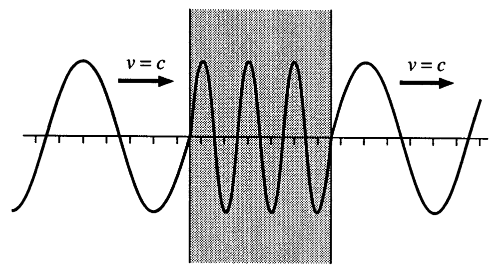
17 Wave Optics

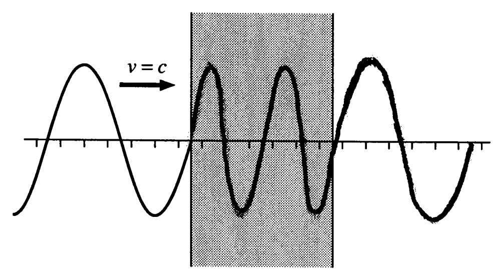
17.1 What is Light?

1. A light wave travels from vacuum, through a transparent material, and back to vacuum. What is the index of refraction of this material? Explain.



n = 3 The frequency does not change. The wavelength change tells the change in speed. Here $\lambda \to \lambda/3$ so $v = \frac{c}{3}$ and n = 3.

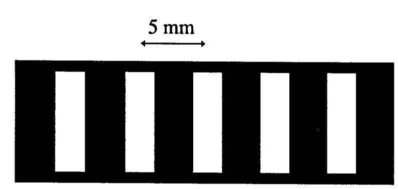
2. A light wave travels from vacuum, through a transparent material whose index of refraction is $n = 2.0$, and back to vacuum. Finish drawing the snapshot graph of the light wave at this instant.



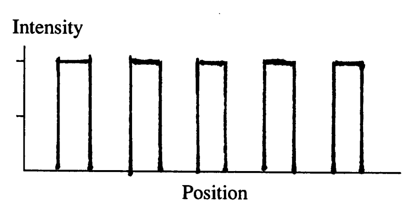
$\lambda \to \lambda/2$

17.2 The Interference of Light

3. The figure shows the light intensity recorded by a detector 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.



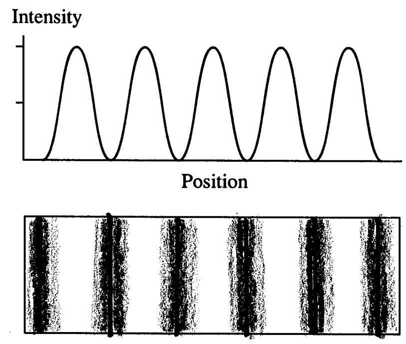
a. Draw a graph of light intensity versus position on the film. Your graph should have the same horizontal scale as the "photograph" above it.



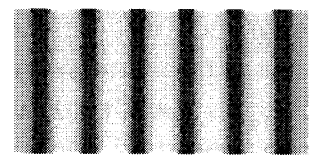
b. Is it possible to tell, from the information given, what the wavelength of the light is? If so, what is it? If not, why not?

No, one would need to know the distance to the detector and other information.

4. The graph shows the light intensity on the viewing screen during a double-slit interference experiment. 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.



5. 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 fringe spacing will increase as the light spreads from the slits.

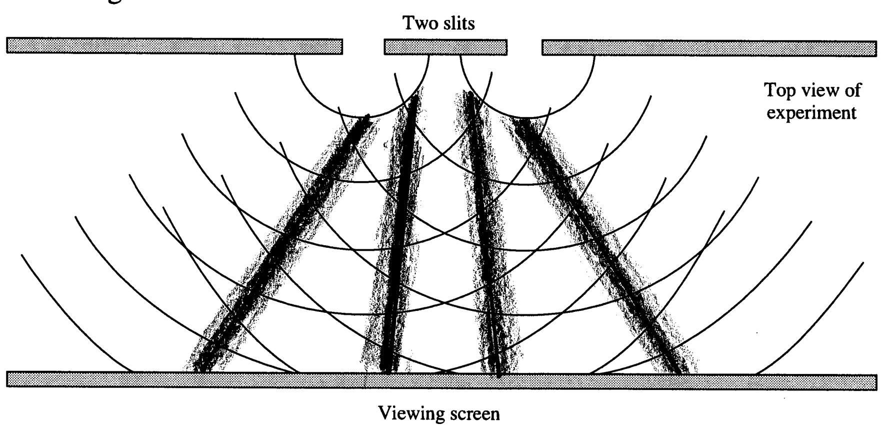
b. The spacing between the slits is increased.

