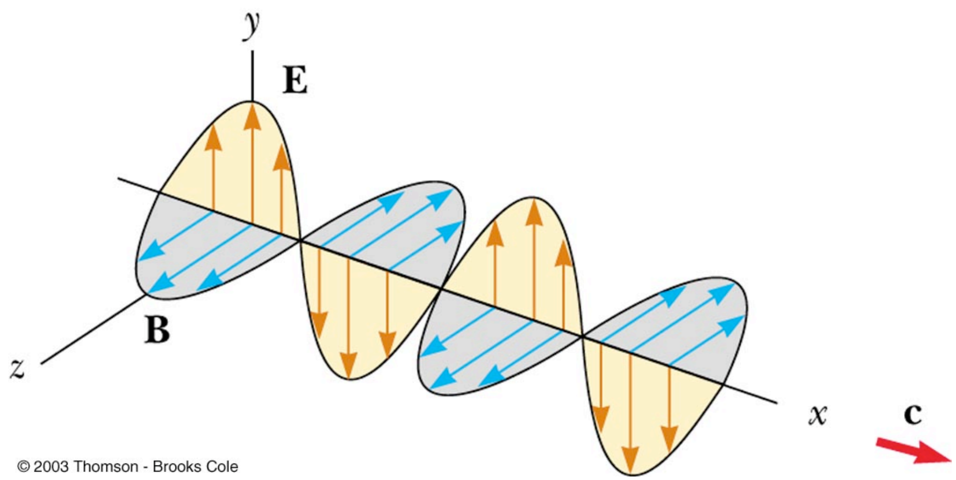
Physical or wave optics

- In the last chapter, we have been studying geometric optics
  - light moves in straight lines
  - can summarize everything by indicating direction of light using a ray
  - light behaves essentially the way a stream of particles (photons) would
- This has worked well for a number of phenomena
  - reflection
  - refraction
- …and has helped us to understand the workings of
  - mirrors
  - thin lenses
- But our particle theory of light gives out when we try to understand phenomena like interference, diffraction and polarization
  - just doesn't work
- Have to resort to wave or physical optics (in this chapter)
  - …and treat light like a wave
- The first thing we'll look at is interference of light waves
  - not easy to observe because of the short wavelengths of light involved ($4X10^{-7}$ m to $7X10^{-7}$ m)
- Along the way we've going to find out why the sky is blue

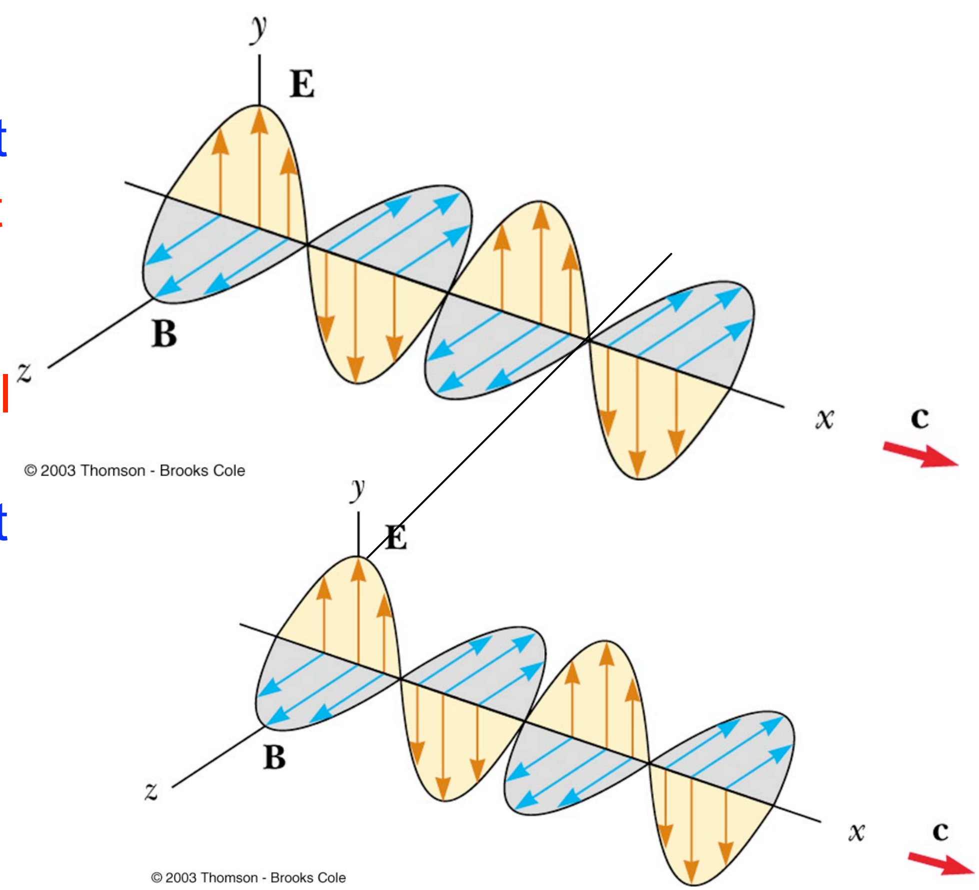
Electromagnetic waves

- Now we're back to thinking of light as specifically being an electromagnetic wave
  - oscillating electric and magnetic fields perpendicular to each other propagating through space
  - equal amounts of energy stored in the electric field and in the magnetic field
  - in interactions with matter, it's the electric component that does most of the work



