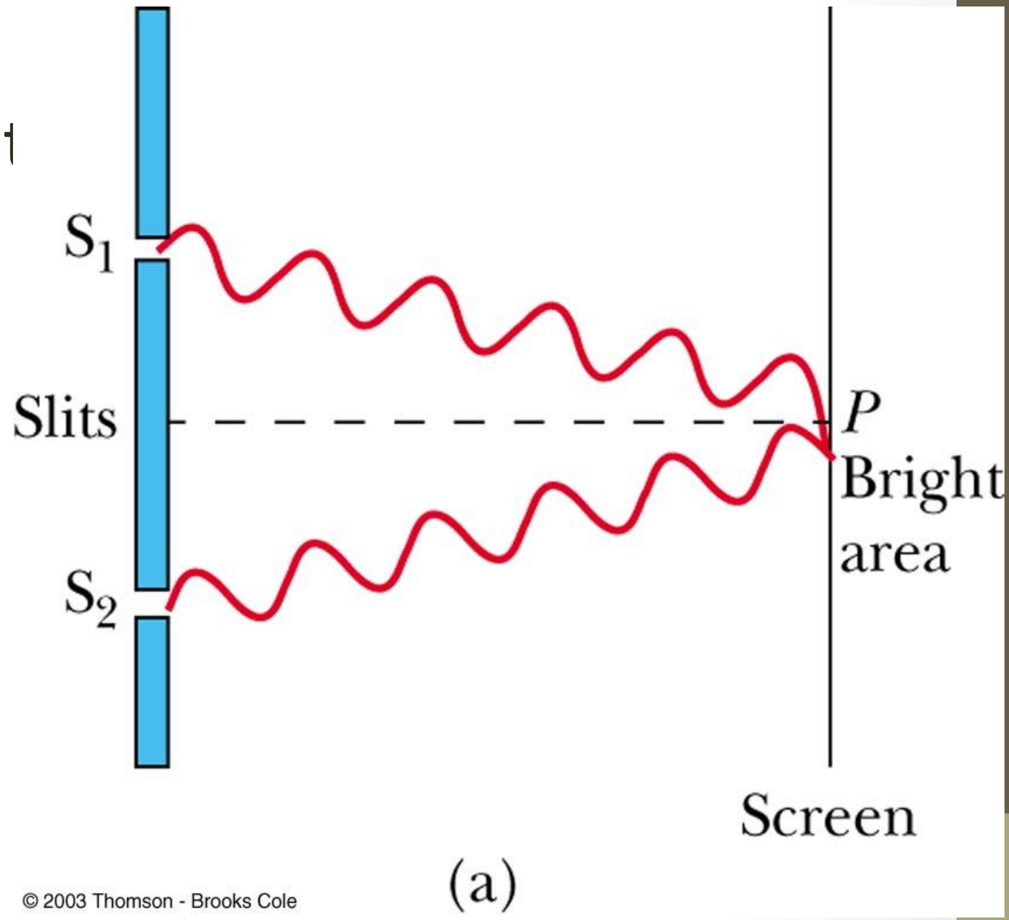
Interference in Thin Films

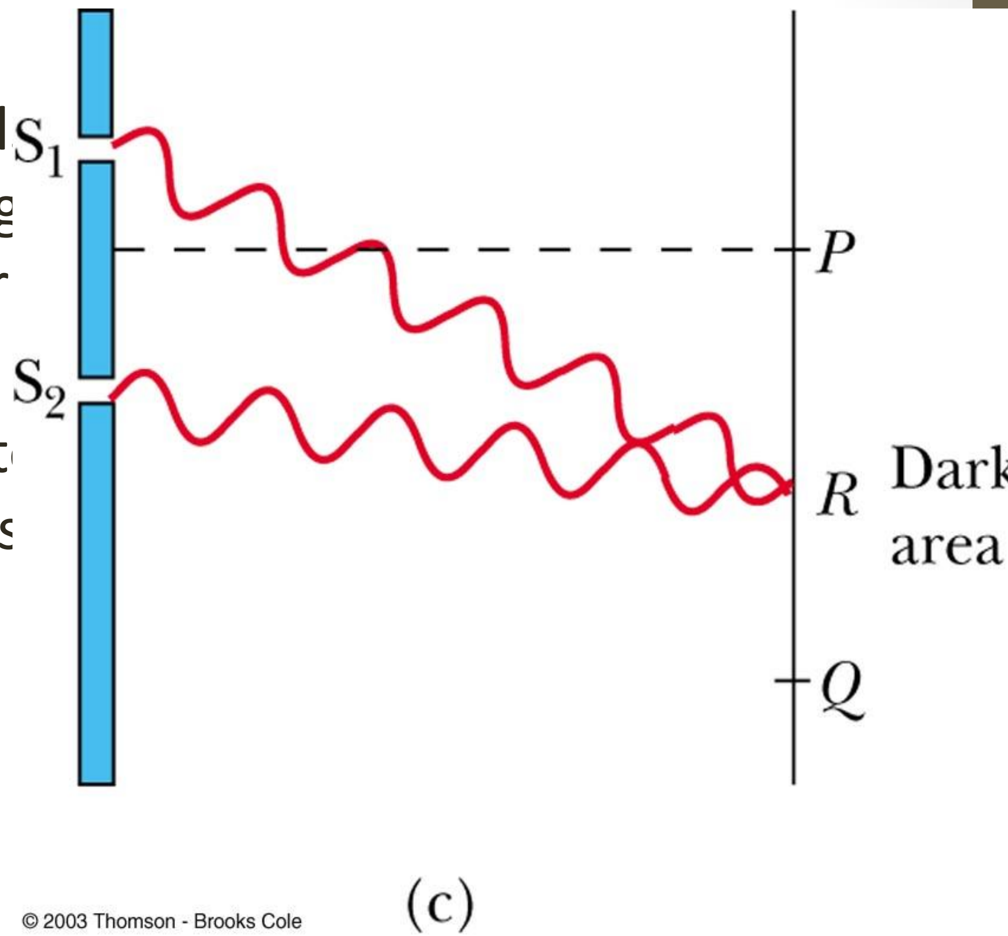
Interference Patterns

- Constructive interference occurs at the center point
- The two waves travel the same distance
  - Therefore, they arrive in phase



