7. WAVE OPTICS

2,3 MARKS QUESTION AND ANSWERS

1. What are the salient features of corpuscular theory of light?

• Sir Isaac Newton gave the corpuscular theory of light.
• According to this theory, light is emitted as tiny, mass less and perfectly elastic particles called corpuscles.
• As the corpuscles are very small, the source of light does not suffer appreciable loss of mass even if it emits light for a long time.
• On account of high speed, they are unaffected by the force of gravity and their path is a straight line in a medium of uniform refractive index.
• The energy of the light is the kinetic energy of the corpuscles.
• When these corpuscles impinge on the retina of the eye, the vision is produced.
•The different size of the corpuscles is the reason for different colours of light.
• When the corpuscles approach a surface between two media, they are either attracted or repelled.
•The reflection of the light is due to the repulsion of the corpuscles by the medium and refraction of light is due to the attraction of the corpuscles by the medium.

LIMITATION OR DRAWBACK

•This theory could not explain the reason why speed of the light is lesser in denser medium than in rarer medium. Further, this theory could not explain the phenomenon like interference, diffraction and polarisation.

2. What are the important points of wave theory of light?

•Christian Huygens proposed the wave theory to explain the propagation of light through a medium.
• According to him, light is a disturbance from a source that travels as longitudinal mechanical waves. Since he assumes that light is a mechanical wave, it need a propagating medium which is **ether** that pervades all spaces.
• The wave theory could successfully explain phenomenon of reflection, refraction, interference and diffraction of light.

LIMITATIONS OR DRAWBACK

•The wave theory could not explain the propagation of light through vacuum, as the existence of ether was proved wrong.
• The phenomenon of polarisation could not be explained by this theory as it is the property of only transverse waves.

3. What is the significance of electromagnetic wave theory of light?

• James clerk Maxwell proposed the electromagnetic theory of light.
• According to him, the light is an electromagnetic wave which is transverse in nature carrying electromagnetic energy.
•He could also show that no medium is necessary for the propagation of electromagnetic waves.
• All the phenomenon of light could be successfully explained by this theory.

LIMITATIONS OR DRAWBACK

•Nevertheless, the interaction phenomenon of light with matter like photoelectric effect, Compton Effect could not be explained by this theory.

4. Write a short note on quantum theory of light.

• Albert Einstein's proposed the quantum of theory of light.
• Einstein endorsing the views of Max Plank , and was able to explain the photoelectric effect in which light(photons) interacts with matter as the result electrons eject out from the surface of matter. This is nothing but photo electric effect.
•According to Plank, a photon is discrete packet of energy. Each photon has energy $E = h\nu$. Here h is called as Plank's constant 6.625×10^{-34} J s. ν is frequency of electromagnetic wave.

NOTE: As light has both wave was well as particle nature it is said to have dual nature. Thus, it is concluded that light propagates as a wave and interacts with matter as a particle.

5. Define wavefront.

A wavefront is the locus of points which are in the same state or phase of vibration.

6. What are the shapes of wavefront for (a) source at infinite, (b) point sour (c) line source.

Source at Infinite: Shape of the wavefront is plane wavefront.
Source at finite distance: Shape of the wavefront is spherical wavefront.
Source is line source: Shape of the wavefront is cylindrical shape.

7. State Huygen's principle.

According to Huygen's principle, each point of the wavefront is the source of secondary wavelets. These wavelets are spreading out in all directions with the speed of the wave. These are called as secondary wavelets.

8. What is interference of light?

The phenomenon of addition or superposition of two light waves which produces increase in intensity at some points and decrease in intensity at some other points is called interference of light.

9. What is phase of a wave?

Phase is the angular position of vibration. We can express the phase in terms of path difference. We can express the wave in terms of path difference and vice versa.

10. Obtain the relation between phase difference and path difference.

In the path of the wave, one wavelength λ corresponds to a phase of 2π. A path difference δ corresponds to a phase difference ϕ can be related by the equation, $\boxed{\phi = \frac{2\pi}{\lambda}\delta}$

11. What are coherent sources?

Two light sources are said to be coherent if they produce waves which have same phase or constant phase difference, same frequency or wavelength (monochromatic), same waveform and preferably same amplitude.

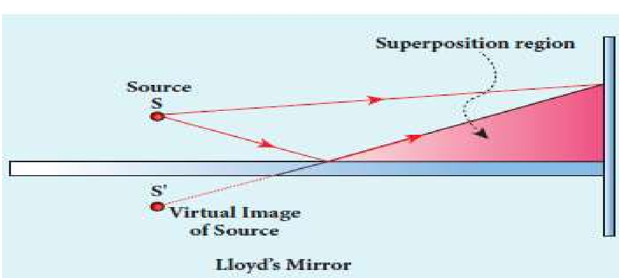
12. How does wavefront division provide coherent sources?

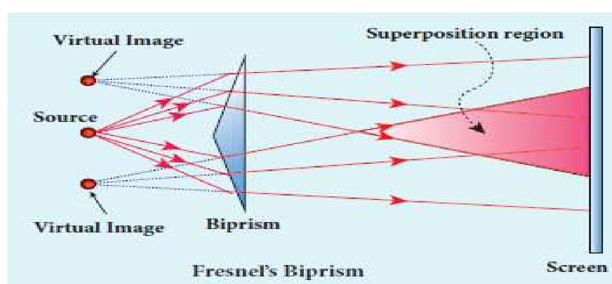
This is the most commonly used method for producing two coherent sources. We know a point source produces spherical wavefronts. All the points on the wavefront are at the same phase. If two points are chosen on the wavefront by using a double slit, the two points will act as coherent sources.

13. What is intensity (or) amplitude division?

If we allow light to pass through a partially silvered mirror(beam splitter), both reflection and refraction take place simultaneously. As the two light beams are obtained from same light source, the two divided light beams will be coherent beams. They will be either in-phase or at constant phase difference. Instruments like Michelson's interferometer, Fabray-Perrot etalon work on this principle.

14. **How do source and images behave as coherent sources?**





In this method a source and its image will act as a set of coherent source, because the source and its image will have waves in-phase or constant phase difference . The instruments, Fresnel's biprism uses two virtual sources as two coherent sources and the instrument, LIoyd's mirror uses a source and its virtual image as two coherent sources.

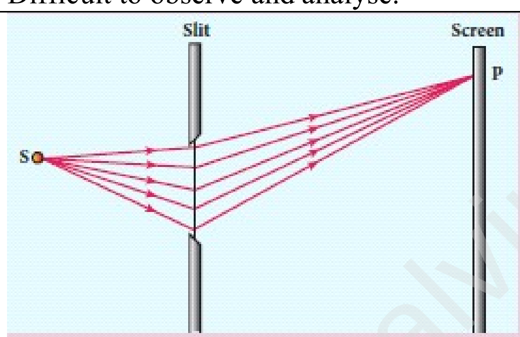
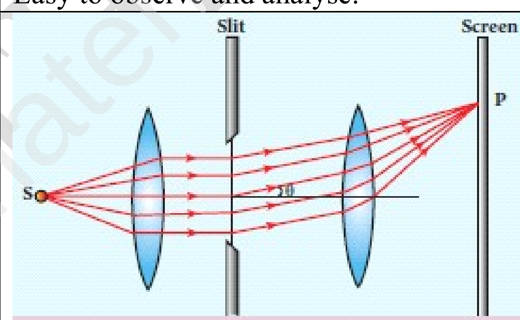
15. What is bandwidth of interference pattern?

The bandwidth (β) is defined as the distance between any two consecutive bright or dark fringes. $\boxed{\beta = \frac{D}{d}\lambda}$ Here, D distance between coherent source and screen; d distance between two coherent sources; λ wavelength of the incident light.

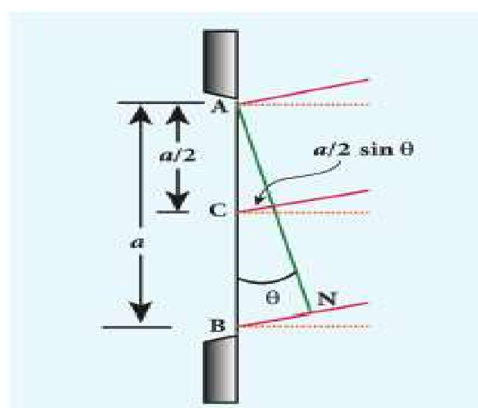
16. What is diffraction?

Diffraction is bending of waves around sharp edges into the geometrically shadowed region.

17. Difference between Fresnel and Fraunhoffer diffraction.

S.No	FRESNEL DIFFRACTION	FRAUNHOFFER DIFFRACTION
1	Spherical or cylindrical wavefront undergoes diffraction	Plane wavefront undergoes diffraction
2	Light wave is from a source at finite distance	Light wave is from a source at infinity
3	For laboratory conditions, convex lenses need not be used	In a laboratory conditions, convex lenses are to be used.
4	Difficult to observe and analyse.	Easy to observe and analyse.
5		

18. Discuss the special cases on first minimum in Fraunhoffer diffraction.



Let us divide the slit AB into two half's AC and CB. Now the width of AC is $(a/2)$. We have different points on the slit which are separated by the same width (here $a/2$)called **corresponding points**.

The path difference of light waves from different corresponding points meeting at point P and interfere destructively to make it first minimum.

The path difference δ between waves from these corresponding points is, $\delta = \frac{a}{2}\sin\theta$. The condition for P to be first minimum is, $\frac{a}{2}sin\theta = \frac{\lambda}{2}$. That is $\boxed{a\,sin\theta = }$. This is the condition for first minimum.

19. What is Fresnel's distance? Obtain the equation for Fresnel's distance.

Fresnel's distance is the distance up to which the ray optics is valid in terms of rectilinear propagation of light. Further, it is the distance up to which ray optics is obeyed and beyond which ray optics is not obeyed but, wave optics becomes significant.

