Physics 202, Lecture 28

Today’s Topics
- Exam information
- Review: Interference
- Thin Film Interference
- Change of Phase at Boundaries
- Thin Film Interference
- Anti-Reflective Coating
- Diffraction
- Single Slit interference

About the Final Exam: Logistics
- The exam will be at 7:25-9:25pm on Tuesday, Dec 20th:
  - Rooms TBA by email
  - It will be exactly 120 minutes.
  - Distribution of tests starts at 7:15pm.
- Four (3+1) 8½ x 11” single sided sheets are allowed.
  - This allows you to use your previous three sheets and prepare one new sheet for the final few chapters
  - Or you can make a completely new set of sheets
  - Put down whatever you like, prepare it yourself. (no photocopying, download-printing of lecture notes/exam solutions/examples etc.)
- Any calculator is fine.
- A 2B pencil for Scantron.
- Contact us if special arrangements are necessary
  - Other exams at the same time. Other conflicting university activities

About the Final Exam: Content
- The Exam is cumulative.
  - 1-2 questions each for chapters 21-30
  - 3-4 questions each for 31-33
  - Will send out practice questions on 31-33 by Friday
- There will be 25 multiple-choice problems.

Interference Quantitatively

Interference: Minima and Maxima
- Maxima: Bright spots
  \[ \frac{2\pi d}{\lambda} \sin \theta = 2m\pi \quad \Rightarrow \quad d \sin \theta = m\lambda \]
  \[ y = m\ell /d \]
  Max angle of maxima: \( \sin \theta = m\ell /d < 1, m < \frac{\ell}{\lambda} \)
- Destructive: \( \Delta \phi = \pi, 3\pi, 5\pi, \ldots \) or \( (2m+1)\pi, m=0,1,2 \ldots \)
  \[ \frac{2\pi d}{\lambda} \sin \theta = (2m+1)\pi \quad \Rightarrow \quad d \sin \theta = (m + \frac{1}{2})\lambda \]
  Minima: Dark spots \( y = (m+\frac{1}{2})\ell /d \)

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?
Single-photon interference

- P.A.M. Dirac (early 20th century):
  "... each photon interferes with itself. Interference between different photons never occurs."

Needed the ideas of quantum mechanics to explain the wavelike and particle-like results of interference experiments.

Possible Phase Change of 180°
For Reflected Light
- When a light traveling in medium 1 of $n_1$ reaches a boundary with medium 2 of $n_2$:
  - The reflected light has a 180° 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 $\rightarrow$ split lights then interfere
- $\Delta \phi_{12} = \frac{2\pi}{\lambda n} (2t) + \pi$
- $\Delta \phi_{34} = \frac{2\pi}{\lambda n} (2t)$

Non Reflective Coating
- Determine the minimum thickness (t) of SiO coating on Si so a light of 550nm is non-reflective at the surface.

Solution:
Non *reflective*
$\rightarrow$ 1 and 2 cancel each other (destructive interference)
$\Delta \phi_{12} = \frac{2\pi}{\lambda n} 2t + 0° = \pi$
$\rightarrow t = \frac{\lambda}{4n} = 94.8 \text{ nm}$.
Note t is $\lambda$ dependent.

Exercise: Pro-Reflective Coating
- Determine the minimum thickness (t) of SiO coating so a light of 550nm is max-reflective at the surface.

Solution: Pro- "reflective"
$\rightarrow$ 1 and 2 interference constructively
$\Delta \phi_{12} = \frac{2\pi}{\lambda n} 2t + 0° = 0$, or $2\pi$
$\rightarrow t = \frac{\lambda}{2} = \lambda/(2n) = 189.6 \text{ nm}$.
Note t is $\lambda$ dependent.

Color Separation:
Make Colorful World Out Of (White) Daylight
- Color: Light with certain frequency.
- Daylight: a mixture of all colors $\rightarrow$ appears white.
- Three ways to make daylight colorful:
  - Filtering: Only one color is allowed to pass
  - Dispersion: Different colors at different refractive angles
  - Interference: Different colors get enhanced/weakened at different path-length difference, which is a function of thickness, observing angle, etc. (pictures next page)
Colorful Interference Patterns

Multi-Slit Interference

Max y = mLλ/d
Min y = (m+½)Lλ/d
Minimum d gives largest maximum.

N slits
2d separated slits will contribute when m=2, 3d when m=3

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

Conditions for Ray Approximation and Diffraction

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

Ray approximation is valid when λ≪d
Ray approximation is not valid near the gap when λ~d. Diffraction occurs

Single-Slit Interference (Single-Slit Diffraction)

If lights were just rays

Where Are the Dark Fringes?

The dark fringes occur at:
I=0 ⇒ sin(β/2)=0 ⇒ (mλ/D)sinθ_m,n=0 ⇒
sinθ_m,n=mλ/D, m=±1, ±2, ±3,...

→ Central bright dot width Δθ=2λ/D, First dark fringes at ±λ/D

Single-Slit Diffraction Pattern Explained

The slit is not a point source → Interference

E_z = ∑ E_i sin(2πz/D)sinθ

I = I_0 [sin(β/2)]^2
β = 2πD/Dsinθ

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Lights As Rays?

- Due to diffraction, light beam of finite size can never travel as perfect straight rays!

- Numerical example: Estimate the size of laser beam on screen ($\lambda \sim 600$nm, $L = 1m$)
  - $a = 1cm$, $\theta / \lambda \sim a = 6 \times 10^{-4}$, $a' \sim 1.01cm \rightarrow +1\%$
  - $a = 2mm$, $\theta / \lambda \sim a = 3 \times 10^{-4}$, $a' \sim 2.6mm + 0.6mm \rightarrow +30\%$
  - $a = 1mm$, $\theta / \lambda \sim a = 6 \times 10^{-5}$, $a' \sim 1mm + 1mm \rightarrow +100\%$
  - $a = 0.1mm$, $\theta / \lambda \sim a = 6 \times 10^{-3}$, $a' \sim 0.1mm + 1.2mm \rightarrow +12000\%$