

Learning Objectives

After studying this chapter, the students will be able to:

- ◆ Explain experiments that demonstrate two-source interference for sound, light and microwaves.
- ◆ Describe the conditions required if two-source interference fringes are to be observed
- ◆ Use $\Delta y = \lambda L / d$ for double-slit interference using light to solve problems
- ◆ Use $d \sin(\theta) = n\lambda$ to solve problems
- ◆ Describe the use of a diffraction grating to determine the wavelength of light [the structure and use of the spectrometer are not included]

The question about the nature of light has turned out to be a difficult one. Does light transmit energy from one point to another as a wave or stream of particles? A wave is being defined as a movable disturbance that can transport energy, light exhibit wave behaviour in several phenomena. Unlike other waves, we cannot easily decide the nature of light as it does not reveal itself in an obvious way. The wave nature of light was first proposed in 1678 by Christiaan Huygens. The experimental evidence in support of wave theory at that time was not convincing. Consequently, the Newton's theory about the corpuscular nature of light in 1672, was more famous and accepted. Young's interference experiment performed in 1801 proved wave nature of light and thus established the Huygens' wave theory. In 1860, Maxwell considered light to be the electromagnetic waves. According to him the oscillating electric charges can produce changing electric and magnetic fields that mutually regenerate each other and can propagate through vacuum. In early twentieth century, the quantum mechanical explanation revealed the dual nature of light, both wave and particle characteristics, depending on the experiment. It propagates as an electromagnetic wave but interacts with matter as discrete, massless particles called photons. However, the wave theory of light is still valid and explains phenomena of light successfully. In this chapter we will study the properties of light, associated with its wave nature such as Interference and Diffraction.

15.1 WAVEFRONT

To understand how energy is spread out in the form of waves, we need to understand the concept of wavefront. A wavefront is an imaginary surface that connects all the points where the waves have the same phase.

Wavefronts can be of three types:

1. **Plane wave fronts:** Represented as a straight line like light waves from the distant stars and water waves in a ripple tank.
2. **Circular wavefronts:** Represented by circles as formed in water inside a pond.
3. **Spherical wavefronts:** Formed in three-dimensional space by a sound or light wave.

For a point source in space, the wavefronts will always be spherical i.e. they spread out in all directions. For very large distances, like light rays coming from sun, these wavefronts can be assumed as planes on the surface of earth. The shortest distance between wavefronts is always equal to wavelength of wave. Direction of transfer of energy of wave is always perpendicular to any point on the surface of a given wavefront.

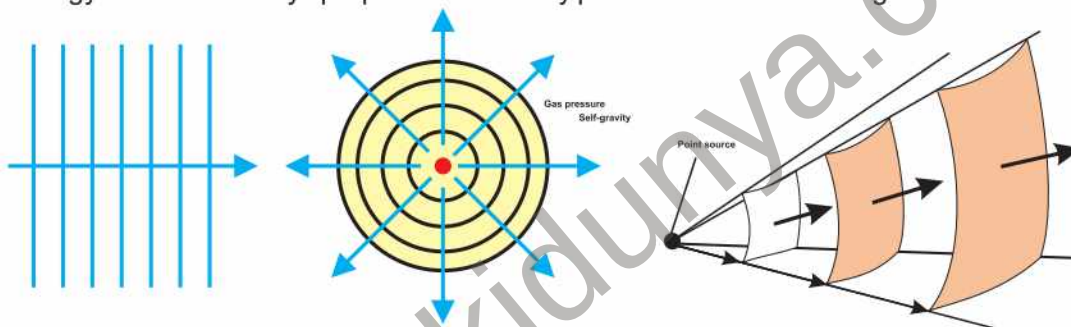


Fig.15.1(a,b,c): Plane and circular waves Parts of spherical wavefronts. For very large distance from source, each part becomes a plane

If the source is periodic, it produces a succession of wavefronts, all of the same shape. Plane wavefronts are produced by a plane source or by any source at distant point. A line source for example a vibrator in a ripple tank creates a wavefronts that are plane and straight in two dimensions. A point source S generates circular wavefronts in two dimensions and spherical wavefronts in three dimensions as shown in the Fig. 15.1, A line at right angle to a wavefront which shows its direction of travel is called a ray, as shown in Fig. 15.1 (a).

Here in this chapter, we will assume plane wavefronts from different sources to study interference and diffraction phenomenon. If a source of light is placed at the focal point of a lens. Plane wavefronts are formed on the other side of lens.

15.2 HUYGENS' PRINCIPLE

This principle, stated originally by the Dutch Scientist Christiaan Huygens, is a geometrical method for finding, from the known shape of a wavefront at some instant, the shape of the wavefront at some later time. Huygens assumed that every point of a wavefront may be considered the source of secondary wavelets that spread out in all directions with a speed equal to the speed of propagation of the wave.

The new wavefront at a later time is then found by constructing a surface tangent to the secondary wavelets or, as it is called, the envelope of the wavelets.

