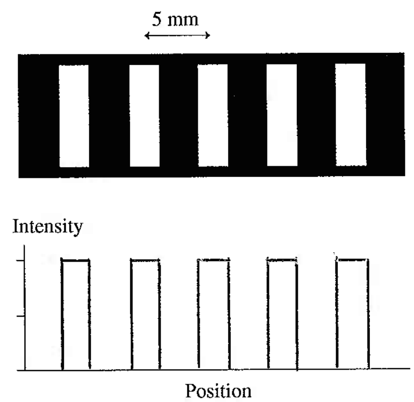
22 Wave Optics

22.1 Light and Optics

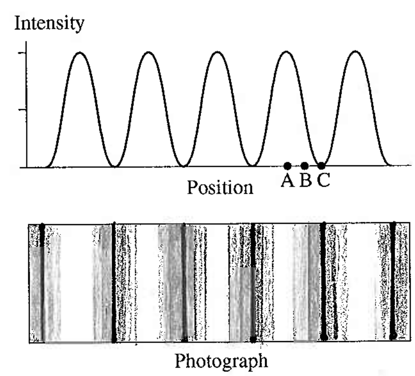
22.2 The Interference of Light

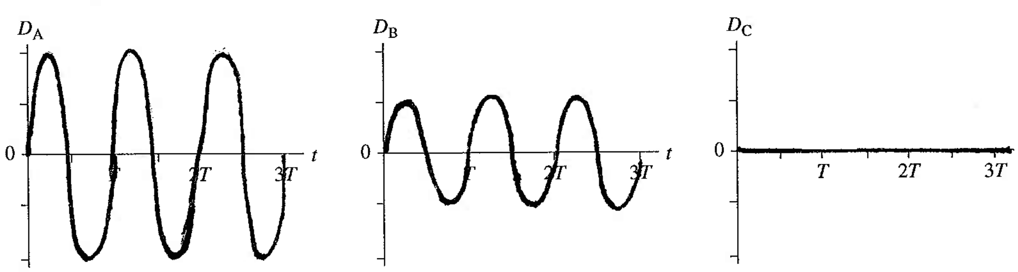
1. The figure shows the light intensity recorded by a piece of film in an interference experiment. Notice that the light intensity comes "full on" at the edges of each maximum, so this is *not* the intensity that would be recorded in Young's double-slit experiment.
   a. Draw a graph of light intensity versus position on the film. Your graph should have the same horizontal scale as the "photograph" above it.
   b. Is it possible to tell, from the information given, what the wavelength of the light is? If so, what is it? If not, why not?

No, one would need to know the distance to the film.

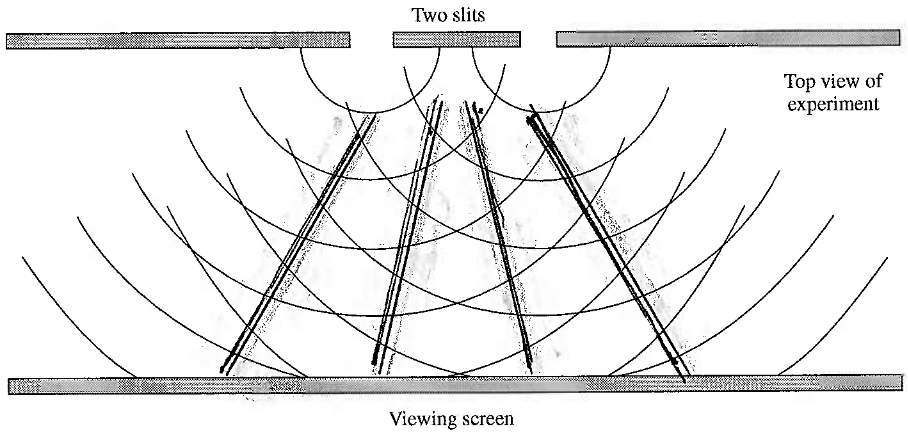


2. The graph shows the light intensity on the viewing screen during a double-slit interference experiment.
   a. Draw the "photograph" that would be recorded if a piece of film were placed at the position of the screen. Your "photograph" should have the same horizontal scale as the graph above it. Be as accurate as you can. Let the white of the paper be the brightest intensity and a very heavy pencil shading be the darkest.
   b. Three positions on the screen are marked as A, B, and C. Draw history graphs showing the displacement of the light wave at each of these three positions as a function of time. Show three cycles, and use the same vertical scale on all three.

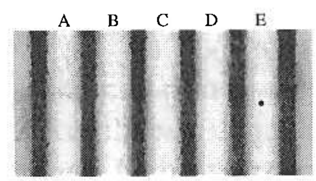




3. The figure below is a double-slit experiment seen looking down on the experiment from above. Although we usually see the light intensity only on a view screen, we can use smoke or dust to make the light visible as it propagates between the slits and the screen. Assuming that the space in the figure is filled with smoke, what kind of light and dark pattern would you see as you look down? Draw the pattern on the figure by shading areas that would appear dark and leaving the white of the paper for areas that would appear bright.



