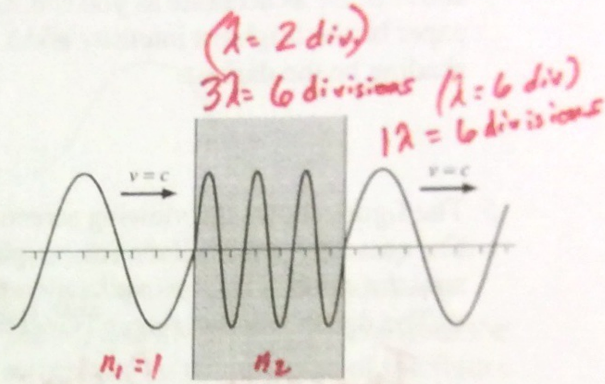
17 Wave Optics

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.



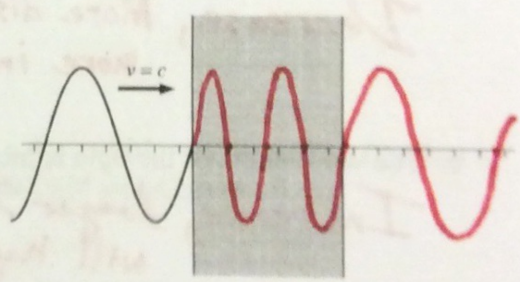
$n = 1$

$n_1 \lambda_1 = n_2 \lambda_2$

$1(6) = n_2(2)$

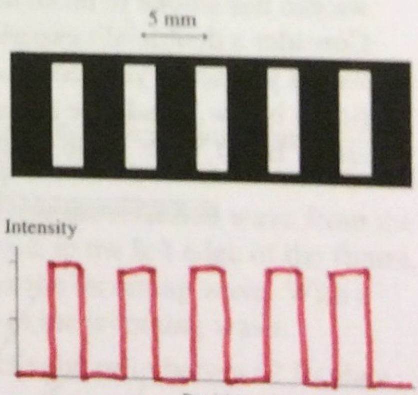
$n_2 = 3$

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.

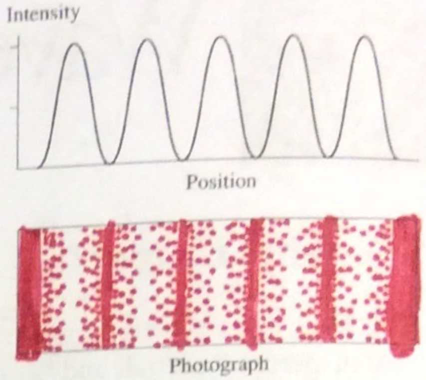


17.2 The Interference of Light

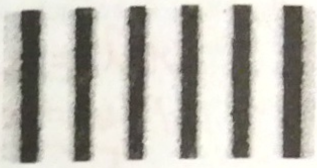
3. The figure shows the light intensity recorded by a detector in an interference experiment. Notice that the light intensity comes "full on" at the edges of each maximum, so this is *not* the intensity that would be recorded in Young's double-slit experiment.
   a. Draw a graph of light intensity versus 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?



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.

Increase, θ stays same, so as L increases, x increases

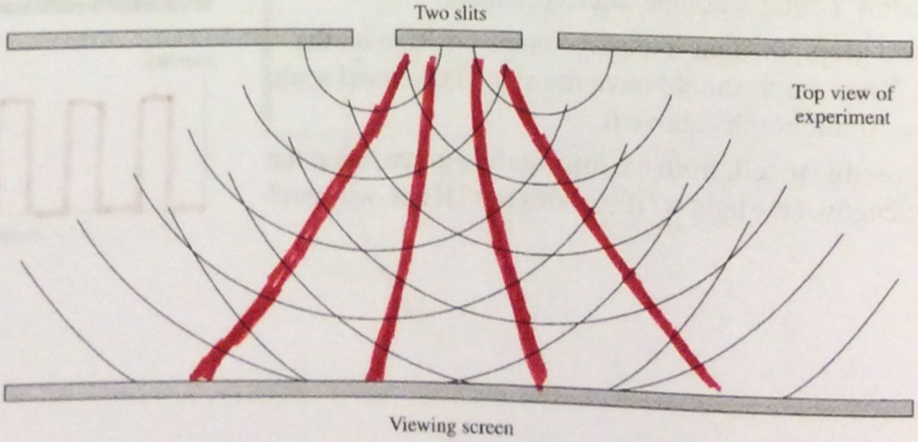
b. The spacing between the slits is increased.

