Tutorial 4 Problems

Tutorials varied this week since it was midterm week. If workbook problems were done, they were a selection of the following problems:

Workbook (2nd edition)
Chapter 23:
22, 27, 28, 30

Chapter 24:
6, 33

Chapter 25:
2, 3

23.5 Color and Dispersion

18. A beam of white light from a flashlight passes through a red piece of plastic.

a. What is the color of the light that emerges from the plastic?

Red

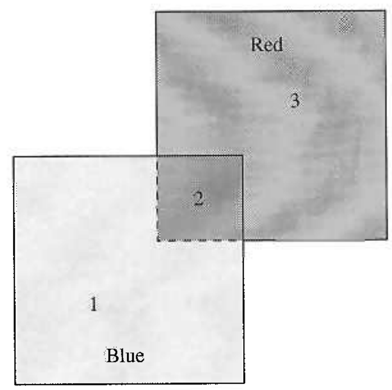
b. Is the emerging light as intense as, more intense than, or less intense than the white light?

Less intense

c. The light then passes through a blue piece of plastic. Describe the color and intensity of the light that emerges.

No light emerges.

19. Suppose you looked at the sky on a clear day through pieces of red and blue plastic oriented as shown. Describe the color and brightness of the light coming through sections 1, 2, and 3.

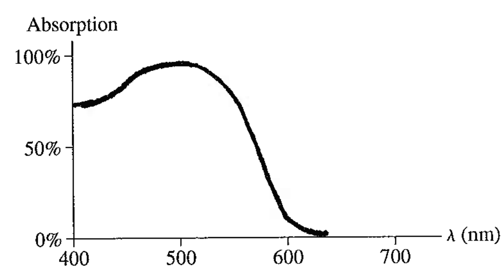


Section 1: Blue; All other colors are absorbed. (lessening the brightness)

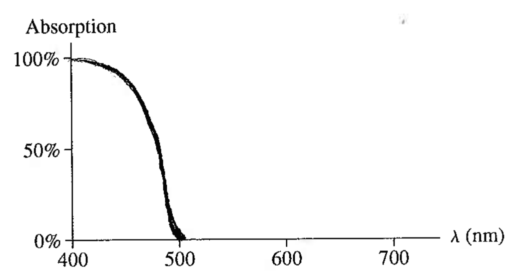
Section 2: Black - light essentially does not get through

Section 3: Red. All other colors are absorbed. (lessening the brightness)

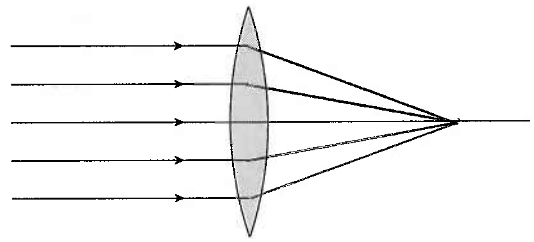
20. Sketch a plausible absorption spectrum for a patch of bright red paint.

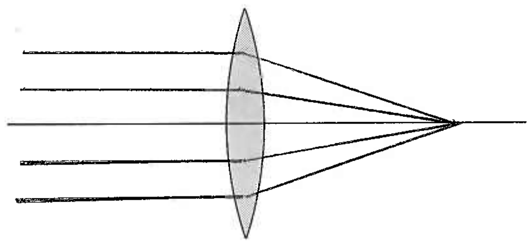


21. Sketch a plausible absorption spectrum for a piece of green plastic.



23.6 Thin Lenses: Ray Tracing





22. a. Continue these rays through the lens and out the right side.

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

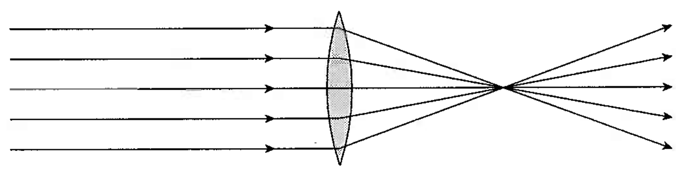
    Yes, it is the focal point where parallel incident rays converge.

