Lecture 37

Chapter 36

Interference

Review

- Light is an electromagnetic wave
- Light waves interact with each other and produce constructive or destructive interference
- Frequency, *f* , of light in medium same as vacuum
- Wavelength and velocity depend on index of refraction, *n*

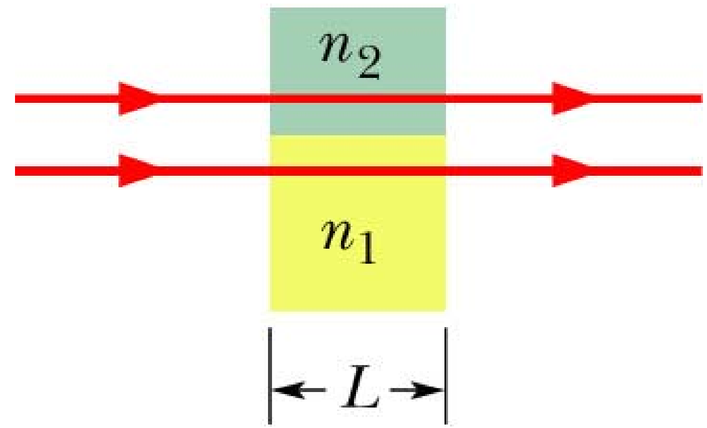
$$\frac{\lambda_1}{\lambda_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

- Wavelength of light in medium, λ_n smaller than in vacuum, λ

$$\lambda_n = \frac{\lambda}{n}$$

Review

- Phase difference between 2 light waves can change if waves travel through different media with different *n*

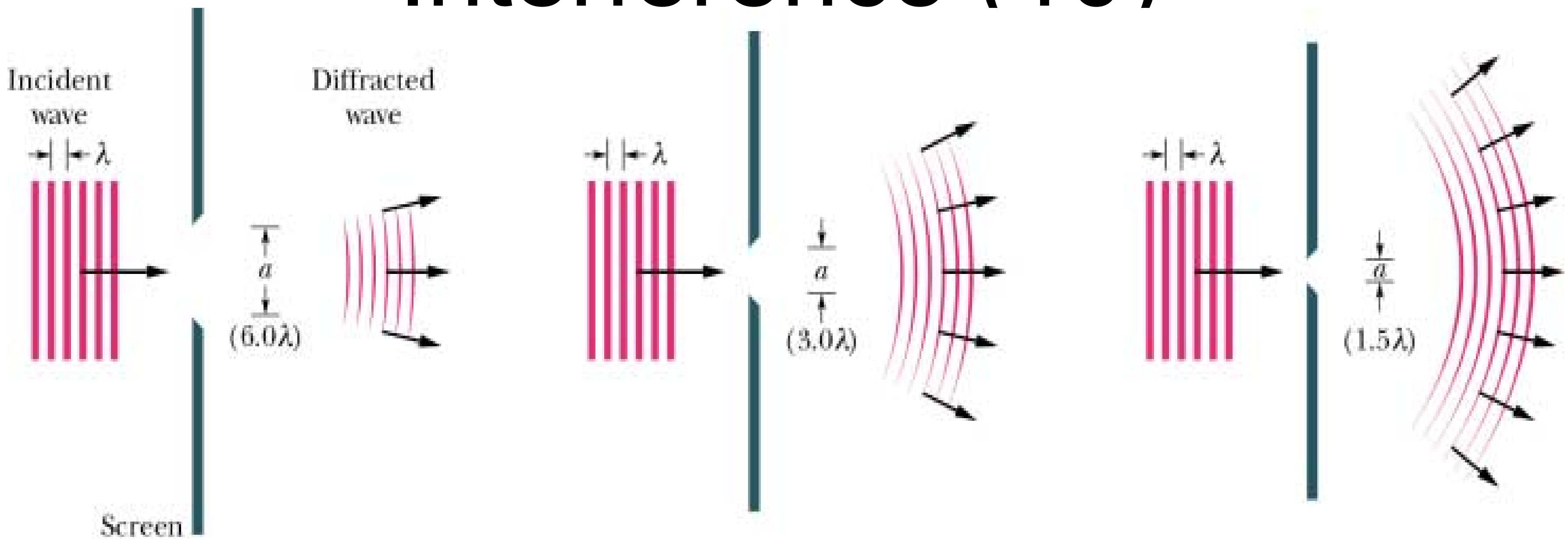


- Phase difference in terms of λ where N is # of λs in length of medium

$$N_2 - N_1 = \frac{L}{\lambda}(n_2 - n_1)$$

- Effective phase difference is decimal fraction
- Phase difference of 0.5 λ waves out of phase, 0.0 or 1.0 λ waves in phase
- 1 λ = 2π radians = 360°