Fig.15.2 illustrates Huygens's principle. The original wave front AB is traveling outward from a source, as indicated by the arrows. We want to find the shape of the wave front after a time interval t . We assume that v , the speed of propagation of the wave, is the same at all points. Then in time t the wavefront travels a distance vt . We construct several circles (traces of spherical wavelets) with radius vt , centered at points along AB. The trace of the envelope of these wavelets, which is the new wavefront, is the curve CD.

All the results that we obtain from Huygens' Principle can also be obtained from Maxwell's equations, but Huygens's simple model is easier to use.

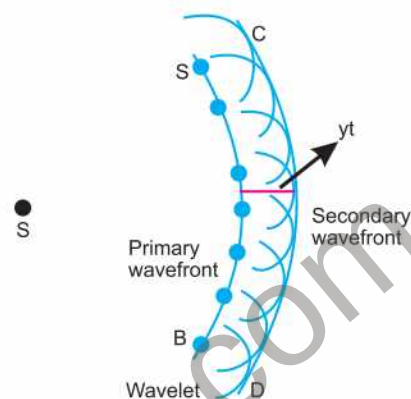


Fig. 15.2: Formation of new Wavefront from a previous wavefront

15.3 INTERFERENCE

Adding waves of different wavelengths and amplitudes results in complex waves. We can find some interesting effects if we consider what happens when two waves of the same wavelength overlap at a point. Two coherent waves, when meet in a region, they reinforce each other at some points and cancel out each other at some other points forming a pattern called interference. Again, we will use the principle of superposition to explain what we observe. Consider two loudspeakers producing sounds of same frequency and wavelength. Figure 15.3 shows how interference arises. The loudspeakers are emitting waves that are in phase because both are connected to the same source. At each point in front of the loudspeakers, waves are arriving from the two loudspeakers. At some points, the two waves arrive in phase (in step) with one another and with equal amplitude (Fig.15.4-a). The principle of superposition predicts that the resultant wave has twice the

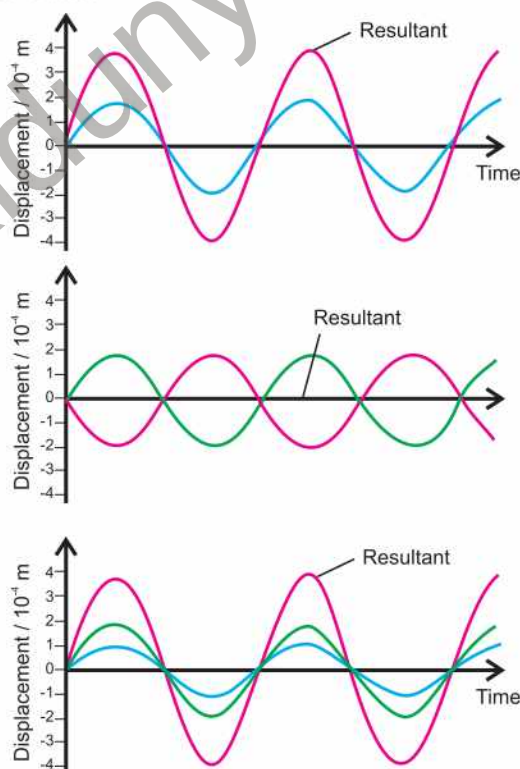


Fig.15.3: Adding waves by the principle of superposition. Blue and green waves of the same amplitude may give a constructive or (b) destructive interference, according to the phase difference between them. (c) Waves of different amplitudes can also interfere constructively.

amplitude of a single wave. We hear a louder sound.

The basic conditions for two waves to produce interference are

- (i) Waves must be of same type i.e. sound waves can only produce interference with other sound waves.
- (ii) Waves must be coherent (having a constant phase difference).
- (iii) Waves must be moving in same or almost same direction.

Two waves can produce interference if amplitudes are different but this will decrease the contrast between different regions in interference pattern.

Coherence

We are surrounded by many types of waves for example visible light, infrared radiations, radio waves and sound. There are waves coming at us from all directions. So, why do we not observe interference patterns all the time? Why do we need specialised equipment in a laboratory to observe these effects?

In fact, we can see interference of light occurring in everyday life. For example, you may have noticed haloes of light around street lamps or the Moon on a foggy night.

You may have noticed light and dark bands of light if you look through fabric at a bright source of light. These are interference effects.

We usually need specially arranged conditions to produce interference effects that we can measure. Think about the demonstration with two loudspeakers. If they were connected to different signal generators with slightly different frequencies, the sound waves might start off in phase with one another, but they would soon go out of phase (Fig.15.4). We would hear loud, then soft, then loud again. The interference pattern would keep shifting around the room.

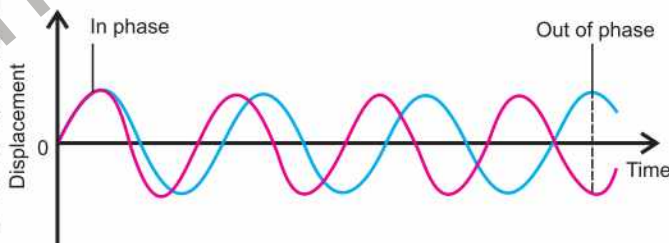


Fig.15.4: Waves of slightly different wavelengths and therefore waves move in and out of phase with one another.

