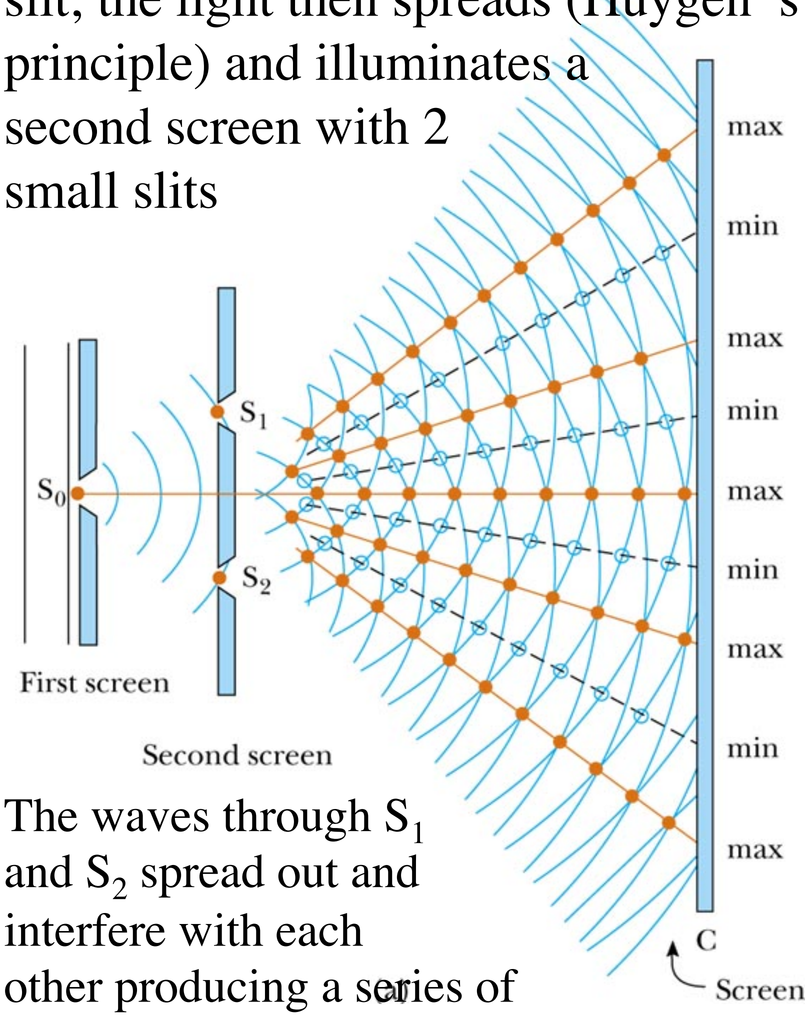
Physics 294H

- Professor: Joey Huston
- email:huston@msu.edu
- office: BPS3230
- Homework will be with Mastering Physics (and an average of 1 hand-written problem per week)
  - **I've assigned 22.62 as a hand-in problem; changed the due date to Thurs Apr 21**
- Quizzes by iclicker (sometimes hand-written)
- **Third exam this coming Tuesday April 19**
  - the exam will cover the material listed on the syllabus, except no numerical questions on diffraction
- **Final exam Thursday May 5 10:00 AM – 12:00 PM 1420 BPS**
  - I'll use the last lecture of the course (Thurs Apr 28) to answer any questions/review
- Course website: www.pa.msu.edu/~huston/phy294h/index.html
  - lectures will be posted frequently, mostly every day if I can remember to do so

Young's Experiment

- In order to observe interference of 2 light waves, need to have 2 things present
  - sources must be coherent (same phase with respect to each other)
  - waves must have identical wavelength
- Laser produces coherent light which can be split into two light beam which then can interfere with each other
- But the first interference experiment was carried out in 1801
  - …no lasers then

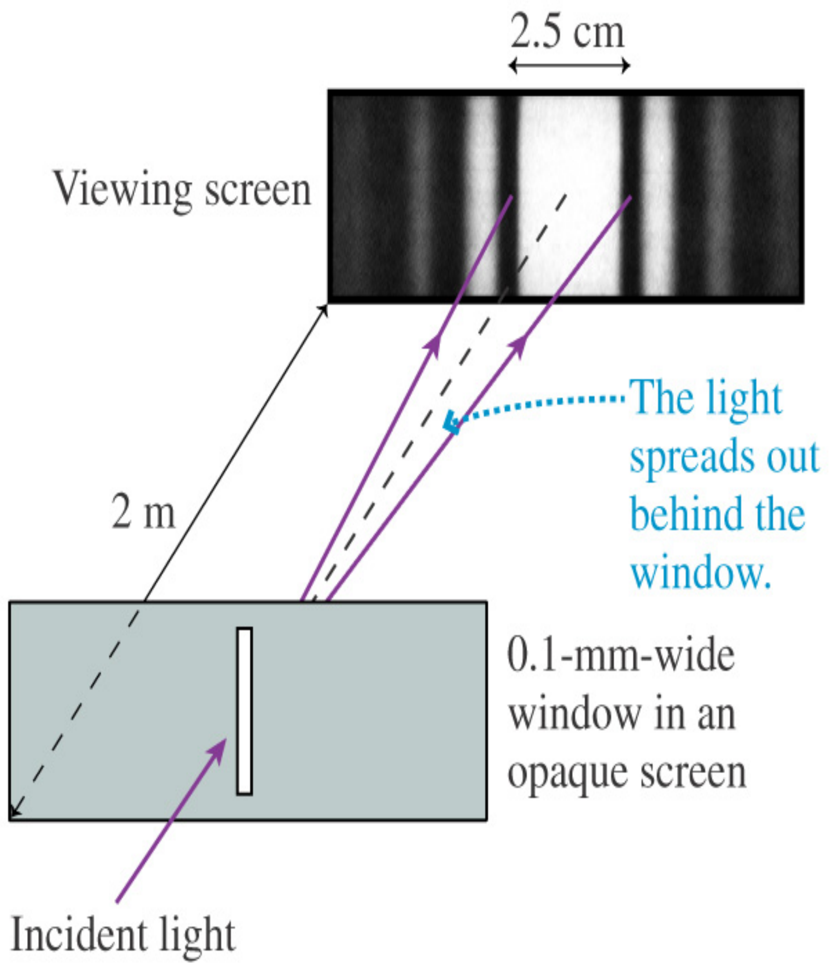
Sunlight shines through a narrow slit; the light then spreads (Huygen's principle) and illuminates a second screen with 2 small slits



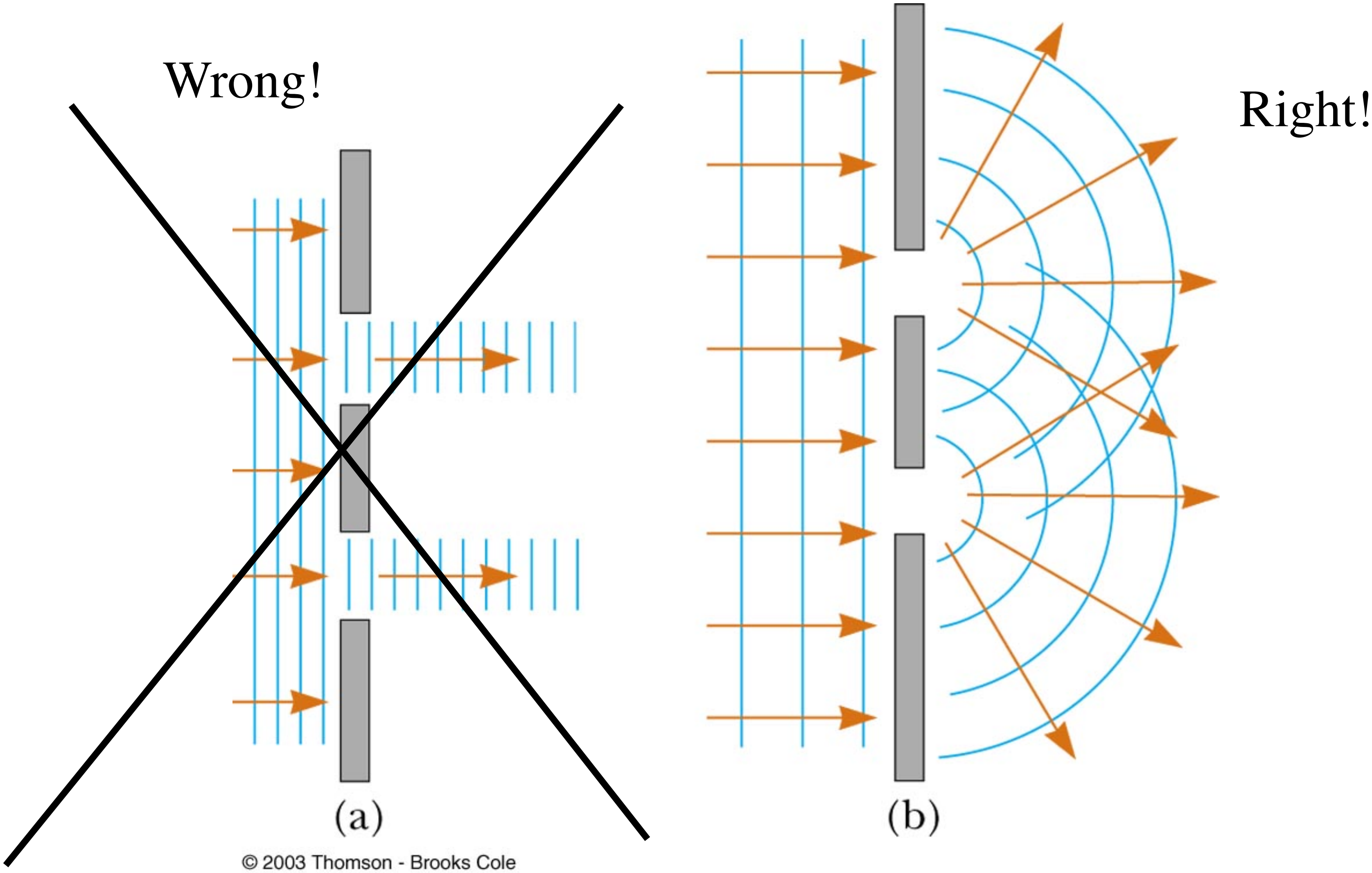
The waves through S_1 and S_2 spread out and interfere with each other producing a series of bright and dark *fringes*

