Unit 13

Physical Optics

Teaching Periods 12 **Weightage %** 8

On earth the shimmering colors of butterflies and beetles and the beautiful color of a peacock dancing in THAR is due to some phenomenon exhibited by light. To understand the Universe the most important tool is light (electromagnetic radiations).

In this unit student should be able to:

- Understand electromagnetic spectrum (ranging from radio waves to γ rays).
- Recall that light is a part of continuous spectrum of electromagnetic waves.
- Describe the concept of wave fronts and its types.
- State Huygens's principle and use it to construct wave front after a time interval
- State the necessary conditions to observe interference of light.
- Describe Young's double slit experiment and the evidence it provides to support the wave theory of light.
- Use the equations of constructive and destructive interference to determine the position of bright and dark fringes also determine the fringe spacing.
- Explain color pattern due to interference in thin films.
- Describe interference pattern produced by Newton's rings.
- Describe the parts and working of Michelson Interferometer and its uses.
- Explain diffraction and identify that interference occurs between waves that have been diffracted.
- Describe that diffraction of light is evidence that light behaves like waves.
- Describe and explain diffraction at a narrow slit.
- Describe the use of a diffraction grating to determine the wavelength of light and Carry out calculation using $d\sin\theta = n\lambda$.
- Describe the phenomenon of diffraction of X-rays through crystals.
- Measure the slit separation /grating element 'd' of a diffracting grating by using the known wavelength of laser light.

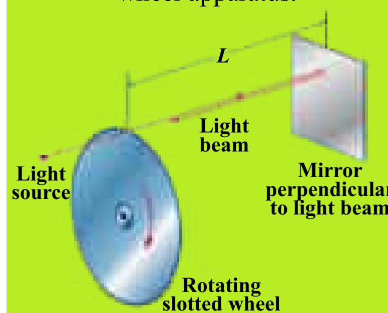
The study of light has been a significant aspect of science since ancient times, with contributions from the Greeks and Islamic scholars. The scientific revolutions of the 16th and 17th centuries, led by Newton, Huygens, Young, Maxwell, and Einstein, expanded the field into what we now call OPTICS.

In secondary classes, we learned about Geometric Optics focusing on reflection and refraction through mirrors, glasses, and lenses. Geometric optics assumes light propagates in straight lines, changing direction through reflection or refraction at different surfaces.

Moving to Physical Optics, we emphasize the wave nature of light. Here, we explore light's behavior around obstacles or small apertures compared to the wavelength. This leads to phenomena like interference, diffraction, and polarization as light transmits through different media.

DO YOU KNOW?

Electromagnetic waves from radio waves to gamma rays all travel with same speed (**$c = \nu\lambda$**) of 3 x10^8 m/s in vacuum. The speed of visible light was first measured by **Armand Hippolyte Louis Fizeau** in 1849, with the help of toothed wheel apparatus.



Fizeau Apparatus.

13.1 Nature of Light:

Light is a captivating phenomenon, described as electromagnetic radiation, with dual characteristics as both particles (photons) and waves. This wave-particle duality is fundamental to its behavior, allowing it to propagate through space, exhibit interference, diffraction, and polarization as a wave, while interacting with matter as quantized packets of energy. Light's constant speed in a vacuum, approximately three lac kilometers per second (3×10^8m/s), is a universal constant. Its interactions with matter lead to various phenomena, like reflection, refraction, and absorption. Understanding light has enriched our knowledge of the cosmos and revolutionized technologies in communication, imaging, and scientific research.

13.1.1 Electromagnetic Spectrum:

The longitudinal mechanical waves like sound waves are propagated through a medium due to the vibrations of massive particles (atom or molecules).

Electromagnetic waves **are transverse waves. as the name depicts these waves possess both electric and magnetic properties.**

We know that a static point charge gives rise to an electric field only. Similarly, a charge moving at constant velocity produces both electric and magnetic fields. But,

When a charge particle accelerates, it produces electromagnetic waves.

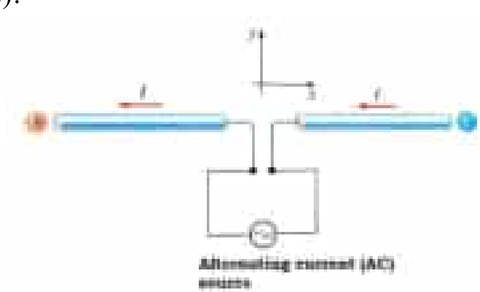


Fig: 13.1
Current in an electric dipole antenna

Oscillations of electric charges due to an ac current in an ***electric dipole*** antenna, (Fig.13.1) or transitions of electrons in an atom from a higher to lower energy level are also some sources of electromagnetic waves. In both examples mentioned above the back and forth movement of charges (Fig.13.2) with a certain frequency produces electric and magnetic fields at the same frequency. According to Faraday's laws of electromagnetic induction a time varying magnetic field induces an electric field. Likewise a Scottish physicist James Clerk Maxwell (1831-1879) showed that a changing electric field does give rise to a magnetic field.

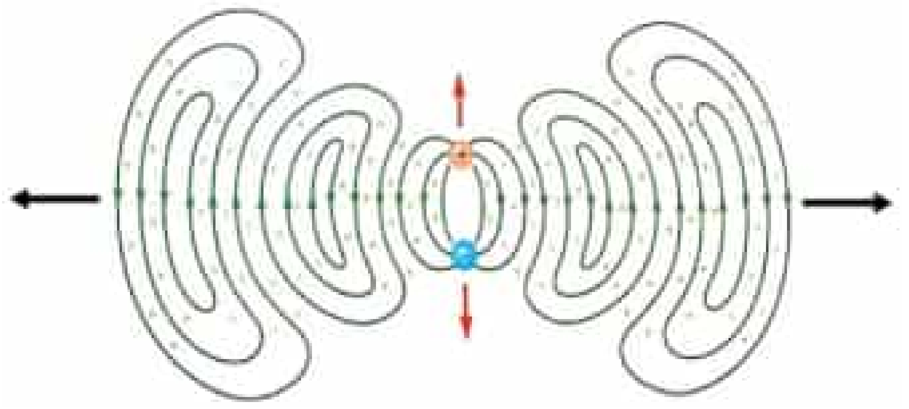


Fig: 13.2

The loops are electric field lines parallel to the plane of page. The dots and crosses are magnetic line of force perpendicular to the plane of page.

The interaction of these time varying electric and magnetic fields produces electromagnetic waves which move away from the source with speed of light (Fig.13.3). With the help of Gauss's law and Ampere's law, Maxwell successfully proved the speed of light can travel in vacuum given as

$$\mathbf{c} = \frac{1}{\sqrt{\epsilon_o \mu_o}} = 3.00 \times 10^8 \text{ m/s.}$$

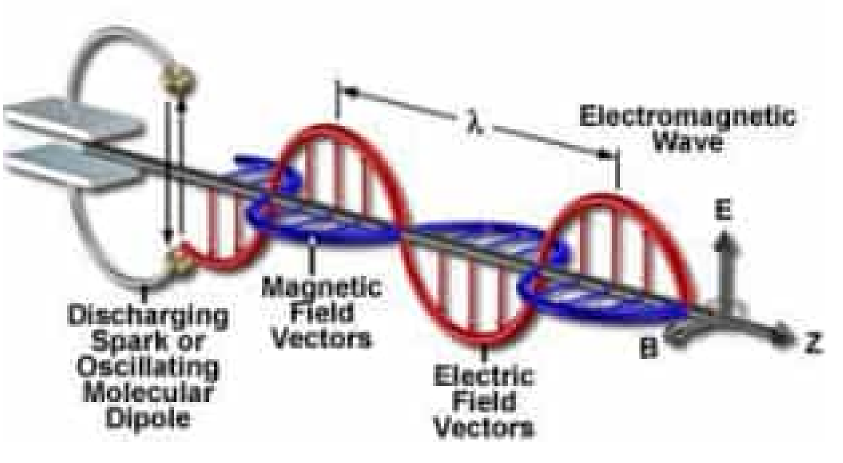


Fig: 13.3 Propagation of electromagnetic waves.

The ***electromagnetic spectrum*** as shown in fig. 13.4 is the broad range of frequencies and wavelengths of electromagnetic waves.

Characteristically electromagnetic spectrum is classified in seven regions from Radio waves to Gamma rays. The boundaries between the regions are somewhat indistinct and arbitrary.

The Electromagnetic Spectrum

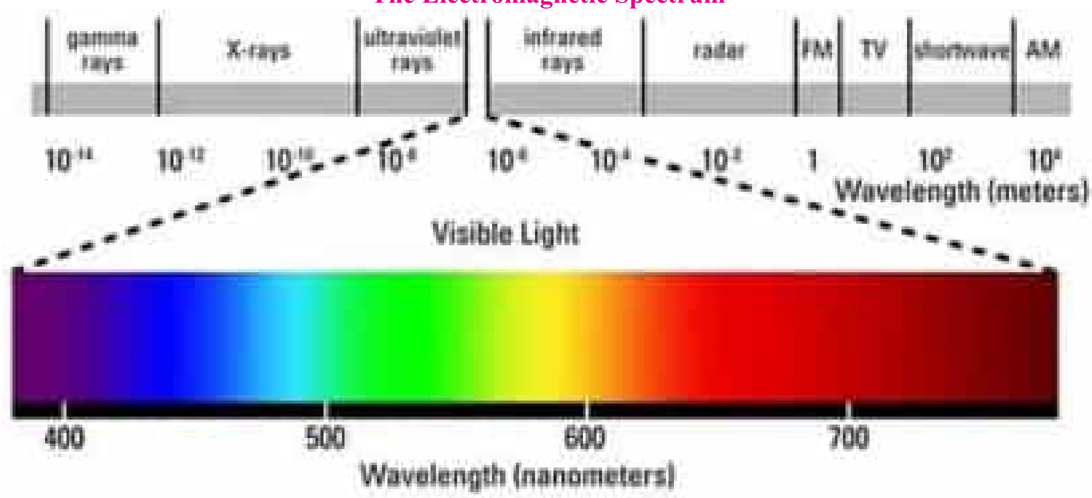


Fig: 13.4 Regions of Electromagnetic Spectrum

Radio waves:

Radio waves were discovered in 1887 by **Heinrich Hertz** a professor of physics in Karlsruhe, Germany. In 1932 **Karl Guthe Jansky** concluded that the source of persistent radio waves came from the centre of our galaxy. These waves are also generated by oscillation of electric charges.