By connecting the two loudspeakers to the same signal generator, we can be sure that the sound waves that they produce are constantly in phase with one another. We say that they act as two coherent sources of sound waves (coherent means sticking together). Coherent sources emit waves that have a constant phase difference. Note that the two waves can only have a constant phase difference if their frequencies are the same and remains constant.

Now think about the laser experiment. Could we have used two lasers producing exactly the same frequency and hence wavelength of light? Figure 15.5 (a) represents the light from a laser. We can think of it as being made up of many separate bursts of light. We cannot guarantee that these bursts from two lasers will always be in phase with one

another.

This problem is overcome by using a single laser and dividing its light using the two slits (Fig. 15.5-b). The slits act as two coherent sources of light. They are constantly in phase with one another (or there is a constant phase difference between them).

If they were not coherent sources, the interference pattern would be constantly changing, far too fast for our eyes to detect. We would simply see a uniform band of light, without any definite bright and dark regions. From this you should be able to see that, in order to observe interference, we need two coherent sources of waves.

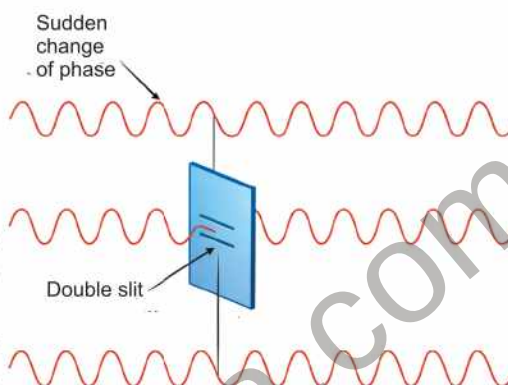


Fig.15.5: Waves must be coherent if they are to produce a clear interference pattern.

15.4 INTERFERENCE OF MICROWAVES

Using 2.8 cm wavelength microwave equipment (Fig. 15.6), we can observe an interference pattern. The microwave transmitter is directed towards the double gap in a metal barrier. The microwaves are diffracted at the two gaps so that they spread out into the region beyond, where they can be detected using the probe receiver. By moving the probe around, it is possible to detect regions of high intensity (constructive interference) and low intensity (destructive interference). The probe may be connected to a meter, or to an audio amplifier and loudspeaker to give an audible output.

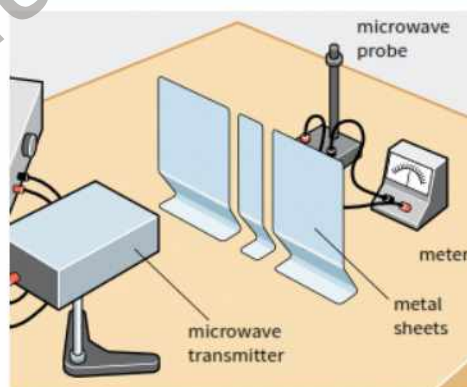


Fig.15.6: Microwaves can also be used to show interference effects.

Interference of light waves

Here is one way to show the interference effects produced by light. A simple arrangement involves directing the light from a laser through two slits (Fig. 15.7). The slits are two clear lines on a black slide, separated by a fraction of a millimeter. Where the light falls on the screen, a series of equally spaced dots of light are seen. These bright dots are referred to as interference 'fringes', and they are regions where light waves from the two slits are arriving in phase with each other, i.e. there is constructive interference. The dark

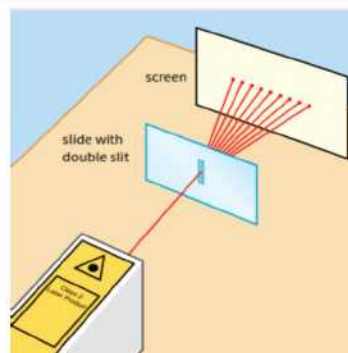


Fig.15.7: Light beams from the two slits interfere in the space beyond.

regions in between are the result of destructive interference.

These bright and dark fringes are the equivalent of the loud and quiet regions that we detected if you investigated the interference pattern of sounds from the two loudspeakers. Bright fringes correspond to loud sound, dark fringes to quiet sound or silence. We can check that light is indeed reaching the screen from both slits as follows. Mark a point on the screen where there is a dark fringe. Now carefully cover up one of the slits so that light from the laser is only passing through one slit. We should find that the pattern of interference fringes disappears. Instead, a broad band of light appears across the screen. This broad band of light is the diffraction pattern produced by a single slit. The point that was dark is now bright. Cover up the other slit instead, and we shall see the same effect. We have now shown that light is arriving at the screen from both slits, but at some points (the dark fringes) the two beams of light cancel each other out.

We can achieve similar results with a bright light bulb rather than a laser, but a laser is much more convenient because the light is concentrated into a narrow, more intense beam. This famous experiment is called the Young double-slit experiment, although Thomas Young had no laser available to him when he first carried it out in 1801.

15.5 YOUNG'S DOUBLE SLIT EXPERIMENT

We will take a close look at a famous experiment which Thomas Young performed in 1801. He used this experiment to show the wave nature of light. A beam of light is shown on a pair of parallel slits placed at right angles to the beam. Light diffracts and spreads outwards from each slit into the space beyond; the light from the two slits overlaps on a screen. An interference pattern of bright and dark bands called 'fringes' is formed on the screen.

