

Practice Problems

16.1 Illumination

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1. A lamp is moved from 30 cm to 90 cm above the pages of a book. Compare the illumination on the book before and after the lamp is moved.

$$\frac{E_{\text{after}}}{E_{\text{before}}} = \frac{\left(\frac{P}{4\pi d_{\text{after}}^2}\right)}{\left(\frac{P}{4\pi d_{\text{before}}^2}\right)} = \frac{d_{\text{before}}^2}{d_{\text{after}}^2}$$

$$= \frac{(30 \text{ cm})^2}{(90 \text{ cm})^2} = \frac{1}{9}; \text{ therefore, after}$$

the lamp is moved the illumination is one-ninth of the original illumination.

2. What is the illumination on a surface that is 3.0 m below a 150-W incandescent lamp that emits a luminous flux of 2275 lm?

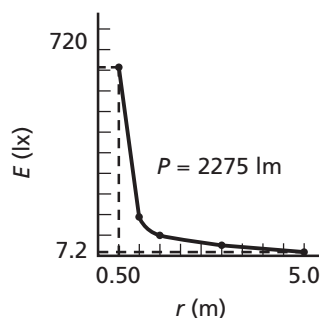
$$E = \frac{P}{4\pi d^2} = \frac{2275 \text{ lm}}{4\pi(3.0 \text{ m})^2} = 2.0 \times 10^1 \text{ lx}$$

3. Draw a graph of the illuminance produced by a 150-W incandescent lamp between 0.50 m and 5.0 m.

Illuminance of a 150-W bulb

$$P = 2275, d = 0.50, 0.75, \dots, 5.0$$

$$E(d) = \frac{P}{4\pi d^2}$$



4. A 64-cd point source of light is 3.0 m above the surface of a desk. What is the illumination on the desk's surface in lux?

$$P = 4\pi(64 \text{ cd}) = 256\pi \text{ lm}$$

$$\text{so } E = \frac{P}{4\pi d^2} = \frac{256\pi \text{ lm}}{4\pi(3.0 \text{ m})^2} = 7.1 \text{ lx}$$

5. A public school law requires a minimum illuminance of 160 lx at the surface of each student's desk. An architect's specifications call for classroom lights to be located 2.0 m above the desks. What is the minimum luminous flux that the lights must produce?

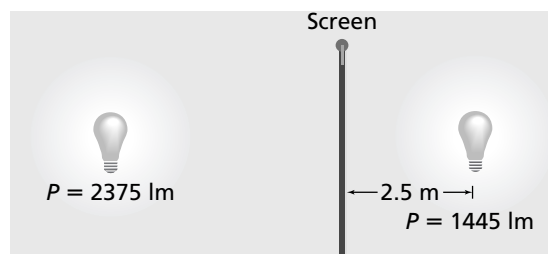
$$E = \frac{P}{4\pi d^2}$$

$$P = 4\pi E d^2$$

$$= 4\pi(160 \text{ lm/m}^2)(2.0 \text{ m})^2$$

$$= 8.0 \times 10^3 \text{ lm}$$

6. A screen is placed between two lamps so that they illuminate the screen equally, as shown in **Figure 16-7**. The first lamp emits a luminous flux of 1445 lm and is 2.5 m from the screen. What is the distance of the second lamp from the screen if the luminous flux is 2375 lm?



■ **Figure 16-7** (Not to scale)

$$E_1 = E_2$$

$$\text{So } \frac{P_1}{d_1^2} = \frac{P_2}{d_2^2}$$

$$\text{or } d_2 = d_1 \sqrt{\frac{P_2}{P_1}}$$

$$= (2.5 \text{ m}) \sqrt{\frac{2375}{1445}}$$

$$= 3.2 \text{ m}$$

Section Review

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- 7. Use of Material Light Properties** Why might you choose a window shade that is translucent? Opaque?

You would use a translucent window shade to keep people from looking in or out, while still allowing daylight in. You would use an opaque window shade to keep the daylight out.

- 8. Illuminance** Does one lightbulb provide more illuminance than two identical lightbulbs at twice the distance? Explain.

