ICT 1107: Physics

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ICT 1107: Physics

Quotes of the Day

Education is what remains after one has forgotten what one has learned in school

Albert Einstein

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4. Physical Optics

Theories of light; Interference of light, Young's double slit experiment; Displacements of fringes and its uses; Fresnel Bi-prism, interference at wedge shaped films, Newton's rings, interferometers; Diffraction of light: Fresnel and Fraunhoffer diffraction, diffraction by single slit, diffraction from a circular aperture, resolving power of optical instruments, diffraction at double slit & N-slits-diffraction grating; Polarization: production and analysis of polarized light, Brewster's law, Malus law, Polarization by double refraction, retardation plates, Nicol prism, optical activity, polarimeters, polaroid.

7 Lectures

Chapter 3: Physical Optics

Books Recommended

1. Fundamentals of Optics- F A Jenkins, H E White
2. Optics- A Ghatak
3. A Text Book of Optics- N Subramanyam, Brijlal, M S Avadhanulu
4. Geometrical and Physical Optics- P K Chakrabarti
5. Physics for Engineers Vol 1- Giasuddin Ahmed

Chapter 3: Physical Optics

Interference of Light

Read the following pages: 1149-1154, 1157-1165, & 1200-1208

Book: Physics for Engineers Vol.1

Theories of Light

1) Corpuscular theory (*Sir Isaac Newton*, 1672)
2) Wave theory (In 1678, Dutch physicist, *Christiaan Huygens)*
3) Electromagnetic theory (Scottish Physicist *James Clerk Maxwell*, 1865)
4) Quantum theory (In 1900 *Max Planck*, and in 1905 *Albert Einstein)*

Corpuscular Theory (Sir Isaac Newton, 1672)

Light is made up of small discrete particles called ‘corpuscles’ which travel in a straight line with a finite velocity.

It was successful in explaining rectilinear propagation of light, reflection, and refraction.

However failed to explain interference, diffraction, and polarization.

Also failed to explain the force of attraction and repulsion experienced perpendicular to the reflecting and refracting surfaces

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Wave theory (*Christiaan Huygens*, 1678)

i. Waves are mechanical and longitudinal in nature

ii. light propagates in the form of waves and need a medium to propagate in all possible direction.

iii. he gave a hypothetical medium which is known as ether .

iv. The velocity of the light was calculated as $v = \sqrt{\frac{E}{\rho}}$, where E is the elasticity of the medium and ρ is the density of that medium

Wave Theory (*Christiaan Huygens*, 1678)

v. The energy is distributed equally in all possible directions

vi. It was successful in explaining the reflection, refraction, double reflection, and interference of light

vii. Fresnel said the light wave is transverse in nature

viii. Fresnel given the concept of ether

Limitations:

1. Can’t explain the rectilinear propagation
2. Can't explain polarization

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Electromagnetic theory (*James Clerk Maxwell*, 1865)

i. Maxwell demonstrated that light as having electric and magnetic fields travel through space as waves moving at the speed of light

ii. The speed of light is given as $c = \sqrt{\frac{1}{\mu_0 \varepsilon_0}}$, μ_0 is the permeability of free space and ε_0 is the permittivity of free space

iii. EM-waves don't need any medium to traverse. Can propagate through medium. But in can travel through media as well but the speed will be changed.

Electromagnetic Theory (*James Clerk Maxwell*, 1865)

Limitations: The following aspects can’t be explained through the em-theory

1. Photoelectric effect
2. Compton effect
3. Raman effect
4. Black body radiation

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Quantum theory (*M Planck & A Einstein*, 1900-1905)

Quantum theory tells us that both light and matter consists of tiny particles which have **wavelike properties** associated with them.

Light is composed of particles called photons, and matter is composed of particles called electrons, protons, neutrons. It's only when the mass of a particle gets small enough that its wavelike properties show up.

To help understand all this we need to look at how light behaves as a wave and as a particle.

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i. It talk about the wave–particle duality

ii. It expresses the inability of the classical concepts 'particle' or 'wave' to fully describe the behaviour of quantum-scale objects

iii. Sometimes the one theory and sometimes the other, while at times we may use either. Since, we have two contradictory pictures of reality; separately none of them fully explains the phenomena of light, but together they do.

iv. The photons or quanta are massless particles and the energy of a photon or quanta is given by

$$E = h\nu, \text{ where } h \text{ is the Planck's constant}$$

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Huygens Principle or Construction

Christiaan Huygens

Dutch Physicist, Mathematician, Astronomer, and Inventor, who is widely regarded as one of the greatest scientists of all time and a major figure in the scientific revolution.

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Huygens Principle or Construction

An approximate geometrical procedure for determining the propagation of electromagnetic waves.

According to this construction, every point of a wave front in a medium at any instant is the source of secondary spherical wavelets propagating with the phase velocity of the medium. The envelope of all these wavelets then determines the wave front at a later instant.

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According to Huygens' principle, each point on a wavefront acts as a secondary source of light producing secondary wavelets in all directions. Alternately, we can say

Huygens principle postulated that points on the wavefronts themselves are the source of small waves and that they combined to produce further wavefronts.

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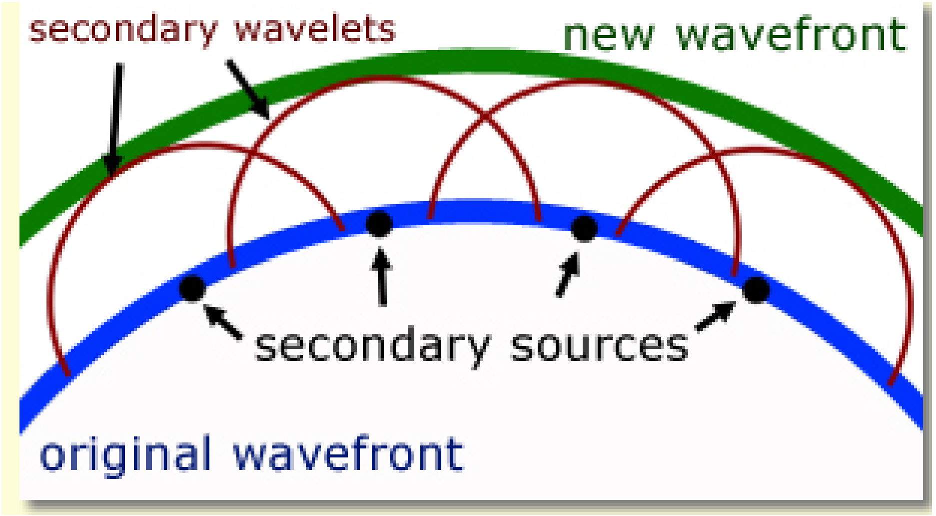
According to Huygens' principle, each point on a wavefront acts as a secondary source of light producing secondary wavelets in all directions.



Principle of Superposition

Whenever two or more waves travelling through the same medium at the same time without being disturbed by each other, then the net displacement of the medium at any point in space or time, is simply the sum of the individual wave displacements. This is true of waves which are finite in length or which are continuous sine waves.

This known as the superposition principle.

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Sample Question

Q.1. Describe the principle of superposition of light.

Q2. State and explain the Huygens principle of secondary waves or secondary wavefronts.

Coherent Sources

1. Coherent sources are those sources of light which emit continuous light waves of same wavelength , same frequency and are in same phase or have constant phase difference.

2. For observing interference phenomenon coherence of light waves is a must.

3. For light waves emitted by two sources of light , to remain coherent the initial phase difference between waves should remain constant in time. If the phase difference changes continuously or randomly with time then the sources are incoherent.

Coherent Sources

4. Two independent sources of light are not coherent and hence can not produce interference because light beam is emitted by millions of atoms radiating independently so the phase difference between waves from such sources fluctuates randomly many times per second.

5. The coherent sources can be obtained either by the source and obtaining its virtual image or by obtaining two virtual images of the same source. This is because any change of phase in real source will cause a simultaneous and equal change in its image.

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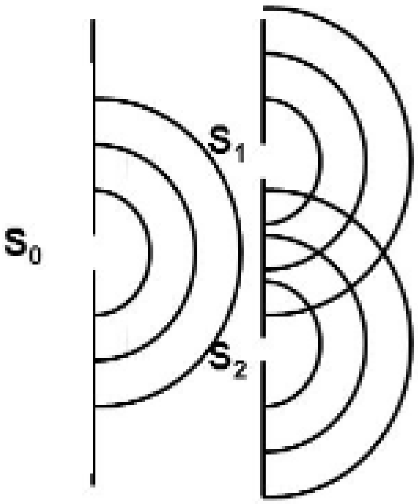
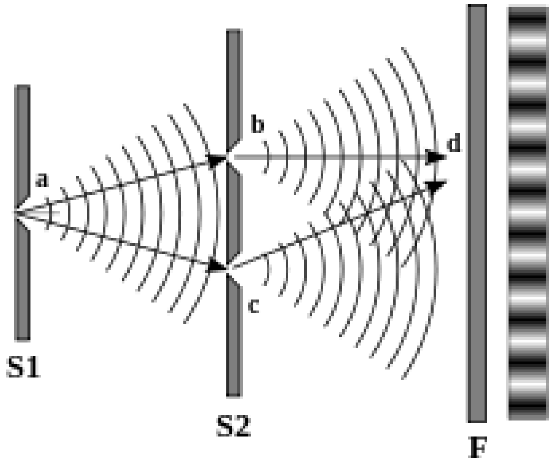
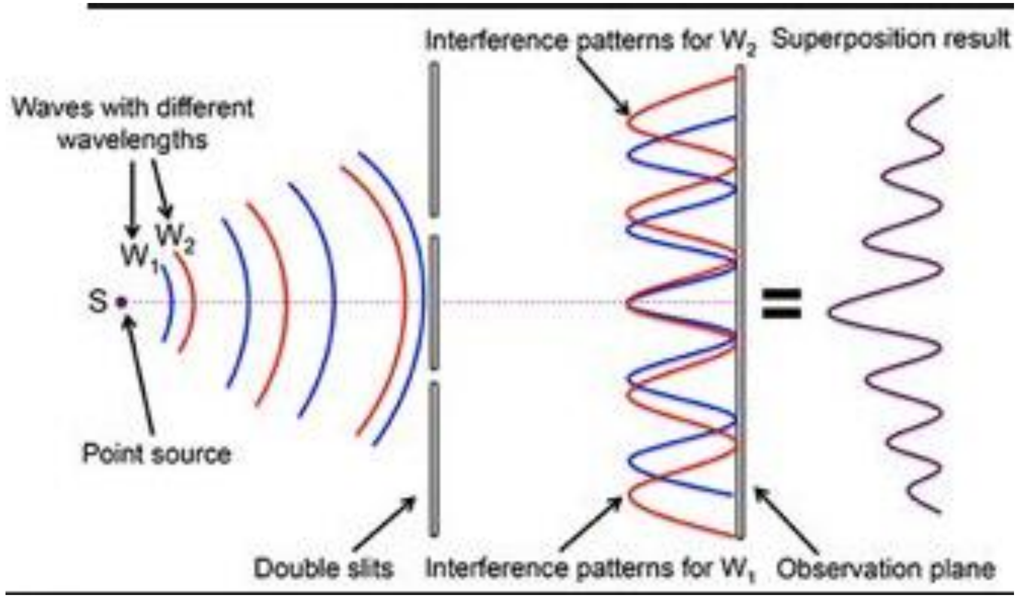
Coherent Sources







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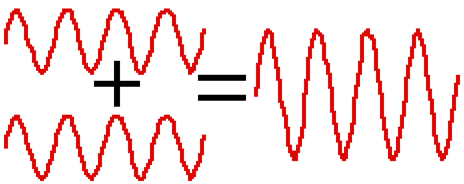
Interference of Light

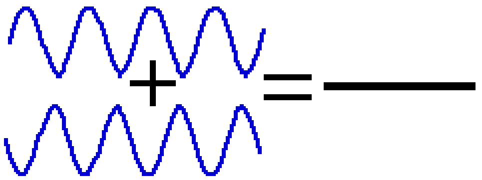
When two or more propagating waves of same type (nearly same frequency and same amplitudes) are incident on the same point, the resultant amplitude at that point is equal to the vector sum of the amplitudes of the individual waves.

Interference is of two types:

1. Constructive interference



2. Destructive interference



Constructive Interference

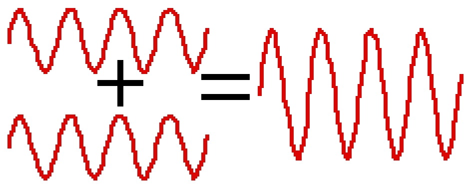
If two waves superimpose with each other in the same phase, the amplitude of the resultant is equal to the sum of the amplitudes of individual waves resulting in the maximum intensity of light, this is known as constructive interference.