The fringe spacing will decrease because $m\lambda = d\sin\theta$ and λ is unchanged, Decreasing d causes $\sin\theta$ to increase.

c. The wavelength of the light is increased.

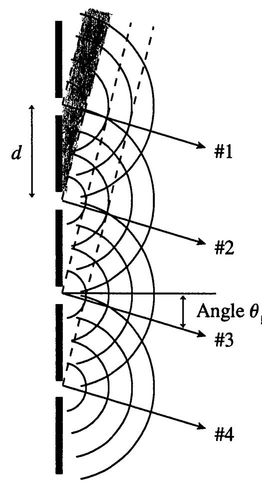
The spacing will increase because the spread $\sin\theta$ is proportional to the wavelength.

6. In a double-slit experiment, we usually see the light intensity only on a viewing screen. However, we can use smoke or dust to make the light visible as it propagates between the slits and the screen. Consider a double-slit experiment in a smoke-filled room. What kind of light and dark pattern would you see if you looked down on the experiment from above? Draw the pattern on the figure below. Shade the areas that are dark and leave the white of the paper for the areas that are bright.



17.3 The Diffraction Grating

7. The figure shows four slits in a diffraction grating. A set of circular wave crests is shown spreading out from each slit. Four wave paths, numbered 1 to 4, are shown leaving the slits at angle θ_1. The dotted 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 wavefronts 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 ($\Delta L = n\lambda$).

8. Suppose the wavelength of the light in Exercise 7 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.

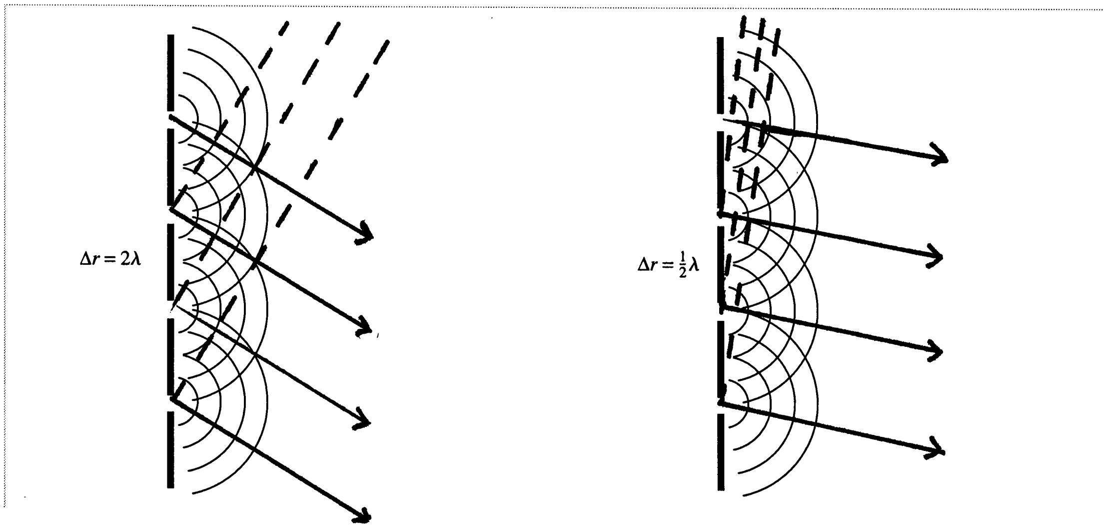
9. Suppose the slit spacing d in Exercise 7 is doubled while the wavelength is unchanged. Would the interference at angle θ_1 then be constructive, destructive, or in between? Again, base your explanation on the figure.

   If the slit spacing were doubled, then the path length difference at θ would increase to <u>two</u> wavelengths and the interference would be constructive.

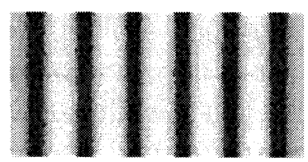
10. These are the same slits as in Exercise 7. Waves with the same wavelength are spreading out on the right side.

   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 7, 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.



11. 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?

   The number of fringes would stay the same.

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

   The spacing would stay the same.

