INTERFERENCE

Q.1) State and explain the Principle of superposition of waves (Short Answer question).

Two or more waves can traverse the same space independently of one another. In the region where they meet, the displacement of the particles of the medium is the algebraic sum of their displacements due to individual waves alone. This process of vector addition of the displacements of a particle is called the principle of superposition.

Using the superposition principle it is possible to analyse a complicated wave motion as a combination of simple waves.

Q.2) State and explain the Principle of superposition of waves.

Two or more waves can traverse the same space independently of one another. In the region where they meet, the displacement of the particles of the medium is the algebraic sum of their displacements due to individual waves alone. This process of vector addition of the displacements of a particle is called the principle of superposition.

Principle of superposition is valid when the equations describing the wave motion are linear i.e., when the wave amplitudes are small. If the equations describing the wave motion are not linear, superposition principle fails. Shock waves produced by violent explosions do not obey the principle of superposition since the equation describing the wave motion is quadratic.

Using the superposition principle it is possible to analyse a complicated wave motion as a combination of simple waves. It is thus possible to represent a periodic pulse *y(t)* as

$y(t) = A_0 + A_1 Sin\ \omega t + A_2 Sin2\ \omega t + ... + B_1 Cos\ \omega t + B_2 Cos2\ \omega t + ...$ where ω gives the angular frequency of the pulse, *A*'s and *B*'s are constants. This expression is called the Fourier series. If the motion is not periodic, the above sum is replaced by an integral called the Fourier integral.

Q.3) Define Interference? (Short Answer question)

Two or more light waves of the same frequency travelling approximately in the same direction with constant phase difference can combine to give rise to redistribution of energy in the form of maxima and minima. This type of redistribution of energy due to superposition is called interference. The series of alternate maxima and minima is called an interference pattern.

Interference provides the most convincing evidence that light is a wave. The formation of bright and dark fringes is in accordance with the law of conservation of energy. The energy which apparently disappears at minima has actually been transferred to the maxima where the intensity is greater than that produced by the two beams acting separately.

Q.4) Discuss the techniques for producing interference of light. (Short Answer question).

To produce a pair of coherent beams of light, two techniques are used. One is the division of wave front and the second is the division of amplitude.

(1) Division of wave front:

The incident wave front is divided into two parts by using the phenomenon of reflection, refraction or diffraction. They travel unequal distances and reunite at small angle to produce interference fringes. Here point sources of light should be used.

Young's double slit experiment, Fresnel's Bi-prism, Lloyd's mirror etc., are examples for this method. Here the waves spread out by diffraction at the point sources.

(2) Division of amplitude:

The amplitude of incoming beam is divided into two parts either by partial reflection or refraction which reunite after travelling along different paths and produce interference. Here extended source of light should be used.

Thin film interference such as Newton's rings, Michelson's interferometer etc., come under this method.

Q.5) What are the essential conditions for producing interference?

(1) Conditions for sustained interference:

(a) The two sources should be coherent. Sources derived from a single source are in phase with each other or maintain a constant phase difference. Coherent beams of light produce a steady interference pattern.

(b) The two interfering waves must be of the same wavelength and periodic time and propagate approximately in the same direction.

(c) Planes of polarization of the waves must be the same. Waves polarized in perpendicular planes cannot produce interference effects.

(2) Conditions for observation:

(a) The separation between the two sources should be small. Large separation leads to smaller fringe width with loss of visibility.
(b) The distance between the sources and screen should be large. If this distance is small then the fringe width will be very small and the fringes will not be separately visible.
(c) The background should be dark. If the source is not strong, the fringes happen to have low intensity losing clarity against bright background.

(3) Conditions for good contrast:

(a) The two sources should be very narrow. A broad source may be thought of as a group of sources with different frequencies / wavelengths so that superposition of light from any pair cannot give an interference pattern.

(b) The sources should be monochromatic. The fringe width β depends upon the wavelength of light. If the source is monochromatic, β will be constant and hence fringes of good intensity can be observed. If the source used is emitting white light, it is equivalent to an infinite number of monochromatic sources. This results in overlapping of fringes due to different wavelengths, and thus only a few colored fringes with poor contrast are visible. When the path difference is large, it results in uniform illumination.

(c) The amplitudes of the interfering waves should be preferably equal. If a_1 and a_2 are the amplitudes of the interfering beams, then Intensity of maxima is $(a_1 + a_2)^2$ and Intensity of minima is $(a_1 - a_2)^2$. If the difference between the amplitudes a_1 and a_2 is very large, then the intensity of minima will be practically the same as that of the maxima and hence the contrast will be poor. For a good contrast $a_1 \approx a_2$, so that the minima have a low intensity.

Q.6) What are the conditions for producing sustained interference of light? (Short Answer question)

(a) The two sources should be coherent. Sources derived from a single source are in phase with each other or maintain a constant phase difference. Coherent beams of light produce a steady interference pattern.

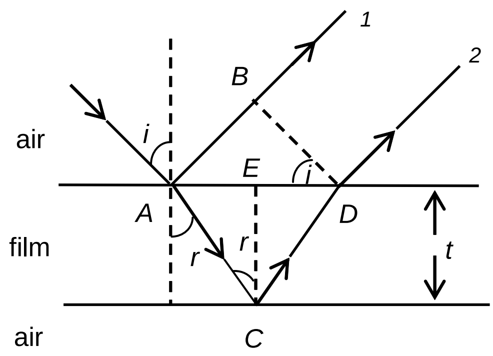
(b) The two interfering waves must be of the same wavelength and periodic time and propagate approximately in the same direction.

