Chapter 24

The Wave Nature of Light

Reminder: Light is an EM wave

$$E_y = E_{\max} \sin(\omega t - kx)$$

$$B_z = B_{\max} \sin(\omega t - kx)$$

$$k = \frac{2\pi}{\lambda} \qquad \omega = \frac{2\pi}{T}$$

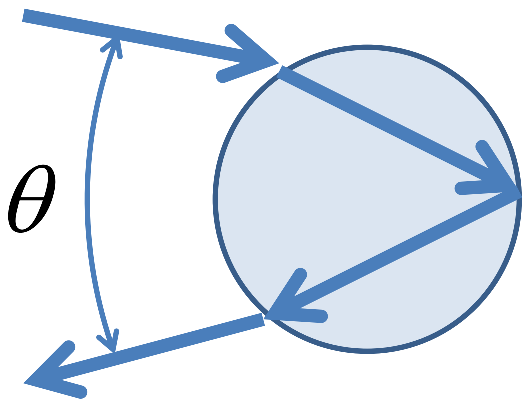
Monochromatic Light

- 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: $\frac{\Delta\lambda}{\lambda} \sim 10^{-9}$

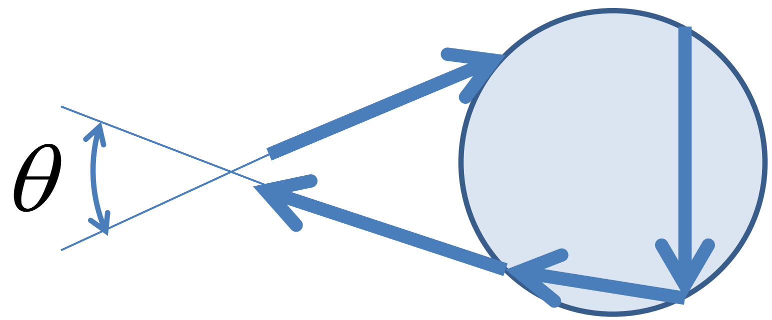
Dispersion

- Visible white light is not monochromatic, it is composed of all colors
- dispersion = dependence of n on λ

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

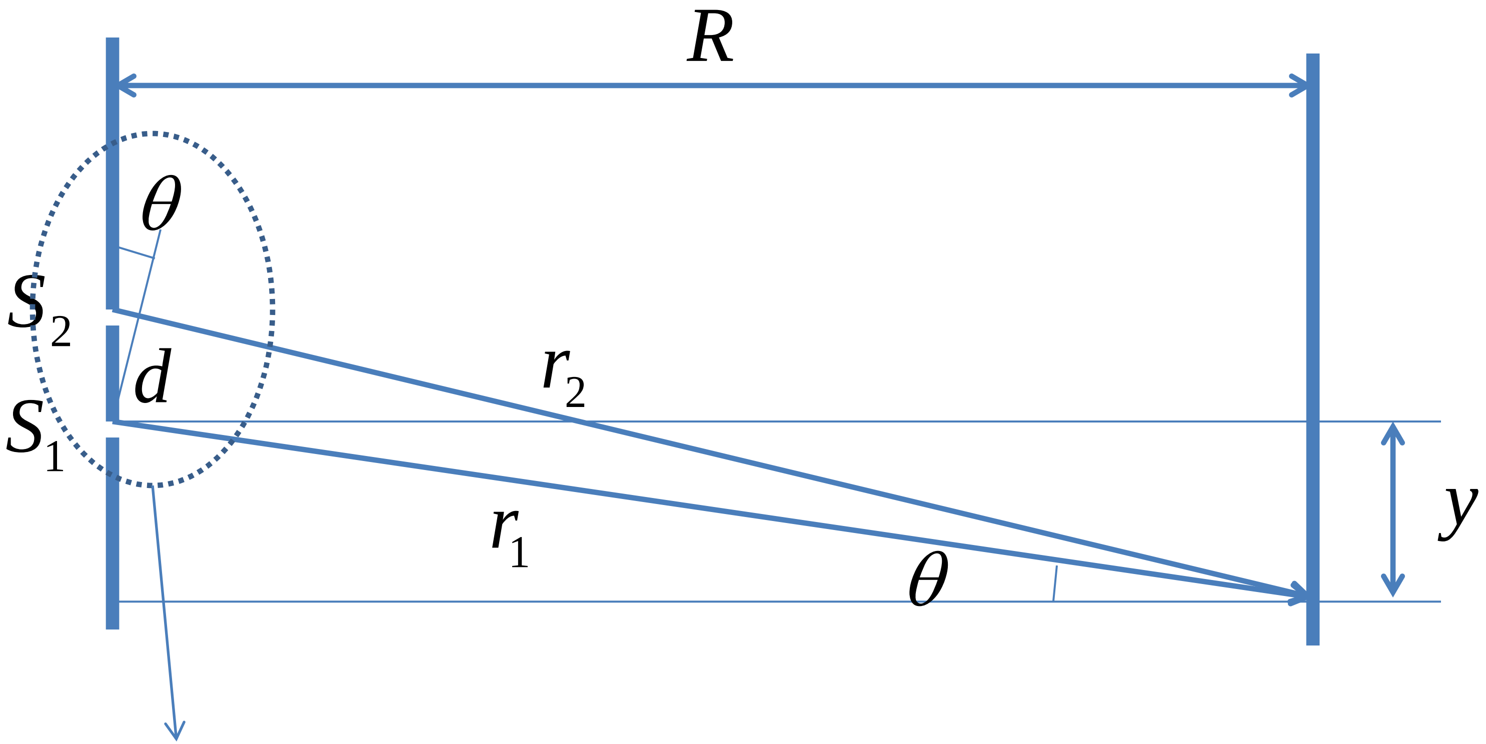
- Constructive interference: two waves arrive at the point in phase

