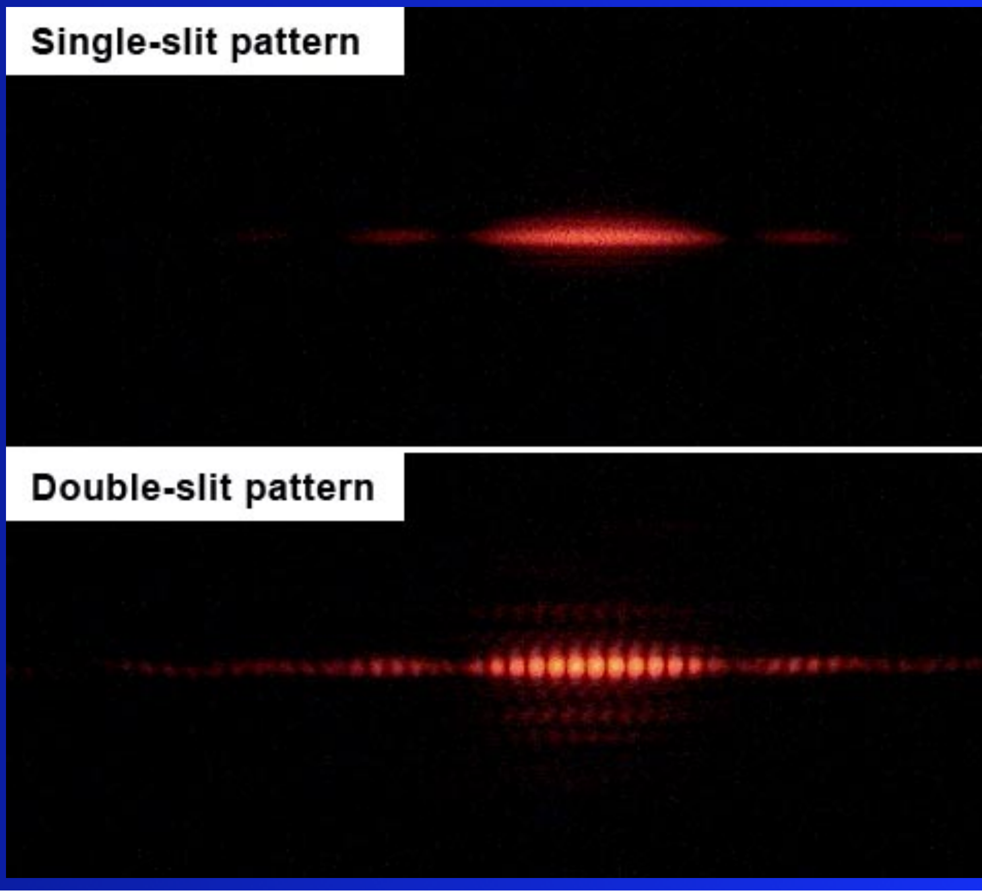
Physics 1C: Interference of Electromagnetic Waves

Monday, 20 April 2015

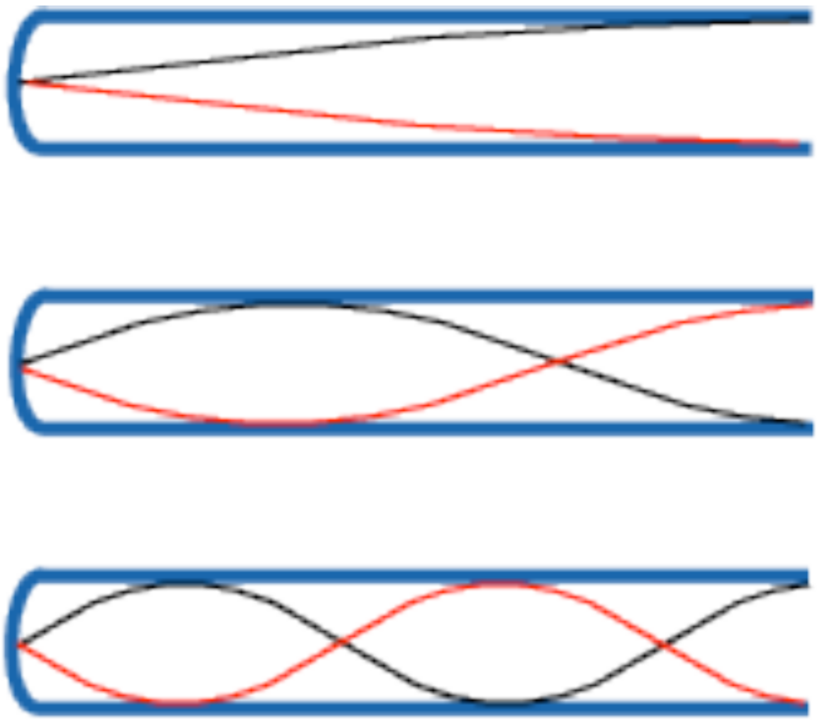


Reminders

- please submit an evaluation for our course this week at `https://academicaffairs.ucsd.edu/Modules/Evals?e1090420`
- Quiz #2 on Friday! It will probably consist of 9 questions or problems again, and you'll have the equations you need.
- study the following material:
  - sound waves and Doppler effect from ch. 13
  - interference of sound waves, harmonics & nodes, waves in air columns, and beats from ch. 14
  - interference of light waves, starting with the double-slit experiment from ch. 27
- if you're interested in extra credit, it's due next Friday

