Announcements 4/20/10

PS12 will be posted later today or tomorrow morning, due next Tuesday. One more PS after that due Tuesday May 4.

Reading for rest of semester:
Today: 32.1-32.2
Thursday: 32.3-5
Tuesday 4/27: 32.6
To review wave mathematics/terms: Wolfson 14.1, 14.2

Still grading exams, hope to finish by the end of Friday; as last time will send an email when they are ready and have them outside my office door for pickup.

Key ideas from last time

Sinusoidal plane waves = building blocks of all EM waves

$\vec{E} = E_p \sin(kx - \omega t)\,\hat{j}$

$\vec{B} = B_p \sin(kx - \omega t)\,\hat{k}$

Relationship between $\vec{E}$ and $\vec{B}$ comes from mutual induction:

- $\vec{E} \times \vec{B}$ points in direction of travel
- $E_p = cB_p$
- $\vec{E}$ and $\vec{B}$ are in phase

Speed of waves is constant: $c = f\lambda$ so $f = c/\lambda$

Polarization is the direction of $\vec{E}$

- conducting wires absorb $\vec{E}$ along the wires
- basis of polarizing filters

(NOTE "direction of polarization" = direction that gets through)

Energy, power, and intensity in waves:

- energy stored in fields is carried along as waves travel
- rate of energy flow per area = intensity (brightness)

time-average intensity $\bar{S} = \frac{1}{2} c\varepsilon_0 E_p^2 = \frac{power}{area}$

Energy in EM waves — particle picture

This suggests we can have an EM wave with any amount of energy we want

In fact that is not the case! Find that no matter how ~~weak~~ we try to make the wave, there is a minimum amount of energy

Also: if we look at how atoms and molecules absorb light, we find that they only absorb certain frequencies (or colors) of light apart from how intense the light is

Other picture: light is ~~not as waves but~~ a stream of "light particles" called photons, each of which is its own wave, but which has a particular energy

$$E = hf = h\frac{c}{\lambda}$$

Then for a photon to be absorbed, its energy must match a transition in atom/molecule

[if we have time the last week, may try to go into some of the crazy conseq.]

This is part of why the f or λ of light determines its properties: X-rays and γ rays have higher photon energy $\Rightarrow$ "ionizing radiation"
- used in ~~chemo~~ radiation cancer therapy b/c damage the tumor's molecules

other part: ω dep of n → dispersion

Why we only see visible light: photoreceptors in our eyes absorb those wavelengths ~700 nm to ~400 nm (red to blue)

higher energy — UV, X-rays, γ — can damage biomolecules — ~~[illegible]~~ our eye photoreceptors don't want to be exposed!

longer λ (IR) = thermal energies and vibrational states of molecules

Producing EM waves

Any motion of charge that oscillates or accelerates can produce EM waves

Simplest case: oscillating dipole

think about what $\vec{E}$ of osc. dipole looks like

Must consider how $\vec{E}$ of accelerating charges travel through space

Three principles:

(1) Field lines of moving charge always point directly to/from the charge right near it

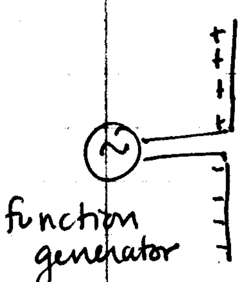
(2) Field pattern travels radially out @ c
(stationary charge: field lines spread out from charge @ c)

(3) As charges move, field lines farther out produced by earlier arrangement must stay continuous – can't break or interrupt field lines

Show Mazur figs – walk through

Can produce an oscillating dipole with a capacitor being charged by oscillating current

Turns out that you actually make sthg most like an osc dipole by an antenna:

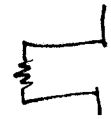


put oscillating current on it → oscillating pattern of charge

Basically a capacitor – but extend plates up & down instead of parallel

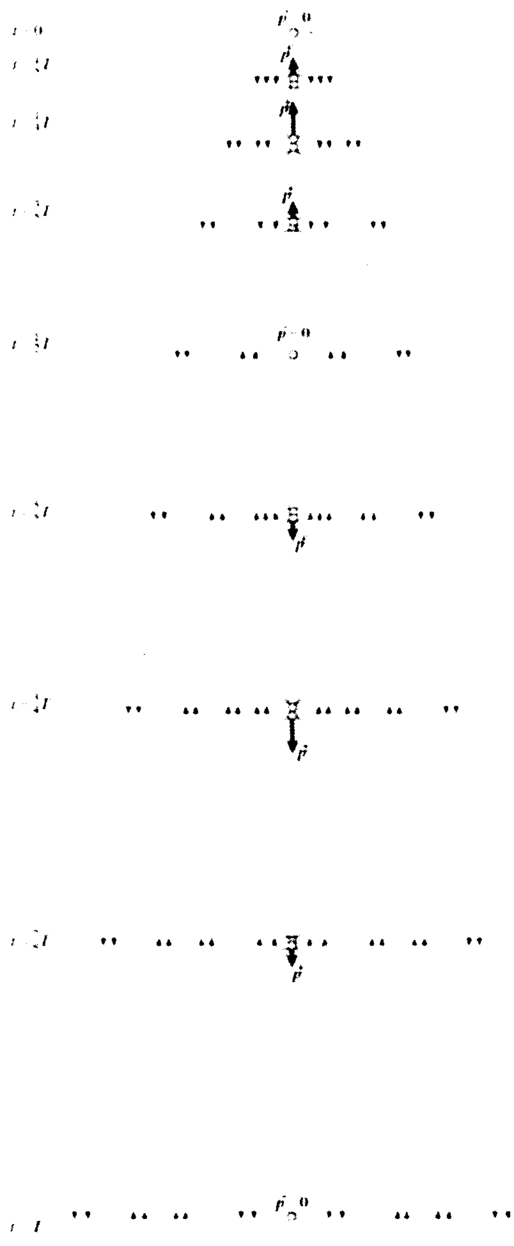
size → λ of resulting waves

If instead wave comes in and antenna is attached to a circuit: get current that oscillates @ f of wave → cell phone, radio, TV signal



Fields of an oscillating dipole

Figures from Mazur, *Principles and Practice of Physics*, to be published by Addison-Wesley



· **Figure 34.12** Snapshots of the field pattern of an oscillating dipole at time intervals of T/8 (T is the period of oscillation).

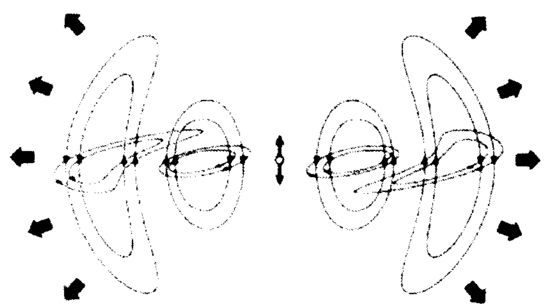


Figure 34.14 Electric (gray) and magnetic (red) field pattern of oscillating dipole after one complete oscillation. The blue arrows indicate the direction of propagation of the electromagnetic wave pulse.

