Today’s Topics

- Wave Nature of Waves: Interference
- Breakdown of ray approximation
- Huygen’s principle
- Light as Waves
- Double-Slit Interference
- Multi-Slit Interference
Reminder: Light and Optics

- Nature of Lights
  - Lights as rays
  - Lights as EM waves: f, $\lambda$, $\phi$, $v$, A, interference ...
  - Lights as group of photons

- Optics: Physics of lights
  - Geometric Optics: Treat light as rays (Ch. 35,36)
    → Ray approximation.
  - Wave Optics: Wave properties becomes important
    Interferences, diffraction…(Ch. 37,38)
Ray Approximation

- When the wavelength of the light is much smaller than the size of the optical objects it encounters, it can be treated as (colored) rays.

Ray approximation is valid when $\lambda << d$

Ray approximation is not valid near the gap when $\lambda \approx d$. OK elsewhere
The Huygens’ Principle

- Every point on a wave front can be considered as a secondary source of waves that spread out in the forward direction. The new wave is the result of the superposition of these secondary waves.
Reminder: Light Waves

- Nature of Lights:
  Rays (classical), \( \rightarrow \) EM waves\( \leftarrow \), \( \rightarrow \) Photons\( \leftarrow \).

- Review: Electromagnetic plane waves
  \[
  E = E_{\text{max}} \sin(\omega t - kx + \phi), \quad B = B_{\text{max}} \sin(\omega t - kx + \phi), \quad \frac{E}{B} = c
  \]

  ➢ As the \( E \) component and \( B \) component of an EM wave are 100% correlated, we can use just one of them to represent an EM wave.
Interference of Light Waves

When two light waves meet at certain location, the resulting effect is determined by the superposition (i.e. sum) of the two individual waves.

- e.g. Two light waves with same color and amplitude.
  \[ E_1 = E_0 \sin(\omega t-kx+\phi_1) = E_0 \sin(\omega t+\phi_1) \]
  \[ E_2 = E_0 \sin(\omega t-kx+\phi_2) = E_0 \sin(\omega t+\phi_2) \]

\[ \rightarrow E = E_1 + E_2 = 2E_0 \cos(\Delta\phi/2) \sin(\omega t + \phi/2) \]

- Resulting amplitude: \( E_{\text{max}} = 2E_0 \cos(\Delta\phi/2) \)
  - Constructive interference: \( \Delta\phi = 0, 2\pi, 4\pi, \ldots \)
    \( E_{\text{max}} = 2E_0 \)
  - Destructive interference: \( \Delta\phi = \pi, 3\pi, 5\pi, \ldots \)
    \( E_{\text{max}} = 0 \)

Quiz: If the intensity of each incoming light is \( I \), what is the resulting intensity when (1): constructive, (2): destructive?
Test of the Wave Nature of Light: Double-Slit Experiment

- Rays or Waves:

  If lights behave as rays

  If lights behave as waves

  Diffraction & interference

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Young’s Famous Double-Slit Experiment
Thomas Young (1803)

See demo
Double-Slit Experiment Explained

- The experiment can be easily explained by interference

Constructive, $\Delta \phi = 0\pi, 2\pi, 4\pi, ..$

Destructive, $\Delta \phi = \pi, 3\pi, 5\pi, ..$
Double-Slit Experiment Explained

- The experiment can be easily explained by interference.

Constructive, $\Delta \phi = 0\pi, 2\pi, 4\pi, \ldots$

Destructive, $\Delta \phi = \pi, 3\pi, 5\pi, \ldots$
Quantitatively

\[ \Delta \phi = k(r_2 - r_1) = kd \sin \theta = \frac{2\pi d}{\lambda} \sin \theta \]

\[ I = I_o \cos^2\left(\frac{\pi d \sin \theta}{\lambda}\right) \]
Double-Slit Experiment Explained

- **Constructive:** $\Delta \phi = 0\pi, 2\pi, 4\pi, \ldots$, or $2m\pi$, $m=0,1,2\ldots$

\[
\frac{2\pi d}{\lambda} \sin \theta = 2m\pi \quad \Rightarrow \quad d \sin \theta = m\lambda
\]

Bright spots

- **Destructive:** $\Delta \phi = \pi, 3\pi, 5\pi, \ldots$, or $(2m+1)\pi$, $m=0,1,2\ldots$

\[
\frac{2\pi d}{\lambda} \sin \theta = 2(m + 1)\pi \quad \Rightarrow \quad d \sin \theta = (m + \frac{1}{2})\lambda
\]

Dark spots
Multi-Slit Interference

- # secondary maxima = N - 2
- Higher N → more suppression on secondary minima
  (Grating: N>1000, highly sensitive to λ, good for measuring λ.)