Standing Waves in an Air Column

- nodes at closed ends, anti-nodes at open ends



$$\lambda_1 = 4L$$

$$\lambda_3 = \frac{4L}{3}$$

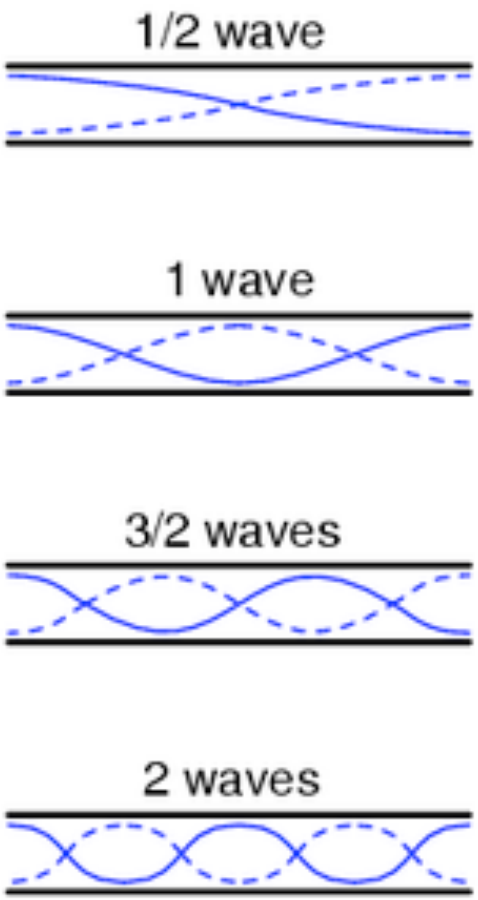
$$\lambda_3 = \frac{4L}{5}$$

$$\lambda_n = \frac{4L}{n} \quad n = 1, 3, 5, \ldots$$

$$f_n = n\frac{v}{4L} \quad n = 1, 3, 5, \ldots$$

Standing Waves in an Air Column

- nodes at closed ends, anti-nodes at open ends



$$\lambda_1 = 2L$$

$$\lambda_2 = L$$

$$\lambda_3 = \frac{2L}{3}$$

$$\lambda_n = \frac{2L}{n} \quad n = 1, 2, 3, \ldots$$

$$f_n = n\,v/(2L)$$

example: wind in a culvert

A section of drainage culvert 1.23m in length makes a howling noise when the wind blows through its open ends. ("culvert" is a fancy name for "tunnel.")

- What is the frequency of the first (fundamental) harmonic if the culvert is cylindrical and open at both ends? Take v=343 m/s as the speed of sound in air.

  a) 69.7 Hz

  b) 139.4 Hz

  c) 209.1 Hz

  d) need to know the sound's wavelength

recall that:

if open at both ends, then $f_n = n\, v/(2L)$

if open at one end, then $f_n = n\, v/(4L)$

example: wind in a culvert

A section of drainage culvert 1.23m in length makes a howling noise when the wind blows across its open ends.

- What is the frequency of the first (fundamental) harmonic if the culvert is cylindrical and open at both ends? Take v=343 m/s as the speed of sound in air.

$$f_1 = \frac{v}{2L} = \frac{343\ \text{m/s}}{2(1.23\ \text{m})} = \boxed{139\ \text{Hz}}$$

$$f_2 = 2f_1 = \boxed{279\ \text{Hz}}$$

$$f_3 = 3f_1 = \boxed{418\ \text{Hz}}$$

example: wind in a culvert

A section of drainage culvert 1.23m in length makes a howling noise when the wind blows across its open ends.

- Now if the culvert were blocked at one end, what are the three lowest natural frequencies?

$$f_1 = \frac{v}{4L} = \frac{343\ \mathrm{m/s}}{4(1.23\ \mathrm{m})} = \boxed{69.7\ \mathrm{Hz}}$$

$$f_3 = 3f_1 = \boxed{209\ \mathrm{Hz}}$$

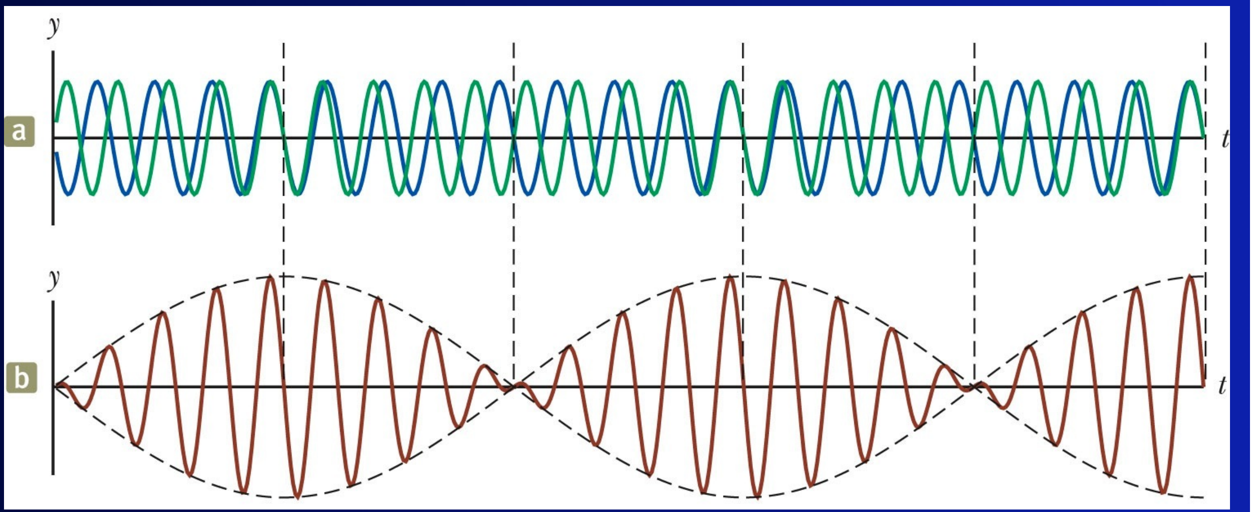
$$f_5 = 5f_1 = \boxed{349\ \mathrm{Hz}}$$

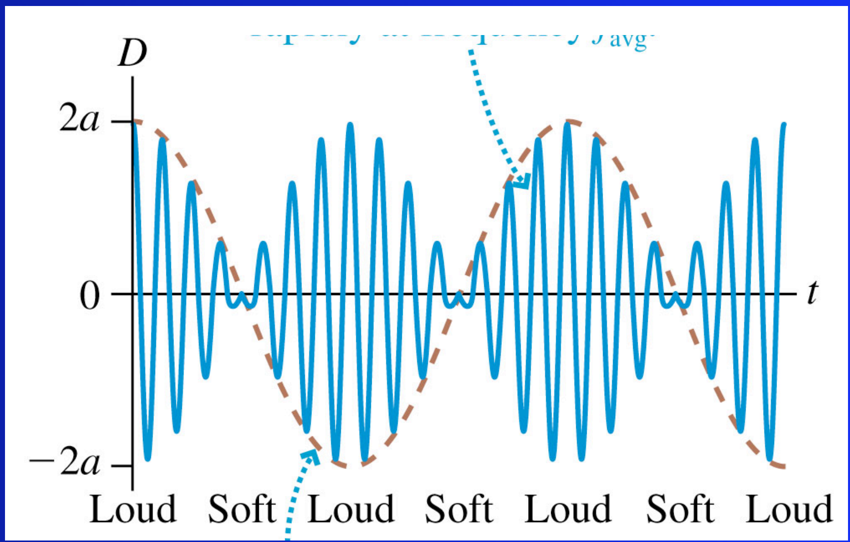
Beats: Interference in Time

beats are due to sound waves with slightly different frequencies

beat frequency: number of amplitude maxima one hears per second:

$$f_b = |f_1 - f_2|$$



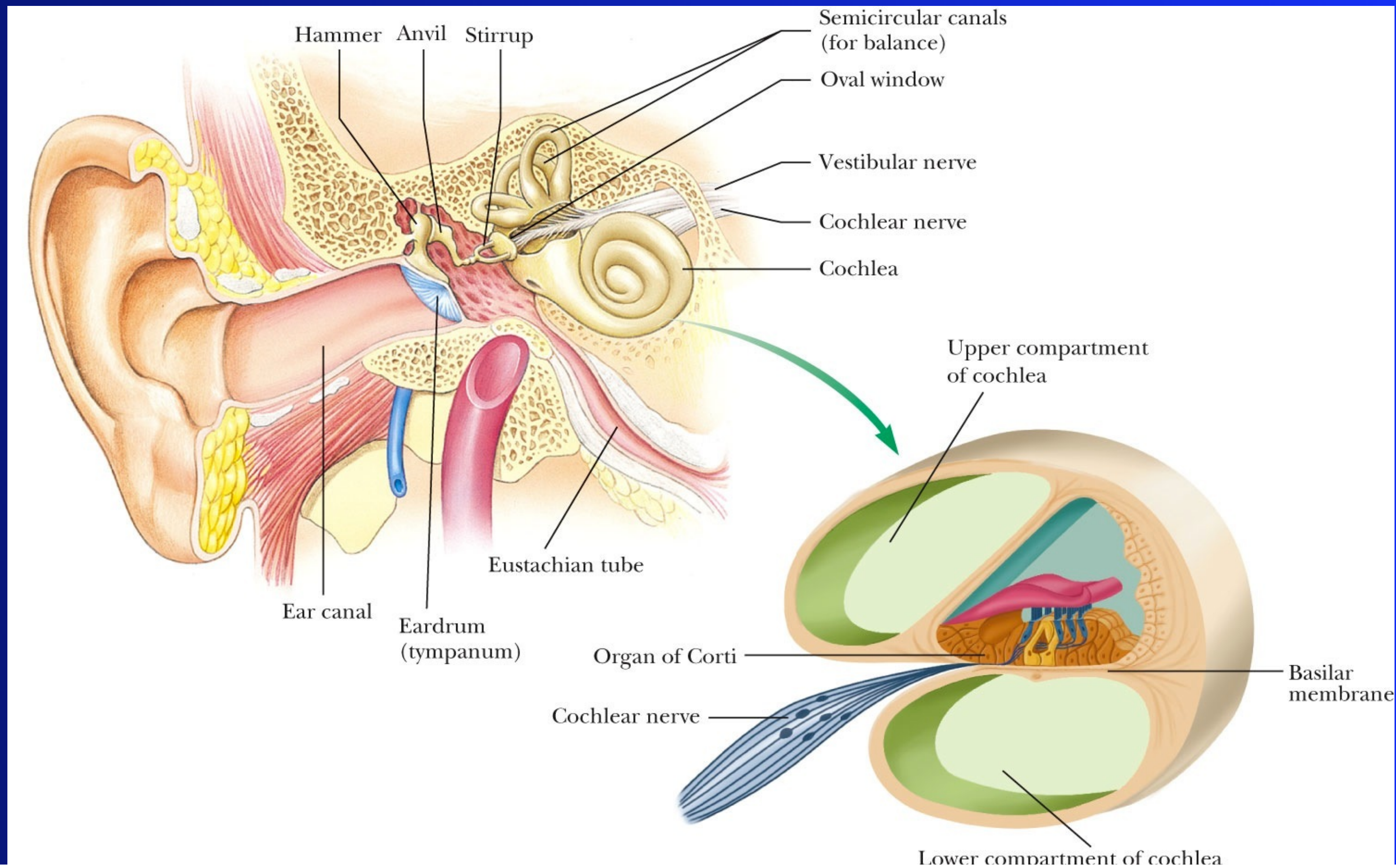


The Ear & Theories of Pitch Perception

The outer ear consists of ear canal (open to the air), which ends at the eardrum.

Sound waves travel down to the eardrum, which vibrates in response to alternating high & low pressures of the waves

Different parts of basilar membrane inside the ear resonate at different frequencies

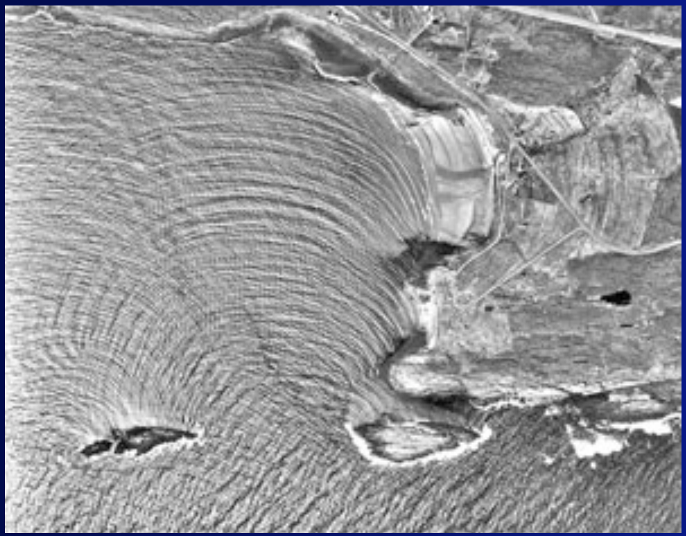


Wave Optics: introduction

- light is an *electromagnetic wave* created by vibration of electric charges
- *wave optics* describe phenomena not explained by geometric (ray) optics
- light experiences constructive & destructive interference
- light also experiences *diffraction*, where waves spread out as they pass through an opening

Diffraction

- waves can bend around obstacles
- waves spread out when traveling through small openings or slits
- small obstacles/openings → lots of diffraction; large obstacles/openings → less diffraction (but depends on wavelength λ)



Diffraction

Why do we more easily notice diffraction in sound waves than in light waves?