4. The figure shows the viewing screen in a double-slit experiment. For questions a–c, will the fringe spacing increase, decrease, or stay the same? Give an explanation for each.



a. The distance to the screen is increased.

The fringes will become more widely separated.
$\sin\theta_m \sim \frac{y_m}{L}$

b. The spacing between the slits is increased.

The fringes will become more closely spaced.
$\sin\theta = \frac{m\lambda}{d}$

c. The wavelength of the light is increased.

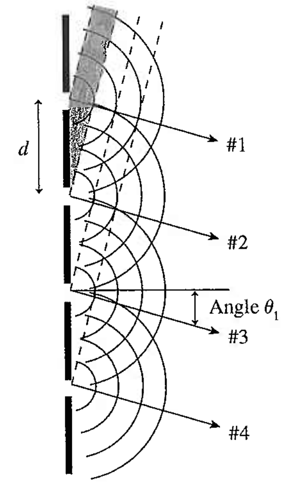
The fringes will become more widely separated.
$\sin\theta = \frac{m\lambda}{d}$

d. Suppose the wavelength of the light is 500 nm. How much farther is it from the dot in the center of fringe E to the more distant slit than it is from the dot to the nearer slit?

Each fringe from C represents an additional path length of λ. Therefore, to the center of fringe E requires a path length difference of $2\lambda = \boxed{1.0\mu m}$

22.3 The Diffraction Grating

5. The figure shows four slits in a diffraction grating. A set of Huygens wavelets is spreading out from each slit. Four wave paths, numbered 1 to 4, are shown leaving the slits at angle θ_1. The dashed lines are drawn perpendicular to the paths of the waves.



a. Use a colored pencil or heavy shading to show *on the figure* the extra distance traveled by wave 1 that is not traveled by wave 2.

b. How many extra wavelengths does wave 1 travel compared to wave 2? Explain how you can tell from the figure.

One wavelength. Each semicircle wavelet represents the crest of a wave front. The distance between wave fronts is one wavelength.

c. How many extra wavelengths does wave 2 travel compared to wave 3?

One wavelength.

d. As these four waves combine at some large distance from the grating, will they interfere constructively, destructively, or in between? Explain.

Constructively. The path length differences are all integer multiples of the same wavelength ($\Delta L = n\lambda$).

e. Suppose the wavelength of the light is doubled. (Imagine erasing every other wave front in the picture.) Would the interference at angle θ_1 then be constructive, destructive, or in between? Explain. Your explanation should be based on the figure, not on some equation.

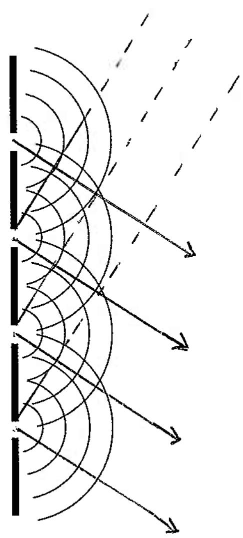
The path length differences would then correspond to one-half wavelength so the interference would be destructive.

f. Suppose the slit spacing is doubled. (Imagine closing every other slit in the picture). Would the interference at angle θ_1 then be constructive, destructive, or in between? Again, base your explanation on the figure.

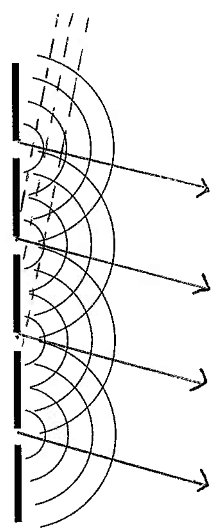
If the slit spacing were doubled, then the path length difference at θ_1 would increase to two wavelengths and the interference would be constructive.

6. These are the same slits as in Exercise 5? Waves with the same wavelength are spreading out on the right side.
   a. Draw four paths, starting at the slits, at an angle θ_2 such that the wave along each path travels *two* wavelengths farther than the next wave. Also draw dashed lines at right angles to the travel direction. Your picture should look much like the figure of Exercise 5, but with the waves traveling at a different angle. Use a ruler!
   b. Do the same for four paths at angle $\theta_{1/2}$ such that each wave travels *one-half* wavelength farther than the next wave.

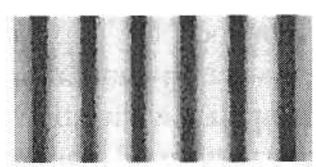
$\Delta r = 2\lambda$



$\Delta r = \frac{1}{2}\lambda$



7. This is the interference pattern on a viewing screen behind two slits. How would the pattern change if the two slits were replaced by 20 slits having the *same spacing d* between adjacent slits?



   a. Would the number of fringes on the screen increase, decrease, or stay the same?