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

- 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



$$r_2 - r_1 = d\sin\theta_m \qquad y_m = R\tan\theta_m$$

angle is small, so sinθ~tanθ~θ

Position of Fringes

constructive interference (maxima):

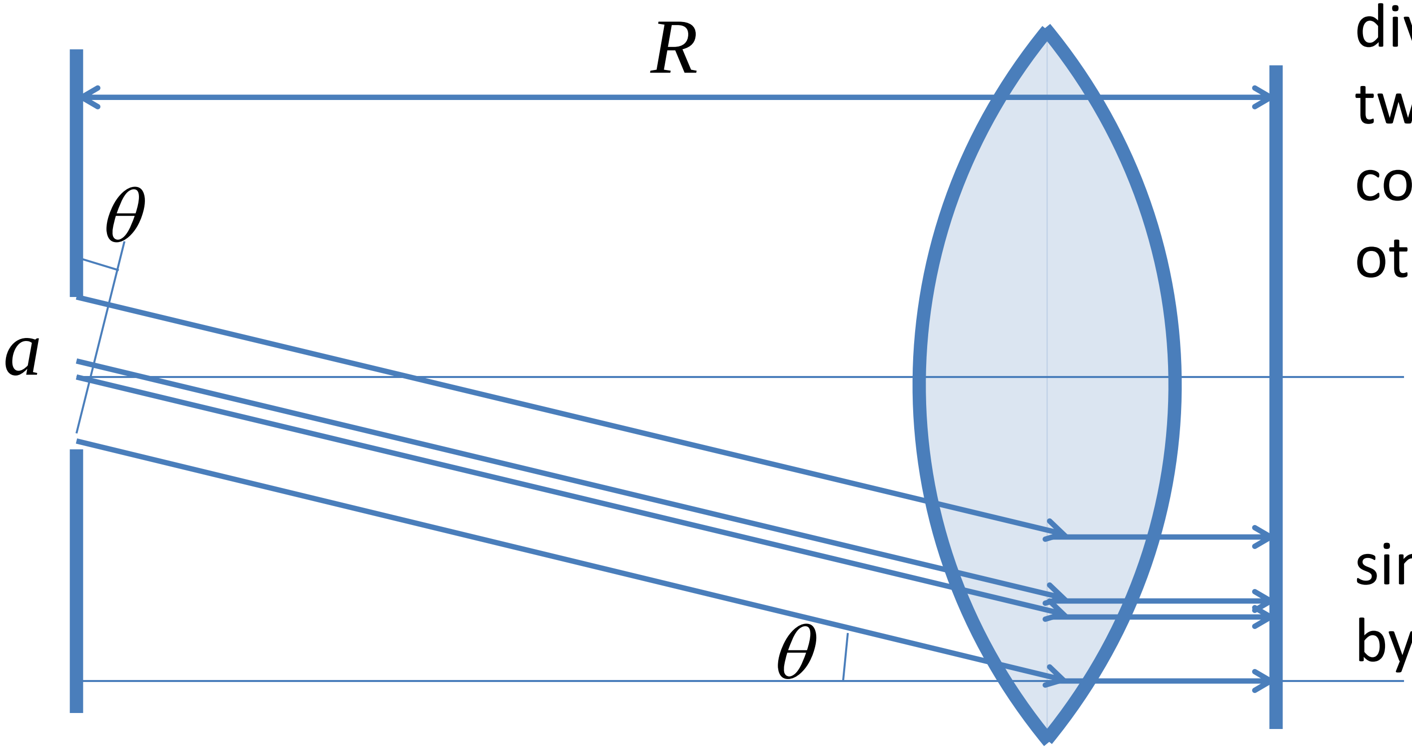
$$r_2 - r_1 = m\lambda \qquad\qquad y_m = Rm\frac{\lambda}{d}$$

destructive interference (minima):

$$r_2 - r_1 = \left(m + \frac{1}{2}\right)\lambda \qquad\qquad y_m = R\left(m + \frac{1}{2}\right)\frac{\lambda}{d}$$

Single Slit Diffraction

- So what happens if there is only one slit?