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

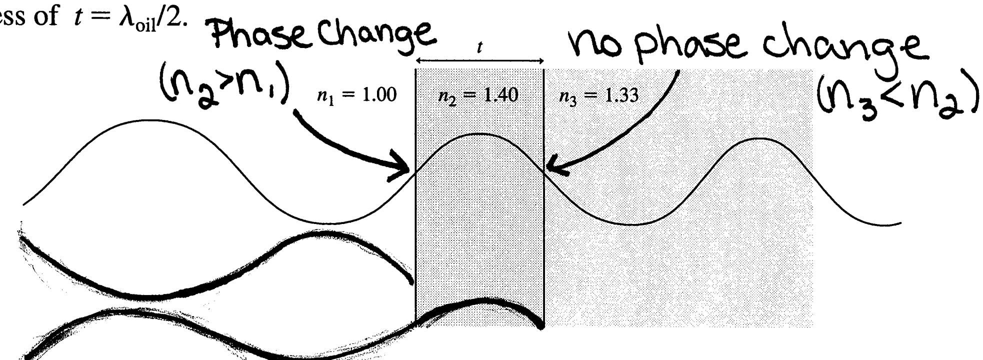
   The fringes would become sharper and narrower.

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

   The brightness would increase as more light reaches the screen in more sharply defined fringes.

17.4 Thin-Film Interference

12. The figure shows a wave transmitted from air through a thin oil film on water. The film has a thickness of $t = \lambda_{oil}/2$.



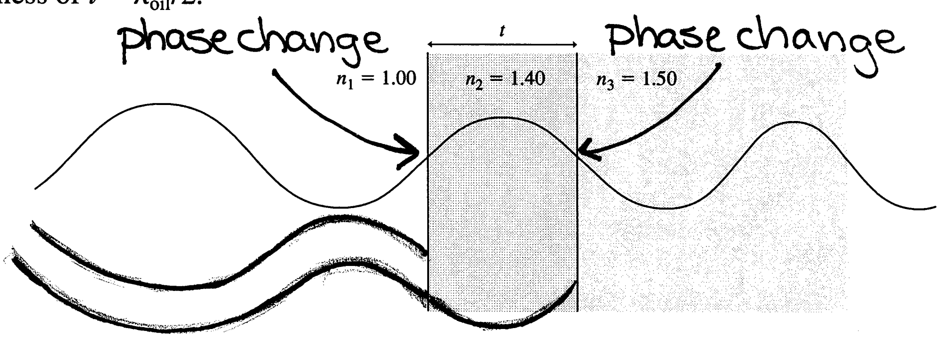
a. Using the indices of refraction that are given, indicate at each boundary on the diagram whether the reflected wave (not shown) undergoes a phase change at the boundary.

b. Draw in the reflected wave from the first boundary (air/oil) and the reflected wave from the second boundary (oil/water). Extend both reflected waves back to the left edge of the figure.

c. Do the two reflected waves interfere constructively, destructively, or in between? Explain.

They interfere destructively. The extra distance traveled is one wavelength but only the 1st reflection undergoes a phase change.

13. The figure shows a wave transmitted from air through a thin oil film on glass. The film has a thickness of $t = \lambda_{oil}/2$.



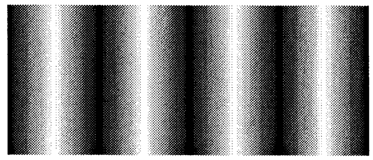
a. Using the indices of refraction that are given, indicate at each boundary on the diagram whether the reflected wave (not shown) undergoes a phase change at the boundary.

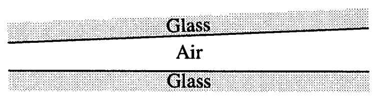
b. Draw in the reflected wave from the first boundary (air/oil) and the reflected wave from the second boundary (oil/glass). Extend both reflected waves back to the left edge of the figure.

c. Do the two reflected waves interfere constructively, destructively, or in between? Explain.

They interfere constructively. The extra distance traveled to the n_2-n_1 surface is one wavelength and the two phase shifts cancel.

14. The figure shows the fringes seen due to a wedge of air between two flat glass plates that touch at one end and are illuminated by light of wavelength $\lambda = 500$ nm.





a. By how much does the wedge of air increase in thickness as you move from one dark fringe to the next dark fringe? Explain.

250nm. Each adjacent destructive interference fringe corresponds to a thickness change of $\lambda/2$, which is traversed twice.

b. By how much does the wedge of air increase in thickness from one end of the above figure to the other?