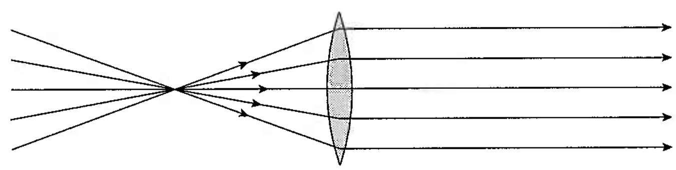
    c. Place a point source of light at the place where the rays converged in part b. Draw several rays heading left, toward the lens. Continue the rays through the lens and out the left side.

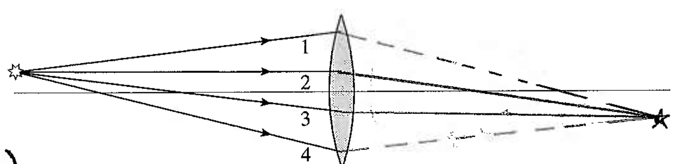
    d. Do these rays converge? If so, where?

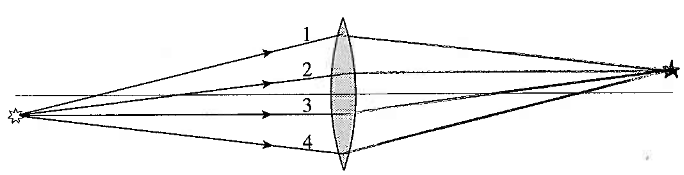
    No, the rays all emerge parallel to the optical axis.

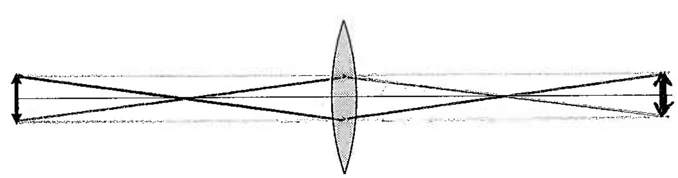
23. The top two figures show test data for a lens. The third figure shows a point source near this lens and four rays heading toward the lens.











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

   Ray 2 passes through the focal point. Ray 3 emerges parallel to the optical axis.

   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. (— — —)

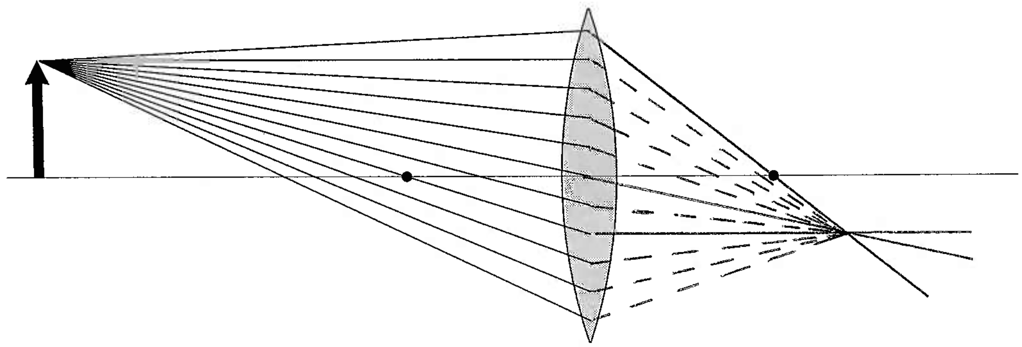
   d. Label the image point. What kind of image is this?

   Real, Inverted

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

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

24. 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. (— — —)

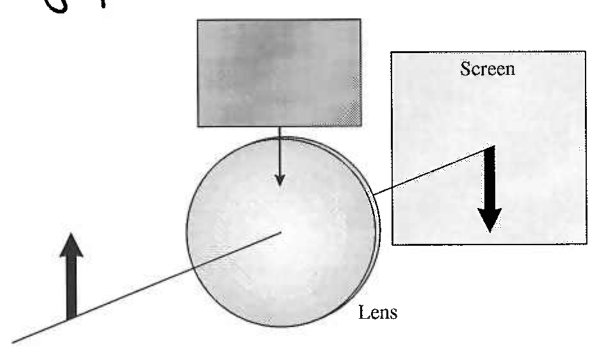
25. a. Consider *one* point on an object near a lens. What is the minimum number of rays needed to locate its image point?