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,...

we assume *R>>a* (Fraunhofer diffraction)

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

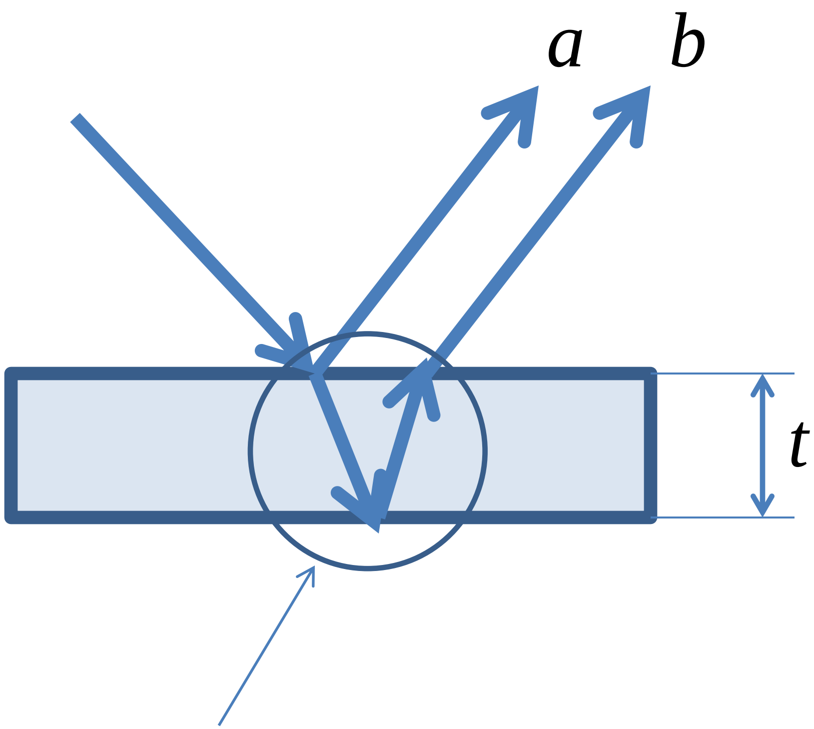
$$d \sin \theta = m\lambda$$

m=0: the same for all colors

m=±1, ±2, …: depends on color

grating works like a prism!

Interference by Thin Films



additional path for ray *b*

constructive interference:

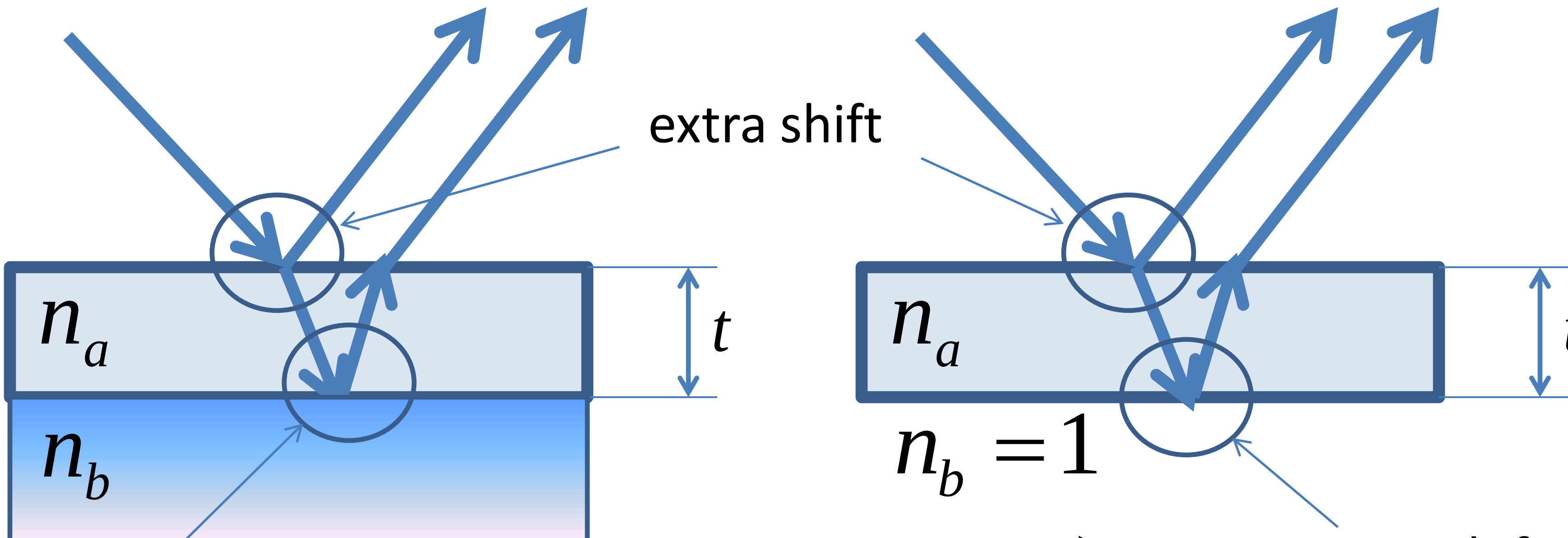
$$\Delta s = m\lambda, \quad m = 0, \pm 1, \pm 2, \ldots$$