Interference

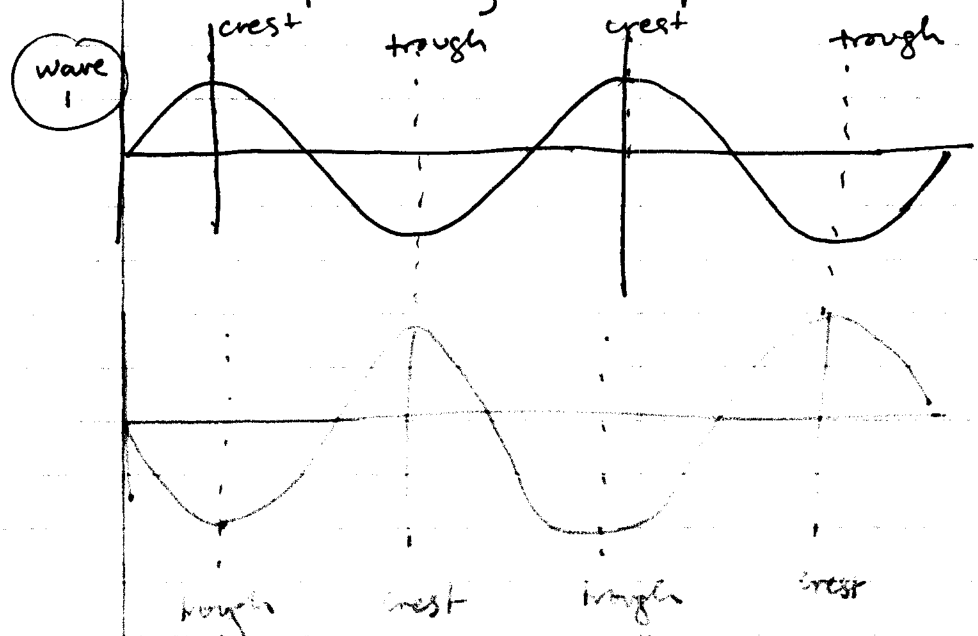
~12:00

Last time we introduced the forms of $\vec{E}$ and $\vec{B}$ corresponding to a plane EM wave

$$\vec{E} = E_p \sin(kx - \omega t)\hat{j}$$
$$\vec{B} = B_p \sin(\underbrace{kx - \omega t}_{\text{"phase" = argument of sine function}})\hat{k}$$

What happens if we combine two plane waves that have different phases?

Specifically consider combining waves that are different in phase by ½ cycle



Add $\vec{E}$ for these two waves together

→ zero! $\vec{E}_1 = -\vec{E}_2$

$\vec{E}_{total} = \vec{E}_1 + \vec{E}_2 = 0$

"Destructive interference"

If instead phases differ by one or more full cycles: "constructive interference"

→ waves add → double the amplitude

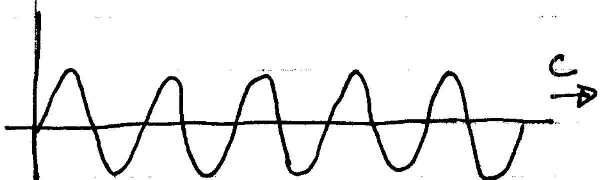
$\vec{E}_1 = \vec{E}_2$

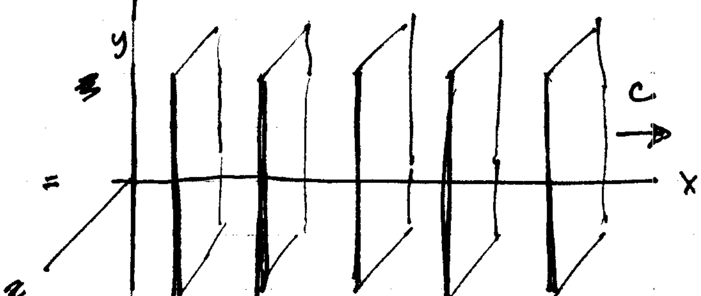
$\vec{E}_{total} = \vec{E}_1 + \vec{E}_2 = 2\vec{E}_1$

How do we get these plane waves with different phases?

