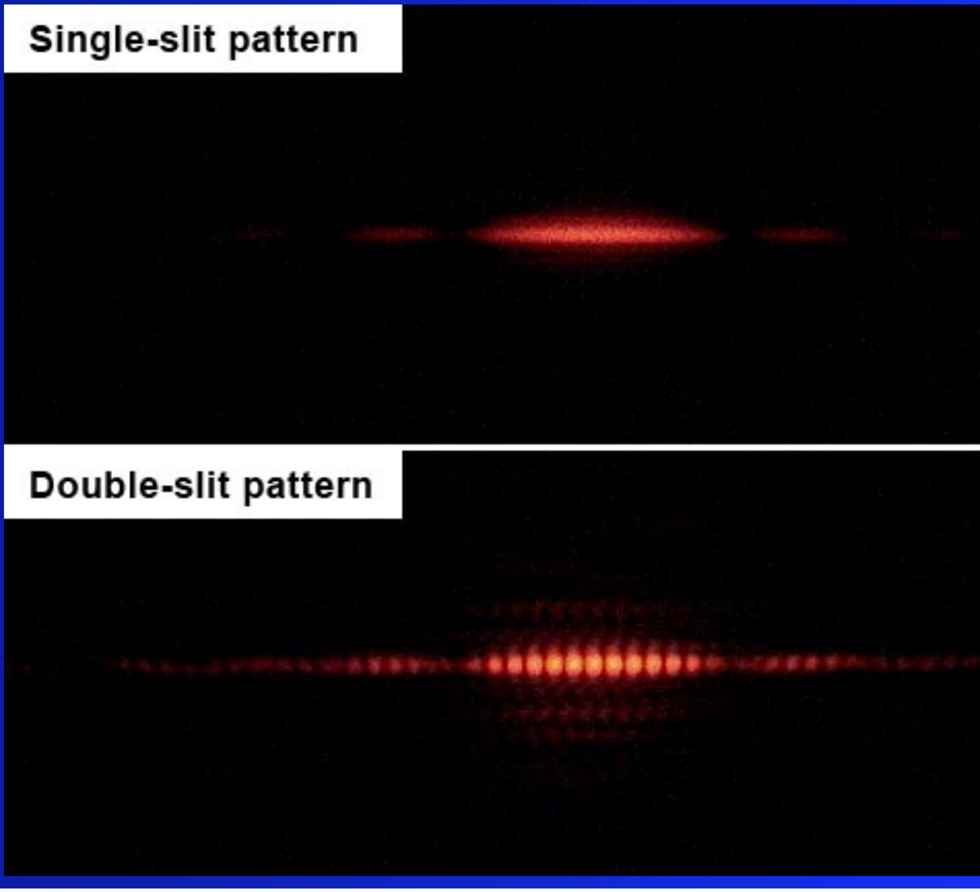
Physics 1C: Interference of Electromagnetic Waves

Wednesday, 22 April 2015



Reminders

- **Quiz #2** on Friday!
- remember that we'll drop your lowest score
- all of the lecture slides are available on TED, and please ask me if you have questions about concepts or HW problems
- if you're interested in **extra credit**, first one's due *next* Friday, and you may also do one during second half of the course
- I'll update scores on TED next week, but so far your average participation score is excellent: 9.2/10 points!

Info for Friday's Quiz/Test

- things you should know:
  - sound waves and Doppler effect from ch. 13
  - interference of sound waves, harmonics and nodes, waves in air columns, and beats from ch. 14
  - interference of light waves, mainly the double-slit experiment, from ch. 27

The questions will be easier than some of the tricky or involved homework problems. Review your lecture notes, quizzes & assignments.

Info for Friday's Quiz/Test

- things you don't need to know:
  - power and rate of energy transfer by waves
  - nonsinusoidal wave patterns
  - the ear and theories of pitch perception
  - dependence of speed of sound on air temperature
  - interference in thin films, diffraction patterns, and later sections of chapter 27
- don't memorize trig identities, but you should be very familiar with sines & cosines and their derivatives
- don't memorize equations, but understand how to use them and what relationships they describe