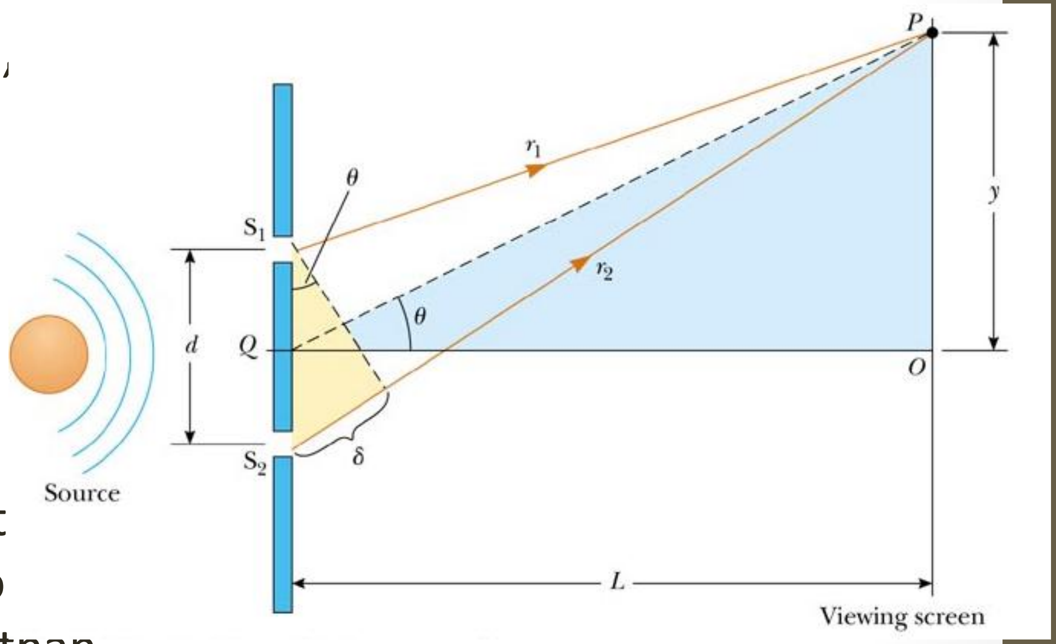
Interference Patterns, 3

- The upper wave travel
one-half of a waveleng
farther than the lower
wave
- The trough of the bott
wave overlaps the cres
the upper wave
- This is destructive
interference
    - A dark fringe occurs



Interference Equations

- The path difference, δ, found from the tan triangle
- $\delta = r_2 - r_1 = d \sin \theta$
  - This assumes the paths parallel
  - Not exactly parallel, but very good approximatio since L is much greater tnan d



Interference Equations, 2

- For a bright fringe, produced by constructive interference, the path difference must be either zero or some integral multiple of the wavelength
- $\delta = d \sin \theta_{bright} = m \lambda$
  - $m = 0, \pm1, \pm2, \ldots$
  - m is called the *order number*
    - When $m = 0$, it is the zeroth order maximum
    - When $m = \pm1$, it is called the first order maximum

Interference Equations, 3

- The positions of the fringes can be measured vertically from the zeroth order maximum
- $y = L \tan \theta \approx L \sin \theta$
- Assumptions
  - $L >> d$
  - $d >> \lambda$
- Approximation
  - θ is small and therefore the approximation $\tan \theta \approx \sin \theta$ can be used

Interference Equations, 4

- When destructive interference occurs, a dark fringe is observed
- This needs a path difference of an odd half wavelength
- $\delta = d \sin \theta_{dark} = (m + \frac{1}{2}) \lambda$
  - $m = 0, \pm 1, \pm 2, \ldots$

Interference Equations, final

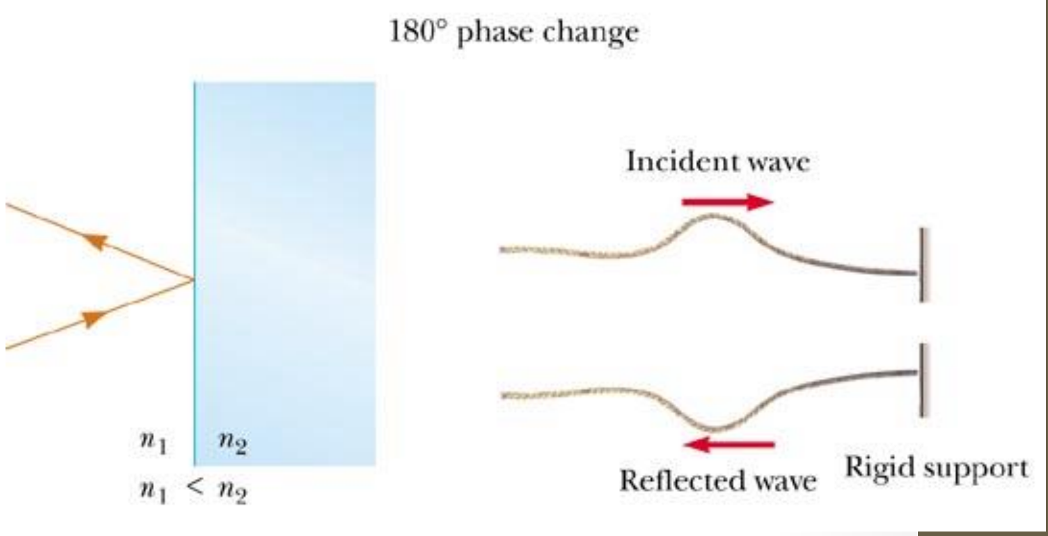
- For bright fringes
- For dark fringes

$$y_{bright} = \frac{\lambda L}{d} m \quad m = 0, \pm 1, \pm 2 \ldots$$

$$y_{dark} = \frac{\lambda L}{d}\left(m + \frac{1}{2}\right) \quad m = 0, \pm 1, \pm 2 \ldots$$