Plane wave passing through small slit = point source

Can represent a plane wave by lines at the wave crests — show surfaces of constant phase





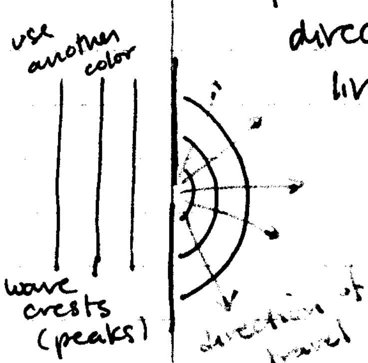
like seeing the tops of water waves

Think about such a wave hitting a barrier w/a small opening

Show Mazur 38.1

effect of small opening: wave spreads out in every direction

lines = wave crests = surfaces where wave is at maximum



Math: $\vec{E} = E_p \sin(kr - \omega t)\,\hat{j}$

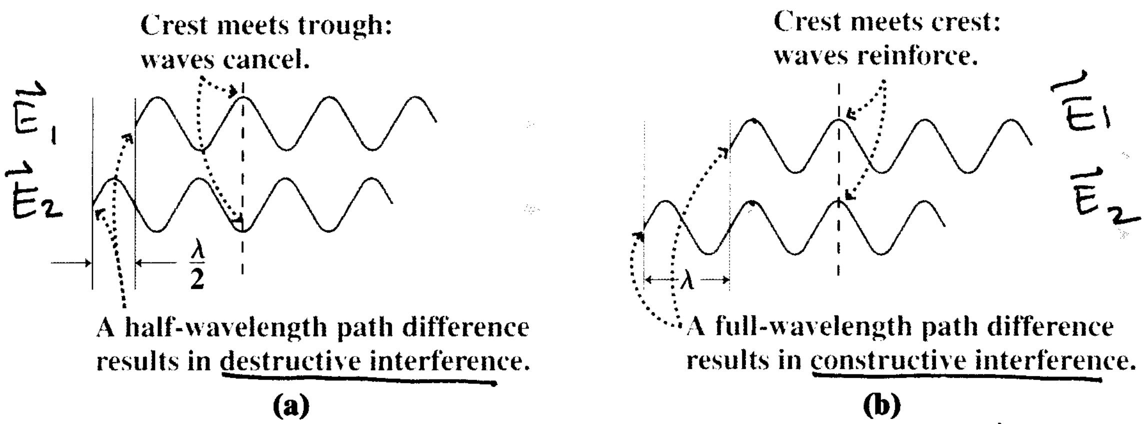
where r = distance from source along direction of travel

Imagine combining two such sources: travel different distances to reach same final location

$$\vec{E}_1 = E_p \sin(kr_1 - \omega t)\,\hat{j}$$
$$\vec{E}_2 = E_p \sin(kr_2 - \omega t)\,\hat{j} = E_p \sin(kr_1 - \omega t + k\Delta r)\,\hat{j}$$

if path difference Δr is integer multiple of $\lambda \rightarrow$ constructive

Interference figures (from Wolfson Ch. 32 and Mazur, *Principles and Practice of Physics*)

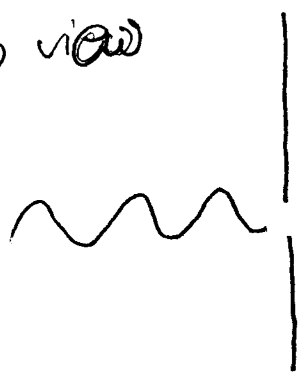


$\vec{E}_1 + \vec{E}_2 = 0$ $\qquad$ $\vec{E}_1 + \vec{E}_2 = 2\vec{E}_1$

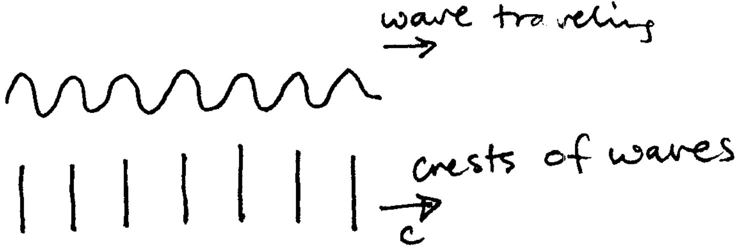
Where do we get wave sources that then travel diff distances?

