Physics 202, Lecture 27

Today’s Topics

- Wave Nature of Lights: Interference
- Light as Waves
- Double-Slit Interference
- Multi-Slit Interference
- Thin film interference

Light and Optics

- Nature of Light
  - Light as rays
  - Light as EM waves: f, \( \lambda \), \( \phi \), v, A, interference ...
  - Light as group of photons

- Optics: Physics of light
  - Geometric Optics: Treat light as rays
    → Ray approximation.
  - Wave Optics: Wave properties becomes important.
    Interferences, diffraction

Reminder: Light Waves

- Nature of Light:
  - 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.

Useful Math Formulas

- Small angle approximations:
  \( \sin \theta \sim \theta \), \( \tan \theta \sim \theta \), when \( \theta \sim 0 \)

- Long distance approximation: \( y \sim L^* \theta \), when \( L > y \)

- \( \cos(0) = 1, \cos\pi = -1, \cos2\pi = 1, ... \)
  \( \cos\pi/2 = \cos3/2\pi = \cos5/2\pi = 0, ... \)

Quick Review

- Superposition Principle (ch. 16).
  - when two waves, \( y_1(x,t) \) and \( y_2(x,t) \) meet, the resulting wave is the algebraic sum of the two waves: \( y(x,t) = y_1(x,t) + y_2(x,t) \)

- Intensity of an EM wave \( I = S/c = E_{\text{max}}^2 = B_{\text{max}}^2 \)

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.
    \( E_1 = E_{\text{max}} \sin(\omega t-kx+\phi_1) = E_{\text{max}} \sin(\omega t+\phi_1) \)
    \( E_2 = E_{\text{max}} \sin(\omega t-kx+\phi_2) = E_{\text{max}} \sin(\omega t+\phi_2) \)
  - using trig ids
    \( E = E_1 + E_2 = 2E_{\text{max}} \cos(\Delta \phi/2) \sin(\omega t + \phi) \)
  - Resulting amplitude: \( E_{\text{max}} = 2E_0 \cos(\Delta \phi/2) \)
  - Constructive interference: \( \Delta \phi = 0, 2\pi, 4\pi, ... \) \( E_{\text{max}}^2 = (+/-)2E_0^2 \)
  - Destructive interference: \( \Delta \phi = \pi, 3\pi, 5\pi, ... \) \( E_{\text{max}} = 0 \)
  - It all depends on \( \Delta \phi \)!
  - If the intensity of each incoming light is 1, what is the resulting intensity when (1): constructive, (2): destructive?
Constructive and Destructive Interference

Resulting amplitude: \( E_{\text{max}} = 2E_0 \cos(\Delta \phi/2) \)

- **Constructive, \( \Delta \phi = 0, 2\pi, 4\pi, \ldots \)**
  - Intensity: \( I \propto E_{\text{max}}^2 = B_{\text{max}}^2, \ 4I \)

- **Destructive, \( \Delta \phi = \pi, 3\pi, 5\pi, \ldots \)**

Test of the Wave Nature of Light: Double-Slit Experiment

- **Rays or Waves?**
  - Diffraction & interference

- **If lights behave as rays:**
  - Diffraction bending or waves around corners when a portion of the wave is cut off by a barrier

- **If lights behave as waves:**
  - Constructive, \( \Delta \phi = 0, \pi, 2\pi, 3\pi, \ldots \)
  - Destructive, \( \Delta \phi = \pi, 2\pi, 3\pi, \ldots \)

Young’s Famous Double-Slit Experiment

Thomas Young (1803)

Double-Slit Experiment Explained

- **The experiment can be easily explained by interference**

- **Constructive, \( \Delta \phi = 0, 2\pi, 4\pi, \ldots \)**
  - Bright spots: \( y = mL \lambda /d \)
  - Dark spots: \( y = (m+1/2)L \lambda /d \)

- **Destructive, \( \Delta \phi = \pi, 3\pi, 5\pi, \ldots \)**
  - Bright spots: \( y = mL \lambda /d \)
  - Dark spots: \( y = (m+1/2)L \lambda /d \)

Quantitatively

- **Path length difference:** \( \delta = dsin \theta = d \lambda \sin \theta /L \)

- **\( \Delta \phi = \frac{2\pi}{\lambda} (r_2 - r_1) = \frac{2\pi d}{\lambda} \sin \theta, k = \frac{2\pi}{\lambda} \)**

- **Intensity:** \( I = I_0 \cos^2 \left( \frac{\pi d \sin \theta}{\lambda} \right) \)

Minima and Maxima

- **Constructive:** \( \Delta \phi = 0, \pi, 2\pi, \ldots, \text{ or } 2m\pi, m=0,1,2,\ldots \)
  - Bright spots: \( y = mL \lambda /d \)
  - Dark spots: \( y = (m+1/2)L \lambda /d \)

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

- **Path length difference:** \( \delta = dsin \theta = d \lambda \sin \theta /L \)

- **Intensity:** \( I = I_0 \cos^2 \left( \frac{\pi d \sin \theta}{\lambda} \right) \)
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).

\[ Y_N = mL/\lambda - d \]

Minimum d gives largest maximum. 2d separated slits will contribute when m=2, 3d when m=3.

Photon interference?

- Do an interference experiment again.
- But turn down the intensity until only ONE photon at a time is between slits and screen.
- Is there still interference?

Possible Phase Change of 180°

- For Reflected Light
  - When a light traveling in medium 1 of \( n_1 \) is reaches at a boundary with medium 2 of \( n_2 \):
    - The reflected light has a 180°(π) phase shift if \( n_1 < n_2 \)
    - There is no phase change for reflected light if \( n_1 > n_2 \)
    - In any case, no phase shift for refracted light

Thin Film Interference

- Thin film splits light → split lights then interfere
- Phase change \( \pi \)
- \( \Delta \phi_{12} \approx (2\pi\lambda/n)(2t) + \pi \)
- \( \Delta \phi_{34} \approx 2\pi\lambda/n(2t) \)