The wavelength range of radio waves is typically of the order of 0.1m to 3×10^4m approximately.

Nowadays radio frequencies are crowded with signals from radio and TV stations as well as gathering information from Universe.

Microwaves:

The wavelength range of microwaves are typically (0.3 m) to (30 cm) in free space.

In 1960, Arno Penzias and Robert Wilson are troubled with their radio telescope due to the noise in the microwave part of their spectrum.

The investigations to set right of this problem led to discover that the entire

Fig: 13.5 The **lovell Telescope at Jordell Bank** located at Cheshire near Manchester (United Kingdom).

universe is immersed in microwaves, remains of cosmic microwave background radiations leftover after ***Big Bang***, the origin of the universe. Significant information about our own and other galaxies are obtained by the microwaves (1420 MHz $\sim 21cm$) emitted by neutral hydrogen atoms distributed over a vast region of space.

DO YOU KNOW?

Infrared penetrates smoke and dust well than visible light so infrared detectors are used by rescue services like fire brigade and by armed forces to make attacks under cover of a smoke screen.

Infrared:

The prefix infra means below.

The frequency of infrared radiation extends from low frequency of red edge of visible light to a frequency of 300 GHz with corresponding wavelength of 1mm.

Infrared radiations were discovered in 1880 by a German born British astronomer (1738-1822) Frederick William Herschel while studying the temperature rise due to the light coming out of a prism. Although the peak of Sun's radiation is in the visible, however about half the energy reaching us from the Sun is infrared. Infrared Astronomy satellites make use of this to survey the sky as well as of earth.

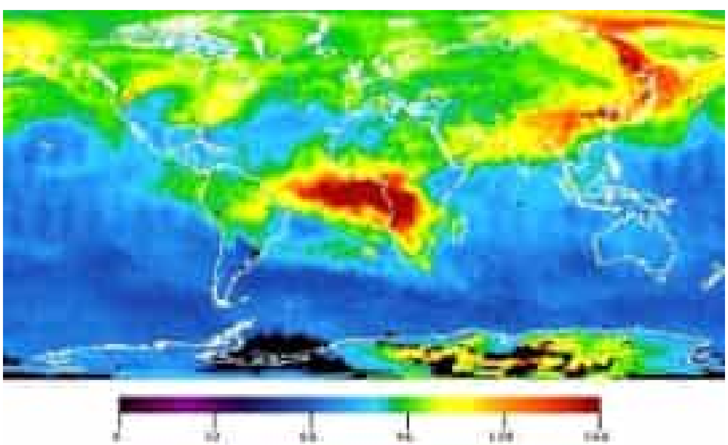
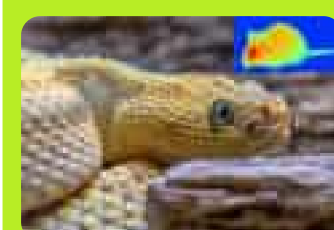


Fig: 13.6
An image of Earth in infrared wavelengths shows relative temperatures in **Fahrenheit** around the world.

DO YOU KNOW?

Rattlesnakes and other pit vipers have infrared detectors on their snouts containing protein channels that are activated by heat from the bodies of their prey. This helps them to detect warm blooded prey. At night, the pit organs allow snakes to 'see' an image of their predator or prey like an infrared camera.



Ultraviolet:

Ultraviolet radiation has higher frequencies than visible light, with wavelengths ranging from 380 nm to 10 nm. The sun is the primary source of UV radiation. UV radiation affects human skin by causing tanning, sunburn, and melanoma. Water vapor transmits much of the Sun's UV radiation, leading to tanning and sunburn even on overcast days. Glass absorbs most UV, preventing tanning through windows. Fluorescent materials can absorb UV and emit visible light, as seen in fluorescent lights.

Fig: 13.7
A sunburn victim due to UV radiations

X – Rays:

X-rays are high-frequency, short-wavelength electromagnetic radiations discovered by Wilhelm Conrad Rontgen in 1895. They have frequencies from approximately 2.4×10^{16} Hz to 5×10^{19} Hz. In medicine and dentistry, X-rays with wavelengths of 10 pm to 60 pm are commonly used. Conventional X-rays use film to record the amount of X-ray radiation passing through tissues..

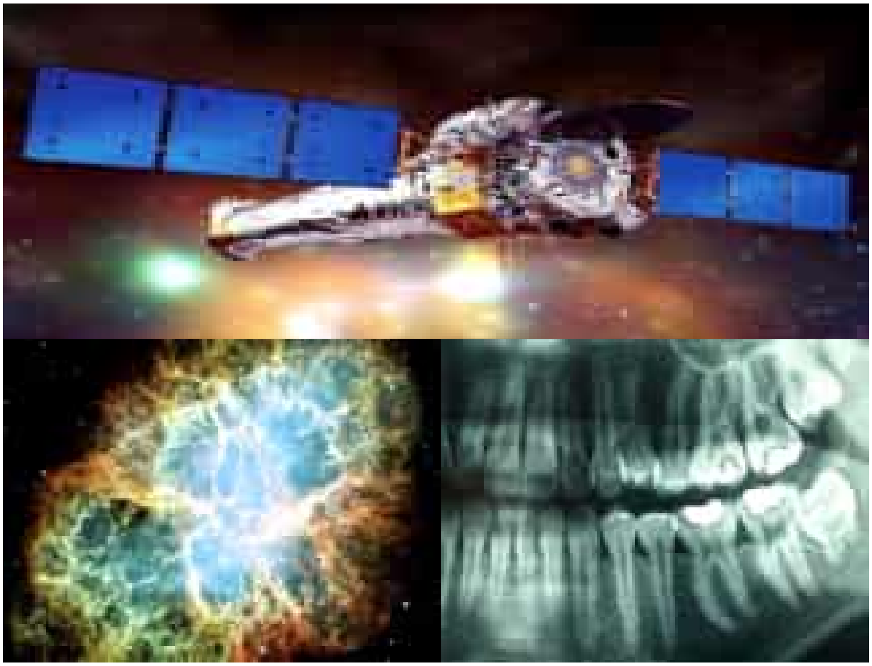


Fig: 13.8 (a, b)
Orbiting X-ray Telescope and X-ray of Teeth
Orbiting X-ray telescopes have given us an exciting new picture of the Universe. An optical image of the Crab Nebula from a X-Ray telescope.

Gamma – Rays:

Gamma rays are high-frequency, short-wavelength electromagnetic radiations emitted during atomic nucleus transitions. They originate from pulsars, neutron stars, black holes, and supernova explosions. Fortunately, the Earth's atmosphere absorbs gamma rays, requiring high-altitude sensors for detection. Gamma-ray bursts occur daily from deep space, lasting from a fraction of a second to a few minutes. These bursts release more energy in seconds than the sun does in its entire lifetime.

DO YOU KNOW?

Each of the colors on the sails of these boats corresponds to a different wavelength in the visible region of the spectrum of electromagnetic waves.

13.1.2 Visible Light and Continuous Spectrum:

When we speak of light **(visible light)**, we mean the small fraction of electromagnetic continuous spectrum that can be seen by unaided human eye. At an average the range of frequencies are from 400 THz to 750 THz (T = tera = 10^{12}) corresponding to wavelength in vacuum of 750 nm to 400 nm.

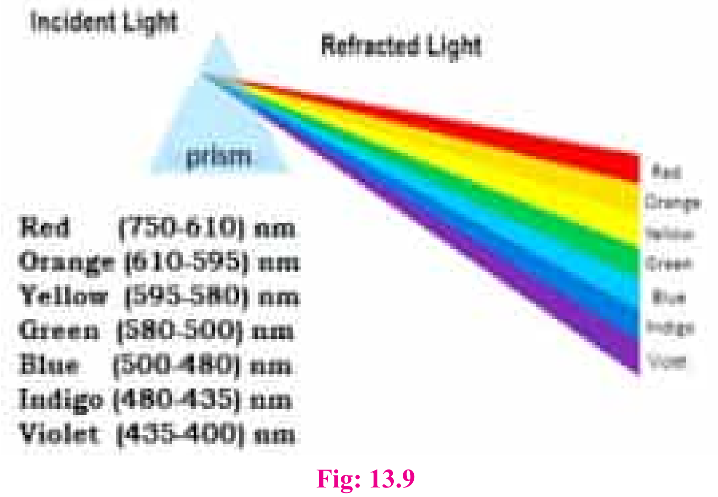
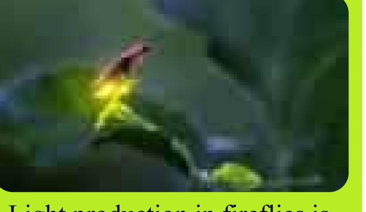


Fig: 13.9
Dispersion of white light through a prism.

DO YOU KNOW?



Light production in fireflies is due to a type of chemical reaction, called bioluminescence. This process occurs in specialized light-emitting organs, usually on a firefly's lower abdomen. The enzyme luciferase acts on the luciferin, in the presence of magnesium ions, ATP **(adenosine triphosphate)**, and oxygen to produce light.

White light is a mixture of all the wavelengths in the visible range. White light can be dispersed through a prism into different colors.

Red has the lowest frequency (longest wavelength) and violet has the higher frequency (shortest wavelength). Light bulbs, fire, the Sun, and fireflies are some sources of visible light.

Self-Assessment Questions:

1. Name the type of electromagnetic radiations corresponding to each of the given wavelengths,
   a) 500 nm b) 10000 Km c) 1 cm
2. State two main properties of electromagnetic waves.

13.2 Wave fronts:

Although electromagnetic waves are different from mechanical waves (sound waves, water waves) but still these waves share many properties in common with all other waves. We can use other waves to understand the behavior of electromagnetic waves. A pebble dropped into a pond starts a disturbance that propagates radially outward in all directions on the surface of water (Fig.13.10).