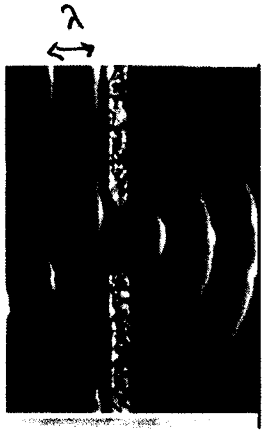
Think about a plane wave passing through a narrow opening

Top view

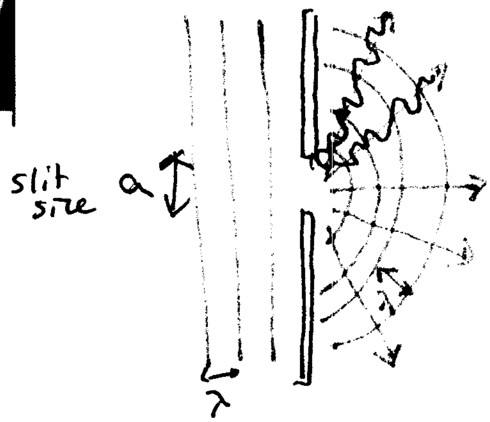


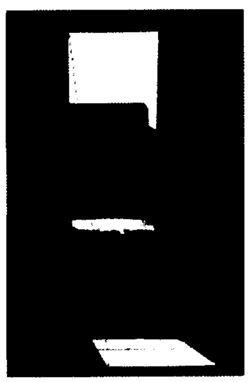
opening similar in size to λ





As wave travels through small opening
the opening serves as a point source –
wave spreads in all directions after
opening





Only get this spreading if opening
is comparable to λ

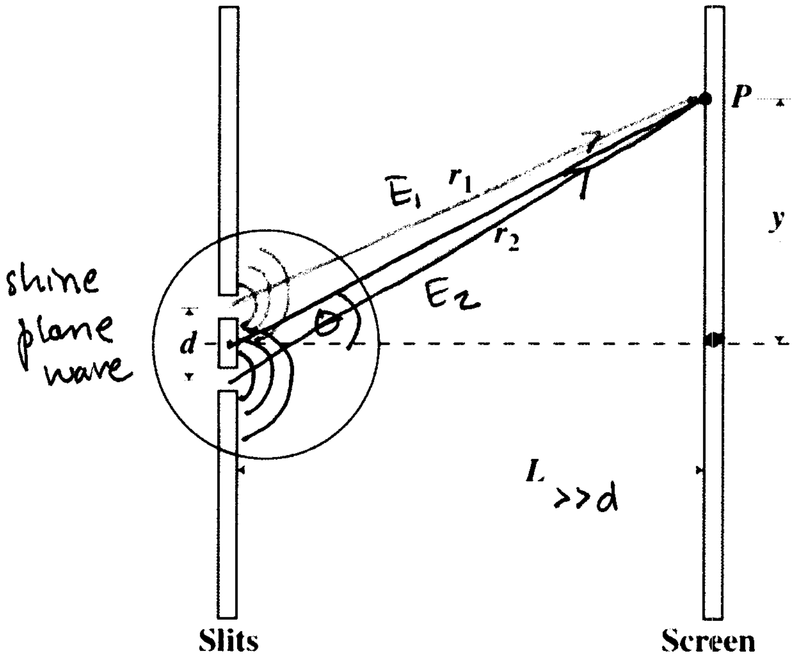
$\lambda \approx a$

(visible light $\lambda \sim 400-700$ nm)

Two point sources: two openings close together

Interference results from combining waves:
depends on how far each travels before
being combined

What do we see on a screen if we put light through two small openings?



