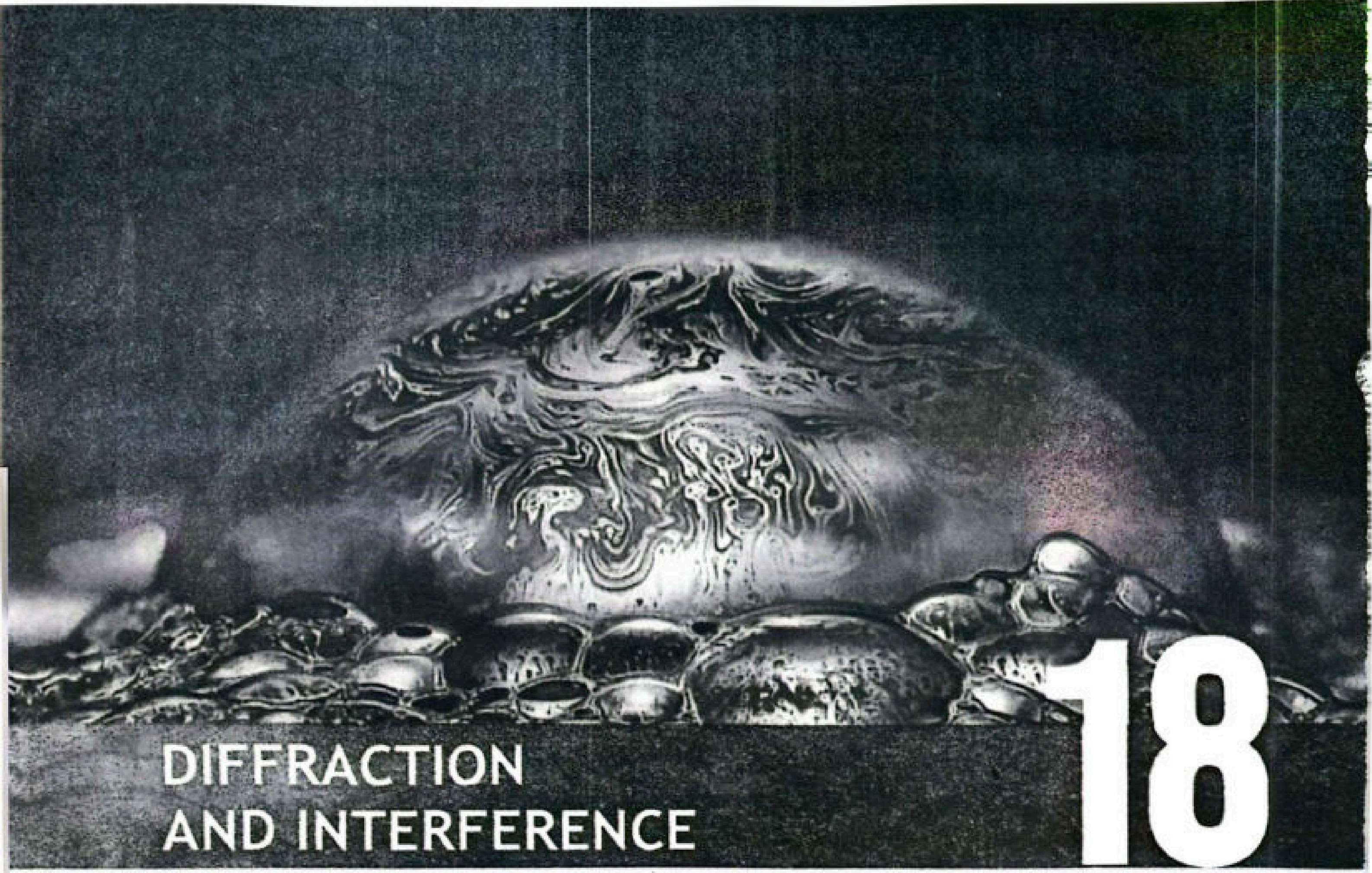

18 DIFFRACTION AND INTERFERENCE

Student Learning Outcomes (SLOs)

The student will

- Explain experiments that demonstrate two-source interference using water waves in a ripple tank, 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].
- with the context of the electron diffraction double slit experiment, explain the below two of the many interpretations of quantum mechanics: (i) copenhagen interpretation (ii) many worlds interpretation.

Have you ever marveled at the vibrant colors of a rainbow, or wondered why sound waves can sometimes cancel each other out, creating silence? These phenomena are a testament to two fascinating wave properties: interference and diffraction.

Interference occurs when two or more waves traveling through the same medium interact and superimpose on each other. This interaction can lead to surprising results. Depending on how the waves are aligned, they can either strengthen each other (constructive interference), creating brighter light or louder sound, or cancel each other out (destructive interference), resulting in darkness or quieter sound. Understanding interference allows us to explain everyday occurrences like the beating sound between slightly off-tune instruments and the formation of colorful bands in soap bubbles. Interference isn't limited to light or sound waves. It's a fundamental property observed in all types of waves, from water ripples in a tank to the intricate quantum waves that make up matter. So, the next time you witness a dazzling rainbow or hear a mesmerizing musical chord, remember, it's all a captivating play of interference.

Diffraction, on the other hand, describes the bending of a wave around the edges of an obstacle or through a narrow slit. Unlike reflection, where a wave bounces off a surface, diffraction causes the wave to spread out and travel into regions beyond the obstacle's shadow. This phenomenon is responsible for the dazzling colors we see in rainbows, where sunlight diffracts through water droplets. Diffraction also plays a crucial role in various technologies like x-ray crystallography, which helps us understand the structure of materials, and optical instruments like diffraction gratings, which separate light into its constituent colors.

Interference and diffraction are not isolated concepts; they are intimately connected. Both phenomena arise from the wave nature of light, sound, and other waves. While interference describes how waves interact and superimpose, diffraction showcases how waves can bend and spread out when encountering obstacles. Understanding these principles unveils a deeper understanding of the behavior of waves and their remarkable effects in the world around us.