Aside: diffraction

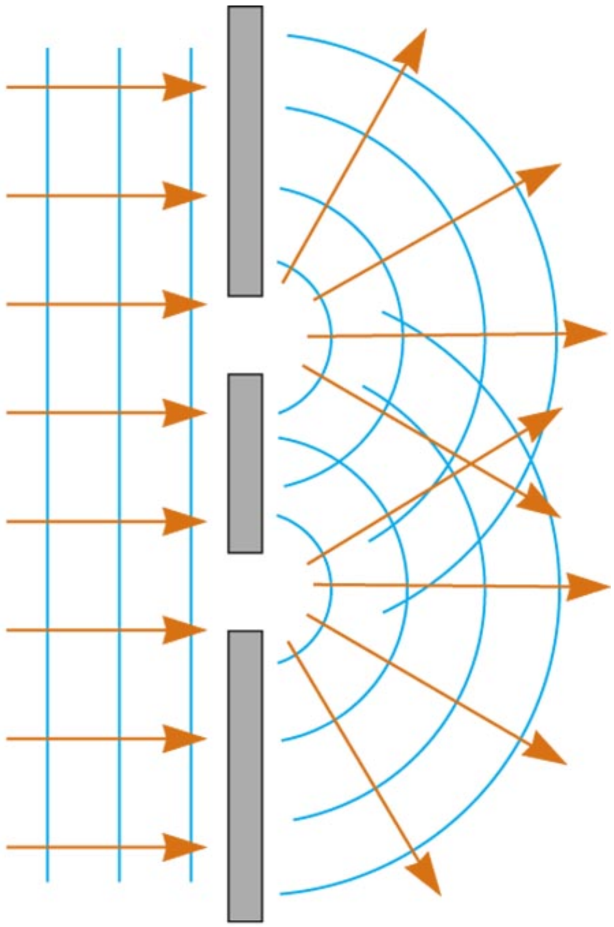
- Like water waves passing through a breakwater, light waves spread out when passing through a narrow opening
- This is called diffraction which we will deal with in more detail later
- Suffice for the moment that the light waves spread out a great deal because they are passing through a very narrow opening



Huygen's principle

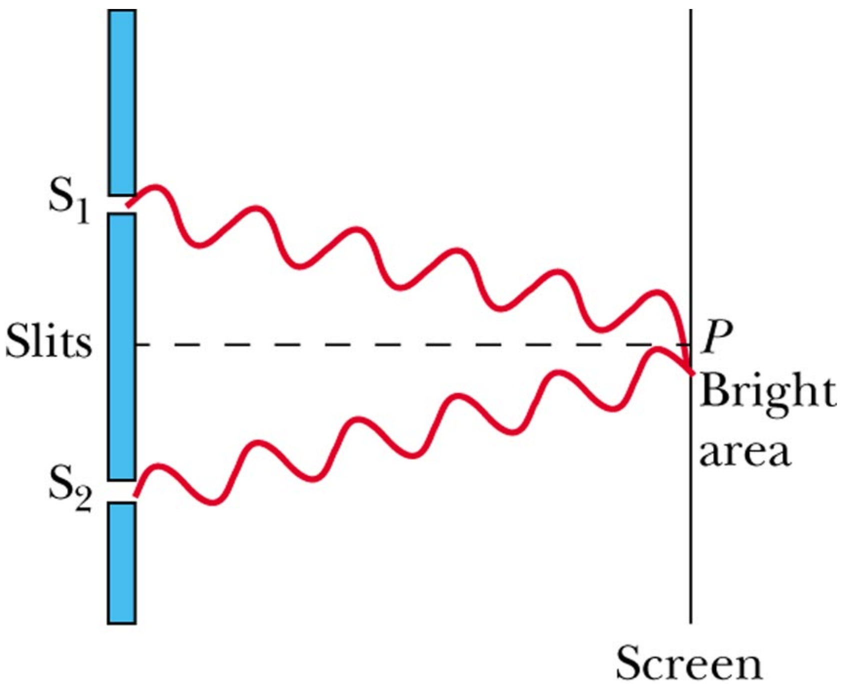


Remember example

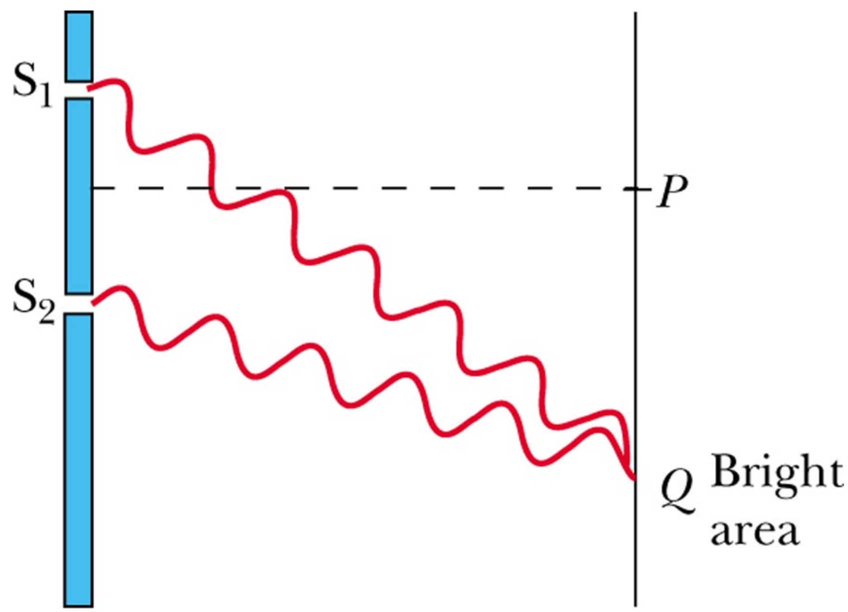

(b)

Constructive interference

When light arrives from S_1 and S_2 so that constructive interference takes place, a bright fringe results



(a)