2 rays cross at the image point.

b. For each point on the object, how many rays from this point actually strike the lens and refract to the image point?

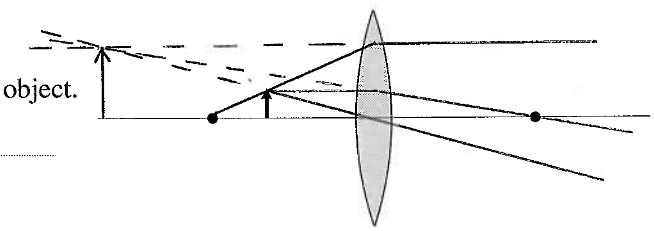
An infinite number! All those that strike the lens from the object point will converge to the image point.

26. 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?



You will still see the entire image, but it will be dimmer as less light passes through the lens.

27. 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?

upright

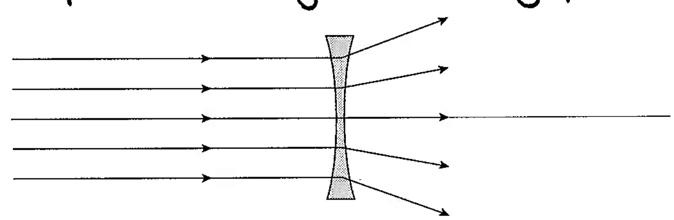
c. Is the image height larger or smaller than the object height?

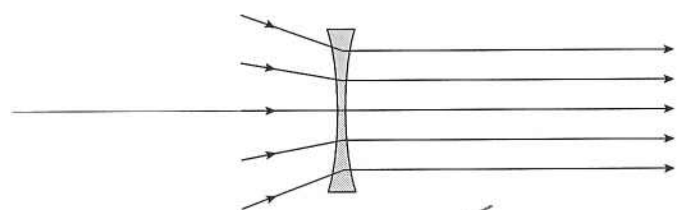
larger

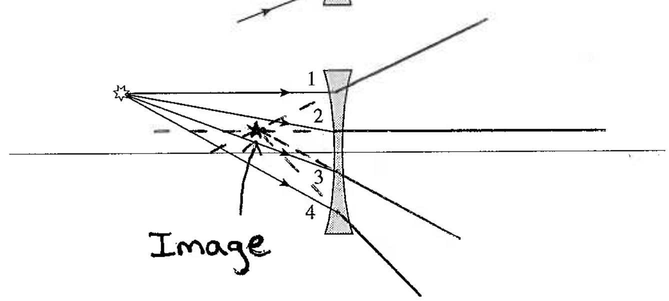
d. Is this a real or a virtual image? Explain how you can tell.

Virtual, the rays do not converge to the image point, but appear to have come from there as they diverge from the lens. The actual light does not pass through the image point.

28. 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?

Rays 1 and 2.

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.

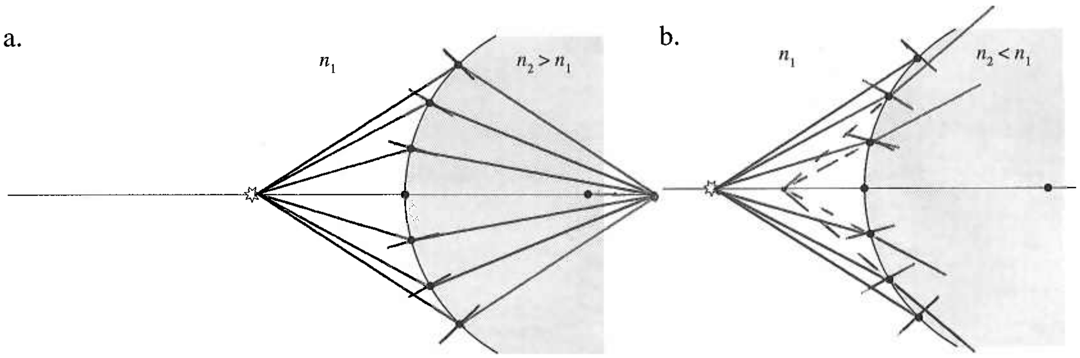
d. Find and label the image point. What kind of image is this?

