Physics 202, Lecture 25

Today’s Topics

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

Exam 3 Result

Average 76.6
Median: 78
A: [89-100]
AB, B: [77-88]
BC, C: [53-76]
D: [<53]

Reminder: Light and Optics

- Nature of Lights
  - Lights as rays
  - Lights as EM waves: f, λ, φ, 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)

Reminder: Light Waves

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

- Review: Electromagnetic plane waves
  - $E = E_{max}\sin(\omega t-kx+\phi)$, $B = B_{max}\sin(\omega t-kx+\phi)$, $E/B = c$
  - 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.
Quick Reviews

- Superposition Principle (ch. 18).
  - 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 (ch. 34)
  - \( I = \frac{S}{c} = E_{\text{max}}^2 = B_{\text{max}}^2 \)

Useful Math Formulas

\[
\sin(\alpha + \beta) = \sin \alpha \cos \beta + \cos \alpha \sin \beta
\]

\[
\cos(\alpha + \beta) = \cos \alpha \cos \beta - \sin \alpha \sin \beta
\]

Small angle approximations:

\[
\sin \theta \approx \theta, \quad \tan \theta \approx \theta, \quad \text{when } \theta \approx 0
\]

Long distance approximation:

\[
d \approx L^* \theta, \quad \text{when } (L >> d)
\]

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.
    - \( E_1 = E_0 \sin(\omega t - kx + \phi_1) = E_0 \sin(\omega t + \phi_1) \)
    - \( E_2 = E_0 \sin(\omega t - kx + \phi_2) = E_0 \sin(\omega t + \phi_2) \)
  - \( \Delta \phi = \phi_1 - \phi_2 \)
  - \( E = E_1 + E_2 = 2E_0 \cos(\Delta \phi/2) \sin(\omega t + \phi/2) \)

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: \( \Delta \phi = \pi, 3\pi, 5\pi, \ldots \) \( E_{\text{max}} = 0 \)

It all depends on \( \Delta \phi \)!

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

(a) Constructive, \( \Delta \phi = 0\pi, 2\pi, 4\pi, \ldots \)

(b) Destructive, \( \Delta \phi = \pi, 3\pi, 5\pi, \ldots \)
Test of the Wave Nature of Light: Double-Slit Experiment

- Rays or Waves:
  - If lights behave as rays
  - If lights behave as waves

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

One More Review (ch. 18)
Path Length And Path Length Difference

- Remember a Phy201 problem like this?

- For two interfering waves coming through different paths the phase difference:
  \[ \phi = k(r_1 - r_2) + \Delta \phi_{\text{at the source}} \]
  where \( r_1 \) and \( r_2 \) are path lengths,
  \( \Delta r = (r_1 - r_2) \) is called path length difference

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

Path length difference
\[ \delta = d \sin \theta - d \frac{\gamma}{l} \]

\[ \Delta \phi = k(s_1 - s_2) = kd \sin \theta = \frac{2\pi d}{\lambda} \sin \theta \]

\[ I = I_0 \cos^2 \left( \frac{\pi d \sin \theta}{\lambda} \right) \]

Double-Slit Experiment Explained

- **Constructive:**
  \[ \Delta \phi = 0, 2\pi, 4\pi, \ldots, \text{or} \ 2m\pi, \ m=0,1,2\ldots \]
  \[ \frac{2\pi d}{\lambda} \sin \theta = 2m\pi \]
  \[ d \sin \theta = m\lambda \]

  Bright spots

- **Destructive:**
  \[ \Delta \phi = \pi, 3\pi, 5\pi, \ldots, \text{or} \ (2m+1)\pi, \ m=0,1,2\ldots \]
  \[ \frac{2\pi d}{\lambda} \sin \theta = 2(m+1)\pi \]
  \[ d \sin \theta = (m + \frac{1}{2})\lambda \]

  Dark spots

Multi-Slit Interference

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

Extra: Lenz’s Law and Jumping Ring

- Lenz’s law in plain words: the induced emf always tends to work against the original cause of flux change

Self reading:
Phasor Method
(Not to be examined)