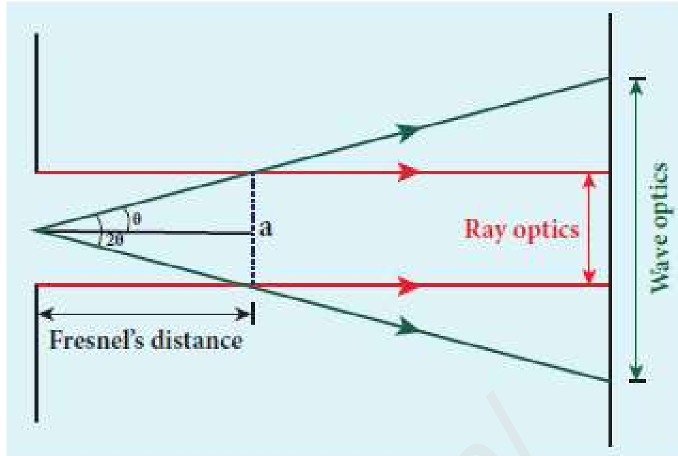
The diffraction equation for first minimum is, $\sin\theta = \frac{\lambda}{a}$; If θ is small, then $\theta = \frac{\lambda}{a}$

From the definition of Fresnel's distance, $2\theta = \frac{a}{z}$ (or) $\theta = \frac{a}{2z}$

By equating the above two equations,

$$\frac{\lambda}{a} = \frac{a}{2z}$$

After rearranging, we get Fresnel's distance z as, $\boxed{z = \frac{a^2}{2\lambda}}$



20. **Mention the differences between interference and diffraction.**

S.No	INTERFERENCE	DIFFRACTION
1	Superposition of two waves	Bending of waves around edges
2	Superposition of waves from two coherent sources.	Superposition wavefronts emitted from various points of the same wavefront.
3	Equally spaced fringes	Unequally spaced fringes
4	Intensity of all the bright fringes is almost same	Intensity falls rapidly for higher orders
5	Large number of fringes are obtained	Less number of fringes are obtained.

21. What is a diffraction grating?

A grating is a plane Sheet of transparent material on which opaque ruling are made. A modern commercial grating contains about 6000 lines per centimeter. The transparent space between the rulings acts as slit of width 'a' and the rulings act as obstacles having a definite width 'b'.

22. What is resolution?

In general, the term resolution is pertaining to the quality of the image and the term resolving power is associated with the ability of the optical instrument. Resolution and resolving power are reciprocal of each other.

23. What is Rayleigh's criterion?

According to Rayleigh's criterion, the two points on an image are said to be just resolved when the central maximum of one diffraction pattern coincide with the first minimum of the other and vice-versa.

24. What is the difference between resolution and magnification?

Resolution	**Magnification**
Resolution is the ability to distinguish between two points on an image-the amount of detail.	Magnification is how much bigger a sample appears to be under the microscope that it is in real life.

Note

Increasing the magnification does not increase the resolution of the images.

25. **What is polarisation?**

The phenomenon of restricting the vibration of light (electric or magnetic field vector) to a particular direction perpendicular to the direction of wave propagation motion is called polarization.

26. Differentiate between polarized and unpolarized light?

S.No	POLARISED LIGHT	UNPOLARISED LIGHT
1	Consists of waves having their electric field vibrations in a single plane normal to the direction of ray.	Consists of waves having their electric field vibrations equally distributed in all direction normal to the direction of ray.
2	Asymmetrical about the ray direction	Symmetrical about the ray direction.
3	It is obtained from unpolarized light with the help of polarisers.	Produced by conventional light sources.

27. **Discuss polarisation by selective absorption.**

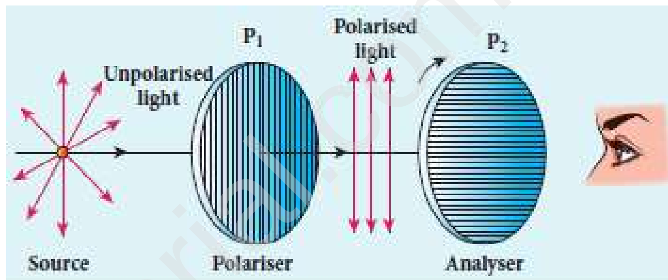
Selective absorption is the property of a material which transmits waves whose electric fields vibrations are in a plane parallel to certain direction of orientation and absorbs all other vibrations. .

The Polaroids or polarisers are thin commercial sheets which make use of the property of selective absorption to produce plane polarized light. Selective absorption is also called as **dichroism.**

28. **What are polariser and analyser?**

Polariser: The light coming out from Polaroid P_1 is said to be plane polarised. The Polaroid (Here P_1) Which plane polarises the unpolarized light passing through it is called a polariser.

Analyser: The Polaroid (here P_2) which is used to examine whether a beam of light is polarised or not is called an analyser.



29. **What are plane polarized, unpolarized and partially polarized light?**

PLANE POLARISED LIGHT:

In a plane polarised light the intensity varies from maximum to zero for every rotation of 90^0 of analyser.

PARTIALLY POLARISED LIGHT:

If the intensity of light varies between maximum and minimum for every rotation of 90^0 of the analyser, the light is said to be partially polarised light.

UNPOLARISED LIGHT:

A transverse wave which has vibrations in all directions in a plane perpendicular to the direction of propagation is said to be unpolarised light.

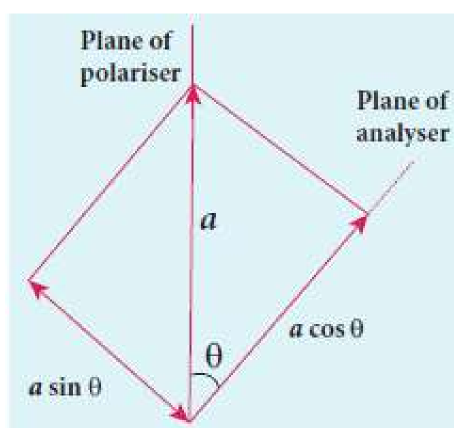
30. **State and obtain Malus' law.**

Malus' Law

When a beam of plane polarised light of intensity I_0 is incident on an analyser, the light transmitted of intensity I from the analyser varies directly as the square of the cosine of the angle θ between the transmission axis of polariser and analyser. $\boxed{I = I_0 cos^2\theta}$

Proof:

- Let us consider the plane of polariser and analyser is inclined to each other at an angle θ.
- Let I_0 be intensity and 'a' be the amplitude of the electric vector transmitted by the polariser.
- The amplitude 'a' of the incident light has two rectangular components, (a cosθ) and (a sinθ) which are the parallel and perpendicular components to the axis of transmission of the analyser.
- Only the component (a cosθ) will be transmitted by the analyser.
- The intensity of light transmitted from the analyser is proportional to the square of the component of the amplitude transmitted by the analyser.



$$I \propto (acos\quad ^{2}\ \ that\ is\ I = k(acos\theta)^2$$
$$Where\ k\ is\ the\ constant\ of\ proportionality.$$

$I = ka^2\cos^2\theta$; further

$I = I_0\cos^2\theta$. Where, $\mathbf{I_0 = ka^2}$ is the maximum intensity of light transmitted from the analyser.

SPECIAL CASE: (1) When $\theta = 0^0$, $\cos 0 = 1$, therefore $I = I_0$, When the transmission axis of polariser is along that of analyser, the intensity of light transmitted from the analyser is equal to the incident light that falls on it from the polariser.

(2) When $\theta = 90^0$, $\cos 90^0 = 0$, $I = 0$. When the transmission axes of polariser and analyser are perpendicular to each other, the intensity of light transmitted from the analyser is zero.

31. List the uses of Polaroids.

(1) Polaroids are used in goggles and cameras to avoid glare of light.
(2) Polaroids are useful in three dimensional motion pictures. i.e., in holography.
(3) Polaroids are used to improve contrast in old oil paintings.
(4) Polaroids are used in optical stress analysis.
(5) Polaroids are used as window glasses to control the intensity of incoming light.
(6) Polarised laser beam acts as needled to read\write in compact discs. (CDs).
(7) Polaroids produce polarised lights to be used in liquid crystal display (LCD).

32. State Brewster's law.

The law states that the tangent of the polarizing angle for a transparent medium is equal to its refractive Index of the medium. $\boxed{\tan i_p = n}$

33. What is angle of polarisation and obtain the equation for angle of polarisation.

Angle of polarisation or Brewster's angle

The angle of incidence at which a beam of unpolarised light falling on a transparent surface is reflected as a beam of plane polarised light is called polarizing angle or Brewster's angle. It is denoted by i_p.

Brewster found that at the incidence of polarizing angle, the reflected and transmitted rays are perpendicular to each other.

From the figure we can write the equation as $\boxed{i_p + 90^0 + r_p = 180^0}$

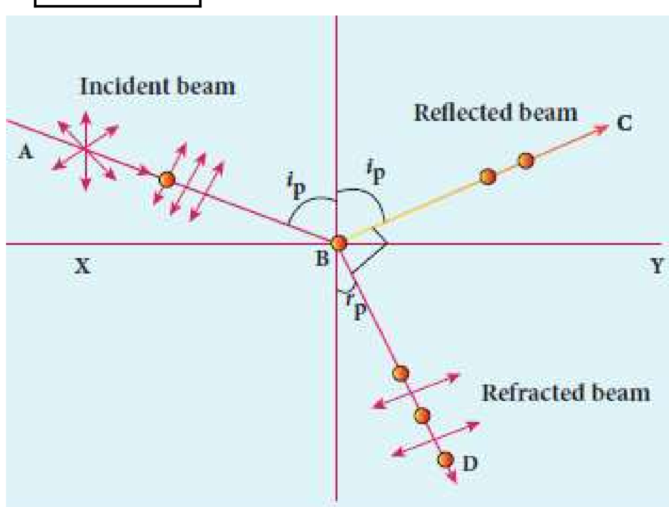
By simplifying the above equation $r_p = 90^0 - i_p$.

From Snell's law the refractive index of the medium is $\boxed{n = \frac{\sin i_p}{\sin r_p}}$

By substitute the value of r_p, we can rewrite the Snell's law as $\boxed{n = \frac{\sin i_p}{\sin(90^0 - i_p)}}$ since $\sin(90^0 - i_p) = \cos i_p$

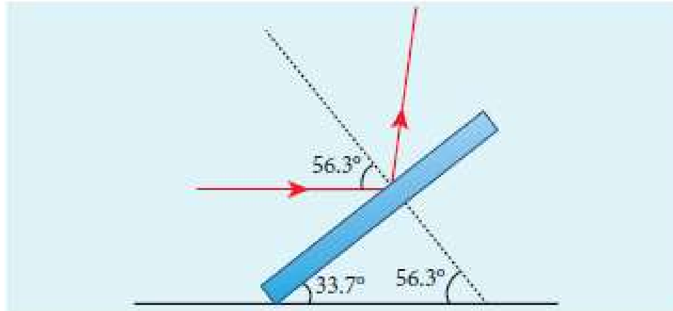
The refractive index $n = \frac{\sin i_p}{\cos i_p}$. That is $\boxed{n = \tan i_p}$. This relation is known as Brewster's law.