(c) Planes of polarization of the waves must be the same. Waves polarized in perpendicular planes cannot produce interference effects.

Q.7) Give the theory of interference of light incident on a thin film.

Thin-film interference is an example of interference by division of amplitude. The striking colours of soap bubbles, oil slicks, peacock feathers, throats of humming birds, Newton's rings, interference patterns in Michelson interferometer are some examples of thin film interference. The condition of coherence is satisfied in thin film interference because the rays are derived from the same ray incident on the film. A thin film has two surfaces, the upper surface and the lower surface of the film. The rays reflected or transmitted from these surfaces participate in the interference process. The interfering waves combine either to enhance or to suppress certain colours in the spectrum of the incident sun light.

The figure shows a film of uniform thickness *t*, index of refraction μ. Let light be incident at *A*. Part of the light is reflected towards *B* and the other part is reflected at *C* and emerges at *D* and is parallel to the first part. The condition of coherence is satisfied here because rays *1* and *2* are derived from a single incident ray. At normal incidence, the path difference Δx between rays *1* and *2* is twice the optical thickness of the film.



$\Delta x = 2\mu t$ where μ is the refractive index of the film. At oblique incidence, the optical path differnce is $\Delta x = \mu(AC + CD) - AB$

In the Δle *ABD*, $Sin\, i = \frac{AB}{AD} = \frac{AB}{2AE}$ or $AB = 2(AE) Sin\, i$

In the Δle *AEC*, $Tan\, r = \frac{AE}{t}$ or $AE = t\, Tan\, r$

$\therefore AB = 2t\, Tan\, r\, Sin\, i = 2t\, Tan\, r\, \mu\, Sin\, r$. Since $AC = \frac{t}{Cos\, r}$ and $AC + CD = \frac{2t}{Cos\, r}$, we have

$$\therefore \Delta x = \frac{2\mu t}{Cos\, r} - 2\mu t\, Tan\, r\, Sin\, r = 2\mu t\left(\frac{1}{Cos\, r} - Tan\, r\, Sinr\right) = 2\mu t\left(\frac{1 - Tan\, r\, Sin\, r\, Cos\, r}{Cos\, r}\right)$$

$\Delta x = 2\mu t\left(\frac{1-Sin^2 r}{Cos\, r}\right)$ or $\Delta x = 2\mu t\, Cos\, r$, where μ is the refractive index of the medium between the surfaces. Since for air $\mu = 1$, the path difference between rays *1* and *2* is given by

$$\Delta x = 2\, t\, Cos\, r$$

However, this is only the apparent path differnce. To calculate the real path difference, one should also consider the change in phase brought in by reflection. According to electromagnetic theory of light, whenever reflection occurs at an interface backed by a denser medium, a phase of change of π or a path difference of $\frac{\lambda}{2}$ is additionally introduced in the reflected component. Hence the real path difference is $\Delta x = 2\mu t\, Cos\, r + \lambda/2$

Hence, the condition for maxima for the thin film to appear bright is

$$2\mu t\, Cos\, r + \frac{\lambda}{2} = m\lambda \text{ or } 2\mu t\, Cos\, r = m\lambda - \frac{\lambda}{2} = (2m-1)\frac{\lambda}{2} \text{ , where } m = 0, 1, 2, \ldots\ldots$$

The film will appear dark in the reflected light when

$$2\mu t\, Cos\, r + \frac{\lambda}{2} = (2m+1)\frac{\lambda}{2} \text{ or } 2\mu t\, Cos\, r = m\lambda \text{ , where } m = 0, 1, 2, 3, \ldots\ldots.$$

One cannot observe any interference pattern in thick films. For observing the interference pattern, the thickness of the film should be comparable with the wavelength of light.

Q.8) Explain the conditions for constructive and destructive superposition of waves. (Short Answer question)

When two waves are displaced through an integral number of wavelengths, constructive interference takes place. In case of reflected light from thin film, the condition for maxima for the thin film to appear bright (constructive interference) is

$$2\mu t\, Cos\, r + \frac{\lambda}{2} = m\lambda \text{ or } 2\mu t\, Cos\, r = m\lambda - \frac{\lambda}{2} = (2m-1)\frac{\lambda}{2} \text{ , where } m = 0, 1, 2, \ldots\ldots$$

When two waves are displaced with respect to each other by an odd number of half-wavelengths, destructive interference results. In case of reflected light from thin film, the condition for minima for the thin film to appear dark (destructive interference) is

$$2\mu t \,Cos\, r + \frac{\lambda}{2} = (2m+1)\frac{\lambda}{2} \quad \text{or } 2\mu t\, Cos\, r = m\lambda \text{ , where } m = 0, 1, 2, 3, \ldots\ldots.$$

Q.9) Write a short note on colours in thin films. (Short Answer question)

The colours exhibited in reflection by thin films of oil, mica, soap bubbles are due to interference of light from an extended source such as sky. The reflected rays from the top and bottom surfaces of the film are very close to each other and are in a position to interfere. The optical path difference between the interfering rays is $\Delta = 2\,\mu\, t\, Cos\, r - \lambda/_2$. It is seen that the path difference depends upon the thickness t of the film, the wavelength λ and the angle r, which is related to the angle of incidence of light on the film.

White light consists of a range of wavelengths and for specific values of thickness t and the angle r, waves of certain wavelengths (colours) constructively interfere. Therefore, only those colours are present in the reflected light. The other wavelengths interfere destructively and hence are absent from the reflected light. Hence, the film at a particular point appears coloured. As the thickness and the angle of incidence vary from point to point, different colours are intensified at different places. The colours seen are not isolated colours, as at each place there is a mixture of colours.