Virtual, upright

23.7 Thin Lenses: Refraction Theory

29. Materials 1 and 2 are separated by a spherical surface. For each part:
    i. Draw the normal to the surface at the seven dots on the boundary.
    ii. Draw the trajectories of seven rays from the object that pass through the seven dots.
    iii. Trace the refracted rays either forward to a point where they converge or backward to a point from which they appear to diverge.

a. b.



30. A converging lens forms a real image. Suppose the object is moved farther from the lens. Does the image move toward or away from the lens? Explain.

The image moves closer to the lens, but never closer than the focal point. $\frac{1}{d_o} + \frac{1}{d_i}$ = constant so increasing d_o must decrease d_i.

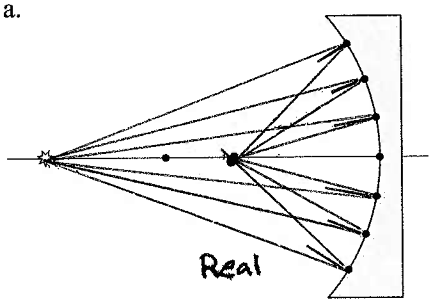
31. A converging lens forms a virtual image. Suppose the object is moved closer to the lens. Does the image move toward or away from the lens? Explain.

The image moves toward the lens. Decreasing d_o causes d_i to increase but d_i is negative, so increasing d_i makes it a smaller negative number.

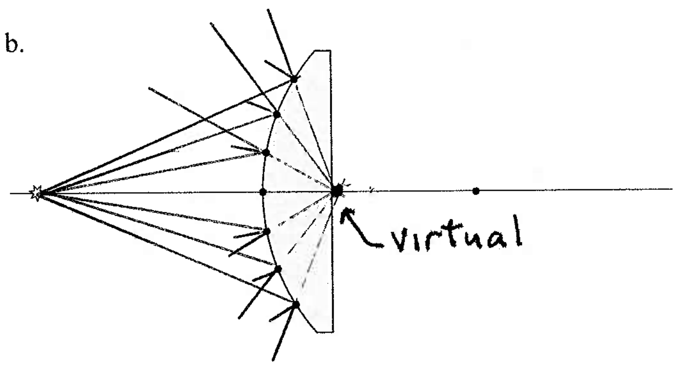
23.8 Image Formation with Spherical Mirrors

32. Two spherical mirrors are shown. The center of each is marked. For each:
    i. Draw the normal to the surface at the seven dots on the boundary.
    ii. Draw the trajectories of seven rays that 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.

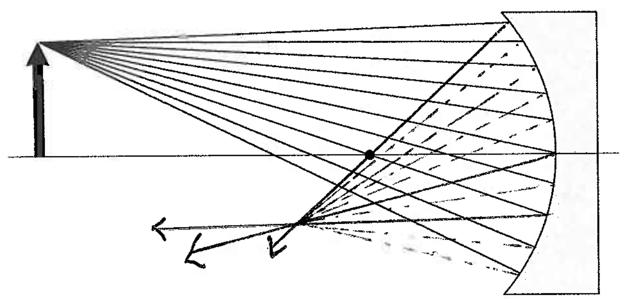
a.



b.



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



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

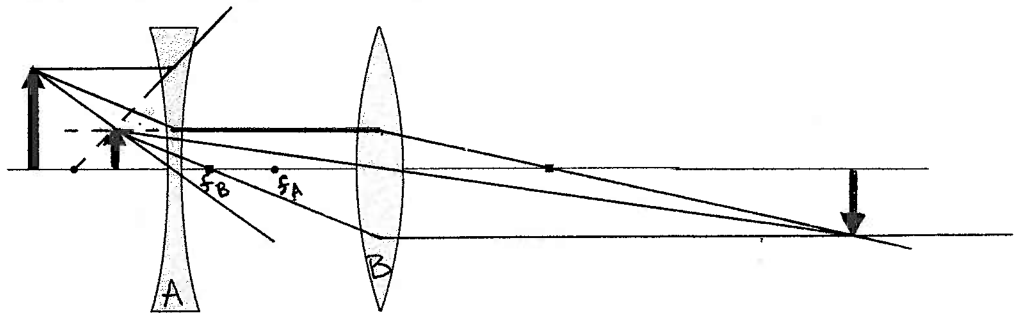
b. Use a different color pen or pencil to draw the trajectories of the other rays.