One lightbulb provides an illuminance that is four times larger than two of the same lightbulb at twice the distance, because $E \propto \frac{P}{d^2}$.

- 9. Luminous Intensity** Two lamps illuminate a screen equally—lamp A at 5.0 m, lamp B at 3.0 m. If lamp A is rated 75 cd, what is lamp B rated?

$$E = \frac{I}{d^2}$$

Since the illumination is equal,

$$E_1 = E_2$$

$$\text{So } \frac{I_1}{d_1^2} = \frac{I_2}{d_2^2}$$

$$\text{or } I_2 = \frac{I_1 d_2^2}{d_1^2}$$

$$= \frac{(75 \text{ cd})(3.0 \text{ m})^2}{(5.0 \text{ m})^2} = 27 \text{ cd}$$

- 10. Distance of a Light Source** Suppose that a lightbulb illuminating your desk provides only half the illuminance that it should. If it is currently 1.0 m away, how far should it be to provide the correct illuminance?

Illumination depends on $1/d^2$,

$$\text{so } \frac{E_i}{E_f} = \frac{d_f^2}{d_i^2} = \frac{1}{2}$$

$$\frac{d_f^2}{(1.0 \text{ m})^2} = \frac{1}{2}$$

$$d_f = \sqrt{\frac{1}{2}} \text{ m} \\ = 0.71 \text{ m}$$

- 11. Distance of Light Travel** How far does light travel in the time it takes sound to travel 1 cm in air at 20°C?

Sound velocity is 343 m/s, so sound takes 3×10^{-5} s to travel 1 cm. In that time, light travels 9 km.

$$v_{\text{sound}} = 343 \text{ m/s}$$

$$t_{\text{sound}} = \frac{d}{v_{\text{sound}}} \\ = \frac{1 \times 10^{-2} \text{ m}}{343 \text{ m/s}}$$

$$= 3 \times 10^{-5} \text{ s}$$

$$v_{\text{light}} = 3.00 \times 10^8 \text{ m/s}$$

$$d_{\text{light}} = v_{\text{light}} t_{\text{sound}}$$

$$= (3.00 \times 10^8 \text{ m/s})(3 \times 10^{-5} \text{ s})$$

$$= 9 \times 10^3 \text{ m} = 9 \text{ km}$$

- 12. Distance of Light Travel** The distance to the Moon can be found with the help of mirrors left on the Moon by astronauts. A pulse of light is sent to the Moon and returns to Earth in 2.562 s. Using the measured value of the speed of light to the same precision, calculate the distance from Earth to the Moon.

$$d = ct$$

$$= (299,800,000 \text{ m/s})\left(\frac{1}{2}\right)(2.562 \text{ s})$$

$$= 3.840 \times 10^8 \text{ m}$$

- 13. Critical Thinking** Use the correct time taken for light to cross Earth's orbit, 16.5 min, and the diameter of Earth's orbit, 2.98×10^{11} m, to calculate the speed of light using Roemer's method. Does this method appear to be accurate? Why or why not?

$$v = \frac{d}{t} = \frac{3.0 \times 10^{11}}{(16 \text{ min})(60 \text{ s/min})}$$

$$= 3.1 \times 10^8 \text{ m/s}$$

Practice Problems

16.2 The Wave Nature of Light

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14. What is the frequency of oxygen's spectral line if its wavelength is 513 nm?

Use $\lambda = \frac{c}{f}$ and solve for f .

$$\begin{aligned} f &= \frac{c}{\lambda} \\ &= \frac{3.00 \times 10^8 \text{ m/s}}{5.13 \times 10^{-7} \text{ m}} \\ &= 5.85 \times 10^{14} \text{ Hz} \end{aligned}$$

15. A hydrogen atom in a galaxy moving with a speed of 6.55×10^6 m/s away from Earth emits light with a frequency of 6.16×10^{14} Hz. What frequency of light from that hydrogen atom would be observed by an astronomer on Earth?