18.1 INTERFERENCE

Two-source interference, also known as double-slit interference, is a phenomenon in which waves from two coherent sources overlap and interfere with each other, creating a pattern of alternating constructive and destructive interference fringes. **Interference of two waves may lead to a resultant wave of either a larger or a smaller displacement.** This phenomenon can be demonstrated using various types of waves, including water waves in a ripple tank (see Fig. 18.1), sound waves, light waves, and microwaves.

Figure 18.1: Interference of water waves.

Conditions for Observing Interference Fringes:

To observe interference fringes in a two-source setup, the following conditions must be met:

1. **Coherent Sources:** The two sources emitting the waves must be coherent, meaning they have a constant phase relationship and emit waves with the same frequency and wavelength.
2. **Narrow Slits:** The slits must be narrow and close together compared to the wavelength of the waves. This ensures that the waves from each slit overlap and interfere with each other.
3. **Monochromatic Waves:** The waves emitted by the sources should ideally have a single wavelength (monochromatic) to produce a clear interference pattern.
4. **Stable Environment:** The experimental setup must be free from disturbances such as vibrations or air currents, which could disrupt the wave patterns and interfere with the observation of fringes.

By satisfying these conditions, two-source interference fringes can be observed across various wave types, demonstrating the wave nature of light, sound, and other phenomena.

18.1.1 Interference of Water Waves

Interference can be demonstrated in a ripple tank by using two-point sources. In a ripple tank experiment (see Fig. 18.2), two coherent sources are created by generating ripples in the water from two separate point sources. The tank is illuminated from above to enhance visibility. When the waves from both sources meet, they interfere with each other. This interference creates regions of constructive interference, where waves reinforce each other and produce larger waves, and regions of destructive interference, where waves cancel each other out. This results in a pattern of alternating crest and trough on the surface of the water.

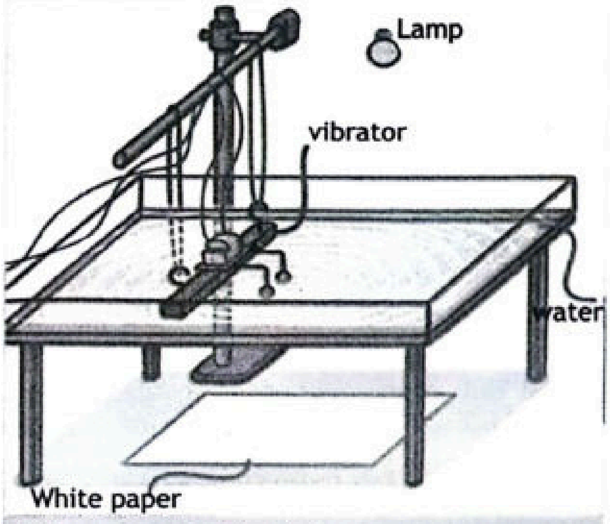

Figure 18.2: Ripple tank.

Interference of two circular waves is shown in Fig. 18.3. If two waves arrive in **phase** (their crests or trough arrive at exactly the same time), they will **interfere constructively**. A resultant wave will be produced, which has crests much higher than the two individual waves, and troughs much deeper.

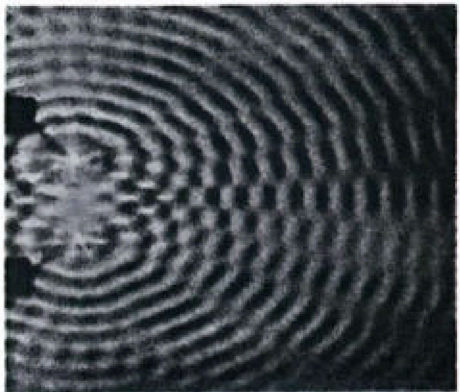
Figure 18.3: Shadow of Interference pattern of two circular waves obtained on white paper under the ripple tank.

If the two waves arrive in **anti-phase** (with a phase difference of π radians or 180°), the peaks of one wave arrive at the same time as the troughs from the other, and they will interfere **destructively**. The resultant wave will have smaller amplitude. This phase difference may be produced by allowing the two sets of waves to travel different distances. This difference in distance of travel is called the **path difference**.

18.1.2 Interference of Sound Waves

Similar to water waves, sound waves can also exhibit interference. Two speakers emitting coherent sound waves are placed facing a screen, as shown in Fig 18.4. The sound waves from both sources overlap, creating regions of constructive and destructive interference. This interference pattern can be visualized by using a microphone or a detector to measure the intensity of sound at various points on the screen.

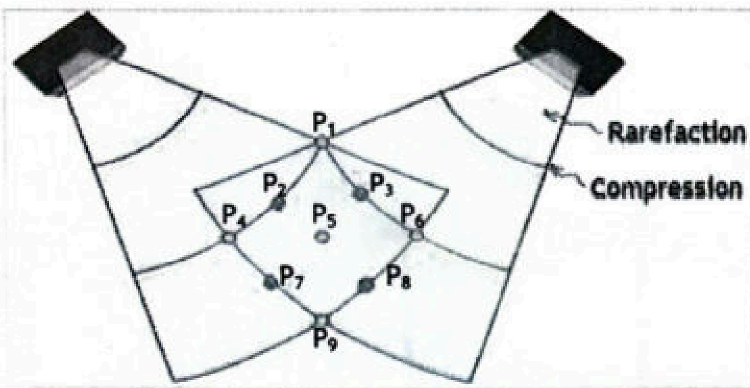

Figure 18.4: Interference of sound wave from two speakers.

Consider sound waves from two loudspeakers connected to the same signal generator and amplifier, producing notes of the same frequency. Sound waves being longitudinal waves, consists of **compressions** and **rarefactions.** At points such as P_1, P_4, P_5, P_6 and P_9 constructive interference occurs because here compressions or rarefactions align and the sound appears louder. Destructive interference occurs at points such as P_2, P_3, P_7 and P_8, when compression align with a rarefaction and vice versa, resulting in a quieter sound. This principle is used in noise-cancelling headphones (you have studied in grade XI).