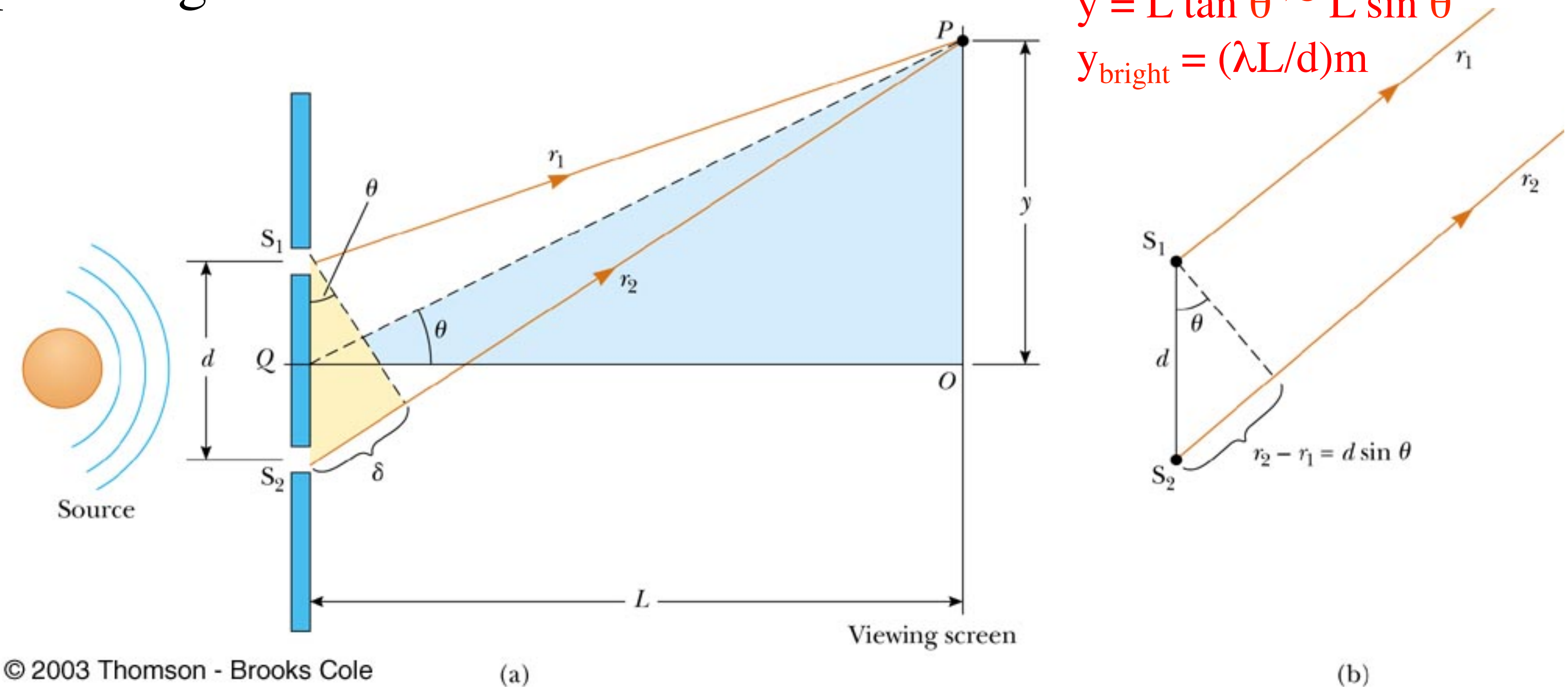


(b)

Interference patterns

Light from slit S_2 has to travel further then light from S_1
path length difference is d sin θ

$y = L \tan\theta \sim L \sin\theta$
$y_{bright} = (\lambda L/d)m$



if d sin θ is a multiple of the wavelength λ, then constructive interference occurs

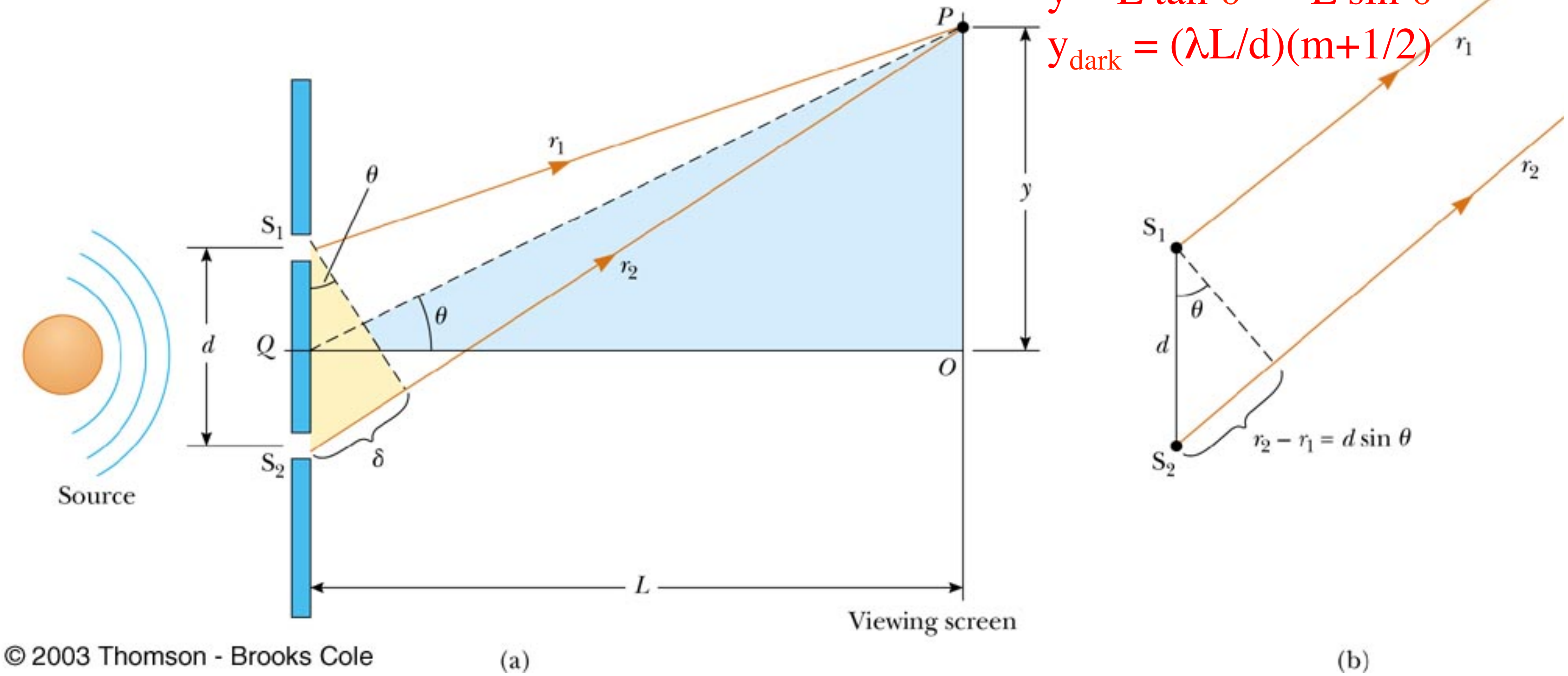
$d \sin\theta = m\lambda$ m=0,+/-1, +/-2, …

Interference patterns

Light from slit S_2 has to travel further then light from S_1
path length difference is d sin θ

$y = L \tan\theta > L \sin\theta$

$y_{dark} = (\lambda L/d)(m+1/2)$



if d sin θ is an odd multiple of the wavelength λ/2, then destructive interference occurs