Destructive Interference

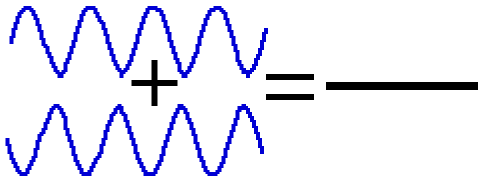
If two waves superimpose with each other in opposite phase, the amplitude of the resultant is equal to the difference in amplitude of individual waves, resulting in the minimum intensity of light, this is known as destructive interference.

Interference of Light

When two waves meet in such a way that their crests line up together, then it's called **constructive interference**. The resulting wave has a higher amplitude.



In **destructive interference**, the crest of one wave meets the trough of another, and the result is a lower total amplitude.



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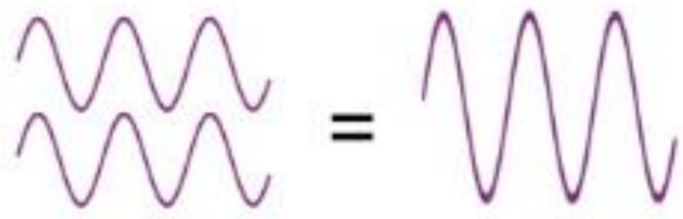
Interference of Light

1. **Constructive interference**

Waves that combine in phase add up to relatively high irradiance.



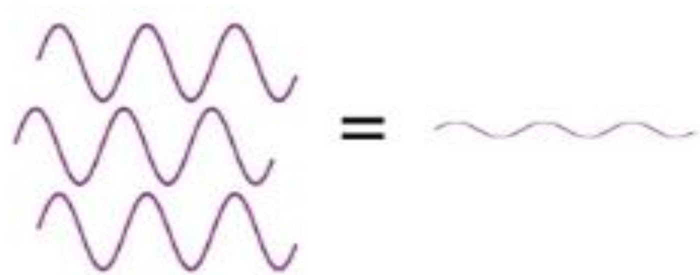
Constructive interference (coherent)

2. **Destructive interference**

Waves that combine 180° out of phase cancel out and yield zero irradiance.

Destructive interference (coherent)

Waves that combine with lots of different phases nearly cancel out and yield very low irradiance.



Incoherent addition

Conditions of Constructive and Destructive Interferences

Constructive interference occurs when the phase difference between the waves is an even multiple of 2π, whereas destructive interference occurs when the difference is an odd multiple of π.

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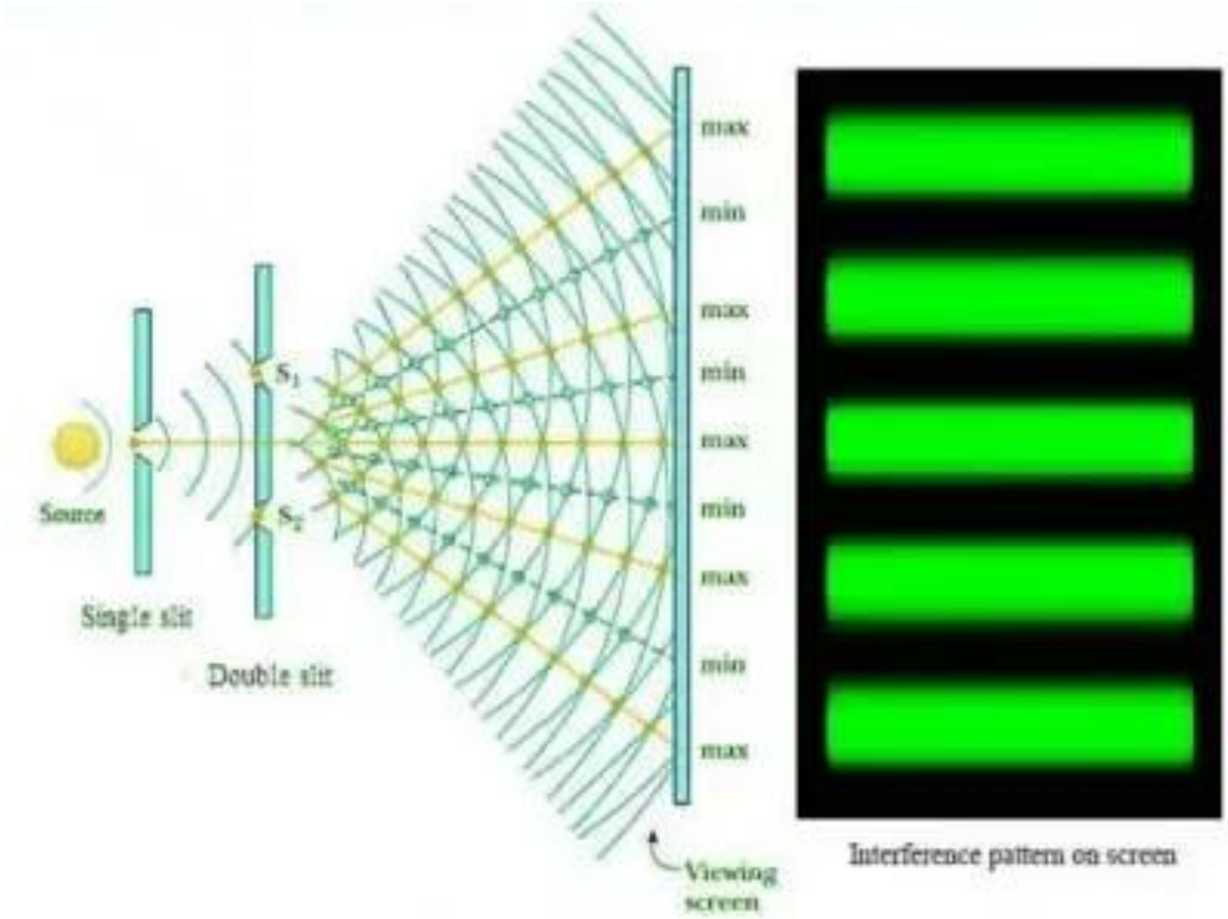
Interference of Light



Conditions of Interference of Light

1. Two sources must be coherent and narrow
2. The two interfering waves must have the same amplitude; otherwise the intensity will not be zero at the regions of destructive interference
3. The separation between the light sources should be as small as possible.
4. The original source must be monochromatic
5. The fringe width should be reasonably as large as possible that each fringe can be recognized distinctly
6. The two interfering waves must be propagated in almost same direction. The small separation between the two sources ensures this.

7. If the beams are polarized, they must be in the same state of polarization.

8. The distance of the screen from the sources should be quite large.

9. The phase difference of the interfering beams should remain constant through out the process.

10. The two interfering waves should have nearly same frequency.

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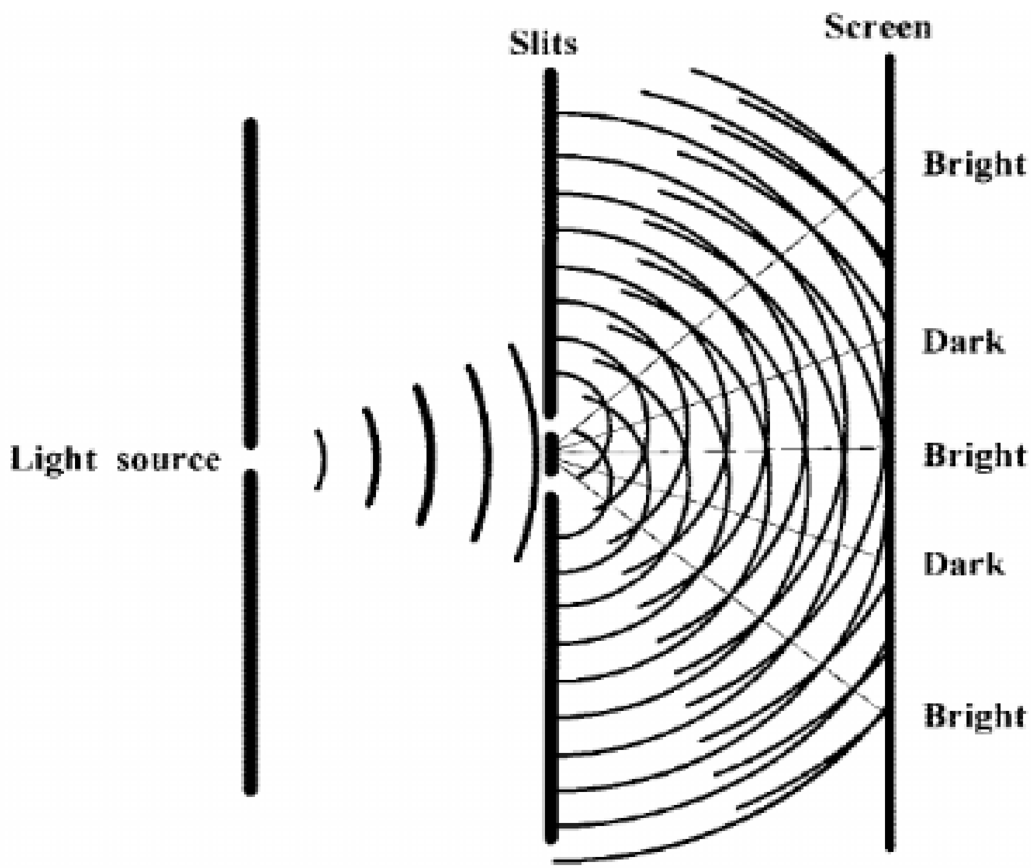
Young's Double-slit Experiment

Thomas Young (1799), English Physician and Physicist



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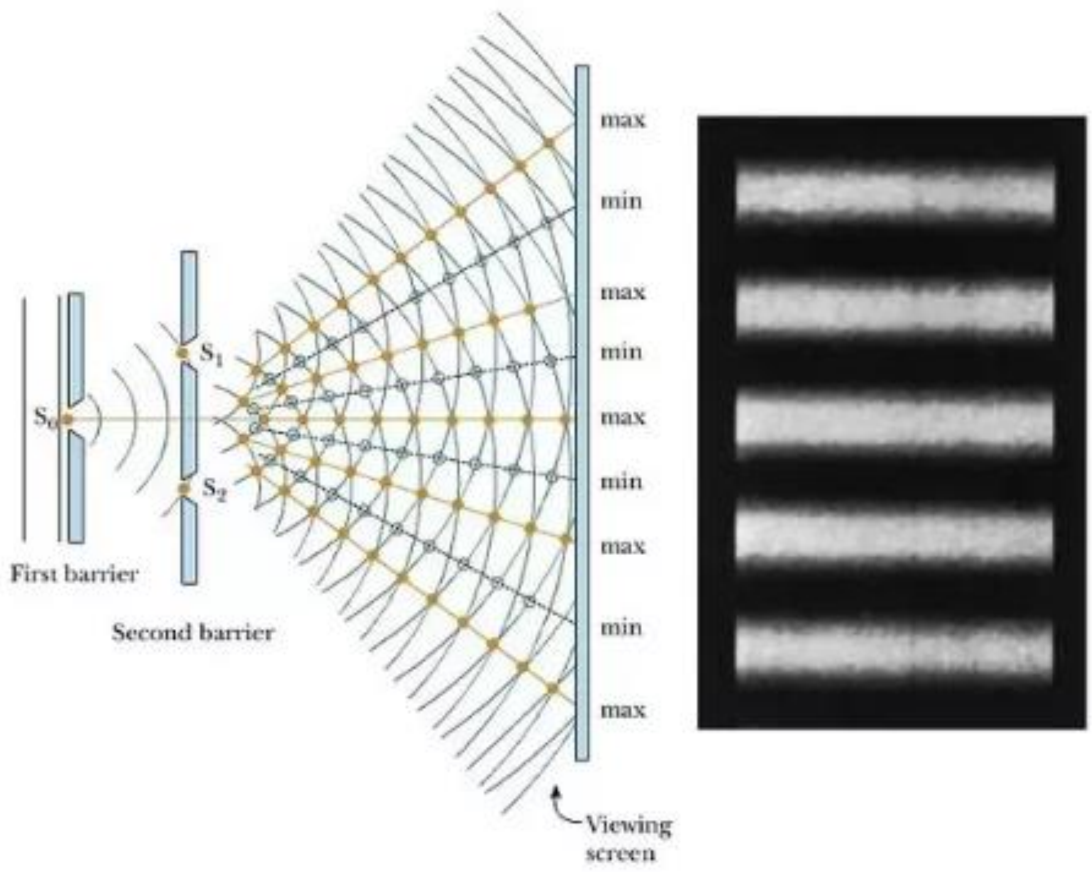

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Analytical Treatment of Interference of Light

$y_1 = a \sin \omega t$

$y_2 = a \sin (\omega t + \delta)$

$y = y_1 + y_2 = a \sin \omega t + a \sin (\omega t + \delta)$

$y = a \sin \omega t + a \sin \omega t \cos \delta + a \cos \omega t \sin \delta$

$= a \sin \omega t (1 + \cos \delta) a \cos \omega t \sin \delta$.