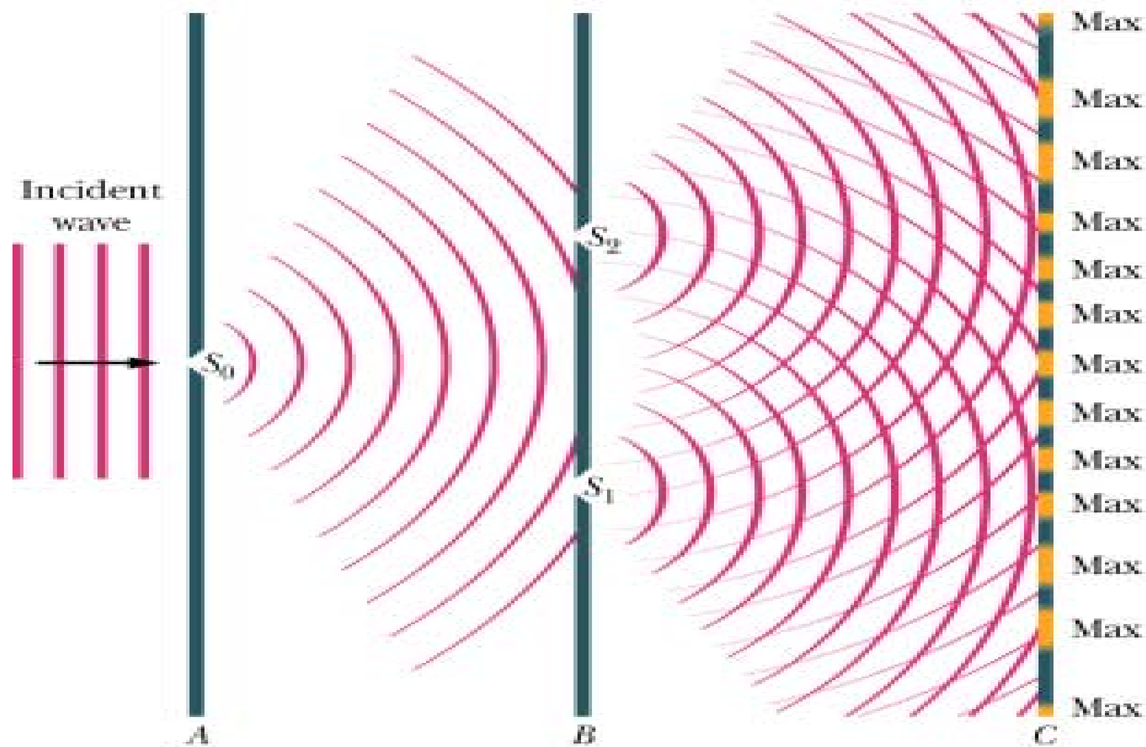
Interference (10)



- Waves diffract if pass through opening whose size is comparable to its wavelength
- Narrower the slit, greater the diffraction
- Geometric optics doesn't work in this case

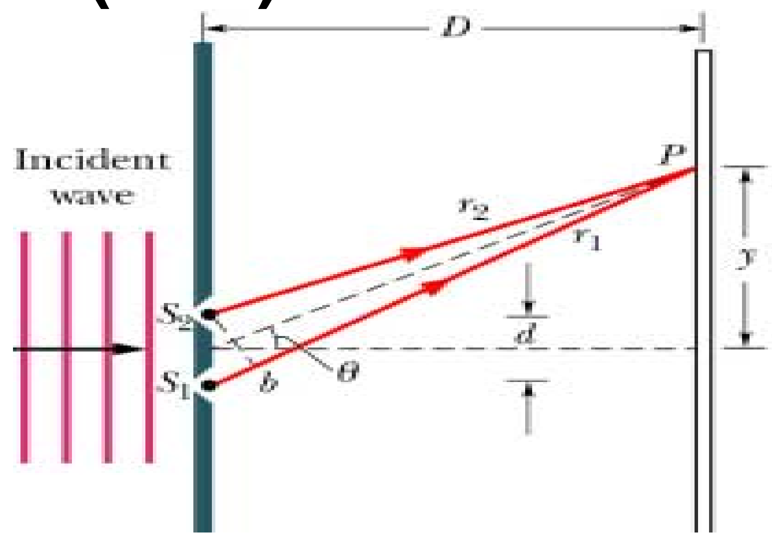
Interference (11)

- Young's double-slit interference experiment proved light was a wave
- Produce interference pattern with
  - Bright bands, fringes, maxima
  - Dark bands, fringes,



Interference (12)

- What causes the fringes?
- Waves from each slit travel different distances which causes a phase difference



- If path length difference, ΔL, is 0 or integer # of wavelengths, waves interfere fully constructively