$d \sin\theta = (m+1/2)\lambda$ m=0,+/-1, +/-2, …

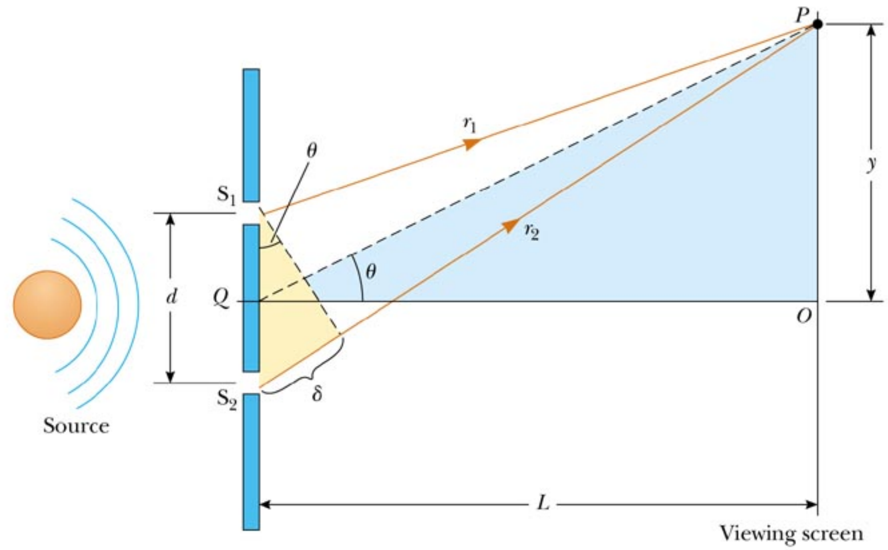
Interference

- For constructive interference, I have

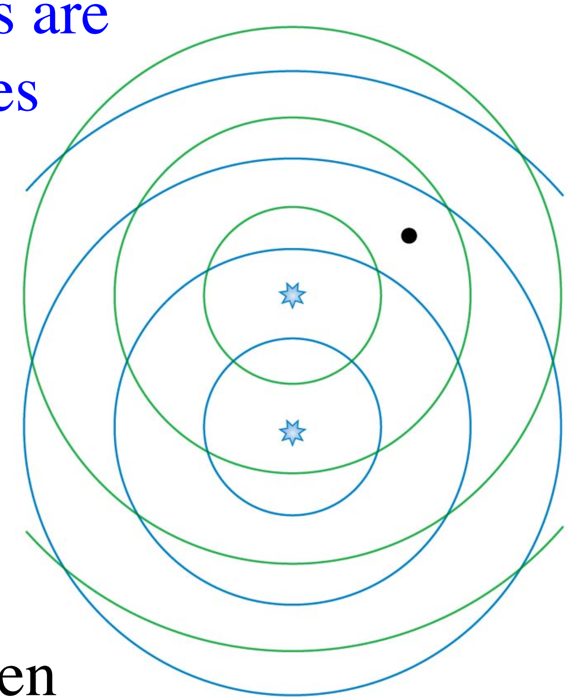
$$d\sin\theta = m\lambda$$

  - where m=0,+/-1,+/-2, …
- I expect that as d gets smaller, sinθ gets larger

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



Two rocks are simultaneously dropped into a pond, creating the ripples shown. The lines are the wave crests. As they overlap, the ripples interfere.
At the point marked with a dot,



A. The interference is constructive.

B. The interference is destructive.

C. The interference is somewhere between constructive and destructive.

D. There’s not enough information to tell about the interference.

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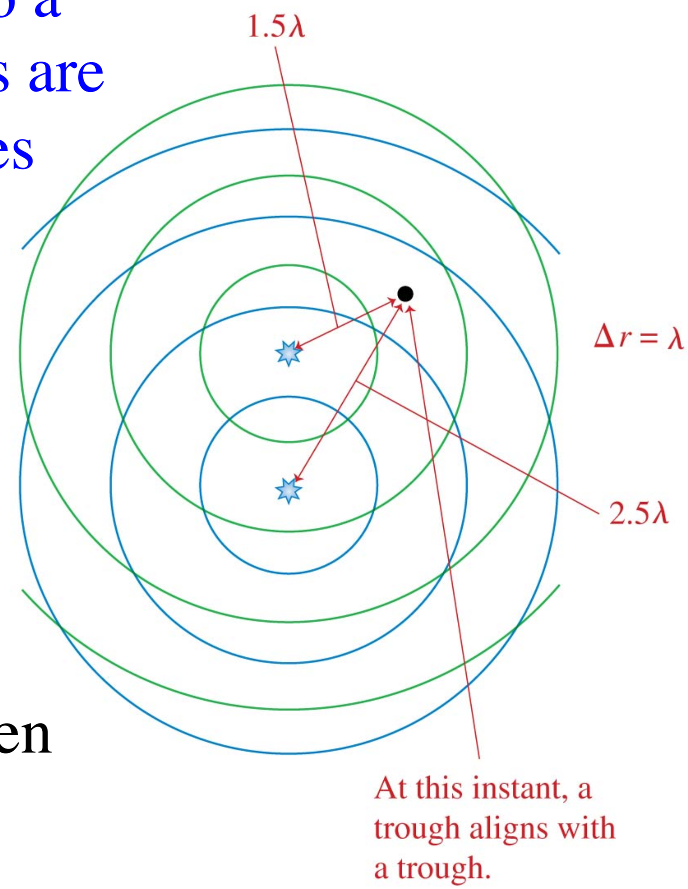

✔ **A. The interference is constructive.**

B. The interference is destructive.

C. The interference is somewhere between constructive and destructive.

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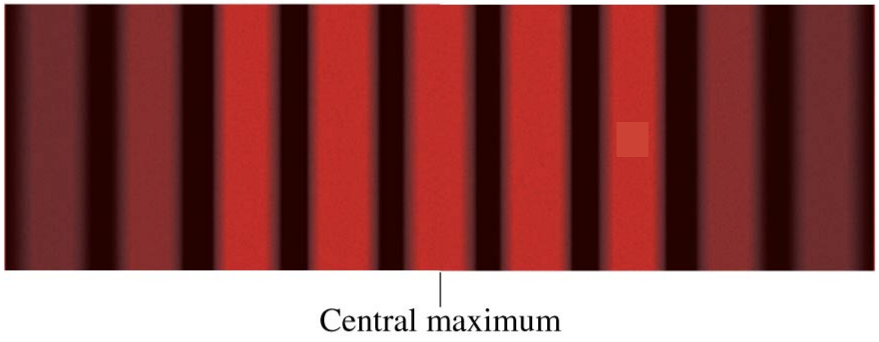
A laboratory experiment produces a double-slit interference pattern on a screen. If the screen is moved farther away from the slits, the fringes will be



A. Closer together.

B. In the same positions.

C. Farther apart.

D. Fuzzy and out of focus.

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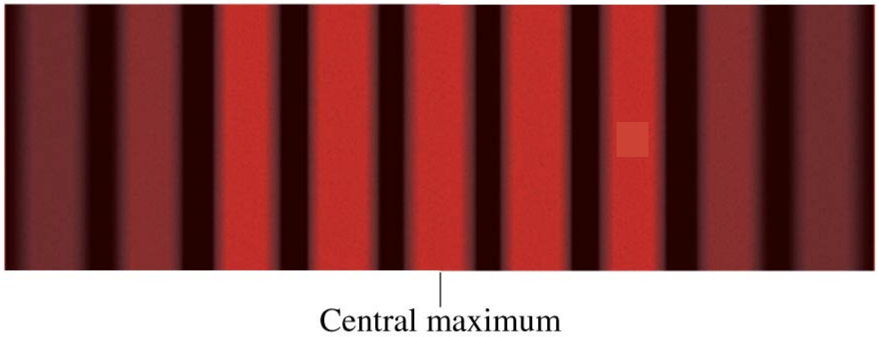

A. Closer together.

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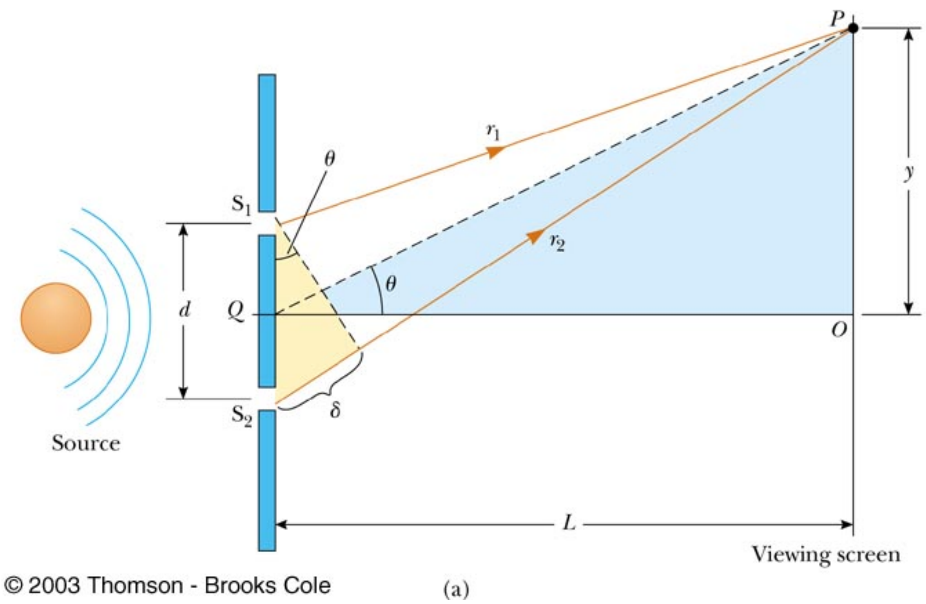
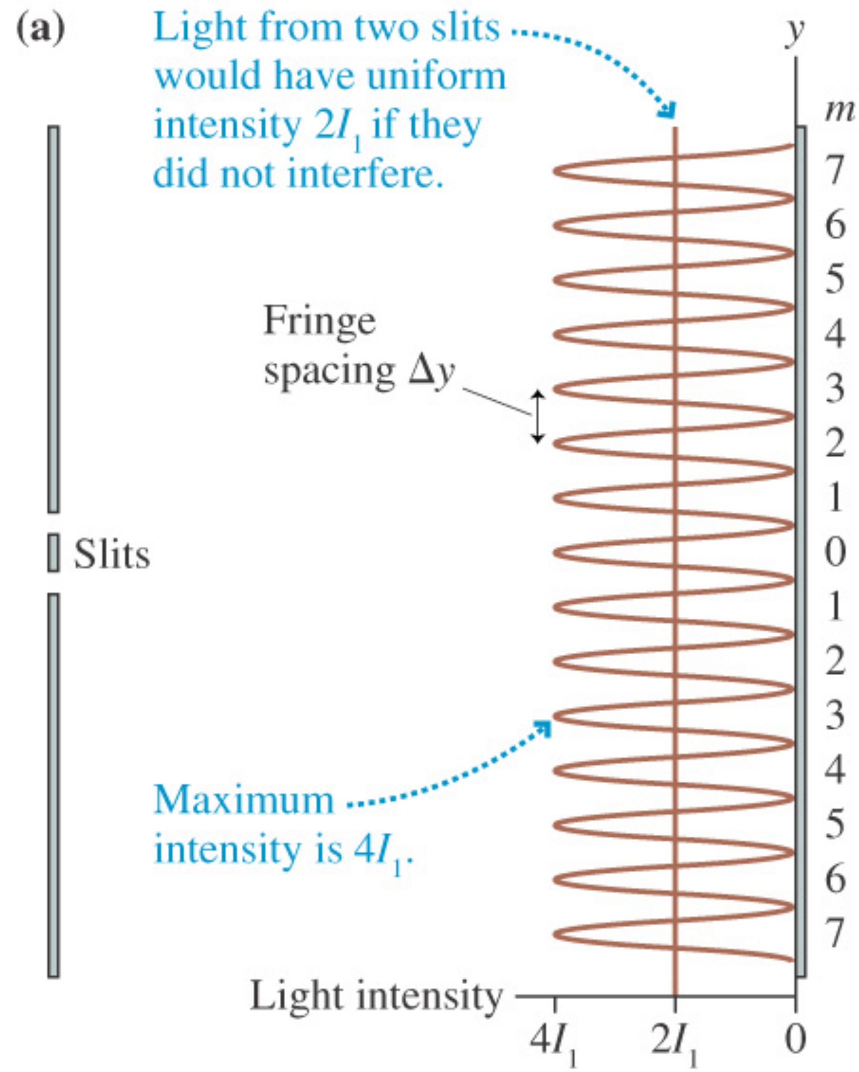
Example