Taking $a(1 + \cos \delta) = R \cos \theta$ (i)

and , $a \sin \delta = R \sin \theta$ (ii)

$Y = R \sin \omega t \cos \theta + R \cos \omega t \sin \theta$

$Y = R \sin (\omega t + \theta)$ (iii)

which represents the equation of simple harmonic vibration of amplitude **R**.

Analytical Treatment of Interference of Light

Squaring (i) and (ii) and adding.

$$R^2 \sin^2\theta = R^2 \cos^2\theta = a^2 \sin^2\delta + a^2 (1 + \cos \delta)^2$$

$$R^2 = a^2 \sin^2\delta + a^2 (1 + \cos^2\delta + 2\cos\delta)$$

$$R^2 = a^2 \sin^2\delta + a^2 + a^2 \cos^2\delta + 2a^2 \cos \delta$$

$$= 2a^2 (1 + \cos \delta)$$

$$R^2 = 2a^2 + 2 \cos^2 \delta/2 = 4a^2 \cos^2 \delta/2$$

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Analytical Treatment of Interference of Light

The intensity at a point is given by the square of the amplitude

$\therefore$ **$I = R^2$**

Or, **$I = 4a^2 \cos^2 \delta/2$** **(iv)**

Special cases: (i) When the phase difference **$\delta = 0, 2\pi, 2(2\pi), \ldots\ldots n(2\pi)$**, or the path difference **$x = 0, \lambda, 2\lambda, n\lambda$**.

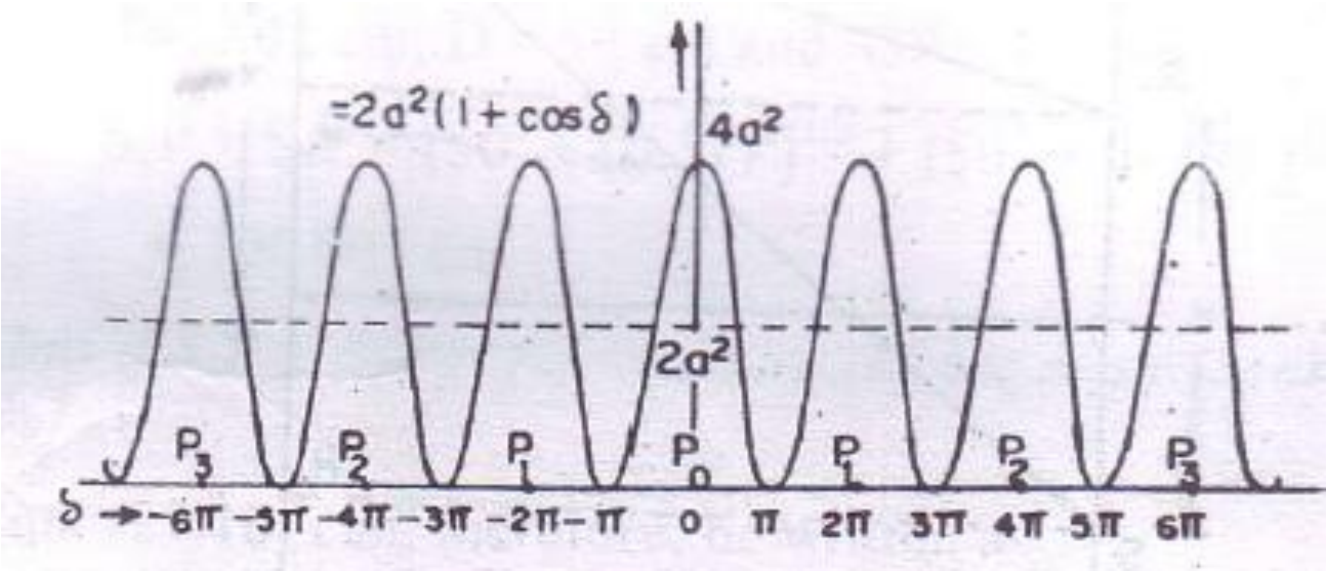
Intensity is maximum when the phase difference is a whole number multiple of **2π** or the path difference is a whole number multiple of wavelength.

(ii) When the phase difference, **$\delta = \pi, 3\pi, \ldots. (2n + 1)\pi$**, or the path difference **$x = \lambda/2, 3\lambda/2, 5\lambda/2, \ldots. (2n + 1)\lambda/2$**.

Intensity is minimum when the path difference is an odd number multiple of half wavelength.

Energy Distribution of Interference Patterns

From equation **(iv)**, it is found that the intensity at bright points is $\mathbf{4a^2}$ and at dark points it is zero. According to the law of conservation of energy, the energy cannot be destroyed. Here also the energy is not destroyed but only transferred from the points of minimum intensity. For, at bright points, the intensity due to the two waves should be $\mathbf{2a^2}$ but actually it is $\mathbf{4a^2}$. As shown in fig. the intensity varies from **0** to $\mathbf{4a^2}$, and the average is still $\mathbf{2a^2}$. It is equal to the uniform intensity $\mathbf{2a^2}$ which will be present in the absence of the interference phenomenon due to the two waves. Therefore the formation of interference fringes is in accordance with the law of conservation of energy.



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Sample Questions

Q.3. What is meant by the interference of light? Explain the analytical treatment of the interference of light and hence obtain the conditions of maximum and minimum intensities.

Q.4. Explain the interference of light. What are the conditions of interference of light.

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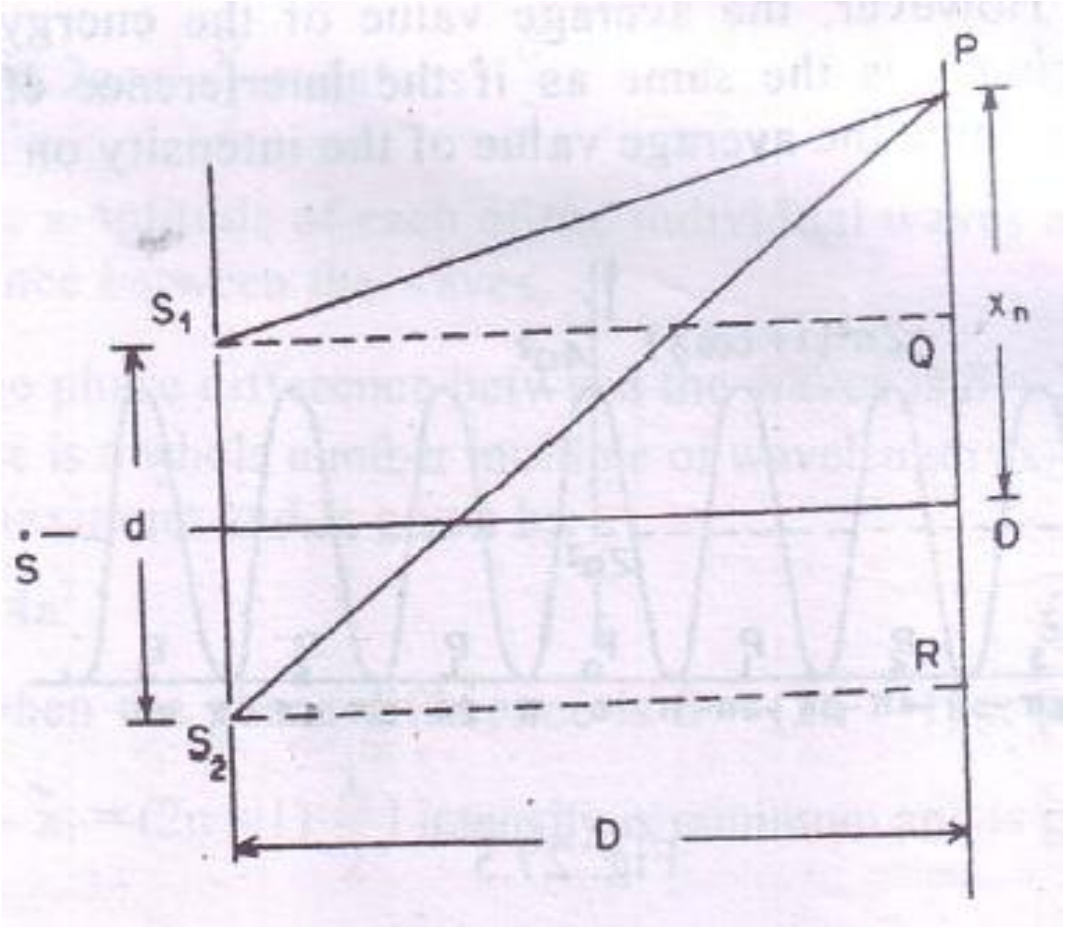
Calculation of the Fringe Widths



Let the point P, located on the screen at a distance x_n from the point 0, represent the n^{th} bright fringe. S_1Q and S_2R are perpendiculars on the screen from the points S_1 and S_2 respectively.

In the right angled triangle S_1PQ,

$$S_1P^2 = S_1Q^2 + PQ^2 = D^2 + (x_n - \frac{d}{2})^2 \quad (1)$$

Similarly from the right-angled triangle S_2PR,

$$S_2P^2 = D^2 + (x_n + \frac{d}{2})^2 \quad (2)$$

Subtracting eqn. (1) from (2)

$$S_2P^2 - S_1P^2 = [D^2 + (x_n + \frac{d}{2})^2] - [D^2 + (x_n - \frac{d}{2})^2] = 2x_nd$$

or, $(S_2P - S_1P)(S_2P + S_1P) = 2x_nd$

or, $$S_2P - S_1P = \frac{2x_nd}{S_2P + S_1P} \quad (3)$$

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Both x_n and d are small compared to D, which is usually several thousand times longer than x_n or d. One can, therefore, write approximately

$S_2P = S_1P \cong D$ or, $S_2P + S_1P \cong 2D$

[In a typical interference experiment,

$d = 0.02$ cm, $D = 50$ cm and $OP = 0.5$ cm,

$$S_2P + S_1P = [50^2 + (0.51)^2]^{1/2} + [50^2 + (0.49)^2]^{1/2}$$
$$= 100.005 \text{ cm.}$$

Thus if $S_2P + S_1P$ is replaced by 2D, the error involved is about 0.005%]

Eqn. (3) can, therefore, be written as

$$S_2P - S_1P = \frac{2x_n d}{2D} = \frac{x_n d}{D} \qquad (4)$$

Now $(S_2P - S_1P)$ is the path difference of the light waves at the point P and according to the condition of interference, must be equal to $n\lambda$, since P represents the n^{th} bright fringe.

Thus, $S_2P - S_1P = \frac{x_n d}{D} = n\lambda$

or, $x_n = n\lambda \frac{D}{d}$ (5)

when $n = 0, 1, 2, \ldots\ldots$

$n = 0$ corresponds to the central bright fringe, $n = 1$ gives the distance of the first bright fringe, $n = 2$ of the second bright fringe and so on. Substituting $n = n + 1$ in eqn. (5)

$$x_{n+1} = (n+1)\lambda \frac{D}{d} \qquad (6)$$

where x_{n+1} is the distance of the $(n+1)^{th}$ bright fringe from the central bright fringe. Subtracting eqn. (5) from (6), we get

$$x_{n+1} - x_n = [n + 1 - n]\lambda \frac{D}{d} = \frac{\lambda D}{d} \qquad (7)$$

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Now $(x_{n+1} - x_n)$ is the distance of separation between the n^{th} and $(n + 1)^{th}$ bright fringe. Substituting $n = 1, 2, 3, 4, \ldots\ldots$

it can be seen that

$$x_4 - x_3 = x_3 - x_2 = x_2 - x_1 = x_{n+1} - x_n = \frac{\lambda D}{d}$$

= constant and independent of the fringe number.

Thus *the distance between any two consecutive bright fringes is same or all bright fringes are equally spaced.*

If P be a point where the n^{th} dark fringe, instead of the bright fringe, appears and if x'_n be its distance from 0, then the path difference

$$S_2P - S_1P = \frac{x'_n d}{D} = (2n - 1)\frac{\lambda}{2}$$

$$\text{or,} \quad x'_n = (2n - 1)\frac{\lambda D}{2d} \qquad (8)$$

Substituting n = n + 1, gives us the distance of the $(n + 1)^{th}$ dark fringe

$$x_{n+1} = \{2(n + 1) - 1\}\frac{\lambda D}{2d} \qquad (9)$$

Subtracting eqn. (8) from (9), we get for the distance of separation between the n^{th} dark fringe

$$x'_{n+1} - x'_n = (2n + 2 - 1 - 2n + 1)\frac{\lambda D}{2d}$$

$$= \frac{2\lambda D}{2d} = \frac{\lambda D}{d} = \text{constant} \qquad (10)$$

Thus we see from eqn. (10) that the *distance between two consecutive dark fringes is constant and independent of the fringe number and is the same as the distance between two consecutive bright fringes.*

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Thus the distance between any two consecutive bright of dark fringes which includes one dark and one bright fringe is same. This distance is called the *fringe-width* (X).

