 10^8$ m/s, 4513 Å, $6.7 \times 10^{14}$ Hz
   (C) $4 \times 10^8$ m/s, 8900 Å, $7.7 \times 10^{14}$ Hz
   (D) $5 \times 10^8$ m/s, 7000 Å, $8.7 \times 10^{14}$ Hz

37. 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 [Mar 09]
   (A) 0.62 (B) 0.9 (C) 1.95 (D) 1.6
38. Monochromatic light of wavelength 6870 Å is refracted through water surface. Determine its wavelength and frequency in water, if its frequency in air is $4.4 \times 10^{14}$ Hz. [Refractive index of water is 1.33.]
   (A) 7100 Å, $3 \times 10^{14}$ Hz
   (B) 4933 Å, $4 \times 10^{14}$ Hz
   (C) 6565 Å, $6 \times 10^{14}$ Hz
   (D) 5165 Å, $4.4 \times 10^{14}$ Hz

39. 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 $5.8 \times 10^{14}$ Hz.
   (A) 5993 Å, $2 \times 10^{14}$ Hz
   (B) 4693 Å, $4 \times 10^{14}$ Hz
   (C) 3000 Å, $7 \times 10^{14}$ Hz
   (D) 2694 Å, $5.8 \times 10^{14}$ Hz

40. When light travels from air to water, its speed is retarded by $\mu_W = \frac{4}{3}$
   (A) $\frac{3}{4} \times 10^7$ m/s
   (B) $\frac{4}{3} \times 10^7$ m/s
   (C) $2.25 \times 10^8$ m/s
   (D) $7.5 \times 10^7$ m/s

41. 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 nm
   (B) 394 nm
   (C) 886.5 nm
   (D) 295.5 nm

42. The number of waves of electromagnetic radiation of wavelengths 5000 Å in a path of 4 cm in vacuum is
   (A) $7.5 \times 10^4$
   (B) $8 \times 10^4$
   (C) $9 \times 10^6$
   (D) $10 \times 10^6$

43. Light of a certain wavelength has a wave number $\nu$ in vacuum. Its wave number in a medium of refractive index $n$ is $\frac{n}{\nu}$.[Oct 15]
   (A) $\frac{n}{\nu}$
   (B) $\frac{1}{n\nu}$
   (C) $\frac{\nu}{n}$
   (D) $n\nu$

44. The frequency of a beam of light in air is $8 \times 10^{14}$ Hz. The wave number of the beam of light in air is
   (A) $1.67 \times 10^6$ m$^{-1}$
   (B) $2.67 \times 10^6$ m$^{-1}$
   (C) $3.67 \times 10^6$ m$^{-1}$
   (D) $4.67 \times 10^6$ m$^{-1}$

45. 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.

46. The transverse nature of light is shown by
   (A) interference of light.
   (B) refraction of light.
   (C) polarisation of light.
   (D) dispersion of light.

47. 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.

48. 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.

49. 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

50. Unpolarised light consists of electric field vectors in _______.
   (A) any one plane  (B) plane of paper  (C) perpendicular to plane of paper  (D) all possible planes

51. Waves that cannot be polarised are _______.
   (A) radio waves  (B) X-rays  (C) visible light  (D) sound waves

52. 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.
53. The critical angle does not depend upon _______.
   (A) wavelength  
   (B) refractive index  
   (C) temperature  
   (D) frequency

54. 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.

55. 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.

56. A ray of light strikes a glass plate at an angle of $60^\circ$. If reflected and refracted rays are perpendicular to each other, the R.I. of glass is _______.
   (A) $\frac{1}{2}$  
   (B) $\frac{\sqrt{3}}{2}$  
   (C) $2/3$  
   (D) 1.732

57. 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

58. 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) $\pi$  
   (C) $\pi/2$  
   (D) $2\pi$

59. A ray of light incident on a glass slab gets completely polarised. If the angle of incidence is $\theta$, then the angle of refraction is _______.
   (A) 0  
   (B) $90^\circ - \theta$  
   (C) $180^\circ - \theta$  
   (D) $90^\circ + \theta$

60. 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 $40^\circ$ to each other.

61. Angle of polarisation for a transparent medium does not depend on wavelength of light.  
   (A) increases as wavelength increases.  
   (B) decreases as wavelength increases.  
   (C) changes irregularly with increase in wavelength.