STATE MENT: The law states that the tangent of the polarizing angle for a transparent medium is equal to its refractive index of the medium.



34. **Discuss about pile of plates.**

The pile of plate is a device which is used to produce plane polarised light by the phenomenon of polarisation by reflection. The piles of plate can be used as a polarizer and also as an analyser.



It consists of a number of glass plates placed one over the other in a tube . The plates are inclined at an angle of 33.7^0, (90^0-56.3^0) to the axis of the tube. A beam of un polarised light is allowed to fall on the pile of plates along the axis of the tube. So, the angle of incidence of light will be at 56.3^o which is the polarizing angle for glass. The vibrations perpendicular to the plane of incidence are reflected to each surface and those parallel to its are transmitted.

The larger the number of surfaces, the greater is the intensity of the reflected plane polarised light.

35. What is double refraction?

When a ray of unpolarised light is incident on a calcite crystal, two refracted rays are produced. Hence, two images of a single object are formed. This phenomenon is called double refraction. It is also called as birefringence. Quarts, Mica crystals produce double refraction.

36. Mention the types of optically active crystals with example.

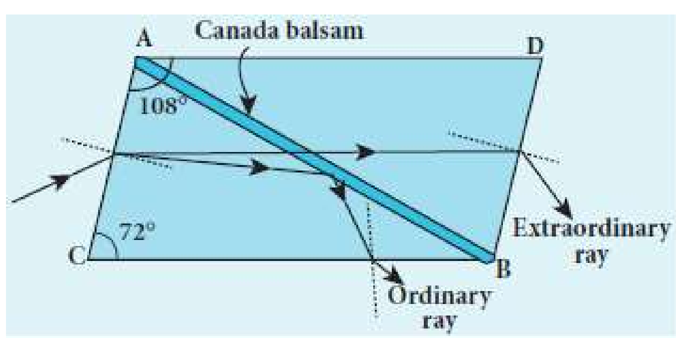
Crystals which has an axis along it both the ordinary and extraordinary rays have same refractive index. Such an axis is called optic axis. These crystals are called as optically active crystals. There are two types.
uniaxial and biaxial crystals
uniaxial crystal: Crystals like calcite quartz, tourmaline and ice having only one optic axis are called un axial crystals.
biaxial crystal: Crystals like Mica Topaz, Selenite and Aragonite having two optic axes are called biaxial crystals.

37. Discuss the optical device Nicol Prism.

Nicol prism is an optical device which is used to produce plane polarised light and it is also act as both polariser and analyser.

- **Principle**: Double refraction.
- **Invention**: William Nicol in 1828.
- **Construction**: Take a calcite crystal ABCD whose length is three times is breadth. It cut into two halves along the diagonal so that their face angles are 72^0 and 108^0. The **two** halves are joined together by a layer of **Canada balsam,** a transparent cement.
- **Working**:

Let us consider a ray of unpolarised light from monochromatic source such as sodium vapour lamp is incident on the face AC of the Nicol Prism. Double refraction takes place and the ray is split into ordinary and extraordinary rays. They travel with different velocities. The refractive index of the crystal for the ordinary ray is 1.658 and for extraordinary ray is 1.486. The refractive index of Canada balsam is 1.523. Since Canada balsam does not polarise light.



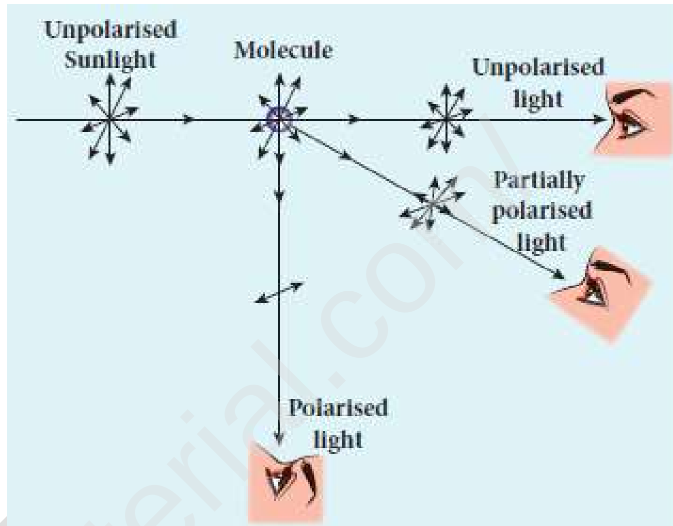
The ordinary ray is total internally reflected at the layer of Canada balsam and is prevented from emerging from the other face. The extraordinary ray alone is transmitted through the crystal which is plane polarised.

- **Uses**: (1) It produces plane polarised light and functions as a polariser. (2) It can also be used to analyse the plane polarised light i.e., used at an analyser.

Draw Backs: (1) Its cost is very high due to scarcity of large and flawless calcite crystals. (2) Due to extraordinary ray passing obliquely through it, the emergent ray is always displaced a little to one side. (3) Light emerging out of it is not uniformly plane polarised.

38. How is polarisation of light obtained by scattering of light?

The light from a clear blue portion of the sky shows a rise and fall of intensity when viewed through a Polaroid which is rotated. This is because of sunlight, which has changed its direction (have been scattered) on encountering the molecules of the earth's atmosphere.



Explanation:

The electric field of light interacts with the electrons present in the air molecules, so the electrons in the molecules acquire components of motion in both these directions.

Assume an observer looking at 90^0 to the direction of the Sun. Clearly, charges accelerating parallel do not radiate energy towards the observer since their acceleration has no transverse component.

The radiation scattered by the molecule is therefore polarized perpendicular to the plane of paper. This explains the reason for polarisation of sunlight by scattering.

39. What are near point and normal point focusing?

Near point focusing: The image is formed at near point, i.e., 25 cm. for normal eye. This distance is also called at least distance D of the distinct vision. On this position, the eye feels comfortable but there is little strain on the eye. $\boxed{m = 1 + \frac{D}{f}}$

Normal focusing or angular magnification: The image is formed at infinity. In this position the eye is most relaxed to view the image. $\boxed{m = \frac{D}{f}}$

40. Why is oil immersed objective preferred in a microscope?

It is contributes to two characteristics of the image, viewed through the microscope (1) fine resolution (2) brightness. These characteristics are most critical under high magnification. So the objectives designed for oil immersion.

41. What are the advantages and disadvantages of a reflecting telescope?

Generally the telescopes with mirror objectives are called reflecting telescopes.

Advantages:

Only one surface is to be polished and maintained. Support can be given from the entire back of the mirror rather than only at the rim for lens. Mirror weigh much less compared to lens.

Disadvantages.

The objective mirror would focus the light inside the telescope tube. One must have an eye piece obstructing some light. This problem could be overcome by introducing a secondary mirror which would take the light outside the tube for view.

42. What is the use of an erecting lens in a terrestrial telescope?

A terrestrial telescope has an additional erecting lens to make the final image to erect.

43. What is the use of collimator in a spectrometer?

The collimator is an arrangement to produce a parallel beam of light.

44. What are the uses of spectrometer?

The spectrometer is an optical instrument used to study the spectra of different sources of light and to measure the refractive indices of materials.

45. What is myopia? What is its remedy?

A person suffering from nearsightedness who cannot see distant object clearly is called myopia.

Cause: It is due to the thickening of eye lens and larger diameter of the eyeball

Remedy: By wearing concave lens.

46. What is hypermetropia? What is its remedy?

A person suffering from farsightedness who cannot see close objects clearly is called hypermetropia or hyperopia.

Cause: When an eye lens has too long focal length due to thinning of eye lens or shortening of the eyeball.

Remedy: By wearing convex lens.

47. What is astigmatism? What is its remedy?

Astigmatism is the effect arising due to different curvatures along different planes in the eye lens.

• Astigmatic person cannot see all the directions equally well. This is more serious that myopia and hyperopia.

Remedy: Lenses with different curvatures in different planes to rectify this defect. Generally these lenses are called as cylindrical lenses.

48. What is presbyopia?

The farsightedness arises due to aging is called presbyopia. **Remedy:** By wearing convex lens.

49. What is grating element?

The combined width of a ruling (b) and a slit (a) is called grating element. (e= a+ b)

50. What is corresponding points?

The points on the slit separated by a distance equal to the grating element are called corresponding points.

51. What are the three techniques to obtain coherent light?

(1) Wavefront division (2) Intensity (or) Amplitude division (3) Source and Image.

FIVE MARK QUESTION AND ANSWERS

1. Prove law of reflection using Huygen's principle.

Law of Reflection

• The incident rays, the reflected rays and the normal are in the same plane (coplanar)

• Angle of incidence = Angle of reflection ($\angle i = \angle r$)

Figure Explanation

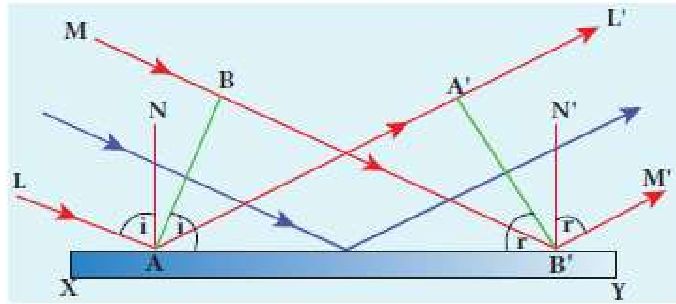
Let us consider a parallel beam of light is incident on a reflecting plane surface such as a plane mirror XY as shown in the figure.

• AB and $A'B'$ are incident and reflected wave front.

• These wavefronts are perpendicular to the incident (LM) ray and reflected ($L'M'$) ray.

Proof

Consider the incident wave front AB, By the time point A of the incident wavefront touches the reflecting surface, the point B is yet to travel a distance BB' to touch the reflecting surface at B', the point A would have reached A'. This is applicable to all the points on the wavefront.



Due to this reflected wavefront $A'B'$ emanates as a plane wavefront. Observe the normal N and N' are the lines where the incident ray L and M touches the reflecting surface XY.