Then

$$X = \frac{\lambda D}{d} \qquad (11)$$

From eqn. (11) it can be seen that

$$\lambda = \frac{Xd}{D} \qquad (12)$$

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Thus if the fringe-width, the distance of separation of the sources and the distance of the screen from the sources are known, then the phenomenon of interference can be employed to determine the wavelength of unknown monochromatic light.

Problem 1

In an interference pattern, at a point we observe the 12^{th} order maximum for $\lambda_1 = 6000$ Å. What order will be visible here if the source is replaced by light of wavelength $\lambda_2 = 4800$ Å ?

Solution to Problem 1

In double slit interference, the distance x of a bright fringe from the centre (zero-order fringe) is

$$x = (D/2d)n\lambda, \text{ where } n = 0,1,2,\ldots.$$

Thus at a given point $n\lambda$ is constant

$$\text{Or, } n_1\lambda_1 = n_2\lambda_2$$

$$n_2 = n_1\lambda_1/\lambda_2 = 12 \times 6000/4800 = 15$$

Problem 2

Two straight narrow parallel slits (2 mm apart) are illuminated with a monochromatic light of wavelength 5896 Å. Fringes are observed at a distance of 60 cm from the slits. Find the width of the fringes?

Solution to Problem 2

The interference fringe-width for a double slit is given by

$$X = \frac{D\lambda}{2d}$$

2d = 2 mm = 0.2 cm,

D = 60 cm,

λ = 5896 Å = 5896 x 10^{-8} cm

Fringe-width = (60 cmx 5896 x 10^{-8} cm)/ 0.2 cm = 1.77 x 10^{-2} cm

Sample Questions

Q5. Describe Young's double-slit experiment and derive an expression for (i) the intensity at a point on the screen and (ii) fringe width .

Q6. Show that the distance between two consecutive bright or dark fringes is constant and is independent of the fringe number.

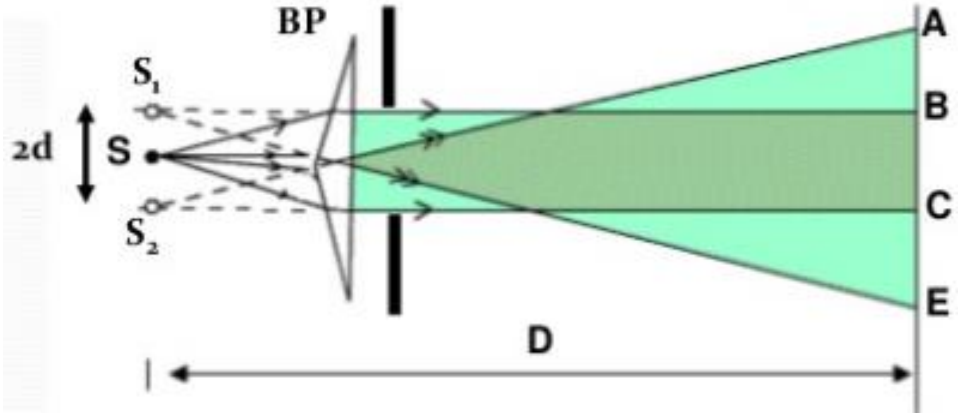
OR

Derive an expression for the width of a fringe in terms of the wavelength of light used, distance between the two coherent sources, and the screen of the screen from the sources.

Biprism

1. An optical device for obtaining interference fringes
2. A prism whose refracting angle is close to 180°
3. It is used to obtain two coherent sources of interference
4. A fusion of two triangular prisms: two prisms of very small refracting angles, places base to base
5. In real practice, the biprism is made from a single plate by grinding and polishing, so that it is a single prism with one of the angles about 179° and the other two about 30° each.

Fresnel’s biprism



Let S is a narrow vertical slit illuminated by a monochromatic source of light. The light symmetrically falls on the biprism BP. The light beams emerging from the upper and lower halves of the prism appears to start from two virtual images of S, namely S_1 and S_2 which act as coherent sources. The cones of light BS_1E and AS_2C, diverging from S_1 and S_2 are superposed and the interference fringes are formed in the overlapping region BC of the screen.

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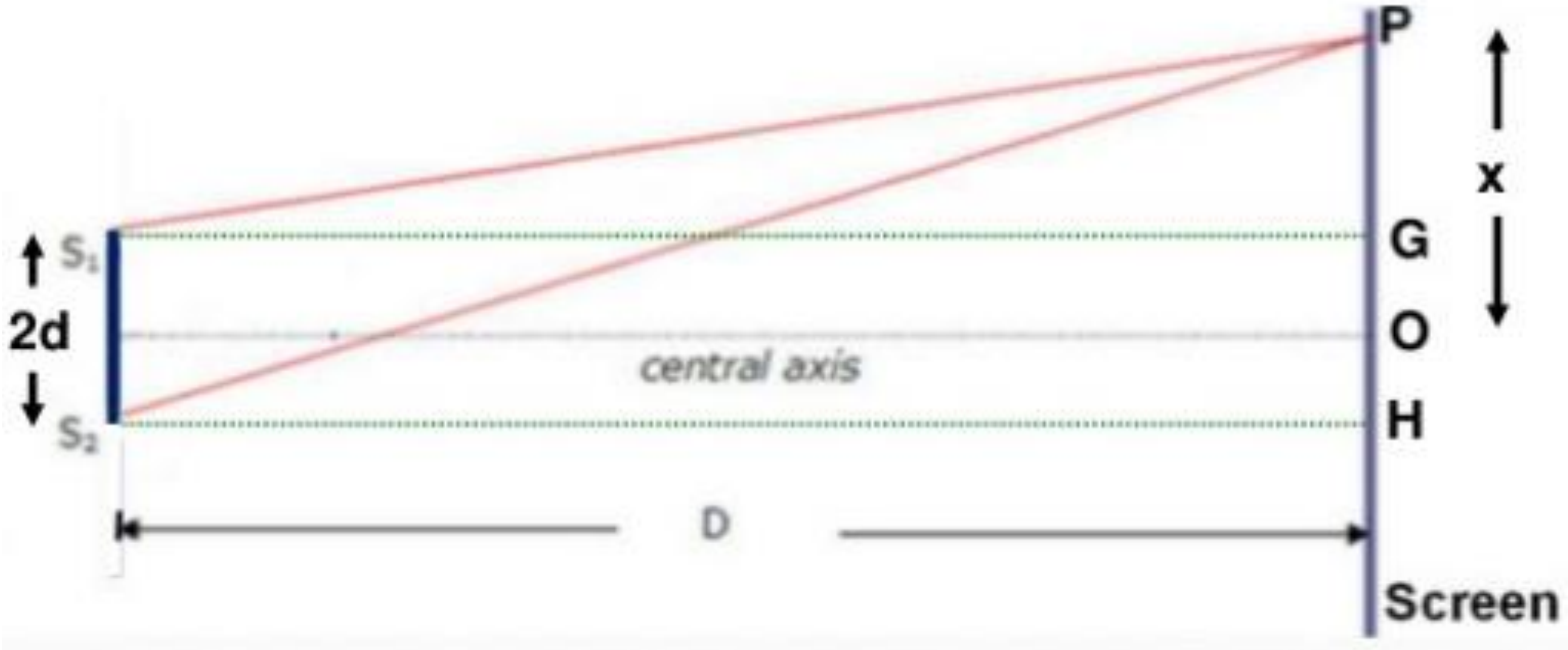

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The point O on the screen is equidistant from S_1 and S_2. Thus, the waves from S_1 and S_2 are in phase and hence the point O is central bright fringe of the interference pattern.

The illumination of any other point P can be obtained by calculating the path difference S_2P-S_1P.

Let us draw perpendiculars S_1G and S_2H on the screen.

Hence, $S_1S_2 = 2d$, $S_1G = S_2H = D$, and $OP = x$

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From S_2PH triangle,

$$(S_2P)^2 = (S_2H)^2 + (PH)^2$$
$$= D^2 + (x+d)^2$$
$$= D^2\left[1 + \frac{(x+d)^2}{D^2}\right]$$

$$S_2P = D\left[1 + \frac{(x+d)^2}{D^2}\right]^{\frac{1}{2}}$$
$$= D\left[1 + \frac{1}{2}\frac{(x+d)^2}{D^2}\right], as\ (x+d) \ll D$$
$$= D + \frac{1}{2}\frac{(x+d)^2}{D}$$

Similarly, $S_1P = D + \frac{1}{2}\frac{(x-d)^2}{D}$

$$S_2P - S_1P = \frac{1}{2}\frac{(x+d)^2}{D} - \frac{1}{2}\frac{(x-d)^2}{D} = \frac{2xd}{D}$$

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The resultant intensity at a point is a maximum or a minimum according as the path difference between the waves is an integral multiple of wavelength or an odd multiple of half-wavelength, respectively.

Thus, for P to be the centre of a bright fringe, we must have

$$S_2P - S_1P = \frac{2xd}{D} = n\lambda, \quad where \quad n = 0, 1, 2, \ldots$$

$$x = \frac{D}{2d}(n\lambda)$$

For P to be centre of a dark fringe, we must have

$$S_2P - S_1P = \frac{2xd}{D} = (2n+1)\frac{\lambda}{2} \quad where \quad n = 0, 1, 2, \ldots$$

$$x = \frac{D}{2d}(2n+1)\frac{\lambda}{2}$$

Let x_n and x_{n+1} denote the distances of the n^{th} and $(n+1)^{th}$ bright fringes.

Then the distance between $(n+1)^{th}$ and n^{th} bright fringes is

$$x_{n+1} - x_n = \frac{D}{2d}(n+1)\lambda - \frac{D}{2d}n\lambda = \frac{D}{2d}\lambda$$

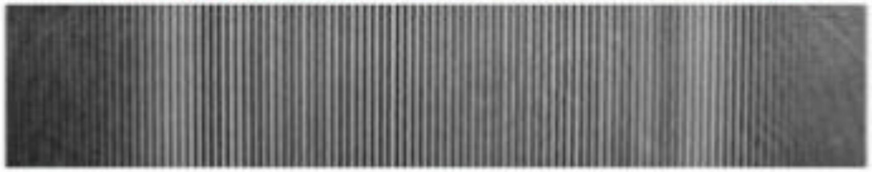
* This is independent of n

* The distance between any two consecutive bright fringe is the same i.e. Dλ/2d.

* Similarly, the distance between any two consecutive dark fringes is the same i.e. Dλ/2d.

* The distance Dλ/2d is called the "Fringe-width" and is denoted by $\bar{X}$

$$\bar{X} = \frac{D\lambda}{2d}$$



The wavelength of unknown light (λ) can be calculated by measuring the values of D, 2d, and $\bar{X}$.

Home Work

Fresnel’s biprism

Q7. Describe the experimental arrangement for the observation of interference fringes using Fresnel’s biprism. How would you determine the wavelength of monochromatic light using the Fresnel’s biprism experiment?

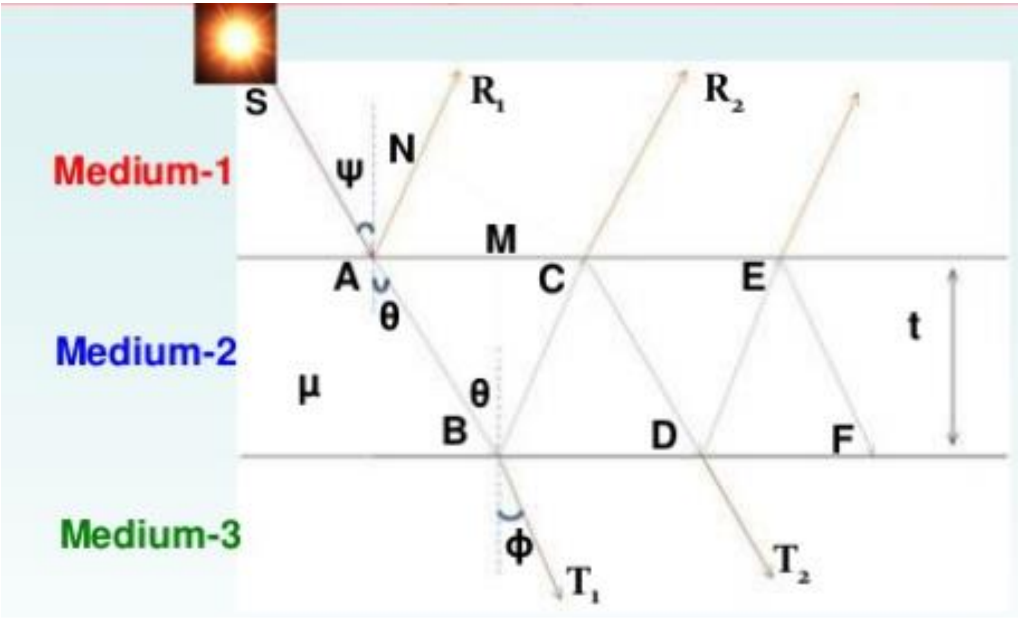
Home Work

Interference of Light by Thin Films

(Interference of Light by Multiple Reflections)

Let a ray of monochromatic light SA incidents at an angle *ψ* on a thin film of thickness *t* and refractive index *μ* (*μ*>1).