Q.10) Describe the formation of Newton's rings in reflected light and derive expressions for the radii of bright and dark rings.

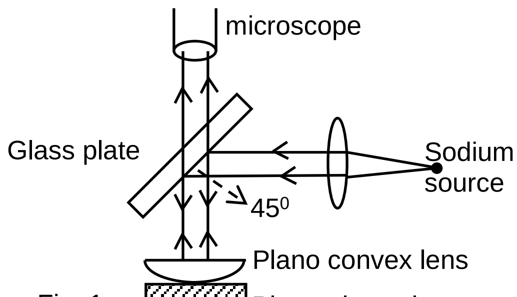


Fig. 1

Newton's rings are classic example of thin film interference by division of amplitude. The experimental arrangement for observing Newton's rings is shown in Figure 1. When a plano-convex lens of long focal length with its convex surface is placed on a plane glass plate, an air film of gradually increasing thickness is formed between the two. The film thickness at the point of contact is zero. If monochromatic light is allowed to fall normally, and the film is viewed in the reflected light, concentric bright and darks rings around the point of contact are seen. These circular fringes were discovered by Newton and are called Newton's rings. When the film is viewed in the reflected light, dark spot is formed at the point of contact of the lens with the glass plate. The circular fringes are localized and are of equal thickness and get crowded away from the point of contact.

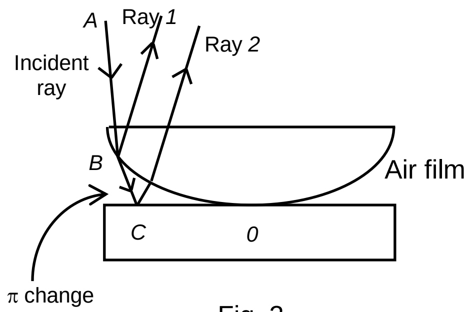


Fig. 2

The ray diagram in the formation of Newton's rings is shown in Figure 2. The ray is incident normally on the lens-plate system. Ray *1* and Ray *2* are the rays reflected from top and bottom surface of the air film. Ray *1* undergoes no phase change but ray *2* acquires a phase change of π upon reflection, because it is reflected from air-glass interface. Rays *1* and *2* are coherent because they are derived from the same incident ray. The conditions for the bright and dark rings are governed by the following relations:

$$2\mu t \, Cos\, r = (2m+1)\frac{\lambda}{2} \qquad \text{(Bright rings) and } 2\mu t \, Cos\, r = m\lambda \qquad \text{(Dark rings)}$$

For normal incidence $Cos\, r = 1$ and for the air film $\mu = 1$

$$\therefore 2t = (2m+1)\frac{\lambda}{2} \qquad \text{(Bright fringes) and } 2t = m\lambda \qquad \text{(Dark fringes)}$$

Dark spot is observed at the point of the contact *0* of the lens with the glass plate. The air film at the point of contact is only a few molecules thick and is very small compared to a wavelength ($t << \lambda$). The path difference introduced between the interfacing waves is zero, i.e, $2t = 0$. But the wave reflected from the glass plate suffers a phase change of π which is equivalent to a path difference of $\frac{\lambda}{2}$. Consequently, the interfering waves at the centre are out of phase and interfere destructively and produce a dark spot. The locus of points where the air film has the same thickness then fall on a circle whose centre is the point of contact. Thus, the thickness of air film is constant at points on any circle having the point of lens-glass plate contact as the centre. The fringes are therefore circular.

Theory of Newton's rings :

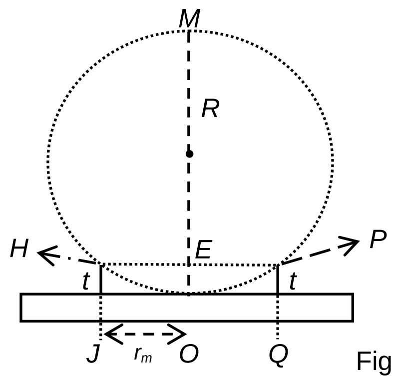


Fig. 3

In the reflected monochromatic light, Newton's rings are alternate bright and dark circles with a central dark spot. Refer to Fig. 3. Let R be the radius of curvature of the lens. At Q, let the thickness of the film $PQ = t$ satisfies the condition for a dark ring to form by interference. Let it be an m^{th} dark ring with a radius $OQ = r_m$. By the theorem of intersecting chords,

$(EP) \times (HE) = (OE) \times (EM)$. But $EP = OQ = HE = r_m$; $OE = PQ = t$ and

$(EM) = (OM - OE) = (2R - t)$

$\therefore r_m^2 = t(2R - t)$ or $r_m^2 = 2Rt - t^2$. As $2Rt >> t^2$, t^2 can be neglected. $\therefore r_m^2 = 2Rt$.

For dark rings, the governing relation is $2t = m\lambda$. $\Rightarrow r_m^2 = m\lambda R$ or $r_m = \sqrt{m\lambda R}$

The diameter of the dark ring is therefore given by $D_m = 2\sqrt{m\lambda R}$. The radii of the dark rings can be found by taking $m = 0, 1, 2, 3$……. It can be seen that

$r_0 = 0,\ r_1 = \sqrt{\lambda R},\ r_2 = \sqrt{2\lambda R},\ r_3 = \sqrt{3\lambda R}, ...$ and so on. Thus, the radii (also diameters) of the dark rings are proportional to the square root of natural numbers.