Decrease, More distance between slits means more interference can occur.

c. The wavelength of the light is increased.

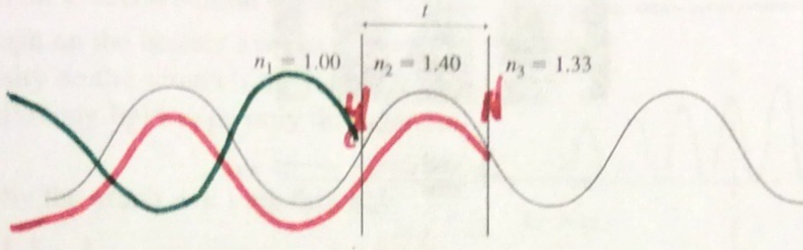
Increase, Longer λ means less interference will happen.

6. In a double-slit experiment, we usually see the light intensity on a viewing screen. However, we can use smoke 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 bright areas. **Hint:** What is the condition for constructive interference? For destructive?



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 $t = \lambda_{oil}/2$, where λ_{oil} is the wavelength of the light while in the oil.



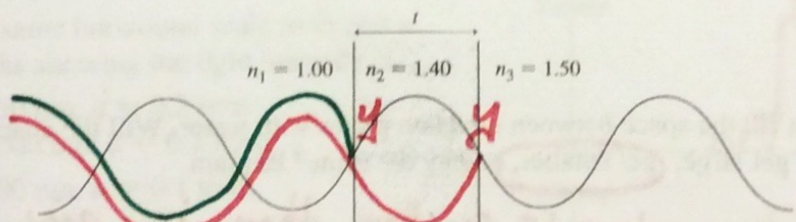
a. Referring to the indices of refraction shown on the figure, indicate at each boundary with a Y (yes) or N (no) whether the reflected wave undergoes a phase change at the boundary.

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. **Hint:** If there's no phase change, the reflected wave retraces the incoming wave. With a phase change, the reflected wave is "upside down" relative to the incoming wave.

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

One has a phase change the other does not

13. The figure shows a wave transmitted from air through a thin oil film on glass. The film has a thickness $t = \lambda_{oil}/2$, where λ_{oil} is the wavelength of the light while in the oil.



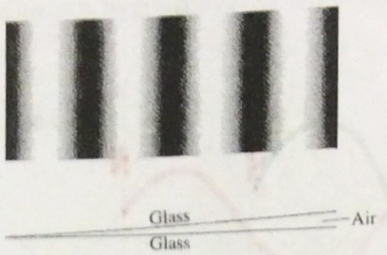
a. Referring to the indices of refraction shown on the figure, indicate at each boundary with a Y (yes) or N (no) whether the reflected wave undergoes a phase change at the boundary.

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. **Hint:** If there's no phase change, the reflected wave retraces the incoming wave. With a phase change, the reflected wave is "upside down" relative to the incoming wave.

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

They both undergo a phase change

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.

Half a wavelength (250 nm); destructive interference is due to a path length difference of $\lambda/2$

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

$4 \times \frac{\lambda}{2} = 2\lambda =$ **1000 nm**

↑ fringes

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.

λ in water is smaller than in air

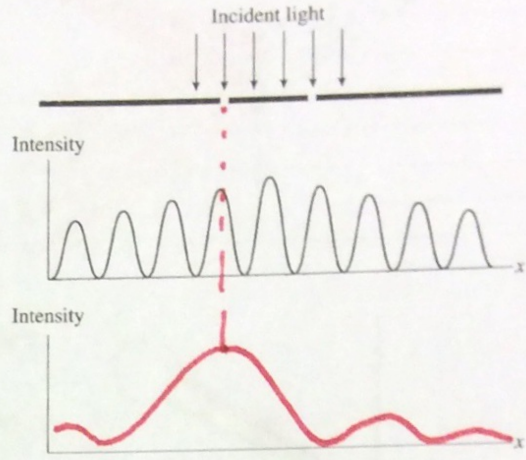
17.5 Single-Slit Diffraction

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 bottom axes 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.