24 Optical Instruments

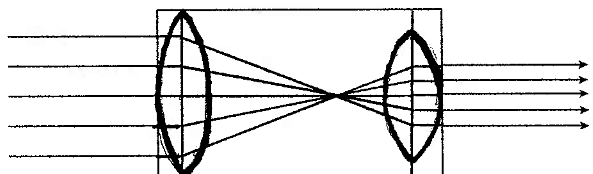
24.1 Lenses in Combination

24.2 The Camera

1. Use ray tracing to locate the final image of the following two-lens system.

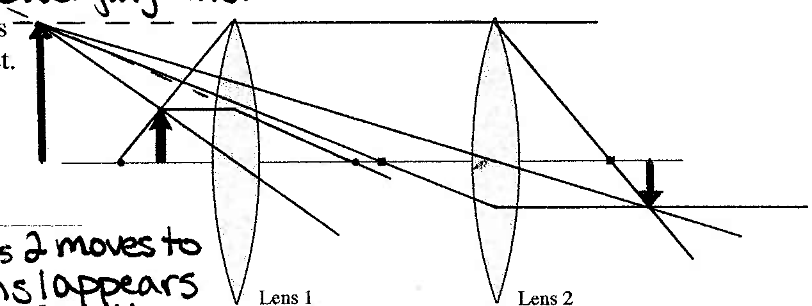


2. Can you tell what's inside the box? Draw one possible combination of lenses inside the box, then show the rays passing through the box.



There are two simple solutions: two converging lenses or one converging and one diverging lens.

3. Two converging lenses, whose focal points are marked, are placed in front of an object.



   a. Suppose lens 2 is moved a little to the left. Is the final image of this two-lens system now closer to or farther from lens 2? Explain.

Farther from lens 2. As lens 2 moves to the left, the image from lens 1 appears closer to lens 2, leading to final image from lens 2 that is further away. (The final image, however, moves to the right by an amount less than lens 2 moves to the left.)

   b. With lens 2 in its original position, suppose lens 1 is moved a little to the left. Is the final image of this two-lens system now closer to or farther from lens 2? Explain.

Farther from lens 2. As lens 1 moves slightly to the left the image that it produces moves by a greater amount to the right. Thus the object for lens 2 is closer to lens 2 (which has not moved) and so its final image must be further to the right because the object and image distances add as reciprocals.

4. A photographer focuses his camera on an object. Suppose the object moves closer to the camera. To refocus, should the camera lens move closer to or farther from the detector? Explain.

As the object moves closer to the camera lens, the image moves away from the lens. To detect the image the lens needs to be moved away to allow for the larger image distance.

5. The aperture of a camera lens has its diameter halved.

a. By what factor does the *f*-number change?

The f-number increases by a factor of 2.
f-number = f/D

b. By what factor does the focal length change?

The focal length does not change.

c. By what factor does the exposure time change?

To achieve the same total light energy on the film, the exposure time must increase by a factor of 4 because the light intensity changes as the diameter squared.

24.3 Vision

6. Two lost students wish to start a fire to keep warm while they wait to be rescued. One student is hyperopic, the other myopic. Which, if either, could use his glasses to focus the sun's rays to an intense bright point of light? Explain.

The hyperoptic (far-sighted) student uses converging lenses to correct his vision for nearby objects, so his lenses could also focus light from a distant source. The myopic student's lenses are diverging.

7. Suppose you wanted special glasses designed to let you see underwater, without a face mask. Should the glasses use a converging or diverging lens? Explain.

Because of the larger refractive index of water compared to air, you would need a strongly converging lens to assist your eyes in compensation for the small refractive index difference between water and the lens of your eye.

24.4 Optical Systems That Magnify

8. a. To double the angular magnification of a magnifier, do you want a lens with twice the focal length or half the focal length? Explain.

Half the focal length.

$$m = \frac{25\text{cm}}{f}$$

b. Does doubling the angular magnification also double the lateral magnification? Explain.

