Physics 272 – Lecture 26
Interference
(Ch 35.1-3)
• Young’s Double Slit Experiment
• Interference
Superposition

Constructive

In Phase
Superposition

Destructive

Out of Phase 180 degrees
Superposition Question

1) Constructive  
2) Destructive  
3) Neither
Interference: Key Idea

Two rays travel almost exactly the same distance.

Bottom ray travels a little further.

Key for interference is this small extra distance.
Interference Requirements

- Two (or more) waves
- Same Frequency
- Coherent (waves must have definite phase relation)
Interference with Light

- Can’t produce coherent light from two separate sources. $f \approx 10^{14} \text{ Hz}$

- Get two waves from single source taking different paths
  - Two slits
  - Reflection (thin films)
  - Diffraction
Young’s Experiment
Young’s Experiment

Constructive Interference:
\[ d \sin \theta = m \lambda, \ m = 0,1,2,\ldots \]

Destructive Interference:
\[ d \sin \theta = \left( m + \frac{1}{2} \right) \lambda, \ m = 0,1,2,\ldots \]

Intensity falls off with increasing angle
Young’s Double Slit Question?

1) Constructive
2) Destructive
3) Depends on L

The rays start in phase, and travel the same distance, so they will arrive in phase.

Single source of monochromatic light $\lambda$

2 slits-separated by $d$

Screen a distance $L$ from slits
Young’s Double Slit Question?

Single source of monochromatic light $\lambda$

2 slits - separated by $d$

The rays start out of phase, and travel the same distance, so they will arrive out of phase.

1) Constructive
2) Destructive
3) Depends on $L$

Screen a distance $L$ from slits
Consider a modified Young two slit experiment, in which the light coming to the lower slit has its phase shifted by one half a wavelength, relative to the light coming to the top slit.

Comparing to the usual Young experiment, which of the following statements is true?

1. The pattern of maxima and minima is the same for original and modified experiments

2. Maxima and minima for the unmodified experiment now become minima and maxima for the modified experiment
Young’s Double Slit w/ 2 sources?

Two sources

2 slits-separated by d

Is the interference
1) Constructive
2) Destructive
3) Depends on L
4) No interference

If the sources are different there is no coherence between phases.

Screen a distance L from slits
Young’s Double Slit Concept

At points where the difference in path length is 0, $\lambda, 2\lambda$, ..., the screen is bright.

At points where the difference in path length is $\frac{\lambda}{2}, \frac{3\lambda}{2}, \frac{5\lambda}{2}, ...$ the screen is dark.

Single source of monochromatic light $\lambda$

2 slits-separated by $d$

Screen a distance $L$ from slits
Young's Double Slit Quantitative

Path length difference

Constructive interference

Destructive interference

where \( m = 0, \text{ or } 1, \text{ or } 2, \ldots \)

Need \( \lambda < d \)
In the Young double slit experiment, is it possible to see interference maxima when the distance between slits is smaller than the wavelength of light?

1. Yes

2. No

Constructive Interference:

\[ d \sin \theta = m\lambda \], \( m = 0, 1, 2, \ldots \)

\[ \sin \theta = m \frac{\lambda}{d} < 1 \]

\[ \frac{\lambda}{d} > 1 \quad \text{is NOT possible.} \]
Young’s Double Slit Quantitative

Constructive interference \( d \sin \theta = m \lambda \)

Destructive interference \( d \sin \theta = (m + \frac{1}{2}) \lambda \)

where \( m = 0, \text{ or } 1, \text{ or } 2, \ldots \)

\[
\sin(\theta) \approx \frac{y}{L}
\]

\[
y = \frac{m \lambda L}{d}
\]

\[
y = \frac{\left( m + \frac{1}{2} \right) \lambda L}{d}
\]
Suppose a Young two slit experiment is totally immersed in water. How does the pattern of maxima and minima change compared to the usual Young experiment conducted in air?

1. the pattern of maxima and minima stays the same.

2. for the experiment in water the maxima and minima occur at smaller angles.

3. for the experiment in water the maxima and minima occur at larger angles.

\[ d \sin \theta = m\lambda' = \frac{m\lambda}{n = 1.3} \]
Thin Film Interference

Get two waves by reflection off of two different interfaces.

Ray 2 travels approximately $2t$ further than ray 1.
Reflection + Phase Shifts

Upon reflection from a boundary between two transparent materials, the phase of the reflected light may change.

If $n_1 > n_2$ there is no phase change upon reflection.
If $n_1 < n_2$ there is a phase change of $180^\circ$ upon reflection. (This is equivalent to the wave shifting by $\lambda/2$.)
Thin Film Interference

Determine $\delta$, number of extra wavelengths for each ray.

Ray 1: $\delta_1 = 0$ or $0.5 + 0$
Ray 2: $\delta_2 = 0$ or $0.5 + 2t/\lambda_{\text{film}}$

If $|(\delta_2 - \delta_1)| = 0, 1, 2, 3 \ldots$ m constructive
If $|(\delta_2 - \delta_1)| = 0.5, 1.5, 2.5 \ldots$ (m+0.5) destructive
A thin film of gasoline ($n_{\text{gas}} = 1.20$) and a thin film of oil ($n_{\text{oil}} = 1.45$) are floating on water ($n_{\text{water}} = 1.33$). The thickness of the two films is exactly one wavelength.

The gasoline film appears to be

A. Bright
B. Dark

Since $n_{\text{air}} < n_{\text{gasoline}} < n_{\text{water}}$, there is no additional phase difference between the two reflected rays - the only phase difference is due to thickness, which is a multiple of $\lambda$. Therefore, this results constructive interference.
Thin Film Interference

A thin film of gasoline (n_{gas} = 1.20) and a thin film of oil (n_{oil} = 1.45) are floating on water (n_{water} = 1.33). The thickness of the two films is exactly one wavelength.

The oil film appears to be

A. Bright
B. Dark

Since n_{oil} > n_{air} & n_{oil} > n_{water}, there is an additional phase difference (180°) between the two reflected rays. Therefore, this results destructive interference.
All 3 rays are interfering constructively at the point shown. If the intensity from ray 1 is $I_0$, what is the combined intensity of all 3 rays?

1) $I_0$  
2) $3I_0$  
3) $9I_0$

Each slit contributes amplitude $E_0$ at screen. $E_{tot} = 3E_0$.

But $I \propto E^2$. \[ I_{tot} = (3E_0)^2 = 9E_0^2 = 9I_0 \]
When rays 1 and 2 are interfering destructively, is the intensity from the three rays a minimum? 1) Yes 2) No

Rays 1 and 2 completely cancel, but ray 3 is still there. Expect intensity $I = \frac{1}{9} I_{\text{max}}$
Three slit interference

\[ d \sin \theta = \frac{\lambda}{3}, \frac{\lambda}{2}, \frac{2\lambda}{3}, \frac{\lambda}{3}, \frac{\lambda}{2}, \frac{2\lambda}{3}, \lambda \]
Multiple Slit Interference
(Diffraction Grating)

Path length difference 1-2

Path length difference 1-3 = 2d sinθ = 2λ
Path length difference 1-4 = 3d sinθ = 3λ

Constructive interference for all paths when

\[ d \sin \theta = m \lambda \]
Multiple Slit Interference
(Diffraction Grating)

For many slits, maxima are still at

\[ \sin \theta = m \frac{\lambda}{d} \]

Region between maxima gets suppressed more and more as no. of slits increases.

\[ N=2 \]

\[ N=10 \]