18.1.3 Interference of Light Waves

In a double-slit experiment with light waves, a laser beam is typically used as the coherent light source. The light beam is directed through a barrier with two narrow slits (Figure 18.5), creating two coherent sources of light waves. A screen placed behind the slits displays the interference pattern. The pattern consists of alternating bright and dark fringes, which can be observed directly or captured using a camera. Here, light of a single wavelength passes through a pair of vertical slits and produces a diffraction pattern on the screen—numerous vertical bright and dark lines that are spread out horizontally. Without diffraction and interference, the light would simply make two lines on the screen.

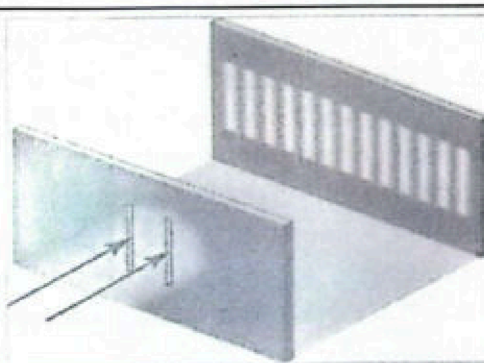

Figure 18.5: Set up of Young's double-slit experiment.

In the early 1800s, the nature of light was still a topic of debate, with Christian Huygens proposing wave-like behavior, Isaac Newton offering an alternative explanation for color and observable effects.

Thomas Young's Double Slit Experiment

In 1801, the English physicist and physician Thomas Young conducted an experiment to demonstrate the wave nature of light. Young's experiment involves a pair of closely spaced vertical slits (the double slit) through which light passes. Initially, Young allowed sunlight (which contains multiple wavelengths) to pass through a single slit, making the light partially coherent (waves with a definite phase relationship). He then directed this partially coherent light through the double slit. The light passes through two narrow slits, producing semicircular waves that overlap and interfere on a screen placed behind the slits.

As the two slits (S_1 and S_2) are narrow, so the light spreads out (diffracts) from each slit, as shown in Fig. 18.6 (a). Two slits provide **two coherent light sources** that interfere and interference fringes will be obtained in the form of bright (constructive interference) and dark (destructive interference) pattern on the screen, as shown in the Fig. 18.6 (b).

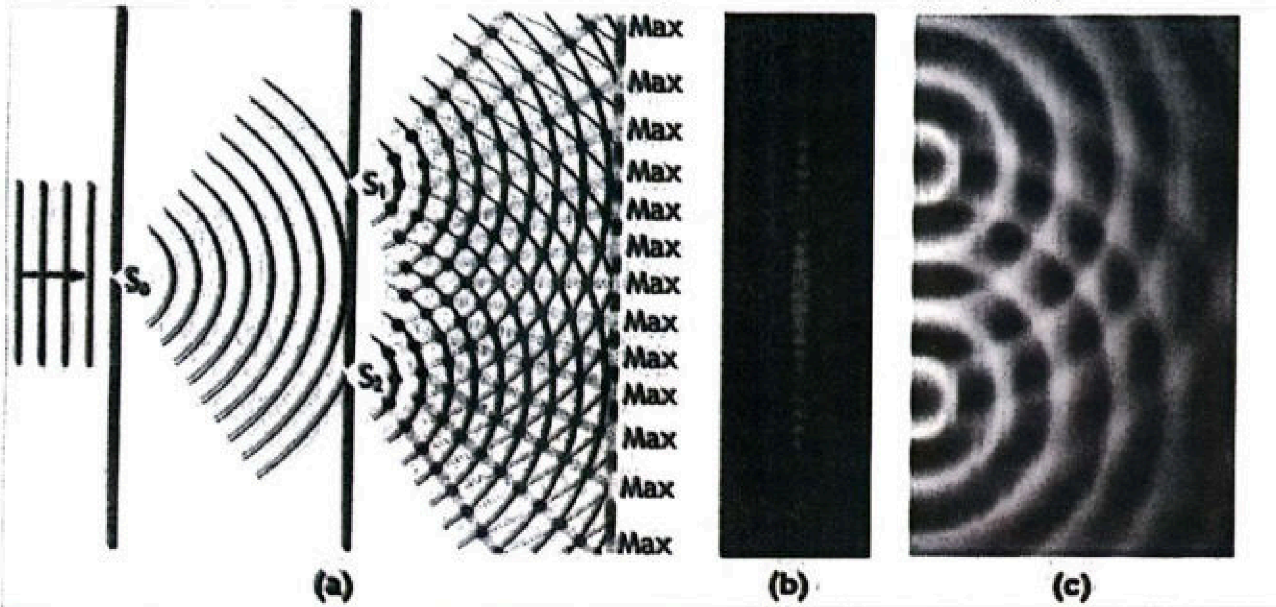

Figure 18.6: Young's double-slit experiment.

Figure 18.6 (c) shows that the double-slit interference pattern for water waves is nearly identical to that for light. Young's use of sunlight in his double-slit experiment made the effect easier to observe. This is because sunlight is a mixture of different wavelengths (colors), and each wavelength formed its own interference pattern on the screen. To observe clear pattern, monochromatic (single-wavelength) light is often used.

Young's experiment confirmed that light exhibits **wave-like behavior**, producing an interference pattern.