The relative speed along the axis is much less than the speed of light. Thus, you can use the observed light frequency equation. Because the astronomer and the galaxy are moving away from each other, use the negative form of the observed light frequency equation.

$$\begin{aligned} f_{\text{obs}} &= f \left(1 - \frac{v}{c} \right) \\ &= (6.16 \times 10^{14} \text{ Hz}) \left(1 - \frac{6.55 \times 10^6 \text{ m/s}}{3.00 \times 10^8 \text{ m/s}} \right) \\ &= 6.03 \times 10^{14} \text{ Hz} \end{aligned}$$

16. A hydrogen atom in a galaxy moving with a speed of 6.55×10^{16} m/s away from Earth emits light with a wavelength of 4.86×10^{-7} m. What wavelength would be observed on Earth from that hydrogen atom?

The relative speed along the axis is much less than the speed of light. Thus, you can use the observed Doppler shift equation. Because the astronomer and the galaxy are moving away from each other, use the positive form of the Doppler shift equation.

$$(\lambda_{\text{obs}} - \lambda) = + \frac{v}{c} \lambda$$

$$\lambda_{\text{obs}} = \lambda \left(1 + \frac{v}{c} \right)$$

$$\begin{aligned} &= (4.86 \times 10^{-7} \text{ m}) \left(1 + \frac{6.55 \times 10^6}{3.00 \times 10^8} \right) \\ &= 4.97 \times 10^{-7} \text{ m} \end{aligned}$$

17. An astronomer is looking at the spectrum of a galaxy and finds that it has an oxygen spectral line of 525 nm, while the laboratory value is measured at 513 nm. Calculate how fast the galaxy would be moving relative to Earth. Explain whether the galaxy is moving toward or away from Earth and how you know.

Assume that the relative speed along the axis is much less than the speed of light. Thus, you can use the Doppler shift equation.

$$(\lambda_{\text{obs}} - \lambda) = \pm \frac{v}{c} \lambda$$

The observed (apparent) wavelength appears to be longer than the known (actual) wavelength of the oxygen spectral line. This means that the astronomer and the galaxy are moving away from each other. So use the positive form of the Doppler shift equation.

$$(\lambda_{\text{obs}} - \lambda) = + \frac{v}{c} \lambda$$

Solve for the unknown variable.

$$\begin{aligned} v &= c \frac{(\lambda_{\text{obs}} - \lambda)}{\lambda} \\ &= (3.00 \times 10^8 \text{ m/s}) \left(\frac{525 \text{ nm} - 513 \text{ nm}}{513 \text{ nm}} \right) \\ &= 7.02 \times 10^6 \text{ m/s} \end{aligned}$$

Section Review

16.2 The Wave Nature of Light pages 439–447

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- 18. Addition of Light Colors** What color of light must be combined with blue light to obtain white light?
yellow (a mixture of the other two primaries, red and green)
- 19. Combination of Pigments** What primary pigment colors must be mixed to produce red? Explain how red results using color subtraction for pigment colors.
Yellow and magenta pigments are used to produce red. Yellow pigment subtracts blue and magenta pigment subtracts green, neither subtracts red so the mixture would reflect red.
- 20. Light and Pigment Interaction** What color will a yellow banana appear to be when illuminated by each of the following?
- white light
yellow
 - green and red light
yellow
 - blue light
black
- 21. Wave Properties of Light** The speed of red light is slower in air and water than in a vacuum. The frequency, however, does not change when red light enters water. Does the wavelength change? If so, how?
Yes, because $v = \lambda f$ and $\lambda = v/f$, when v decreases, so does λ .

- 22. Polarization** Describe a simple experiment that you could do to determine whether sunglasses in a store are polarizing.

See if the glasses reduce glare from the reflective surfaces, such as windows or roadways. Polarization of light allows photographers to photograph objects while eliminating glare.