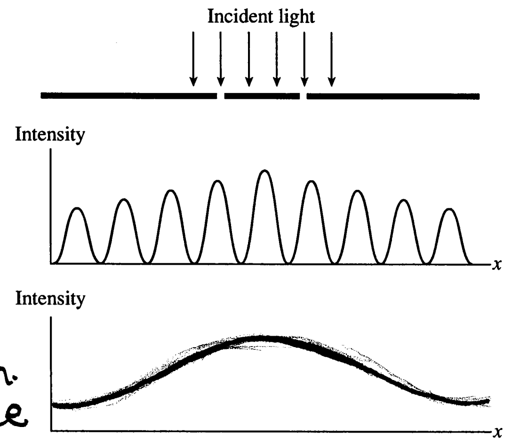
The pattern shows 4½ fringes corresponding to $4.5 \times \lambda/2$ separation = 1.125 μm.

c. Suppose you fill the space between the glass plates with water. Will the spacing between the dark fringes get larger, get smaller, or stay the same? Explain.

The spacing will decrease because the wavelength is shorter in water than in air.

17.5 Single-Slit Diffraction

15. 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.

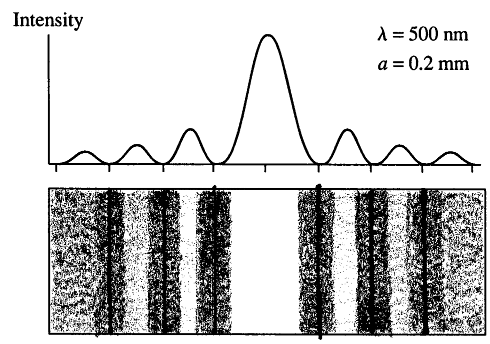


   a. Draw a graph on the axes below right to show the light intensity on the screen if the right slit is blocked, allowing light to go only through the left slit.

   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.

16. 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.

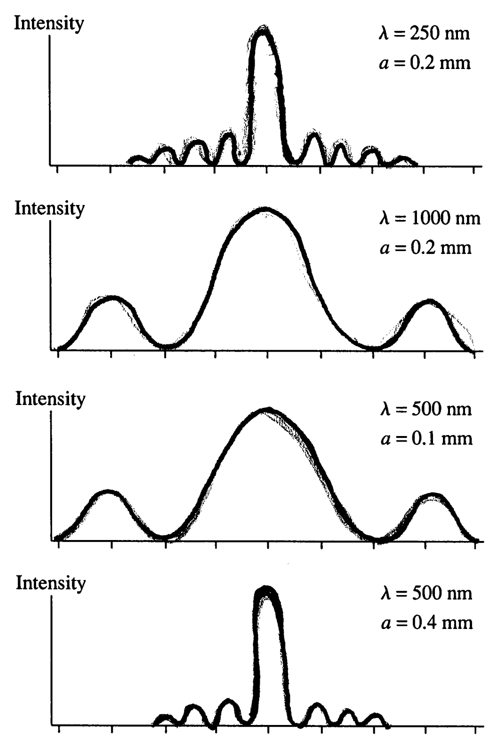
   b. Using the same horizontal scale as in part a, draw graphs showing the light intensity if

   i. $\lambda = 250$ nm, $a = 0.2$ mm. $a/\lambda = 800$

   ii. $\lambda = 1000$ nm, $a = 0.2$ mm. $a/\lambda = 200$

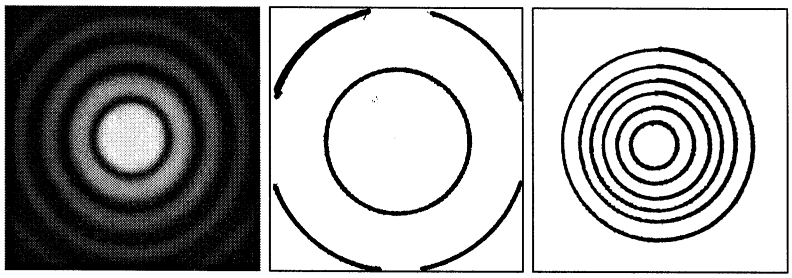
   iii. $\lambda = 500$ nm, $a = 0.1$ mm. $a/\lambda = 200$

   iv. $\lambda = 500$ nm, $a = 0.4$ mm. $a/\lambda = 800$



17.6 Circular-Aperture Diffraction

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



a. In the middle box, sketch how the pattern would appear if the wavelength of the light were doubled. Explain.

Doubling the wavelength causes the angle between the fringes to double.

$$\theta \sim \frac{\lambda}{D}$$

b. In the far right box, sketch how the pattern would appear if the diameter of the aperture were doubled. Explain.

Doubling the aperture diameter causes the angle between fringes to decrease by half.

$$\theta \sim \frac{\lambda}{D}$$