As the incident and reflected ray travels in the same medium, their velocity is same. Therefore, the time taken for the light to travel from B to B' and A to A' are the same. That is $BB' = AA'$.
That is they are **coplanar.**(First part of law of reflection)

Apply the geometric concepts in the figure,

- **Angle of Incidence**

$$\angle i = \angle NAL = 90^{\circ} - \angle N'A'B' = \angle BAB'$$

- **Angle of Reflection**

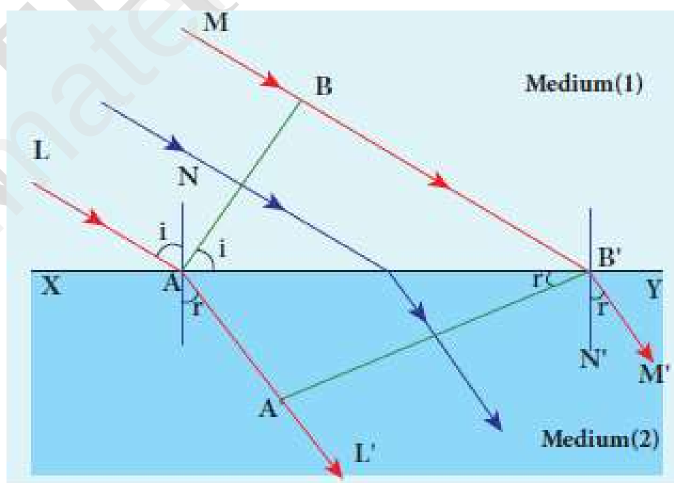
$$\angle r = \angle N'B'M' = 90^{\circ} - \angle N'B'A' = \angle A'B'A$$

Consider the two right angle triangle, $\Delta AA'B'$ and $\Delta ABB'$. In this two triangles $\angle B = \angle A' = 90^{\circ}$. The sides $AA' = BB'$ and the side AB' is common for two triangles. So for we can say the two triangles are **congruent.**

As per the property of congruency, the two angles, $\angle BAB' = \angle A'B'A$. That is $\angle \boldsymbol{i} = \angle \boldsymbol{r}$. **(**second part of law of reflection) Hence, the law of reflection is proved.

2. Prove the law of refraction using Huygens' Principle.

Law of Refraction



- The incident rays, the refracted rays and the normal are in the same plane. (**coplanar**)
- The ratio of the sine of angle of incidence to the sine of angle or refraction is a constant. That constant is the refractive index of the second medium with respect to the first medium. $\frac{n_2}{n_1} = \frac{\sin i}{\sin r}$ (This is Snells' law)

Figure Explanation

Let us consider a parallel beam of light is incident on a refracting surface XY such as a glass as shown in the following figure.

- AB is the incident wavefront in the rarer medium (1)
- $A'B'$ is the refracted wavefront in the denser medium (2).
- These wavefronts are perpendicular to the incident (LM) ray and refracted ($L'M'$) ray.

Proof

Consider the incident wavefront AB, by the time the point A of the incident wavefront touches the refracting surface, the point B is yet to travel a distance BB' to touch the refracting surface at B', at the same time the point A would have reached A' in the denser medium. This is applicable all points in the wave front. Thus, the refracted wavefront $A'B'$ *emanates as a plane wavefront.*

- Observe the normal N and N' are the lines where the incident ray L and M touches the reflecting surface XY. Assume v_1 and v_2 are the velocity of the incident and refracted rays in rarer and denser medium. $(v_1 > v_2)$
- Let us assume within the time interval 't' both the incident and refracted ray travel the distance BB' *and* AA'. From the mechanics, $time = \frac{distance}{velocity}$

$t = \frac{BB'}{v_1} = \frac{AA'}{v_2}$, by rearranging the equation,

$\frac{BB'}{AA'} = \frac{v_1}{v_2} \rightarrow\rightarrow\rightarrow$ **(1)**

That is they are **coplanar.**(First part of law of refraction)

• **Angle of Incidence**

$$\angle i = \angle NAL = 90^\circ - \angle N'A'B' = \angle BAB'$$

• **Angle of refraction**

$$r = \angle N'B'M' = 90^\circ - \angle N'B'A' = \angle A'B'A$$

Consider the two right angle triangle, $\Delta AA'B'$ and $\Delta ABB'$. In this two triangles $\angle B = \angle A' = 90^\circ$. the side A$B'$ is common for two triangles.

By apply the Snells' law,

$$\frac{\sin i}{\sin r} = \frac{BB'/AB'}{AA'/AB'} = \frac{BB'}{AA'} = \frac{v_1}{v_2} = \frac{c/v_2}{c/v_1}$$

Here, C is speed of light in vacuum. The ratio c/v is a constant, called refractive index of the medium. That is, refractive index of the first medium $n_1 = c/v_1$; similarly the refractive index of the second medium $n_2 = c/v_2$.

Substitute these in the above equation, we will get Snells' law in ratio form,

$$\boxed{\frac{\sin i}{\sin r} = \frac{n_2}{n_1}}$$

Hence, the second part of law of refraction is proved.

Note

The speed of light is inversely proportional to the refractive index of the medium$\left(v \propto \frac{1}{n}\right)$ and also directly proportional to wavelength of light$(v \propto \lambda)$. Hence,

$$\boxed{\frac{n_1}{n_2} = \frac{v_2}{v_1} = \frac{\lambda_2}{\lambda_1}}$$

3. Obtain the equation for resultant intensity due to interference of light.

Interference of light

The phenomenon of addition or superposition of two light waves which produces increase in intensity at some points and decrease in intensity at some other points is called interference of light.

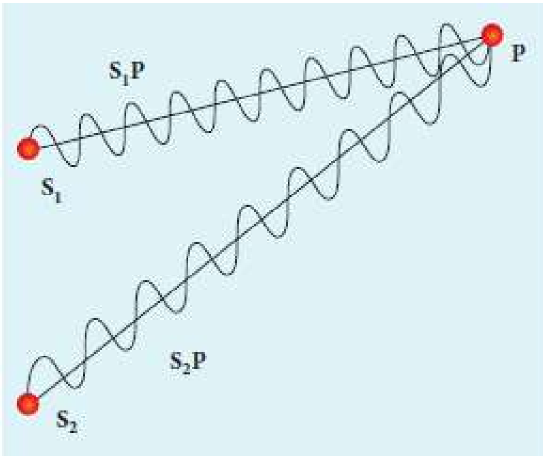


Figure Explanation

Let us consider two light waves from the two sources S_1 and S_2 meeting at a point P as shown in the following figure.

The wave from S_1 at an instant't' at P is,

$$y_1 = a_1 \sin \omega t$$

The wave from S_2 at an instant't' as P is,

$$y_2 = a_2 \sin(\omega t + \phi)$$

The two waves have different amplitudes a_1 and a_2, same angular frequency ω, and a phase difference of ϕ between them. The resultant displacement will be given by,

$y = y_1 + y_2 = a_1 \sin \omega t + a_2 \sin(\omega t + \phi) \rightarrow\rightarrow\rightarrow (1)$

$$y = a_1 \sin \omega t + a_2(\sin \omega t \cos \phi + \cos \omega t \sin \phi)$$

$$y = a_1 \sin \omega t + (a_2 \sin \omega t \cos \phi + a_2 \cos \omega t \sin \phi)$$

$y = \sin \omega t\,(a_1 + a_2 \cos \phi) + a_2 \cos \omega t \sin \phi \rightarrow\rightarrow\rightarrow (2)$

Let us re-define,

$a_1 + a_2 \cos \phi = A \cos \theta$ and $a_2 \sin \phi = A \sin \theta \rightarrow\rightarrow\rightarrow (3)$

Substitute (3) in (2),

$$\sin\omega t\,(A\cos\theta) + \cos\omega t\,(A\sin\theta)$$
$$y = A(\sin\omega t\cos\theta + \cos\omega t\sin\theta)$$

$y = A\sin(\omega t + \theta) \rightarrow\rightarrow\rightarrow (4)$

By squaring and adding the eqn. (3)

$A^2cos^2\theta = {a_1}^2 + {a_2}^2cos^2\theta + 2a_1a_2\cos\theta \rightarrow\rightarrow\rightarrow (5)$

$A^2sin^2\theta = a_2^2sin^2\theta \rightarrow\rightarrow\rightarrow (6)$

By adding (5) and (6),

$$A^2(sin^2\theta + cos^2\theta) = a_2^2(sin^2\theta + cos^2\theta) + a_1^2 + 2a_1a_2\cos\theta$$

$A^2 = a_2^2 + a_1^2 + 2a_1a_2\cos\theta$

$A = \sqrt{a_2^2 + a_1^2 + 2a_1a_2\cos\theta} \rightarrow\rightarrow\rightarrow (7)$

From the eqn.(3),

$a_1 + a_2\cos\phi = A\ \cos\theta$ and $a_2\sin\phi = A\ \sin\theta$

$$\frac{A\sin\theta}{A\cos\theta} = \frac{a_2\sin\phi}{a_1 + a_2\cos\phi}$$
$$\tan\theta = \frac{a_2\sin\phi}{a_1 + a_2\cos\phi}$$

$\theta = tan^{-1}\left(\frac{a_2\sin}{a_1+a_2\cos\phi}\right) \rightarrow\rightarrow\rightarrow (8)$

From the definition, the resultant amplitude is maximum for,

$$A_{maximum} = \sqrt{(a_1 + a_2)^2}$$

Where, $\phi = 0, \pm2\pi, \pm4\pi \ldots\ldots$

From the definition, the resultant amplitude is minimum for,

$A_{minimum} = \sqrt{(a_1 - a_2)^2}$

Where, $\phi = \pm\pi, \pm3\pi \ldots\ldots$

We know that the intensity of light is proportional to square of amplitude.

$$I \propto A^2$$

Square the eqn.(7) on both sides,

$A^2 = a_2^2 + a_1^2 + 2a_1a_2\cos\theta$

$I = I_1 + I_2 + 2\sqrt{I_1I_2}\ \cos\phi \rightarrow\rightarrow\rightarrow (9)$

In equation, (9) if the phase difference, $\phi = 0, \pm2\pi, \pm4\pi \ldots\ldots$ it corresponds to the condition for maximum intensity of light called **constructive interference.**

The resultant maximum intensity is,

$$I_{maximum} \propto (a_1 + a_2)^2$$

$I_{maximum} = I_1 + I_2 + 2\sqrt{I_1I_2} \rightarrow\rightarrow\rightarrow (10)$

In equation, (9) if the phase difference, $\phi = \pm\pi, \pm3\pi \ldots\ldots$ it corresponds to the condition for minimum intensity of light called **destructive interference.**

The resultant minimum intensity is,

$$I_{minimum} \propto (a_1 - a_2)^2$$

$I_{maximum} = I_1 + I_2 - 2\sqrt{I_1I_2} \rightarrow\rightarrow\rightarrow (11)$