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



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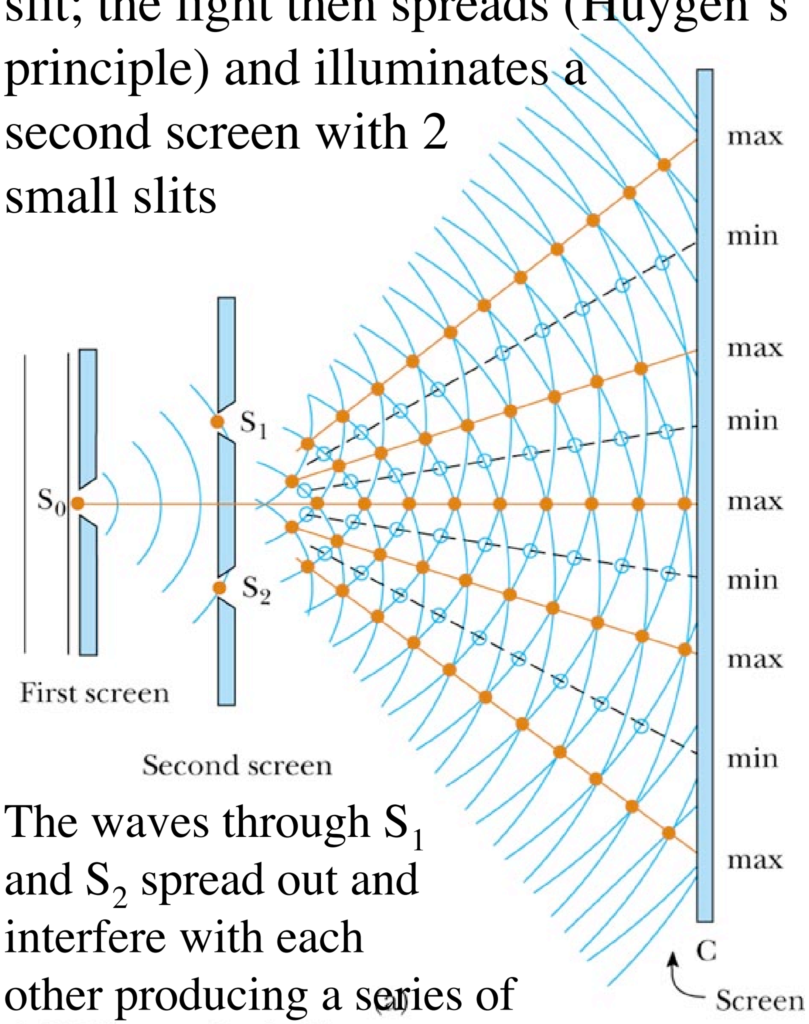
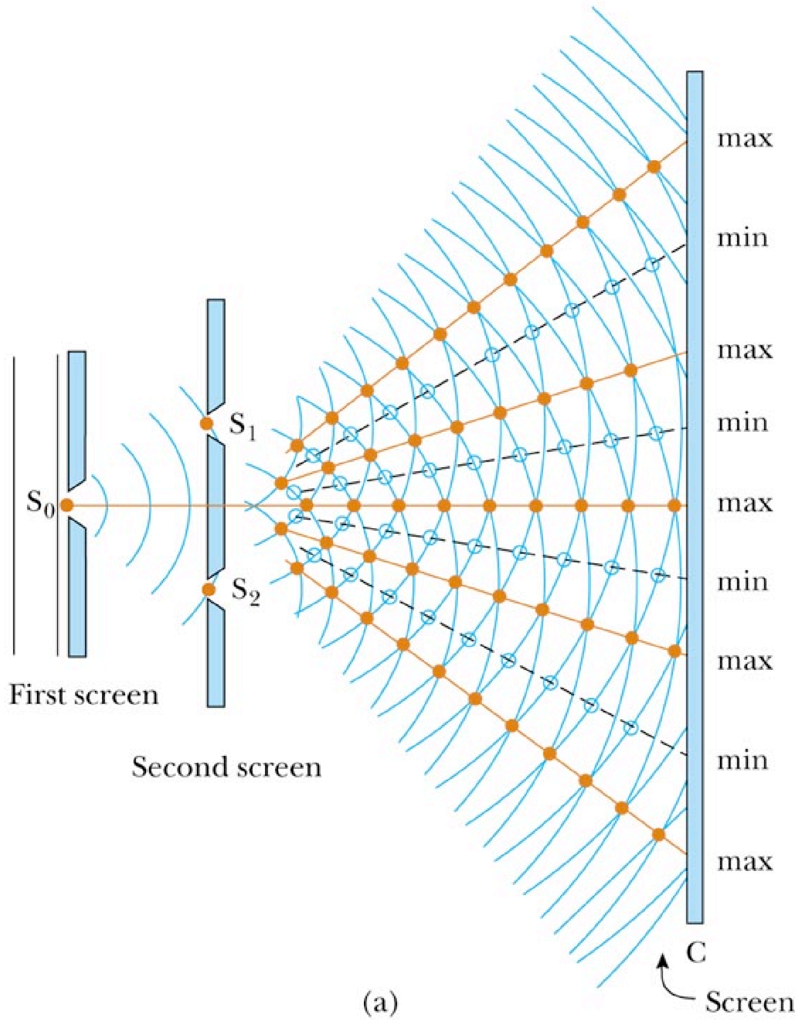
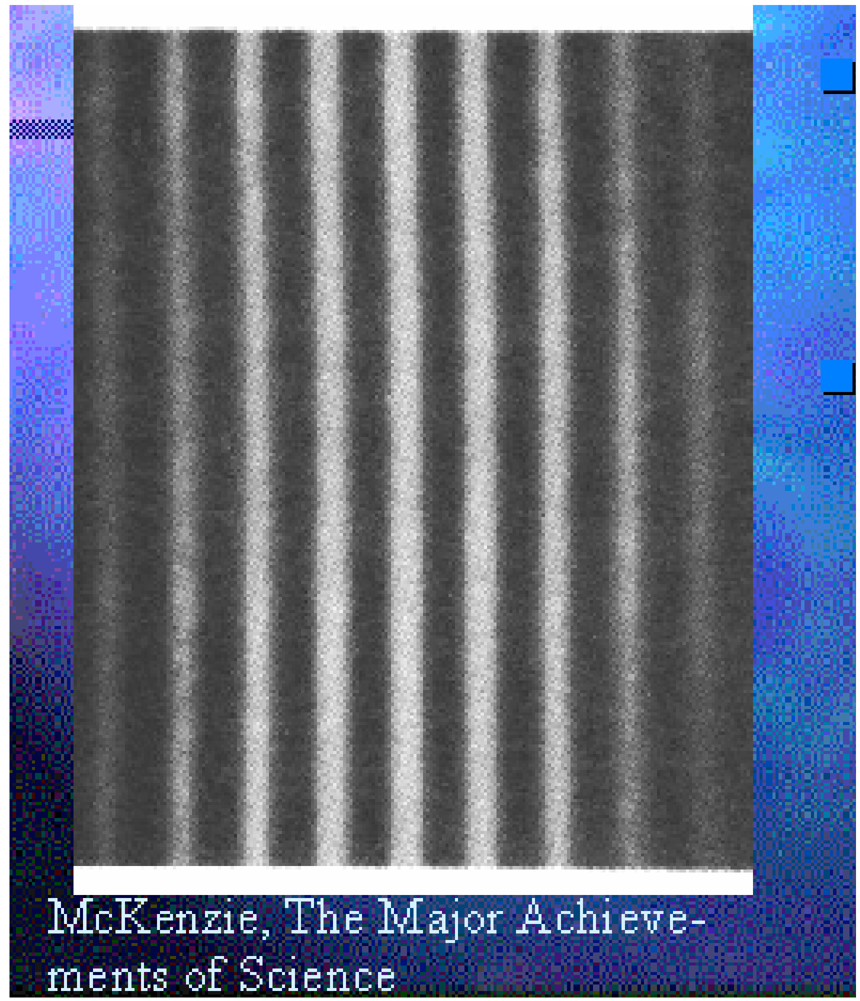
Sunlight shines through a narrow slit; the light then spreads (Huygen's principle) and illuminates a second screen with 2 small slits



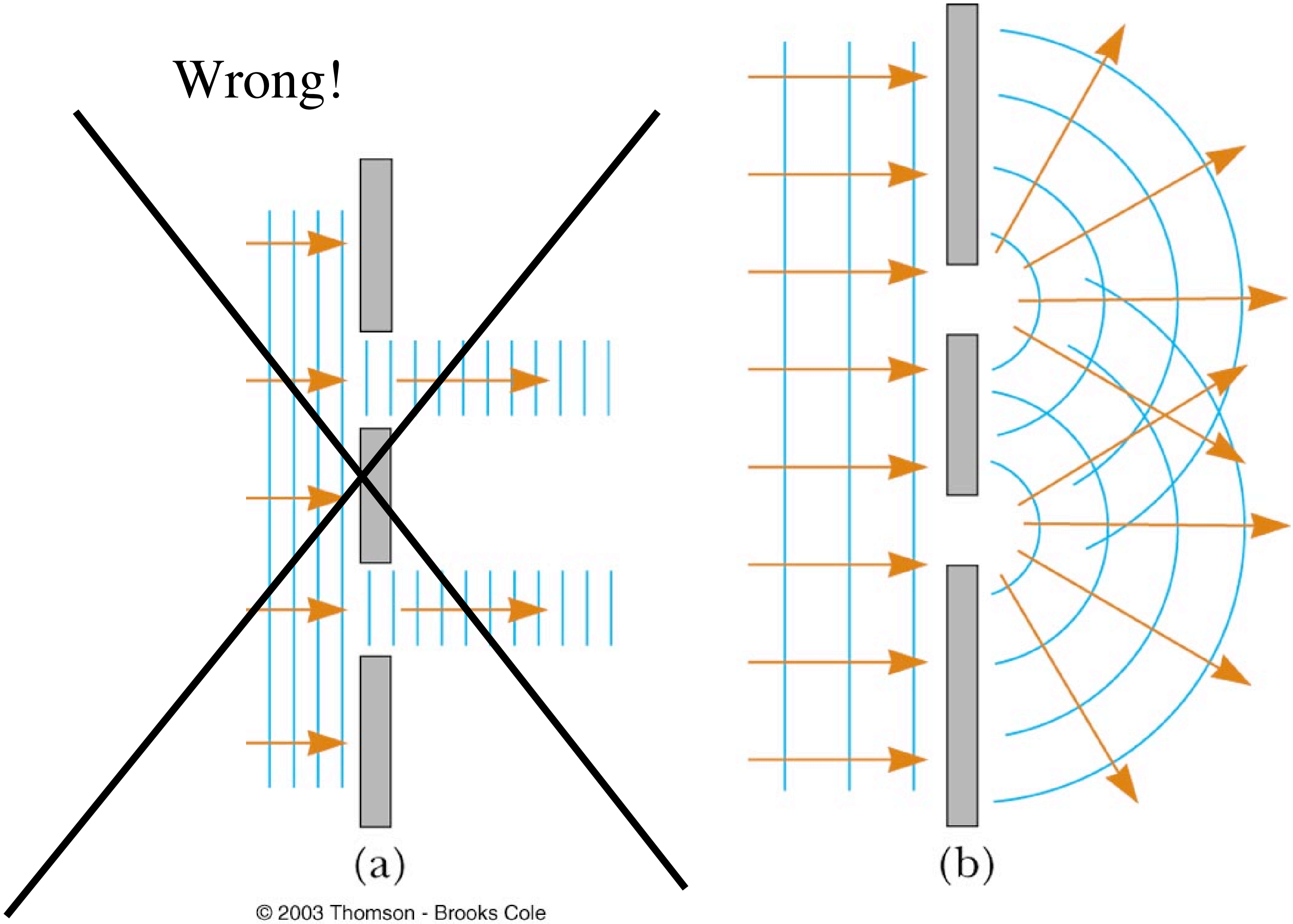
The waves through S_1 and S_2 spread out and interfere with each other producing a series of bright and dark *fringes*