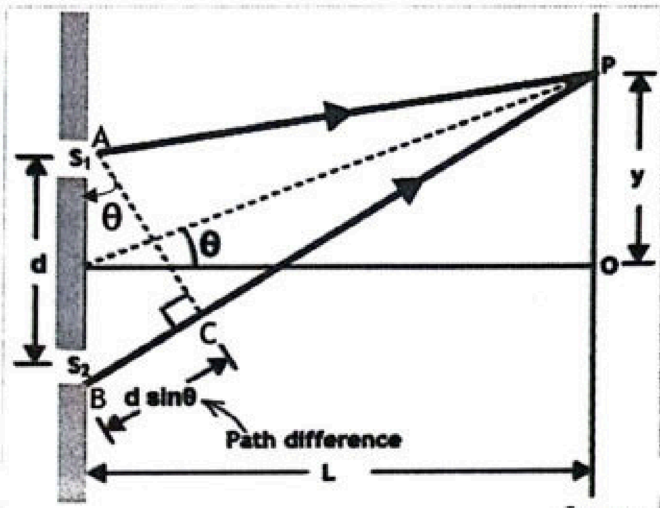

Figure 18.7: Schematic diagram of Young's double slit experiment.

Path Difference: The wave from slit S_2 has to travel slightly larger than that from S_1 to reach the point P on the screen, as shown in Fig. 18.7. The difference in this distance is the path difference. When two waves interfere, the resultant wave depends on the phase difference between the two waves, which is proportional to the path difference between the waves which can be expressed in terms of the wavelength 'λ' of the wave.

If 'd' is the separation distance between the slits, 'L' is distance between the slits and the screen, and 'y' is the distance from the central maximum to the point 'P' on the screen. Then

from the ΔABC: $\sin\theta = \dfrac{BC}{AB}$ or $BC = AB \sin\theta$

Hence, the path difference BC between the waves reaching a point on the screen from the two slits is:

$$\text{Path difference} = d \sin\theta \qquad \text{\_\_\_\_\_ (18.1)}$$

Constructive Interference: Light waves show constructive interference when their crests (peaks) overlap, leading to a bright maximum on the screen. This occurs when the path difference is an integer multiple of the wavelength, i.e.,

$$\text{Path difference} = m\,\lambda$$

or $$d \sin\theta = m\,\lambda \qquad \text{\_\_\_\_\_ (18.2)}$$

Where m is an integer (0, ±1, ±2, ±3, ...) representing the order of the maxima (central maxima is 0^{th} order). When m = ±1, then two bright fringes are obtained one above and one below the central point O, which are called 1^{st} order bright fringes, and so on.

Destructive Interference: Destructive interference happens when the crests of one wave cancel out the troughs of another, resulting in a dark fringe called minima. This occurs when the path difference is an odd multiple of half the wavelength, i.e.,

$$\text{Path difference} = \left(m + \frac{1}{2}\right)\lambda$$

or $$d \sin\theta = \left(m + \frac{1}{2}\right)\lambda \qquad \text{\_\_\_\_\_ (18.3)}$$

Where 'm' is still an integer (0, ±1, ±2, ±3, ...) representing the order of the minima (first minima occurs at m = 0, and is called 1st order minima).

Positions of Maxima and Minima: Let P is the position of m^{th} order bright fringe on screen

then $d \sin\theta = m\lambda$

If 'θ' is very small then $\sin\theta = \tan\theta$

so, $d \tan\theta = m\lambda$

As, $\tan\theta = \dfrac{y}{L}$, so $d\,\dfrac{y}{L} = m\lambda$

or $$y = m\,\frac{\lambda L}{d} \qquad \text{\_\_\_\_\_ (18.4)}$$

Similarly, for the position of m^{th} order dark fringe on screen, we can get:

or $$y = \left(m + \frac{1}{2}\right)\frac{\lambda L}{d} \qquad \text{\_\_\_\_\_ (18.5)}$$

These equations allow you to calculate the positions of maxima and minima on the screen based on the known values of d, L, and λ. Note that the central maxima (m = 0) will always be at y = 0.

Fringe Spacing: **The distance between two consecutive bright or dark fringes is called fringe spacing. For bright fringes, the fringe spacing is:**

$$\Delta y = y_{m+1} - y_m$$

or
$$\Delta y = (m+1)\frac{\lambda L}{d} - m\frac{\lambda L}{d}$$

or
$$\Delta y = \frac{\lambda L}{d} \qquad \text{\_\_\_\_\_ (18.6)}$$

Eq. 18.6 can be used to find fringe spacing if values of d, L, and λ are known. Similarly, for dark fringes, the fringe spacing is:

$$\Delta y = y_{m+1} - y_m$$

or
$$\Delta y = \left(m+1+\frac{1}{2}\right)\frac{\lambda L}{d} - \left(m+\frac{1}{2}\right)\frac{\lambda L}{d} = \frac{\lambda L}{d}$$

So, fringe spacing between the bright and dark fringe is same.

18.1.4 Interference of Microwaves

Microwaves can also be used to demonstrate two-source interference. Two-source interference experiments using microwaves are a fascinating demonstration of wave physics. These experiments typically involve two coherent microwave sources, i.e. microwaves of the same frequency and phase. When these microwaves overlap, they create an interference pattern characterized by alternating regions of constructive and destructive interference.

To observe this pattern, a detector is moved through the various points of interference, registering the intensity of the microwaves. At points of constructive interference, the detector records a higher intensity, while at points of destructive interference, the intensity is significantly lower or even zero. This pattern can be visualized on a screen or through a recording device connected to the detector.