Double-Slit Experiment

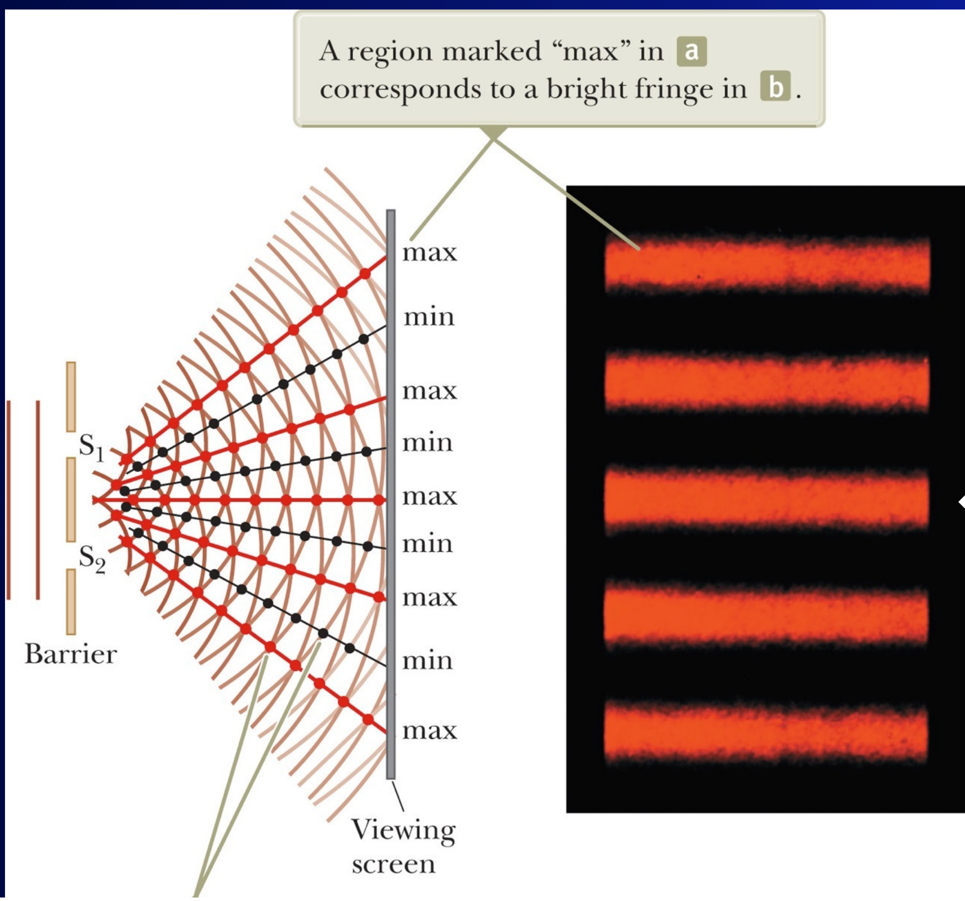
- for the small-angle approximation, $\tan(\theta) \approx \sin(\theta) \approx \theta$
- so for constructive interference, $d\,\theta_{\text{bright}} \approx m\lambda$
- and for destructive interference, $d\,\theta_{\text{dark}} \approx (m+1/2)\lambda$
- these then are the distances to the fringes (from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