- A double slit interference pattern is created by two narrow slits spaced 0.20 mm apart
- The distance between the central maximum and the fourth maximum on a screen 60 cm behind the slits is 6.0 mm.
- What is the wavelength of the light used for this experiment?



Intensity of interference pattern

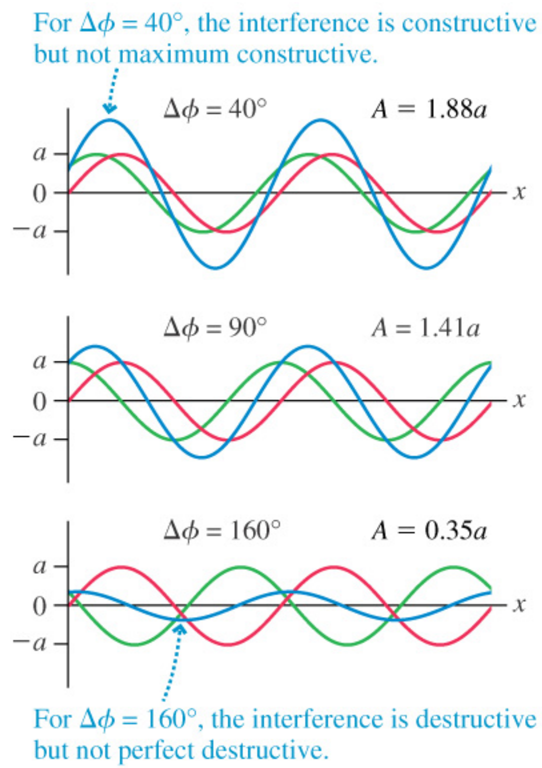
- We've calculated formulas for the location of the maxima and minima of intensity
- But we'd also like to calculate the value of those intensities
- If there were no interference, and each wave had maximum amplitude a (and intensity $I_1=Ca^2$, with C a proportionality constant), then the intensity of the two waves would be $I_2=2I_1=2Ca^2$

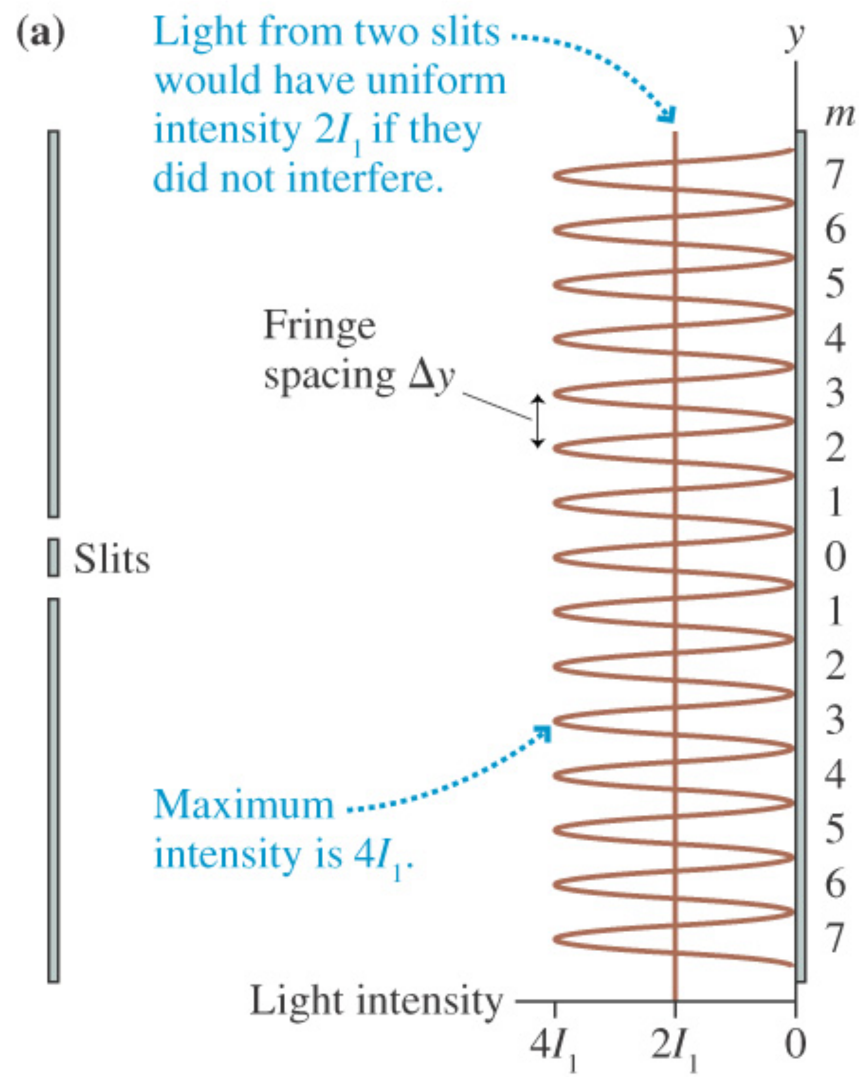


Intensity of interference pattern

- But there is interference
- The amplitude of the two waves with a phase difference ϕ is