Generally no. Angular magnification depends only on f, but lateral magnification depends upon S and S' (or S and f).

9. For a telescope, increasing the focal length of the objective increases the overall magnification. For a microscope, increasing the focal length of the objective decreases the overall magnification. Why are they different?

For the microscope, the image distance is fixed by the tube length and the object is beyond the object focal length so a larger objective focal length leads to a larger object distance and smaller magnification. For a telescope, the object is at infinity and the intermediate image is at the objective focal length, so a larger focal length gives greater magnification.

24.5 The Resolution of Optical Instruments

10. A diffraction-limited lens can focus light to a 10-μm-diameter spot on a screen. Do the following actions make the spot diameter larger, smaller, or leave it unchanged?

   a. Decreasing the wavelength of the light: Smaller

   b. Decreasing the lens diameter: larger

   c. Decreasing the lens focal length: larger (out of focus)

   d. Decreasing the lens-to-screen distance: larger (out of focus)

11. An astronomer is trying to observe two distant stars. The stars are marginally resolved when she looks at them through a filter that passes green light near 550 nm. Which of the following actions would improve the resolution? Assume that the resolution is not limited by the atmosphere.

   a. Changing the filter to a different wavelength? If so, should she use a shorter or a longer wavelength?

   She would obtain better resolution with a shorter wavelength. $\theta_1 = \frac{1.22\lambda}{D}$

   b. Using a telescope with an objective lens of the same diameter but a different focal length? If so, should she select a shorter or a longer focal length?

   It will not make a difference.

   c. Using a telescope with an objective lens of the same focal length but a different diameter? If so, should she select a larger or a smaller diameter?

   Larger diameter leads to better resolution.

   d. Using an eyepiece with a different magnification? If so, should she select an eyepiece with more or less magnification?

   It will not make a difference. Magnification is not a factor in resolution.

25 Modern Optics and Matter Waves

25.1 Spectroscopy: Unlocking the Structure of Atoms

25.2 X-Ray Diffraction

25.3 Photons

1. The figure shows the spectrum of a gas discharge tube.

What color would the discharge appear to your eye? Explain.

Blue, because most of the emitted wavelengths fall in the 430-510 nm range.

2. The first-order x-ray diffraction of monochromatic x rays from a crystal occurs at angle θ_1. The crystal is then compressed, causing a slight reduction in its volume. Does θ_1 increase, decrease, or stay the same? Explain.

θ_1 decreases. As the crystal is compressed, the spacing 'd' between planes of atoms decreases. The Bragg condition is $m\lambda = 2d\cos\theta_m$ so as d decreases, $\cos\theta_m$ must increase. But $\cos\theta$ increases as θ decreases.

3. Three laser beams have wavelengths $\lambda_1 = 400$ nm, $\lambda_2 = 600$ nm, and $\lambda_3 = 800$ nm. The power of each laser beam is 1 W.

a. Rank in order, from largest to smallest, the photon energies E_1, E_2, and E_3 in these three laser beams.

Order: $E_1 > E_2 > E_3$

Explanation:

The energy per photon depends only on the frequency so $E = hf = hc/\lambda$. The smaller wavelengths correspond to higher frequencies.

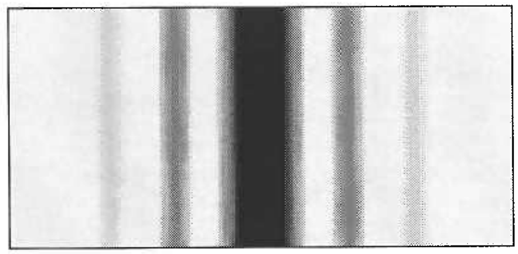
b. Rank in order, from largest to smallest, the number of photons per second N_1, N_2, and N_3 delivered by the three laser beams.

Order: $N_3 > N_2 > N_1$

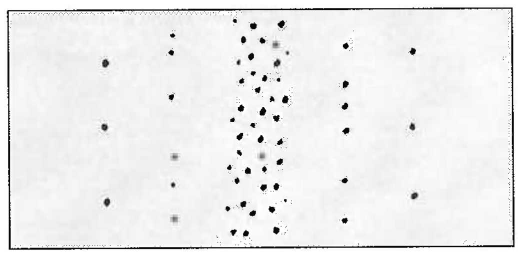
Explanation:

Because the powers are equal, there must be more photons when the energy per photon is less.