    Single slits have a wide, central peak and the fringes get dim quickly.

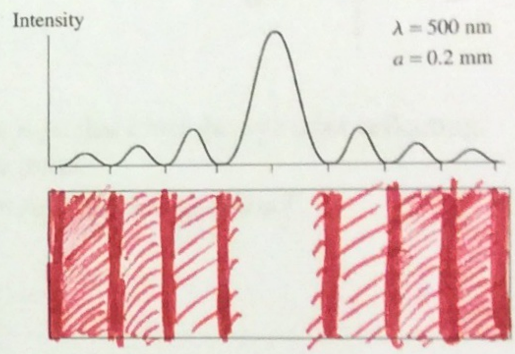


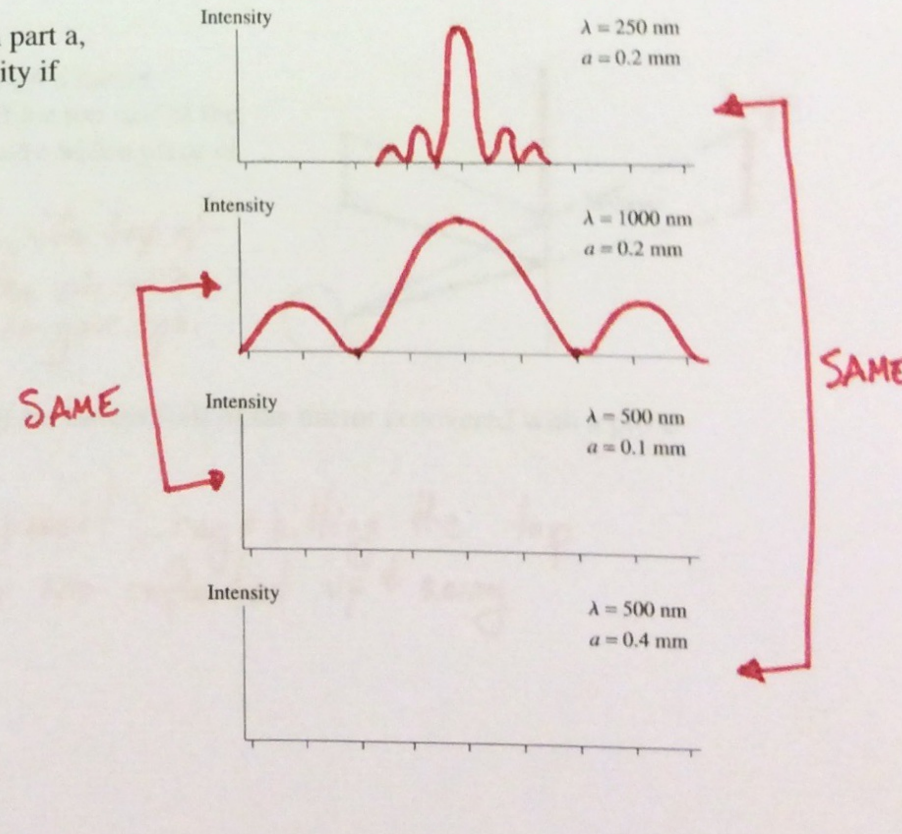
16. The graph shows the light intensity on a screen behind a 0.2-mm-wide slit illuminated by light with a 500 nm wavelength.

    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

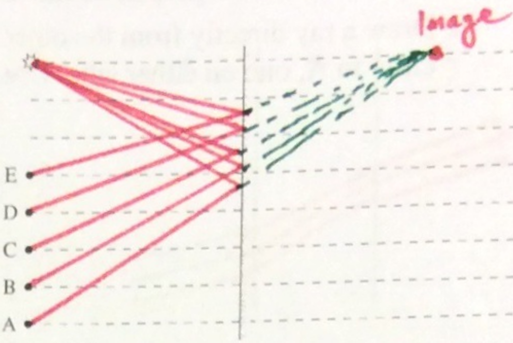
       i. $\lambda = 250$ nm, $a = 0.2$ mm.
       ii. $\lambda = 1000$ nm, $a = 0.2$ mm.
       iii. $\lambda = 500$ nm, $a = 0.1$ mm.
       iv. $\lambda = 500$ nm, $a = 0.4$ mm.