$$\Delta L = m\lambda, \quad \mathrm{m} = 0,1,2,...$$

- If ΔL is odd multiple of 1/2 wavelength, waves interfere fully destructively

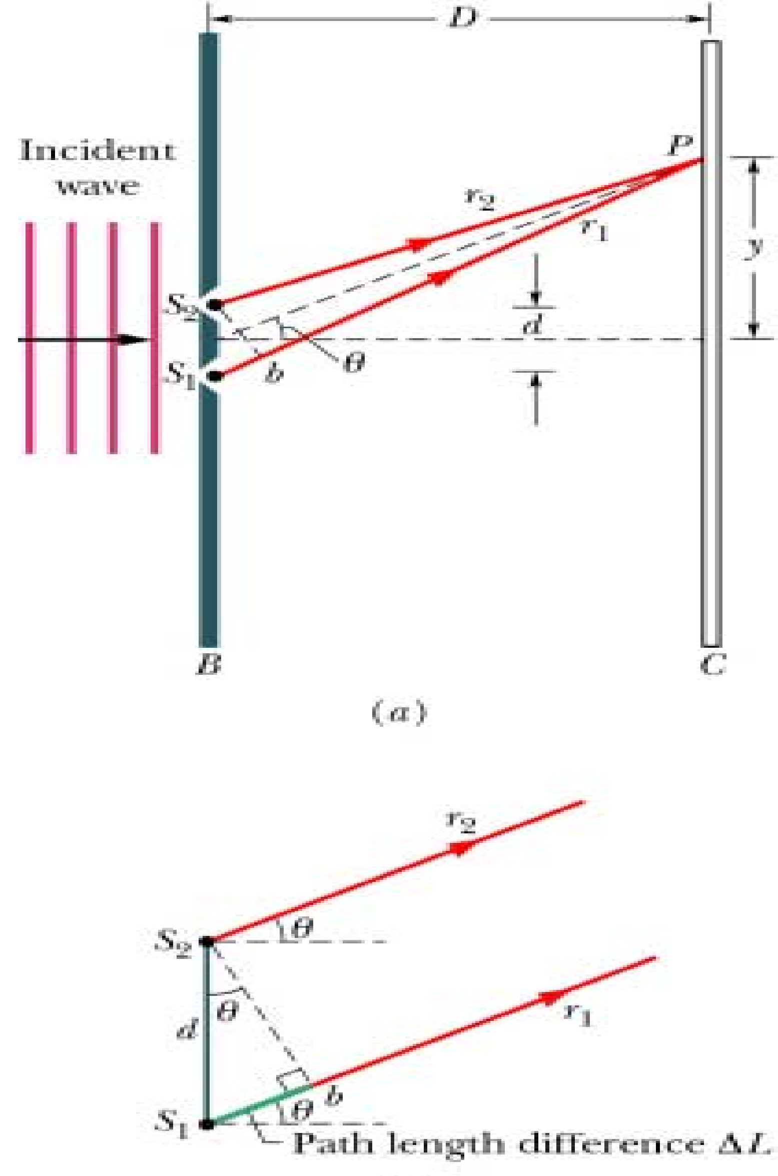
$$\Delta L = (m + 1/2)\lambda, \quad \mathrm{m} = 0,1,2,...$$

Interference (13)

- Find location of fringes on screen from distance
- If distance to screen, D, is much greater than distance between slits, d, rays are || and at angle θ to central axis and right triangle, S_1S_2b, relates ΔL to d

$$\sin\theta = \Delta L / d$$

$$\Delta L = d \sin\theta$$



Interference (14)

- Bright fringes or maxima –

$$\Delta L = d \sin\theta = m\lambda, \ \ \mathrm{m} = 0,1,2,...$$

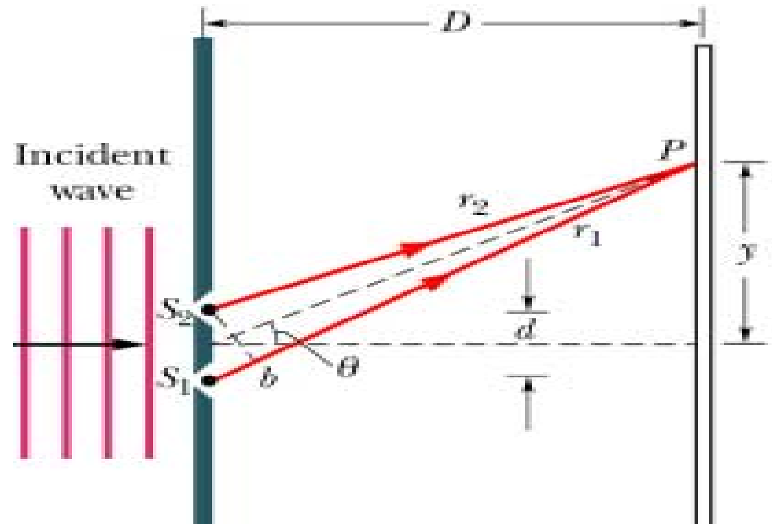
  - Central maximum when m=0, $\Delta L = 0$
  - First order fringe or first maxima at m=1, $\Delta L = 1\lambda$
  - Second maxima or second order fringe at m=2
- Dark fringes or minima –

$$\Delta L = d \sin\theta = (m + 1/2)\lambda, \ \ \mathrm{m} = 0,1,2,...$$

  - First order minima at m=0, $\Delta L = 0.5\lambda$
  - Second minima when m=1, $\Delta L = 1.5\lambda$

Interference (15)

- Checkpoint #3 – What is ΔL for two rays if point P is A) a third side maximum and B) third minimum