At A, the ray is partly reflected along AR1 and partly refracted along AB at an angle *θ*.



Chapter 3: Physical Optics

At B, the ray is again partly reflected along BC and partly refracted along BT_1.

Similarly, consequent reflections (AR_1, CR_2, ….) and refractions (BT_1, DT_2, ….) light will take place.

Let us first consider the reflected rays only. At each of the points A, B, C, D, only a small part of light is reflected, the rest is refracted. Therefore, the rays AR_1 and CR_2 (each having one reflection) have almost equal intensities.

The rest have rapidly decreasing intensities and can be ignored.

The rays AR_1 and CR_2 being derived from the same incident ray are coherent and have ability to interfere.

Therefore, we have to calculate the path difference between them.

Let CN and BM be perpendicular to AR_1 and AC.

As the paths of the rays AR_1 and CR_2 beyond CN is equal, the path difference between AR_1 and CR_2 is

p = path ABC in film-path AN in air

$= \mu(AB+BC)-AN$

$$AB = BC = \frac{BM}{cos\theta} \qquad (From\ ABM\ triangle, cos\ \theta = \frac{b}{h})$$

$$= \frac{t}{cos\theta}$$

Similarly, $AN = AC \sin \psi$

$= (AM+MC) \sin \psi$

$= (BM \tan \theta + BM \tan \theta) \sin \psi$

$= 2t \tan \theta \sin \psi$

$$= 2t\frac{sin\ \theta}{cos\ \theta}(\mu\ sin\ \theta) \qquad (As\ \ \mu = \frac{sin\ \psi}{sin\ \theta})$$

$$AN = 2\mu t \frac{\sin^2\theta}{\cos\theta}$$

Substituting the values of AB, BC and AN, the path difference will be

$$p = \mu\left(\frac{t}{\cos\theta} + \frac{t}{\cos\theta}\right) - 2\mu t \frac{\sin^2\theta}{\cos\theta}$$

$$= \frac{2\mu t}{\cos\theta}\left(1 - \sin^2\theta\right) = 2\mu t \cos\theta$$

At A, the ray is reflected while going from a rarer to a denser medium and suffers a phase change of π.

At B, The reflection takes place when the ray is going from a denser to a rarer medium and there is no phase change.

Hence, the ray AR1, having suffered a reflection at the surface of a denser medium, undergoes a phase change of π, which is equivalent to the a path difference of λ/2, because phase diff. = path diff. × 2π/ λ

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Hence the "effective" path difference between AR_1 and CR_2 is

$$= 2\mu t\cos\theta - \frac{\lambda}{2}$$

Conditions of Maxima in Reflected Light:

The two rays will reinforce each other if the path difference between them is an integral multiple of λ.

$$2\mu t\cos\theta - \frac{\lambda}{2} = n\lambda, \quad where = 0, 1, 2, \dots$$

$$2\mu t\cos\theta = (2n+1)\frac{\lambda}{2} \qquad (condition\ of\ maxima)$$

When this condition is satisfied, the film will appear bright in the reflected light.

Conditions of Minima in Reflected Light:

The two rays will destroy each other if the path difference between them is an odd multiple of λ/2.

$$2\mu t\cos\theta - \frac{\lambda}{2} = (2n-1)\frac{\lambda}{2} \qquad where \quad n = 1, 2, \ldots$$

$$2\mu t\cos\theta = n\lambda \qquad\qquad (condition\ of\ minima)$$

When this condition is satisfied, the film will appear dark in the reflected light.

Similarly, the path difference between the transmitted rays BT1 and DT2 can be calculated as

$$p = \mu\,(BC+CD) - BL = 2\mu t\cos\theta$$

In this case, there is no phase difference due to reflection at B or C, because in either case the light is travelling from denser to rarer medium.

Hence the "effective" path difference between BT_1 and DT_2 will be $2\mu t\cos\theta$

Maxima:

The rays BT_1 and DT_2 will reinforce each other if

$2\mu t\cos\theta = n\lambda$ where $n = 0,1,2,\ldots\ldots$ (condition of maxima)

The film will then appear bright in the transmitted light

Minima:

Two rays will destroy each other if,

Hence the "effective" path difference between BT_1 and DT_2 will be $2\mu t\cos\theta$

$$2\mu t\cos\theta = (2n+1)\frac{\lambda}{2} \qquad where\ \ n = 0,1,2,\ldots$$

This is the condition of minima.

The thin film will appear dark in the transmitted light

Chapter 3: Physical Optics

Home Work

Interference of Light by Thin Films

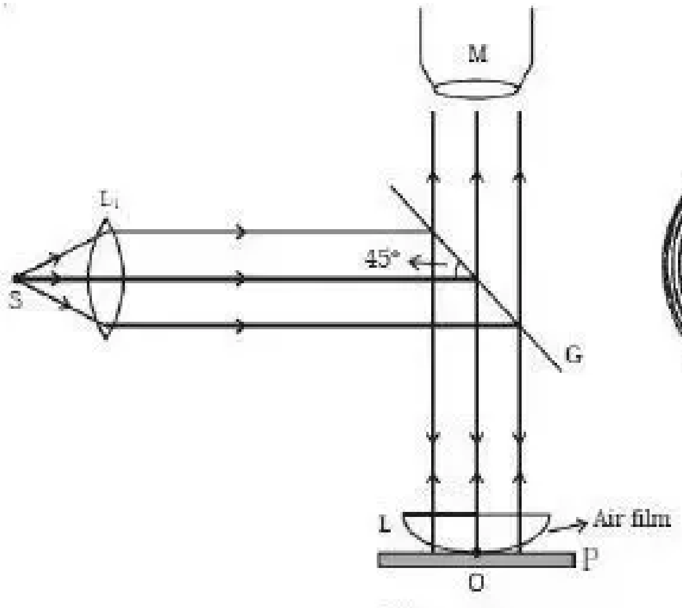
(Interference of Light by Multiple Reflections)

Q.8. Describe the phenomenon of interference of light due to multiple reflections and hence find the conditions of maxima and minima due to reflected light.

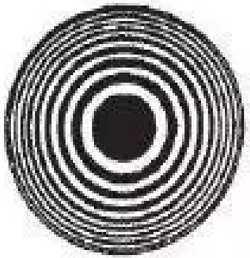
Chapter 3: Physical Optics

Newton's Rings

Newton's rings formed as concentric circular alternate dark and bright interference fringes due to the superimposition of light beam reflected from a thin air film of varying thickness.



Newton's rings



The formation of Newton’s rings is due to interference of light reflected, from the curved surface of the plano-convex lens, and the plane glass plate surface upon which this lens rests.

1. Both these rays travel vertically up and parallel to each other and along this path they interfere

2. The path difference between them is the thickness of the air film between the lens and the base plate

3. Due to the large radius of curvature of the lens, varying film thickness, and inevitable dust which introduces additional path difference; we see a dark circle in the centre surrounded by concentric rings

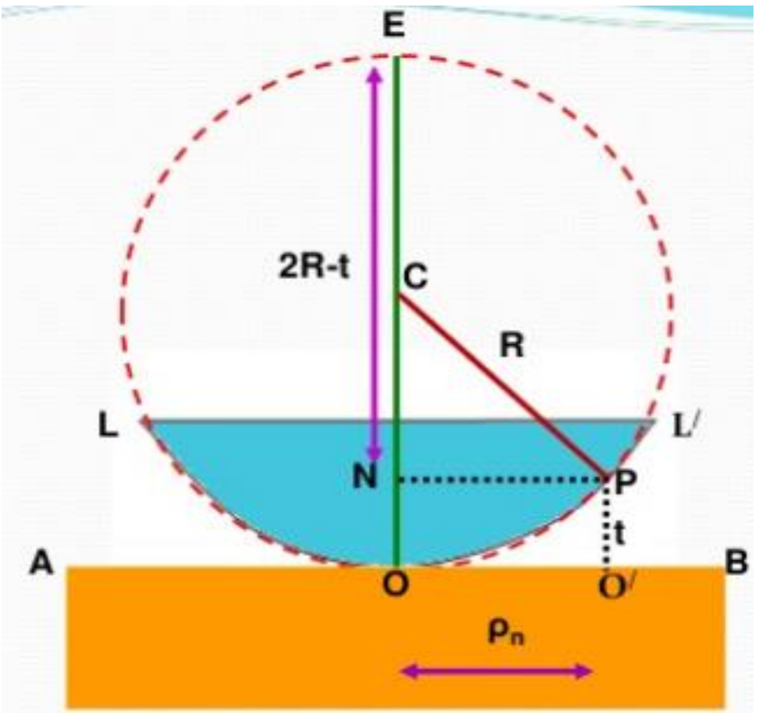
4. The fringe pattern gets compressed as one moves away from the centre

5. However central spot should have been bright if we can make use of the transmitted light.

Chapter 3: Physical Optics

Newton's Rings by Reflected Light

Suppose the radius of curvature of the lens is R and the air film is of thickness t at a distance of $OO' = \rho_n$. Let ρ_n be the radius of the Newton's ring corresponding to a point at P where the film thickness is t. Let LOL' be a lens placed on the glass plate AB, the point of contact being O.



An air film is formed between the lower surface of the lens and the upper surface of the glass plate. The thickness of the film gradually increases from the point of contact outwards. If the monochromatic light is allowed to fall normally on the air film, a system of alternate bright and dark concentric rings with their centre dark is formed in the air film. These are called the Newton's rings.

Chapter 3: Physical Optics

Newton's rings are formed as a result of interference between the light waves reflected from the upper and lower surfaces of the air film.

The effective path difference between the two rays is

$$p = 2\mu t\cos\theta + \frac{\lambda}{2}$$

Where μ is the refractive index of the film (air), t is the thickness of the film at the point D and θ is the inclination of the ray.

The factor λ/2 accounts for the phase change of π on reflection at the lower surface of the film.

For air-film (μ = 1) and normal incidence of light (θ = 0º)

$$p = 2t + \frac{\lambda}{2}$$

The effective path difference between two rays for air-film ($\mu = 1$) and normal incidence of light ($\theta = 0^{\circ}$)

$$p = 2t + \frac{\lambda}{2}$$

The condition for maximum intensity (bright-fringe) is

$$p = n\lambda \qquad n = 0, 1, 2, \ldots\ldots$$

$$2t + \frac{\lambda}{2} = n\lambda$$

$$2t = (2n - 1)\frac{\lambda}{2} \qquad (Maxima)$$

The condition for minimum intensity (dark fringe) is

$$p = (2n + 1)\frac{\lambda}{2}$$

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

$$2t = n\lambda$$

For $t = 0$, at the point of contact of the lens and the plate

$$p = \lambda/2$$

This is the condition for minimum intensity and hence the central spot is dark

* It is clear that a bright or dark fringe of any particular order n will occur for a constant value of t.
* Since in the air film "t" remains constant along a circle with its centre at the point of contact, the fringes are in the form of concentric circles.
* Since each fringe is the locus of constant film thickness, these are called fringes of constant thickness.

Chapter 3: Physical Optics

* Draw a perpendicular PN.

According to the property of the circle,

$$PN^2 = ON \times NE$$

Or, $\rho_n{}^2 = t \times (2R-t) = 2Rt-t^2$

Since t is small compared to R, one can neglect t^2

$$\rho_n{}^2 = t \times (2R-t) = 2Rt$$

$$2t = \rho_n{}^2 / R$$

The condition for a bright ring is

$$2t = (2n-1)\lambda/2$$

$$\rho_n{}^2 / R = (2n-1)\lambda/2$$

$$\rho_n{}^2 = (2n-1)\lambda R/2$$

If D_n be the diameter of the n^{th} bright ring, then $D_n = 2\rho_n$

$$D_n^2 = 2\,(2n-1)\,\lambda R$$

$$D_n = (2\lambda R)^{1/2}\,(2n-1)^{1/2}$$

$$D_n \propto (2n-1)^{1/2}$$

As n is an integer, (2n-1) is an odd number

Thus the diameter of the bright rings are proportional to the square-root of the odd natural number.

The diameters of the first few rings are in the ratio

$1 : \sqrt{3} : \sqrt{5} : \sqrt{7}$ ....

The condition for a dark ring is

$$2t = n\lambda$$

$$\rho_n^2 / R = n\lambda$$

If D_n be the diameter of the n^{th} bright ring, then $\rho_n = D_n/2$

$$D_n^2/4R = n\lambda$$

$$D_n = (4nR\lambda)^{1/2}$$

$$D_n = (4nR\lambda)^{1/2} (n)^{1/2}$$

$$D_n \alpha\, n^{1/2}$$

Thus the diameter of the dark fringes are proportional to the square root of natural numbers.

Applications of Newton's Rings

1. To calculate the thickness of a surface
2. To estimate the wavelengths of light
3. To measure the refractive index of a liquid

Problem 3

Calculate the thickness of the thinnest film ($\mu=1.4$) in which interference of violet component (λ = 4000 Å) of incident light can take place by reflection.