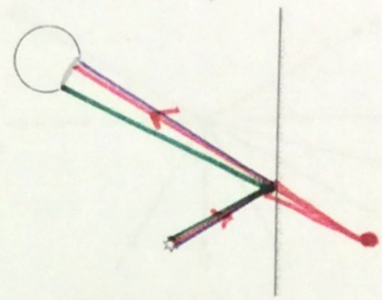
18.2 Reflection

6. a. Draw five rays from the object that pass through points A to E after reflecting from the mirror. Make use of the grid to do this accurately.
   b. Extend the reflected rays behind the mirror.
   c. Show and label the image point.



7. a. Draw *one* ray from the object that enters the eye after reflecting from the mirror.
   b. Is one ray sufficient to tell your eye/brain where the image is located?

No, at least 2 rays are necessary to determine where their intersection would appear to be.

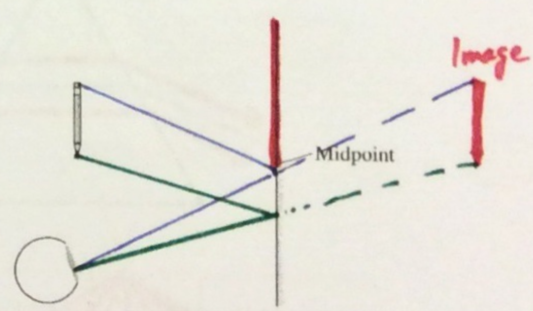


   c. Use a different color pen or pencil to draw two more rays that enter the eye after reflecting. Then use the three rays to locate (and label) the image point.
   d. Do any of the rays that enter the eye actually pass through the image point?

No, it's virtual

8. You are looking at the image of a pencil in a mirror.
   a. What happens to the image you see if the top half of the mirror, down to the midpoint, is covered with a piece of cardboard? Explain.

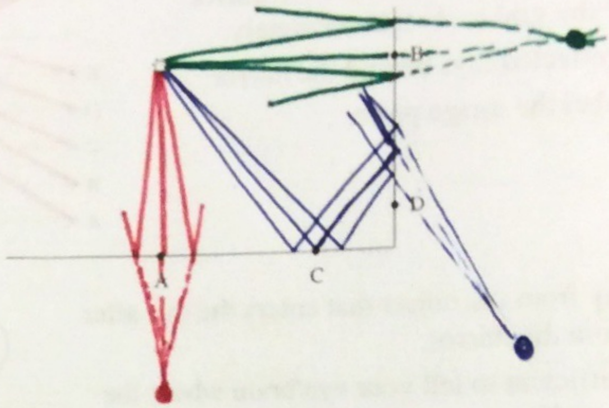
Nothing; even rays from the top of the pencil that hit the mirror's midpoint still reflect to your eye.



   b. What happens to the image you see if the bottom half of the mirror is covered with a piece of cardboard? Explain.

You can't see the pencil; rays hitting the top half of the mirror are reflected up & away from your eye.

9. The two mirrors are perpendicular to each other.
   a. Draw a ray directly from the object to point A. Then draw two rays that strike the mirror *very close* to A, one on either side. Use the reflections of these three rays to locate an image point.

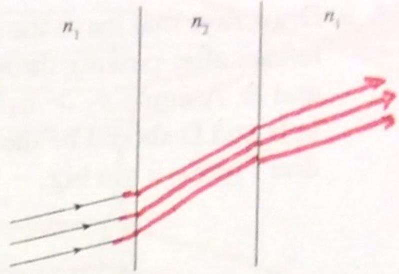


   b. Do the same for points B, C, and D.
   c. How many images are there? Identify them on the sketch above.