A *wave front* is a set of all points of equal phase. Each of circular wave crests in figure.13.18 can be considered as wave front.

Fig.13.10
Spherical waves produce in water

A **ray** points in the direction of propagation of a wave and is perpendicular to the wave fronts. For a circular wave, the rays are radii pointing outward from the point of origin of the wave. For a linear wave, the rays are a set of lines parallel to each other, perpendicular to the wavefronts. Like water waves, light waves which propagate in three dimensions can have wavefronts that are circles or lines.

If a point source S emits light equally in all directions, the wavefronts are *spherical*
(fig.13.11a) and light rays point radially outward. Far away from such a point source, the rays are nearly parallel to each other and the wavefronts are nearly ***planar*** (fig.13.11b). So the waves can be considered as plane wave.

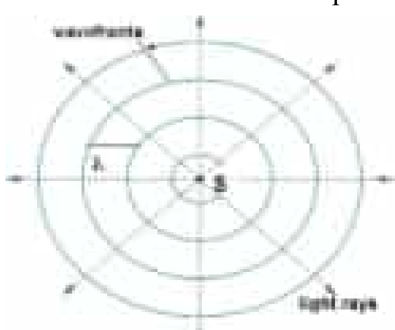


Fig: 13.11
Circular wave fronts

Fig: 13.11 (a)
Spherical wave fronts

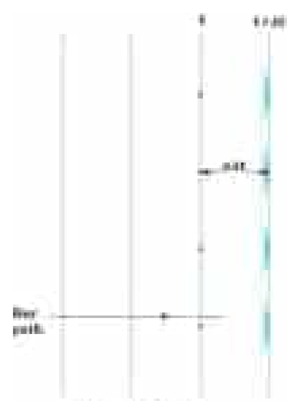


Fig: 13.11 (b)
Plane wave fronts

13.3 Huygens's Principle:

Long before the time development of electromagnetic theory, the Dutch physicist Christian Huygens (1629-1695) developed a geometrical method for explaining the behavior of light when it travels through a medium, when it passes from one medium to another, or when it travels into reflected back from a plan surface.

Huygens's Principle states as,

i) At some time t, consider every point on a wave front as a source of a new spherical wave. These wavelets move in forward direction from the source as the same speed as the original speed of wave. Fig. 13.11a.

ii) At a later time $t + \Delta t$, each wave has a radius (distance) $c\Delta t$, where c is the speed of wave (light). The new position of the wave front after time $t+\Delta t$ can be found by drawing a plane tangential to all the secondary wavelets**.**

Huygens's principle has provided a logical reasoning to understand the phenomena of interference and diffraction of light.

Self-Assessment Questions:

1. Describe a wavefront. How plane wavefronts are emerged out of spherical wave fronts?
2. What is meant by Huygens's Principle?

13.4 Interference of Light:

Interference of light waves, like interference of sound waves, is a manifestation of the principle of superposition which says that

The net wave amplitude (intensity) at any point due to two or more waves, is the sum of the amplitudes of each individual wave.

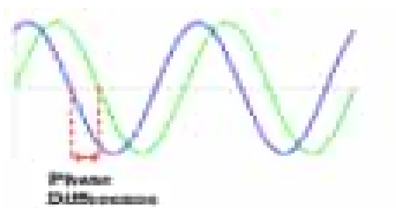


Fig: 13.12

13.4.1 Conditions for interference of light:

Coherent and Incoherent Sources:

Although any number of waves can in principle interfere, but in order to keep the case simple we consider here the interference of only two waves. To produce observable interference effect, it is necessary to have

- Two **coherent** sources. i.e., they must have the same frequency.
- The two waves must be **monochromatic** i.e, they must have the same color (wavelength).
- Be always in phase with each other or have a constant phase difference.

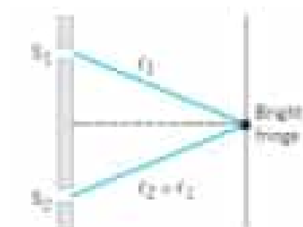


Fig: 13.12 (a)

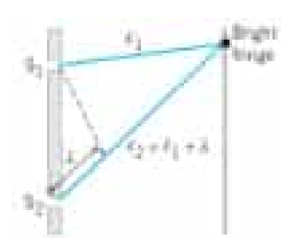


Fig: 13.12 (b)

- For Constructive Interference (Bright Fringes) the path difference must be
  Phase difference = 2mπ rad
  Path difference ΔS = mλ
  (m = 0, ±1, ±2, ±3…..) Fig. (13.13 a,b)

- For Destructive Interference (Dark Fringes) the phase difference must be
  Phase difference $= (m+\frac{1}{2})\,2\pi$ **rad**
  Path difference $\Delta S = (m+\frac{1}{2})\,\lambda$
  (m = 0, ±1, ±2, ±3,…..) Fig. (13.13 c)

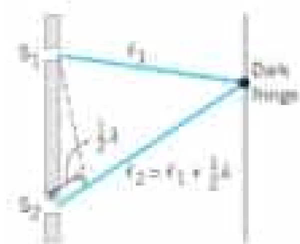


Fig: 13.13 (c)
Phase difference and path difference between two coherent sources

13.4.2 Young's Double Slit Experiment:

Thomas Young performed his double slit experiment not only demonstrated the wave nature of light, but also allowed the first measurement of wavelength of light. Figure.13.14 shows the setup for Young's experiment.

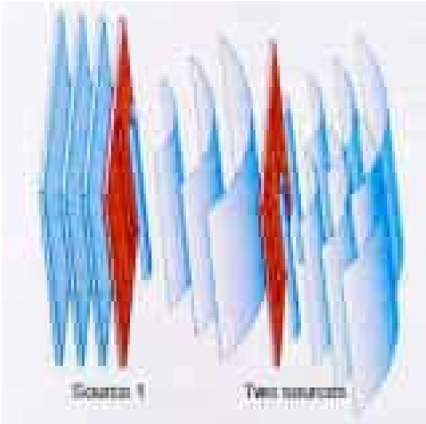


Fig: 13.14
Thomas Young's technique for obtaining two coherent sources from one source.

The Principle:

The interference of light waves in Young's experiment can be explained using Huygens's principle.

The Experiment:

Monochromatic light of wavelength "λ" illuminates a narrow slit of width comparable to wavelength of light λ. The light waves that pass through the slit C spread out as spherical wavefronts. The single slit C acts as a single coherent source to illuminate two other slits A and B equidistant from slit C. The two slits are separated by a distance d from their centers. These two slits then act as source of coherent light for interference. Spherical waves spread out of both slits and interfere on a screen at a distance L from the slits. The light from the two narrow slits A and B start out in phase, but travel different paths to reach the screen. We expect constructive interference (red maxima) at O the centre of the screen as the waves travel the same distance and so are in phase and having zero path difference.

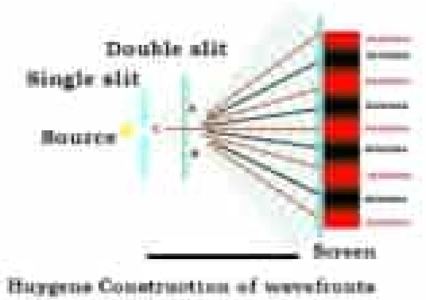


Fig: 13.15 A double slit interference pattern from two coherent sources using Huygens's principle.

13.4.3 Analytical Treatment of Interference:

To find where constructive or destructive interference occurs, we need to calculate the path difference ΔS. Figure.13.16 shows that two rays from two narrow slits A and B separated by a distance d arriving at an arbitrary point P on the screen. The screen is at a distance L from the slits such that L >> d. it is clear from the figure that the waves travelling from the slit B to point P covers distance ΔS greater than the waves from slit A.

The path difference ΔS can be calculated by considering the right angle triangle ABD.

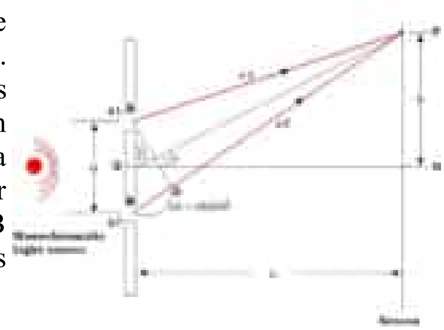


Fig: 13.16 A geometrical illustration of Young's double slit

$$\sin\theta = \frac{BD}{AB} = \frac{\Delta S}{d}$$

$$\Delta S = d\sin\theta \quad \text{......(13.1)}$$

If the path difference between two waves arriving at point P on screen is integral multiple of **λ** than constructive interference is observed

Therefore : $m\lambda = d\sin\theta$ ...... (13.2)

Where: m = 0, ±1, ±2, ±3,.....

For the central point O, we have m = 0 called zeroth order maxima and bright fringe is observed. The higher order maxima (bright fringes) are symmetrically located on right and left of the point O. Conversely, if the path difference between the two waves reaching at point P is half integral multiple of wavelength λ, then a dark fringe is obtained.

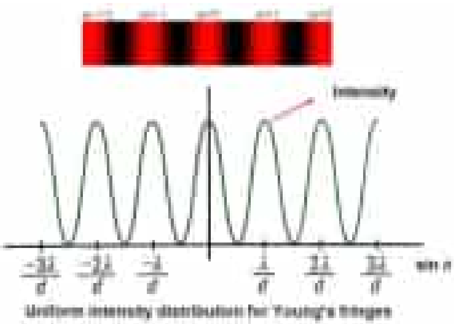


Fig: 13.17
Uniform intensity pattern of fringes. Red (constructive interference) black (destructive interference).