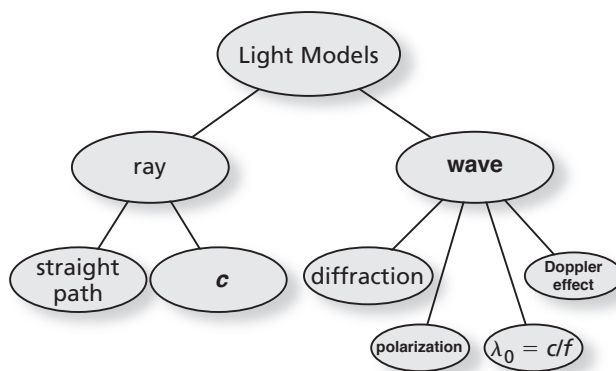
- 23. Critical Thinking** Astronomers have determined that Andromeda, a neighboring galaxy to our own galaxy, the Milky Way, is moving toward the Milky Way. Explain how they determined this. Can you think of a possible reason why Andromeda is moving toward our galaxy?

The spectral lines of the emissions of known atoms are blue-shifted in the light we see coming from Andromeda. Andromeda would be moving toward us due to gravitational attraction. This gravitational attraction could be due to the mass of the Milky Way or other objects located near the Milky Way.

Chapter Assessment Concept Mapping

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- 24.** Complete the following concept map using the following terms: *wave*, *c*, *Doppler effect*, *polarization*.



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Mastering Concepts

page 452

25. Sound does not travel through a vacuum. How do we know that light does? (16.1)
Light comes through the vacuum of space from the Sun.
26. Distinguish between a luminous source and an illuminated source. (16.1)
A luminous body emits light. An illuminated body is one on which light falls and is reflected.
27. Look carefully at an ordinary, frosted, incandescent bulb. Is it a luminous or an illuminated source? (16.1)
It is mainly illuminated. The filament is luminous; the frosted glass is illuminated. You barely can see the hot filament through the frosted glass.
28. Explain how you can see ordinary, nonluminous classroom objects. (16.1)
Ordinary nonluminous objects are illuminated by reflected light, allowing them to be seen.
29. Distinguish among transparent, translucent, and opaque objects. (16.1)
A transparent object is a material through which light can pass without distortion. A translucent object allows light to pass but distorts the light to the point where images are not discernable. An opaque object does not allow light to pass through.
30. To what is the illumination of a surface by a light source directly proportional? To what is it inversely proportional? (16.1)
The illumination on a surface is directly proportional to the intensity of the source and inversely proportional to the square of the distance of the surface from the source.
31. What did Galileo assume about the speed of light? (16.1)
The speed of light is very fast, but finite.
32. Why is the diffraction of sound waves more familiar in everyday experience than is the diffraction of light waves? (16.2)
Diffraction is most pronounced around obstacles approximately the same size as the wavelength of the wave. We are more accustomed to obstacles of the size that diffract the much larger wavelengths of sound.
33. What color of light has the shortest wavelength? (16.2)
Violet light has the shortest wavelength.
34. What is the range of the wavelengths of light, from shortest to longest? (16.2)
400 nm to 700 nm
35. Of what colors does white light consist? (16.2)
White light is a combination of all the colors, or at least the primary colors.
36. Why does an object appear to be black? (16.2)
An object appears to be black because little, if any, light is being reflected from it.
37. Can longitudinal waves be polarized? Explain. (16.2)
No. They have no vertical or horizontal components.
38. If a distant galaxy were to emit a spectral line in the green region of the light spectrum, would the observed wavelength on Earth shift toward red light or toward blue light? Explain. (16.2)
Because the galaxy is distant, it is most likely moving away from Earth. The wavelength actually would shift away from the wavelength of green light toward a longer red wavelength. If it

Chapter 16 continued

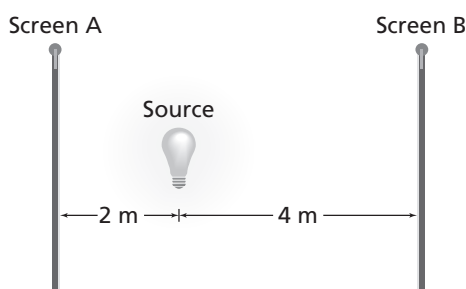
shifted toward the blue wavelength, the wavelength would be shorter, not longer. This would indicate the galaxy is getting closer to Earth, and no galaxy outside the Local Group has been discovered moving toward us.