Interference fringes

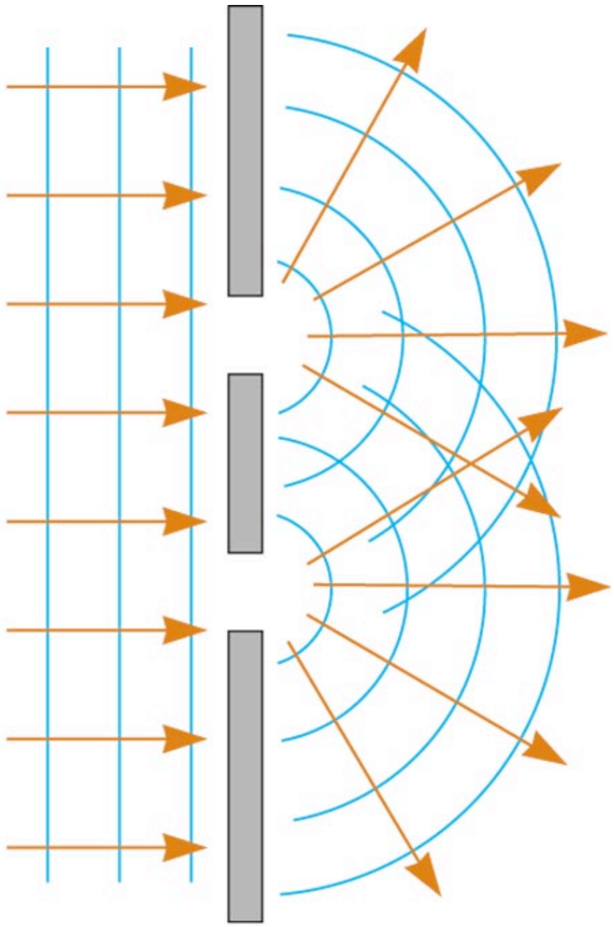




Huygen's principle



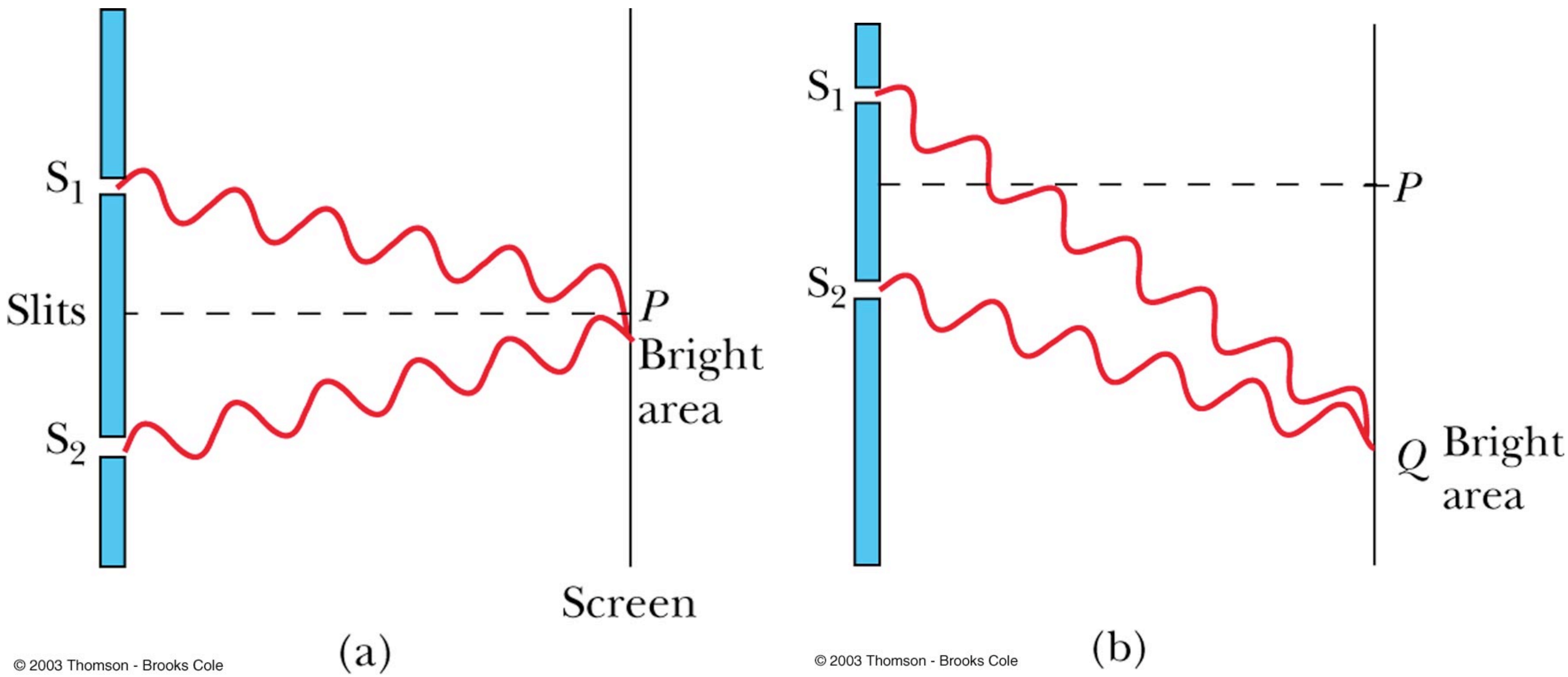
Remember example



(b)

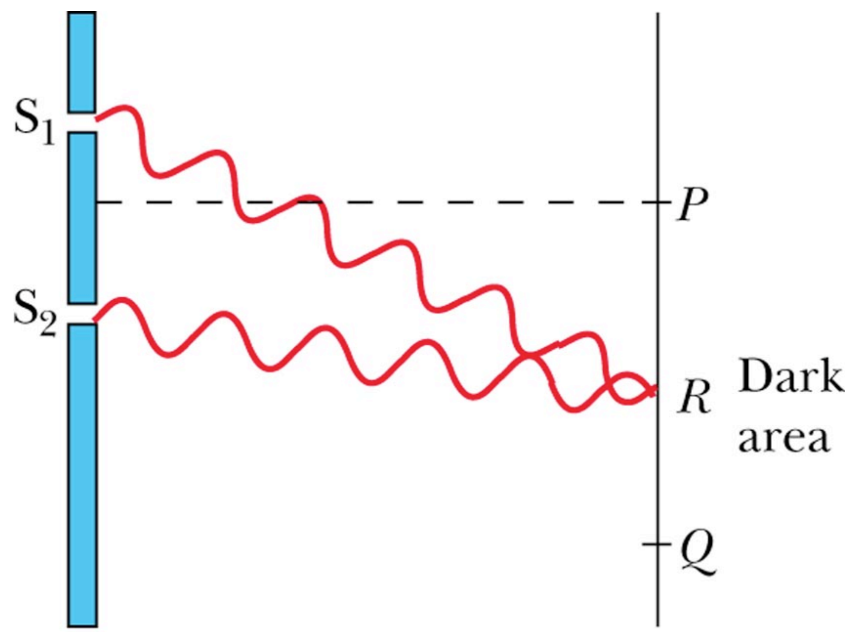
Constructive interference

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



Destructive interference

- If the light arrives from S_1 and S_2 at a point on the screen and there is destructive interference, then there is a dark spot