- A) For maximum, third is m=3 so

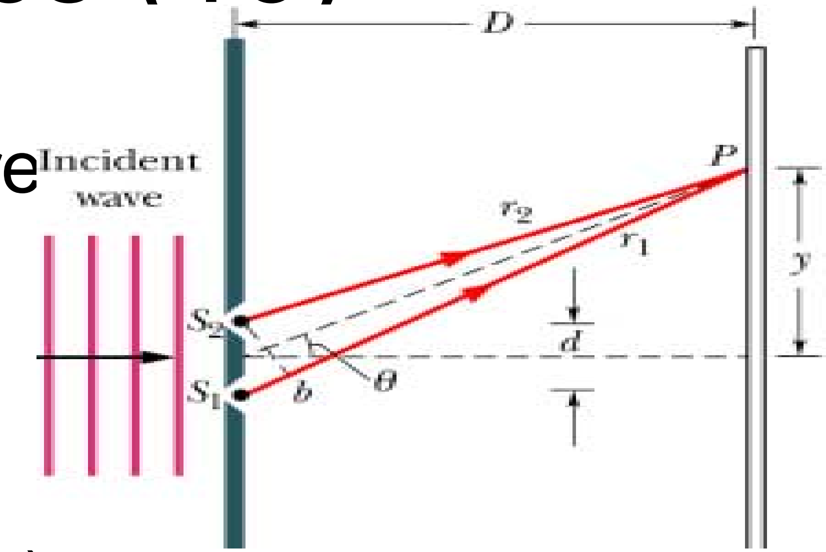
$$\Delta L = m\lambda = 3\lambda$$

- B) For minimum, third side is m=2 so

$$\Delta L = (m + 1/2)\lambda = 2.5\lambda$$

Interference (16)

- What is location of maxima minima on screen, *y* in re to central axis?



$$\tan\theta = \frac{y}{D}$$

- For small angles (in radians)

$$\tan\theta = \sin\theta = \theta$$

- From path difference interference

$$\sin\theta = \frac{m\lambda}{d}$$

- Location of maxima or minima on the screen is

$$y = \frac{mD\lambda}{d}$$

Interference (17)

- What is the intensity of the fringes?
- If waves coherent, phase difference ϕ does not change with time
- Intensity *I* depends on intensity of single slit I_0 and phase difference ϕ between waves

$$I = 4I_0 \cos^2\left(\tfrac{1}{2}\phi\right)$$

- Phase difference is related to distance between slits *d* and central axis θ

$$\phi = \frac{2\pi d}{\lambda}\sin\theta$$

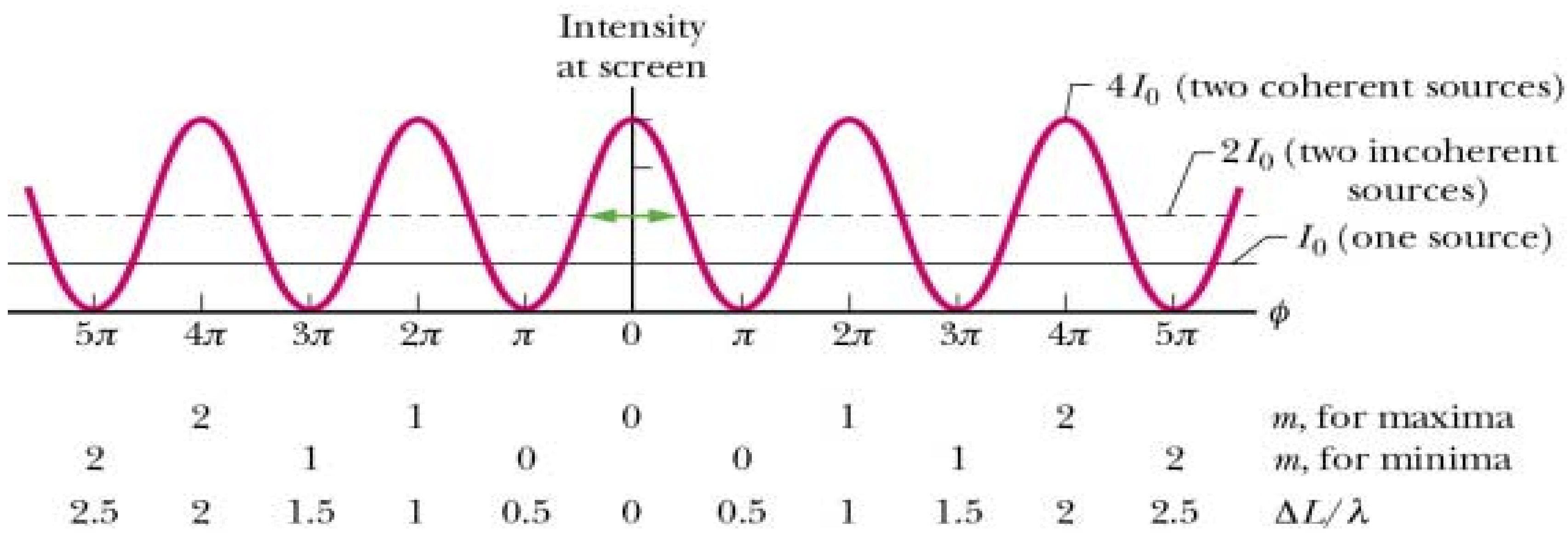
- Proof on p.873-874

Interference (18)