Experimental setup: **One common setup for such an experiment includes a microwave transmitter and a receiver, as shown in Fig 18.8. The transmitter emits microwaves towards**

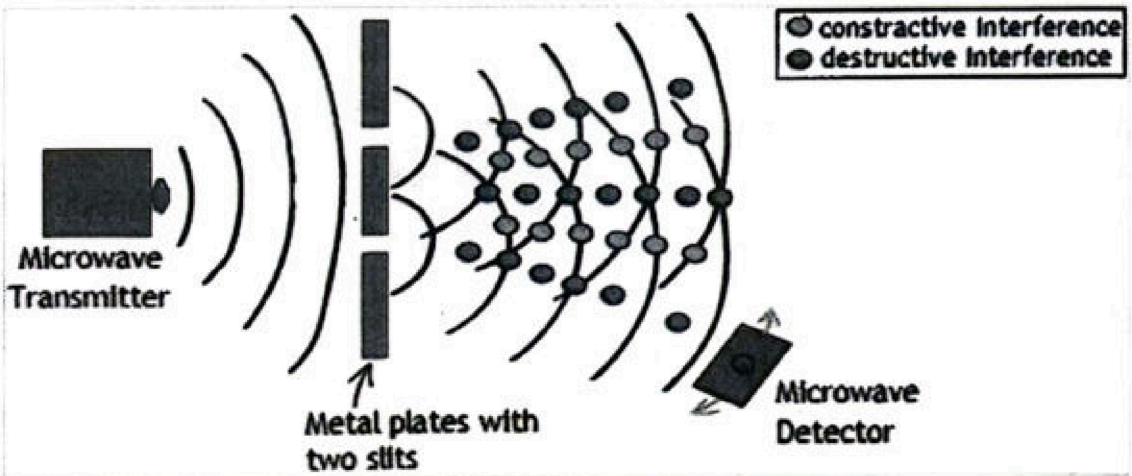

Figure 18.8: Microwave interference experiment.

two slits or openings, which then act as the new sources of waves. As the waves emanate from these slits, they overlap and interfere with each other. The receiver, which is placed at variable distances and angles from the slits, measures the intensity of the resulting microwaves.

The data collected from these experiments can be used to calculate the wavelength of the microwaves, as the distance between the points of maximum or minimum intensity is related to the wavelength and the geometry of the setup. This is a practical application of the principles of wave superposition and interference.

These experiments not only demonstrate the wave nature of microwaves but also have practical implications. For instance, understanding microwave interference is crucial in designing microwave communication systems to avoid signal loss due to destructive interference. Moreover, the principles observed in microwave interference are analogous to those in other wave phenomena, including sound waves, water waves, and even quantum mechanics, where particles exhibit wave-like behavior. Thus, two-source interference experiments with microwaves provide a valuable insight into the broader wave phenomena that govern various aspects of the physical world.

Example 18.1: The fringe spacing between the central maxima and 1st minima is 2 mm. If a light of 500 mm is used then find the separation between the slits. The distance between the slit and screen is 1 m.

Given: Distance between central maximum and 1st minimum $y_1 = 2.0\ mm = 0.002\ m$

Wavelength of light $\lambda = 500\ nm = 5.00 \times 10^{-7}\ m$

Distance between the slits and screen $L = 1.0\ m$

To Find: Slit separation = d = ?

Solution: We can use the relationship between fringe spacing and slit separation, as:

$$y = m\frac{\lambda L}{d}$$

For 1st minima, put m = 1, so we get:

$$y = \frac{\lambda L}{d}$$

Rearranging the equation to solve for d, we get:

$$d = \frac{\lambda L}{y}$$

or

$$d = \frac{(5.00 \times 10^{-7})(1.0)}{0.002} = 2.50 \times 10^{-4}\ m$$

Therefore, the separation between the slits is about 250 micrometers.

Assignment 18.1

Light from a He-Ne laser pass through two slits separated by 0.0100 mm. The third bright line on a screen is formed at an angle of 10.95° relative to the incident beam. What is the wavelength of the light?

18.2 DIFFRACTION GRATING

A diffraction grating is an optical device consisting of a transparent material, such as glass or plastic, having a large number of equally spaced parallel slits or grooves etched or ruled over it, as shown in Fig. 18.9 (a). These slits are closely spaced together and act as individual sources of secondary waves when illuminated by incident light.

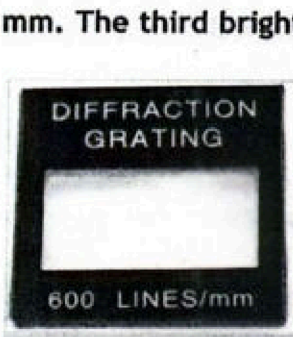

Figure 18.9 (a): Diffraction Grating

The distance between two adjacent slits is called grating element.

Grating element is represented by d, and can be calculated by using the following formula:

$$d = \frac{\text{unit length of grating}}{\text{total number of lines ruled on it}}$$

Grating element is typically of the order of the wavelength of light or smaller. The number of slits per unit length, denoted by "N," determines the resolving power of the diffraction grating.

18.2.1 Diffraction of Light through Diffraction Grating

The principle behind using a diffraction grating, to determine the wavelength of light, is based on the interference pattern produced when light passes through the grating. When monochromatic light (light of a single wavelength) illuminates a diffraction grating, the light waves passing through the slits interfere constructively and destructively, creating a pattern of bright and dark fringes, as shown in Fig. 18.9 (b).

The angle at which the bright fringes (maxima) occur depends on the wavelength of light and the spacing between the slits in the grating. This relationship is described by the equation:

$$d \sin\theta = m\lambda$$

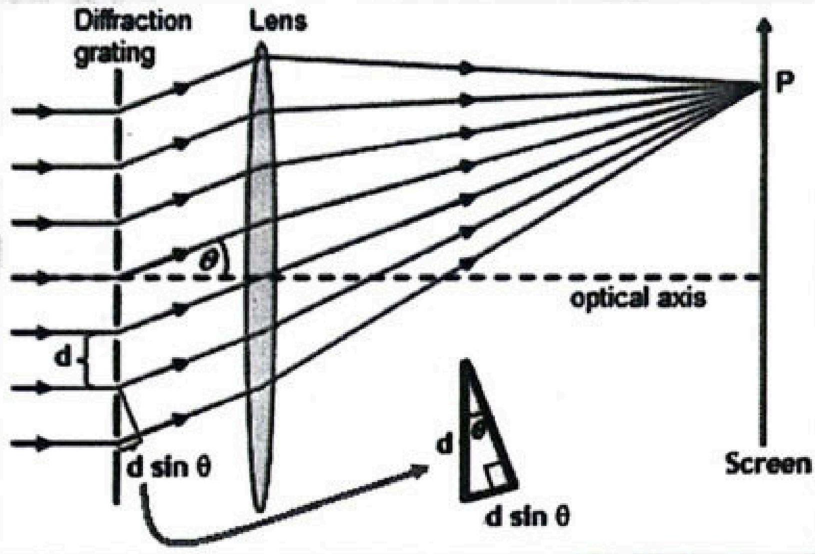

Figure 18.9 (b): Diffraction of light through diffraction grating.