   Stays the same.

   b. Would the fringe spacing increase, decrease, or stay the same?

   Stays the same.

   c. Would the width of each fringe increase, decrease, or stay the same?

   Decreases. The fringes become narrower.

   d. Would the brightness of each fringe increase, decrease, or stay the same?

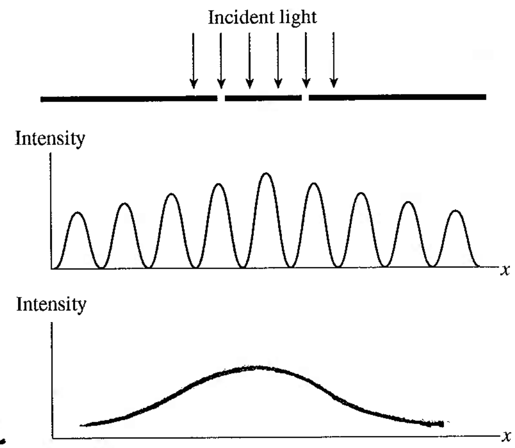
   The fringes become brighter. $I_{max} = N^2 I_1$

22.4 Single-Slit Diffraction

8. Plane waves of light are incident on two narrow, closely-spaced slits. The graph shows the light intensity seen on a screen behind the slits.

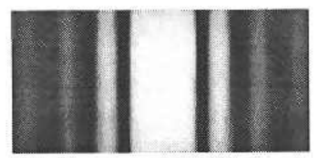
   a. Draw a graph on the axes below to show the light intensity on the screen if the right slit is blocked, allowing light to go only through the left slit.

   b. Explain why the graph will look this way.



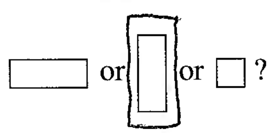
The single slit diffraction pattern contains a broad Central maximum. The narrower two slit interference pattern disappears when one slit is covered.

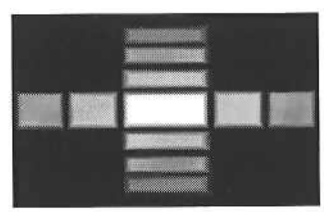
9. This is the light intensity on a viewing screen behind a slit of width a. The light's wavelength is λ. Is $\lambda < a$, $\lambda = a$, $\lambda > a$, or is it not possible to tell? Explain.



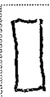
$\boxed{\lambda < a}$ Several secondary maxima appear. For $a\sin\theta_p = p\lambda$, the first minima from the central maximum requires $\sin\theta_1 = \frac{\lambda}{a}$, which must be less than 1.

10. This is the light intensity on a viewing screen behind a rectangular opening in a screen. Is the shape of the opening





Explain.



The narrower the opening is in a particular direction, the greater the spreading of the light in that direction.

11. The graph shows the light intensity on a screen behind a 0.2-mm-wide slit illuminated by light with a 500 nm wavelength.

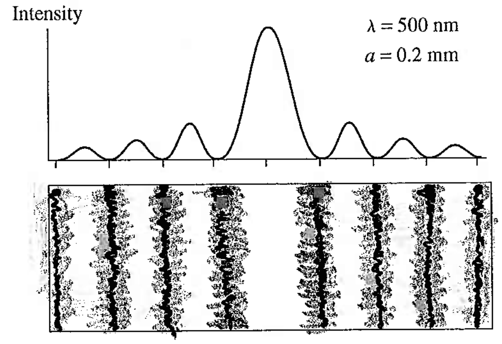
    a. Draw a *picture* in the box of how a photograph taken at this location would look. Use the same horizontal scale, so that your picture aligns with the graph above. Let the white of the paper represent the brightest intensity and the darkest you can draw with a pencil or pen be the least intensity.

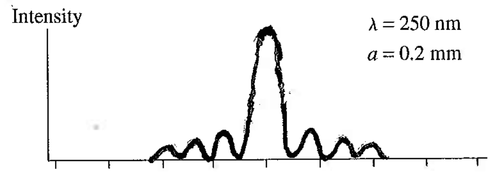
    b. Using the same horizontal scale as in part a, draw graphs showing the light intensity if

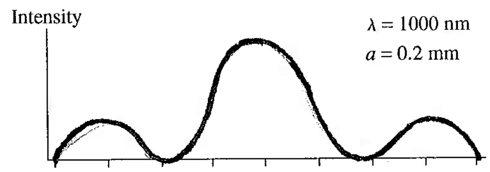
       i. $\lambda = 250$ nm, $a = 0.2$ mm.

       ii. $\lambda = 1000$ nm, $a = 0.2$ mm.