Therefore $(m+\frac{1}{2})\lambda = d\sin\theta$

where: m = 0, ±1, ±2, ±3,..... (13.3)

Position of Fringes on the Screen:

The position of bright and dark fringes can be calculated by determining an expression for Y = OP on the screen (Fig. 13.17). As mentioned earlier that L the distance from the slits to screen is much larger than the slit spacing d. In actual practices L is of the order of 1m compared to slits spacing which is of the order of fractions of millimeters. Since θ is very small, hence Y is much smaller than L and PQ ≈ QO. Under this condition the right angle triangles ABD and PQO are similar,

Therefore: $\sin\theta \approx \tan\theta$

In Fig.13.17 consider the right angle triangle PQO

$\sin\theta \approx \tan\theta = \frac{Y}{L}$ ...... (13.4)

Comparing the equation (13.4) with the condition of constructive interference from equation (13.2), we can locate the positions of bright fringes on the screen

$$m\lambda = d\frac{Y}{L} \quad \text{or} \quad Y = \frac{\lambda L}{d} m \quad \ldots\ldots (13.5)$$

For the m^{th} bright fringe replace Y by Y_m. Therefore equation (13.5) can now be written as,
Position of m^{th} Bright Fringe

$$\mathbf{Y_m = \frac{L}{d} m \lambda} \quad \ldots\ldots (13.6)$$

Similarly for the position of dark fringes, equation (13.4) is compared with the condition of destructive interference from equation (13.3).
Position of m^{th} Dark Fringe

$$\mathbf{Y_m = \frac{L}{d} (m + \frac{1}{2}) \lambda} \quad \ldots\ldots (13.7)$$

Fringe Spacing:

Fringe spacing Δx is the distance between two consecutive bright or dark fringes. Using equation (13.6) or (13.7) the fringe spacing of two bright or dark fringes can be calculated.
For first and second bright fringe;

$$\Delta x = Y_2 - Y_1 = 2(\frac{L}{d}\lambda) - 1(\frac{L}{d}\lambda)$$

Fringe spacing between two consecutive bright fringes

$$\mathbf{\Delta x = \frac{L}{d}\lambda} \quad \ldots\ldots (13.8)$$

Worked Example 13.1

In a Young's double slit experiment a beam of light consisting of two wavelengths, 6500 A° and 5200 A°, is used to obtain interference fringes on a screen 120 cm away from two slits 2 mm apart. (i) Find the distance of the third bright fringe on the screen from the central maxima for the wavelength 6500 A° (ii) What is the least distance from the central maximum where the bright fringes due to both the wavelengths coincide.

Solution:

Step 1: Write the known quantities and point out quantities to be found.

Distance of the screen from slits; $L = 120\text{ cm} = 120 \times 10^{-2}\text{ m}$

Slits spacing; $d = 2\text{ mm} = 2 \times 10^{-3}\text{ m}$

Wavelength of light; $\lambda_1 = 6500 A^o = 6500 \times 10^{-10}\text{ m}$

Wavelength of light; $\lambda_2 = 5200 A^o = 5200 \times 10^{-10}\text{ m}$

Required:

a) Distance of third bright fringe from central maxima for 6500 A°; $\Delta x = ?$

b) Least distance from the central maximum where the bright fringes due to both the wavelengths coincide; $x = ?$

Step 2: Write down the formula and rearrange if necessary

$$Y_m = \frac{L}{d} m\lambda; \text{ for } m = 3$$

$$Y_3 = \frac{L}{d} 3\lambda$$

$$\Delta x = Y_3 - Y_0 = \frac{L}{d} 3\lambda$$

Step 3: Put the values in the formula and calculate.

a) $\Delta x = \frac{120 \times 10^{-2}}{2 \times 10^{-3}} \times 3 \times 6500 \times 10^{-10}$

$\Delta x = 1.17 \times 10^{-3}$ m = 117 mm Answer

b)

Suppose the mth bright fringe due to wavelength 6500 A^o coincides with the nth bright fringe due to wavelength 5200 A^o then,

$$Y_m = Y_n \rightarrow \frac{L}{d} m\,\lambda_1 = \frac{L}{d} n\,\lambda_2 \quad \rightarrow m\,\lambda_1 = n\,\lambda_2$$

$$\frac{m}{n} = \frac{5200\ A^o}{6500\ A^o} = \frac{4}{5}$$

Hence the minimum values of m and n for the two bright fringes coincide are m = 4 and n = 5

Therefore; $\mathbf{x = \frac{L}{d} m\,\lambda_1} \quad \rightarrow \quad x = \frac{120 \times 10^{-2}}{2 \times 10^{-3}} \times 4 \times 6500 \times 10^{-10}$

$x = 1.56 \times 10^{-3}$ m = 1.56 mm

Similarly; $\mathbf{x = \frac{L}{d} n\,\lambda_2} = \frac{120 \times 10^{-2}}{2 \times 10^{-3}} \times 5 \times 5200 \times 10^{-10}$

$x = 1.56 \times 10^{-3}$ m = 1.56 mm

13.4.4 Interference in Thin Films:

In search of the true mechanism of formation of colors through interference in thin films, we consider a thin film of thickness **t** and index of refraction **n**. From (Fig.13.19) the ray OA assume to be the part of monochromatic source of light of wavelength **λ** incident normally on the film. The ray OA is partly reflected as ray AB from the air-glass interface and partly transmitted through the film as ray AC. At point C at the glass-air boundary another partial reflection and refraction occur.

Fig: 13.18
The rainbow – like colors seen in soap bubbles and oil slicks are produced by interference

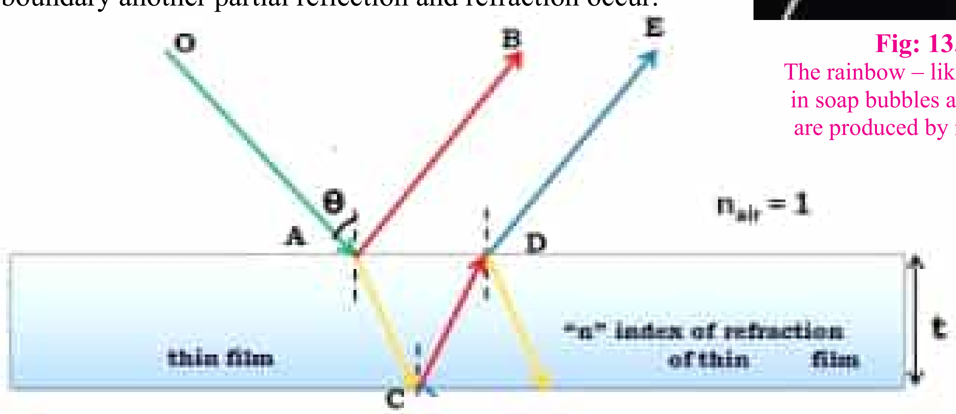


Fig: 13.19
Multiple reflection (red) and refraction (blue) of rays through the top and bottom interfaces of thin film.

Reflected light (CD) emerges from the film as a refracted ray (DE). The interference between these rays (AB and DE) leads to constructive or destructive interference, determined by their phase difference. Reflection occurs when a wave encounters a medium with a higher refractive index, resulting in a completely inverted reflected wave with a phase shift of 180 degrees as shown in figure 13.19. The refracted ray experiences no phase change. In the case of transmission from a highe r to a lower refractive index medium, no phase change occurs. The reflected ray (AB) undergoes a phase reversal, while the refracted ray (DE) passes through without any phase change. Consequently, the 180-degree phase difference between rays AB and DE causes them to interfere constructively or destructively.

Phase Reversal due to Reflection

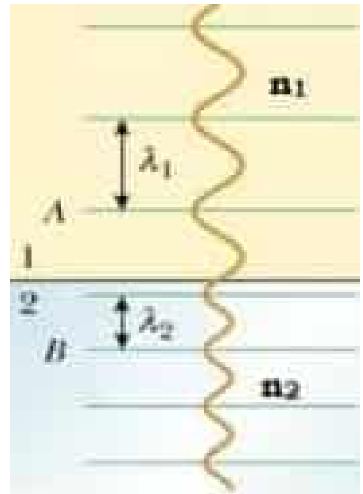


Fig.13.20
Change of wavelength between incident and refracted wave due to different indices of refraction.

Path Difference for a Normal Incidence of light:

In figure 13.19 the monochromatic light of wavelength λ incident perpendicularly on a thin film of thickness t. The refracted ray from A has to travel twice in the film before transmitting out of the film at D. Thus the path difference between AB and DE will be:

Path Difference = 2t ...... (13.9)

$2t = (m+1/2)\,\lambda$ = constructive

$2t = m\,\lambda$ = destructive

Wavelength Shift due to Refraction:

In figure 13.20, Interference through thin films involves two media of different indices of refraction. The wave (AB) reflected through the interface has wavelength λ, while the wave (DE) transmitted through the medium of refractive index n having slightly different wavelength, mark as λ_n.

Given as $\lambda_n = \dfrac{\lambda}{n}$ ...... (13.10)

By virtue of the phase reversal between the ray AB and DE the conditions for constructive and destructive interference are reversed compared to Young's double slit experiment

DO YOU KNOW?

The shimmering blue color of Morpho butterflies is a striking example of interference in thin film. The tree-like structures on their wings made of transparent material reflect light from a series of steps, creating different path lengths for interfering rays and angles of view, resulting in the beautiful sparkling blue color.

Worked Example 13.2

A soap bubble in air is of thickness 320 nm. If it is illuminated with white light at near normal incidence, what color will appear to be in reflected light?
(Refractive index of soap bubble n= 1.50).

Solution:

Step 1: Write the known quantities and point out the quantities to be found.

Thickness of film, $t = 320$ nm
Refractive index, $n = 1.50$
Wavelength $\lambda = ?$
Colors $= ?$

Step 2: Write the formula and rearrange if necessary.

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

$$\lambda = \frac{2nt}{m+\frac{1}{2}}$$

$$m = 0, 1, 2, 3, \ldots\ldots.$$

Step 3: Put the values in the formula and calculate.

$$\lambda = \{\frac{2nt}{m+\frac{1}{2}}\} \text{ nm}$$

for m = 0,

$$\lambda = \{\frac{2 \text{ x } 1.50 \text{ x } 320}{0+\frac{1}{2}}\} \text{ nm} = \{\frac{2 \text{ x } 1.50 \text{ x } 320}{0+\frac{1}{2}}\} \text{ nm}$$

λ =1920 nm , similarly
for m = 1, λ = 640 nm
for m = 2, λ = 384 nm
for m = 3, λ = 274 nm

We note that only the maxima, for m=1 and m=2 lies in the visible region and the colors for 640 nm 384 nm are nearly red and violet.

