Chapter 24

The Wave Nature of Light
Reminder: Light is an EM wave

\[ E_y = E_{\text{max}} \sin(\omega t - kx) \]

\[ B_z = B_{\text{max}} \sin(\omega t - kx) \]

\[ k = \frac{2\pi}{\lambda} \quad \omega = \frac{2\pi}{T} \]
Monochromatic Light

• monochromatic light = composed of radiation of a certain wavelength
• There is no such thing (there always is some wavelength range), but:
  – We can use a filter
  – We can use a laser: \( \frac{\Delta \lambda}{\lambda} \sim 10^{-9} \)
Dispersion

- Visible white light is not monochromatic, it is composed of all colors
- dispersion = dependence of \( n \) on \( \lambda \)
Rainbow

θ greater for red

θ greater for violet
color sequence reversed
Interference and Diffraction

• Interference = result of two (or more) waves overlapping in space
• Diffraction = ability of waves to “go around the corner”
• There is no fundamental distinction between the two phenomena: both are the result of two fundamental principles – the superposition principle (oscillations add up linearly) and the Huygens’ principle (every point of a wavefront becomes a source of spherical waves)
Coherent Light

• Coherent sources of light: waves leaving them have the same wavelength and frequency and fixed phase shift
• Example of coherent sources: a screen containing two closely spaced slits
• Example of incoherent sources: two light bulbs
• Interference can only be observed for coherent sources
Interference

• Constructive interference: two waves arrive at the point in phase

\[ r_2 - r_1 = m\lambda, \quad m = 0, \pm 1, \pm 2, \ldots \]

• Destructive interference: two waves arrive at the point in antiphase

\[ r_2 - r_1 = \left( m + \frac{1}{2} \right)\lambda, \quad m = 0, \pm 1, \pm 2, \ldots \]
Double Slit: Position of Fringes

\[ r_2 - r_1 = d \sin \theta_m \]

\[ y_m = R \tan \theta_m \]

angle is small, so \( \sin \theta \approx \tan \theta \approx \theta \)
Position of Fringes

constructive interference (maxima):

\[ r_2 - r_1 = m \lambda \]

\[ y_m = Rm \frac{\lambda}{d} \]

destructive interference (minima):

\[ r_2 - r_1 = \left( m + \frac{1}{2} \right) \lambda \]

\[ y_m = R \left( m + \frac{1}{2} \right) \frac{\lambda}{d} \]
Single Slit Diffraction

• So what happens if there is only one slit?

we assume $R \gg a$ (Fraunhofer diffraction)

divide the slit by 2: two halves compensate each other if

$$\frac{a}{2} \sin \theta = \pm \frac{\lambda}{2}$$

similarly, can divide by 3,4,...
Position of Fringes

• Compensation occurs at

\[ \sin \theta = \frac{m\lambda}{a}, \quad m = \pm 1, \pm 2, \ldots \]

similar to interference, we conclude that

\[ y_m = Rm \frac{\lambda}{a} \]

• this is position of **minima**, not maxima!
• \( m=0 \) is **not** a minimum!
Grating

$d \sin \theta = m \lambda$

$m=0$: the same for all colors

$m=\pm 1, \pm 2, \ldots$: depends on color

grating works like a prism!
Interference by Thin Films

constructive interference:
\[ \Delta s = m\lambda, \quad m = 0, \pm 1, \pm 2, \ldots \]
destructive interference:
\[ \Delta s = \left( m + \frac{1}{2} \right)\lambda, \quad m = 0, \pm 1, \pm 2, \ldots \]

watch for extra phase shifts!

additional path for ray \( b \)
Interference by Thin Films

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bright fringes (constructive interference):

\[ 2t = \left( m + \frac{1}{2} \right) \lambda \]

dark fringes (destructive interference):

\[ 2t = m \lambda \]

Example: air wedge
Newton’s Rings

radius of bright fringes: \[ r = \sqrt{(m + \frac{1}{2})R\lambda} \]
Polarization

• Polarized light = EM waves oscillate in certain direction rather than in any transverse direction

\[
E_y = E_{\text{max}} \sin(\omega t - kx) \quad E_z = E_{\text{max}} \sin(\omega t - kx)
\]

\[
B_z = B_{\text{max}} \sin(\omega t - kx) \quad B_y = B_{\text{max}} \sin(\omega t - kx)
\]
Polarization

• If the light is polarized in direction perpendicular to the polarized film axis, it can’t pass through

\[ I = I_0 \cos^2 \theta \]