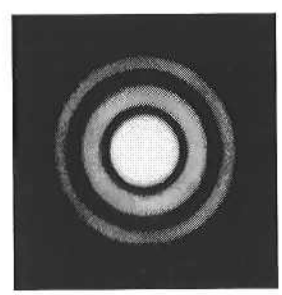
       iii. $\lambda = 500$ nm, $a = 0.1$ mm.







22.5 Circular-Aperture Diffraction



12. This is the light intensity on a viewing screen behind a circular aperture.

    a. If the wavelength of the light is increased, will the width of the central maximum increase, decrease, or stay the same? Explain.

    The width increases.
    $\theta_1 = \frac{1.22\lambda}{D}$ so θ_1 increases with λ.

    b. If the diameter of the aperture is increased, will the width of the central maximum increase, decrease, or stay the same? Explain.

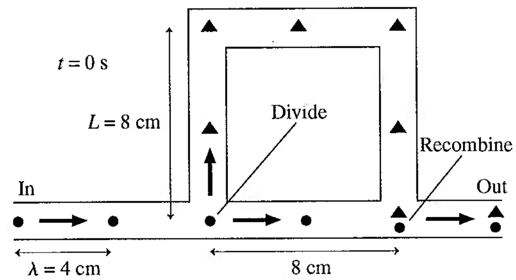
    The width decreases.
    θ_1 decreases with increasing D.

    c. How will the screen appear if the aperture diameter is decreased to less than the wavelength of the light?

    uniformly gray. No minima would appear.

22.6 Interferometers

13. The figure shows a tube through which sound waves with $\lambda = 4$ cm travel from left to right. Each wave divides at the first junction and recombines at the second. The dots and triangles show the positions of the wave crests at $t = 0$ s—rather like a very simple wave front diagram.



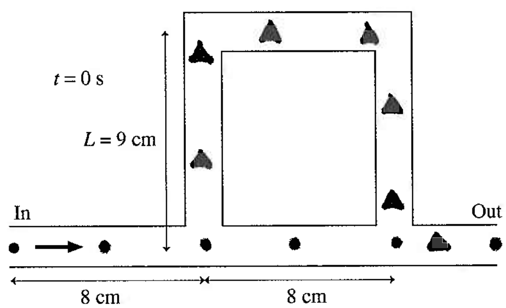
a. Do the recombined waves interfere constructively or destructively? Explain.

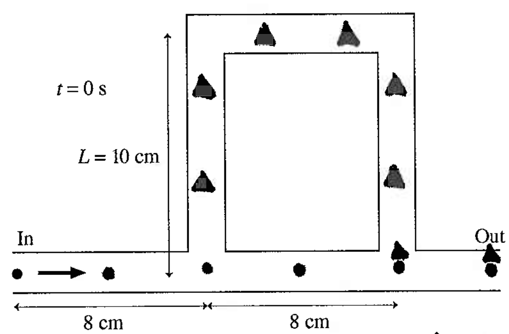
Constructively. The path length difference is an integer multiple of the wavelength. The wave crest positions are the same at the output.

b. How much *extra* distance does the upper wave travel? 16cm

How many wavelengths is this extra distance? 4

c. Below are tubes with $L = 9$ cm and $L = 10$ cm. Use dots to show the wave crest positions at $t = 0$ s for the wave taking the lower path. Use triangles to show the wave crests at $t = 0$ s for the wave taking the upper path. The wavelength is $\lambda = 4$ cm. Assume that the first crest is at the left edge of the tube, as in the figure above.





d. How many *extra* wavelengths does the upper wave travel in the $L = 9$ cm tube? 4.5

What kind of interference does the $L = 9$ cm tube produce? Destructive

e. How many *extra* wavelengths does the upper wave travel in the $L = 10$ cm tube? 5

What kind of interference does the $L = 10$ cm tube produce? Constructive

14. A Michelson interferometer has been adjusted to produce a bright spot at the center of the interference pattern.
   a. Suppose the wavelength of the light is halved. Is the center of the pattern now bright or dark, or is it not possible to say? Explain.

The center of the pattern will still be bright. For a bright spot to appear, the pathlengths can only differ by integer "m" multiples of the wavelength. If the wavelength is halved, the pathlengths will now differ by 2m, which is still constructive interference.

   b. Suppose the wavelength of the light doubled to twice its original value. Is the center of the pattern now bright or dark, or is it not possible to say? Explain.

It is impossible to say. Preveously, the pathlengths differed by an integer multiple of the wavelength. If that integer is odd, then the path difference is now an odd multiple of a half wavelength, which would cause destructive interference or a dark spot. If the integer was even, then the paths will still differ by an integer multiple of a wavelength and the center will be bright.