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

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

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

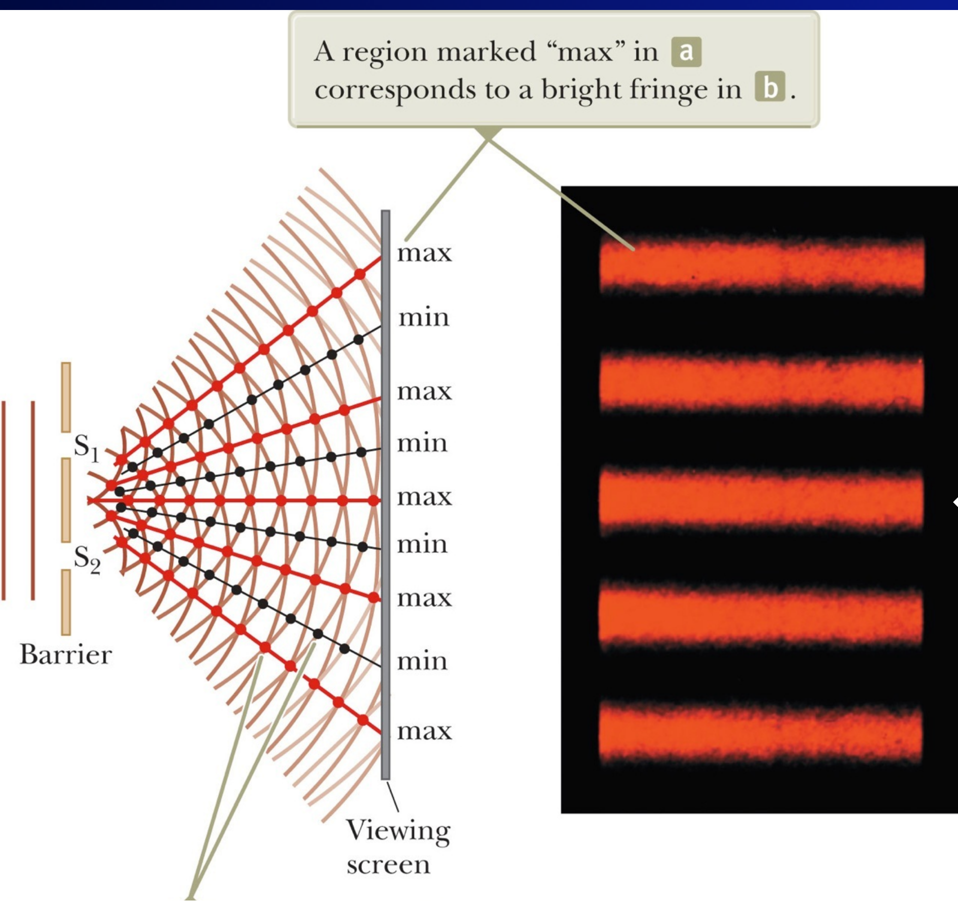
←m=2

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

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

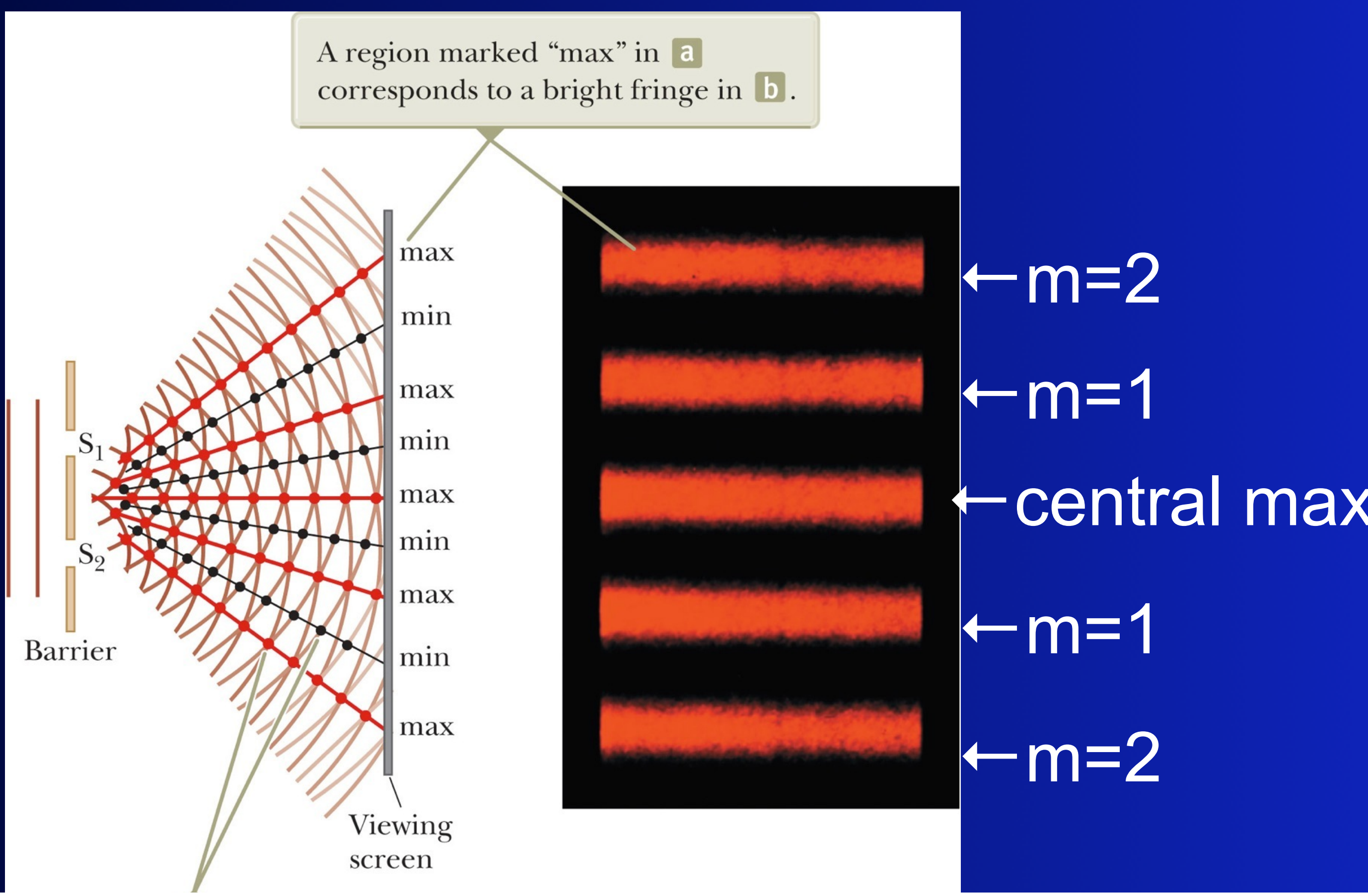
If the screen is moved closer to the double slits, the distance between the bright fringes…



A. **increases**
B. decreases
C. is unchanged

example: double-slit experiment

If we use green or blue light (shorter wavelength) rather than red light, the distance between the bright fringes…



A. increases

B. decreases

C. is unchanged

interference: intensity distribution

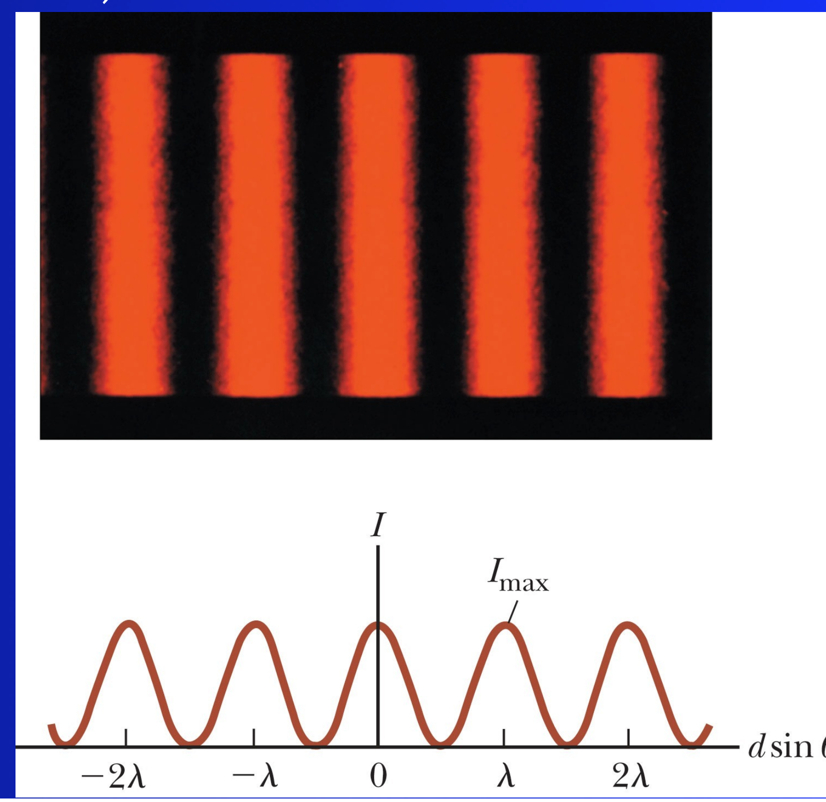
The phase difference at a point on the screen depends on the distances from the slits (Δr) or the angle θ:

$\phi = 2\pi\,\Delta r/\lambda = (2\pi/\lambda)\,d\sin\theta$

We can use this to quantify the distribution of the light's intensity (energy delivered/area/time):

$$I = I_{\max}\cos^2\left(\frac{\pi d \sin\theta}{\lambda}\right)$$

Then $I=I_{max}$ when $\theta=0$ ($\Delta r=0$) and when $\Delta r=\lambda$, 2λ, 3λ, etc…



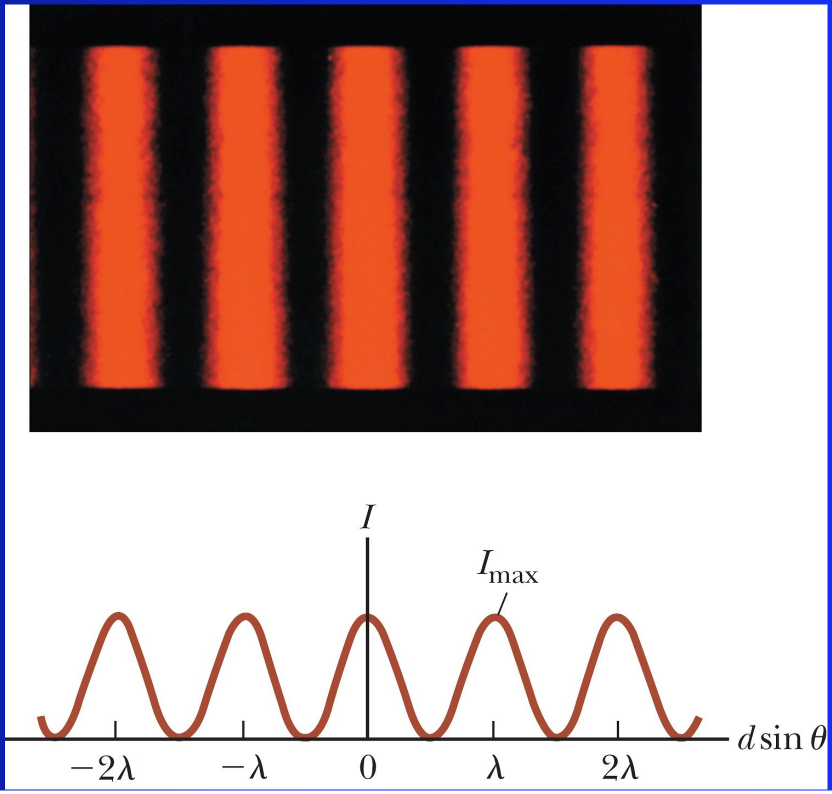
interference: intensity distribution

What happens to the intensity as we go from the central maximum to the first-order max to the second-order max?

$$I = I_{max} \cos^2\left(\frac{\pi d \sin\theta}{\lambda}\right)$$

Answer: the intensity is the same at each maximum.

$I = I_{max}$ when $\theta = 0$ ($\Delta r = 0$) and when $\Delta r = \lambda, 2\lambda, 3\lambda$, etc…



interference in thin films

We might come back to this after we study the ***reflection and refraction of light*** next week…