Solution to Problem 3

The condition for constructive interference of light reflected from a film of thickness t is

$$2\mu t \cos\theta = (2n+1)\lambda/2 \qquad n = 0,1,2,\ldots\ldots$$

For normal incident $\theta = 0$ and for minimum thickness n should be 0.

$$2\mu t = \lambda/2$$

$$t = 714.3 \text{ Å}$$

Problem 4

A thin soap film (μ=1.33) seen by sodium light (λ = 5893 Å) by normal reflection appears dark. Find the minimum thickness of the film.

Solution to Problem 4

The condition for destructive interference of light reflected from the a film of thickness t is

$$2\mu t \cos\theta = n\lambda$$

For normal incident $\theta = 0$ and for minimum thickness n should be 1.

$$t = \lambda/2\mu = 2215 Å$$

Problem 5

Newton's rings are observed normally in reflected light of wavelength 5.9×10^{-5} cm. The diameter of the 10^{th} dark ring is 0.5 cm. Find the curvature of the lens and the thickness of the film.

Solution to Problem 5

The diameter of the n^{th} dark ring is given by

$$D_n^2 = 4n\lambda R$$

After putting the values of $D_n = 0.5$ cm, $n = 10$ and $\lambda = 5.9 \times 10^{-5}$ cm,

$$R = 106 \text{ cm}$$

If t is the thickness of the film corresponding to a ring of diameter D, then we have

$$2t = D^2/4R$$

$$t = 3 \times 10^{-4} \text{ cm}$$

Problem 6

A convex lens of radius 350 cm placed on a flat plate and illuminated by monochromatic light gives the 6^{th} bright ring of diameter 0.68 cm. calculate the wavelength of light used.

Solution to Problem 6

The diameter of the n^{th} bright fringe is

$$D_n^2 = 2(2n-1)\lambda R, \qquad \text{where } n = 1,2,3,\ldots\ldots$$

$R = 350$ cm, $n = 6$, $D_n = 0.68$ cm

$$\lambda = 6.0 \times 10^{-5} \text{ cm} = 6000 \text{ Å}$$

Determination of the Wavelength of Light (using the Newton's Rings)

The diameter of the nth dark ring is given by,

$$D_n = 2\sqrt{n\lambda R}$$

Hence,

$$D_n^2 = 4n\lambda R \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

Similarly the diameter of the (m+n)th dark ring is given by,

$$D_{m+n} = 2\sqrt{(m+n)\lambda R}$$

Hence,

$$D_{m+n}^2 = 4(m+n)\lambda R \ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

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Subtracting Eq. (1) from Eq. (2), we get

$$D_{m+n}^2 - D_n^2 = 4(m+n)\lambda R - 4n\lambda R$$

Hence,

$$D_{m+n}^2 - D_n^2 = 4m\lambda R$$

Thus,

$$\lambda = \frac{D_{m+n}^2 - D_n^2}{4mR} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Using Eq. (3), we can calculate the wavelength of the light used to conduct the Newton's rings experiment.

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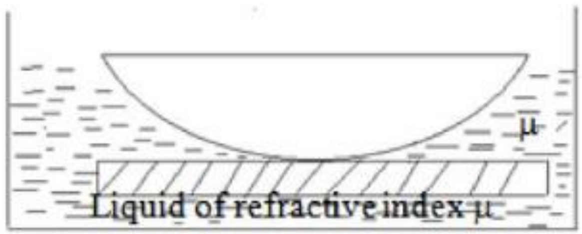
Determination of the Refractive Index of a Liquid (using the Newton's Rings)

The liquid whose refractive index is to be determined is filled between the lens and glass plate. Now air film is replaced by liquid. The condition for interference then (for darkness)

$$2\mu t \cos r = m\lambda$$



For normal incidence $\cos r = 1$

Therefore $2\mu t = m\lambda$ but $t = \dfrac{r^2}{2R}$

$$2\mu \frac{r^2}{2R} = m\lambda \Rightarrow D^2 = \frac{4m\lambda R}{\mu}$$

Following the above relation the diameter of mth dark ring is $[D_m^2]_{liq} = \dfrac{4m\lambda R}{\mu}$

Similarly diameter of (m+p)th ring is given by $\left[D_{m+p}^2\right]_{liq} = \dfrac{4(m+p)\lambda R}{\mu}$

$$\left[D_{m+p}^2\right]_{liq} - [D_m^2]_{liq} = \frac{4p\lambda R}{\mu}$$

$$\left[D_{m+p}^2\right]_{air} - [D_m^2]_{air} = 4p\lambda R$$

$$\boxed{\mu = \frac{\left[D_{m+p}^2\right]_{air} - [D_m^2]_{air}}{\left[D_{m+p}^2\right]_{liq} - [D_m^2]_{liq}}}$$

Self-Assessment 1

A man whose eyes are 150 cm above the oil film on water surface observes the greenish color at a distance of 100 cm from his feet. Calculate the probable thickness of the film. (λ=500nm, μ_{oil}=1.4 , μ_{water}=1.33)

$9.725\times10^{-6}(2n-1)$ cm

Chapter 3: Physical Optics

Sample Questions

Q9. Describe the phenomenon of interference in thin films. Give the necessary theory.

Q10. Explain the formation of Newton's rings. Show how would you use the Newton's rings experiment to calculate (i) the refractive index of a liquid and (ii) radius of curvature of lens.

Q.11. How Newton's rings are formed? Describe the experimental features of Newton's rings.

Q.12. Describe the method of determination of wavelength of light using the Newton's rings experiment.

Self-Assessment 2

A parallel film of sodium light of wavelength 5880Å is incident on a thin glass plate of μ=1.5 such that the angle of refraction in the plate is 60°. Calculate the smallest thickness of the plate which will make it appear dark at reflection.

3920Å

Self-Assessment 3

Light of wavelength 589.3nm is reflected at nearly normal incidence from a soap film of refractive index 1.42. what is the least thickness of the film that will appear (I) black, (II) bright?

Ans: 207.5 nm, 103.75 nm.

Self-Assessment 4

A parallel beam of sodium light (589nm) is incidenting on an oil film on water. When viewed at an angle of 30^0 from normal, 8^{th} dark band is seen. What is the thickness of oil film?

Ans: 1.7 μm

Chapter 3: Physical Optics

Self-Assessment 5-7

In a Newton's ring experiment the diameter of the 12th dark ring changes from 1.40 cm to 1.27 cm when a liquid is introduced between the lens and the plate. Calculate the refractive index of the liquid.

$\mu = 1.215$

In Newton's ring exp., the diameter of 4^{th} and 12^{th} dark rings are 0.4 and 0.7 cm, what will be the diameter of 20^{th} dark ring.

$D_{20} = 0.905cm$

If the diameter of nth ring change from 0.3cm to 0.25 cm after filling a liquid b/w the lens and plate, find out the refractive index of liquid.

$\mu = 1.44$

Self-Assessment 8

Newton's rings by reflection are formed between two plano-convex lenses having equal radii of curvature being 100 cm each. Calculate the distance between 5th and 15th dark rings for monochromatic light of wavelength 5400 Å in use.

$$D_{15} - D_5 = 1.701\text{mm}$$

Self-Assessment 9

The convex surface of radius 40 cm of a plano-convex lens rests on the concave spherical surface of radius 60 cm. If the Newton's rings are viewed with reflected light of wavelength 6000 Å, calculate the radius of 4th dark ring.

$$D_4 = 1.697\ \mathrm{mm}$$

Interference of Light

Solve a few problems related to the theories of INTERFERENCE of light of the given questions

Diffraction of Light

Read the following pages: 1231-1242

Book Physics for Engineers Vol.1

Diffraction of Light

The **interference** is the combination of superposition of two or more waves that are in a point of space.

The **diffraction** is the deviation suffering waves around the edges and corners that occurs when a portion of a wavefront is interrupted or cut it by a barrier or obstacle. Fringes width in interference of light is equal while in the diffraction of light fringes width is not equal.

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The bending of light around an obstacle is called diffraction of light.

The bending of light *i.e.*, the diffraction of light depends upon the size of the obstacle. Diffraction effects are large if the edges of the obstacle are sharp and aperture is comparable in size of the wavelength of light of the order of 10^{-7} m.

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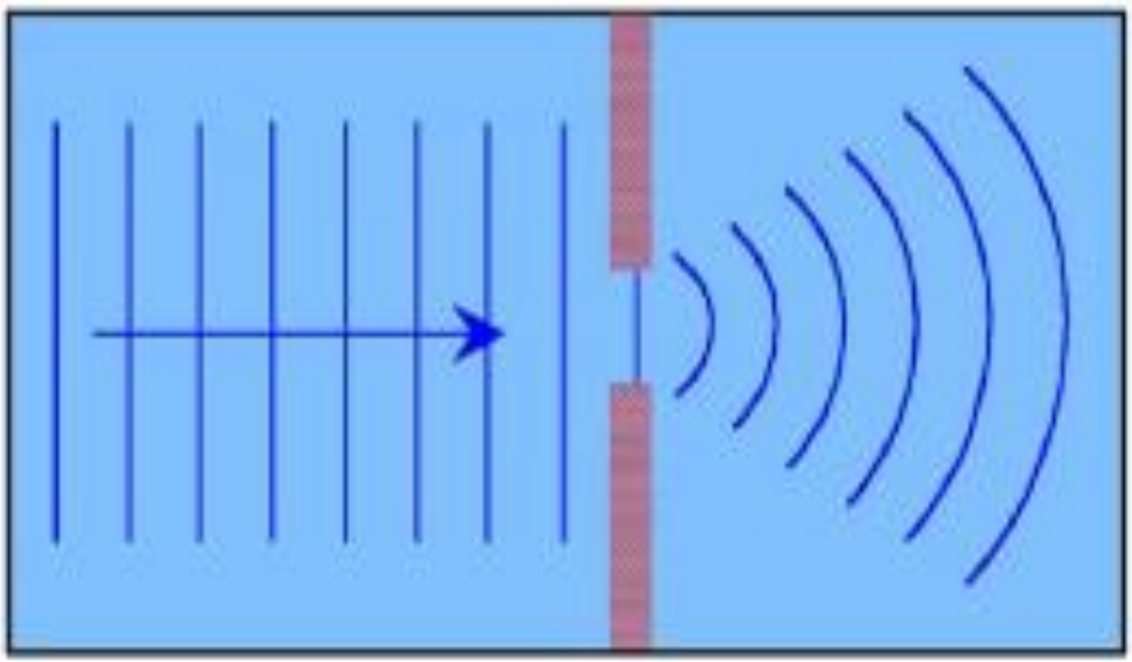
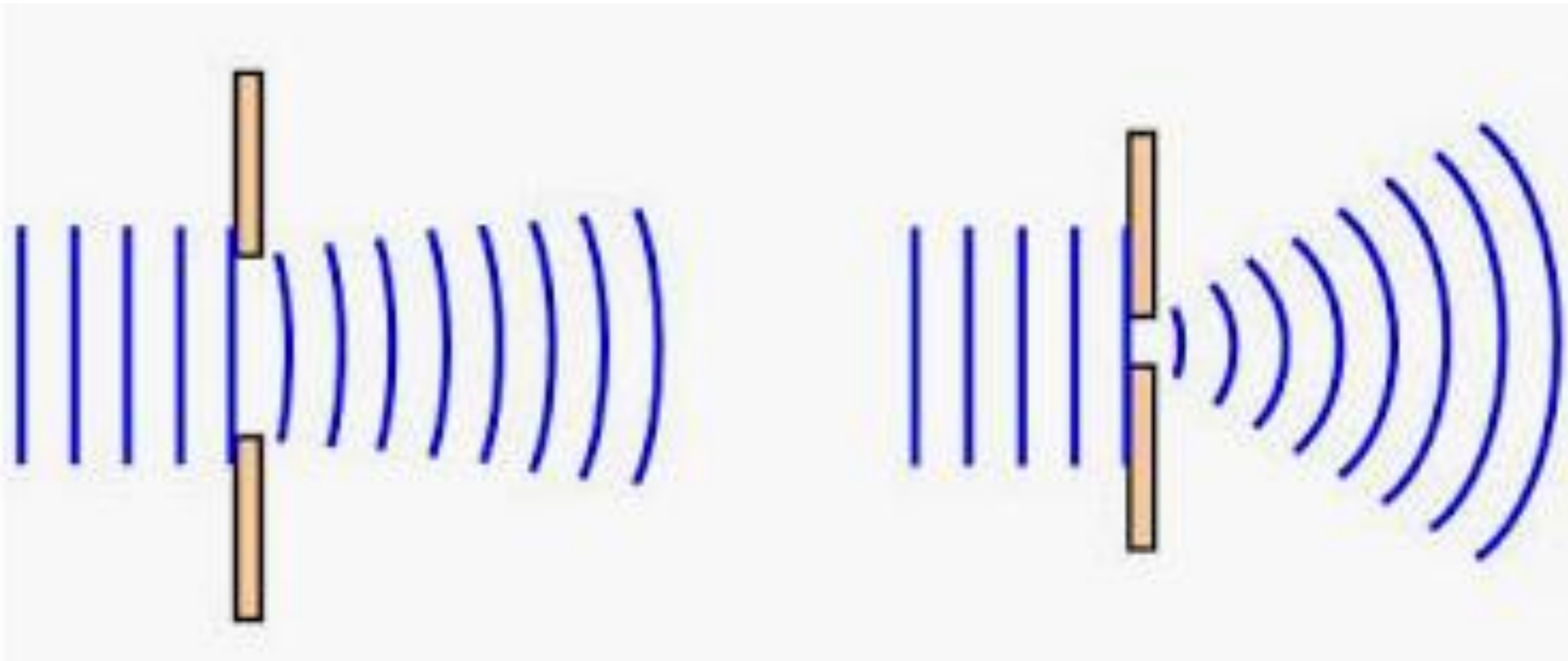
Diffraction of light is defined as the spreading out of the light waves as it passes through a small opening or around an obstacle.