Considering bright rings, let us suppose that a bright ring is located at the point Q. The radius of the m^{th} bright ring is given by $r_m^2 = 2Rt$. For bright rings, the governing relation is

$$2t = (2m+1)\frac{\lambda}{2}$$

$\therefore r_m^2 = \dfrac{(2m+1)\lambda R}{2}$ or $r_m = \sqrt{\dfrac{(2m+1)\lambda R}{2}}$. The radii of different bright rings can be found by putting $m = 0, 1, 2, 3,$……………. in above equation. It is seen that $r_0 = \sqrt{\dfrac{\lambda R}{2}},\ r_1 = \sqrt{\dfrac{3\lambda R}{2}},\ r_2 = \sqrt{\dfrac{5\lambda R}{2}}$ and so on. It is clear that the radii (also diameters) of bright rings are proportional to the square root of the odd natural numbers.

Q. 11) Describe the formation of Newton's rings in reflected light and describe how the wavelength of sodium light can be determined by forming Newton's rings.

Newton's rings are classic example of thin film interference by division of amplitude. The experimental arrangement for observing Newton's rings is shown in Figure 1. When a plano-convex lens of long focal length with its convex surface is placed on a plane glass plate, an air film of gradually increasing thickness is formed between the two. The film thickness at the point of contact is zero. If monochromatic light is allowed to fall normally, and the film is viewed in the reflected light, concentric bright and darks rings around the point of contact are seen. These circular fringes were discovered by Newton and are called Newton's rings. When the film is viewed in the reflected light, dark spot is formed at the point of contact of the lens with the glass plate. The circular fringes are localized and are of equal thickness and get crowded away from the point of contact.

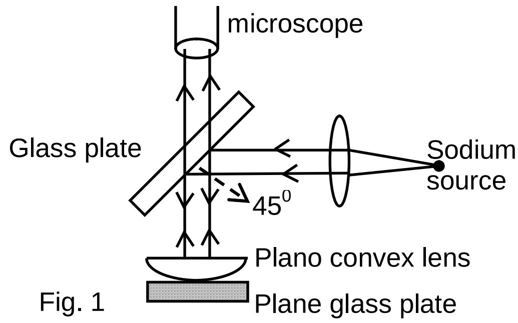


Fig. 1

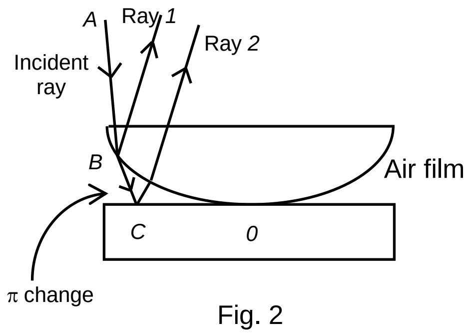


Fig. 2

The ray diagram in the formation of Newton's rings is shown in Figure 2. The ray is incident normally on the lens-plate system. Ray *1* and Ray *2* are the rays reflected from top and bottom surface of the air film. Ray *1* undergoes no phase change but ray *2* acquires a phase change of π upon reflection, because it is reflected from air-glass interface. Rays *1* and *2* are coherent because they are derived from the same incident ray. The conditions for the bright and dark rings are governed by the following relations:

$$2\mu\, t\, Cos\, r = (2m+1)\frac{\lambda}{2} \qquad \text{(Bright rings) and } 2\mu\, t\, Cos\, r = m\lambda \qquad \text{(Dark rings)}$$

For normal incidence $Cos\, r = 1$ and for the air film $\mu = 1$

$$\therefore 2\,t = (2m+1)\frac{\lambda}{2} \qquad \text{(Bright fringes) and } 2\,t = m\lambda \qquad \text{(Dark fringes)}$$

Dark spot is observed at the point of the contact *0* of the lens with the glass plate. The air film at the point of contact is only a few molecules thick and is very small compared to a wavelength ($t \ll \lambda$). The path difference introduced between the interfacing waves is zero, i.e, $2t = 0$. But the wave reflected from the glass plate suffers a phase change of π

which is equivalent to a path difference of $\frac{\lambda}{2}$. Consequently, the interfering waves at the centre are out of phase and interfere destructively and produce a dark spot.

In Newton's ring arrangement, the thickness of the air film at the point of contact is zero and gradually increases as we move outward. The locus of points where the air film has the same thickness then fall on a circle whose centre is the point of contact. Thus, the thickness of air film is constant at points on any circle having the point of lens-glass plate contact as the centre. The fringes are therefore circular.

The wave length of incident monochromatic light can be determined by forming Newton's rings and measuring the diameters of the dark rings using travelling microscope. For the m^{th} dark ring, $D_m^2 = 4m\lambda R$. For the n^{th} dark ring, $D_n^2 = 4n\lambda R$.

$$\therefore D_m^2 - D_n^2 = 4(m-n)\lambda R \quad or \quad \lambda = \frac{D_m^2 - D_n^2}{4(m-n)R}.$$

In practice, the diameters of successive dark rings are measured with a travelling microscope and a plot is drawn between D_m^2 and m. The plot is a straight line as shown in Fig.4.

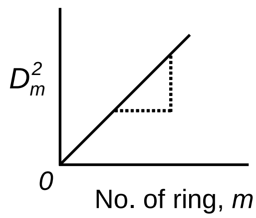


Fig. 4

The slope of the line gives the value of $4\lambda R$. Thus $\lambda = \frac{\text{Slope}}{4R}$.

The radius of curvature R of the lens is measured using a spherometer and λ is determined using the above equation.