39. What happens to the wavelength of light as the frequency increases? (16.2)
As the frequency increases, the wavelength decreases.

Applying Concepts

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40. A point source of light is 2.0 m from screen A and 4.0 m from screen B, as shown in **Figure 16-21**. How does the illuminance at screen B compare with the illuminance at screen A?



■ **Figure 16-21**

Illumination $E \propto 1/r^2$; therefore, the illumination at screen B will be one-fourth of that at screen A because it is twice as far from the source.

41. **Reading Lamp** You have a small reading lamp that is 35 cm from the pages of a book. You decide to double the distance.
- Is the illuminance at the book the same?
No.
 - If not, how much more or less is it?
Distance is doubled, so the illumination of the page is one-fourth as great.
42. Why are the insides of binoculars and cameras painted black?
The insides are painted black because black does not reflect any light, and thus there is no interference while

observing or photographing objects.

43. **Eye Sensitivity** The eye is most sensitive to yellow-green light. Its sensitivity to red and blue light is less than 10 percent as great. Based on this knowledge, what color would you recommend that fire trucks and ambulances be painted? Why?
Fire trucks should be painted yellow-green, 550 nm, because less light has to be reflected to the eye for the fire truck to be seen.

44. **Streetlight Color** Some very efficient streetlights contain sodium vapor under high pressure. They produce light that is mainly yellow with some red. Should a community that has these lights buy dark blue police cars? Why or why not?

Blue pigment of a police car will absorb the red and yellow light. Dark blue police cars would not be very visible. If a community wants its police cars to be visible, they should buy yellow cars.

Refer to Figure 16-22 for problems 45 and 46.



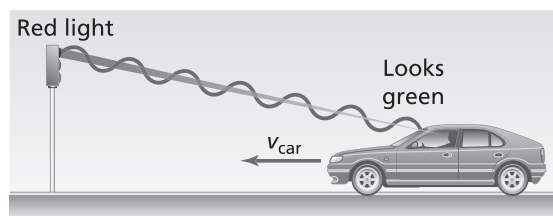
■ **Figure 16-22**

45. What happens to the illuminance at a book as the lamp is moved farther away from the book?
Illuminance decreases, as described by the inverse-square law.
46. What happens to the luminous intensity of the lamp as it is moved farther away from the book?
No change; distance does not affect the luminous intensity of the lamp.

Chapter 16 continued

- 47. Polarized Pictures** Photographers often put polarizing filters over camera lenses to make clouds in the sky more visible. The clouds remain white, while the sky looks darker. Explain this based on your knowledge of polarized light.
- Light scattered from the atmosphere is polarized, but light scattered from the clouds is not. By rotating the filter, the photographer can reduce the amount of polarized light reaching the film.**
- 48.** An apple is red because it reflects red light and absorbs blue and green light.
- Why does red cellophane look red in reflected light?
Cellophane reflects red light and absorbs blue and green light.
 - Why does red cellophane make a white lightbulb look red when you hold the cellophane between your eye and the lightbulb?
Cellophane transmits red light.
 - What happens to the blue and green light?
Blue and green light are absorbed.
- 49.** You put a piece of red cellophane over one flashlight and a piece of green cellophane over another. You shine the light beams on a white wall. What color will you see where the two flashlight beams overlap?
yellow
- 50.** You now put both the red and green cellophane pieces over one of the flashlights in Problem 49. If you shine the flashlight beam on a white wall, what color will you see? Explain.
Black; almost no light would get through because the light transmitted through the first filter would be absorbed by the second.
- 51.** If you have yellow, cyan, and magenta pigments, how can you make a blue pigment? Explain.
Mix cyan and magenta.

- 52. Traffic Violation** Suppose that you are a traffic officer and you stop a driver for going through a red light. Further suppose that the driver draws a picture for you (**Figure 16-23**) and explains that the light looked green because of the Doppler effect when he went through it. Explain to him using the Doppler shift equation just how fast he would have had to be going for the red light ($\lambda = 645 \text{ nm}$), to appear green ($\lambda = 545 \text{ nm}$). *Hint: For the purpose of this problem, assume that the Doppler shift equation is valid at this speed.*



■ Figure 16-23

$$\left(\frac{645 \text{ nm} - 545 \text{ nm}}{645 \text{ nm}} \right) (3.00 \times 10^8 \text{ m/s}) = 4.65 \times 10^7 \text{ m/s}$$

That is over 100 million mph. If he does not get a ticket for running a red light, he will get a ticket for speeding.