62. If the polarizing angle for a given medium is $60^\circ$, then the refractive index of the medium is _______.
   (A) $\frac{1}{\sqrt{3}}$  
   (B) $\frac{\sqrt{3}}{2}$  
   (C) 1  
   (D) $\sqrt{3}$

63. For a given medium, the polarising angle is $60^\circ$. The critical angle for this medium is _______.
   (A) $47^\circ23'$  
   (B) $60^\circ10'$  
   (C) $23^\circ30'$  
   (D) $35^\circ16'$

64. The angle of incidence at which the polarisation of light reflected from the surface of glass occurs is $58^\circ$. The refractive index of glass is _______.
   (A) 1.9  
   (B) 1.8  
   (C) 1.7  
   (D) 1.6

65. If the critical angle for total internal reflection from a medium to vacuum is $30^\circ$, then velocity of light in the medium is _______.
   (A) $6 \times 10^8$ m/s  
   (B) $3 \times 10^8$ m/s  
   (C) $2 \times 10^8$ m/s  
   (D) $1.5 \times 10^8$ m/s

66. The angle of incidence is $60^\circ$ and the angle of refraction is $30^\circ$. The polarising angle for the same medium is _______.
   (A) $55^\circ$  
   (B) $45^\circ$  
   (C) $30^\circ$  
   (D) $60^\circ$

67. 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.
68. Dichroism is the property where
(A) unequal absorption of O-ray and E-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.

69. 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.

70. If a star is moving towards the earth, then the lines are shifted towards ________.
(A) red (B) infrared
(C) blue (D) green

71. 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 in frequency towards longer wavelengths.
(B) shift in 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.

72. A rocket is going away from the earth at a speed 0.2c, where c = speed of light. It emits a signal of frequency $4 \times 10^7$ Hz. What will be the frequency as observed by an observer on the earth?
(A) $4 \times 10^6$ Hz  (B) $3.2 \times 10^7$ Hz
(C) $3 \times 10^6$ Hz  (D) $5 \times 10^7$ Hz

**ANSWERS**

Section A
1. $4.5 \times 10^5$ m$^{-1}$
2. 1.5
3. 1.847
4. 6150 Å

Section D
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. (A) 23. (B) 24. (B)
25. (C) 26. (C) 27. (A) 28. (B)
29. (A) 30. (B) 31. (C) 32. (D)
33. (A) 34. (C) 35. (B) 36. (A)
37. (D) 38. (D) 39. (D) 40. (D)
41. (B) 42. (B) 43. (D) 44. (B)
45. (B) 46. (C) 47. (A) 48. (B)
49. (B) 50. (D) 51. (D) 52. (B)
53. (D) 54. (C) 55. (B) 56. (D)
57. (C) 58. (B) 59. (B) 60. (C)
61. (C) 62. (D) 63. (D) 64. (D)
65. (D) 66. (D) 67. (C) 68. (A)
69. (B) 70. (C) 71. (A) 72. (B)
Chapter 10: Wave Theory of Light

Hints to Multiple Choice Questions

25. \[ \mu = \frac{\sin i}{\sin r} \]
   Given that, \( i = 2r \)
   \[ \Rightarrow \mu = \frac{2 \sin r \cos r}{\sin r} = 2 \cos r \]
   \[ \Rightarrow \cos r = \frac{\mu}{2} \Rightarrow r = \cos^{-1} \left( \frac{\mu}{2} \right) \]
   \[ \frac{i}{2} = \cos^{-1} \left( \frac{\mu}{2} \right) \Rightarrow i = 2 \cos^{-1} \left( \frac{\mu}{2} \right) \]

31. \( \mu_{\text{glass}} = 1.68 \) and \( \mu_{\text{oil}} = 1.2 \)
   \[ \frac{\mu_{\text{oil}}}{\mu_{\text{glass}}} = \frac{1.2}{1.68} \]
   \[ \Rightarrow v_{\text{oil}} = \frac{1}{1.4} v_{\text{glass}} \]
   \[ \Rightarrow \text{velocity changes by a factor} \frac{1}{1.4} \]

32. \( \nu = 4 \times 10^{14} \) Hz, \( \Delta \mu_g = 1.5 \)
   \[ \Rightarrow \text{Using} \ c = \nu \lambda, \]
   \[ \lambda = \frac{c}{\nu} = \frac{3 \times 10^8}{4 \times 10^{14}} = \frac{3}{4} \times 10^{-6} \text{ m} \]
   \[ \text{Now,} \ \Delta \mu_g = \frac{\lambda_a}{\lambda_g} \Rightarrow \lambda_g = \frac{\lambda_a}{\Delta \mu_g} \]
   \[ \Rightarrow \lambda_g = \frac{3}{4} \times 10^{-6} \times \frac{1}{1.5} \]
   \[ = \frac{3}{4} \times \frac{2}{3} \times 10^{-6} \]
   \[ = \frac{1}{2} \times 10^{-6} \text{ m} \]
   \[ \Rightarrow \text{% change in wavelength} = \frac{\lambda_a - \lambda_g}{\lambda_a} \times 100 \]
   \[ = \frac{3 \times 10^{-6} - \frac{1}{2} \times 10^{-6}}{3 \times 10^{-6}} \times 100 \]
   \[ = \frac{3 \times 10^{-6}}{3 \times 10^{-6}} - \frac{1}{2} \times 10^{-6} \times 100 \]
   \[ = \frac{100}{3} = 33.33\% \approx 33\% \]