13.4.5 Newton's Rings:

If a plano convex lens of radius of curvature R is placed on a flat glass plate. The air gap between the two surfaces will increase from zero at the point of contact of lens and plate to a thickness equal to t, as we move out from the point of contact of lens and flat glass plate to the edge of the lens (Fig.13.21a). If the setup is illuminated by monochromatic light of wavelength λ incident normally on the plano convex lens. Due to the curvature of lens the air film between the lens and glass plate is also spherical.

The interference pattern we obtain is in the form of alternate dark and bright concentric rings called Newton's rings.

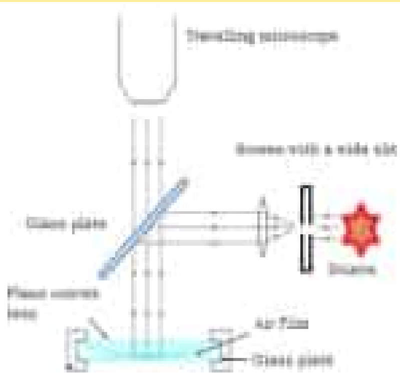


Fig: 13.21 (a)
Experimental set up to observe Newton's rings.

The center of the rings is the point where air film thickness is zero. Thomas Young figured out that the central ring of the interference pattern is a dark spot due to zero path difference and phase reversal of 180° between the rays reflected from the upper and lower surfaces.

Using the geometrical theorem that the product of intercepts of intersecting chords is equal, from figure.13.21 b, we have

$$r^2 = (AB) \times (BC) \qquad \ldots\ldots (13.11)$$

Here, OA = (2R-t) and BC = t

Therefore, equation (13.13) can now be written as,

$$r^2 = (2R-t) \times (t)$$

$$r^2 = 2Rt - t^2$$

Since t is much smaller than the R, therefore neglecting t^2, we get

$$r^2 = 2Rt \qquad \ldots\ldots (13.12)$$

$$\mathbf{r = \sqrt{2Rt}} \qquad \ldots\ldots (13.13)$$

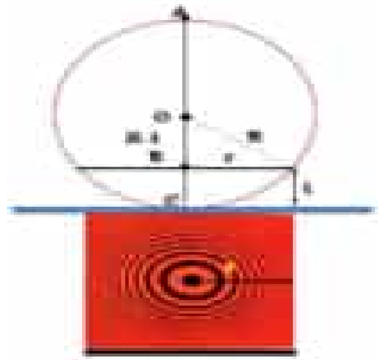


Fig: 13.21 (b)
Experimental set up to observe Newton's rings.

Since the condition for bright ring in thin films is give by equation

$$2nt = (m + \tfrac{1}{2})\lambda \quad \text{For air } n = 1$$

Therefore, $2t = (m + \tfrac{1}{2})\lambda$

Hence for first bright ring m =0 $\qquad 2t_1 = \tfrac{1}{2}\lambda$

For second bright ring, m=1 We write, $\qquad 2t_2 = \tfrac{3}{2}\lambda$

Similarly for N^{th} bright ring N = m+1, therefore m = N – 1

$$2t_N = (N - \tfrac{1}{2})\lambda$$

Substituting the value of $2t_N$ in equation 13.13, we get the radius of N^{th} bright ring.

$$\mathbf{r = \sqrt{R\left(N - \tfrac{1}{2}\right)\lambda\lambda}} \qquad \ldots\ldots (13.14)$$

Similarly the condition for destructive interference in thin films is give by equation 13.14 and hence the radius of m^{th} dark ring.

$$\mathbf{r = \sqrt{m\lambda R}} \qquad \ldots\ldots (13.15)$$

Worked Example 13.3

In a Newton's ring experiment the diameter of the 16^{th} bright ring was found to be 0.653 cm and that of 5^{th} bright ring is 0.346 cm. if the radius of curvature of the lens is 100 cm, find the wavelength of light.

Solution:

Step 1: Write the known quantities and point out the quantities to be found.

Diameter of Newton's 16^{th} bright ring

$(d_{16}) = 0.653\ cm = 0.653\times10^{-2}\ m$

Radius of Newton's 16^{th} bright ring

$r_{16}^{b} = 3.265\times10^{-3}\ m$

Diameter of Newton's 5^{th} dark ring

$(d_5) = 0.346$ cm $= 0.346 \times 10^{-2}$ m

Radius of Newton's 5^{th} dark ring

$r_5^d = 1.73\times10^{-3}$ m

Radius of curvature of lens, R = 100 cm = 1 m

Wave length of light (λ) =?

Step 2: Write the formula and rearrange if necessary.

From equation 13.17 and 3.18,

$r_b^2 = R(N-\frac{1}{2})\lambda$ and $r_d^2 = m\lambda R$

$r_b^2 - r_d^2 = R(N-\frac{1}{2})\lambda - m\lambda R$

$$\lambda = \frac{r_b^2 - r_d^2}{(N-\frac{1}{2}-m)}$$

Step 3: Put the values in the formula and calculate.

$$\lambda = \frac{(3.265\times10^{-3})^2 - (1.73\times10^{-3})^2}{(16 - \frac{1}{2} - 5)}$$

$\lambda = \mathbf{7302 \times 10^{-10}\ m}$

DO YOU KNOW?

It was made and used in the United States by Albert Michelson (1852-1931) in 1887.

The Michelson Interferometer:

Michelson Interferometer is an important device of second class having very high sensitivity and accuracy to measure the wavelength of light.

Experimental Setup:

The main optical parts of Michelson interferometer shown in figure.13.22 consists of two highly polished plane mirrors M_1 and M_2 and two parallel plane plate of glasses, A which is half silvered used as beam splitter inclined at an angle of 45^o relative to the path of incident light and B a plain glass plate with same angle and thickness used as compensator plate. Monochromatic light of wavelength λ from an extended source S probably obtained through a sodium flame or mercury arc is divided by beam splitter into (i) a reflected beam and (ii) a transmitted or refracted beam of equal intensity. The two beams emerging from beam splitter A travel perpendicular paths to mirrors M_1 and M_2 as reflected and refracted beams respectively, where they are directed back to be recombined at the beam splitter. The beam from mirror M_1 is partly reflected at A, but part of that

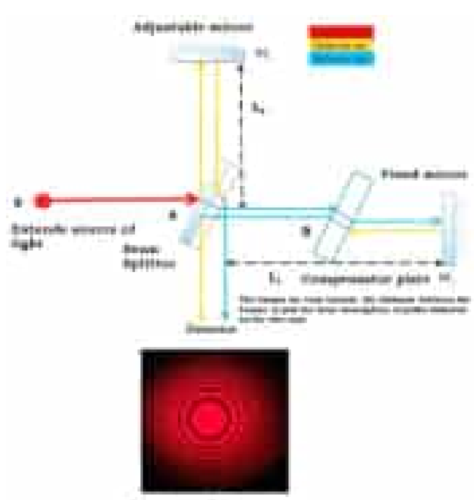


Fig: 13.22 The Michelson Interferometer, showing the path of light and interference pattern.

beam refracts through A and goes to the detector. The beam from mirror M_2 partially refracts through A and lost, but part of that beam is also reflected towards the detector. The purpose of compensator plate B is to ensure the same path length for the two rays. Since the transmitted ray through A towards M_1 pass through plate B twice (Fig. 13.22) and thus the path length across in glass by the light in this arm is identical to that travelled in the glass in the other arm. If fringes are produced with monochromatic light, presence of B is not essential. But it produces a serious problem when white light is used because white light has broad spectrum. Inclusion of compensator negates the effect of dispersion. Thus, the two waves will interfere constructively or destructively as per following the conditions of path difference. Path difference between the two rays can be varied by moving M_2.

DO YOU KNOW?

The Michelson Interferometer

Michelson interferometer is a versatile optical instrument used in various scientific and engineering applications to measure small displacements, wavelengths of light, and refractive indices, among other parameters.

Nature of Fringes:

If M_1 and M_2 are equidistant from the beam splitter A the field of view will be perfectly dark. If the mirror M_1 is kept fixed and the mirror M_2 is moved a distance of $\lambda/4$ with the help of the fine movement screw the path difference changes to $\lambda/2$ and the number of fringes that cross the field of view is counted. The wavelength is determined from the fact that for one fringe shift, the mirror moves through a distance equal to half the wavelength. If d is the distance moved by M_2 and m the number of fringes shifted, then,

$$x = m\frac{\lambda}{2}$$

Self-Assessment Questions:

1. Describe the conditions for constructive and destructive interference.
2. What causes the change of interference conditions in thin films?
3. Why compensator plate is important in Michelson interferometer?

13.5 Diffraction of Light:

Suppose a plane wave approaches an obstacle. Using geometric optics, we would expect the rays not blocked by the obstacle to continue straight ahead, forming a sharp, well-defined shadow on a screen beyond the obstacle. If the obstacle is large compared to (Fig.13.23) the wavelength of light, then geometric optics gives a good approximation to what actually happens and we will observe that,

(i) Geometrical shadow of the obstacle is uniformly dark because no light is reaching within the geometry of object.

(ii) The surrounding of geometrical shadow is uniformly illuminated.

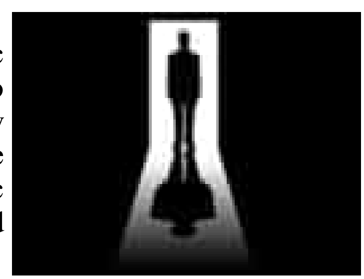


Fig: 13.23
The geometrical shadow of an extended obstacle.

13.5.1 Diffraction of light is an interference phenomenon:

If the obstacle is not large compared to the wavelength, we must return to Huygens's principle to show how a wave bends within the geometry of obstacle. In (Fig. 13.24 a), a wavefront just reaches a barrier with an opening in it. Every point on that wavefront acts as a source of spherical wavelets. Points on the wavefront that are behind the barrier have their wavelets absorbed or reflected. Therefore, the propagation of the wave is determined by the wavelets generated by the unobstructed part of the wavefront.