In order to observe interference, we need two sets of waves. The sources of the waves must be coherent – the phase difference between the waves emitted at the sources must remain constant. This also means that the waves must have the same wavelength. Today, this is readily achieved by passing a single beam of laser light through the two slits. A laser produces intense coherent light. As the light passes through the slits, it is diffracted so that it spreads out into the space beyond (Fig.15.8). Now we have two overlapping sets of waves, and the pattern of fringes on the screen shows us the result of their interference. How does this pattern arise? We will consider three points on the screen (Fig.15.9-a,b,c), and work out what we would expect to observe at each point.

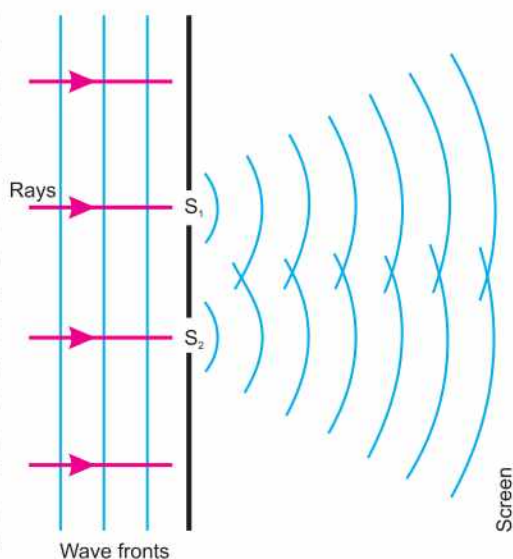


Fig.15.9: Double Slit Arrangement

Point A

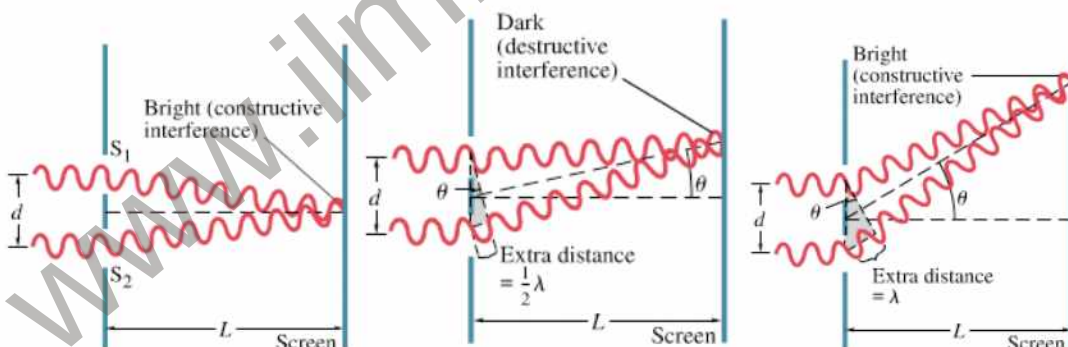
This point is directly opposite the midpoint of the slits. Two rays of light arrive at A, one from slit 1 and the other from slit 2. Point A is equidistant from the two slits, and so the two rays of light have travelled the same distance. The path difference between the two rays of light is zero. If we assume that they were in phase (in step) with each other when they left the slits, then they will be in phase when they arrive at A. Hence they will interfere constructively, and we will observe a bright fringe at A.

Point B

This point is slightly to the side of point A, and is the midpoint of the first dark fringe. Again, two rays of light arrive at B, one from each slit. The light from slit 1 has to travel slightly further than the light from slit 2, and so the two rays are no longer in step. Since point B is at the midpoint of the dark fringe, the two rays must be in antiphase (phase difference of 180°). The path difference between the two rays of light must be half a wavelength and so the two rays interfere destructively.

Point C

This point is the midpoint of the next bright fringe, with $AB = BC$. Again, ray 1 has travelled further than ray 2; this time, it has travelled an extra distance equal to a whole wavelength λ . The path difference between the rays of light is now a whole wavelength. The two rays are in phase at the screen. They interfere constructively and we see a bright fringe. The complete interference pattern (Fig. 15.21) can be explained in this way.

**Fig. 15.9:**

(a) for $\theta = 0$ Central Bright region. Fig. 15.9 (b) For first order bright region (c) For first dark region

To simplify the analysis of Young's experiment, we assume that the distance L from the slits to the screen is so large in comparison to the distance d between the slits that the lines from S_1 and S_2 to P , are very nearly parallel, as in Fig. 15.9 c. This is usually the case for experiments with light; the slit separation is typically a few millimeters, while the screen may be a meter or more away. The difference in path length is then given by

$$r_2 - r_1 = d \sin \theta \quad \dots\dots\dots (15.1)$$

Where θ is the angle between a line from slits to screen and the normal to the plane of the slits (shown as a thin black line).