destructive interference:

$$\Delta s = \left(m + \tfrac{1}{2}\right)\lambda, \quad m = 0, \pm 1, \pm 2, \ldots$$

watch for extra phase shifts!

Interference by Thin Films



$n_a > n_b$: no extra shift

$n_a < n_b$: extra ½ cycle phase shift

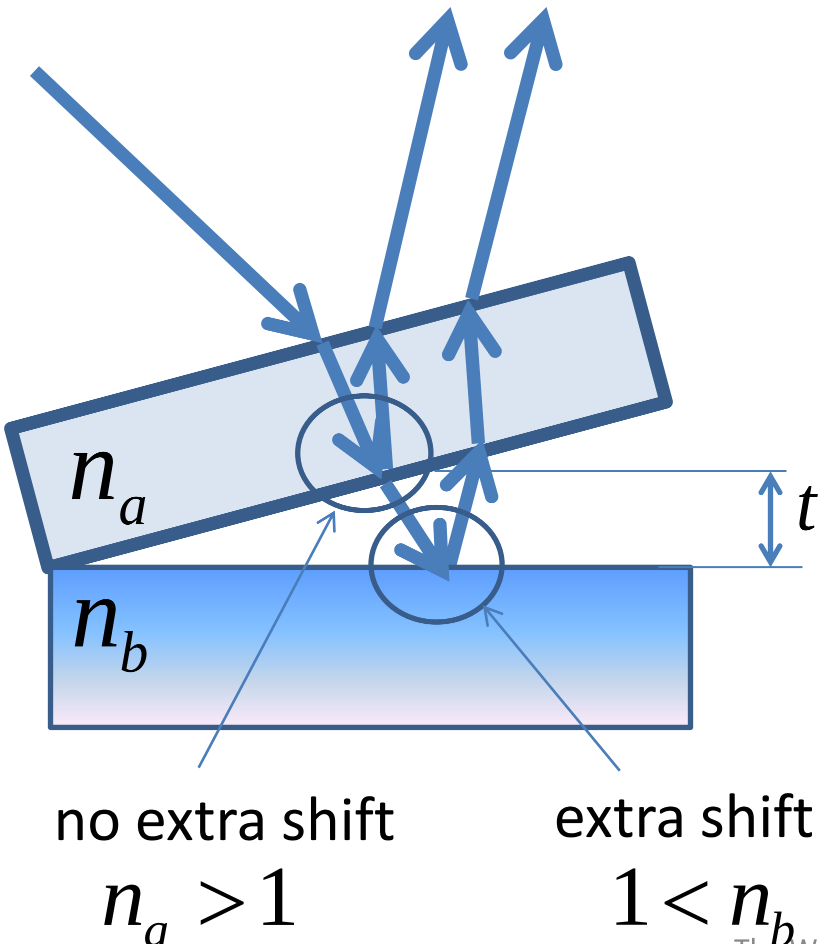
bright fringes (constructive interference):

$$2t = m\lambda$$

bright fringes:

$$2t = \left(m + \tfrac{1}{2}\right)\lambda$$

Interference by Thin Films



bright fringes (constructive interference):

$$2t = \left(m + \tfrac{1}{2}\right)\lambda$$

dark fringes (destructive interference):

$$2t = m\lambda$$

Example: air wedge

Newton's Rings

radius of bright fringes: $$r = \sqrt{\left(m + \tfrac{1}{2}\right) R\lambda}$$

Polarization

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

$$E_y = E_{\max} \sin(\omega t - kx)$$

$$B_z = B_{\max} \sin(\omega t - kx)$$

$$E_z = E_{\max} \sin(\omega t - kx)$$

$$B_y = B_{\max} \sin(\omega t - kx)$$

Polarization

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

$$I = I_0 \cos^2 \theta$$