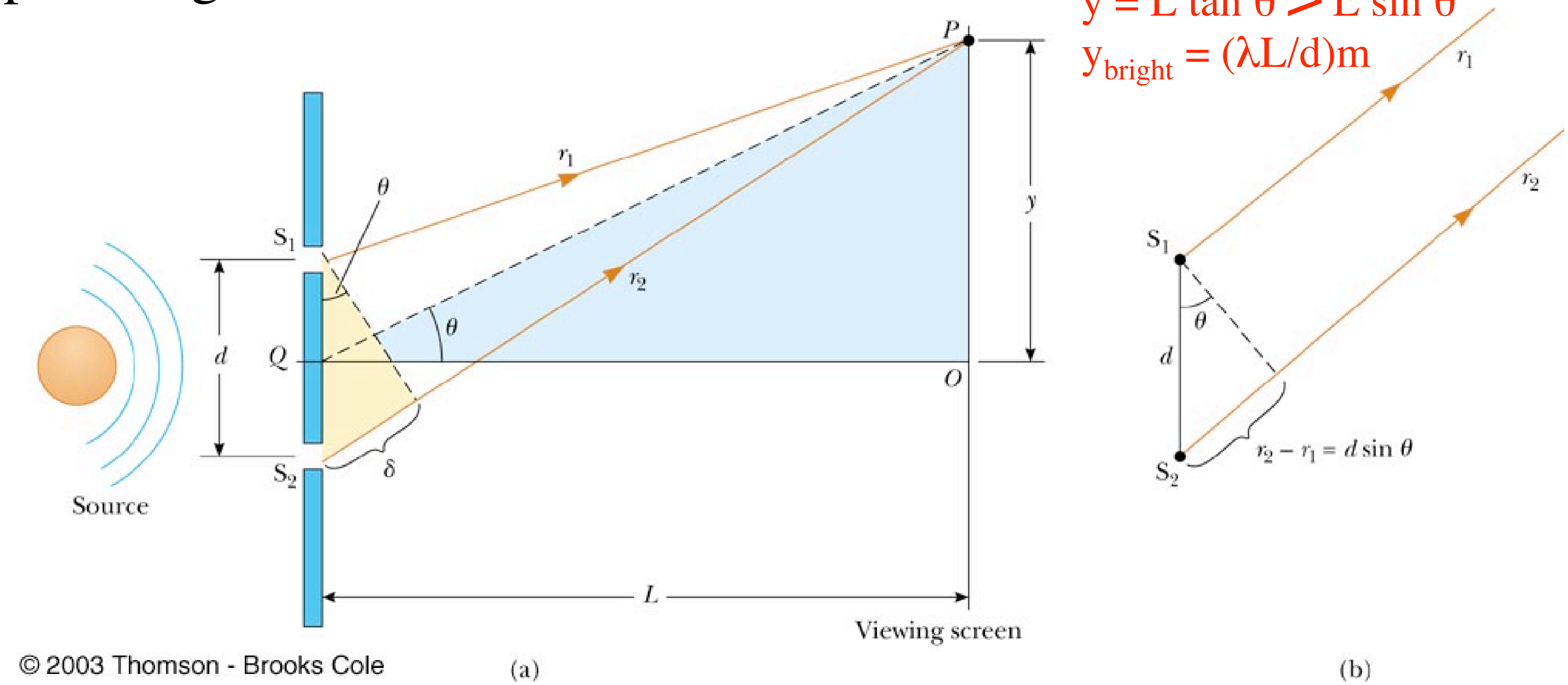


(c)

Interference patterns

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

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



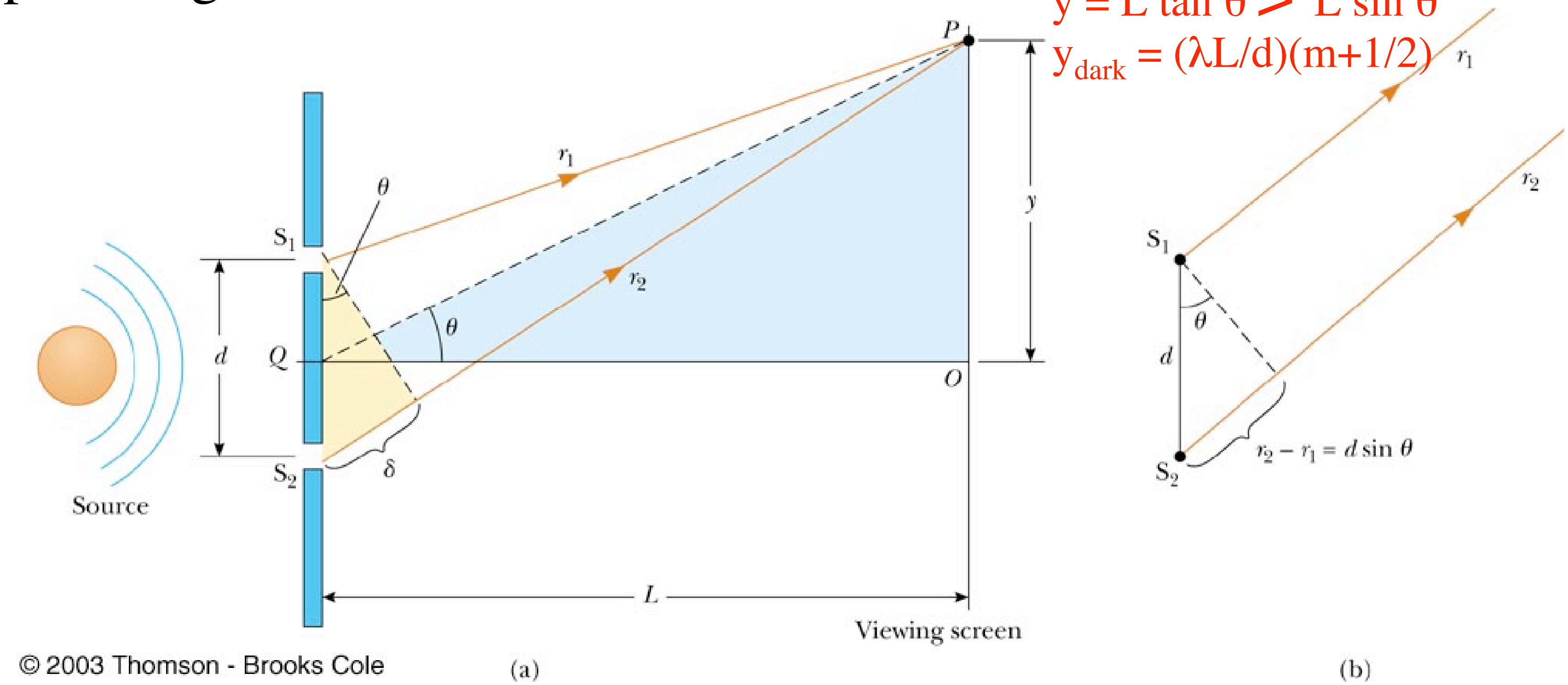
if d sin θ is a multiple of the wavelength λ, then constructive interference occurs

$d \sin\theta = m\lambda$ 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

$y = L \tan\theta > L \sin\theta$
$y_{dark} = (\lambda L/d)(m+1/2)$



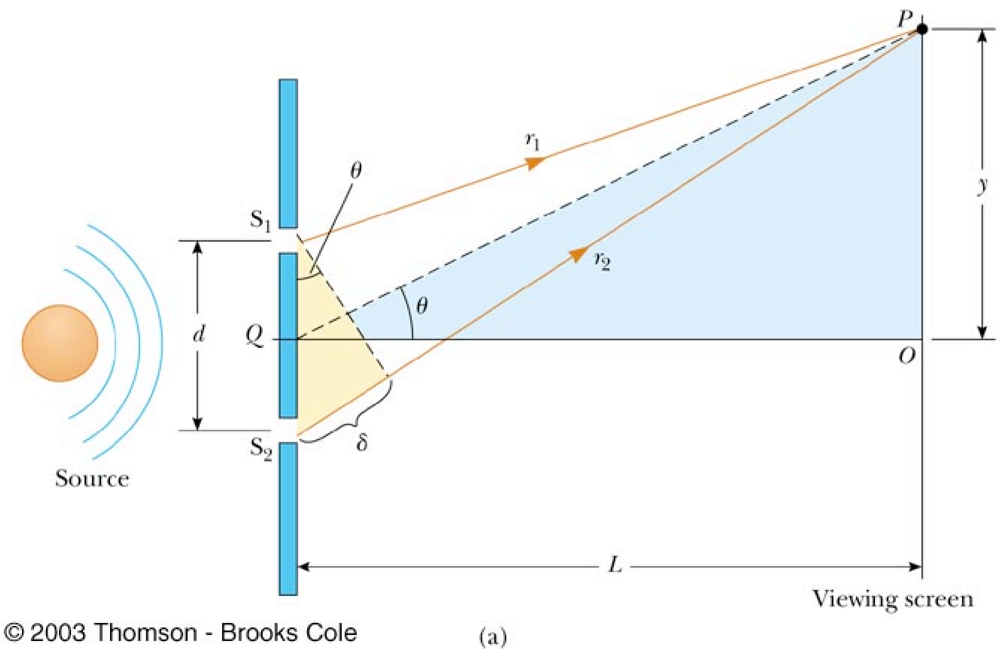
if d sin θ is an odd multiple of the wavelength λ/2, then destructive interference occurs