Constructive and Destructive Two-Slit Interference

We have learnt that constructive interference (reinforcement) occurs at points where the path difference is an integer number of wavelengths, $m\lambda$, where $m = 0, 1, 2, 3$. So the bright regions on the screen in Fig. 15.10 occur at angles θ for which

$$d \sin \theta = m\lambda \quad (m = 0, 1, 2, 3, \dots) \quad (15.2)$$

Similarly, destructive interference (cancellation) occurs, forming dark regions on the screen, at points for which the path difference is a half-integer number $(m + \frac{1}{2})$ of wavelengths,

$$d \sin \theta = (m + \frac{1}{2}) \lambda \quad \text{and} \quad (m = 0, 1, 2, 3, \dots)$$

Thus, the pattern on the screen of Fig. 15.9 is a succession of bright and dark bands, or interference fringes, parallel to the slits S_1 and S_2 . A photograph of such a pattern is shown in Fig. 15.9.

We can derive an expression for the positions of the centers of the bright bands on the screen. In Fig., y is measured from the center of the pattern, corresponding to the distance from the center of Fig. 15.10. Let y_m be the distance from the center of the pattern ($\theta = 0$) to the center of the m th bright band. Let θ_m be the corresponding value of θ ; then

$$y_m = L \tan \theta_m \quad (15.3)$$

Fig.15.10: Schematic double slit arrangement

In such experiments, the distances y_m are often much smaller than the distance L from the slits to the screen. Hence θ_m is very small, Hence, $\sin \theta_m = \tan \theta_m$ and

$$y_m = L \sin \theta_m \quad (15.4)$$

Hence for small angles, positions of m th bright band is given by

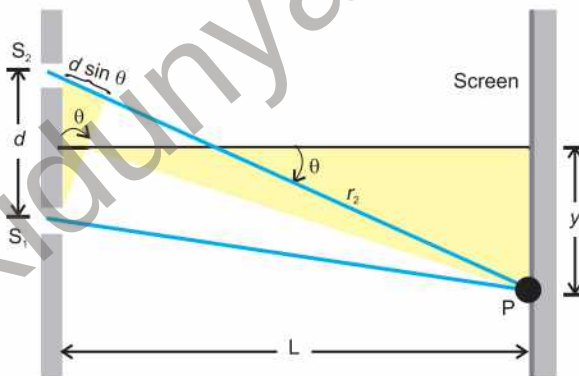
$$y_m = m L \lambda / d \quad (15.5)$$

The distance between centers of consecutive bright or dark fringes is given by

$$\Delta y = L \lambda / d \quad (15.6)$$

The distance between adjacent bright bands in the pattern is *inversely* proportional to the distance d between the slits. The closer together the slits are, the more the pattern spreads out. When the slits are far apart, the bands in the pattern are closer together.

While we have described the experiment that Young performed with visible light, the results given in Equation are valid for *any* type of wave, provided that the resultant wave from two coherent sources is detected at a point that is far away in comparison to the separation d .



15.6 INTERFERENCE IN THIN FILMS

We often see bright bands of color when light reflects from a thin layer of oil floating on water or from a soap bubble. These are the results of interference. Light waves are reflected from the front and back surfaces of such thin films, and constructive interference between the two reflected waves (with different path lengths) occurs in different places for different wavelengths. Fig.15.11 shows the situation. Light shining on the upper surface of a thin film with thickness t is partly reflected at the upper surface (path abc) of thin film. Light *transmitted* through the upper surface is partly reflected at the lower surface (path $abdef$). The two reflected waves come together at point P on the retina of the eye. Depending on the phase relationship, they may interfere constructively or destructively. Different colors have different wavelengths, so the interference may be constructive for some colors and destructive for others.

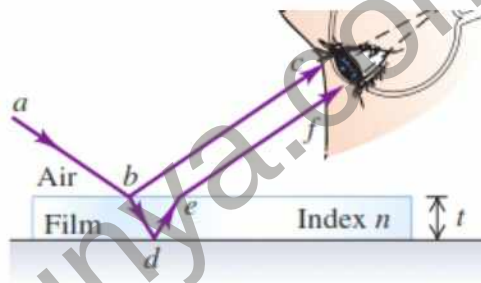


Fig.15.11: Thin Film

That's why we see coloured patterns in thin film as in Fig.15.12 (which shows thin films of soap solution that make up the bubble walls). In similar fashion, thin film of floating on water shows same pattern. The complex shapes of the colored patterns result from variations in the thickness of the film.



Fig.15.12: White light falling on soap bubble

Let's look at a simplified situation in which *monochromatic* light reflects from two nearly parallel surfaces at nearly normal incidence. Fig 15.13 shows two plates of glass separated by a thin wedge, or film, of air. We want to consider interference between the two light waves reflected from the surfaces adjacent to the air wedge. (Reflections also occur at the top surface of the upper plate and the bottom surface of the lower plate; to keep our discussion simple, we won't include these.) The situation is the same as in Fig. 15.13(a) except that the film (wedge) thickness is not uniform. The path difference between the two waves is just twice the thickness t of