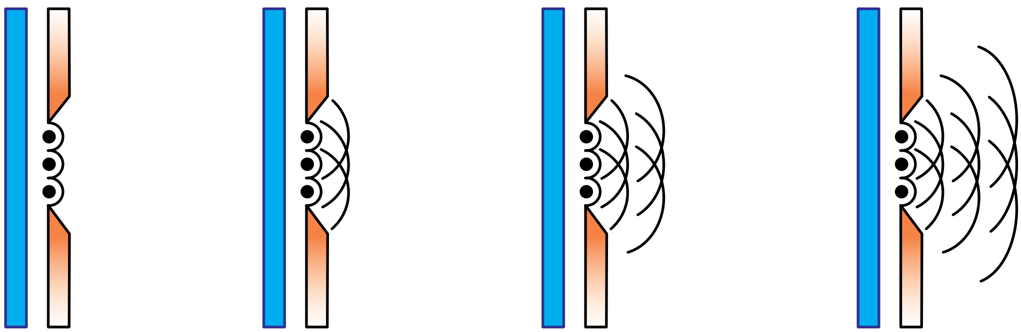


Fig: 13.24 (a) A plane wave reaches the barrier. Points along the wavefront act as sources of spherical wavelets. (b,to d) At later times, the initial wavelets are propagating outward as new ones from the wavefront bends around the edges of the barrier.

The Huygens's construction in (Fig. 13.24 b-d) shows that, the wave bends around the edges of the barrier, something that would not be expected in geometric optics. Fig.13.25 shows the shadow of a razor blade illuminated by a monochromatic source of light. The bright and dark fringes are observed near the edges of geometrical shadow of the blade. This confirms the novel idea of

"Bending of light around obstacles and spreading of light waves into the geometrical shadow of an obstacle". This phenomenon is called Diffraction of Light"

$$\frac{GmM_e}{r_1}$$

Fig: 13.25 Difference pattern formed when a razor blade is illuminated with a monochromatic light

13.5.2 Wave nature of Light through Diffraction:

In general, Interference refers to situations where waves from a small number of sources, travel different paths and arrive at a point with different phases. Diffraction is the bending of waves when they travel around obstacles or through apertures. According to Huygens's principle, *every point on a wave front is a source of secondary wavelets*. Thus the superposition (interference) of light from all these point sources is called diffraction of light, provided the conditions of phase coherence and path difference are fulfilled.

DO YOU KNOW?

Discovered by Francesco Maria Grimaldi (1618-1663). The distinction between interference and diffraction is not always straightforward.

Interference	*Diffraction*
Interference fringes are obtained due to the superposition of light coming from two different wavefronts originating from two coherent sources.	Diffraction fringes are obtained due to the superposition of light coming from different parts of same wavefront.
The width of interference fringes is generally same.	The width of interference fringes is not same.
The intensity of all the bright fringes is same.	The intensity of all the bright fringes is not same. It is maximum for central fringe and decreases sharply for first, second fringes and so on.

13.5.3 Diffraction by a Single Slit:

In a more detailed treatment of diffraction, we must consider the phases of all the Huygens wavelets and apply the principle of superposition. (Fig.13.26) shows the diffraction pattern formed by light passing through a single slit. A wide central maximum contains most of the light energy. (Central maximum is the usual way to refer to the entire bright band in the center of the pattern, although the actual maximum is just at $\theta = 0$. A more accurate name is central bright fringe.) The intensity is brightest right at the center and falls off gradually until the first minimum on either side, where the screen is dark. According to Huygens's principle, the diffraction of the light is explained by considering every point along the slit as a source of wavelets (Fig. 13.27). The light intensity at any point beyond the slit is the superposition of these wavelets. The wavelets start out in phase, but travel different distances to reach at a given point on the screen. The structure in the diffraction pattern is a result of the interference of the wavelets. This is a much more complicated interference problem than the interference we have encountered in Young's experiment because an infinite number of waves interfere, and every point along the slit is a source of wavelets. Figure.13.27 shows two rays that represent the propagation of two wavelets: ray 1from the top edge of the slit and ray 2 from exactly half way down. The rays are off at the same angle θ to reach the same point on a distant screen. The lower one travels an extra distance ($\frac{1}{2}$ a $\sin\theta$) to reach the screen. If this extra distance is equal to $\frac{1}{2}\lambda$ then these two wavelets interfere destructively. Now let's look at two other wavelets, shifted down distance ΔS so that they are still separated by half the slit width ($\frac{1}{2}$ a). The path difference between these two rays must be $\frac{1}{2}\lambda$ so

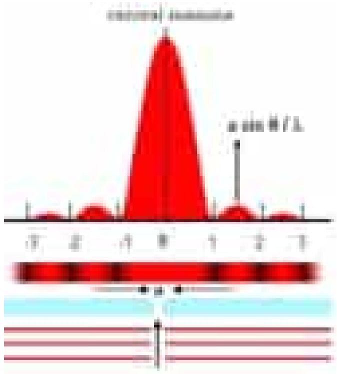


Fig: 13.26 Single slit diffraction. The intensity of light is gradually decreasing from right and left of central maxima

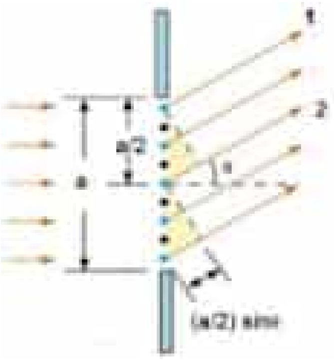


Fig: 13.27
Every point along a slit serves as a source of Huygens wavelets. Ray 2 travels a greater distance to reach the screen than the ray 1.

that these two interfere destructively. All the wavelets can be paired off; since each pair interferes destructively, no light reaches the screen at that angle. Therefore, the first diffraction minimum occurs where;

$$\frac{1}{2}\text{a}\sin\theta = \frac{1}{2}\lambda$$

$$\text{a}\sin\theta = \lambda$$

The other minima are found in a similar way, by pairing off wavelets separated by a distance of $\frac{1}{4}$a, $\frac{1}{6}$a, $\frac{1}{8}$a, ………$\frac{1}{2m}$a, where, m is any integer other than zero. The diffraction minima are given by

$$\frac{1}{2m}\text{a}\sin\theta = \frac{1}{2}\lambda \quad (m=\pm1, \pm2, \pm3\ldots.)$$

$$\text{a}\sin\theta = m\lambda \qquad \ldots\ldots (13.16)$$

What happens if the slit is made narrower? As a (slit width) gets smaller, the angle θ for the minima get larger-the diffraction pattern spreads out. If the slit is made wider, then the diffraction pattern shrinks as the angles for the minima get smaller. The angles at which the lateral maxima occur are much harder to find than the angles of the minima: there is no comparable simplification we can use. The central maximum is at θ = 0, since the wavelets all travel the same distance to the screen and arrive in phase.

13.5.4 Diffraction Grating:

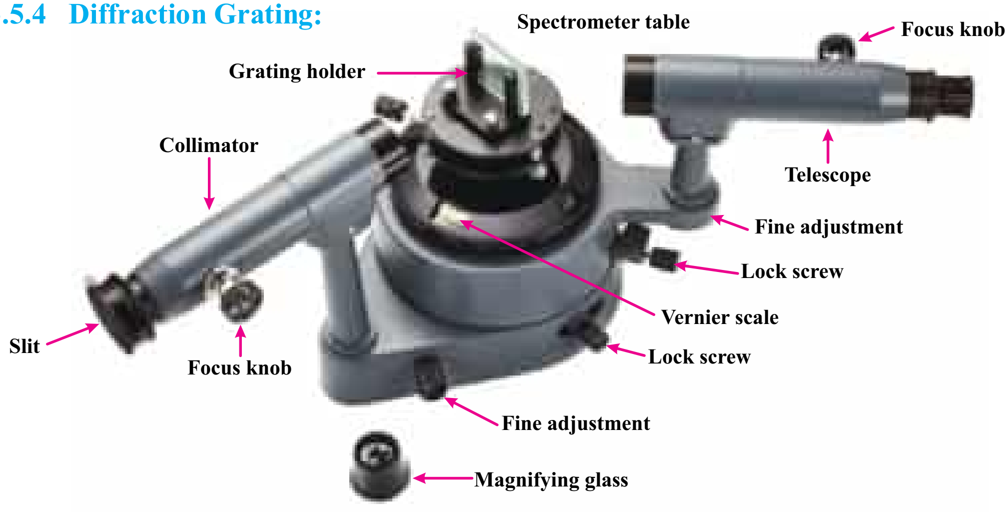


Figure.13.28. A Diffracting spectroscope

Suppose that parallel light is incident on two more parallel close slits, and the light passing through the slits is received by a telescope focused at infinity (Fig.13.28). Since each slit produces a similar diffraction effect in the same direction, the observed diffraction pattern will have an intensity variation identical to that of a single slit. This time however, the pattern is crossed by a number of interference bands, which are due to interference between slits. As more parallel equidistant slits are introduced, the intensity and sharpness of the principal maxima increase and those of the subsidiary maxima decrease. Any arrangement which is equivalent in its action to a large number of parallel evenly spaced slits of equal width is called diffraction grating. Diffraction grating is a very useful and powerful instrument to study and explore the nature of light.

***A diffraction grating is a large number of close parallel equidistant slits, ruled on glass or metal surface*;**

If the width of a slit or clear space is a and the thickness of a ruled opaque line is b, the spacing d of the slits (Fig. 13.29) is (a + b). Where d is called grating element. If N is the number of slits per unit length, lets for example per cm. Then,

$$N = \frac{1}{d} \qquad \text{......} \ (13.17)$$

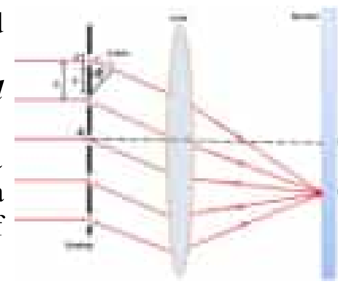


Fig: 13.29 Geometrical illustration of a diffraction grating.

Figure 13.29 shows monochromatic light rays travelling from the slits of the grating to a distant screen. The light from all the evenly spaced slits are collected at a point P on the screen by means of a converging lens. If the path difference d sinθ, between the light waves from any adjacent pair of slits arriving at P is integral multiple of wavelength λ, they will interfere constructively.