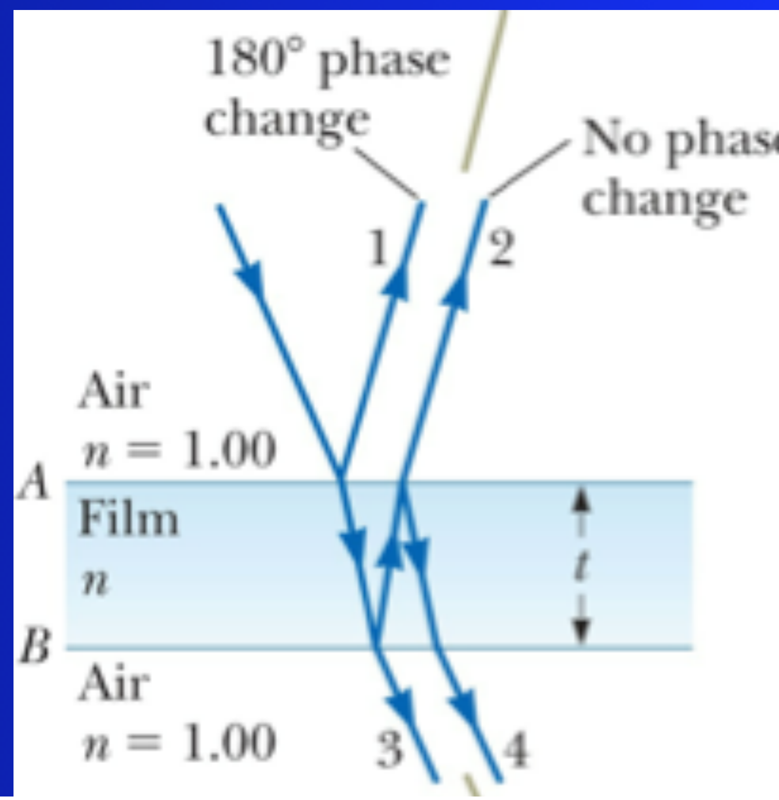
Constructive interference

$$2nt = (m + \tfrac{1}{2})\lambda \qquad m = 0, 1, 2, \ldots$$

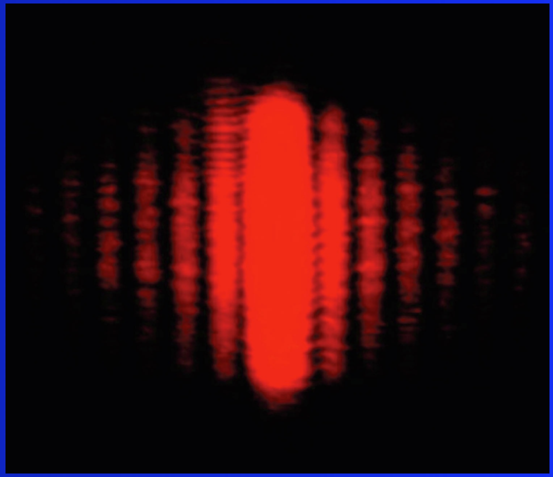
and destructive interference

$$2nt = m\lambda \qquad m = 0, 1, 2, \ldots$$

depend on the index of refraction *n*

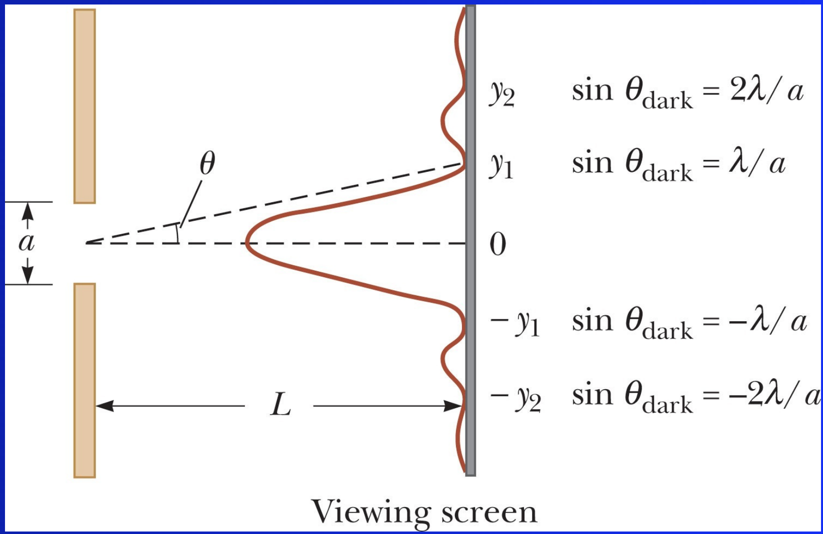


diffraction patterns



- light passing through a *single slit* (if sufficiently narrow) can produce a diffraction pattern
- note that the central maximum is much more intense than neighboring maxima
- unlike what happens with particles (like sand grains), waves from the the upper half of the slit interfere *destructively* with waves from lower half!
- condition for destructive interference:

$$\sin\theta_{\text{dark}} = m\frac{\lambda}{a} \qquad m = \pm 1, \pm 2, \pm 3, \ldots$$