Chapter 3: Physical Optics



Types of Diffraction of Light

Diffraction of light is of two types:

1. Fresnel Diffraction
2. Fraunhofer diffraction

Difference between the Interference and Diffraction of Light

Interference of Light	*Diffraction of Light*
1: Interference is due to the interaction of light coming from two different wavefronts originating from the same source.	1:Diffraction is due to the interaction of light coming from different parts of the same wavefront.
2:Interference fringes are of the same width.	2:Diffraction fringes are not of the same width.
3: All bright fringes are of the same intensity.	3:All bright fringes are not of the same intensity.
4:All point of minimum intensity are perfectly dark.	4:All point of minimum intensity is not perfectly dark.
5:The spacing between fringes is uniform.	5:The spacing between fringes is not uniform.

Types of Diffraction of Light

Fraunhofer diffraction

- Source and the screen are far away from each other.
- Incident wave fronts on the diffracting obstacle are plane.
- Diffracting obstacle give rise to wave fronts which are also plane.
- Plane diffracting wave fronts are converged by means of a convex lens to produce diffraction pattern.

Fresnel Diffraction

- Source and screen are not far away from each other.
- Incident wave fronts are spherical.
- Wave fronts leaving the obstacles are also spherical.

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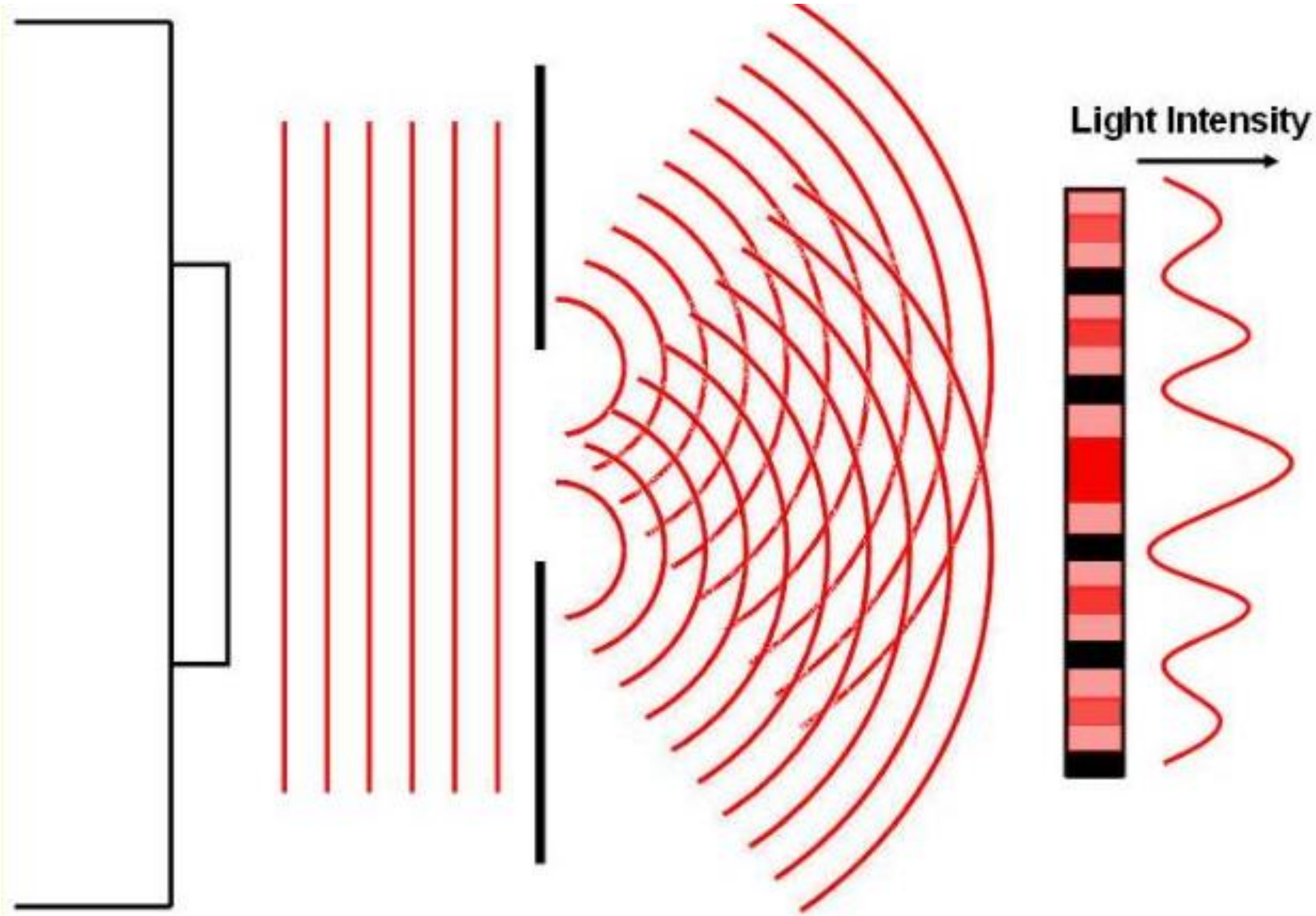
Intensity Pattern of Diffraction of Light



Chapter 3: Physical Optics

Sample Questions

Q.1. What do you mean by diffraction of light? Distinguish between interference and diffraction of light.

Q.2. Distinguish between Fraunhoffer and Fresnel class of diffractions. Describe the Fraunhoffer diffraction pattern produced by a single slit illuminated by monochromatic light.

Q.3. Discuss the Fraunhofer diffraction pattern at a single slit. Draw the intensity distribution curves for the diffraction pattern.

Q.4. In the case of Fraunhoffer diffraction pattern show that the intensity of the first secondary maxima is roughly 4.96% of that of the principal maxima.

Diffraction of Light

Solve a few problems related to the theories of DIFFRACTION of light of the given questions

Polarization of Light

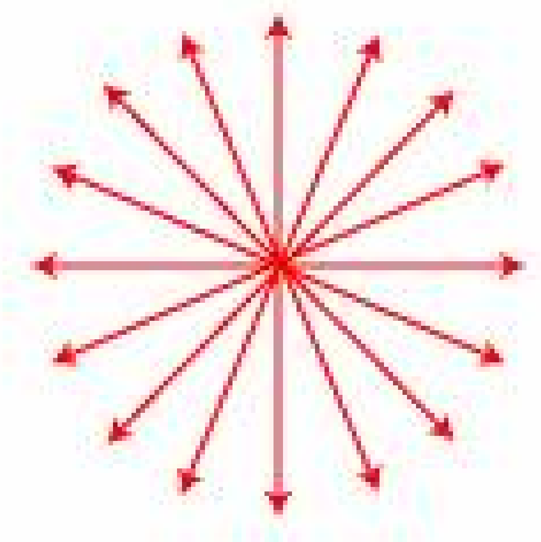
Read the following pages: 1306-1315 & 1332-1334

Book Physics for Engineers Vol.1

Polarization of Light

Unpolarised light is polarized in all directions.

The electric fields are oriented in all directions. The light that we see (with our eyes) is unpolarised.

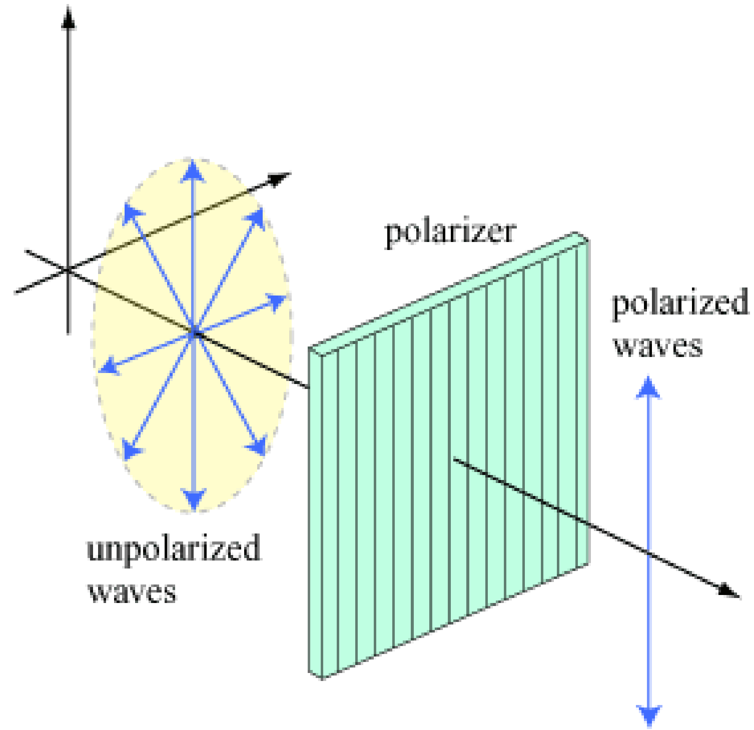


Direction of propagation

Unpolarised light

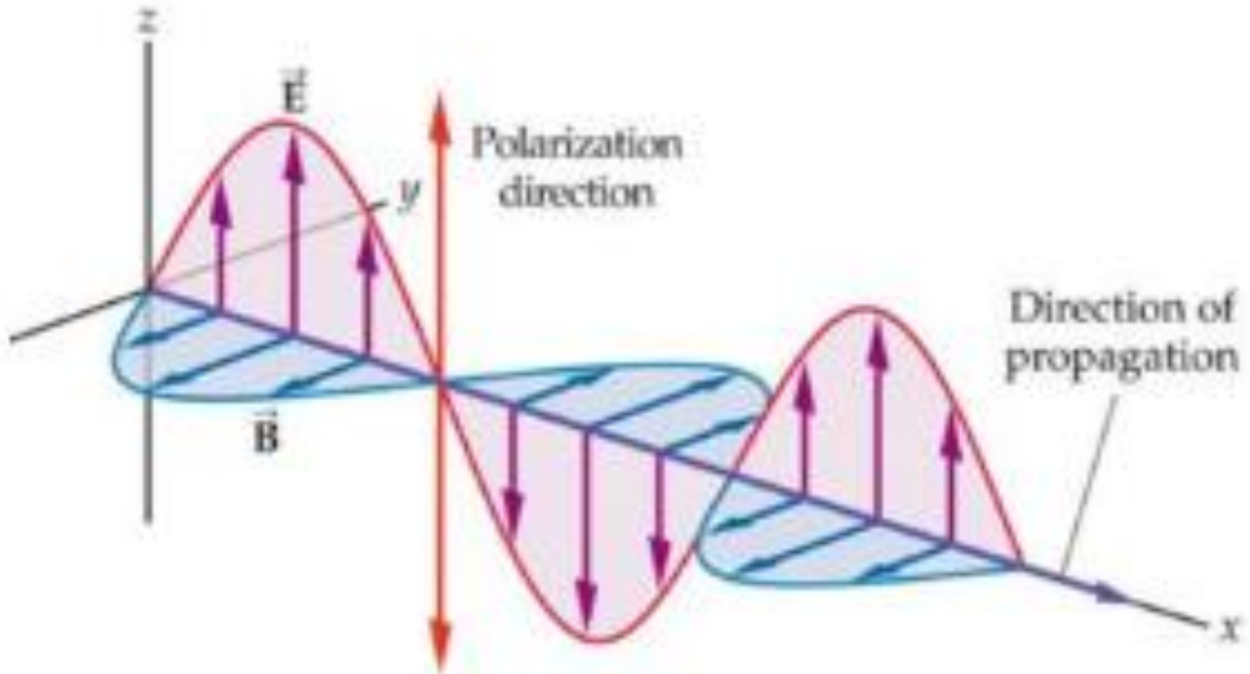
Chapter 3: Physical Optics

The polarization of an electromagnetic wave (made up of electric and magnetic fields) is defined as the direction along which the electric field vector (***E***) points.



In polarized light, the electric field is oriented in a single direction.