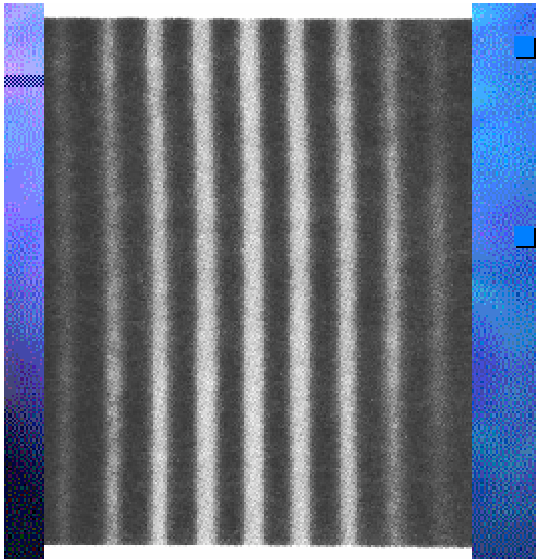
$d \sin\theta = (m+1/2)\lambda$ m=0,+/-1, +/-2, …

Example

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

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

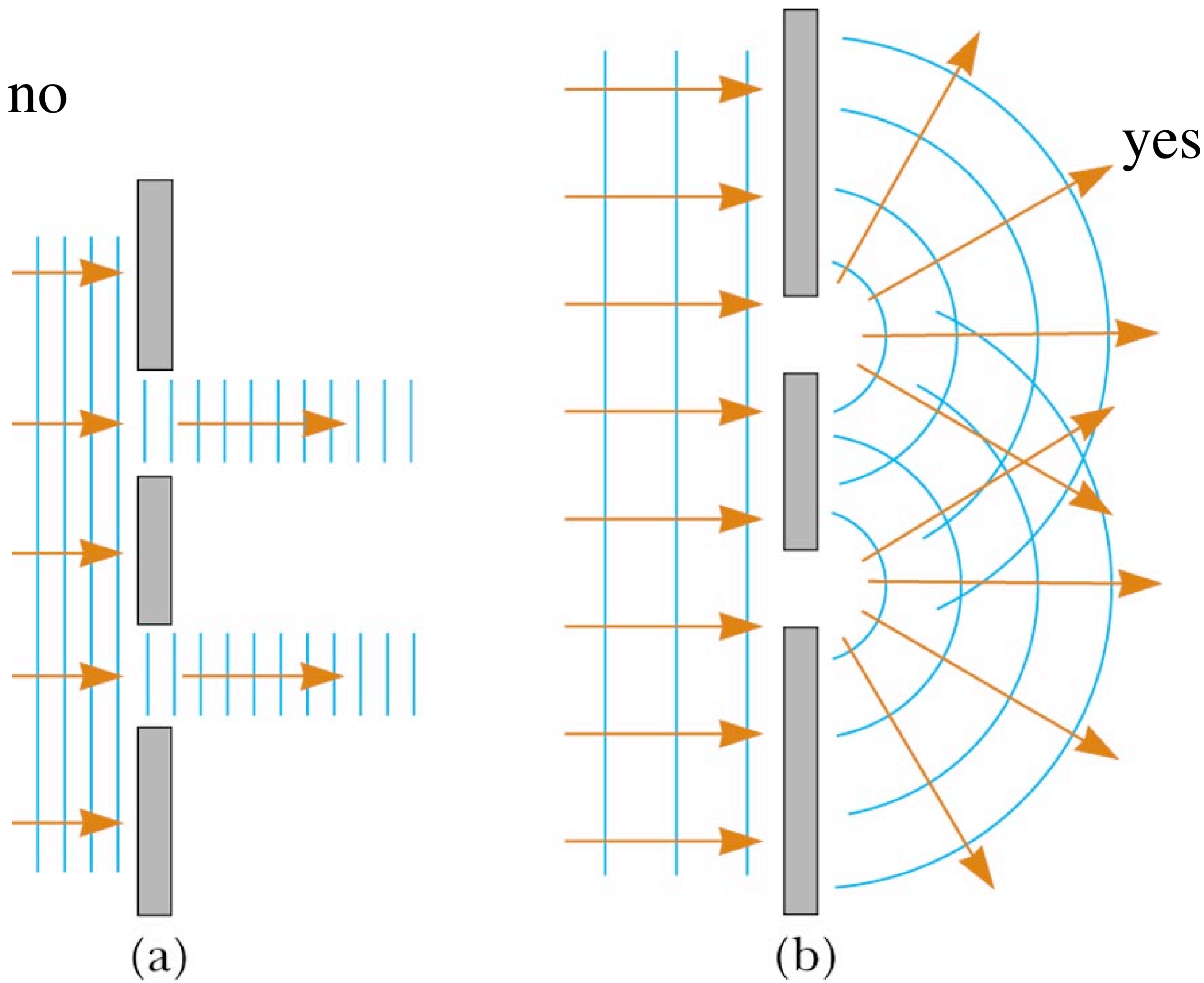




McKenzie, The Major Achieve-
ments of Science

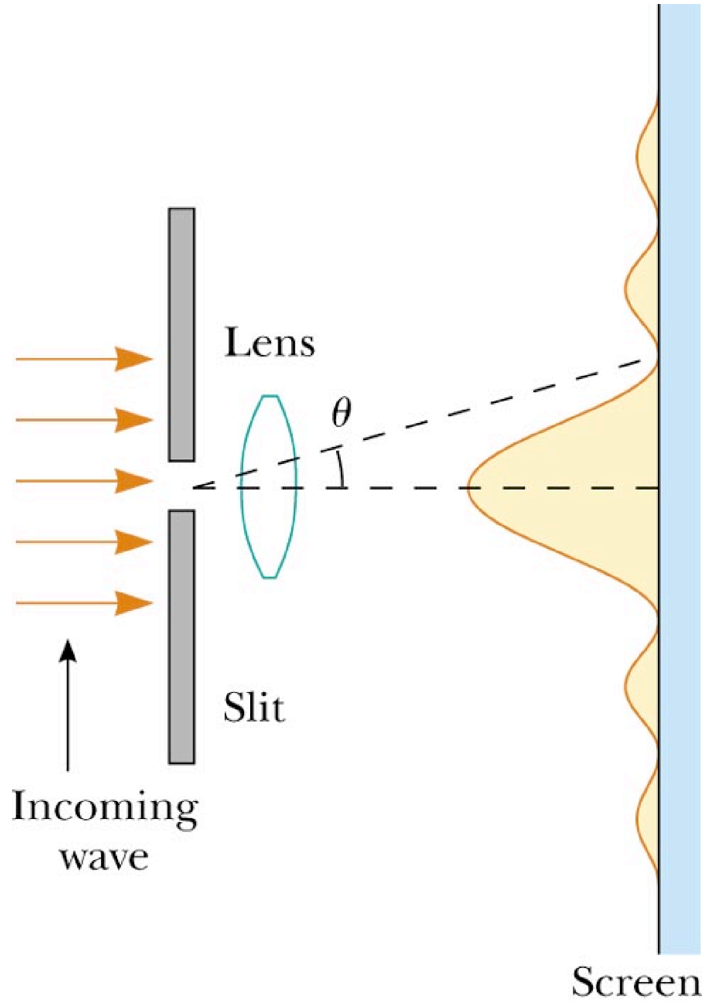
if d sin θ is an even multiple of the wavelength λ, then constructive interference occurs
$d \sin\theta = m\lambda$ m=0,+/-1, +/-2, …