- Intensity of 2 coherent sources at bright fringe is

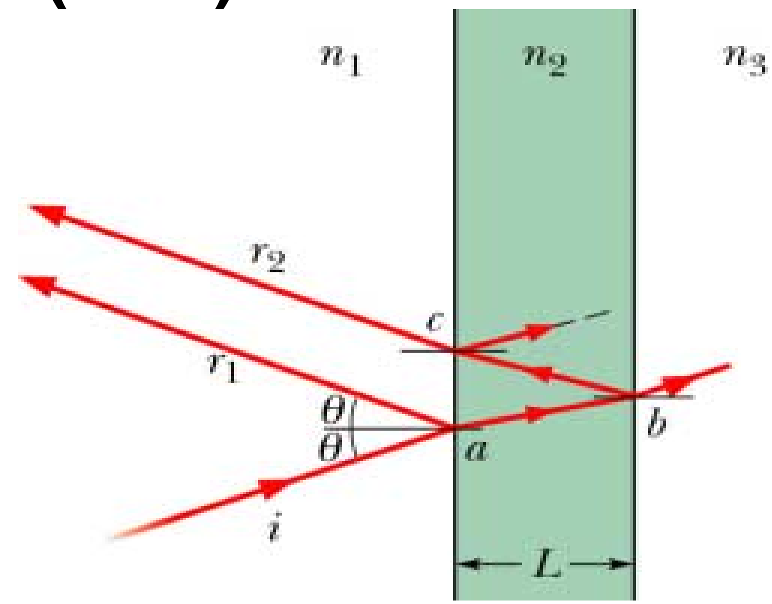
$$I = 4I_0 \cos^2(\tfrac{1}{2}\phi) \qquad I_{max} = 4I_0$$

- No fringe pattern is sources incoherent, intensity have uniform value of $2I_0$
- Average intensity of coherent waves is $I_{avg}=2I_0$



Interference (19)

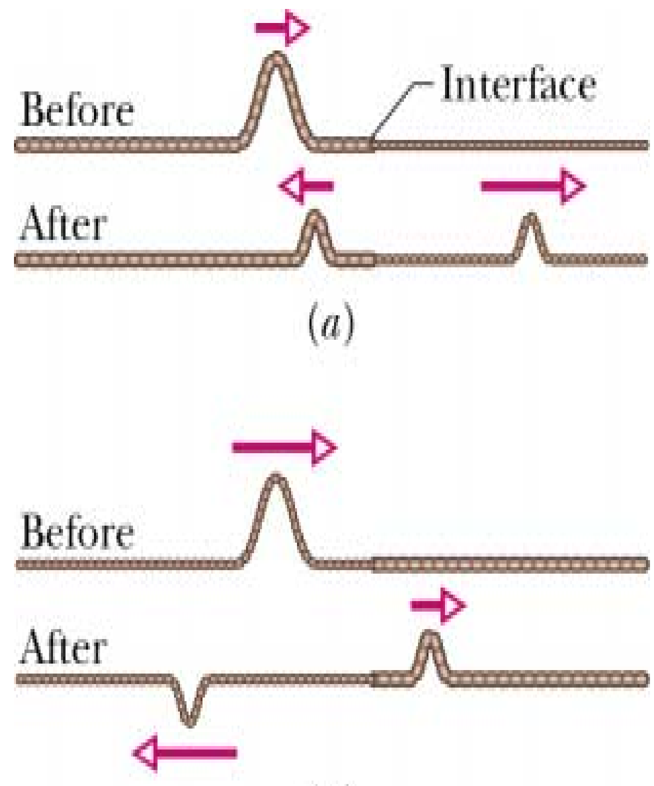
- Interference of light occurs in thin films when light waves are reflected from front and back surfaces
  - Thickness of film, *L* , must be order of light's wavelength



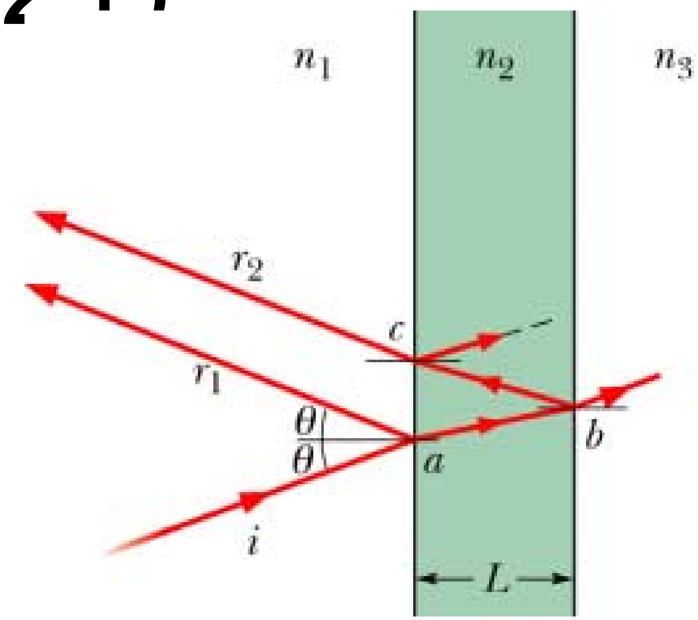
- Reflection and refraction occur at surfaces
- Region *ac* is bright (dark) if waves are in (out) of phase
- Assume light almost ⊥ to film (θ=0) so path length difference between ray 1 and 2 is 2L