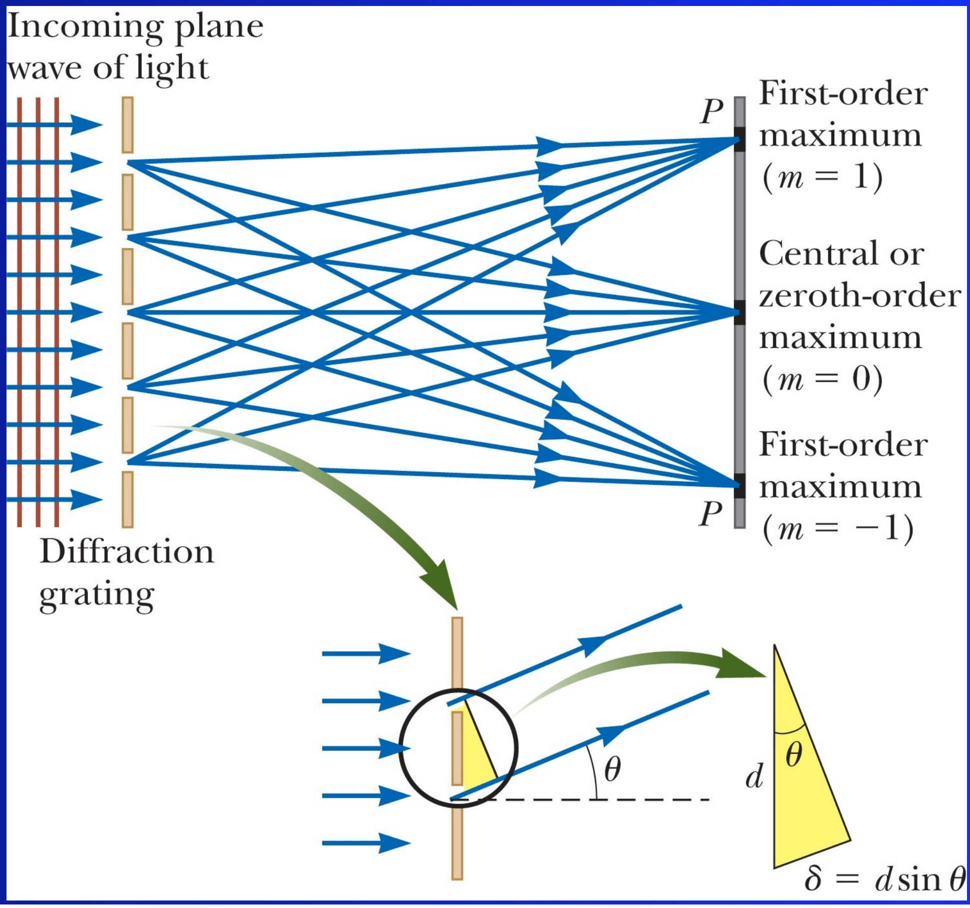


compare to destr. interference with double-slit:

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

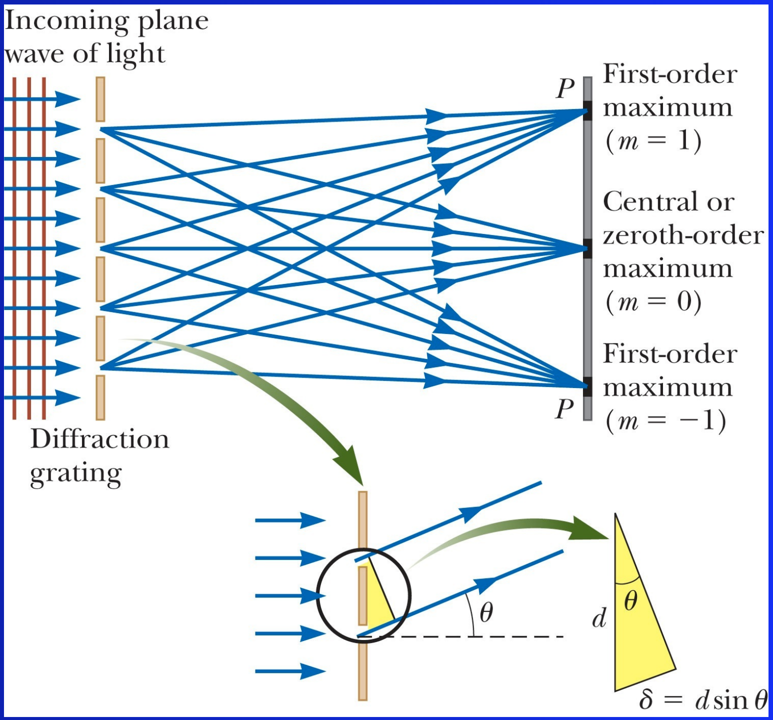
diffraction patterns with gratings

- *diffraction grating*: many equally-spaced parallel slits
- gratings often have thousands of lines/cm
- we see a *diffraction pattern* due to interference of light waves
- as before, each slit acts as a source of waves and all waves start at the slits *in phase*

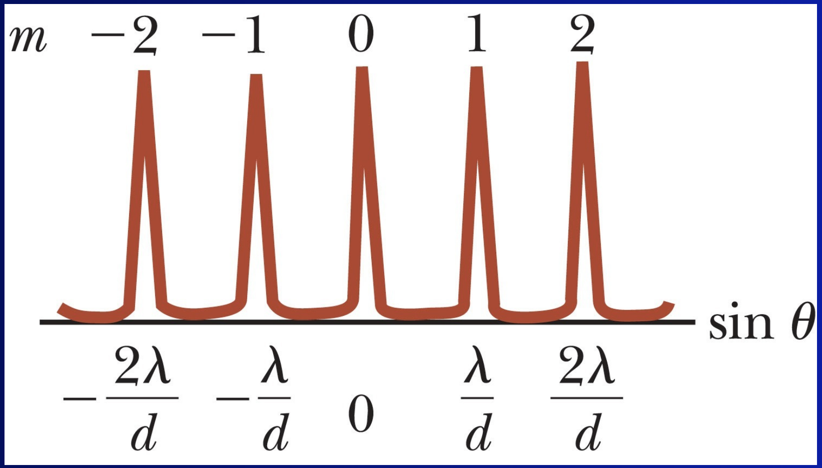


diffraction patterns with gratings

- *path difference* Δr between waves from adjacent slits:
  $\Delta r = d\sin(\theta)$
- if light from neighboring slits constructively interfere, we will have a maximal constructive interference:
  $\boldsymbol{d\sin(\theta) = m\lambda}$,
  where m=0, ±1, ±2… is *order number*