Diffraction



Diffraction

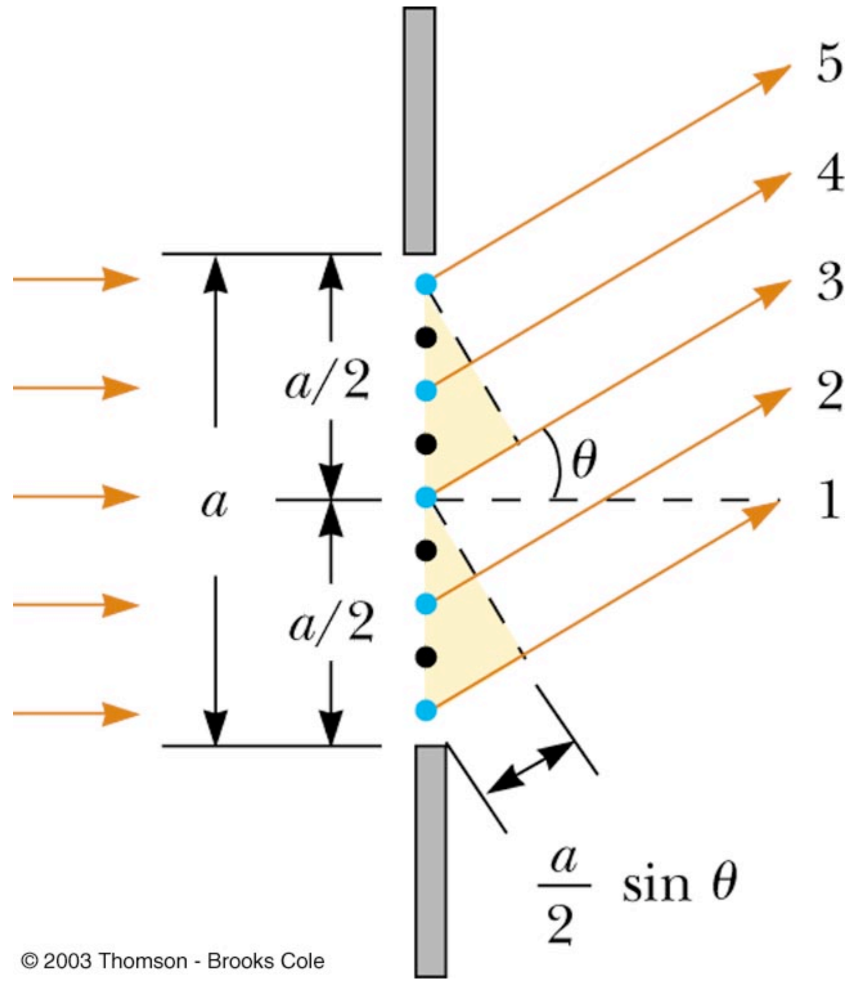
- Diffraction occurs when a wave passes through a small opening not so different in size from the wavelength of the wave
- The wave spreads out as we saw on the previous slide
- So instead of a bright spot just in the middle we see a spread-out distribution of light
  - but with some structure to it
- Type of diffraction we're studying is called Fraunhofer diffraction
  - screen is far away from slit
  - …or there's a converging lens just after the slit
  - Demo



Don't worry about the lens;
Just think of the screen as far away

Where are the dark spots?

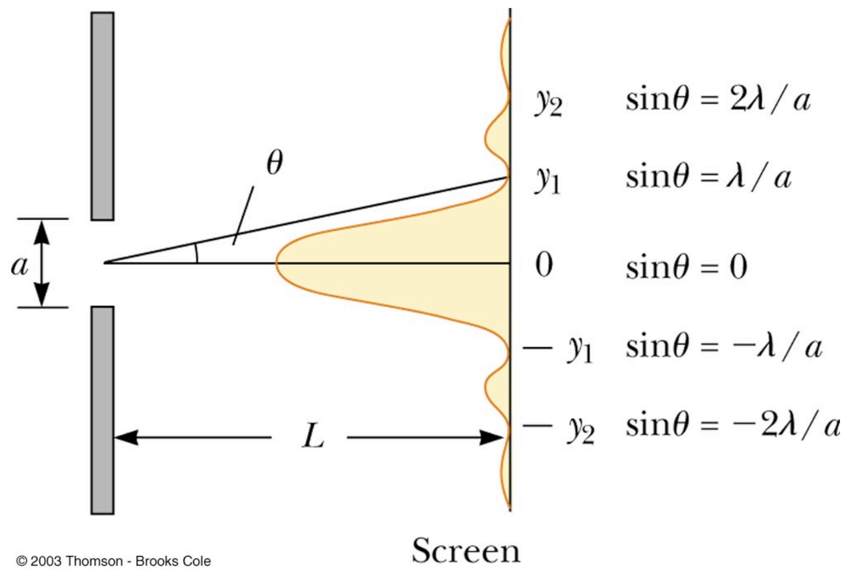
- Here's where Huygen's principle comes in handy
- As the wave travels through the slit, treat each point in the slit as a source of waves
- Light from one part of the slit can interfere with light from another part
- Let's divide the slit into halves and consider the wavelets coming from point 1 and from point 3
- Wavelet 1 has to travel further
- IF the additional distance, a/2sinθ is equal to λ/2, then the wavelets from points 1 and 3 are exactly half of a wavelength out of phase
  - destructive interference
- Also true for 3 and 5, 2 and 4, any two points in the top and bottom of the slit separated by a/2



Can go through the same exercise dividing the screen in 4 parts, 6 parts,…

Dark spots

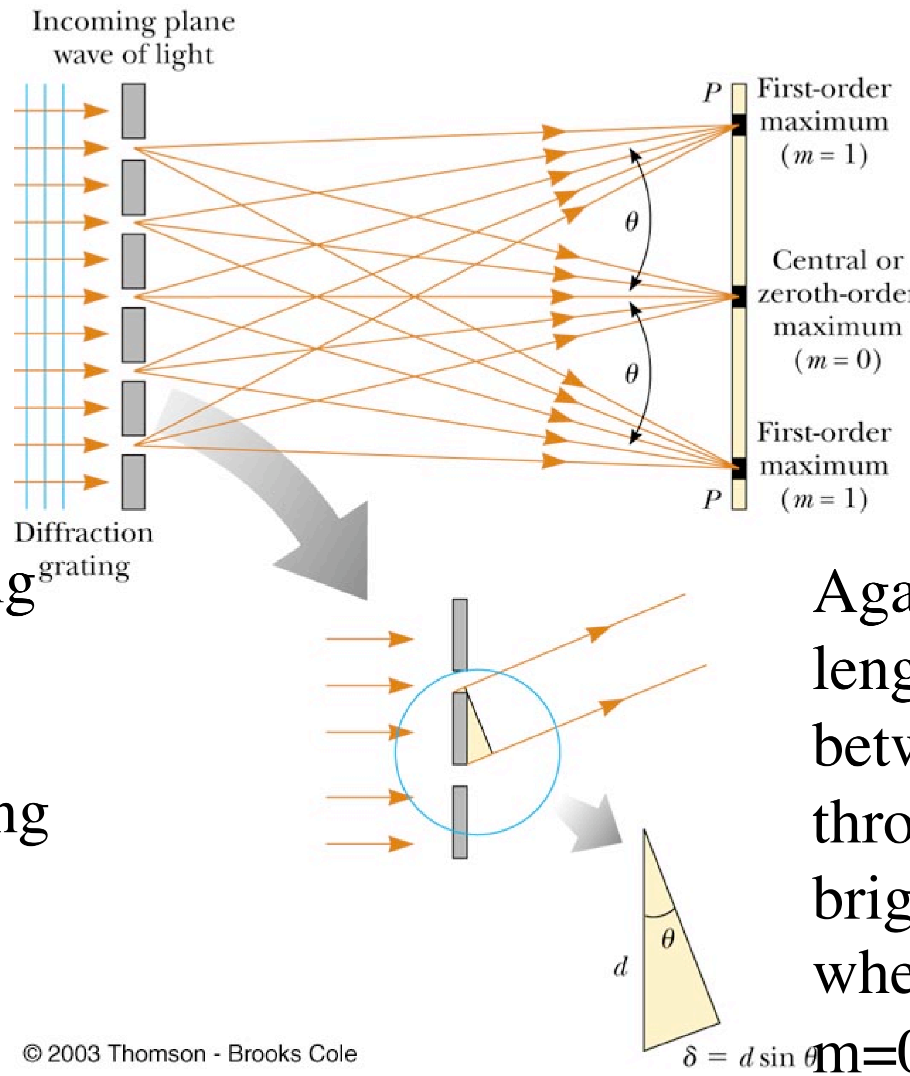
- So dark spots when
  - $a/2 \sin\theta = \lambda/2$
  - …or $a/2 \sin\theta = 2\lambda/2$
  - …or $a/2 \sin\theta = 3\lambda/2$
- Corresponding to
  - $\sin\theta_1 = \lambda/a$
  - $\sin\theta_2 = 2\lambda/a$
  - $\sin\theta_3 = 3\lambda/a$
  - …
- Everything is in phase at $\theta=0$, so there's a bright spot there
  - and other bright spots roughly half-way between the dark spots