By measuring the angle of diffraction (θ) for a specific order of the bright fringe (m) and knowing the spacing between the slits (d), one can determine the wavelength of light (λ).

By following this procedure, the wavelength of light can be accurately determined using a diffraction grating, making it a valuable tool in spectroscopy and various scientific applications.

An idealized graphs of the intensity of light passing through a double slit and a diffraction grating for monochromatic light is shown in Fig.18.10. Maxima can be produced at the same angles, but those for the diffraction grating are narrower, and hence sharper. The maxima become narrower and the regions between become darker as the number of slits is increased.

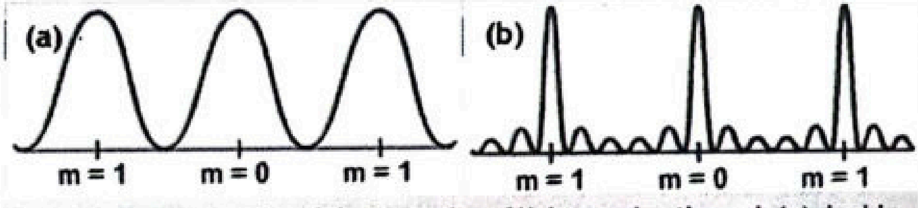

Figure 18.10: Graphs of the intensity of light passing through (a) double slit (b) diffraction grating.

18.2.2 Applications

1. **Wavelength Measurement:** Diffraction grating is used to determine the wavelength of light.

2. **Atomic Spectra Analysis:** Diffraction gratings help analyzing the wavelengths emitted by atoms and molecules.

3. **Biomedical Imaging:** Gratings can be used to selectively analyze specific wavelengths for disease detection in biopsy samples.

4. **Spectroscopy:** Gratings disperse light into its constituent wavelengths for detailed analysis.

Australian opal and the butterfly wings have rows of reflectors that act like diffraction gratings, reflecting different colors at different angles, as shown in Fig. 18.11.

Figure 18.11: Australian opal and the butterfly wings.

Example 18.2: Diffracted light observed at an angle of 30° in the 2nd order (m = 2) with grating constant 2.0 μm. Find the wavelength of the diffracted light.

Given: $\theta = 30^\circ$ $\quad m = 2$

$d = 2.0\ \mu m$

To Find: $\lambda = ?$

Solution: We can use the grating equation, as:

$$m\lambda = d\sin\theta$$

Rearranging the equation to solve for λ, as:

$$\lambda = \frac{d\sin\theta}{m}$$

Putting values, we get:

$$\lambda = \frac{(2\times10^{-6})(\sin 30^\circ)}{2} = 0.50\ \mu m$$

Therefore, the wavelength of the diffracted light is about 0.50 micrometers.

Assignment 18.2

Visible light of wavelength 550 nm falls on a single slit and produces its second diffraction minimum at an angle of 45° relative to the incident direction of the light. What is the width of the slit?

For Your Information

Have you ever seen the grooves on a CD or DVD? Grooves are there, but they are extremely narrow—1,600 in a millimeter. Because the width of the grooves is similar to wavelengths of visible light, they form a diffraction grating. That is why you see rainbows on a CD. The colors are attractive, but they are incidental to the functions of storing and retrieving audio and other data.

18.3 Electron Double Slit Experiment and Interpretations of Quantum Mechanics

The Electron Double Slit Experiment is a classic physics experiment that demonstrates the principles of wave-particle duality and the nature of reality at the quantum level.

Experimental setup of electron double slit experiment is shown in Fig. 18.12. It consists of:

- Electron gun: Electrons are emitted from an electron gun.
- Double slits: The electrons pass through two parallel slits, creating a pattern on a screen behind the slits.
- Screen: The electrons hit the screen, creating a visible pattern.

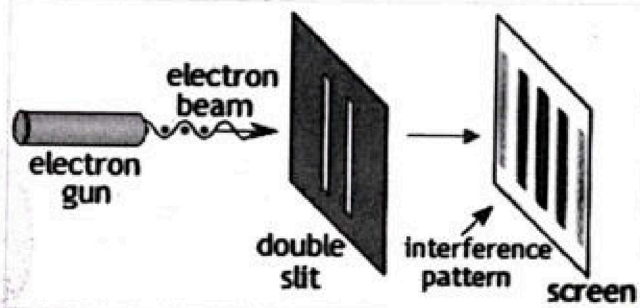

Figure 18.12: Experimental setup of electron double slit experiment.

If electrons were considered classical particles, we would expect two distinct patterns on the screen, corresponding to the two slits. However, the actual outcome is an interference pattern, similar to what we would expect from waves. This suggests that electrons exhibit wave-like behavior.

The Electron Double Slit Experiment has far-reaching implications for our understanding of reality, including:

- Quantum mechanics: It laid the foundation for quantum mechanics, which describes the behavior of particles at the atomic and subatomic level.
- Limits of classical physics: It showed that classical physics is insufficient to describe the behavior of particles at the quantum level.
- Philosophical implications: It raises questions about the nature of reality, observation, and the role of the observer in shaping reality.