$\vec{E}_1 = E_p \sin(kr_1 - \omega t)\hat{j}$

$\vec{E}_2 = E_p \sin(kr_2 - \omega t)\hat{j}$

write $r_2 = r_1 + \Delta r$

$\Rightarrow \vec{E}_2 = E_p \sin(\underbrace{kr_1 - \omega t}_{\text{same as } E_1} + \underbrace{k\Delta r}_{\text{difference in phase } \phi})$

$\vec{E}_{total} = \vec{E}_1 + \vec{E}_2$

if Δr = # of wavelengths → reinforce

if $\Delta r = \frac{1}{2}\lambda$ → cancel

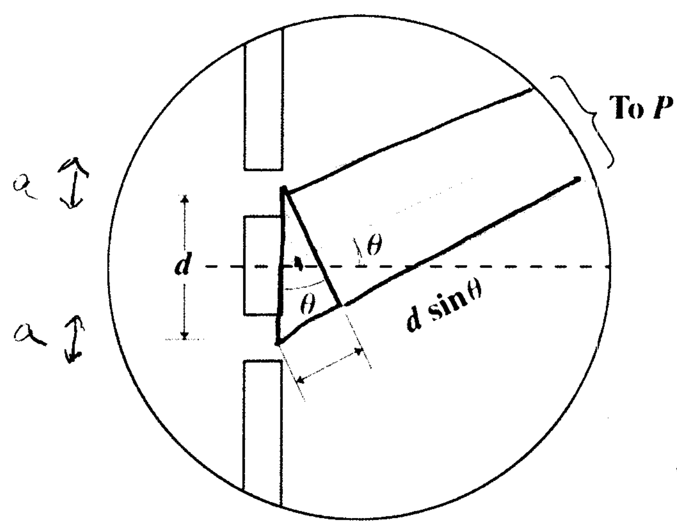
[Question here]

Constructive interference if

$\Delta r = m\lambda \quad m = 0, \pm 1, \ldots$

$(\phi = 2\pi m)$

If $d \ll L$, $L \gg y$



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

$d \frac{y}{\sqrt{L^2+y^2}} \approx d\frac{y}{L} = m\lambda$

$\Rightarrow y = m\frac{\lambda}{d}L$

Bright!

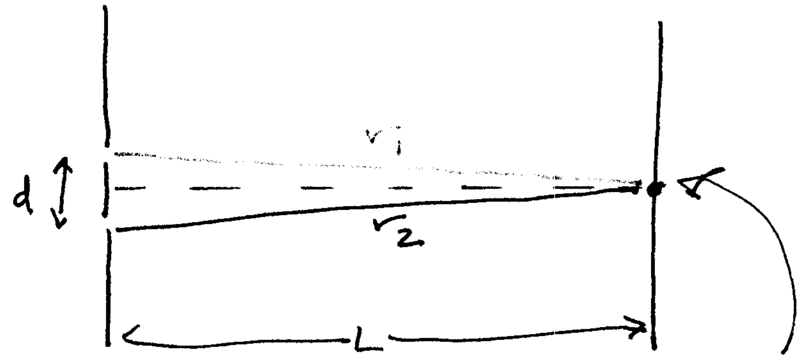
Destructive $\Delta r = (m+\frac{1}{2})\lambda$