Q.12) How will you measure the refractive index of a liquid using Newton's rings ?

The liquid whose refractive index is to be determined is filled in the gap between the lens and plane glass plate. The condition for interference may then be written as

$2\,\mu\, t\, Cos\, r = m\,\lambda$ (Darkness) where μ is the refractive index of the liquid.

For normal incidence the equation becomes $2\,\mu\, t = m\,\lambda$.

The diameter of m^{th} dark ring is given by $(D_m^2)_L = \frac{4\, m\,\lambda\, R}{\mu}$.

Similarly, the diameter of the $(m + p)^{th}$ ring is given by $\left(D_{m+p}^2\right)_L = \frac{4\,(m+p)\,\lambda\, R}{\mu}$.

Subtracting the above two equations, we get $\left(D_{m+p}^2\right)_L - (D_m^2)_L = \frac{4\,p\,\lambda\,R}{\mu}$.

But we know that $\left(D_{m+p}^2\right)_{air} - (D_m^2)_{air} = 4\,p\,\lambda\,R$.

$$\mu = \frac{\left(D_{m+p}^2\right)_{air} - (D_m^2)_{air}}{\left(D_{m+p}^2\right)_L - (D_m^2)_L}$$

Q.13) What are Newton’s rings and how they are formed ? (Short Answer question)

Newton's rings are classic example of thin film interference by division of amplitude. When a plano-convex lens of long focal length with its convex surface is placed on a plane glass plate, an air film of gradually increasing thickness is formed between the two. If monochromatic light is allowed to fall normally, and the film is viewed in the reflected light, concentric bright and darks rings around the point of contact are seen. These circular fringes were discovered by Newton and are called Newton's rings. When the film is viewed in the reflected light, dark spot is formed at the point of contact of the lens with the glass plate. The circular fringes are localized and are of equal thickness and get crowded away from the point of contact.

The condition of coherence is satisfied in thin film interference because the rays are derived from the same ray incident on the film. A thin film has two surfaces, the upper surface and the lower surface of the film. The rays reflected or transmitted from these surfaces participate in the interference process.

Q.14) What are the important applications of Newton’s rings phenomena? (Short Answer question)

1. Newton's rings find application in testing the surface finish of lenses and other optical components used in telescopes and other optical instruments like cameras etc.

2. The refractive indices of liquids and gases can be conveniently measured.

3. Small displacements such as those produced by compression or elongation of crystals can be measured.

4. To determine the wavelengths of monochromatic light radiation.

Q.15) Discuss the applications of interference.

The applications of interference phenomenon are wide and varied. Some of the applications are :

1. Interference is used for making precision measurement. For example, the wavelength of light can be measured using Michelson's interferometer up to an accuracy eight significant digits. Interferometer methods are used to determine and redefine the length standard, namely, the metre. The resolution between two closely spaced spectral lines such as D_1 and D_2 lines of a sodium doublet can be accurately determined.

2. Double-slit interference method is used to determine the angular separation of double stars and the diameter of fixed stars.

3. The refractive indices of liquids and gases can be conveniently measured using interference methods.

4. Interference method is used for measuring small displacements such as those produced by compression or elongation of a metal rod, crystals etc.

5. Newton's rings find application in testing the surface finish of lenses and other optical components used in telescopes and other optical instruments.

6. Wedge-film interference is effectively employed in testing the planeness of glass plates and extremely thin metallic plates.

7. Dielectric transparent thin films are often coated on optical components, solar cells etc. Multiple beam interference method is used to determine the thickness of such films coatings.

8. Thin-film interference is used to enhance or suppress certain colors in the spectrum of the incident sunlight. This selective enhancement or suppression of selected wavelengths has many applications. Such transparent thin film coating are called antireflection coatings or AR coatings. Camera lenses appear slightly bluish because of the presence of such coatings.

9. Optical interference coatings are also used sometimes to enhance the reflectivity of a surface. The coated surface acts like a mirror. Such interference coatings are electrically non -conducting and hence are called dielectric mirrors.

In fact, an interference stack of a number films, with differing thickness and indices of refraction, can be designed to give almost any desired wavelength profile for a reflected or transmitted light. For example, windows can be provided with coatings that have a high reflectivity in the infrared, thus admitting the visible component of sunlight but reflecting its infrared or heating component.

SOLVED PROBLEMS

Example 1: Two coherent sources whose intensity ratio is *81:1* produce interference fringes. Deduce the ratio of maximum intensity to minimum intensity?

Since intensity I is square of the amplitude a,

$$\frac{I_1}{I_2} = \frac{a_1^{\,2}}{a_2^{\,2}} = \frac{81}{1} \Rightarrow \frac{a_1}{a_2} = \frac{9}{1} \Rightarrow a_1 = 9a_2$$

$$\frac{I_{max}}{I_{min}} = \frac{(a_1 + a_2)^2}{(a_1 - a_2)^2} = \frac{(9a_1 + a_2)^2}{(9a_1 - a_2)^2} = \frac{(10a_2)^2}{(8a_2)^2} = \frac{100}{64} = \frac{25}{16} \Rightarrow I_{max} : I_{min} = 25:16$$

Example 2 : A monochromatic beam of light travels through a medium of refractive index *1.33* and thickness $0.75\ \mu m$. Calculate its optical path ?

Optical path = $\mu \times$ geometrical path = $1.33 \times 0.75 = 0.998\ \mu m$.

Example 3 : A parallel beam of light of wavelength $5890\ A^0$ is incident on a thin glass plate (μ = *1.5*) such that the angle of refraction into the plate is 60^0. Calculate the smallest thickness of the glass plate which will appear dark in reflected light.