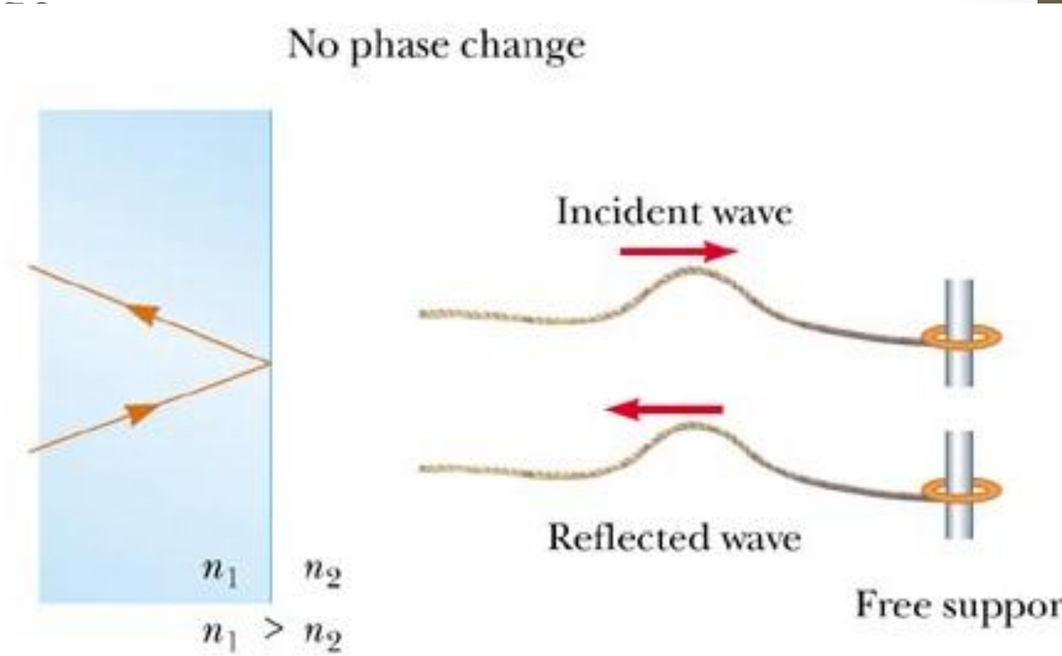
Phase Changes Due To Reflection

- An electromagnetic wave undergoes a phase change of 180° upon reflection from a medium of higher index of refraction than the one in which it was traveling
  - Analogous to a reflected pulse on a string



Phase Changes Due To Reflection, cont

- There is no phase char when the wave is reflected from a bound leading to a medium o lower index of refracti
  - Analogous to a pulse in string reflecting from a f support