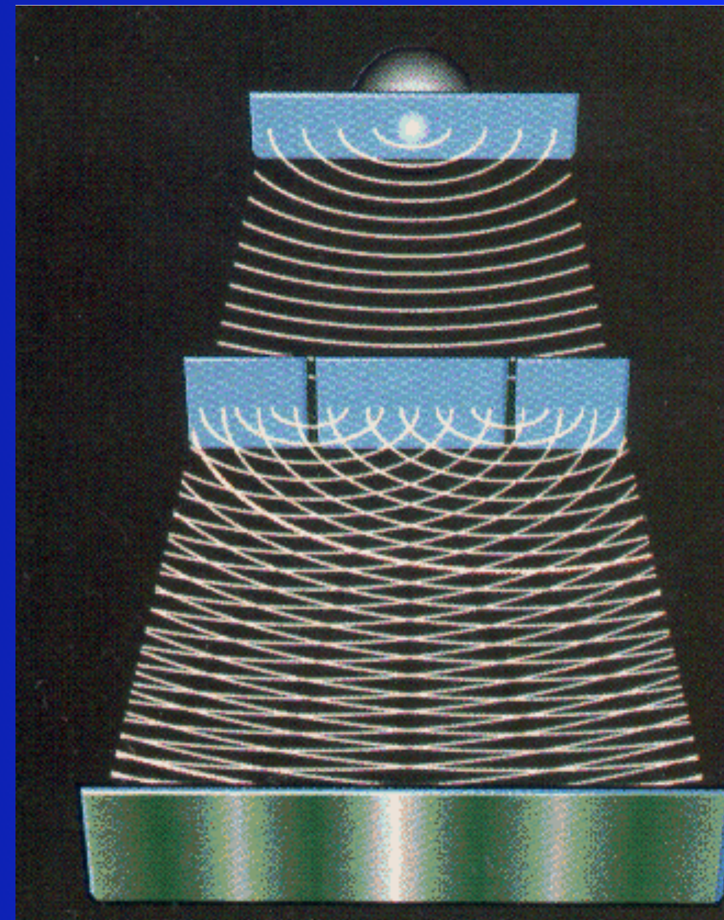
- sound wavelengths often ~centimeters, but visible light wavelengths in nanometers (nm, or 10^{-9} m)
- diffraction occurs when obstacle size is approx same size or smaller than wavelength
- example: Young's famous double-slit experiment

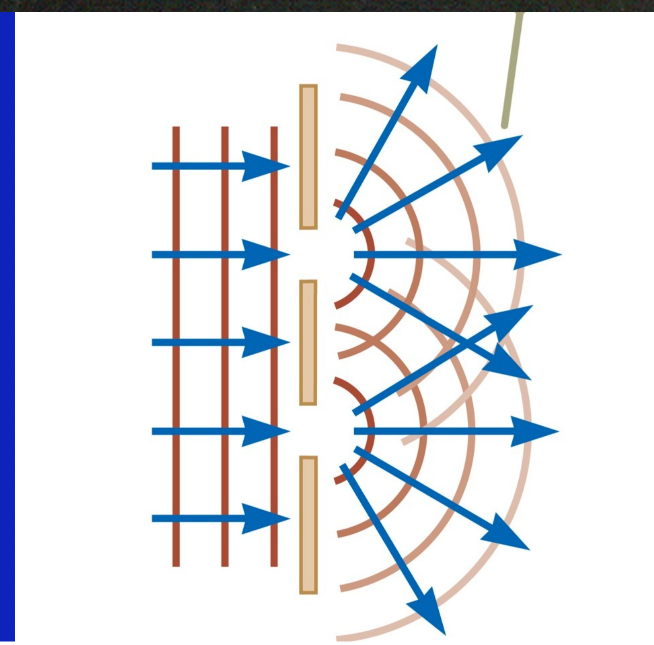
Young's Double-Slit Experiment

- developed by English physicist Thomas Young in early 19th century to demonstrate *interference of light waves*

- later extended by French physicist/engineer Augustin-Jean Fresnel, who also researched thin lenses (used in lighthouses) and reflection & refraction

Young's Double-Slit Experiment

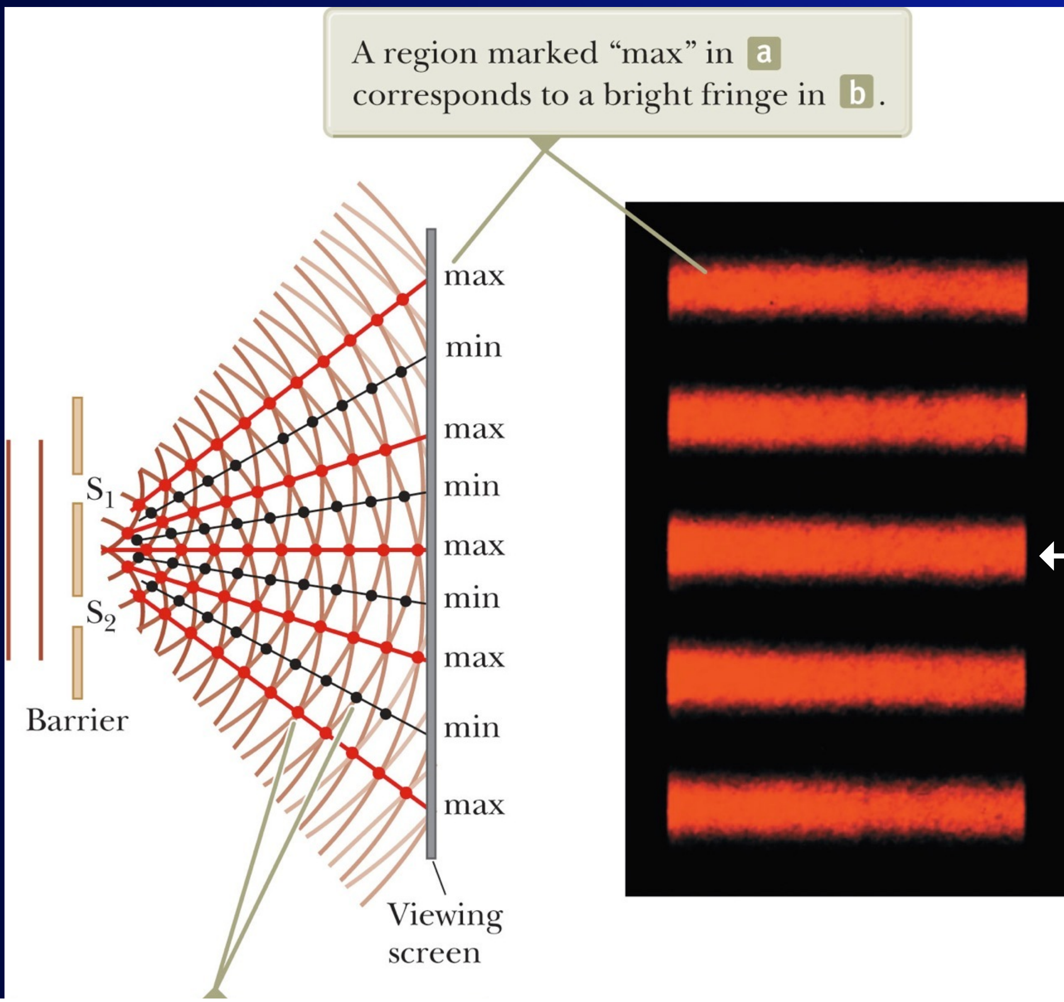




- **diffraction**: divergence of light from its initial line of travel
- as waves spread out from narrow slits, we see an interference pattern: alternating constructive & destructive interference
- by looking at the wavefronts, each slit acts as a coherent source of light