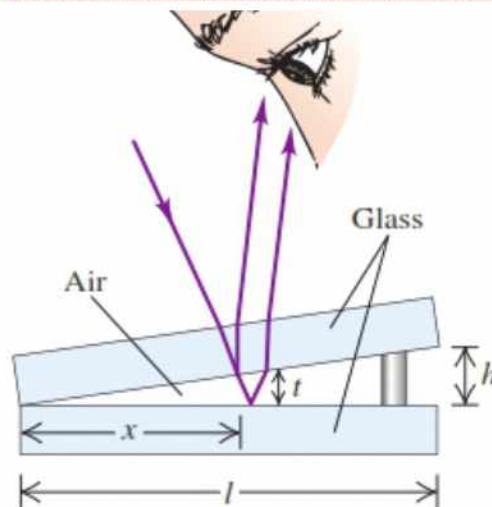


Fig.15.13: Thin film

the air wedge at each point. At points where $2t$ is an integer number of wave lengths, we expect to see constructive interference and a bright area; where it is a half-integer number of wavelengths, we expect to see destructive interference and a dark area. Where the plates are in contact, there is practically *no* path difference, and we expect a bright area.

When we carry out the experiment, the bright and dark fringes appear, but they are interchanged! Along the line where the plates are in contact, we find a *dark* fringe, not a bright one. This suggests that one or the other of the reflected waves has undergone a half cycle phase shift during its reflection. In that case the two waves that are reflected at the line of contact are a half-cycle out of phase even though they have the same path length.

In fact, this phase shift can be predicted from Maxwell's equations and the electromagnetic nature of light.

15.7 NEWTON'S RINGS

Fig 15.14 shows the convex surface of a lens in contact with a plane glass plate. A thin film of air is formed between the two surfaces. When we view the setup with monochromatic light, you see circular interference fringes (Fig.15.15). These were studied by Newton and are called Newton's rings.

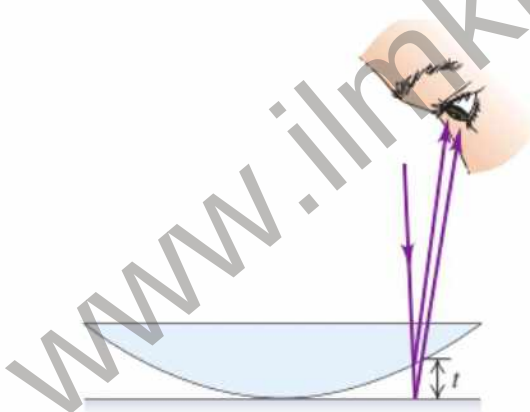


Fig.15.14: convex lens in contact with glass plate

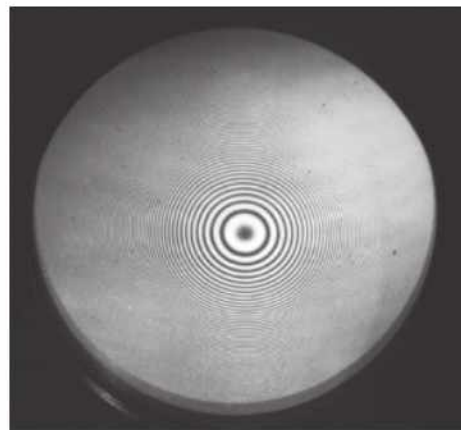


Fig.15.15: Circular interference fringes

Newton's rings are formed when a **plano-convex lens** is placed on a flat glass plate, a thin air film forms between them. Light from a **monochromatic source** (like a sodium lamp) reflects off both the top and bottom surfaces of this air film. The reflected rays interfere-constructively (bright rings) or destructively (dark rings)-depending on the **path difference** and **phase shift** between them. Newton's Rings can be used to calculate the wavelength of monochromatic light, helps determine the radius of curvature of lenses and used in precision optics to detect surface irregularities

15.8 DIFFRACTION GRATING

The property of bending of light around obstacles and spreading of light waves into the geometrical shadow of an obstacle is called diffraction.

If we increase the number of slits in an interference experiment (while keeping the spacing of adjacent slits constant) gives interference patterns in which the maxima are in the same positions, but progressively narrower, than with two slits. Because these maxima are so narrow, their angular position, and hence the wavelength, can be measured to very high precision. As we'll see, this effect has many important applications.

An array of a large number of parallel slits, all with the same width d and spaced equal distances d between centers, is called a **diffraction grating**. The first one was constructed by Fraunhofer using fine wires. Gratings can be made by using a diamond point to scratch many equally spaced grooves on a glass or metal surface, or by photographic reduction of a pattern of black and white stripes on paper. For a grating, what we have been calling *slits* are often called *rulings* or *lines*.