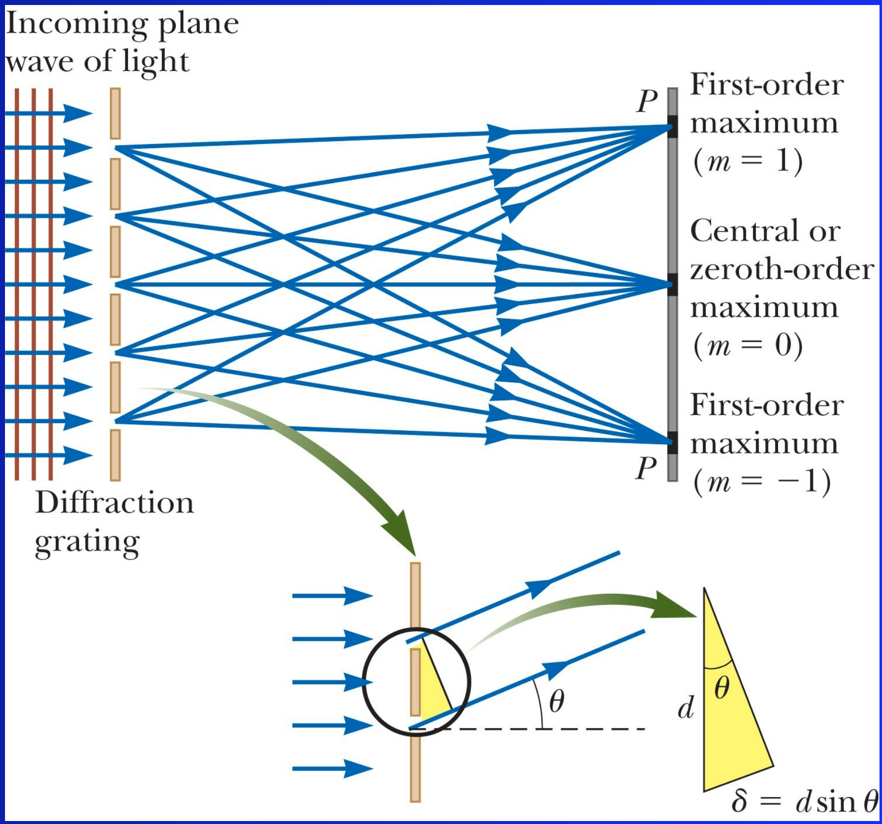


intensity distribution:



diffraction patterns with gratings

- if light from neighboring slits constructively interfere, we will have a maximal constructive interference:
  $$d\sin(\theta) = m\lambda,$$
  where m=0, ±1, ±2… is *order number*
- we can also calculate the distance to maxima as before:
  $$\Delta y = L\tan(\theta)$$



example: diffraction grating

- A diffraction grating has 900 slits per mm, so what is the slit spacing?
- A diffraction pattern is viewed 10cm behind the grating. If light is emitted at 400nm wavelength, what is the distance on the viewing screen between the first-order maxima for that color? [Try this without the small-angle approx.]
- What is that distance for 700nm wavelength light?

remember: $d\,\mathbf{sin(\theta)} = m\,\lambda$ and $\Delta y = L\,\mathbf{tan(\theta)}$

Electromagnetic Waves: introduction

- light is created by vibration of electric charges
- *electromagnetic waves*: electric and magnetic fields oscillate, and E and B are in phase and perpendicular
- relationship between field strengths: $E/B = c$

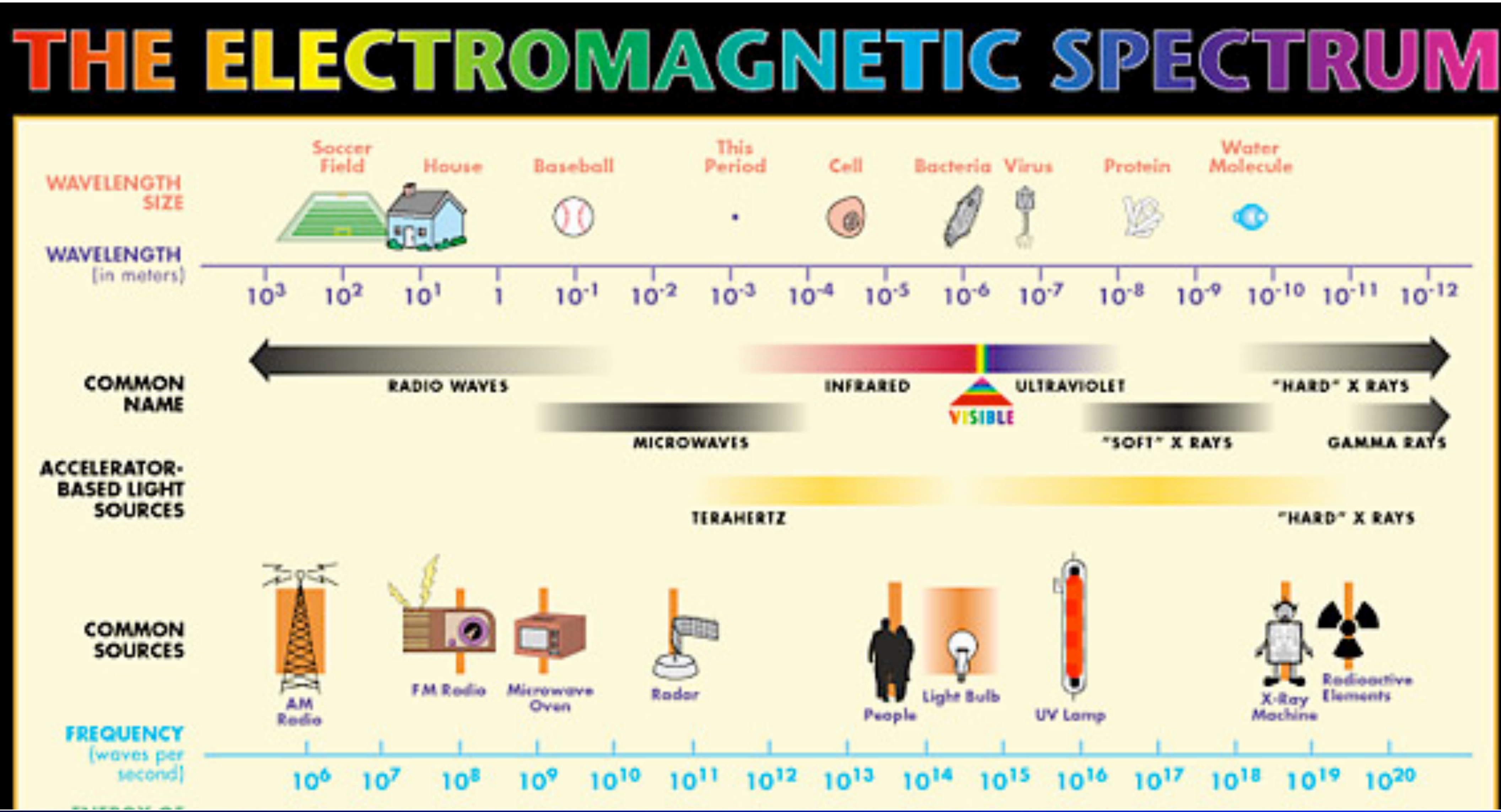
Power = energy transfer / time (units of Watts)