Let's go crazy and put in lots of slits

Light diffracts through each of the slits

A device like this is called a diffraction grating but there's both diffraction and interference taking place

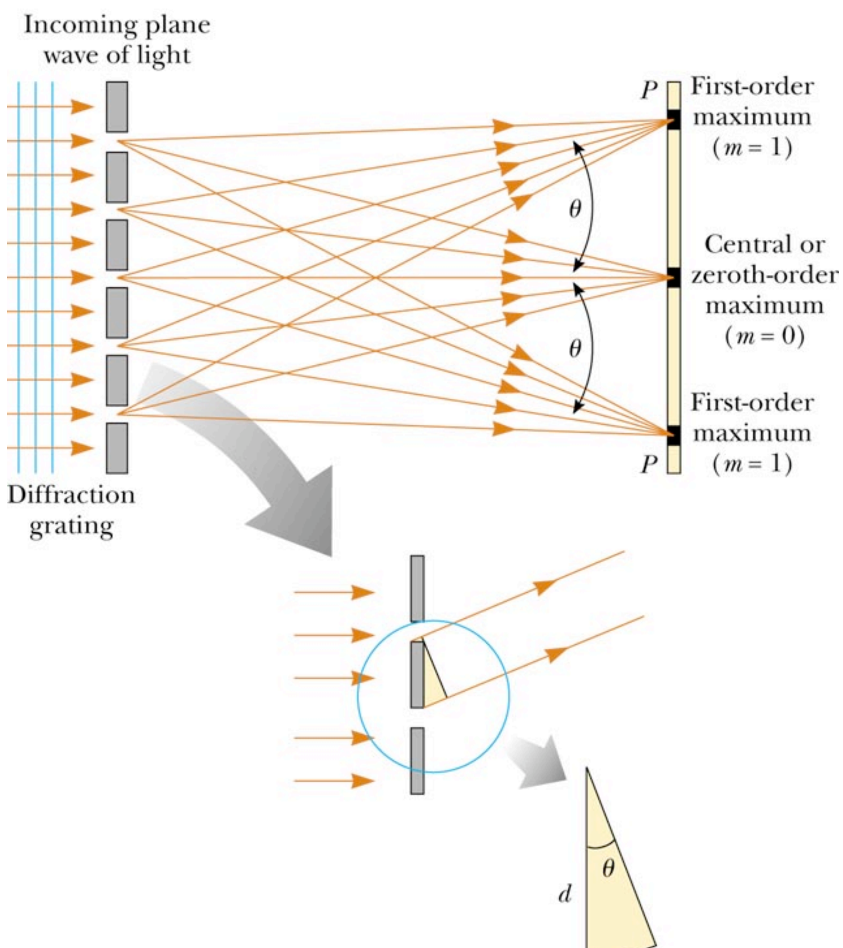


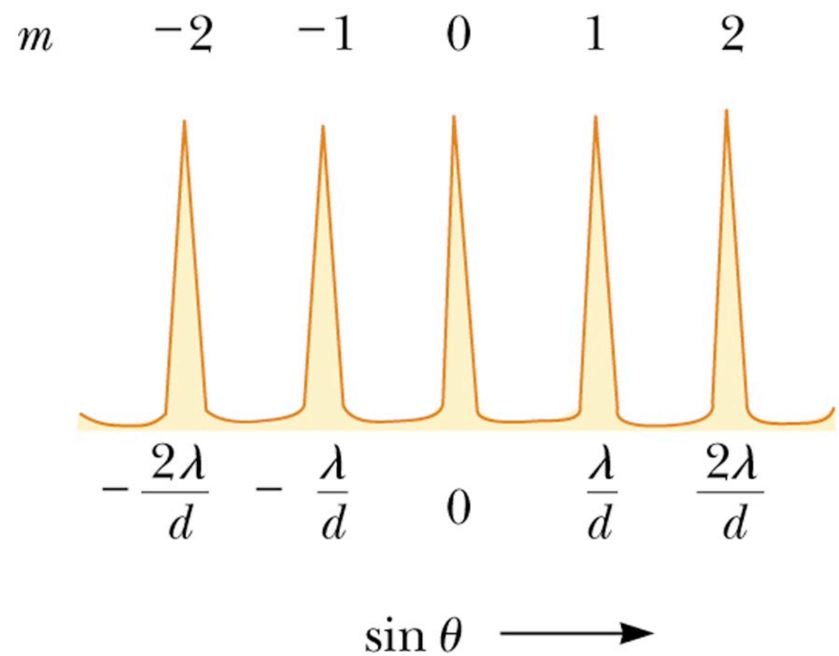
and we get interference between each of the diffracted waves

Again, there's a path length difference between light passing through different slits bright lines or spots when $d \sin\theta_{bright} = m\lambda$

$m = 0, 1, 2, \ldots$

Intensity pattern

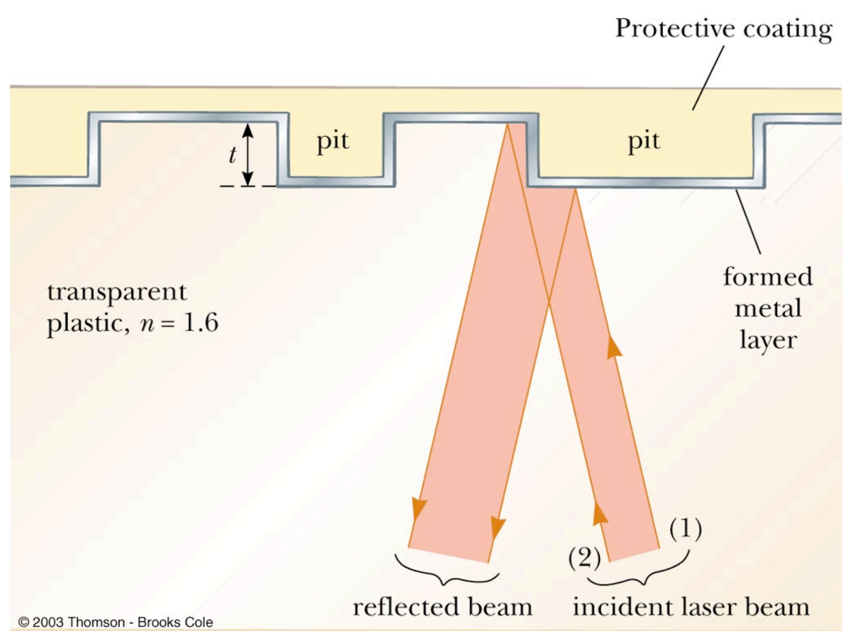




The more slits in the grating the sharper are the interference peaks;
Can also make a diffraction grating by having finely etched lines on a reflective surface