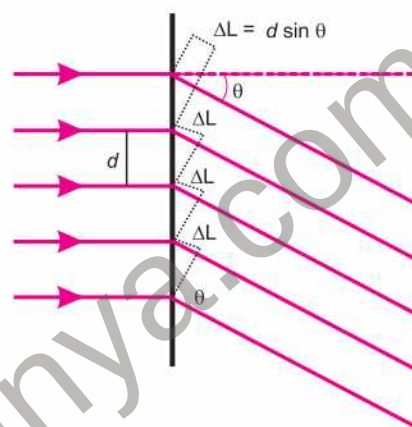


Fig.15.16: Diffraction Grating

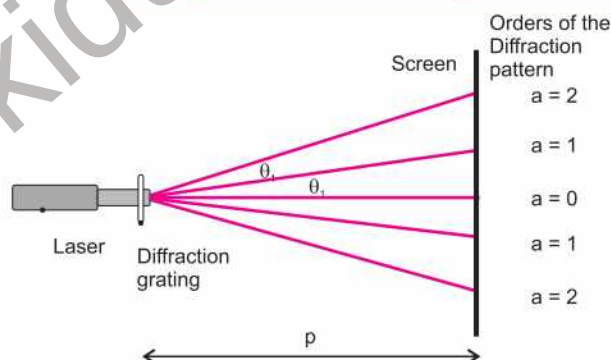


Fig.15.17: Orders of Pattern

Fig. 15.16 is a cross section of a *transmission grating*; the slits are perpendicular to the plane of the page, and an interference pattern is formed by the light that is transmitted through the slits. The diagram shows only five slits; an actual grating may contain several thousand. The spacing d between centers of adjacent slits is called the *grating spacing*. A plane monochromatic wave is incident normally on the grating from the left side. We assume far-field (Fraunhofer) conditions; that is, the pattern is formed on a screen that is far enough away that all rays emerging from the grating and going to a particular point on the screen can be considered to be parallel.

The principal intensity maxima with multiple slits occur in the same directions as for the two-slit pattern. These are the directions for which the path difference for adjacent slits is an integer number of wavelengths. So the positions of the maxima are once again.

$$d \sin \theta = n\lambda \quad \text{where } n = 0, \pm 1, \pm 2, \pm 3, \dots \quad (15.7)$$

When a grating containing hundreds or thousands of slits is illuminated by a beam of parallel rays of monochromatic light, the pattern is a series of very sharp lines at angles determined by this formula. The $n = \pm 1$ lines are called the *first-order lines*, the $n = \pm 2$ lines the *second-order lines*, and so on. If the grating is illuminated by white light with a continuous distribution of wavelengths, each value of n corresponds to a continuous spectrum in the pattern. The angle for each wavelength is determined by Eq. (15.7) for a given value of n , long wavelengths (the red end of the spectrum) lie at larger angles (that is, are deviated more from the straight-ahead direction) than do the shorter wavelengths at small angles (blue end of the spectrum).

As Eq. (15.7) shows, the sines of the deviation angles of the maxima are proportional to the ratio λ/d . For substantial deviation to occur, the grating spacing d should be of the same order of magnitude as the wavelength λ . Gratings for use with visible light (λ from 400 to 700 nm) usually have about 1000 slits per millimeter; the value of d is the reciprocal of the number of slits per unit length, so d is of the order of 1000 nm.

15.9 DIFFRACTION OF X-RAY BY CRYSTALS

X-rays is a type of electromagnetic radiation of much shorter wavelength, about 10^{-10} m.

In order to observe the effects of diffraction, the grating spacing must be of the order of the wavelength of the radiation used. The regular array of atoms in a crystal forms a natural diffraction grating with spacing that is typically $\approx 10^{-10}$ m. The scattering of X-rays from the atoms in a crystalline lattice gives rise to diffraction effects very similar to those observed with visible light incident on ordinary grating.

The study of atomic structure of crystals by X-rays was initiated in 1914 by W.H. Bragg and W.L. Bragg with remarkable achievements. They found that a monochromatic beam of X-rays was reflected from a crystal plane as if it acted like mirror. To understand this effect, a series of atomic planes of constant interplanar spacing d parallel to a crystal face are shown by lines PP' , $P_1P'_1$, $P_2P'_2$, and so on, in Fig. 9.18.

Suppose an X-rays beam is incident at an angle θ on one of the planes. The beam can be reflected from both the upper and the lower planes of atoms. The beam reflected from lower plane travels some extra distance as compared to the beam reflected from the upper plane. The effective path difference between the two reflected beams is $2d \sin \theta$. Therefore, for reinforcement, the path difference should be an integral multiple of

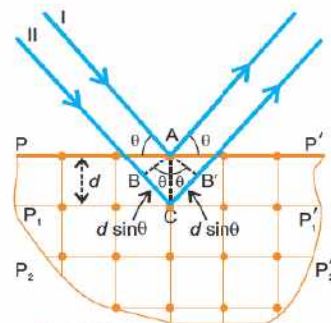


Fig.15.18: Diffraction of X-rays by crystal.

Interesting Application



Diffraction of radio waves

the wavelength. Thus,

$$2d \sin \theta = n\lambda \dots\dots\dots (15.8)$$

The value of n is referred to as the order of reflection. The equation 15.8 is known as the Bragg equation. It can be used to determine interplanar spacing between similar parallel planes of a crystal if X-rays of known wavelength are allowed to diffract from the crystal.

X-rays diffraction has been very useful in determining the structure of biologically important molecules such as hemoglobin, which is an important constituent of blood, and double helix structure of DNA.

Interesting Information



The spectrum of white light due to diffraction grating of 100 slits.



The spectrum of white light due to diffraction grating of 2000 slits.