The electron double-slit experiment has led to several interpretations of quantum mechanics. The two prominent interpretations in this context are Copenhagen interpretation and many-worlds interpretation.

i) Copenhagen Interpretation

The Copenhagen Interpretation (CI) is a widely-held interpretation of quantum mechanics that was formulated by Niels Bohr and Werner Heisenberg. It states that a quantum system, like an electron before measurement, doesn't possess a definite position or momentum. Instead, it exists in a superposition of all possible states simultaneously. Here's how CI explains the Electron Double Slit Experiment:

- Before detection, the electron is considered to be in a superposition of states, passing through both slits simultaneously (wave-like behavior).

- The act of measurement (detecting the electron on the screen) forces the wave function to collapse into a definite position, explaining why we see a single electron hit at a specific point on the screen (particle-like behavior).
- The interference pattern observed on the screen arises from the probability distribution of where the electron might be detected. Regions with higher probability density correspond to bright fringes, while regions with lower probability density correspond to dark fringes.

Criticisms:

- The "collapse of the wave function" due to measurement seems like an arbitrary break from the deterministic nature of physics.
- It doesn't explain what happens to the "other possibilities" in the superposition before measurement.

The Copenhagen Interpretation remains a widely-held and influential interpretation of quantum mechanics, but its implications and limitations continue to be debated among physicists and philosophers.

ii) Many-Worlds Interpretation

The many-worlds interpretation, proposed by Hugh Everett III in 1957, presents a radically different view of quantum mechanics. It proposes that every interaction in the quantum realm splits the universe into multiple realities (worlds), one for each possible outcome. Each branch of reality carries forward one possibility from the superposition. Here's how many-worlds interpretation explains the Electron Double Slit Experiment:

- The electron initially exists in a superposition, going through both slits in all the newly created worlds.
- In each world, the electron interacts with the detector screen and leaves its mark (particle-like behavior) at a specific location.
- The interference pattern observed on the screen is a reflection of the combined effect of electrons hitting the screen in all the parallel universes. We only experience one world (the one where the electron interacted with our detector), but the interference pattern signifies the existence of the other possibilities.

Criticisms:

- The concept of multiple universes is difficult to test experimentally.
- It doesn't provide a clear explanation of the transition from superposition to a definite state upon measurement.

Both the Copenhagen and Many-Worlds interpretations are attempts to explain the puzzling behavior of quantum systems at the microscopic level. Neither interpretation is universally accepted, and physicists continue to debate their implications. While the experiment demonstrates the wave-particle duality, the underlying reality behind it remains an ongoing exploration in quantum mechanics.

SUMMARY

- **Interference:** The interaction of two or more waves propagating through the same medium, resulting in a superposition effect that can lead to constructive or destructive interference.
- **Constructive Interference:** When the crests (peaks) of two or more waves overlap, they reinforce each other, producing a resultant wave with a higher intensity (brighter light, louder sound) compared to the individual waves.
- **Destructive Interference:** When the crest of one wave coincides with the trough (valley) of another wave, they cancel each other out partially or completely. This results in a weaker resultant wave with a lower intensity (darkness, quieter sound) compared to the individual waves.
- **Superposition Principle:** A fundamental principle in wave physics stating that the resultant wave at any point in space is the sum of the individual waves present at that point. The individual waves can add up constructively or destructively depending on their relative phases (alignment).
- **Coherent Sources:** Waves that have the same frequency and a constant phase relationship are considered coherent. This means the crests and troughs of the waves occur at the same time, allowing for predictable interference patterns.
- **Wavelength (λ):** The distance between two consecutive crests (or troughs) of a wave.
- **Frequency (f):** The number of wave cycles that pass a point in a given unit of time (usually measured in Hertz or Hz).
- **Diffraction:** The bending of a wave around the edges of an obstacle or through a narrow slit. Unlike reflection, where the wave bounces off a surface, diffraction causes the wave to spread out and travel into regions beyond the geometrical shadow of the obstacle.
- **Wave front:** A surface connecting points in a wave that are in the same phase (at the same point in their cycle). In diffraction, the wave front is altered as it interacts with the diffracting object.
- **Slit Width:** The width of the opening through which the wave passes in diffraction. The smaller the slit width compared to the wavelength, the more pronounced the diffraction effect will be.
- **Diffraction Grating:** A periodic structure with many closely spaced parallel slits or grooves. When light or other waves pass through a diffraction grating, they diffract and create a specific pattern of diffracted beams due to constructive and destructive interference.
- **Diffraction Pattern:** The spatial distribution of intensity observed after a wave diffracts around an obstacle or through a slit. This pattern typically consists of alternating bright and dark bands due to constructive and destructive interference of the diffracted waves.
- **Grating Constant (d):** The distance between the centers of two adjacent slits (or grooves) in a diffraction grating. The grating constant plays a crucial role in determining the angles at which the diffracted beams emerge.
- **Copenhagen interpretation** emphasizes indeterminism, complementarity, and the role of measurement, while the **many-worlds interpretation** posits a multitude of parallel universes where all quantum outcomes coexist.

Formula Sheet

$d \sin\theta = m\lambda$ $\quad$ $d \sin\theta = \left(m + \frac{1}{2}\right)\lambda$ $\quad$ $y = m\frac{\lambda L}{d}$

$y = \left(m + \frac{1}{2}\right)\frac{\lambda L}{d}$ $\quad$ $\Delta y = \frac{\lambda L}{d}$ $\quad$ $d = \frac{\text{unit length of grating}}{\text{total number of lines ruled on it}}$

EXERCISE

Multiple Choice Questions

Encircle the Correct option.