The condition is given by $2\mu\, t \,Cos\, r = m\lambda$. Taking $m = 1$, the smallest thickness of plate that causes destructive interference is

$$t = \frac{\lambda}{2\mu\, Cos\, r} = \frac{5890 \times 10^{-10}}{2 \times 1.5 \times Cos\ 60^0} = 0.39\,\mu m$$

Example 4: A Newton's ring arrangement is used with a source emitting two wavelengths $\lambda_1 = 6 \times 10^{-5}\,cm$ and $\lambda_2 = 4.5 \times 10^{-5}\,cm$. It is found that n^{th} dark ring due to λ_1 coincides with $(n+1)^{th}$ dark ring for λ_2. If the radius of curvature of the curved surface is *90cm*, find the diameter of n^{th} dark ring for λ_1.

$r = \sqrt{m\lambda R}$, $m = 0,1,2,....$ for dark ring $\Rightarrow r_n = \sqrt{n \times 6 \times 10^{-5} \times 90}$

$r_{n+1} = \sqrt{(n+1) \times 4.5 \times 10^{-5} \times 90}$ and $n \times 6 \times 10^{-5} \times 90 = (n+1)4.5 \times 10^{-5} \times 90$

$6n = 4.5(n+1) \Rightarrow 6n = 4.5n + 4.5 \Rightarrow 1.5n = 4.5 \Rightarrow n = 4.5/1.5 = 3$

$r_n = \sqrt{3 \times 6 \times 10^{-5} \times 90} = \sqrt{1620 \times 10^{-5}} = \sqrt{0.0162} = 0.127cm$

Diameter of n^{th} ring = $0.127 \times 2 = 0.254 cm$.

Example 5: Newton's rings are observed in the reflected light of wavelength 5900 A^0. The diameter of 10^{th} dark ring is 0.5 cm. Find the radius of curvature of lens used.

Wavelength of reflected light, $\lambda = 5900\ A^0 = 5900 \times 10^{-10}\ m$

Diameter of 10^{th} dark ring, $D_{10} = 0.5\ cm = 5 \times 10^{-3}\ m$

Diameter of n^{th} dark ring, $D_n = 2\sqrt{n\,\lambda\,R}$

$$R = \frac{D_n^2}{4\,n\,\lambda} = \frac{(5 \times 10^{-3})^2}{4 \times 10 \times 5900 \times 10^{-10}} = 1.059\ m$$

Radius of curvature of the lens = 1.059 m

Example 6: In Newton's rings experiment, the diameter of 15^{th} ring was found to be 0.59 cm and that of 5^{th} ring 0.336 cm. The radius of curvature of the lens is 100 cm. Find the wavelength of light.

The diameter of 15^{th} ring, $D_{15} = 0.59\ cm = 5.9 \times 10^{-3}\ m$

The diameter of 5^{th} ring, $D_5 = 0.336\ cm = 3.36 \times 10^{-3}\ m$

The radius of curvature of the lens, $R = 100\ cm = 1\ m$

The expression for wavelength of light is, $\lambda = \frac{D_m^2 - D_n^2}{4\,(m-n)\,R}$

$$\lambda = \frac{(5.9 \times 10^{-3})^2 - (3.36 \times 10^{-3})^2}{4 \times 10 \times 1} = 0.588 \times 10^{-6}\ m$$

Example 7: In Newton's rings experiment the diameter of the 12^{th} ring changes fro 1.45 cm to 1.25 cm when a liquid is introduced between the lens and the plate. Calculate the refractive index of the liquid.

For n^{th} ring in air, $(D_n^2)_{air} = 4\,n\,\lambda R$

For n^{th} ring in liquid, $(D_n^2)_{liquid} = \frac{4\,n\,\lambda\,R}{\mu}$

$$\mu = \frac{(D_n^2)_{air}}{(D_n^2)_{liquid}} = \frac{(1.45)^2}{(1.25)^2} = 1.3456$$

DIFFRACTION

Q.1) Define diffraction?

When waves encounter obstacles or small apertures, they apparently bend round the edges of the obstacles if the dimensions of the obstacles are comparable to the wavelength of the waves. The apparent bending of waves around the edges of an obstacle (or aperture) is called diffraction.

Q.2) Explain diffraction phenomena?

Fresnel explained diffraction using Huygen's principle of secondary wavelets in conjunction with the principle of superposition. The diffraction phenomenon is due to mutual interference of secondary wavelets originating from various parts of a wave front which are not blocked off by the obstacle.

Diffraction sets a limit to the image formation ability of optical instruments. Diffraction phenomenon demonstrates wave behavior of light.

Q.3) Distinguish between Fresnel and Fraunhoffer classes of diffraction.

Fresnel's diffraction:

In this type of diffraction, the source of light or screen or both are at finite distances from the obstacle or aperture. The incident wave front is either spherical or cylindrical. As a result, the phase of secondary wavelets is not the same at all points in the plane of the aperture. No lenses are used to make the rays parallel or convergent. The treatment of Fresnel diffraction is mathematically complex.

Fraunhoffer diffraction:

In this class of diffraction, the source of light and the screen are effectively placed at infinite distances from the aperture. This may be achieved by using two convex lenses. The incident wave front is plane. As a result, the secondary wavelets are in the same phase at every point in the plane of aperture. Fraunhoffer diffraction is a special case of the more general Fresnel diffraction and is easier to handle mathematically.

Q.4) Distinguish between interference and diffraction.