As a special case, if a_1=a_2=a, then eqn.(7) becomes,

$A = \sqrt{2a^2 + 2a^2\cos\phi} = \sqrt{2a^2(1 + \cos\phi)}$

By using **reduction identity**$(\mathbf{1 + \cos 2\theta = 2co\ ^2\theta})$ and **Half angle concept (2θ=ϕ)**

The above equation can be rewritten as,

$$A = \sqrt{2a^2 2cos^2(\phi/2)}$$
$$A = 2acos(\phi/2)$$

We know that $I \propto A^2$

$$I \propto 4a^2 cos^2(\phi/2)$$

But, $I_0 \propto a^2$

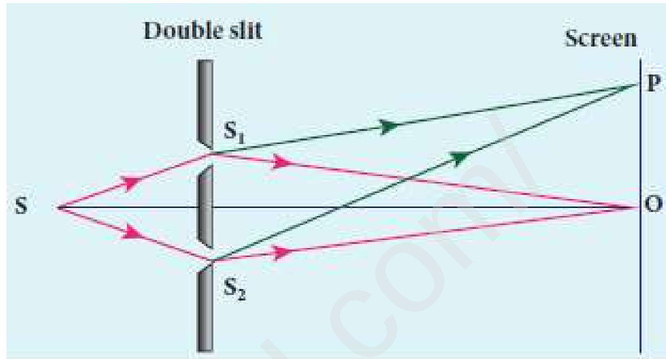
$$I = 4I_0 cos^2(\phi/2)$$

When, $\phi = 0, \pm 2\pi, \pm 4\pi \ldots\ldots$ then the above eqn. become, $I_{maximum} = 4I_0$

When, $\phi = \pm\pi, \pm 3\pi \ldots\ldots$ Then the above eqn. becomes, $I_{minimum} = 0$

4. Explain the Young's double slit experimental setup and obtain the equation for path difference.

Experimental Setup



Consider a opaque screen with two small openings called double slit S_1 and S_2 kept equidistance from a source S as shown in the following figure. The width of each slit is about 0.03 millimeter and they are separated by a distance of about 0.3 millimeter.

As S_1 and S_2 are equidistant from S the same wavefront is cut by S_1 and S_2. The light waves at S_1 and S_2 act as coherent sources which is the requirement for obtaining interference pattern.

Wavefronts From S_1 and S_2 spread out and overlap on the other side of the double slit. When a screen is placed at a distance of about 1 meter from the slits, alternate bright and dark fringes which are equally spaced appear on the screen. These are called **interference fringes (or) bands.**

Using an eyepiece, the fringes can be seen directly. At the center point O on the screen, the waves from S_1 and S_2 travel equal distances and arrive in phase. These two waves constructively interfere and a bright fringe is observed at O. This is called **central bright fringe.**

Note

When one of the slits is closed, the fringes disappear and there is uniform illumination on the screen. This shown clearly that the bands are due to interference.

Equation for path difference

The schematic diagram of the experimental setup is as shown in the above figure. Let 'd' be the distance between the double slits, which are acts as the coherent sources of wavelength λ. A screen is placed parallel to the double slit at a distance 'D' from it. The mid-point of S_1 and S_2 is 'C' and the mid-point of the screen 'O' is equidistant from S_1 and S_2. P is any point at a distance y from O.

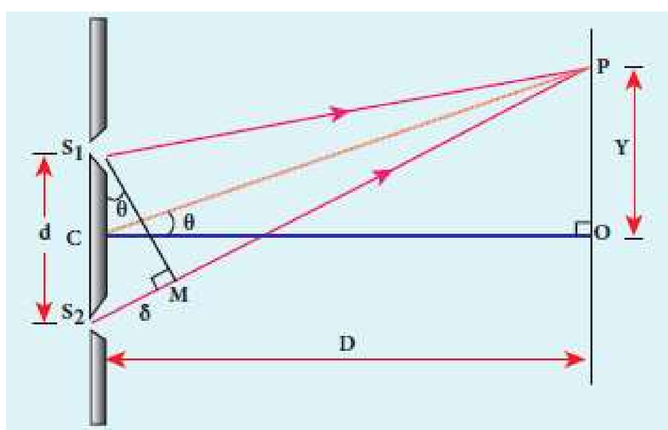
The waves from S_1 and S_2 meet at P either in-phase or out-phase depending upon the path difference between the two waves.

The path difference δ between the light waves from S_1 and S_2 to the point P is,

$\delta = S_2P - S_1P \rightarrow\rightarrow\rightarrow (1)$

A perpendicular is dropped from the point S_1 to the line S_2P at M to find the path difference more precisely.

$\delta = S_2P - MP = S_2M \rightarrow\rightarrow\rightarrow (2)$



The angular position of the point P from C is θ.

$\angle OCP = \theta$.

From the geometry, the angles $\angle OCP$ and $\angle S_2S_1M$ are equal. That is,

$$\angle OCP = \angle S_2S_1M = \theta$$

In right angle triangle ΔS_1S_2M, the path difference,

$S_2M = d\sin\theta \rightarrow\rightarrow\rightarrow (3)$

Substitute (2) in (3),

$\delta = d\sin\theta = d\,\theta \rightarrow\rightarrow\rightarrow (4)$

If the angle θ is small, $\sin\theta = \tan\theta = \theta$. From the right angle triangle ΔOCP,

$\tan\theta = \frac{y}{D} = \theta = \frac{y}{D} \rightarrow\rightarrow\rightarrow (5)$

Substitute (5) in (4),

The path difference, $\boxed{\boldsymbol{\delta = \frac{dy}{D}}}$

Note

Based on the condition of path difference, the point P may have a bright (or) dark fringe.

5. Obtain the equation for bandwidth in Young's double slit experiment.

Band width($\boldsymbol{\beta}$)

The bandwidth (β) is defined as the distance between any two consecutive bright or dark fringes.

$\boxed{\beta = \frac{D}{d}\lambda}$

Condition for bright fringes

The path difference is equal to nλ

That is, $\frac{dy}{D} = n\lambda$ From this $y = \frac{Dn\lambda}{d}$

The distance between $(n+1)^{th}$ and nth consecutive bright fringes from O is given by,

$$\beta = y_{(n+1)} - y_n = \left[(n+1)\frac{\lambda D}{d}\right] - \left[n\frac{\lambda D}{d}\right]$$

B for bright, $\beta = n\frac{\lambda D}{d} + \frac{\lambda D}{d} - n\frac{\lambda D}{d}$

β for bright, $\boxed{\beta = \frac{D\lambda}{d}} \rightarrow\rightarrow\rightarrow (1)$

Condition for dark fringes

The path difference is equal to $(2n-1)\frac{\lambda}{2}$

That is, $\frac{dy}{D} = (2n-1)\frac{\lambda}{2}$ From this $y = \frac{(2n-1)}{2}\frac{\lambda D}{d}$

Similarly, the distance between $(n+1)^{th}$ and nth consecutive dark fringes from O is given by,

$$\beta = y_{(n+1)} - y_n = \left(\frac{(2(n-1)-1)}{2}\frac{D\lambda}{d}\right) - \left(\frac{(2n-1)}{2}\frac{D\lambda}{d}\right)$$

β for dark, $\boxed{\beta = \frac{D\lambda}{d}} \rightarrow\rightarrow\rightarrow (2)$

From the equation (1) and (2), we understand that the bright and dark fringes are of same width equally spaced on either side of the central bright fringe.

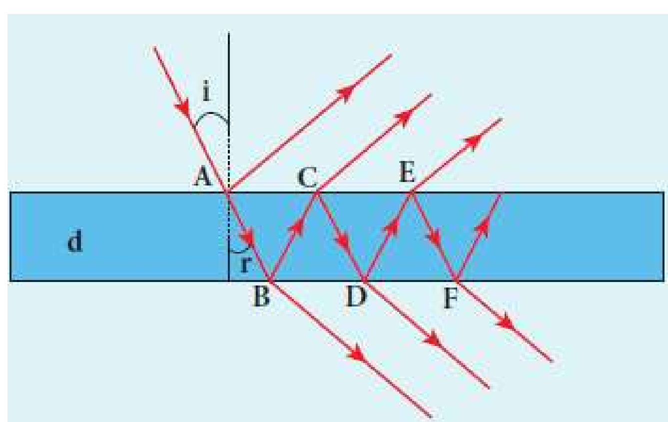
6. Discuss the interference in thin films and obtain the equations for constructive and destructive interference for transmitted and reflected light.

Interference in thin films

Dazzling colours are exhibited by thin films of oil spread on the surface of water and also soap bubbles.

Figure explanation

Let us consider a thin film of transparent material of refractive index μ and thickness'd'. A parallel beam of light is incident on the film at an angle 'I' as shown in the following figure.



The wave is divided into two parts at the point of incidence, as

(1) Reflected

(2) Refracted lights.

The refracted part, which enters into the film, again gets divided at the lower surface into two parts; one is transmitted out of the film and the other is reflected back into the film. The reflected as well as refracted parts are further formed as multiple reflections take place inside the film. Thus the **interference occurs** in both the reflected and transmitted light.

Transmitted light

Let us consider the path difference between the two light waves transmitted from B and D. The extra path travelled by the wave transmitted from D is BC+CD. If we consider 'i' is nearly equal to zero and the thickness of the film'd' is very small, then,

$$BC + CD = 2d$$

The above extra path is traversed in medium of refractive index μ. Therefore the optical path difference can be written as, $\delta = 2\mu d \rightarrow\rightarrow\rightarrow (1)$

The condition for constructive interference for transmitted ray is,

$$2\mu d = n\lambda$$

Similarly, the condition for destructive interference for transmitted ray is,

$$2\mu d = (2n-1)\frac{\lambda}{2}$$

Reflected light

Let us consider light from the points A and C producing interference. Among the two light extra path travelled by the wave from C is AB + BC. If we consider 'i' is nearly equal to zero and the thickness of the film'd' is very small, then,

$$AB + BC = 2d$$

The above extra path is traversed in medium of refractive index μ. Therefore the optical path difference can be written as, $\delta = 2\mu d \rightarrow\rightarrow\rightarrow (2)$

Note

Among the two rays which producing the interference pattern, if one ray is reflected by denser medium, it automatically undergoes a phase change of π (OR) path difference of $\left(\frac{\lambda}{2}\right)$.