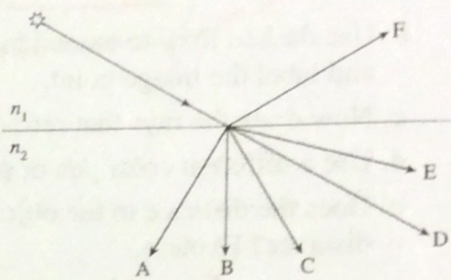
3 images

18.3 Refraction

10. Complete the trajectories of these three rays through material 2 and back into material 1. Assume $n_2 < n_1$.



11. The figure shows six conceivable trajectories of light rays leaving an object. Which, if any, of these trajectories are impossible? For each that is possible, what are the requirements of the index of refraction n_2?



Impossible A, B

Requires $n_2 > n_1$ C

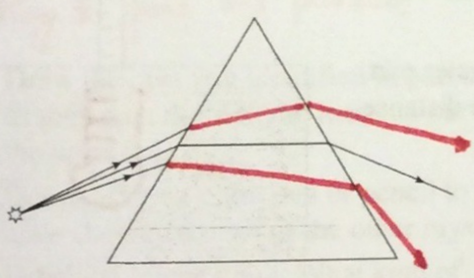
Requires $n_2 = n_1$ D

Requires $n_2 < n_1$ E

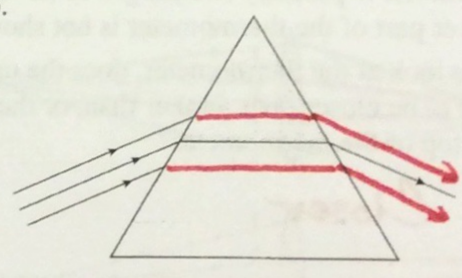
Possible for any n_2 $\neq n_1$ F

12. Complete the ray trajectories through the two prisms shown below.

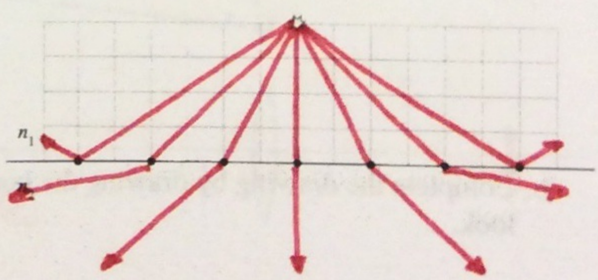
a.



b.

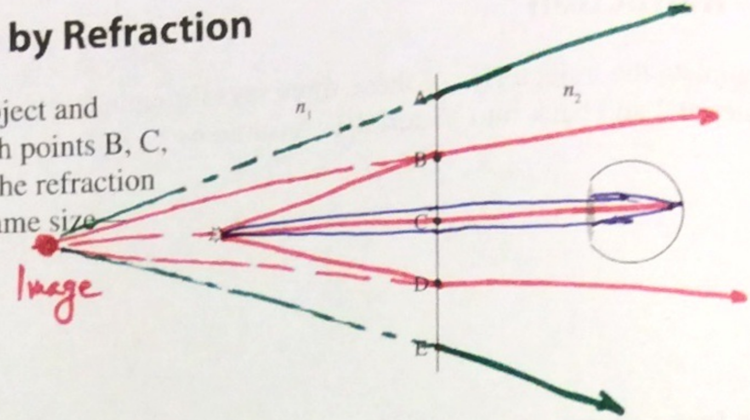


13. Draw the trajectories of seven rays that leave the object heading toward the seven dots on the boundary. Assume $n_2 < n_1$ and $\theta_c = 47°$.



18.4 Image Formation by Refraction

14. a. Draw rays that leave the object and refract after passing through points B, C, and D. Assume $n_2 > n_1$. The refraction at B and D should the same size don't make it too big.



b. Use dashed lines to extend the three refracted rays backward into medium 1. Then locate and label the image point.

c. Now draw the rays that refract at A and E.

d. Use a different color pen or pencil to draw three rays from the object that enter the eye.

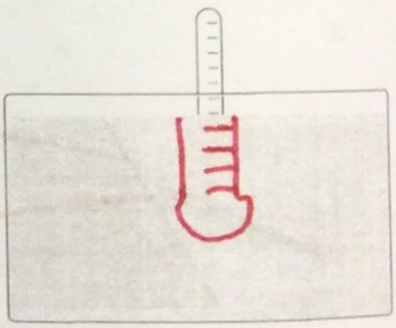
e. Does the distance to the object *appear* to be greater than, less than, or the same as the true distance? Explain.