A diffraction grating with 600 lines per mm.

Maxima for grating, $d \sin\theta = n\lambda$ **......** (13.18)

($n = 0, \pm 1, \pm 2, \pm 3, \ldots$)

For the central maxima there is no path difference, so it is called "Zeroth" order maxima. For the subsequent maxima, first, second orders and so on the path difference should be,

$d\sin\theta = \lambda$ first order maxima

$d\sin\theta = 2\lambda$ second order maxima

For two slits, there is a gradual change in the intensity from maximum to minimum and back to maximum, by contrast, for a grating with a large number of slits, the maxima are narrow and the intensity everywhere else is negligibly small as shown in figure. 13.30.

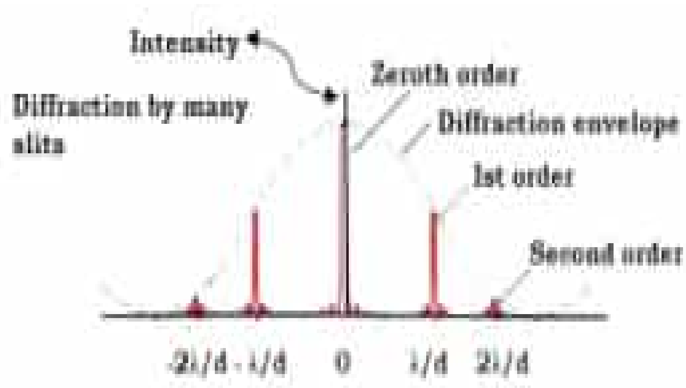


Fig: 13.30
Multiple slits sharp energy spectrum maxima.

DO YOU KNOW?

To manufacture a CD a disk of polycarbonated plastic 1.2 mm thick is impressed with a series of pits (holes) arrange in a spiral track. The pits are 0.5 μm wide and at least 0.83 μm long. These pits function as a diffraction grating. So when white light shines the surface of disc it diffracts through the pits and formed a rainbow like pattern.

13.5.5 X- Ray Diffraction:

The interference and diffraction examples discussed so far have dealt mostly with visible light. However, the same effects occur for wavelengths longer and shorter than those visible to our eyes. X-ray radiation has wavelengths much shorter than those of visible light, so to do such an experiment, the size and spacing of the slits in a grating (for example) would have to be much smaller than in a visible-light grating. **Typical X-ray wavelengths range from about 10 nm to about 0.01 nm.**

There is no way to make a parallel-slit grating small enough to work for X-rays: the diameter of an atom is typically around 0.2 nm, so the slit spacing would be about the size of a single atom. In 1912, Max von Laue (1879–1960) realized that the regular arrangements of atoms in a crystal make a perfect grating for x-rays. The regular arrangement and spacing of the atoms is analogous to the regular spacing of the slits in a conventional grating, but a crystal is a *three-dimensional* grating (as opposed to the two-dimensional gratings we use for visible light). Figure 13.31a shows the atomic structure of NaCl. When a beam of x-rays passes through the crystal, the x-rays are scattered in all directions by the atoms. The x-rays scattered in a particular direction from different atoms interfere with each other. In certain directions they interfere constructively, giving maximum intensity in those directions. Photographic film records those directions as a collection of spots for a single crystal, (Fig. 13.31b).

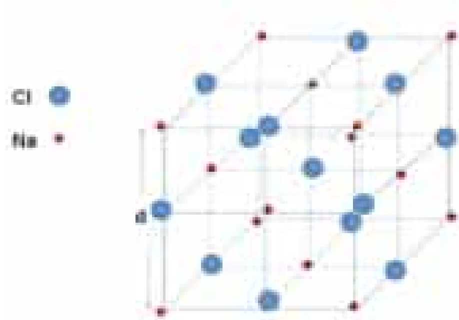


Fig: 13.31 (a) Crystal structure of NaCl (Rock salt).

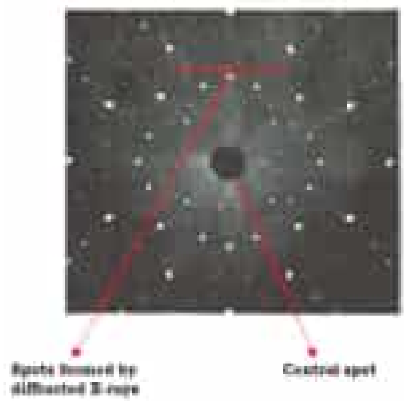


Fig: 13.31 (b) The X-ray diffraction pattern of NaCl. The central spot created by X – rays that are not scattered by the sample.

Measurement of Interplanar Spacing 'd':

Determining the directions for constructive interference is a difficult problem due to the three-dimensional structure of the grating. W. L. Bragg discovered a great simplification. He showed that we can think of the x-rays as if they reflect from planes of atoms (Fig. 13.32a).

Constructive interference occurs if the path difference between X-rays reflecting from an adjacent pair of planes is an integral multiple of the wavelength.

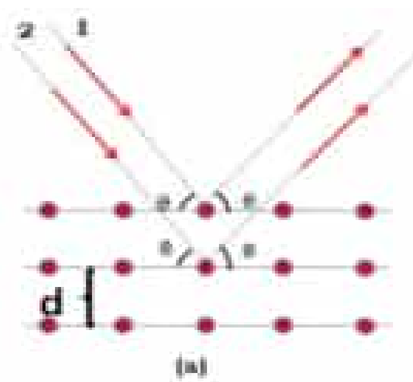


Fig: 13.32 (a) Incident X-rays behave as if they reflect from parallel planes of atoms.

Figure 13.32b shows that the path difference is 2dsinθ, where d is the distance between the planes and θ is the angle that the incident and reflected beams make with the plane (not with the normal). Then, constructive interference occurs at angles given by Bragg's law:

$$p.d = BD + CD = d\sin\theta + d\sin\theta = 2d\sin\theta \ldots (13.19)$$

X-ray diffraction maxima

$$2d\sin\theta = m\lambda \quad \ldots\ldots(13.20)$$

$$(m = \pm 1, \pm 2, \pm 3 \ldots.)$$

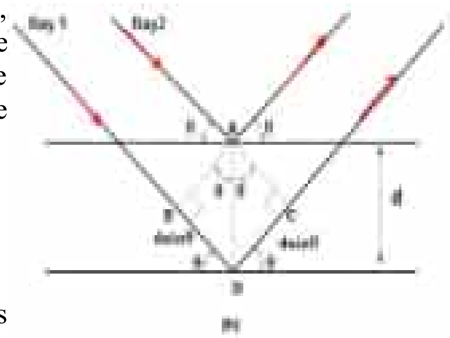


Fig: 13.32 (b) Geometry for finding the path difference for rays reflecting from two adjacent planes.

Although Bragg's law is a great simplification, x-ray is still very complicated because there are many sets of parallel planes in a crystal each with its own plane spacing. In practice, the largest plane spacing contains the largest number of scattering centers (atoms) per unit area so they produce the strongest maxima.

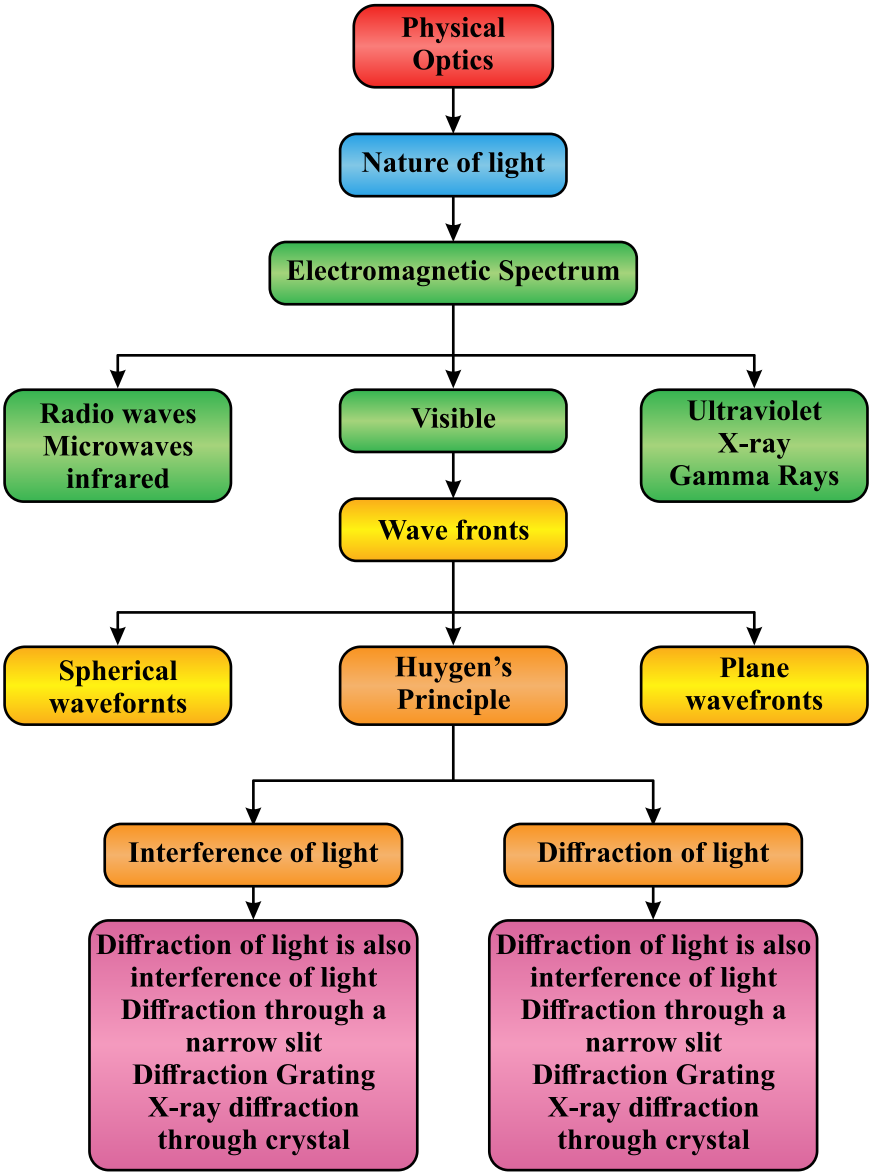
Self-Assessment Questions:

1. Why do you think the diffraction of light is an interference phenomenon?
2. What are the factors which determine the number of order of diffraction obtainable when light is incident normally on a diffraction grating?
3. Why do x-rays are used to obtain a diffraction pattern through crystal?