$d\sin\theta = (m+\frac{1}{2})\lambda$

$\Rightarrow y = (m+\frac{1}{2})\frac{\lambda}{d}L$

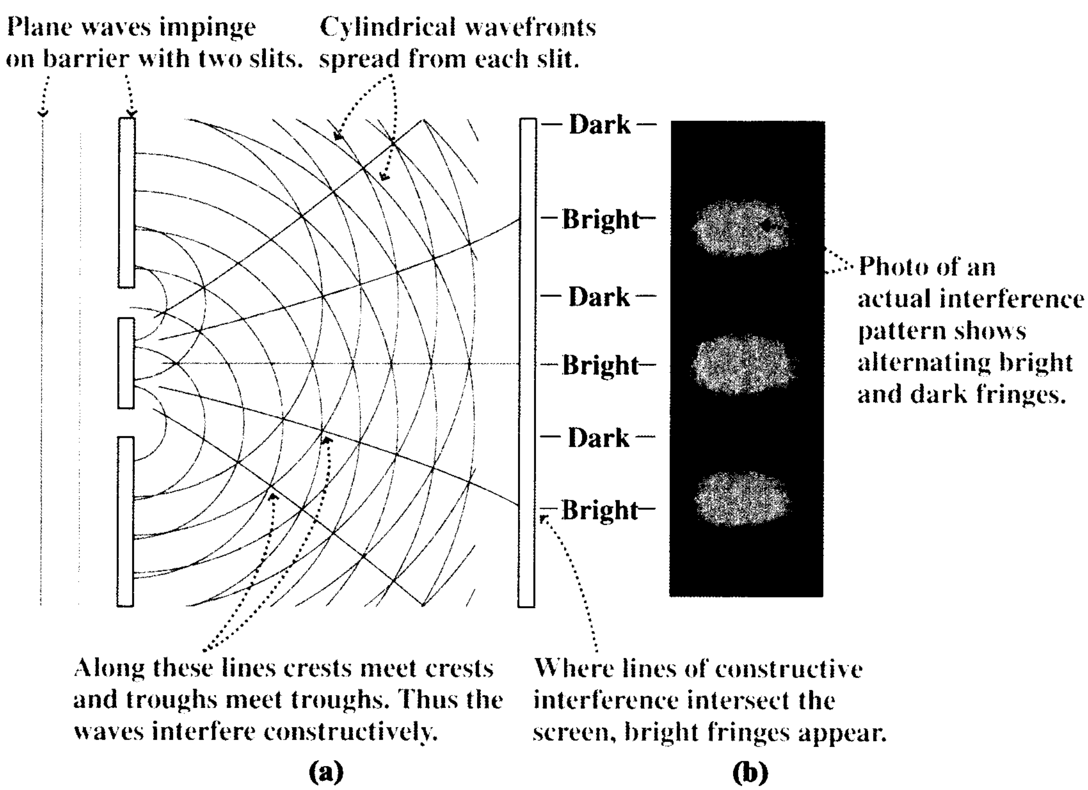
Consider two slits illuminated with a plane wave of visible light.

brightness $\propto E^2$



At the center of the screen opposite the two slits

1. The brightness can be maximum, minimum, or in between depending on the distance *L*.
2. The brightness is a minimum for any *L*.
3. The brightness is a maximum for any *L*.


Plane waves impinge on barrier with two slits.
Cylindrical wavefronts spread from each slit.
Dark
Bright
Dark
Bright
Dark
Bright
Photo of an actual interference pattern shows alternating bright and dark fringes.
Along these lines crests meet crests and troughs meet troughs. Thus the waves interfere constructively.
Where lines of constructive interference intersect the screen, bright fringes appear.
(a)
(b)

12:15 CT

If ~~[illegible]~~ $L \gg y$ and d then

CONSTRUCTIVE $\frac{dy}{L} = m\lambda \Rightarrow y = m\frac{\lambda}{d} L$

DESTRUCTIVE $\frac{dy}{L} = (m+\frac{1}{2})\lambda \Rightarrow y = (m+\frac{1}{2})\frac{\lambda}{d} L$

$\boxed{\text{CT}}$ screen moved closer to slits:
peaks get ~~farther apart~~ closer together (y values of peaks get ~~larger~~ smaller)