The condition for constructive interference for transmitted ray is,

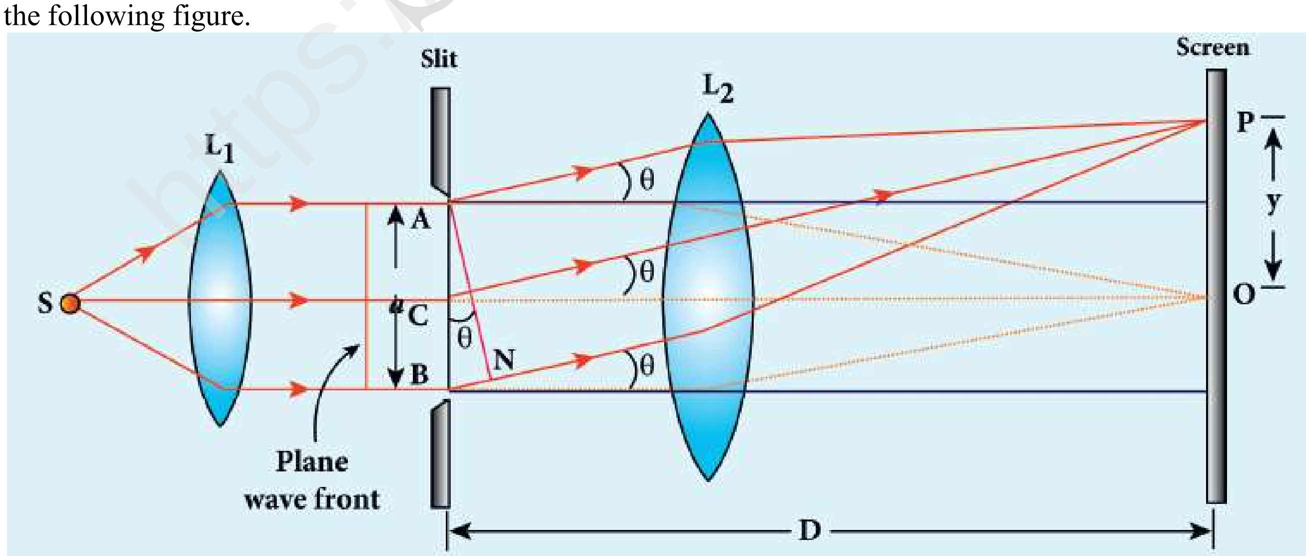
$2\mu d + \frac{\lambda}{2} = n\lambda$ (or) $2\mu d \quad (2n-1)\frac{\lambda}{2}$

The condition for destructive interference for transmitted ray is,

$2\mu d + \frac{\lambda}{2} = (2n+1)\frac{\lambda}{2}$ (or) $2\mu d = n\lambda$

7. Discuss the diffraction at single slit and obtain the condition for the n^th minimum.

Let a parallel beam of light (plane wavefront) fall normally on a single slit AB of width 'a' as shown in the following figure.



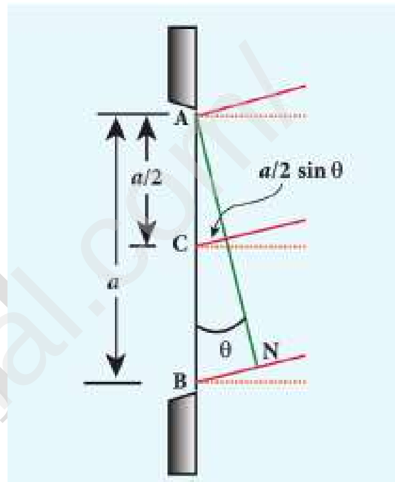
Explanation of figure

The diffracted beam falls on a screen kept at a distance D from the slit. The center of the slit is C. A straight line through C perpendicular to the plane of slit meets the center of the screen at O. Consider any point P on the screen. All the light reaching the point P from different points on the slit make an angle θ with the normal CO.

All the light waves coming from different points on the slit interfere at point P on the screen to give the resultant intensities. The point P is in the geometrically shadowed region, up to which the central maximum is spread due to diffraction. We need to give the condition for the point P to be of various minima.

The basic idea is to divide the slit into even number of smaller parts. Then add their contributions at P with the proper path difference to show that destructive interference takes place at that point to make it minimum.

To explain maximum, the slit is divided into odd number of parts.



Condition for P to be first minimum

Let us divide the slit AB into two halves AC and CB. Now the width of each part is $a/2$. We have different points on the slit which are separated by the same width $a/2$ called as corresponding points.

The light waves from different corresponding points meet at point P and interfere destructively to make it a minimum. The path difference δ between the waves from these corresponding points is,

$$\delta = \frac{a}{2}\sin\theta$$

The condition for P to be the first minimum is, $\frac{a}{2}\sin\theta = \frac{\lambda}{2}$

That is, $\boldsymbol{a\ \sin\theta = \lambda}$

Condition for P to be second minimum

Let us divide the slit AB into four equal parts. Now, the width of each part is $a/4$. We have several corresponding points on the slit which are separated by the same width $a/4$. The path difference δ between the waves from these corresponding points is,

$$\delta = \frac{a}{4}\sin\theta$$

The condition for P to be second minimum is, $\frac{a}{4}\sin\theta = \frac{\lambda}{2}$

That is, $\boldsymbol{a\ \sin\theta = 2\lambda}$

Condition for P to be third minimum

The same way the slit is divided into six equal parts to explain the third minimum is, $\frac{a}{6}\sin\theta = \frac{\lambda}{2}$

That is, $\boldsymbol{a\ \sin\theta = 3\lambda}$

Condition for P to be the nth minimum

Dividing the slit into 2n number of equal parts makes the light produced by one of the corresponding points to be cancelled by its counterpart. Thus, the condition for nth minimum is, $\frac{a}{2n}\sin\theta = \frac{\lambda}{2}$

That is, $\boldsymbol{a\ \sin\theta = n\lambda}$. Where n = 1,2,3,… is the order of diffraction minimum.

Note

• Similarly we can able to prove the condition for nth maxima is,

$$\boldsymbol{a\ \sin\theta = (2n+1)\frac{\lambda}{2}}$$

Where, n = 0,1,2,3…. Is the order of diffraction maximum.

• The central maximum is called 0th order maximum. The points of the maximum intensity lie nearly midway between the successive minima.

8. Discuss the diffraction at a grating and obtain the condition for the mth maximum.

Diffraction grating

A grating is a plane Sheet of transparent material on which opaque ruling are made. A modern commercial grating contains about 6000 lines per centimeter. The transparent space between the rulings acts as slit of width 'a' and the rulings act as obstacles having a definite width 'b'.

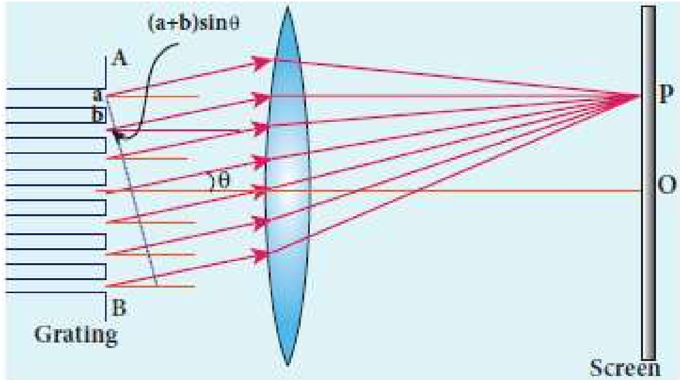


Figure Explanation

A plane transmission grating is represented as AB as shown in the figure. Let, a plane wavefront of monochromatic light with wavelength λ be incident on the grating.

As the width of the slit is comparable to that of wavelength, the incident light undergoes diffraction.

Discussion on Diffraction

A diffraction pattern is obtained on the screen when the diffracted waves are focused on a screen using a convex lens.

Let us consider a point P at an angle θ with the perpendicular drawn from the center of the grating to the screen. The path difference δ between the diffracted waves from one pair of adjacent corresponding point is,

$$\delta = (a+b)\sin\theta$$

This path difference is the same for any pair of adjacent corresponding points. The point P on the screen will be maximum when,

$$\delta = m\lambda \quad Where, m = 0,1,2,3, \ldots.$$

By combining the above two equations,

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

Here, m is called as order of diffraction maximum.

Condition for P to be zeroth maximum, m = 0

Now $(a+b)\sin\theta = 0$ thus, (a+b) cannot be zero. So for, $\sin\theta = 0$, That is its position $\theta = 0$. This is called zeroth diffraction (or) central maximum. It is formed at an angle 0^0.

Condition for P to be first maximum, m = 1

Now, $(a+b)\sin\theta_1 = 1\,\lambda$. The first maximum is obtained at an angle θ_1.

Condition for P to be second maximum, m = 2

Now, $(a+b)\sin\theta_2 = 2\,\lambda$. The second maximum is obtained at an angle θ_2.

Condition for P to be the mth maximum

On either side of central maximum, different higher order diffraction maxima are formed at different angular positions. If we take, $N = \frac{1}{a+b}$; Here, N is number of grating elements or ruling drawn per unit width of the grating.

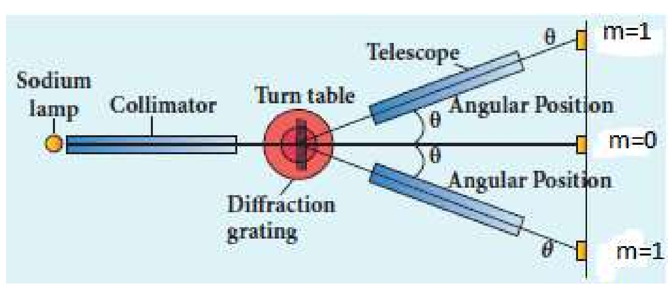
Normally, this number N is specified on the grating itself. Now, the equation $(a+b)\sin\theta = m\lambda$ becomes,

$\frac{1}{N}\sin\theta = m\lambda$, That is,

$$\boxed{\sin\boldsymbol{\theta} = \boldsymbol{Nm\lambda}}$$

9. **Discuss the experiment to determine the wavelength of monochromatic light using diffraction grating.**

The wavelength of a spectral line can be very accurately determined with the help of a plane transmission grating. For that we need to use an instrument called **spectrometer.** After preliminary adjustment the slit of collimator is illuminated by a monochromatic light, whose wavelength is to be determined. The telescope brought in line with collimator to view the image of slit.