Young's Double-Slit Experiment

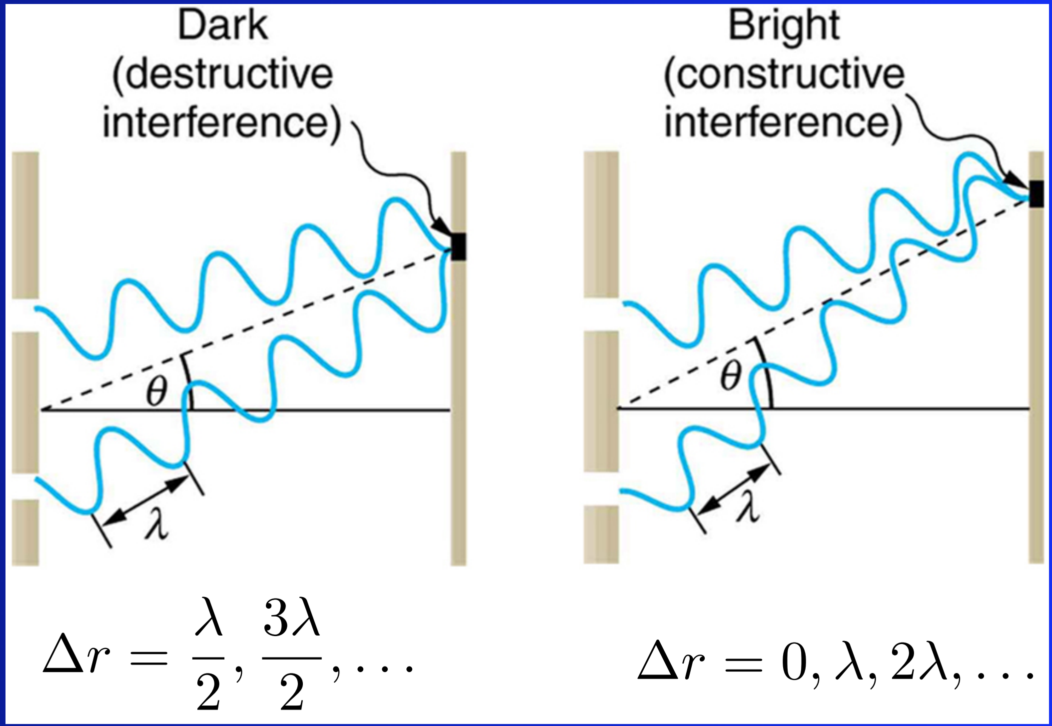
- **bright fringes** indicate *constructive interference* and **dark fringes** indicate *destructive interference*

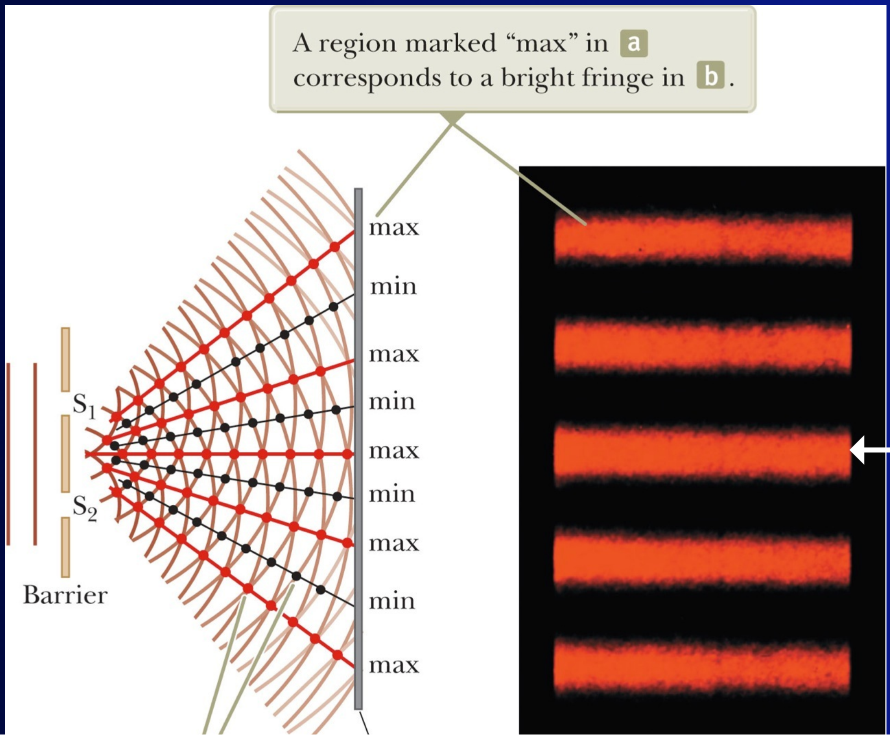


← central maximum

Young's Double-Slit Experiment

- note that the waves arrive on the screen *in phase*, and we calculate Δr just like for sound waves





←central max

Young's Double-Slit Experiment

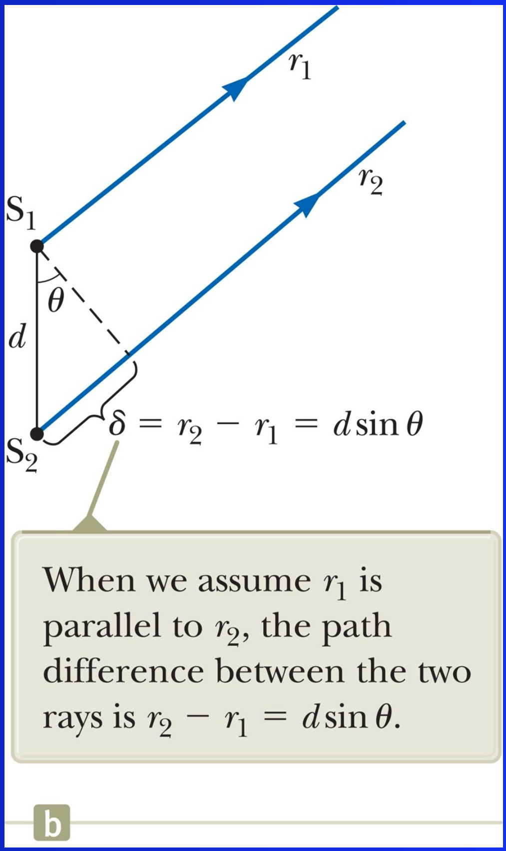
- for *constructive interference,* we calculate Δr:

$$\delta = d \sin \theta_{\text{bright}} = m\lambda \qquad m = 0, \pm 1, \pm 2, \ldots$$

- for *destructive interference,* we calculate Δr:

$$\delta = d \sin \theta_{\text{dark}} = (m + \tfrac{1}{2})\lambda \qquad m = 0, \pm 1, \pm 2, \ldots$$

- m is called the **order number**.
  m=0 refers to zeroth-order maximum
  and m=±1 is 1st order maximum, etc.