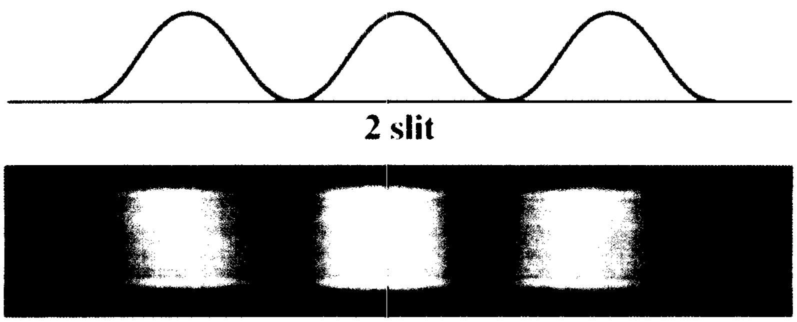
~~CT Slit width reduced:~~
~~pattern does not change!~~
~~d is distance between slits; slit width~~

$\boxed{\text{CT}}$ Red light rather than green:
λ is longer
→ pattern spreads out (y values larger)

$\boxed{\text{CT}}$ Slits narrower:
if you answered either 2 or 5 reasonable based on our discussions
positions y do not depend on slit width → no change to pattern
$\boxed{\text{BUT}}$ less light gets through slits to begin with
Recall we said for
~~idealization no change to brightness~~

$\boxed{\text{CT}}$ Polarizers over ~~[illegible]~~ slits → vert @ one horiz @ other
→ no interference pattern!

A double-slit experiment with green light produces the intensity pattern shown below.

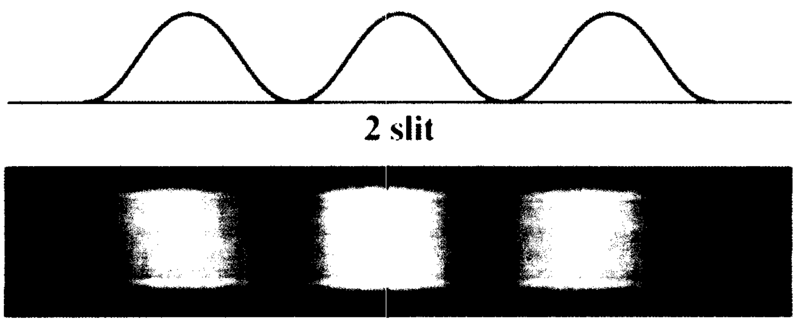


If the screen is moved closer to the slits, does the pattern change, and if so, how?

1. The pattern gets brighter (peaks are higher)
2. The pattern gets dimmer (peaks are lower)
3. The peaks become closer together
4. The peaks become farther apart
5. The pattern does not change

$\lambda = 532$ nm

A double-slit experiment with green light produces the intensity pattern shown below.

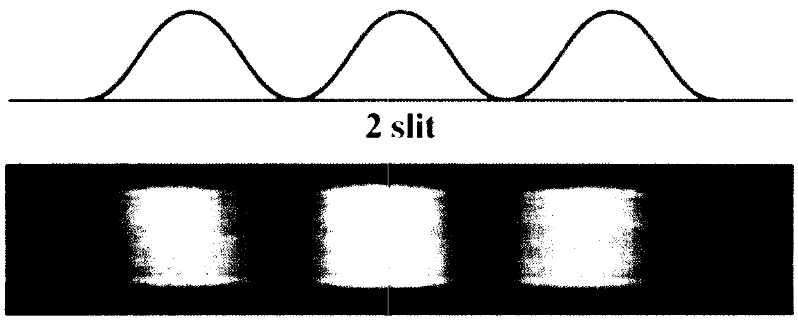


$\lambda = 620$ nm

If the same slits are illuminated with red light, does the pattern change, and if so, how?

1. The pattern gets brighter (peaks are higher)
2. The pattern gets dimmer (peaks are lower)
3. The peaks become closer together
4. The peaks become farther apart
5. The pattern does not change

A double-slit experiment with UNPOLARIZED green light produces the intensity pattern shown below.



If a horizontal polarizer is placed over one slit and a vertical polarizer is placed over the other slit, does the pattern change, and if so, how?

1. The pattern gets brighter (peaks are higher)
2. The pattern gets dimmer (peaks are lower)
3. The pattern does not change
4. The screen becomes uniformly illuminated.