SUMMARY

- Only accelerating charges produce electromagnetic waves. EM waves consist of oscillating electric and magnetic fields that propagate away from the source.
- EM waves always have both electric and magnetic fields. Just as hanging magnetic fields give rise to electric fields, changing electric fields give rise to magnetic fields.
- The electromagnetic spectrum, the range of frequencies and wavelengths of EM waves is traditionally divided into named regions. From lowest to highest frequency, they are radio waves, microwaves, infrared, visible, ultraviolet, x-rays, and gamma rays.
- A wavefront is asset of points of equal phase. A ray points in the direction of propagation of a wave and is perpendicular to the wavefront.
- Huygens's principle is a geometric construction used to analyze the propagation of a wave.
- Every point on a wave is considered to be a source of spherical wavelets. A surface tangent to the wavelets at a later time is the wavefront at that time.
- When two coherent waves are in phase, their superposition results in constructive interference.
- When two coherent waves are 180° out of phase, their superposition results in destructive interference.
- For Constructive interference phase difference = $2m\pi$ rad and path difference = $\Delta S = m\lambda$, ($m = 0, \pm1, \pm2, \pm3, \ldots$)
- For Destructive interference phase difference = $(m+\frac{1}{2})\,2\pi$ rad and path difference = $\Delta S = (m+\frac{1}{2})\,\lambda$, ($m = 0, \pm1, \pm2, \pm3 \ldots$)
- A path length difference equal to λ causes a phase shift of 360° (2π rad). A path length difference of (½)λ causes a phase shift of 180° (π rad).
- When light reflects from a boundary with higher index of refraction, it is inverted 180° out of phase. When light reflects from the boundary of lower index of refraction it is not inverted.
- The angle at which the bright (maxima) and dark fringe (minima) occur in a double slit experiment are $m\lambda = d\sin\theta$ and $(m+\frac{1}{2})\,\lambda = d\sin\theta$, d is the distance between the slits and m is the order of maxima or minima.
- A grating with N slits produces maxima that are narrow and bright (width = 1/N).
- The minima in a single slit diffraction pattern occur at angles given by $a\sin\theta = m\lambda$.
- A wide central maximum contains most of the light energy, the other maximum are approximately half way between adjacent maxima.
- The rectangular arrangement of atoms in a crystal makes a grating for x-rays.
- The x-rays behave as they reflect from the atomic planes. Constructive interference occurs if the path difference between x-rays reflecting from an adjacent pair of planes is an integral multiple of wavelength.

CONCEPT MAP


Physical Optics
Nature of light
Electromagnetic Spectrum
Radio waves Microwaves infrared
Visible
Ultraviolet X-ray Gamma Rays
Wave fronts
Spherical wavefornts
Huygen's Principle
Plane wavefronts
Interference of light
Diffraction of light
Diffraction of light is also interference of light Diffraction through a narrow slit Diffraction Grating X-ray diffraction through crystal
Diffraction of light is also interference of light Diffraction through a narrow slit Diffraction Grating X-ray diffraction through crystal

EXERCISE

Section (A): Multiple Choice Questions (MCQs)

1. If the wavelength of an electromagnetic wave is about the diameter of a cricket ball, what type of radiation is it.
   a) X-ray b) Ultraviolet
   c) Radio waves d) Visible light
2. Electromagnetic waves from an unknown source in space are found to be diffracted when passing through gaps of the order of 10^{-5} m, which type of the wave are they most likely to be?
   a) microwaves b) Ultraviolet
   c) Radio waves d) infra-red waves
3. Huygens's conception of secondary waves
   a) helps us to find the focal length of a thick lens
   b) is a geometrical method to find a wavefront
   c) is used to determine the velocity of light
   d) is used to explain the polarization of light
4. Interference fringes are produced using monochromatic light of same intensity from a double slit screen. If the intensity of light emerging from one of the slit is reduced, the effect on interference pattern will be
   a) All the dark and bright fringes become brighter.
   b) All the dark and bright fringes become darker.
   c) Bright fringes become brighter and dark fringes become darker.
   d) Bright fringes become darker and dark fringes become brighter.
5. In Young's experiment when the distance between slits and screen is doubled, while separation of slits is halved, then fringe width will be;
   a) 4 times b) ¼ times c) doubled d) unchanged
6. A ray of light passes from air into water. Striking the surface of the water with an angle of incidence 45°. Which of these quantities change as the light enters the water.i) Wavelength ii) frequency iii) speed of propagation iv) direction of propagation
   a) i and ii only. b) iii and iv only.
   c) i, iii, and iv only. d) all of them.
7. A hill separates a television (TV) transmitter from a house. The Transmitter cannot be seen from the house but still the TV in the house has good reception. What wave phenomena make it possible?
   a) Coherence of waves b) Diffraction of waves
   c) Interference of waves d) Refraction of waves
8. Monochromatic light is incident on a diffraction grating and a diffraction pattern is observed. Which effects is observed by replacing the grating with one that has more lines per millimeter?
   a) Number of maxima decreases with decrease in angle between first and second order maxima.

b) Number of maxima decreases with increase in angle between first and second order maxima.
c) Number of maxima increases with decrease in angle between first and second order maxima.
d) Number of maxima increases with increase in angle between first and second order maxima.

9. Optically active substances are those substances which
   a) produce polarized light
   b) rotate the plane of polarization of polarized light
   c) produce double refraction
   d) convert a plane polarized light into circularly polarized light
10. Plane polarized light is passed through a Polaroid. On viewing through the Polaroid we find that when Polaroid is given one complete rotation about the direction of light
    a) The intensity of light gradually decreases to zero and remains at zero.
    b) The intensity of light gradually increases to maximum and remains at maximum.
    c) There is no change in the intensity of light.
    d) The intensity of light varies such that it is twice maximum and twice zero.

CRQs

1. In every day experience, visible light seem to travel in straight lines while radio waves do not, Explain.
2. Explain why two waves of significantly different frequencies cannot be coherent?
3. In a Young's double slit experiment, how the interference phenomenon is affected by changing the slits separation and the distance between the slits and screen?
4. Explain how the double-slit experiment provides evidence for the wave nature of light.
5. Discuss the concept of monochromatic light in the context of Newton's rings.
6. Explain why monochromatic light is preferred for obtaining clear and well-defined interference patterns in the experiment.
7. Discuss how the interference of light waves leads to the formation of bright and dark rings in the experiment.

ERQs

1. Explain the concept of interference in physical optics. Discuss constructive and destructive interference.
2. Discuss the conditions required for interference and provide examples of interference in daily life.
3. Describe the setup and working principle of the Michelson interferometer. Also explain how the Michelson interferometer can be used to measure the wavelength of monochromatic light.
4. Describe the setup and procedure of the diffraction of X-rays through a crystal experiment.

Numerical:

1. A monochromatic light of wavelength 6900A° is used to illuminate two parallel slits. On a screen that is 3.30 m away from the slits, interference fringes are observed. The distance between adjacent bright fringes in the centre of the pattern is 1.80 cm. what is the distance between the slits. **($1.265\text{x}10^{-4}$ m)**

2. A Michelson interferometer is adjusted so that a bright fringe is appears on the screen. As one of the mirrors is moved 25.8 micrometer, 92 bright fringes are counted on the screen. What is the wavelength of light used in the interferometer? **(560 nm)**

3. In section 13.4 we studied interference due to thin films. Why must the film be thin? Why don't we see the interference effect when looking through a window or at a poster covered by a plate of glass, even if the glass is optically flat.

4. Newton's rings are formed by the light of 400 nm wavelength. Determine the change in air film thickness between the third and sixth bright fringe. If the radius of curvature of the curved surface is 5.0 m what is the radius of third bright fringe?**(600, 2.236 mm)**

5. A soap film has an index of refraction n = 1.50. The film is viewed in reflected light.
   (a) At a spot where the film thickness is 910.0 nm, which wavelengths are missing in the reflected light?
   (b) Which wavelengths are strongest in the visible light?
   [(a), (683 nm, 546 nm, 455 nm)] [(b), (607 nm, 496 nm, 420 nm)]

6. What is the difference between deviation and diffraction? What do diffraction and interference have in common?

10. Is it possible to increase the orders of maxima for a given energyspectrum from a diffraction grating?

11. Describe what happens to a single slit diffraction pattern as the width of the slit is slowly decreased.

12. The diffraction pattern from a single slit of width 0.020 mm is viewed on a screen. If the screen is 1.20 m from the slit and light of wavelength 430 nm is used. What is the width of the central maximum? **(5.16 cm)**

13. A grating has exactly 8000 lines uniformly spaced over 2.54 cm and is illuminated by light from a mercury vapor discharge lamp. What is the expected angle for the third order maximum of the light of wavelength 546 nm. **($31^{o}3'29''$)**

14. How many lines per centimeter are there in a grating which gives 1st order spectra at an angle of 30° when the wavelength of light is 6 x 10^{-5} cm?**(No.of lines / cm = 8333)**

15. Light of wavelength 450 nm is incident on a diffraction grating on which 5000 lines/cm have been ruled. Determine
    (i) How many orders of spectra can be observed on either side of spectra?
    (ii) Determine the angle corresponding to each order.
    (i) = 4, (ii) = 13°, 26.7°, 42.5°, 64.2°)

16. Why does a crystal act as a three dimensional grating for X-rays but not for visible light?

17. A beam of X-rays of wavelength 0.071 nm is diffracted by a diffracting plane of rock salt with distance between the atomic planes are 1.98A° Find the glancing angle for the second-order diffraction. **(21°)**

18. Unpolarized light passes through two polarizers in turnwith polarization axes at 45° to each other. What is the fraction of the incident light intensity that is transmitted?
    ($0.25I_o$)