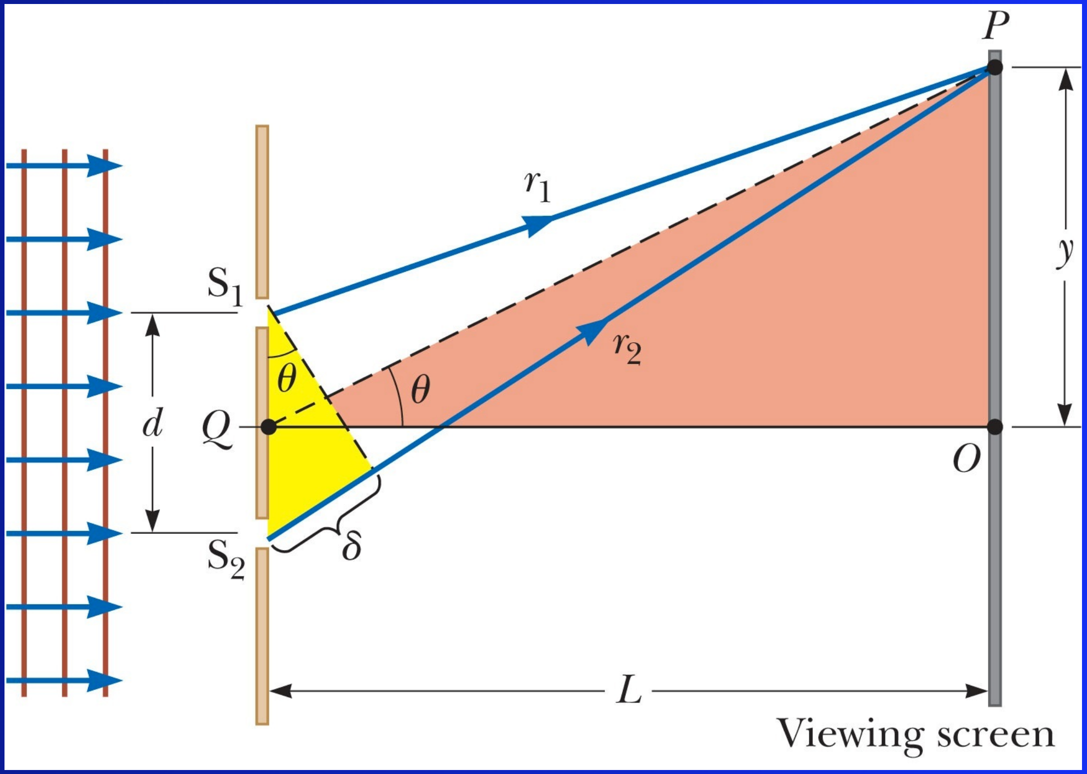


Young's Double-Slit Experiment

- Since tan(θ)=y/L, we can measure the distances to the bright (and dark) fringes from the central maximum, which is at θ=0 and y=0:

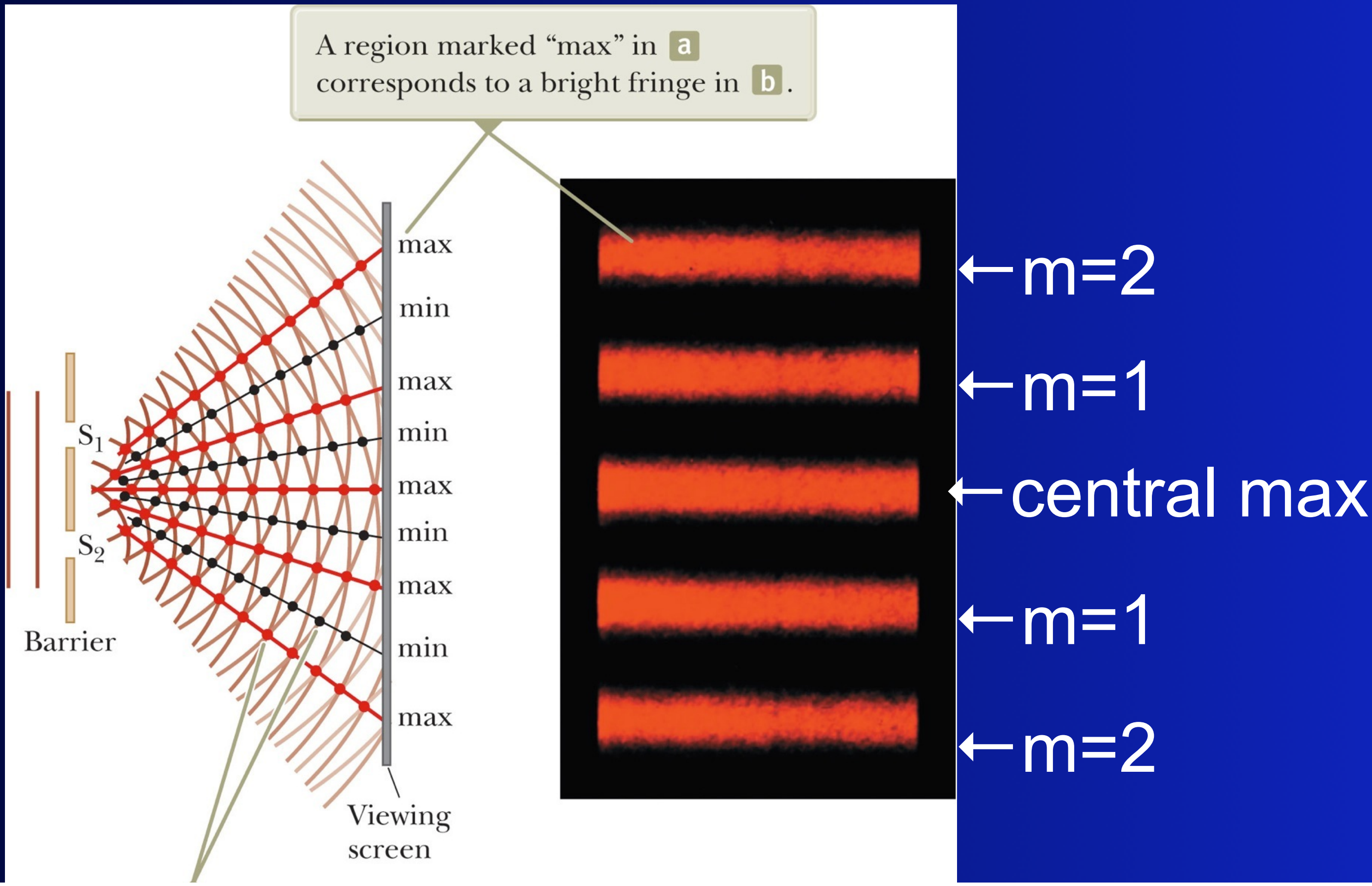
$$y_{\text{bright}} = L \tan \theta_{\text{bright}}$$

$$y_{\text{dark}} = L \tan \theta_{\text{dark}}$$



example: double-slit experiment

Two slits, spaced by 1.0mm are illuminated by a red laser with wavelength 650 nm. If a screen is placed 1.5 m away, what is the distance on the screen between the central maximum and the m=2 maximum?



