Module 10: Interference and Diffraction (PHY 1200)

Introduction

In the previous module we introduced the basic properties of waves, including wavelength, frequency, and wave speed.

When waves interact with one another or encounter obstacles, new wave patterns can emerge. Two important wave behaviors are interference and diffraction.

These phenomena provide strong evidence that light behaves as a wave.

Understanding interference and diffraction helps explain many physical systems, including:

- sound waves interacting in air
- light patterns produced by lasers
- imaging techniques used in scientific instruments

Wave Interference

Interference occurs when two or more waves overlap in space.

The resulting wave pattern depends on how the individual waves combine.

This combination follows the principle of superposition.

Principle of Superposition

The principle of superposition states that when waves overlap, their displacements add together.

The total displacement at any point is the sum of the individual displacements.

This principle explains how waves interact to produce different interference patterns.

Types of Interference

There are two main types of interference:

- constructive interference
- destructive interference

Constructive Interference

Constructive interference occurs when two waves combine so that their amplitudes reinforce each other.

This happens when:

- crest meets crest
- trough meets trough

The result is a wave with greater amplitude.

Constructive interference increases the energy carried by the wave at that location.

Destructive Interference

Destructive interference occurs when waves combine so that their amplitudes cancel.

This happens when:

• crest meets trough

The result is a wave with reduced amplitude, and in some cases the waves may cancel completely.

Example of Interference

Imagine two identical water waves moving toward each other.

When the crests of the waves meet, the water rises higher than either wave individually.

This is constructive interference.

When a crest meets a trough, the waves partially cancel.

This is destructive interference.

Path Difference and Interference

In many interference problems, waves travel different distances before meeting.

The difference between these distances is called the path difference.

Constructive interference occurs when the path difference equals an integer multiple of the wavelength:

path difference = $n\lambda$

where n is an integer (0, 1, 2, 3, ...).

Destructive interference occurs when the path difference equals a half-integer multiple of the wavelength:

path difference = $(n + ½)\lambda$

Diffraction

Diffraction occurs when waves pass through a narrow opening or around an obstacle.

Instead of continuing in a straight line, the waves spread out.

Diffraction is especially noticeable when the opening is similar in size to the wavelength of the wave.

Examples include:

• sound waves bending around corners
• water waves spreading after passing through a gap
• light waves spreading through narrow slits

Diffraction of Light

Light can exhibit diffraction patterns when it passes through very small openings.

This behavior demonstrates that light behaves as a wave.

When monochromatic light passes through a narrow slit, the light spreads and produces a pattern of bright and dark regions on a screen.

The Double-Slit Experiment

One of the most famous experiments demonstrating the wave nature of light is the double-slit experiment.

In this experiment:

1. Light passes through two closely spaced slits.
2. The light waves emerging from the slits overlap.
3. An interference pattern forms on a screen.

The pattern consists of alternating bright and dark bands.

Bright bands occur where constructive interference occurs.

Dark bands occur where destructive interference occurs.

Path Difference in the Double-Slit Experiment

Constructive interference occurs when:

$d \sin\theta = n\lambda$

where:

d = distance between slits
θ = angle of the bright fringe
λ = wavelength of light
n = integer

This equation allows physicists to predict where bright fringes will appear.

Worked Example

Light with wavelength 600 nm passes through a double-slit apparatus.

If the path difference between the two waves is 600 nm, will the interference be constructive or destructive?

Because the path difference equals one wavelength:

$600 \text{ nm} = 1\lambda$

This produces constructive interference.

A bright fringe appears on the screen.

Example

Suppose the path difference between two waves is 300 nm, while the wavelength is 600 nm.

300 nm = ½λ

This produces destructive interference.

A dark fringe appears on the screen.

Diffraction Gratings

A diffraction grating is an optical device containing many closely spaced slits.

When light passes through a diffraction grating, an interference pattern with many bright fringes appears.

Diffraction gratings are widely used in instruments that measure the wavelengths of light.

Examples include:

- spectrometers
- optical analysis equipment

Applications of Interference and Diffraction

Interference and diffraction play important roles in many technologies.

Examples include:

- optical instruments
- fiber-optic communication
- spectroscopy
- holography

These technologies rely on understanding how waves interact.

Practice Problems

1. What is the principle of superposition?
2. What type of interference occurs when two crests meet?
3. What type of interference occurs when a crest meets a trough?
4. If the path difference equals one wavelength, what type of interference occurs?
5. Describe what happens during diffraction.

Challenge Problems

1. Light with wavelength 500 nm produces constructive interference.
   What is the smallest nonzero path difference?
2. If the path difference equals ½ wavelength, what type of interference occurs?
3. Explain why diffraction becomes more noticeable when the opening size is similar to the wavelength.