$$A = \left| 2a\cos\left(\frac{\Delta\phi}{2}\right) \right|$$





Intensity

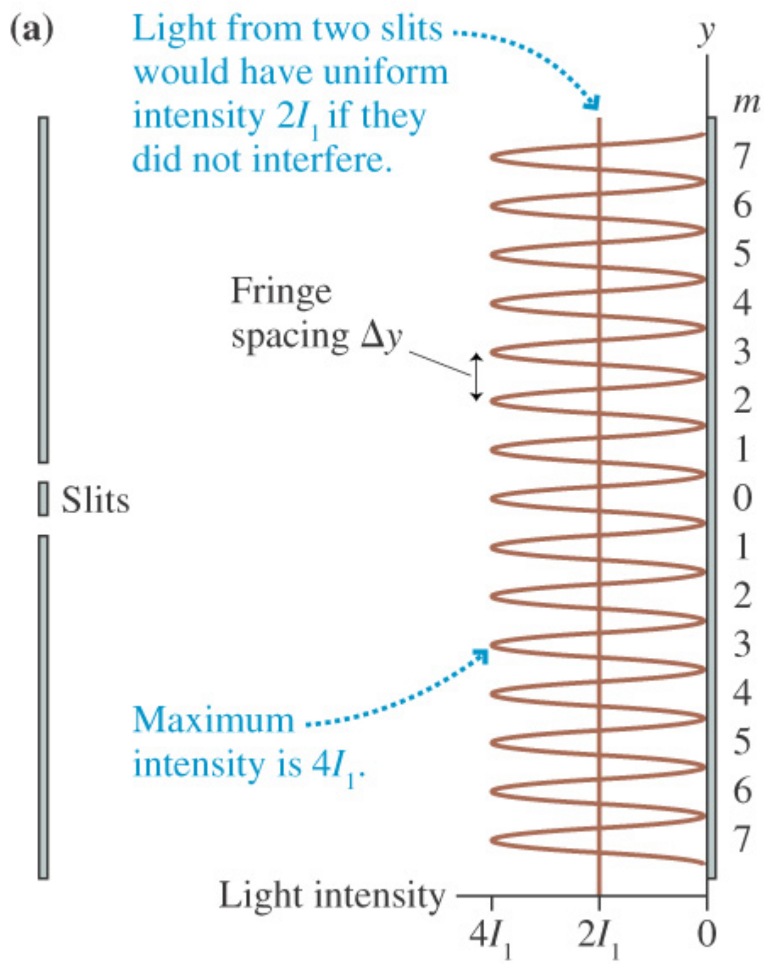
- Thus the intensity is given by

$$I = CA^2 = 4Ca^2 \cos^2\left(\frac{\pi d}{\lambda L} y\right)$$

- Since Ca^2 is I_1

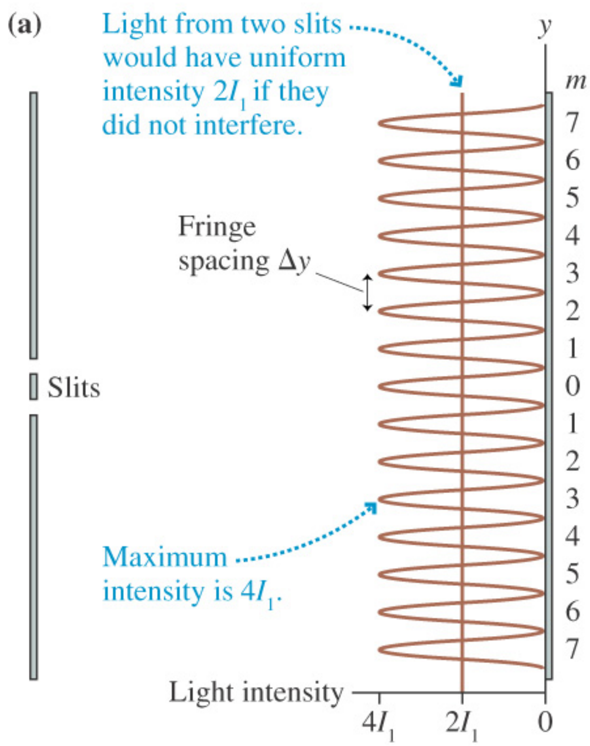
$$I_{double} = 4I_1 \cos^2\left(\frac{\pi d}{\lambda L} y\right)$$

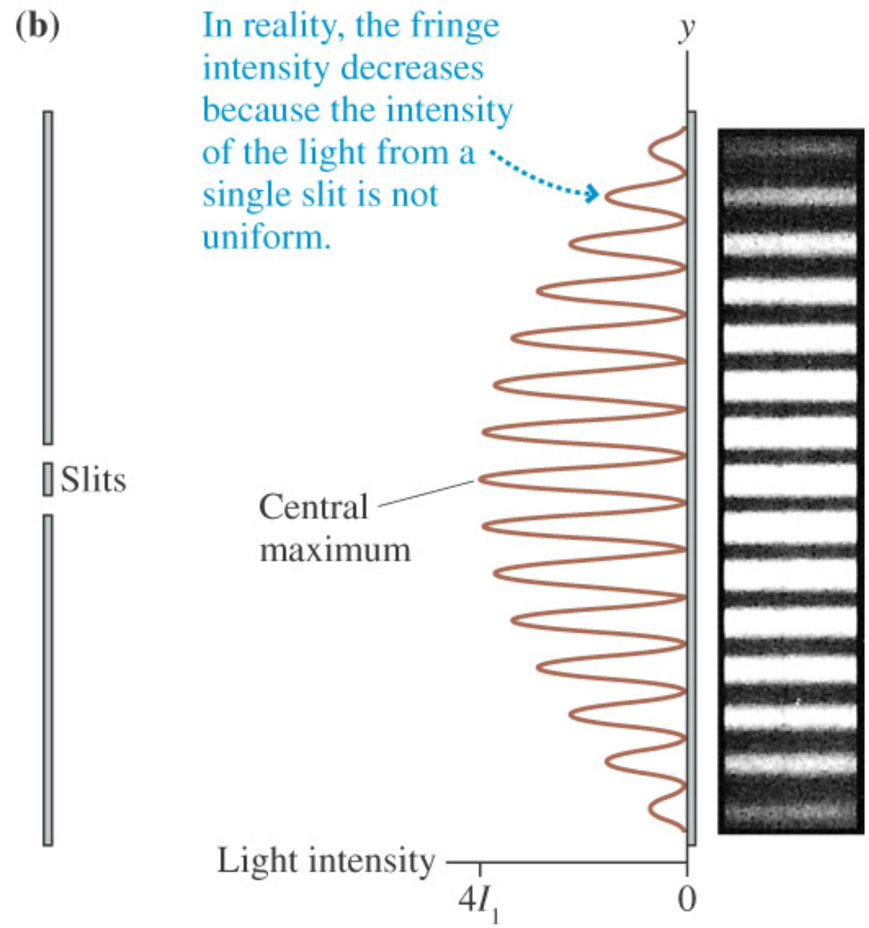
- Note that average intensity is $2I_1$
- Interference does not change the amount of energy coming through the two slits, but it does redistribute the light energy on the viewing screen



Intensity

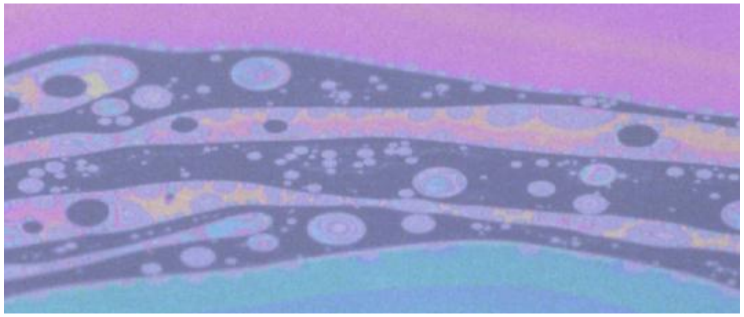
- Note that our formula predicts an equal intensity for each bright fringe
- In reality, the intensity fades as you move away from the center because of the effects of diffraction

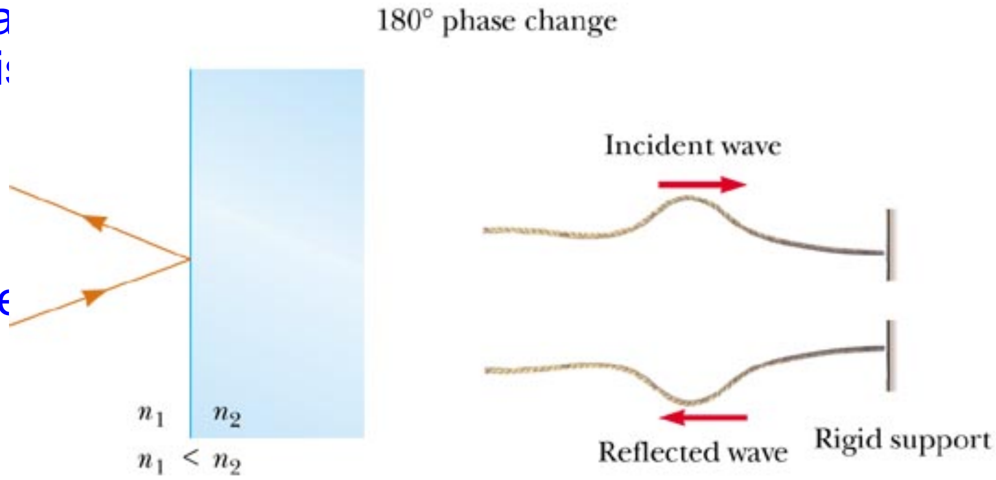




Thin film interference

- Interference can also be observed in other situations such as thin oil films
- But before we talk about thin films, we have to talk about phase changes when waves reflect at an interface
- For example, when a light wave reflects from a surface that has a higher index of refraction, there is a phase shift of 180°
  - electric field reverses direction
- Similar to the reflection of a wave travelling on a rope when the wave hits a rigid support