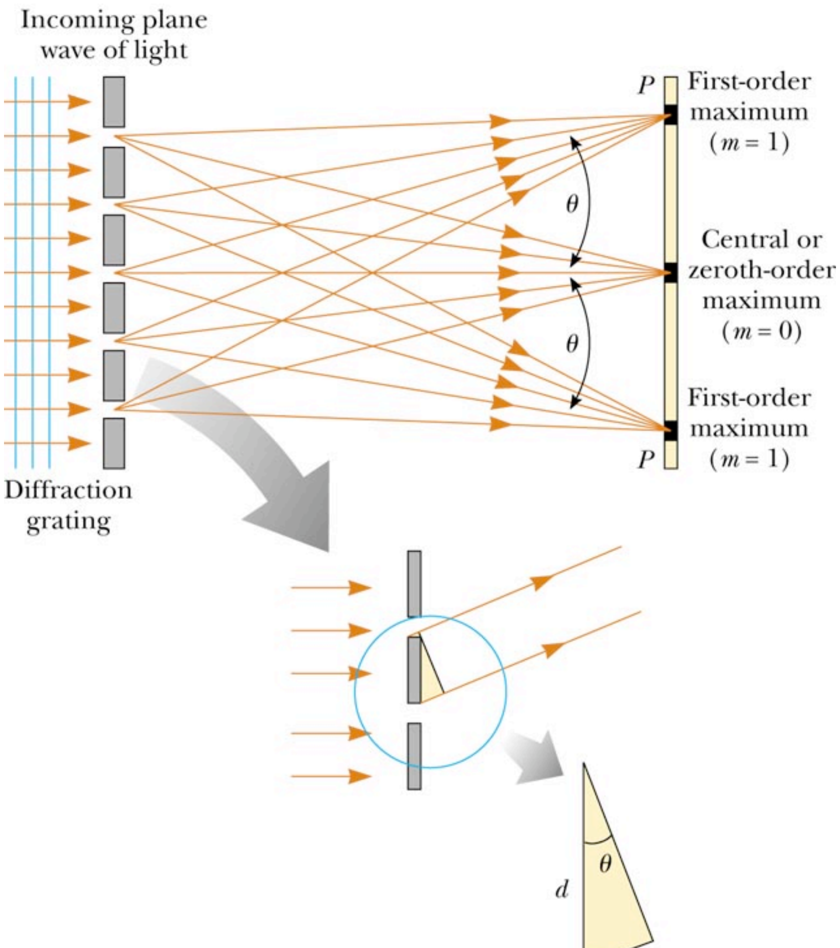
Application of interference

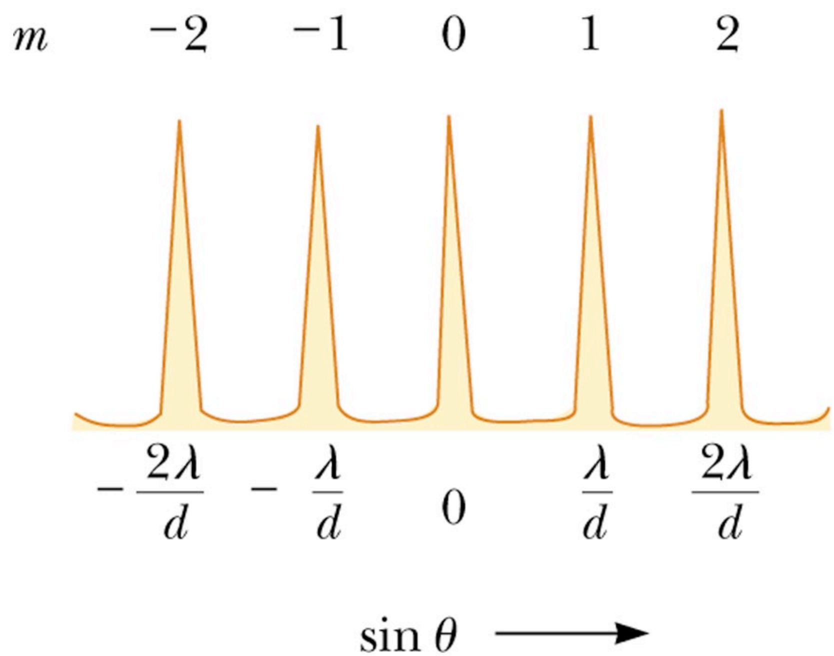
- Laser is set up to reflect off of CD surface
- Surface has a series of bumps and pits encoding information (i.e. the music)
  - depth of depression is equal to 1/4 of the wavelength of the laser light
- So when the laser light comes to an edge (leading or trailing), part of the light reflects from the top of the bump and part from the depression (with a path length difference then of 1/2 of a wavelength)
  - this insures destructive interference
- Bump edges interpreted as one's and depressions as 0's



DVD player uses a shorter wavelength laser and smaller track separation, pit depth and length
DVD can store 30X as much info

Intensity pattern

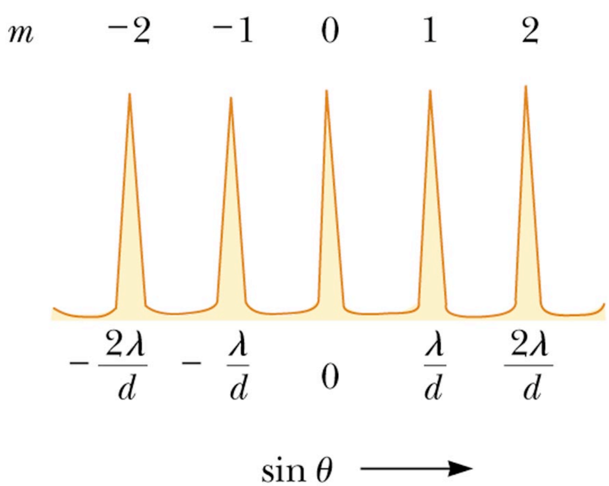


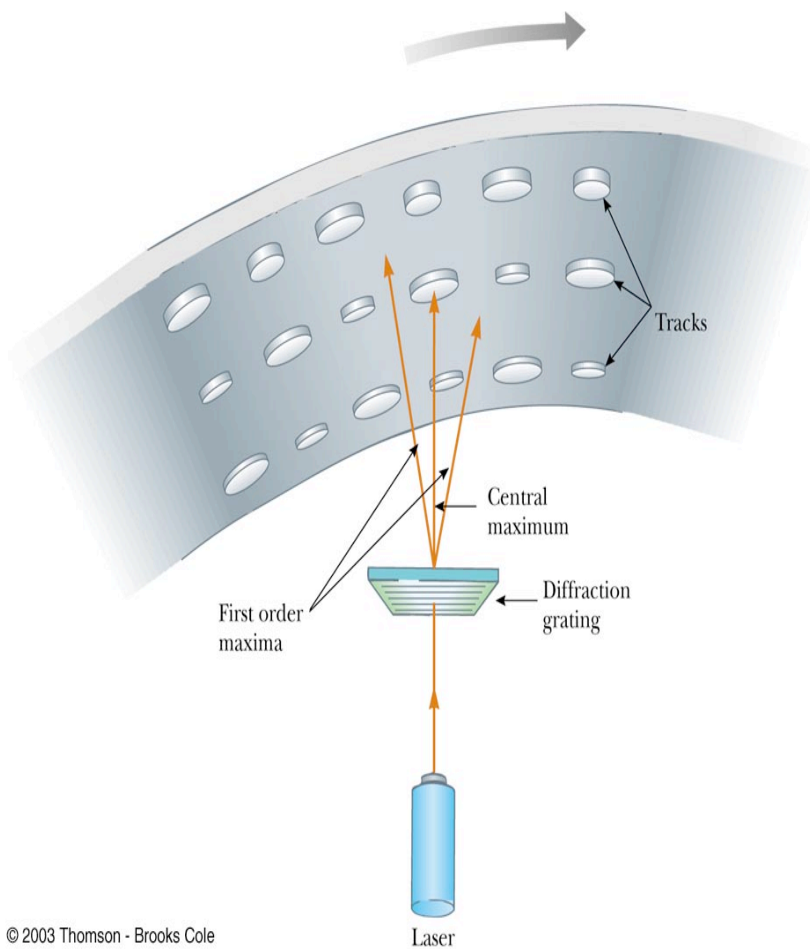


The more slits in the grating the sharper are the interference peaks; Can also make a diffraction grating by having finely etched lines on a reflective surface, i.e. a CD (or DVD)

Diffraction gratings in CD players

- Diffraction gratings are also involved in CD players
- Laser must follow the spiral track correctly
- Laser light fed through a diffraction grating
    - central maximum is used to read info
    - maxima on either sided are used for steering





Babinet's principle

- Diffraction pattern from a thin object is the same as diffraction pattern from a thin slit of the same size
  - minima at $a\sin\theta = m\lambda$
- Can use to measure diameter of an object, for example students' hair