Greater than; image is behind the object

15. A thermometer is partially submerged in an aquarium. The underwater part of the thermometer is not shown.

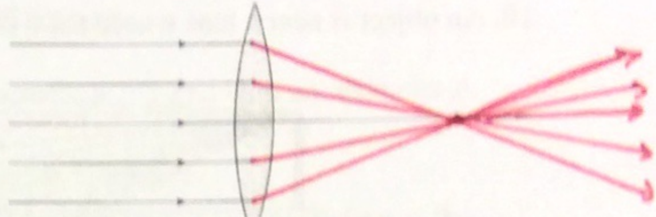
a. As you look at the thermometer, does the underwater part appear to be closer than, farther than, or the same distance as the top of the thermometer?

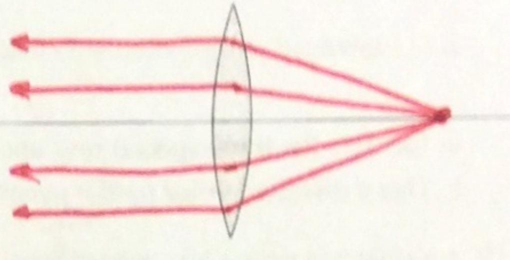
Closer



b. Complete the drawing by drawing the bottom of the thermometer as you think it would look.

18.5 Thin Lenses: Ray Tracing





16. a. Continue these rays through the lens and out the other side.

b. Is the point where the rays converge the same as the focal point of the lens? Or different? Explain.

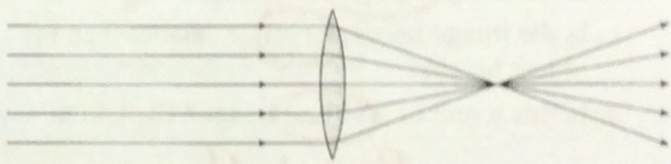
Same; parallel rays pass through the focal point.

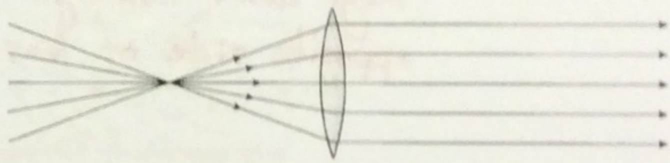
c. Place a point source of light at the place where the rays converged in part b. Draw several rays heading left, toward the lens. Continue the rays through the lens and out the other side.

d. Do these rays converge? If so, where?

No; rays passing through f refract parallel to the axis

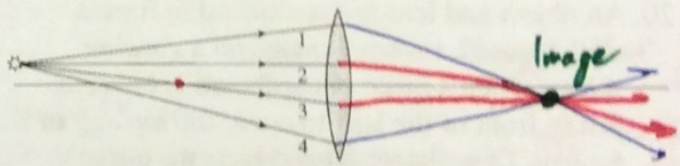
17. The top two figures show test data for a lens. The third figure shows a point source near this lens and four rays heading toward the lens.





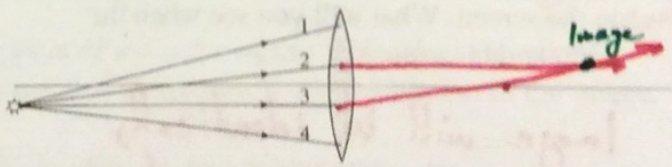
a. For which of these rays do you know, from the test data, its direction after passing through the lens?

Ray 2 goes through f
Ray 3 goes out parallel



Should be to the right a bit — my rays weren't quite straight. :)

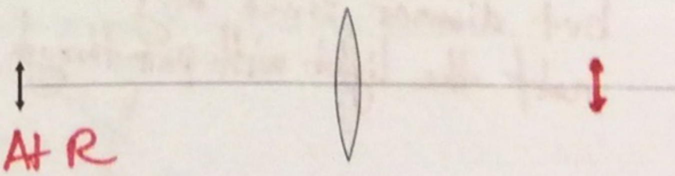
b. Draw the rays you identified in part a as they pass through the lens and out the other side.



c. Use a different color pen or pencil to draw the trajectories of the other rays.

d. Label the image point. What kind of image is this?

