Physics 202, Lecture 26

Today’s Topics

- Wave Nature of Waves: Interference
  - The Huygens’ Principle
    - Derivation of the Law of Refraction
  - 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. 32, 33)
    - Ray approximation.
  - Wave Optics: Wave properties becomes important
    Interferences, diffraction…(Ch. 34, 35)
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.
The Huygens’ Principle and Refraction

\[
\sin \theta_1 = \frac{v_1 t}{AD} \\
\sin \theta_2 = \frac{v_2 t}{AD}
\]

\[
\frac{\sin \theta_1}{\sin \theta_2} = \frac{v_1}{v_2}
\]
Reminder: Light Waves

- **Nature of Lights:**
  - Rays (classical), ➔ EM waves ⇐, ➔ Photons ⇐.

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

  - 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.
    \[ E_1 = E_0 \sin(\omega t - kx + \phi_{10}) = E_0 \sin(\omega t + \phi_1) \]
    \[ E_2 = E_0 \sin(\omega t - kx + \phi_{20}) = E_0 \sin(\omega t + \phi_2) \]

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

\[ \Rightarrow \text{Resulting amplitude: } E_{\text{max}} = 2E_0 \cos(\Delta \phi/2) \]
  - 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**
Young’s Famous Double-Slit Experiment
Thomas Young (1803)

See demo
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,** $\Delta \phi = 0\pi, 2\pi, 4\pi, ..$

**Destructive,** $\Delta \phi = \pi, 3\pi, 5\pi, ..$
Quantitatively

\[ \Delta \phi = k(s_2 - s_1) = kd \sin \theta = \frac{2\pi d}{\lambda} \sin \theta \]
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 $(2m+1)\pi$, $m=0,1,2\ldots$

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

Dark spots
# secondary maxima = N - 2

Higher N \rightarrow more suppression on secondary minima

(Grating: N>1000, highly sensitive to \( \lambda \), good for measuring \( \lambda \).)