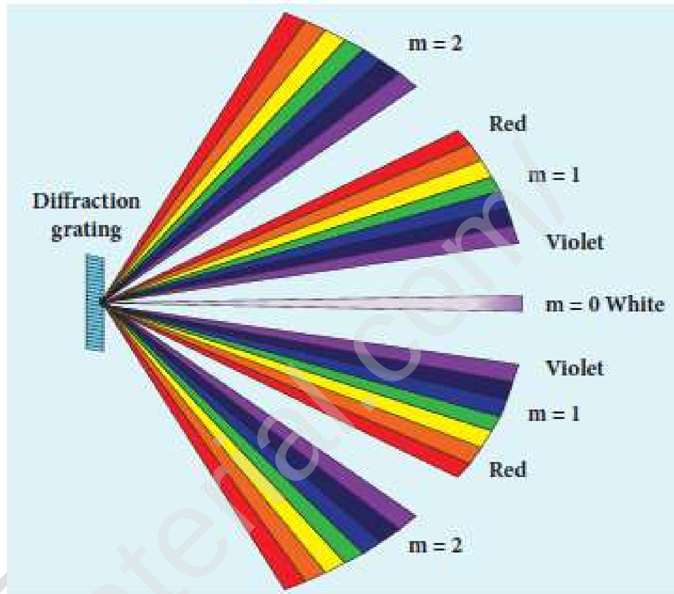
The given grating is then mounted on the prism table with its plane perpendicular to the incident beam of light coming from the collimator. The telescope is turned to one side until the first order diffraction image of the slit is seen. The reading of the position of the telescope is noted.

Similarly, the first order diffraction image on the other side is captured and the reading is noted. The difference between two readings gives 2θ. Half of its value gives θ. The angle for first order maximum is shown in the above figure. The wavelength of light is calculated from the equation.

$$\boxed{\sin\theta = Nm\lambda}$$

Here, N is the number of ruling per meter in the grating and m is the order of diffraction image.

10. Discuss the experiment to determine the wavelength of different colour using diffraction grating.



The diffraction pattern for white light consists of a white central maximum and continuous coloured diffraction of pattern on its both sides.

The central maximum is white as all the colours constructively meet at centre with no path difference. As θ increases, the path difference fulfills the condition for maxima of different orders for all colours from violet to red.

It produces a spectrum of diffraction pattern from violet to red on either side of central maximum as shown in the figure.

By measuring the angle at which these colours appear for various orders of diffraction, the wavelength of different colours could be calculated using the formula given by the equation.

$$\boxed{\sin\theta = Nm\lambda}$$

Here, N is the number of ruling per meter in the grating and m is the order of diffraction image.

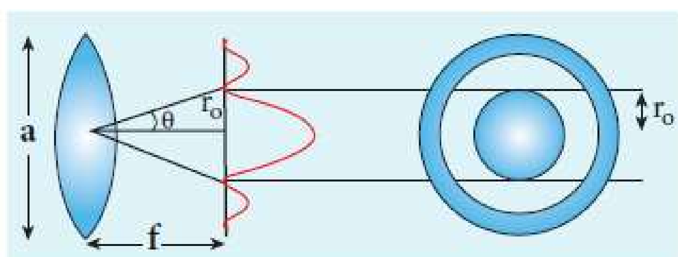
11. Obtain the equation for resolving power of optical instruments.

Airy's Discs.

A circular slit produces diffraction pattern of concentric circles called as Airy's discs.

Most of the optical instruments form images of objects only through the circular slits. The condition for central maximum (or) first minimum for circular slit is,

$a\sin\theta = 1.22\lambda$ →→→ (1)



Here, the numerical value 1.22 appears in the expression for central maximum formed by circular slits.

For small angles, $\sin\theta \approx \theta$, the above equation becomes,

$$a\theta = 1.22\lambda$$

Rearrange the above equation,

$$\theta = \frac{1.22\lambda}{a}$$

From the geometry, $\theta = \frac{r_0}{f}$

By substituting this in the above equation,

$$r_0 = \frac{1.22\lambda f}{a}$$

Here, a – diameter of the lens, θ- angular resolution, λ-wavelength of the light used, r_0 – Spatial resolution or radius of central maxima.

From the above equation, for better resolution, the wavelength of light used must be as small as possible and the size of the aperture of the instruments must be as large as possible.

Resolving Power

The ability of optical instruments to distinguish the two closely adjacent objects (or) two points on the same object is said to be the resolving power of the instrument. In general, the term resolution is pertaining to the quality of the image and the term resolving power is associated with the ability of the optical instrument. Resolution and resolving power are reciprocal of each other.

12. Discuss about the simple microscope and obtain the equations for magnification for near point focusing and normal focusing.

Simple Microscope

A simple microscope is a single magnifying (convex) lens of small focal length which must produce an erect, magnified and virtual image of the object.

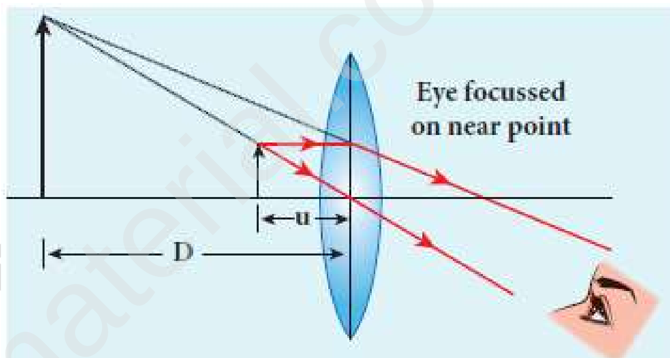
Near and Far point

The object is placed within the focal length f (between the points F and P) on one side of the lens and viewed through the other side of it. The nearest point where an eye can clearly see is called the **near point** and the farthest point up to which an eye can clearly see is called the **far point**.

For a healthy eye, the distance of the near point is 25 cm., which is denoted as D and the far point should be at infinity.

Near point focusing

The eye is least strained when image is formed at near point, i.e., 25 cm. The near point is also called as least distance of distinct vision. This is shown in the adjacent figure. The object distance 'u' should be less than 'f'. The image distance as the near point D. The magnification 'm' of this lens is given by the equation,



$$m = \frac{v}{u}$$

Substituting, v = -D and u = -u, as both the distances are measured to the left of the lens. Hence,

$$m = \frac{-D}{-u}$$

That is, $m = \frac{D}{u}$

We can also write the equation for magnification m in terms of focal length f by using lens equation,

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

Multiply the above equation by v,

$$\frac{v}{f} = \frac{v}{v} - \frac{v}{u}$$

$$\frac{v}{f} = 1 - m$$

That is, $m = 1 - \frac{v}{f}$; By substituting, v = - D gives,

$$\boxed{\boldsymbol{m = 1 + \frac{D}{f}}}$$

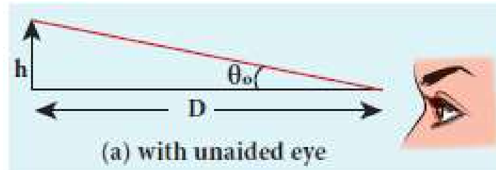
This is the magnification for near point focusing.

Normal Focusing

The eye is most relaxed when the image is formed at infinity. The focusing is called normal focusing when the image is formed at infinity. This is shown in the adjacent figure. To find the magnification 'm' if we take the ratio of the height of the image to the height of the object

$$\left[m = \frac{h'}{h}\right]$$

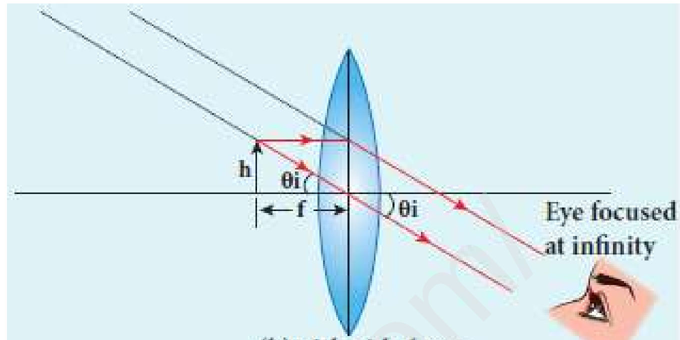
Here, the image is infinite size and at infinite distance. So the above equation is not meaningful. Hence, practically we use the concept of angular magnification,



(a) with unaided eye

Angular Magnification

The angular magnification is defined as the ratio of angle θ_i subtended by the image with aided eye to the angle θ_o subtended by the object with unaided eye.



(b)with aided eye

$$m = \frac{\theta_i}{\theta_0}$$

For unaided eye, from the figure,

$$\tan\theta_0 \approx \theta_0 = \frac{h}{D}$$

For aided eye, from the figure,

$$\tan\theta_i \approx \theta_i = \frac{h}{f}$$

From the definition of angular magnification,

$$m = \frac{\theta_i}{\theta_0} = \frac{h/f}{h/D}$$

$$\boxed{\boldsymbol{m = \frac{D}{f}}}$$

This is the magnification for normal focusing.

13. Explain compound microscope and obtain the equation for the magnification.

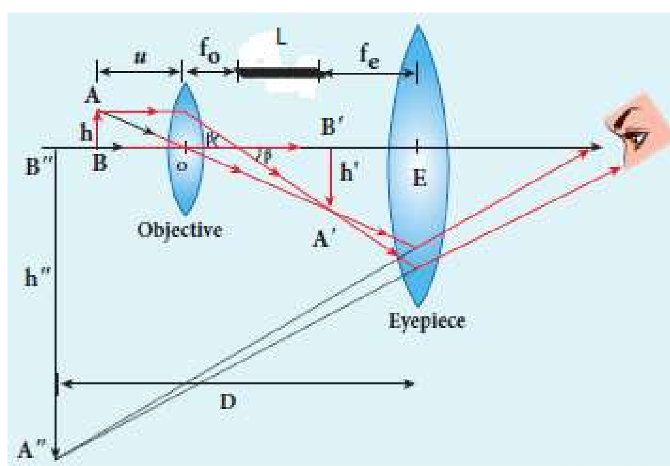
Compound Microscope

An optical Microscope with more than one lens is called as compound microscope. One lens is called objective and the other is eyepiece. Compound microscopes have a combination of these lenses that enhances both magnifying power as well as the resolving power.

The lens near the object is called as objective. It forms a real, inverted and magnified image of the object. This serves as the object for the lens close to the eye called as eyepiece. The eyepiece serves as a simple microscope that produces finally an enlarged and virtual image.

The first inverted image formed by the objective is to be adjusted within the focus of the eyepiece so that the final image is formed nearly at infinity (or) at the near point. The final image is inverted with respect to the object.