Chapter 3: Physical Optics



Polarization along *z*-direction

Types of Polarization

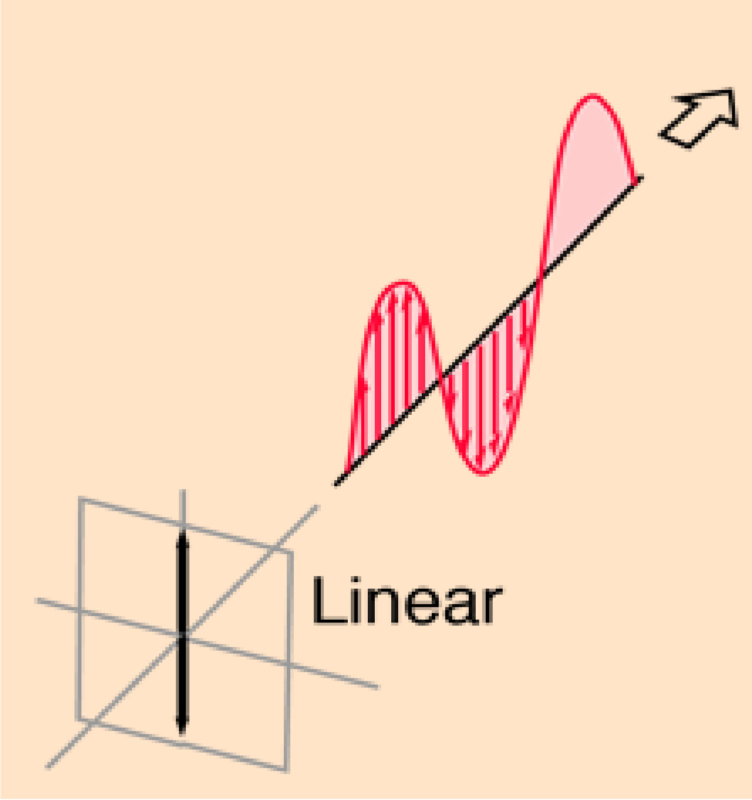
Polarized lights are of 3 types:

1. Linearly polarized light
2. Circularly polarized light
3. Elliptically polarized light

Linear Polarized Light

A plane electromagnetic wave is said to be linearly polarized.

The electric field of light is confined to a single plane along the direction of propagation



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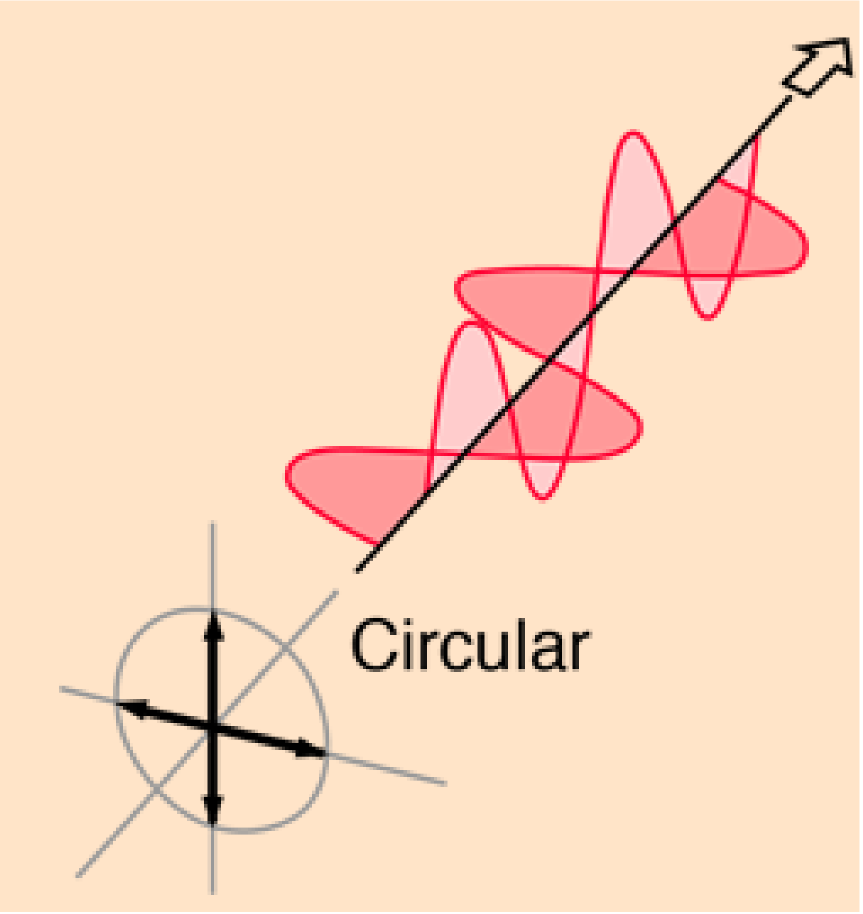
Circularly Polarized Light

The electric field of light consists of two linear components that are perpendicular to each other, equal in amplitude, but have a phase difference of $\pi/2$.

The resulting electric field rotates in a circle around the direction of propagation and, depending on the rotation direction, is called left- or right-hand circularly polarized light



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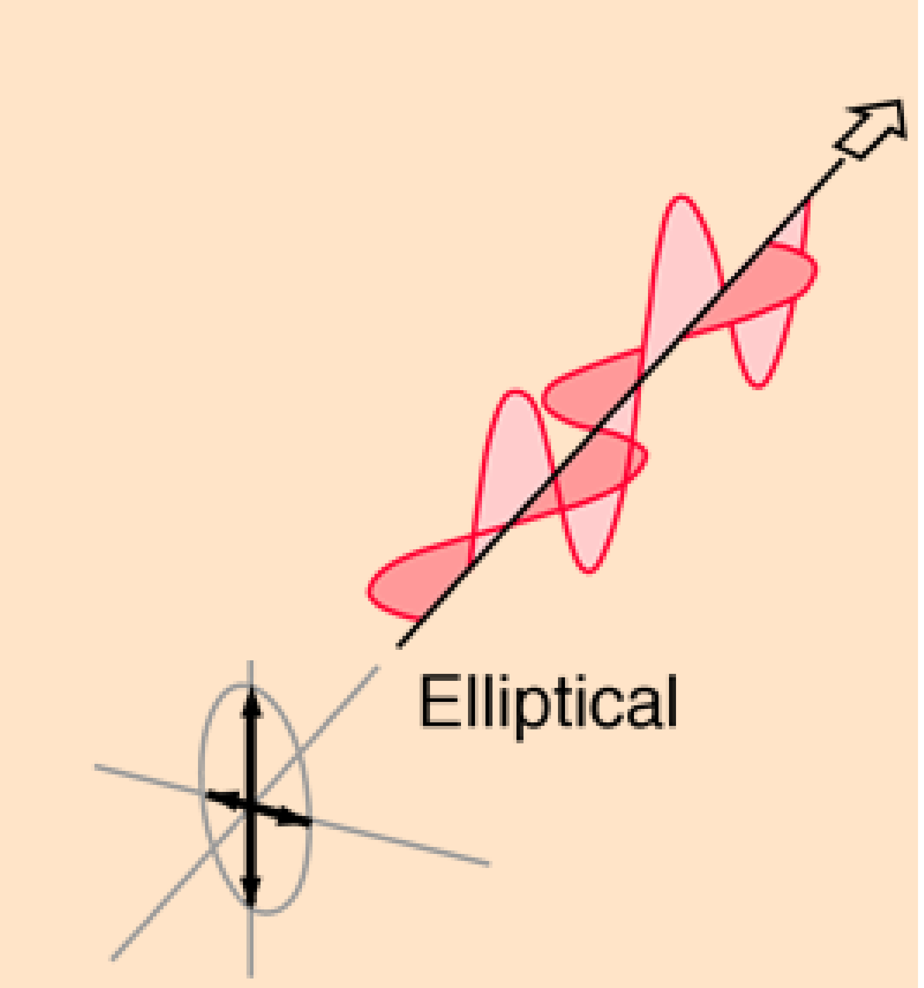
Elliptically Polarized Light

The electric field of light describes an ellipse. This results from the combination of two linear components with differing amplitudes and/or a phase difference that is not $\pi/2$.

This is the most general description of polarized light, and circular and linear polarized light can be viewed as special cases of elliptically polarized light



Plane of Polarization

The plane passing through the direction of wave propagation and plane perpendicular to the plane of vibration is called the plane of polarisation. No vibration occurs in the plane of polarisation.

It is perpendicular to the direction of propagation of light.

Plane of Vibration

A plane including the direction of light propagation and the direction of electric field is called the plane of vibration. The angle between them is 90°.

In other words, the plane containing the optic axis in which the vibrations occur is known as plane of vibration.

It is the plane in which the electric and magnetic fields vibrate and it is always perpendicular plane with direction of propagation.

Brewster's Law

Sir David Brewster, in 1811

Brewster's law states that when unpolarized light of a given wavelength is incident upon the surface of a transparent substance it will experience maximum polarization when it is incident to the surface at an angle (angle of polarization or polarizing angle, also known as Brewster's angle) having a tangent equal to the refractive index of the surface. Mathematically,

$$\mu = tan i$$

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Mathematically,

$$\mu = tani$$

Where, μ = Refractive index of the medium

i = Polarization angle.

From Snell's Law: $\mu = \frac{\sin i}{\sin r}$

From Brewster's Law: $\mu = \tan i = \frac{\sin i}{\cos i}$

Comparing both formulas:

$\cos i = \sin r = \cos\left(\frac{\pi}{2} - r\right)$

$i = \frac{\pi}{2} - r, or\ i + r = \frac{\pi}{2}$

As, $i + r = \frac{\pi}{2} < ABC$ is also equal to the $\frac{\pi}{2}$. Therefore, the reflected and the refracted rays are at right angles to each other.

Malus Law

Malus’ law states that the intensity of a plane-polarized light that passes through an analyser varies as the square of the cosine of the angle between the plane of the polarizer and the transmission axes of the analyser. Mathematically,

$$I \propto \cos^2\theta$$

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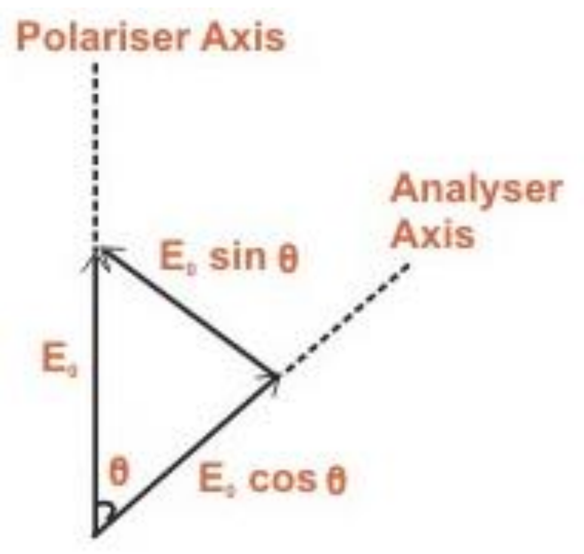
Suppose the angle between the transmission axes of the analyser and the polarizer is θ. The completely plane polarized light form the polarizer is incident on the analyser. If E_0 is the amplitude of the electric vector transmitted by the polarizer, then intensity I_0 of the light incident on the analyser is $I \propto E_0^2$.



The electric field vector E_0 can be resolved into two rectangular components *i.e.*, $E_0 cos\theta$ and $E_0 sin\theta$. The analyser will transmit only the component (*i.e.*, $E_0 cos\theta$) which is parallel to its transmission axis. However, the component $E_0 sin\theta$ will be absorbed by the analyser.

Therefore, the intensity I of light transmitted by the analyser is,

$I \propto (E_0 cos\theta)^2$

$I/I_0 = (E_0 cos\theta)^2/E_0^2 = cos^2\theta$

$I = I_0 cos^2\theta$

Therefore, $I \propto cos^2\theta$. This proves law of malus.

When $\theta = 0°$ (or $180°$), $I = I_0 cos^2 0° = I_0$.

That is, the intensity of light transmitted by the analyser is maximum when the transmission axes of the analyser and the polarizer are parallel.

When $\theta = 90°$, $I = I_0 cos^2 90° = 0$.

That is the intensity of light transmitted by the analyser is minimum when the transmission axes of the analyser and polarizer are perpendicular to each other.

Home Work

Optical activity and

Specific rotation of a substance.

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Sample Questions

Q.1. What do you mean by polarization of light? Distinguish between the ordinary and polarized light.

Q.2. Explain the plane of polarization and the plane of vibration.

Q.3. State and explain Brewster's law. Show that at the polarizing angle of incidence, the reflected and refracted rays are mutually perpendicular to each other.

Q4. State and explain Malus' law.

Q5. Write up short notes on: (i) Optical activity and (ii) specific rotation of a substance.

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Polarization of Light

Solve a few problems related to the theories of POLARIZATION of light of the given questions

"Thank You"