remember:

$d \sin(\theta_m) = m\lambda$

$\Delta y_m = L \tan(\theta_m)$

Double-Slit Experiment

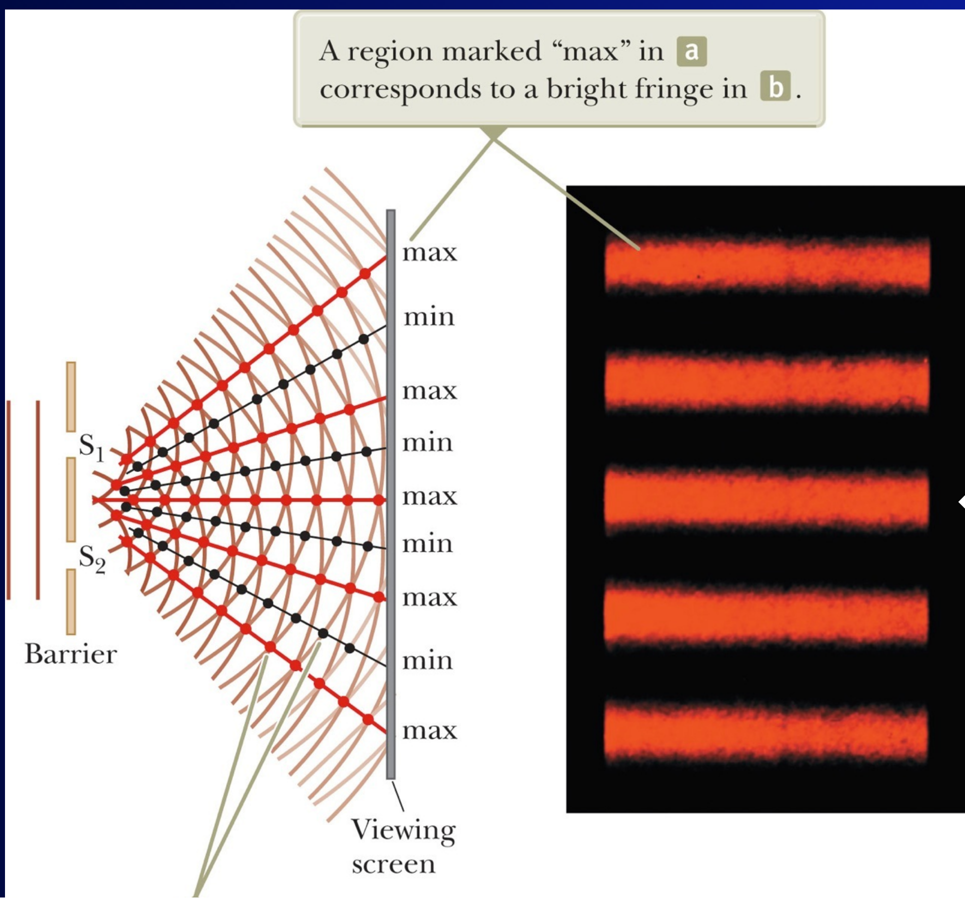
- for the small-angle approximation, $\tan(\theta) \approx \sin(\theta) \approx \theta$
- so for constructive interference, $d\,\theta_{\text{bright}} \approx m\lambda$
- and for destructive interference, $d\,\theta_{\text{dark}} \approx (m+1/2)\lambda$
- these then are the distances to the fringes (from m=0):

$$y_{\text{bright}} = L\left(\frac{m\lambda}{d}\right) \qquad \text{(small angles)}$$

$$y_{\text{dark}} = L\,\frac{(m + \frac{1}{2})\lambda}{d} \qquad \text{(small angles)}$$

example: double-slit experiment

Two slits, spaced by 1.0mm are illuminated by a red laser with wavelength 650 nm. If a screen is placed 1.5 m away, what is the distance on the screen between the central maximum and the *m*=2 maximum?