Magnification in Compound Microscope



The lateral magnification produced by the objective is given $m_0 = \frac{h'}{h}$

From the above figure, $\tan\beta = \frac{h}{f_0} = \frac{h'}{L}$

That is, $\frac{h}{f_0} = \frac{h'}{L}$; Rearrange this equation, $\frac{L}{f_0} = \frac{h'}{h}$;

Substitute this in lateral magnification equation,

$$m_0 = \frac{h'}{h} = \frac{L}{f_0}$$

Here, L is the distance between the focal point of the eyepiece to the focal point of the objective.

The final image is formed at the near point, so for from the magnification at the near point,

$m_e = 1 + \frac{D}{f_e}$

The total magnification 'm' for near point focusing is,

$$m = m_o m_e = \left[\frac{L}{f_o}\right]\left[1 + \frac{D}{f_e}\right]$$

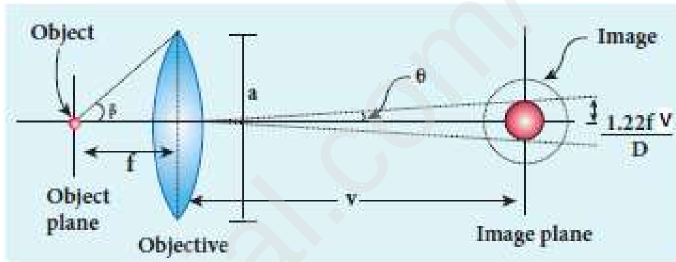
If the final image is formed at infinity (normal focusing). The magnification m_e of the eyepiece is,

$$m_e = \frac{D}{f_e}$$

The total magnification 'm' for normal focusing is,

$$\boldsymbol{m = m_o m_e = \left[\frac{L}{f_o}\right]\left[\frac{D}{f_e}\right]}$$

14. **Obtain the equation for resolving power of microscope.**



We know that the expression for spatial resolution or radius of central maxima, is

$r_0 = \frac{1.22\lambda f}{a} \longrightarrow\longrightarrow\longrightarrow (1)$

In microscope, the object distance is just more than the focal length f and the image is formed at v as shown in the adjacent figure. Hence, f in equation is replaced by v,

$r_0 = \frac{1.22\lambda v}{a} \longrightarrow\longrightarrow\longrightarrow (2)$

Here, in the place of focal length f we have the image distance v. If the difference between the two points on the object to be resolved is $d_{minimum}$, (d_{min})then the magnification 'm' is,

$$m = \frac{r_0}{d_{min}}$$

$d_{min} = \frac{r_0}{m} = \frac{1.22\lambda v}{am} = \frac{1.22\lambda v}{a(v/u)} = \frac{1.22\lambda u}{a}$ (Since, $m = v/u$)

$d_{min} = \frac{1.22\lambda f}{a} \longrightarrow\longrightarrow\longrightarrow (3)$ (Since $u \approx f$)

Now let we come to the object side,

$\sin\beta = \frac{a/2}{f}$; That is $\frac{f}{a} = \frac{1}{2\sin\beta} \longrightarrow\longrightarrow\longrightarrow (4)$

Substitute, (4) in (3),

$d_{min} = \frac{1.22\lambda}{2\sin\beta} \longrightarrow\longrightarrow\longrightarrow (5)$

To further reduce the value of d_{min} the optical path of the light is increased by immersing the objective of the microscope into a bath containing oil of refractive index 'n'

$$d_{min} = \frac{1.22\lambda}{2n\sin\beta}$$

Such an objective is called oil immersed objective. **The term n$\sin\beta$ is called numerical aperture NA.**

$$d_{min} = \frac{1.22\lambda}{2(NA)}$$

The resolving power R_M of microscope is,

$$R_M = \frac{1}{d_{min}} = \frac{2(NA)}{1.22\lambda}$$

Resolving Power of telescope

The resolving power of telescope is the reciprocal of the spatial resolution.

$$R_T = \frac{1}{r_0} = \frac{a}{1.22\lambda f}$$

15. **Discuss about astronomical telescope.**

Astronomical Telescope

An astronomical telescope is used to get the magnification of distant astronomical objects like stars, planets, moon etc., The image formed by astronomical telescope will be inverted.

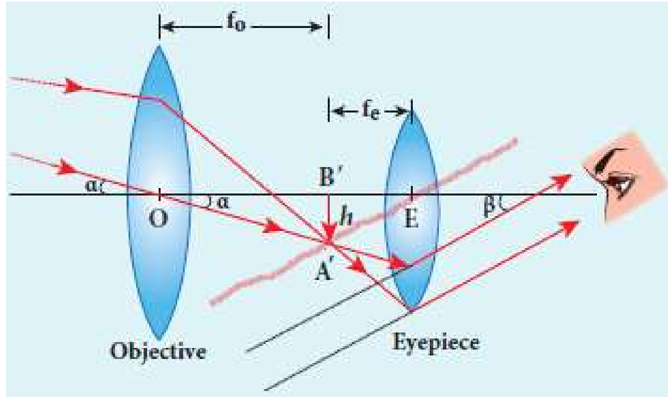


Figure Explanation

It has an objective of long focal length and a much larger aperture than the eyepiece as shown in the figure.

Light from a distant object enters the objective and a real image is formed in the tube at its focal point. The eyepiece magnifies this image producing a final inverted image.

Magnification

The magnification 'm' is the ratio of the angle β subtended by the image to the angle α subtended by the object with the principal axis.

$$m = \frac{\beta}{\alpha}$$

From the figure, $\alpha = \frac{h}{f_o}$ and $\beta = \frac{h}{f_e}$

Substitute these, in the above equation,

$$m = \frac{f_o}{f_e}$$

The length of the telescope is approximately,

$$L = f_o + f_e$$

16. Mention different parts of spectrometer and explain the preliminary adjustments.

Spectrometer

The spectrometer is an optical instrument used to analyse the spectra of different sources of light, to measure the wavelength of different colours and to measure the refractive indices of materials of prisms.

The main parts of the spectrometer are

- **Collimator**

The collimator is used for producing parallel beam of light. It has a convex lens and a vertical slit of adjustable width which faces the sources. The position of slit can be adjusted so that it is kept at the focus of the lens. The collimator is rigidly fixed to the base.

- **Prism Table**

The prism table is used to mounting the prism, grating et., It consists of two circular discs provided with three leveling screws. It can be rotated and its position can be read from two verniers V_1 and V_2. The prism table can be fixed at any desired height.

- **Telescope**

The telescope is an astronomical type. It consists of both eyepiece and objective. The distance between the objective and the eyepiece can be adjusted so that the telescope forms a clear image at the cross wires.

The telescope is attached to a circular scale and both can be rotated together. The telescope and prism are provided with radial screws for fixing them at a desired position and tangential screws for fine adjustments.

Preliminary adjustments of the spectrometer

- **Adjustment of the eyepiece**

The telescope is turned towards an illuminated surface and the eyepiece is moved to and fro until the cross wires are clearly seen.

- **Adjustment of the telescope:**

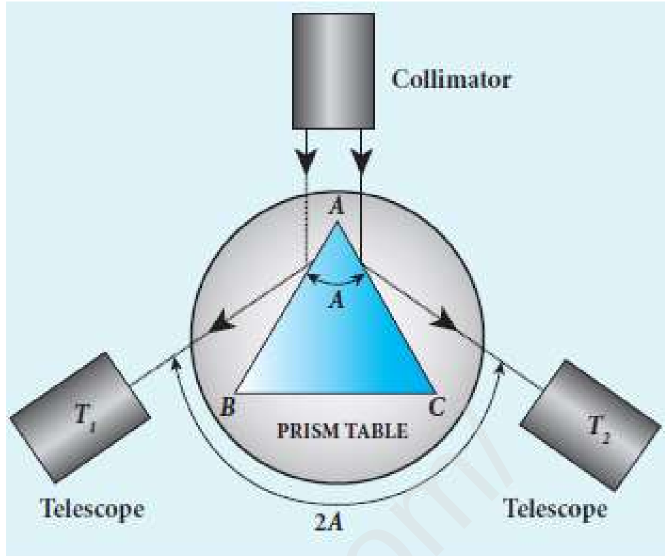
The telescope is adjusted to receiver parallel rays be focusing it to a distant object to get a clear image on the cross wire.

- **Adjustment of the collimator**

The telescope is brought in line with the collimator. The distance between the illuminated slit and the lens of the collimator is adjusted until a clear image of the slit is seen at the cross wire.

• **Leveling of the prism table**

The prism table is brought to the horizontal level by adjusting the leveling screws and it is ensured by using sprit level



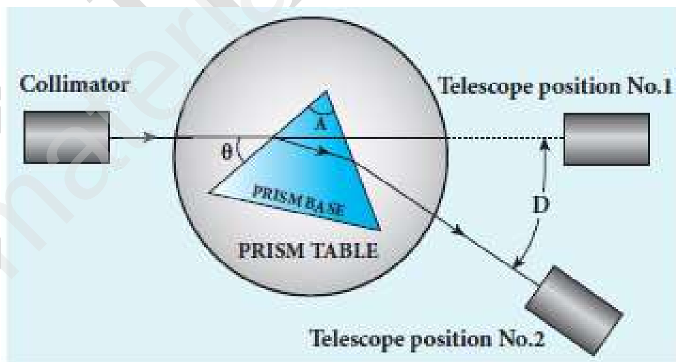
17. Explain the experimental determination of refractive index of the material of the prism using spectrometer.

After the preliminary adjustments are done, the refractive index of the prism can be determined by measuring the angle of the prism A and the angle of minimum deviation D.

Angle of the prism A

The prism is placed on the prism table with its refracting angle A facing the collimator. The slit is illuminated by sodium light. The parallel rays coming from the collimator fall on the two faces AB and AC and get reflected. The telescope is rotated to the position T_1 and T_2 to capture the reflected rays and the two reading are noted.

The difference between these two readings gives the angle rotated by the telescope, which is twice the angle of the prism. Half of this value gives the angle of the prism A.



Angle of minimum Deviation D

The prism is placed on the prism table so that the light from the collimator falls on a refracting face and the refracted image is observed through the telescope. The prism table alone is rotated so that the angle of deviation decreases. A stage comes when the image stops and returns on further rotation of the prism table.

This is ensured by looking through the telescope simultaneously. The reading in this position gives the minimum deviation position.

Now, the prism is removed and the telescope is turned to receive the direct ray and the reading is noted.

The difference between the two readings gives the angle of minimum deviation. The refractive index of the material of the prism 'n' is calculated using the equation,

$$\boxed{n = \frac{\sin\left(\frac{A+D}{2}\right)}{\sin\left(\frac{A}{2}\right)}}$$

Note

The refractive index of a liquid may be determined in the same way by using a hollow glass prism filled with the liquid.