QUESTIONS

Multiple Choice Questions

Choose the correction answer.

- 15.1 When the light from two lamps falls on a screen, no interference pattern can be obtained. Why is this?
- (a) The lamps are not point sources.
 - (b) The lamps emit light of different amplitudes.
 - (c) The light from the lamps is not coherent.
 - (d) The light from the lamps is white
- 15.2 Monochromatic light illuminates two narrow parallel slits. The interference pattern which results is observed on a screen some distance beyond the slits. Which change increases the separation between the dark lines of the interference pattern?
- (a) Decreasing the distance between the screen and the slits
 - (b) Increasing the distance between the slits
 - (c) Monochromatic light of higher frequency
 - (d) Using monochromatic light of longer wavelength
- 15.3 Using monochromatic light, interference fringes are produced on a screen placed a distance L from a pair of slits of separation d . The separation of the fringes is y . Both d and L are now doubled. What is the new fringe separation?
- (a) $y/2$
 - (b) y
 - (c) $2y$
 - (d) $4y$
- 15.4 Which of the following is not a necessary condition for two waves to produce interference.
- (a) Waves must be of same type
 - (b) Waves must be coherent

- (c) Waves must have same amplitude
- (d) Waves must be moving in same direction

15.5 The colours appeared on a soap bubble are due to which phenomenon of light?

- (a) Reflection
- (b) Refraction
- (c) Interference in thin film
- (d) Diffraction

15.6 Continuous water waves are diffracted through a gap in a barrier in a ripple tank. Which change will cause the diffraction of the waves to increase?

- (a) Increasing the frequency of the waves
- (b) Increasing the width of the gap
- (c) Reducing the wavelength of the waves
- (d) Reducing the width of the gap

15.7 Which property of a light wave can be determined using a diffraction grating?

- (a) Amplitude
- (b) Intensity
- (c) Speed
- (d) Wavelength

15.8 The central maximum in a diffraction grating is called:

- (a) zero order
- (b) first order
- (c) second order
- (d) higher order

Short Answer Questions

- 15.1 Can Huygens' Principle be applied on sound and water waves? Explain briefly.
- 15.2 Why interference pattern is produced due to headlights of a car? Explain briefly.
- 15.3 Why interference pattern is observed on soap bubbles but not on window glass or windscreens of cars?
- 15.4 If the whole apparatus of Young's double slit experiment is submerged in water, what will be the effect on fringes?
- 15.5 Compare the Double slit experimental arrangements for light and sound waves, similarities and differences.
- 15.6 For a diffraction grating, what are the advantages of using (a) many slits, (b) narrow slits and (c) closely spaced slits? Explain
- 15.7 How the number of orders in a given diffraction grating can be increased?
- 15.8 Explain how the pattern would change if red light is replaced with blue light in a given diffraction grating?
- 15.9 Why central spot in Newton's rings is dark?

Constructed Response Questions

- 15.1 Light sometimes describes as rays and sometimes as waves. Construct diagrams to explain differences in both.

- 15.2 Suppose white light is falling on a double slit arrangement, such that one slit is covered with red filter (400 nm) and other is with blue filter (650 nm), explain what would be observed on the screen?
- 15.3 What will be the effect on width and brightness of the fringes in a double slit interference experiment if we decrease the width of one slit to half keeping all other thing same?
- 15.4 Why can we readily observe diffraction effects for sound wave and water waves, but not for light? Is this because light travels so much faster than these other waves? Explain.
- 15.5 What is the significance of path difference in deriving Bragg's equation?

Numerical Problems

- 15.1 Coherent light of wavelength 500 nm is incident on two very narrow and closely spaced slits. The interference pattern is observed on a very tall screen that is 2.00 m from the slits. Near the center of the screen the separation between two adjacent interference maxima is 3.53 cm. What is the distance on the screen between the $m = 49$ and $m = 50$ maxima?
- 15.2 Young's experiment is performed with light from excited helium atoms $\lambda = 502$ nm. Fringes are measured carefully on a screen 1.20 m away from the double slit, and the center of the 20th fringe (not counting the central bright fringe) is found to be 10.6 mm from the center of the central bright fringe. What is the separation of the two slits?
- 15.3 Coherent light with wavelength 450 nm falls on a pair of slits. On a screen 1.80 m away, the distance between dark fringes is 3.90 mm. What is the slit separation?
- 15.4 Two slits spaced 0.450 mm apart are placed 75.0 cm from a screen. What is the distance between the second and third dark lines of the interference pattern on the screen when the slits are illuminated with coherent light with a wavelength of 500 nm?
- 15.5 Two very narrow slits are spaced 1.80 mm apart and are placed 35.0 cm from a screen. What is the distance between the first and second dark lines of the interference pattern when the slits are illuminated with coherent light of wavelength 550 nm?
- 15.6 Monochromatic light is at normal incidence on a plane transmission grating. The first-order maximum in the interference pattern is at an angle of 11.3° . What is the angular position of the fourth-order maximum?
- 15.7 If a diffraction grating produces a third-order bright spot for red light of wavelength 700 nm at 65° from the central maximum, at what angle will the second-order bright spot be for violet light of wavelength 400 nm?

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