Interference (20)

- Refraction at interface never changes the phase
- Reflection of wave can cause phase difference
- Wave in denser string (moving slower) hits interface with lighter string
  - Transmitted wave has same phase
  - Reflected wave has same phase
- Wave in lighter string (moving faster) hits interface with denser string
  - Transmitted wave has same phase
  - Reflected wave phase shifts by



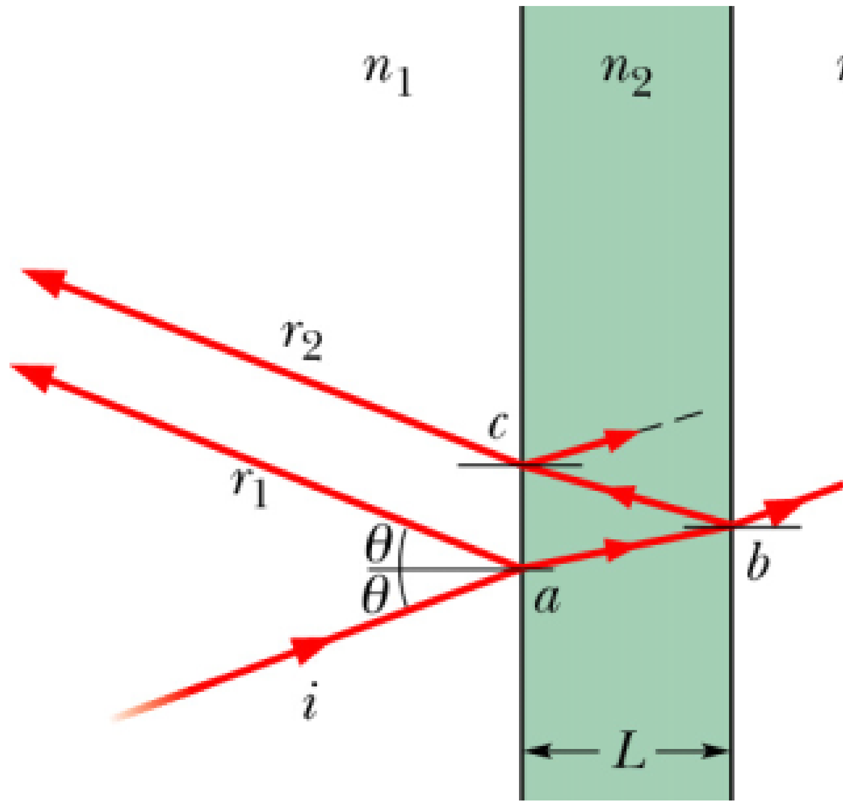
Interference (21)



- For light, incident wave in medium with larger n (slower speed) does not change phase
- For light, incident wave in medium with smaller n (faster speed) phase shift of ½λ or π
- No phase shift for refracted light
- If n_1, n_3 = 1.0 for air, and n_2=1.5 for glass
- Ray 1 is phase shifted by ½ λ since $n_1 < n_2$
- Ray 2 has no phase shift since $n_2 > n_3$ and refracted ray at point c

Interference (22)

- For thin films 3 ways get phase difference between waves
  - By reflection
  - By waves traveling along different path lengths
  - By waves traveling through different media of different n



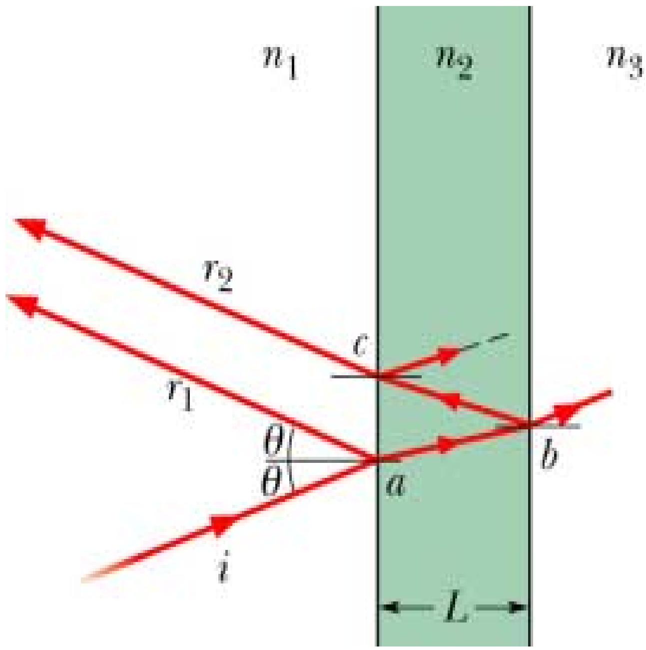
Interference (23)