Real

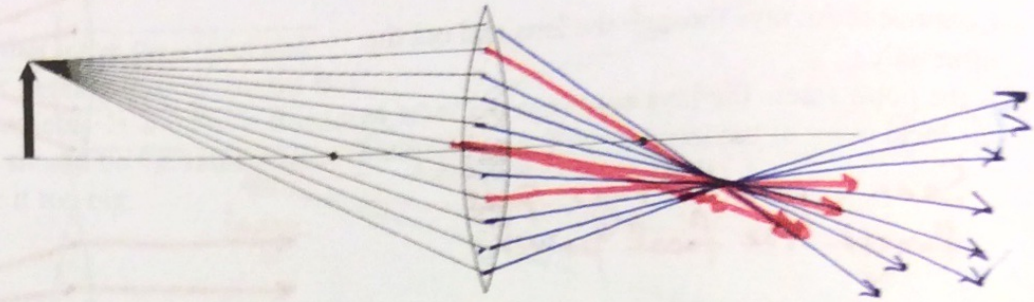


e. The fourth figure shows a second point source. Use ray tracing to locate its image point.

At R

f. The fifth figure shows an extended object. Have you learned enough to locate its image? If so, draw it.

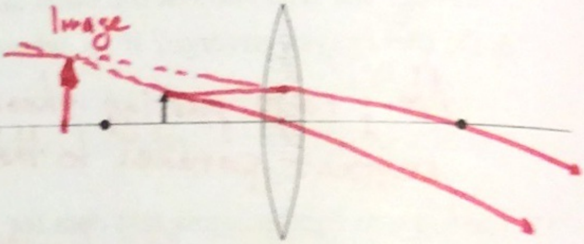
18. An object is near a lens whose focal points are marked with dots.



a. Identify the three special rays and continue them through the lens.

b. Use a different color pen or pencil to draw the trajectories of the other rays.

19. An object is near a lens whose focal points are shown.



a. Use ray tracing to locate the image of this object.

b. Is the image upright or inverted?

c. Is the image height larger or smaller than the object height?

d. Is this a real or a virtual image? Explain how you can tell.

Rays don't converge on opposite side of lens.

20. An object and lens are positioned to form a well-focused, inverted image on a viewing screen. Then a piece of cardboard is lowered just in front of the lens to cover the *top half* of the lens. Describe what happens to the image on the screen. What will you see when the cardboard is in place?

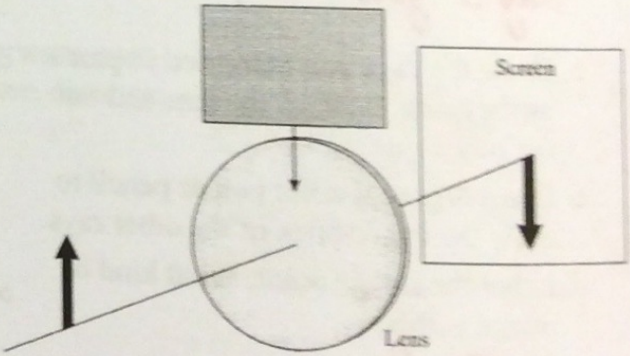
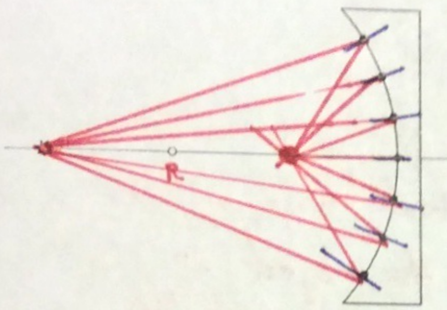


Image will be identical, but dimmer since only half the light will pass through.