Intensity = power / area (units of W/m^2)

related to field strength E^2 and B^2

Pressure = intensity/c (units of N/m^2)

Electromagnetic Waves: the spectrum



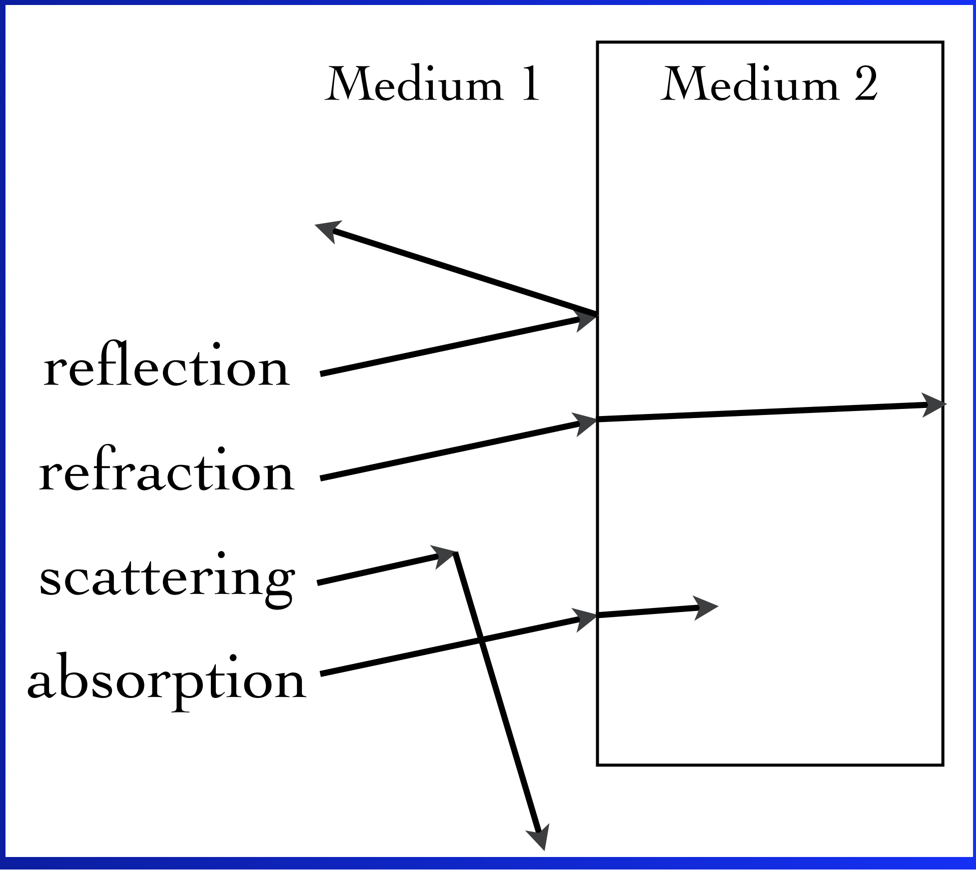
Electromagnetic Waves: Doppler effect

- as with sound waves, we observe the Doppler effect of light waves too
- but we use *c* for the speed of light (which is constant!) and *v* for the *relative* velocity between source & observer
- “red-shift” means source/object are moving apart and “blue-shift” means source/object are moving closer

$$f' = f_0 \sqrt{\frac{c+v}{c-v}}$$

next: ray model of light

- light rays travel in straight lines in a given medium
- light rays can cross without affecting each other
- objects are sources of light rays
- light rays can interact with matter



For Friday:

1. good luck on the quiz! don’t forget to bring your scantron sheet, calculator and pencil

2. please submit an evaluation for our course this week at http://academicaffairs.ucsd.edu/Modules/Evals?e1090420