- Look at phase diff. from path length diff. ΔL
- Assume θ=0 so ΔL=2L where L is thickness of film
- Assume n1<n2>n3 (air to glass to air)
- Ray 1 is ½λ out of phase from reflection
- For in-phase waves, ray 2 =½λ

$$2L = \frac{\text{odd}\,\#}{2} \times \lambda_{n2} = (m + \tfrac{1}{2})\frac{\lambda}{n_2},\ \text{m} = 0,1,2,...$$

- For out-of-phase waves

$$2L = \text{integer} \times \lambda_{n2} = m\frac{\lambda}{n_2},\ \text{m} = 0,1,2,...$$



Interference (24)

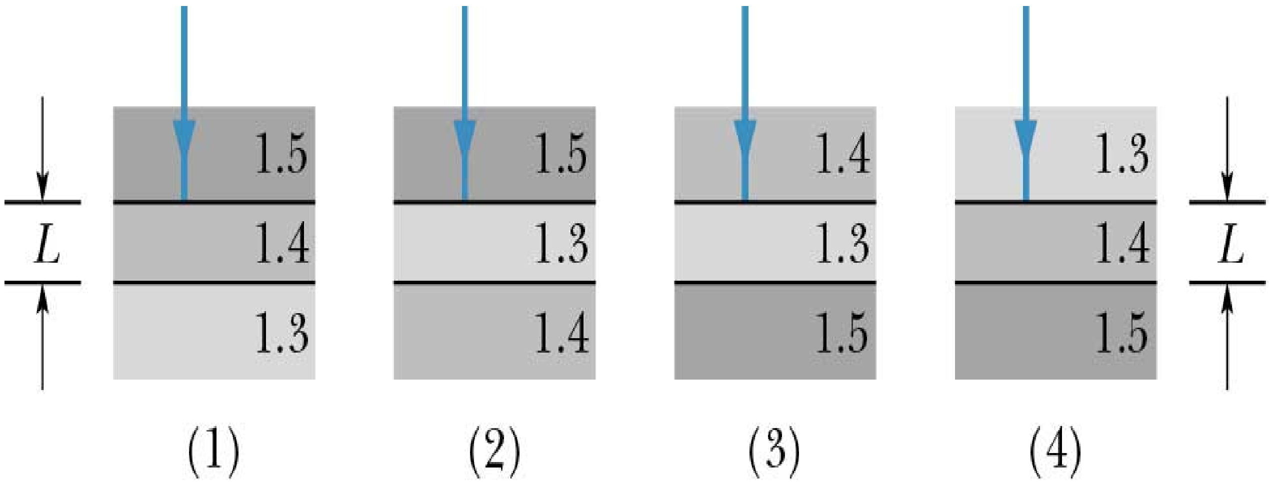
- Need combination of phase shifts from reflection and path length difference to determine what wavelengths of light will interfere destructively or constructively
- Equations for path length always hold but which equation gives in-phase and which gives out-of-phase waves depends on index of refractions of media

$$2L = (m + \tfrac{1}{2})\frac{\lambda}{n_2},\ \ \mathrm{m} = 0,1,2,\ldots$$

$$2L = m\frac{\lambda}{n_2},\ \ \mathrm{m} = 0,1,2,\ldots$$

Interference (25)

- Checkpoint #5 – Light reflects ⊥ from film of thickness L between 2 other media. For given index of refractions, which situations will A) give zero phase difference from reflection at film interfaces

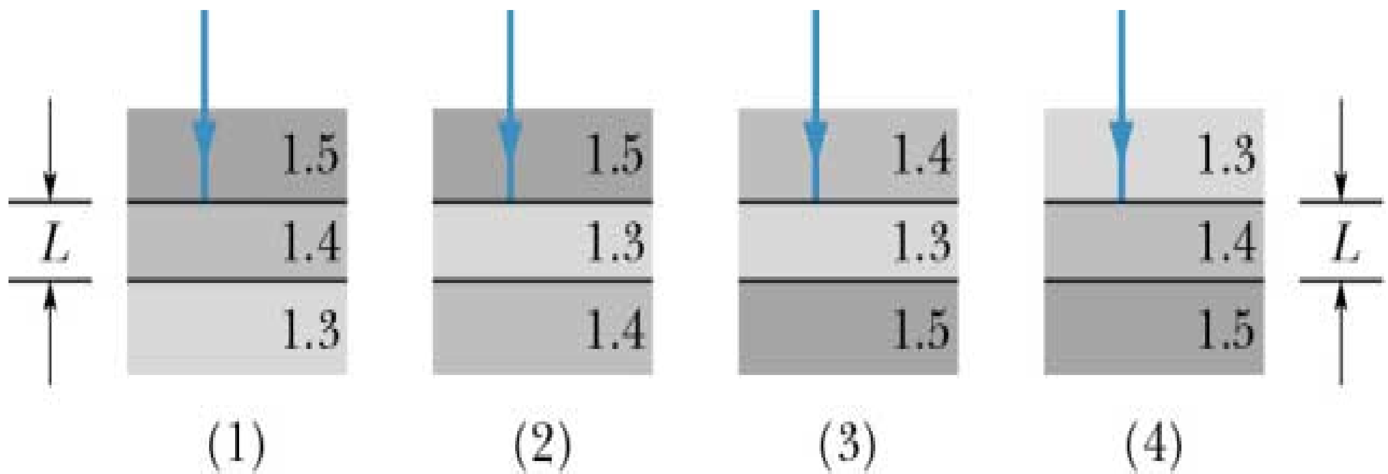


- n1>n2, no change
- n1<n2, ½λ change

A) 1 & 4

Interference (26)