1) Rainbows are formed due to:
   A. Reflection of sunlight by water droplets
   B. Refraction of sunlight by water droplets
   C. Interference of sunlight by water droplets
   C. Diffraction of sunlight by water droplets
2) In the double-slit experiment, a pattern of bright and dark bands is observed on the screen. This pattern is evidence of:
   A. Reflection of light
   B. Refraction of light
   C. Wave nature of light
   D. All of the above
3) Monochromatic light from a laser passes through two slits separated by 0.00500mm. The third bright line on a screen is formed at an angle of 18.0° relative to the incident beam. What is the wavelength of the light?
   A. 51.5 nm
   B. 77.3 nm
   C. 515 nm
   D. 773 nm
4) What is the width of a single slit through which 610-nm orange light passes to form a first diffraction minimum at an angle of 30°?
   A. 0.863 μm
   B. 0.704 μm
   C. 0.610 μm
   D. 1.22 μm
5) Two slits are separated by a distance of 3500 nm. If light with a wavelength of 500 nm passes through the slits and produces an interference pattern, the m = _______ order minimum appears at an angle of 30°.
   A. 0
   B. 1
   C. 2
   D. 3
6) What is a diffraction grating?
   A. A single slit that produces a diffraction pattern.
   B. A double slit that produces an interference pattern.
   C. A periodic arrangement of slits or lines that produces a diffraction pattern.
   D. A random arrangement of slits or lines that produces a diffraction pattern.
7) When light travels through a narrow slit, it bends slightly around the edges. This phenomenon is called:
   A. Reflection
   B. Refraction
   C. Diffraction
   D. Dispersion
8) A diffraction grating separates white light into its constituent colors because:
   A. It absorbs certain colors.
   B. It reflects different colors at different angles.
   C. It diffracts different colors at different angles.
   D. It refracts different colors at different angles.

9) Light passing through double slits creates a diffraction pattern. How would the spacing of the bands in the pattern change if the slits were closer together?
A. The bands would be closer together. B. The bands would spread farther apart.
C. The bands would remain stationary. D. The bands would fade and eventually disappear.

10) What is diffraction of light?
A. The bending of light around an obstacle. B. The reflection of light from a surface.
C. The refraction of light through a medium. D. The interference of light waves.

11) The tip of a needle does not give a sharp image. It is due to
A. Polarization B. Interference C. Diffraction D. Refraction

12) What is the pattern formed on a screen when light passes through two parallel slits?
A. A bright central maximum with alternating dark and bright fringes.
B. A dark central minimum with alternating bright and dark fringes.
C. A uniform intensity pattern.
D. A random pattern.

13) What is the wavelength of light falling on double slits separated by 2.0 μm if the third-order maximum is at an angle of 60°?
A. 667nm B. 471nm C. 333nm D. 577nm

14) What is the longest wavelength of light passing through a single slit of width 1.20 μm for which there is a first-order minimum?
A. 1.04 μm B. 0.849 μm C. 0.600 μm D. 2.40 μm

15) What is the distance between lines on a diffraction grating that produces a second-order maximum for 760-nm red light at an angle of 60°?
A. 2.28×10^4 nm B. 3.29×10^2 nm C. 2.53×10^1 nm D. 1.76×10^3 nm

Short Questions

1) How is an interference pattern formed by a diffraction grating different from the pattern formed by a double slit?
2) A beam of light always spreads out. Why can a beam not be produced with parallel rays to prevent spreading?
3) In the sunlight, the shadow of a building has fuzzy edges even if the building does not. Is this a refraction effect? Explain.
4) A laser pointer emits a coherent beam of parallel light rays. Does the light from such a source spread out at all? Explain.
5) A beam of light passes through a single slit to create a diffraction pattern. How will the spacing of the bands in the pattern change if the width of the slit is increased?
6) Describe a diffraction grating and the interference pattern it produces.
7) Suppose a monochromatic light falls on a diffraction grating. What happens to the interference pattern if the same light falls on a grating that has more lines per centimeter.
8) What is the significance of the equation $d\sin(\theta) = m\lambda$ in the context of (a) diffraction gratings (b) Young's double-slit experiment?
9) What is the effect of following aspects of diffraction grating on the resulting interference pattern: (a) number of slits (b) width of the slits?

10) Describe the conditions necessary for sustained interference patterns to be observed in Young's double-slit experiment.

Comprehensive Questions

1) Design an experiment using a ripple tank to demonstrate the principles of interference with water waves. Describe what you expect to observe when two wave sources are introduced.

2) Briefly explain why we see a spectrum of colors (red, orange, yellow, green, blue, indigo, violet) in a rainbow. Is it due to reflection, refraction, or interference of light?

3) Describe two examples of how interference of light waves plays a role in natural phenomena you can observe in everyday life (excluding rainbows).

4) Sometimes, when two tuning forks with slightly different frequencies are struck close together, you hear a wavering sound instead of a clear tone. Explain what causes this "beat" phenomenon, and how is it related to the interference of sound waves?

5) Both CDs and DVDs use lasers to store information, but DVDs hold much more data. How might the principles of diffraction be used in DVD design to achieve this higher storage capacity?

6) Describe a diffraction grating and its key features like grating constant and slit width. How does a diffraction grating separate white light into its constituent colors?

7) Scientists use X-ray diffraction to determine the structure of crystals. Briefly explain how the diffraction pattern of X-rays helps reveal the arrangement of atoms within a crystal lattice.

Numerical Problems

1) The light with wavelength (λ) 633 nm is used at a distance of 2 m from the screen. The separation between the slits is 10 μm. Find the distance between adjacent maxima (fringe width) for the first ($m = 1$) and second ($m = 2$) order of interference?

(Ans: 0.127 mm, fringe width for first order, 0.063 mm, fringe width for second order)

2) Find the distance from the central maximum to the third minimum on the screen, if the light of wavelength 400 nm is used. The distance between the slits and screen is 0.5 m and slit separation is 5 μm? (Ans: 0.024 mm)

3) The distance between the slits and screen is 1m, fringe spacing on screen is 1 mm. Find the slit separation when light wavelength is 500 nm. (Ans: 0.05 mm)

4) Find the minimum angle for non-zero diffracted light, having slit spacing 2.0 μm with 400 nm light wavelength. (Ans: $\theta_{min} = 11.54^\circ$ (minimum angle for first minimum))

5) The deviation of second order diffracted image formed by an optical grating having 5000 lines per centimeter is 32^0. Calculate the wavelength of light used. (Ans: 5.3×10^{-5} cm)