Interference	Diffraction
1) Interference is the result of interaction of light coming from two different wave fronts originating from the same source.	1) Diffraction is the result of interaction of light coming from different parts of the same wave front.
2) Interference fringes may or may not be of the same width.	2) Diffraction fringes are not of the same width.
3) Points of minimum intensity may or may not be perfectly dark.	3) Points of minimum intensity are not perfectly dark.
4) All bright bands are of uniform intensity.	4) All bright bands are not of the same intensity.

Q.5) Discuss the distinction between single slit and double slit diffraction patterns.

The single slit diffraction pattern consists of a central bright maximum with secondary maxima and minima of gradually decreasing intensity. The double slit diffraction pattern consists of equally spaced interference maxima and minima within the central maximum. The intensity of the central maximum in the diffraction pattern due to a double slit is four times that of the central maximum due to diffraction at a single slit.

The spacing of the diffraction maxima and the minima depends on the width of the slit. The spacing of the interference maxima and minima depends on the width of the slit and width of the opaque spacing between the two slits.

Q.6) What is diffraction grating?

When there is a need to separate light of different wavelengths with high resolution, then a diffraction grating is most often the tool of choice. A large number of parallel, closely spaced slits constitutes a diffraction grating. A device consisting of a large number of parallel slits of equal width and separated from one another by equal opaque spaces is called a diffraction grating. The distance between the centres of the adjacent slits is known as grating period.

Q.7) What is Rayleigh's criterion for resolving power of an optical instrument?

To express the resolving power of an optical instrument as a numerical value, Rayleigh proposed an arbitrary criterion. According to him, two nearly images are said to be resolved if the position of the central maximum of one coincides with the first minimum of the other and vice versa.

Q.8) Define resolving power of a grating?

The resolving power of a grating is its ability to show two neighbouring lines in a spectrum as separate. If we consider two very close spectral lines of wavelength λ and $\lambda + d\lambda$, its spectral resolution is given by, spectral resolving power = $\frac{\lambda}{d\lambda}$, where $d\lambda$ is the smallest difference in wavelengths that can be resolved by the grating and viewed separately.

Q.9) Define Dispersive power of a grating?

Dispersive power is the change in the angle of diffraction per unit change in wave length.

$$\frac{d\theta}{d\lambda} = \frac{m\,N}{Cos\,\theta}$$

Q.10) What are the applications of diffraction?

(i) The wavelength of spectral lines can be measured by using diffraction grating.

(ii) The wavelength of X-rays can be determined by X-ray diffraction.

(iii) The structures of the crystals can be determined by X-ray diffraction.

(iv) The velocity of sound in liquids can be determined by using ultrasonic diffraction.

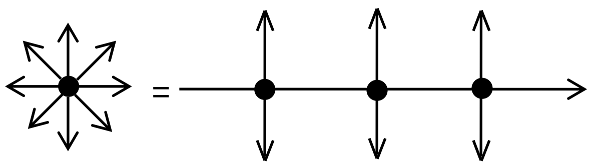
(v) The size and shape of tumours, ulcers inside the human body can be assessed by ultrasound scanning.

Polarization

Q 1) What is Unpolarized light?

Light which has the same property in all directions or a light wave symmetrical about a direction is called unpolarized light. Unpolarized light is a light wave, in which Electric field vector oscillates in more than one plane. Examples are light emitted by the Sun, an incandescent lamp or flame.

Q 2) What is Polarized light?



Unpolarized light

Light which has acquired the property of one-sideness or a light wave unsymmetrical about a direction is called polarized light. A polarized light wave is a light wave with a definite direction of oscillation of the electric field vector, which occurs in a single plane or in some specific way. Light with vertical vibration that travels within a single plane is called linearly polarized light while circularly polarized light and elliptically polarized light are the other types of linearly polarized light in which the vibration plane rotates forward.

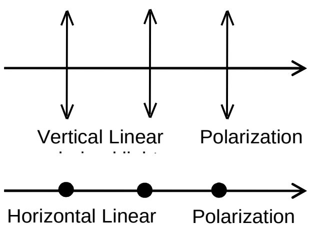
Polarized light is not produced naturally. It is obtained by converting natural light into polarized light using optical elements.

Q 3) Distinguish between Unpolarized light and Polarized light?

	Unpolarized light	Polarized light
1	Consists of waves with planes of vibration equally distributed in all directions about the ray direction.	Consists of waves having their electric vector vibrating in a single plane normal to ray direction.
2	Symmetrical about the ray direction.	Asymmetrical about the ray direction.
3	Produced by conventional light sources.	Is to be obtained from unpolarized light with the help of polarizers.
4	May be regarded as the resultant of two incoherent waves of equal intensity but polarized in mutually perpendicular planes.	May be regarded as the resultant of two mutually perpendicular coherent waves having zero phase difference.

Q 4) What is linear polarized light or plane polarized light?

A light wave is said to be linearly polarized, if in the course of wave propagation, the direction of electric field vector ***E*** does not vary with time, but its magnitude varies sinusoidally with time. If the field is pointing either up or down, one can call it as vertical polarization, and if it is pointing either right or left, one can call it as horizontal polarization.



The representation of plane polarized light is shown in the figure.

Q 5) What is circularly polarized light?

A light wave is said to be circularly polarized, if in the course of wave propagation, the magnitude of the electric vector ***E*** stays constant but it rotates at a constant rate about the direction of propagation and sweeps a circular helix in space. In circularly polarized light, there is no preference to specified direction of oscillation.