- Checkpoint #5 – Light reflects ⊥ from film of thickness L between 2 other media. For given index of refractions, which situations will B) film be dark if 2L=0.5λ phase difference

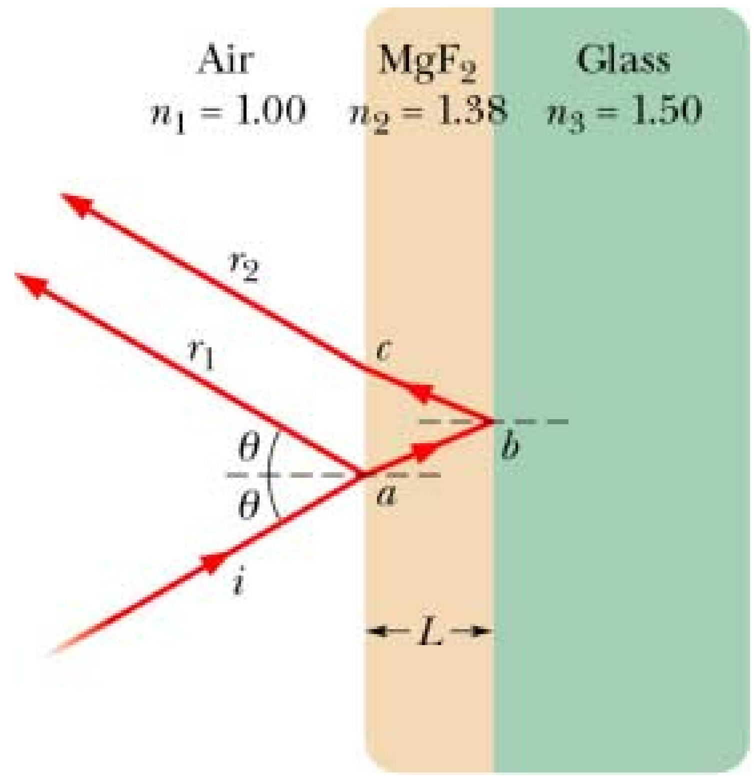


- Reflection causes 1&4 (2&3) to be in (out) phase
- For dark want rays out of phase

B) 1 & 4

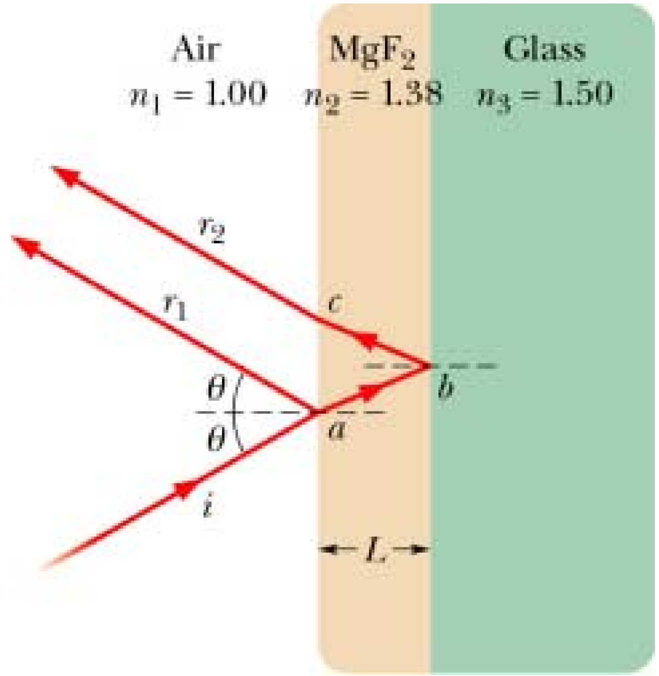
Interference (27)

- Sample problem 36-5 – What thickness, L, is needed to eliminate reflections at middle of visible spectrum λ=550nm?
- Need light waves reflected from 2 surfaces to be exactly out of phase
- First look at phase due to reflection
  - Ray 1 is ½λ since $n_1 < n_2$
  - Ray 2 is ½λ since $n_2 < n_3$



Interference (28)

- Sample problem 36-5 – What thickness, L, is needed to eliminate reflections at middle of visible spectrum λ=550nm?



- Need path length difference to put rays out of phase

$$2L = \frac{\text{odd\#}}{2} \times \lambda_{n2} = (m + \tfrac{1}{2})\frac{\lambda}{n_2}, \ \text{m} = 0,1,2,\ldots$$

- Least thickness is m=0

$$L = \frac{\lambda}{4n_2} = \frac{550nm}{4(1.38)} = 99.6nm$$