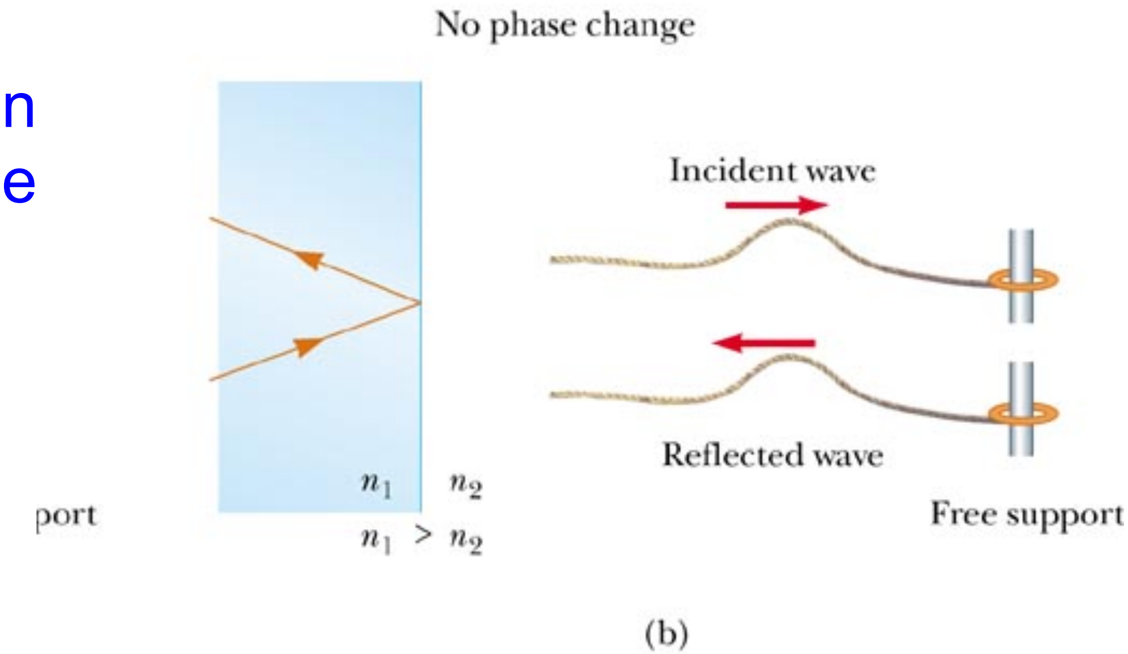




(a)

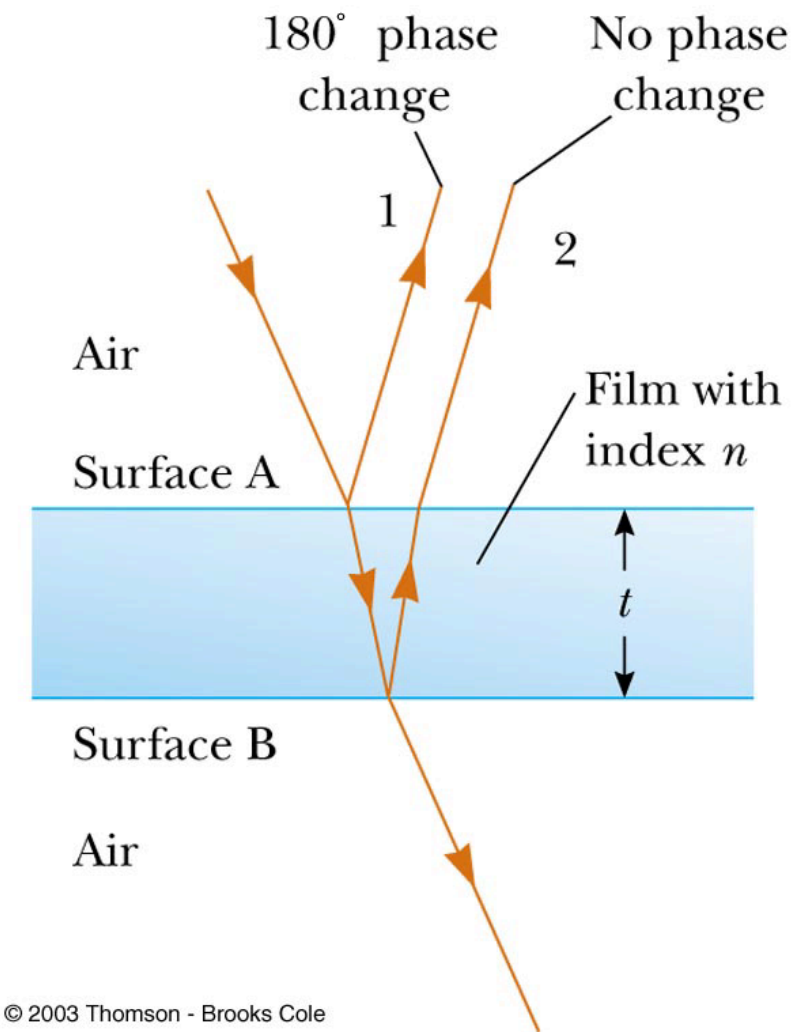
Thin film interference

- But when a light wave reflects from a surface that has a lower index of refraction, there is no phase shift
- Similar to the situation where the support is e not rigid



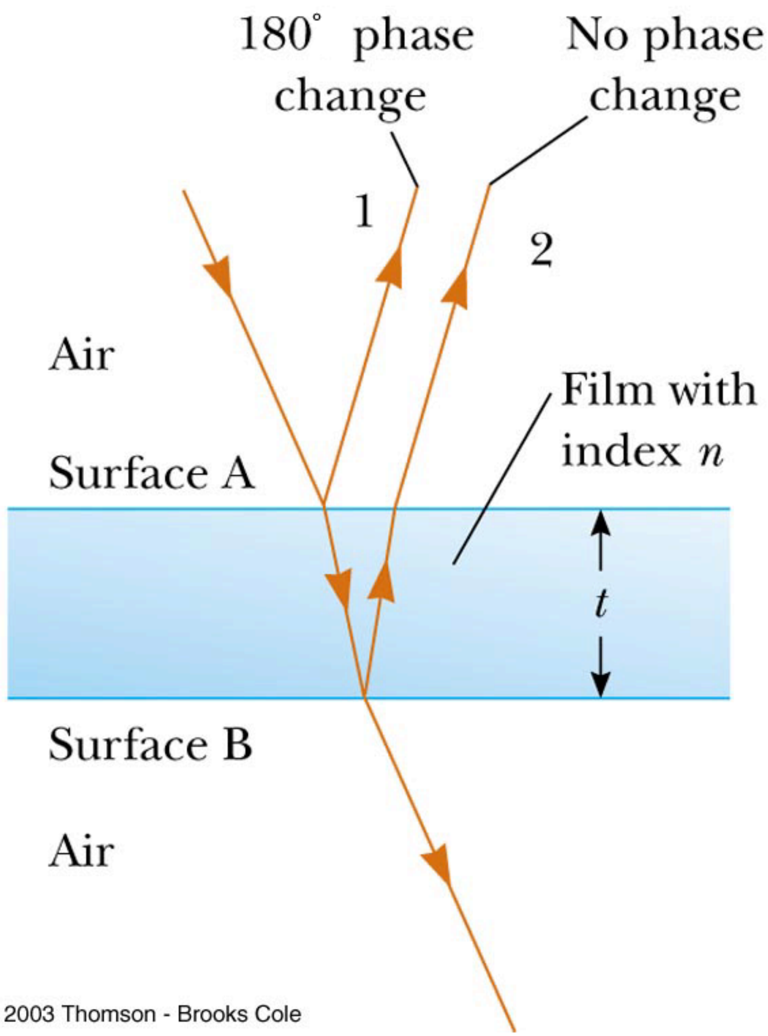
Reflections from a thin film

- Part of the wave reflects from the top surface and part from the bottom surface
- The part that reflects from the top surface has a 180º phase change while the part that reflects from the bottom does not
- When will there be constructive interference between the two reflected waves?