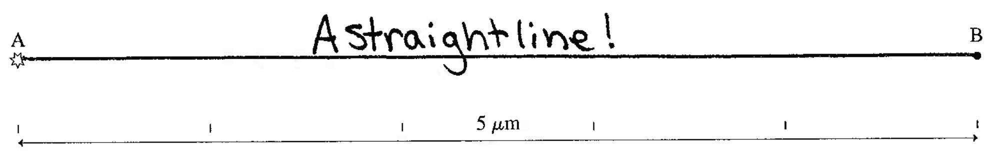
4. The top figure is the *negative* of the photograph of a single-slit diffraction pattern. That is, the darkest areas in the figure were the brightest areas on the screen. This photo was made with an extremely large number of photons.



Suppose the slit is illuminated by an extremely weak light source, so weak that only 1 photon passes through the slit every second. Data are collected for 60 seconds. Draw 60 dots on the empty screen to show how you think the screen will look after 60 photons have been detected.

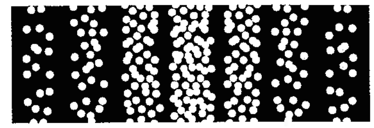


5. A light source at point A emits light with a wavelength of 1.0 μm. One photon of light is detected at point B, 5.0 μm away from A. On the figure, draw the trajectory that the photon follows from A to B.



25.4 Matter Waves

6. The figure is a simulation of the electrons detected behind a very narrow double slit. Each bright dot represents one electron. How will this pattern change if the following experimental conditions are changed? Possible changes you should consider include the number of dots and the spacing, width, and positions of the fringes.



   a. The electron-beam intensity is increased.

   The number of dots will increase, but will still appear in bands of the same width.

   b. The electron speed is reduced.

   When the speed is reduced, the wavelength increases leading to wider, more spread-out fringes with the same number of dots in each.

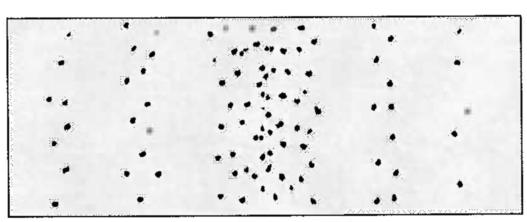
   c. The electrons are replaced by positrons with the same speed. Positrons are antimatter particles that are identical to electrons except that they have a positive charge.

   The fringe pattern is unchanged.

   d. One slit is closed.

   The pattern becomes a single slit diffraction pattern. The two-slit interference pattern is eliminated.

7. Very slow neutrons pass through a single, very narrow slit. Use 50 or 60 dots to show how the neutron intensity will appear on a neutron-detector screen behind the slit.



8. To have the best resolution, should an electron microscope use very fast electrons or very slow electrons? Explain.

Fast electrons will have a shorter wavelength leading to less diffraction spreading and better resolution.

25.5 Energy Is Quantized

9. a. For the first few allowed energies of a particle in a box to be large, should the box be very big or very small? Explain.

The box should be very small. $E_n = n^2 \frac{h^2}{8mL^2}$, where L is the length of the box. For a given n, small L leads to large energy.

b. Which is likely to have larger values for the first few allowed energies: an atom in a molecule, an electron in an atom, or a proton in a nucleus? Explain.

A proton in a nucleus, then an electron in an atom, and finally, an atom in a molecule. As the size scale increases, the allowed energies become smaller. Though the proton's mass is 1800x greater than the electron's, the nuclear length scale is much smaller and a more significant factor (L^2).

10. The smallest allowed energy of a particle in a box is 2.0×10^{-20} J. What will be the smallest allowed energy if the length of the box is doubled and the particle's mass is halved?

The smallest allowed energy is halved. 1.0×10^{-20} J

$$E = \frac{h^2}{8m_0L_0^2} \qquad E' = \frac{h^2}{8\left(\frac{m_0}{2}\right)(2L_0)^2} = \frac{E}{2}$$