←m=2

←m=1

←central max

←m=1

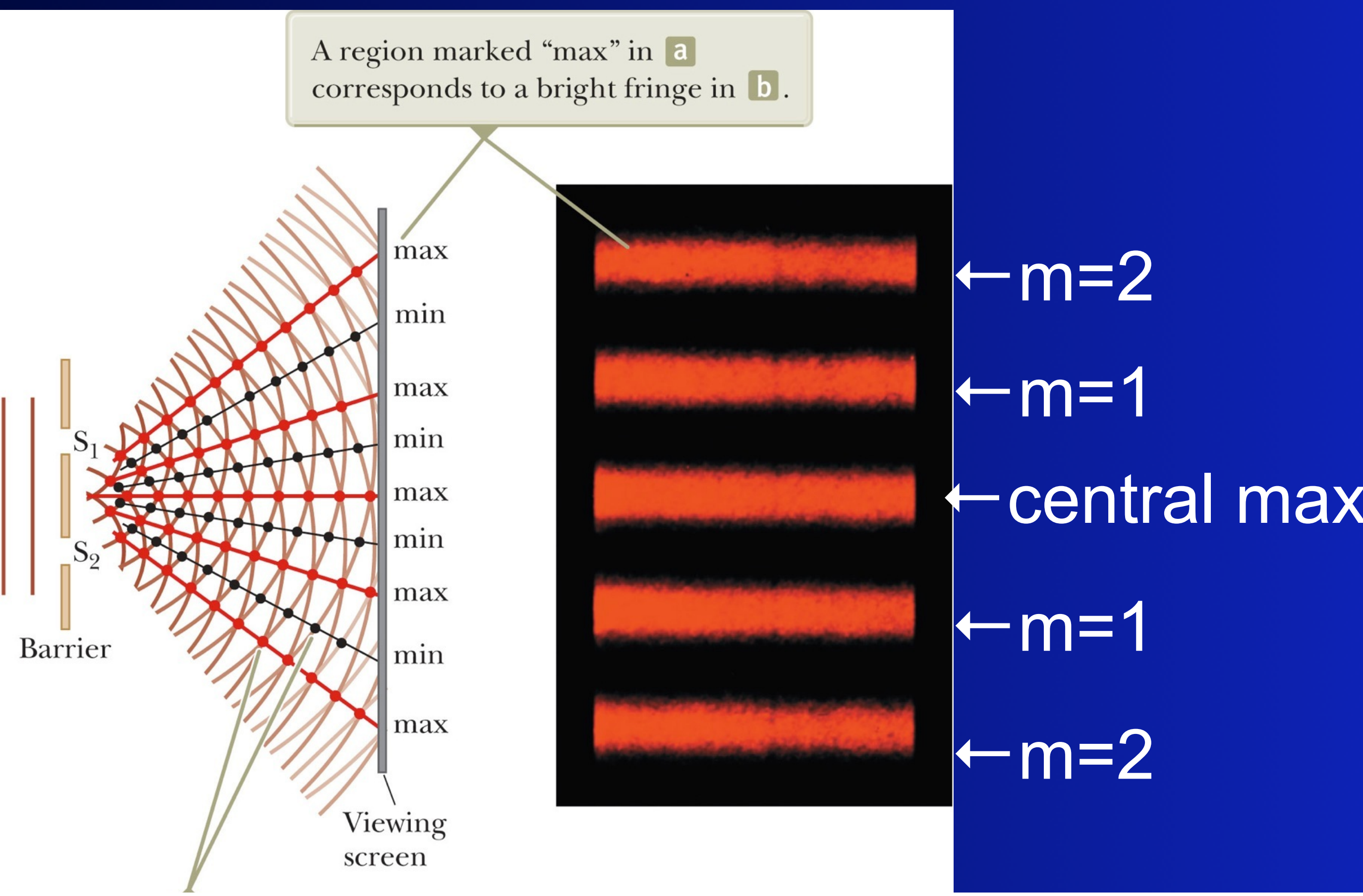
←m=2

$\Delta y_{bright} \approx L\, m\lambda / d$

so $\Delta y_2 \approx (1.5\text{m})2(650\times10^{-9})/(1.0\times10^{-3}) = 0.00195\text{m}$

example: double-slit experiment

If the screen is moved closer to the double slits, the distance between the bright fringes…



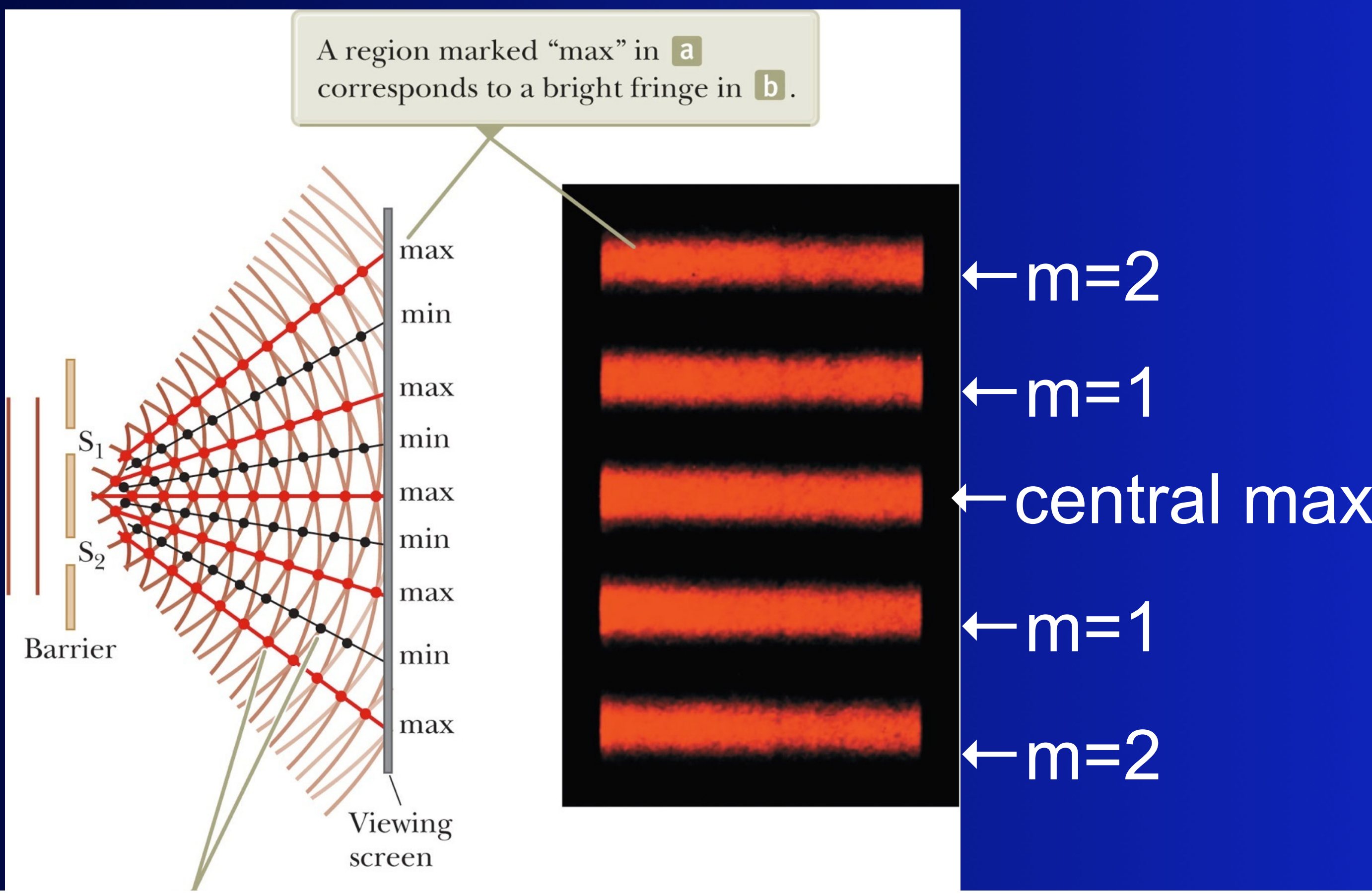
A. increases

B. decreases

C. is unchanged

example: double-slit experiment

and what happens if the slits are more closely spaced together? or if we use green light (shorter wavelength) rather than red light?



For Wednesday:

1. make sure you understand all aspects of the double-slit experiment

2. continue reading chapter 27 if you have time

3. homework & reading quiz due on Friday

4. prepare for Quiz #2 on Friday