Reflections from a thin film

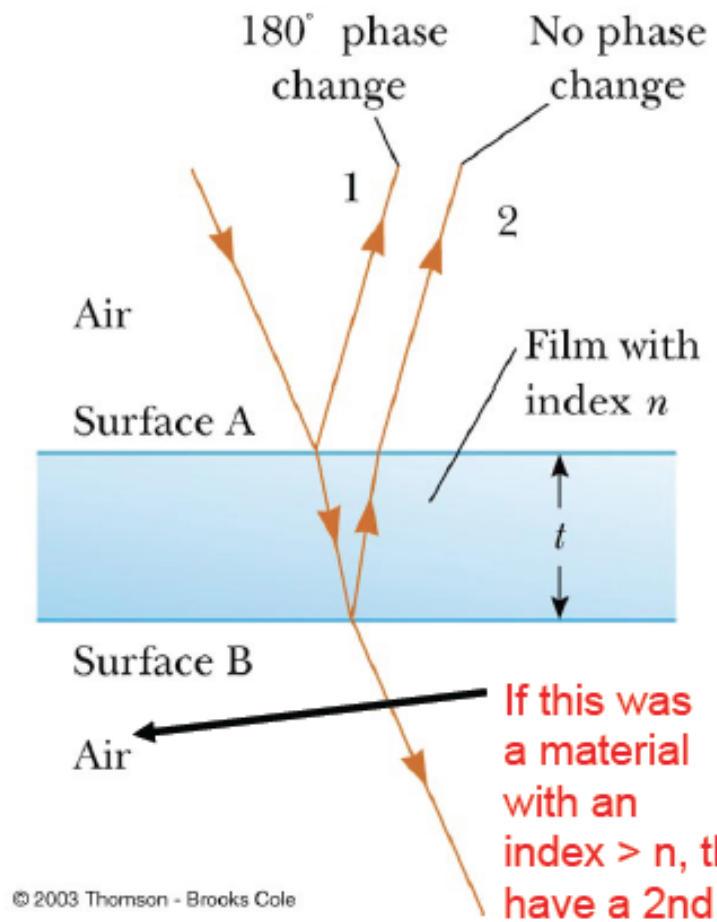
- Wave #2 has to travel further by a distance 2t (ignore any angle)
- So you might think that if 2t = mλ(where m is an integer) that you would get constructive interference
- But…ahh…the phase shift…so I get constructive interference when 2t = (m+1/2)λ
- But…ahh…I remember that the wavelength changes inside the film to $\lambda_n = \lambda/n$
- …so, finally, I get constructive interference when
  - $2t = (m+1/2)\,\lambda_n$
  - or $2nt = (m+1/2)\lambda$



Reflections from a thin film

- So I get destructive interference when
  - $2t = m\,\lambda_n$
  - or $2nt = m\lambda$

- Two things influence whether I have constructive or destructive interference (or somewhere in between)
  - difference in path length traveled
  - any phase changes on reflection
    - in this example, I have one 180º phase shift because I' m going from air to a film with an index n back to air

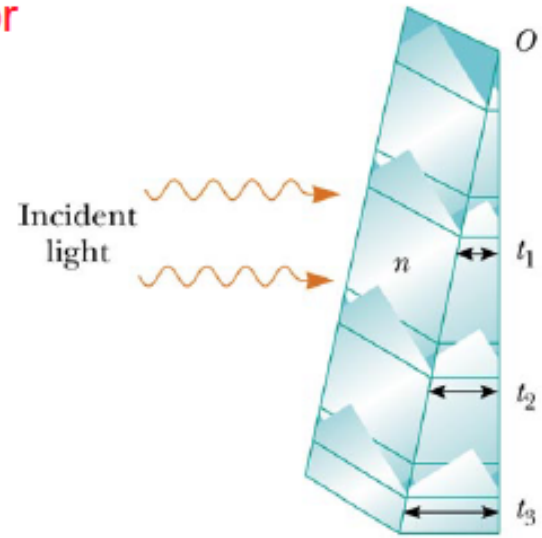


If this was a material with an index > n, then I' c have a 2nd 180º phase shift

What happens when I have a wedge-shaped film

have constructive interference when $2nt = (m+1/2)\lambda$

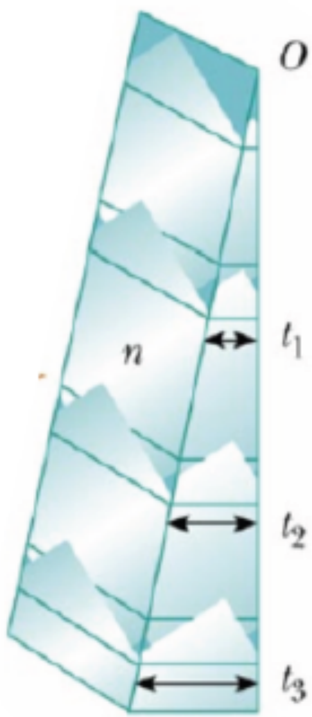
Note that bands of color show up whenever the thickness leads to constructive interference for that color



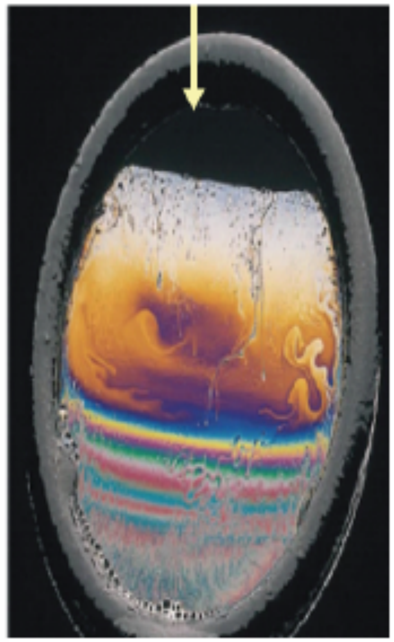
(a)

(b)

Soap film, air on both sides



The top, t~0, is black.



Reflected light undergoes a phase change from the front of the soap film ($n_{air} < n_{water}$) but not from the back of the soap film ($n_{water} > n_{air}$).

→ There will be only **1 reflective** phase change. So we add ½λ (or change the phase by $\boldsymbol{\pi}$).

In this case the two waves will interfere **constructively** if

$$2t = \left(m + \frac{1}{2}\right)\frac{\lambda_{air}}{n_{film}}$$

The two waves will interfere **destructively** if

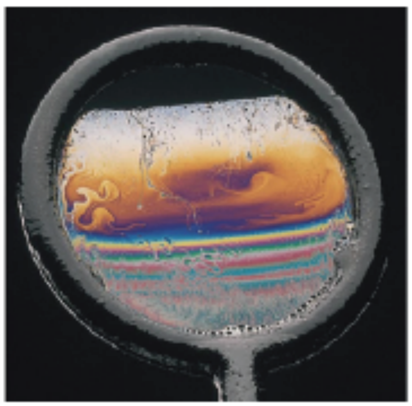
$$2t = m\frac{\lambda_{air}}{n_{film}}$$

$$m = 0,1,2,3,...$$

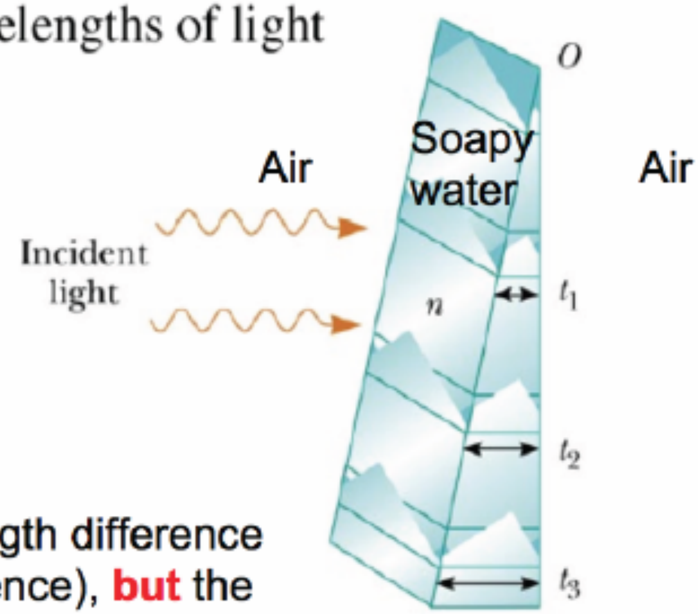
■

470-nm-thick soap bubble. Visible wavelengths are shown in **bold.**

Equation	$m = 1$	$m = 2$	$m = 3$
$\lambda_{con} = \dfrac{2nt}{m+\frac{1}{2}}$	833 nm	**500 nm** Green	357 nm
$\lambda_{des} = \dfrac{2nt}{m}$	1250 nm	**625 nm** Red	**417 nm** Violet



Light reflecting from top surface interferes with light reflecting from back surface; depending on differences in path lengths can have constructive or destructive interference for specific wavelengths of light



At the top the film is very thin so no path length difference between the 2 waves (constructive interference), **but** the wave reflected off the front undergoes a reflective phase change and is out of phase with the wave reflected off the back so the 2 waves always interfere **destructively**.

video