A circularly polarized light wave may be regarded as the resultant wave produced due to superposition of two coherent linearly polarized waves of equal amplitude oscillating in mutually perpendicular planes, and are out of phase by 90^0.

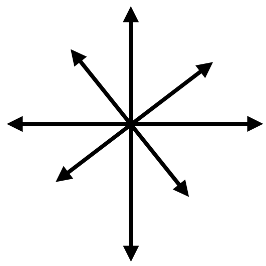
Q 6) What is elliptically polarized light?

A light wave is said to be elliptically polarized, if the magnitude of electric vector ***E*** changes with time and the vector ***E*** rotates about the direction of propagation and sweeps a flattened helix in space. If we imagine that we are looking at the light wave advancing towards us, we would observe that the tip of the ***E*** vector traces an ellipse in space.

An elliptically polarized light wave may be regarded as the resultant wave produced due to superposition of two coherent linearly polarized waves of different amplitudes, oscillating in mutually perpendicular planes and are out of phase by $90^{0.}$

Q 7) What is partially polarized light?

Usually, light is neither totally polarized nor unpolarized but a mixture of the two types. It can be viewed as a mixture of plane polarized light and unpolarized light. Partially polarized light is represented in the following figure.



It can be represented in the form of a superposition of two incoherent plane polarized waves having different amplitudes and polarized in mutually orthogonal planes.

Q 8) Write a short note on Double refraction.

When a beam of unpolarized light is allowed to fall on a calcite crystal or quartz crystal, it is split up into two refracted beams in place of the usual one as in glass. The phenomenon is called double refraction or birefringence and such crystals are called doubly-refracting crystals.

The two refracted rays are plane polarized. The refracted ray which obeys the laws of refraction and having vibrations perpendicular to the principal section of the calcite crystal is known as the ordinary ray or the 0 - ray. The other refracted ray which does not obey the laws of refraction and having vibrations in the principal section is called the extraordinary ray or the e-ray.

Q 9) What is a Quarter wave plate?

This plate is made from a doubly refracting uniaxial crystal with its refracting faces cut also parallel to the optic axis. The thickness of the plate t is such that it introduces a phase difference of $\frac{\pi}{2}$ or a path difference of $\frac{\lambda}{4}$ between the ordinary ray and extraordinary ray in passing through it when light is incident normally on the face of the crystal.

For a negative crystal, like calcite, the thickness of the crystal is $t = \frac{\lambda}{4(\mu_0 - \mu_e)}$

Q 10) What is a Half - Wave plate?

This plate is made from a doubly refracting uniaxial crystal with its refracting faces cut also parallel to the optic axis. The thickness of the plate t is such that it introduces a phase difference of π or a path difference of $\frac{\lambda}{2}$ between the ordinary ray and extraordinary ray in passing through it when light is incident normally on the face of the crystal.

For a negative crystal, like calcite, the thickness of the crystal is $t = \frac{\lambda}{2(\mu_0 - \mu_e)}$.

Q 11) Describe the production of plane polarized light.

A) By double refraction:

When unpolarized light is incident on a Nicol prism, the emergent light from the Nicol is plane polarized. When Nicol's are used to produce plane polarized light, they are called as polarizers.

B) By refraction:

When unpolarized light is incident at Brewester angle on a smooth glass surface, the reflected light totally polarized, while the refracted light is partially polarized. A stack of glass plates is used.

It is found that a stack of about 15 glass plates is required for this purpose. The glass plates are supported in a tube of suitable size and inclined at an angle of about 33^0 to the axis of the tube. Such an arrangement is called a pile of plates. Unpolarized light enters the tube and is incident on the plates at Brewester angle and the transmitted light will be totally polarized parallel to the plane of incidence.

C) By reflection:

When ordinary light is reflected from the surface of a transparent medium like glass, it becomes partially polarized. The degree of polarization varies with the angle of incidence. At a certain angle of incidence called the polarizing angle (angle of polarization), the reflected light is completely polarized.

Q 12) Describe the production of circularly polarized light.

Circularly polarized light is the resultant of two light waves of equal amplitudes vibrating at right angles to each other and having a phase difference of $\pi/2$.

Plane polarized light from a Nicol prism is made to fall normally on a quarter wave plate such that its vibration makes an angle of 45^0 with the direction of the optic axis of the quarter wave plate. It is broken into extraordinary ray and ordinary ray of equal amplitudes. On emergence a phase change of $\pi/2$ is introduced between them which results in the formation of a circular vibration and hence outgoing light is circularly polarized.

Q 13) Describe the production of elliptically polarized light.

Elliptically polarized light is the resultant of two light waves of unequal amplitudes vibrating at right angles to each other and having a phase difference of $\pi/2$.

Plane polarized light obtained from a Nicol prism is made to fall normally on a quarter wave plate so that the plane of vibration of this light makes an angle other than 45^0 with the direction of the optic axis of the quarter wave plate. It is broken into extraordinary ray with vibrations parallel to the optic axis and ordinary ray with vibrations perpendicular to the optic axis. The amplitudes of extraordinary ray and ordinary ray are different because θ is not equal to 45^0. On emergence through quarter wave plate, a phase difference of $\pi/2$ is introduced between the two rays which combine resulting into elliptic vibration. Hence the outgoing light is elliptically polarized.

Q 14) What is the significance or applications of Polarization?

A thorough understanding of the concept of polarization is highly essential in the wave propagation through wave guides and optical fibres. Polarization has many useful engineering applications, one of them being in liquid crystal displays which are widely used in wrist watches, calculators and video displays etc. Optical activity found in bigger organic molecules provided a number of clues which help us understanding biological activity.