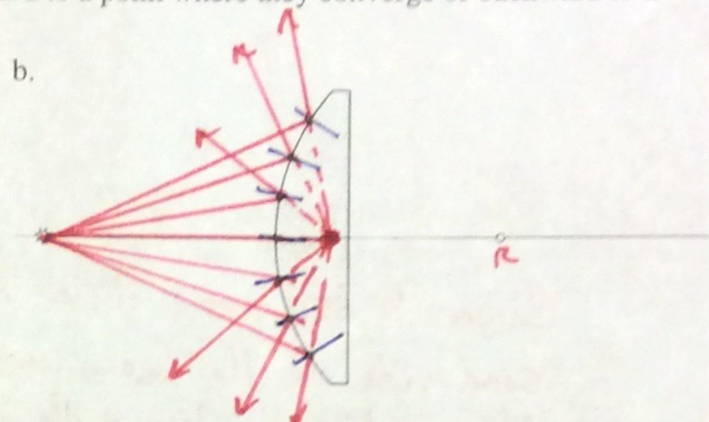
18.6 Image Formation with Spherical Mirrors

21. Two spherical mirrors are shown. The center of each sphere is marked with an open circle. For each:
    i. Draw the normal to the surface at the seven dots on the boundary.
    ii. Draw the trajectories of seven rays that leave the object, strike the mirror surface at the dots, and then reflect, obeying the law of reflection.
    iii. Trace the reflected rays either forward to a point where they converge or backward to a point from which they diverge.

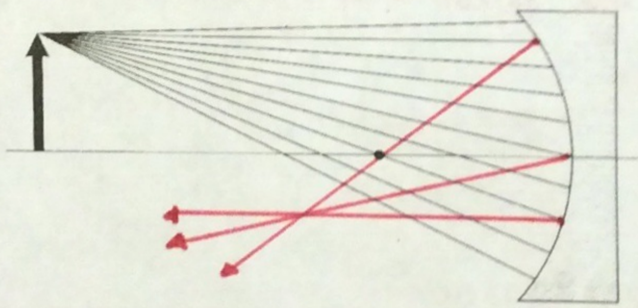
a.



b.



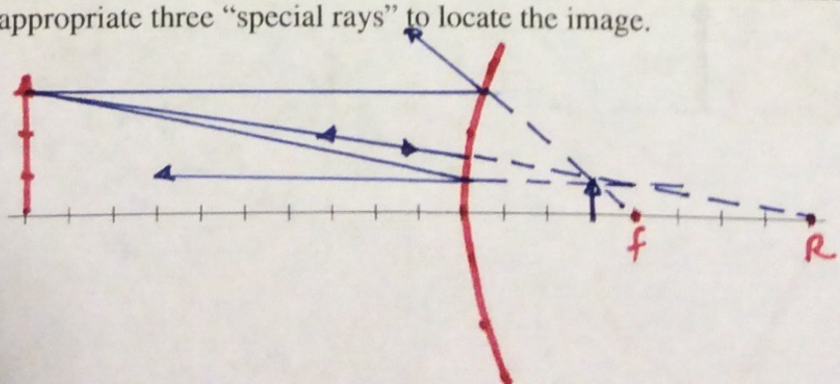
22. An object is placed near a spherical mirror whose focal point is marked.



a. Identify the three special rays and show their reflections.

b. Use a different color pen or pencil to draw the trajectories of the other rays. — All other rays would reflect off to same point of convergence.

23. A 3.0-cm-high object is placed 10.0 cm in front of a convex mirror with a focal length of −4.0 cm. Use ray tracing to determine the location of the image, the orientation of the image, and the height of the image.
    - Locate the mirror on the optical axis shown. Show its focal point with a dot.
    - Represent the object with an upright arrow at distance 10.0 cm from the mirror.
    - Draw the appropriate three "special rays" to locate the image.



24. A converging lens forms a real image. Suppose the object is moved farther from the lens. Does the image get closer to or farther from the lens? Explain.

Closer to the lens; the further the object is, the closer the image gets to the focal point.

25. A converging lens forms a virtual image. Suppose the object is moved closer to the lens. Does the image get closer to or farther from the lens? Explain.

Closer to the lens; it's a virtual image on the same side of the lens — move the object so it's touching the lens & the image will look the same as the object & up against the lens.

18.7 The Thin-Lens Equation

26. The figure is a ray diagram of image formation by a mirror. In this situation,

do Is s positive, negative, or zero? ____________

di Is s' positive, negative, or zero? ____________

Is f positive, negative, or zero? ____________

Is m positive, negative, or zero? ____________