Interference in Thin Films, final

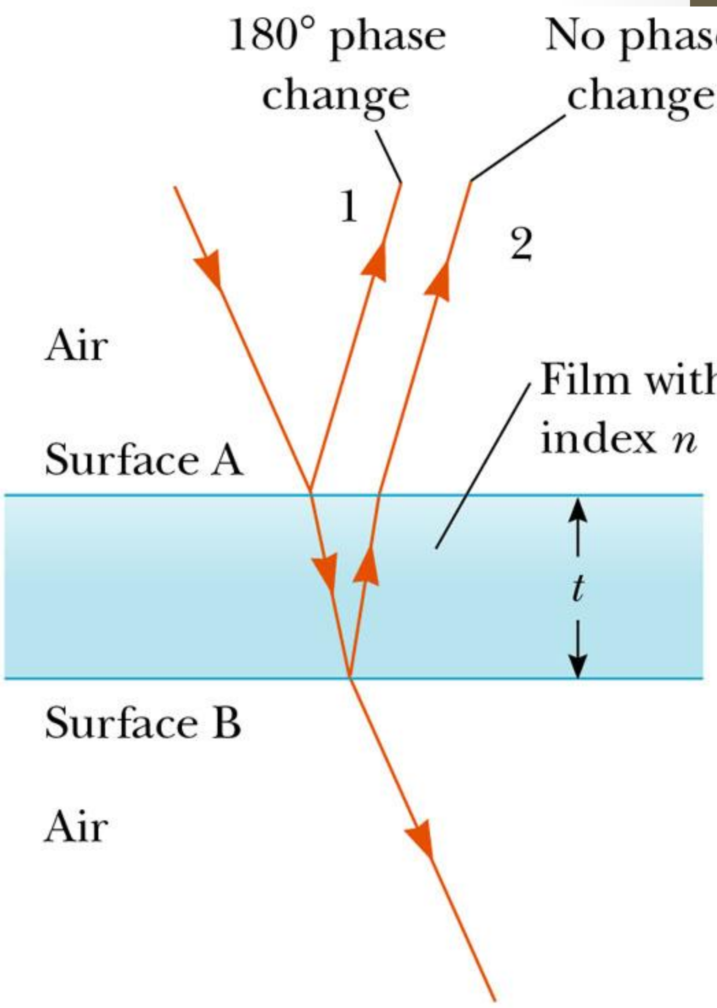
- Be sure to include two effects when analyzing the interference pattern from a thin film
  - Path length
  - Phase change

Interference in Thin Films, 2

- Facts to remember
  - An electromagnetic wave traveling from a medium of index of refraction n_1 toward a medium of index of refraction n_2 undergoes a 180° phase change on reflection when $n_2 > n_1$
    - There is no phase change in the reflected wave if $n_2 < n_1$
  - The wavelength of light λ_n in a medium with index of refraction n is $\lambda_n = \lambda/n$ where λ is the wavelength of light in vacuum

Interference in Thin Films, 3

- Ray 1 undergoes a phase change of 180° with respect to the incident ray
- Ray 2, which is reflected from the lower surface, undergoes no phase change with respect to the incident wave



Interference in Thin Films, 4

- Ray 2 also travels an additional distance of 2t before the waves recombine
- For constructive interference
  - $2nt = (m + \frac{1}{2})\lambda \quad m = 0, 1, 2 \ldots$
    - This takes into account both the difference in optical path length for the two rays and the 180° phase change
- For destruction interference
  - $2 n t = m \lambda \quad m = 0, 1, 2 \ldots$

Interference in Thin Films, 5

- Two factors influence interference
  - Possible phase reversals on reflection
  - Differences in travel distance
- The conditions are valid if the medium above the top surface is the same as the medium below the bottom surface
- If the thin film is between two different media, one of lower index than the film and one of higher index, the conditions for constructive and destructive interference are *reversed*

Thin Films, 1

- Identify the thin film causing the interference
- Determine the indices of refraction in the film and the media on either side of it
- Determine the number of phase reversals: zero, one or two

Thin Films, 2

- The interference is constructive if the path difference is an integral multiple of λ and destructive if the path difference is an odd half multiple of λ
  - The conditions are reversed if one of the waves undergoes a phase change on reflection

Problem Solving with Thin Films, 3

Equation	1 phase reversal	0 or 2 phase reversals
$2nt = (m + ½)\lambda$	constructive	destructive
$2nt = m\lambda$	destructive	constructive

Interference in Thin Films, Example

- An example of different indices of refraction
- A coating on a solar cell
- There are two phase changes