Mastering Problems

16.1 Illumination

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Level 1

- 53.** Find the illumination 4.0 m below a 405-lm lamp.

$$E = \frac{P}{4\pi d^2} = \frac{405 \text{ lm}}{4\pi(4.0 \text{ m})^2} = 2.0 \text{ lx}$$

- 54.** Light takes 1.28 s to travel from the Moon to Earth. What is the distance between them?

$$d = vt = (3.00 \times 10^8 \text{ m/s})(1.28 \text{ s}) = 3.84 \times 10^8 \text{ m}$$

Level 2

- 55.** A three-way bulb uses 50, 100, or 150 W of electric power to deliver 665, 1620, or 2285 lm in its three settings. The bulb is placed 80 cm above a sheet of paper. If an

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illumination of at least 175 lx is needed on the paper, what is the minimum setting that should be used?

$$E = \frac{P}{4\pi d^2}$$

$$P = 4\pi E d^2 = 4\pi(175 \text{ lx})(0.80 \text{ m})^2 \\ = 1.4 \times 10^3 \text{ lm}$$

Thus, the 100-W (1620-lm) setting is needed.

- 56. Earth's Speed** Ole Roemer found that the average increased delay in the disappearance of Io from one orbit around Jupiter to the next is 13 s.

- a. How far does light travel in 13 s?

$$3.9 \times 10^9 \text{ m}$$

- b. Each orbit of Io takes 42.5 h. Earth travels the distance calculated in part a in 42.5 h. Find the speed of Earth in km/s.

$$v = \frac{d}{t} \\ = \left(\frac{3.9 \times 10^9 \text{ m}}{1.53 \times 10^5 \text{ s}} \right) \left(\frac{1 \text{ km}}{1000 \text{ m}} \right) \\ = 25 \text{ km/s}$$

- c. Check to make sure that your answer for part b is reasonable. Calculate Earth's speed in orbit using the orbital radius, $1.5 \times 10^8 \text{ km}$, and the period, 1.0 yr.

$$v = \frac{d}{t} = \left(\frac{2\pi(1.5 \times 10^8 \text{ km})}{365 \text{ d}} \right) \left(\frac{1 \text{ d}}{24 \text{ h}} \right) \\ \left(\frac{1 \text{ h}}{3600 \text{ s}} \right) \\ = 3.0 \times 10^1 \text{ km/s, so fairly accurate}$$

Level 3

- 57.** A student wants to compare the luminous flux of a lightbulb with that of a 1750-lm lamp. The lightbulb and the lamp illuminate a sheet of paper equally. The 1750-lm lamp is 1.25 m away from the sheet of paper; the lightbulb is 1.08 m away. What is the lightbulb's luminous flux?

$$E = \frac{P}{4\pi d^2}$$

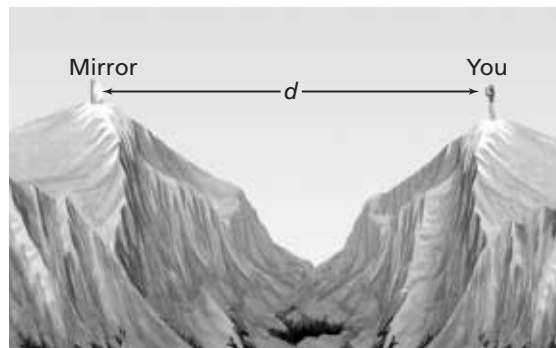
Since the illumination is equal,

$$E_1 = E_2$$

$$\text{So } \frac{P_1}{d_1^2} = \frac{P_2}{d_2^2}$$

$$\text{or } P_2 = \frac{P_1 d_2^2}{d_1^2} \\ = \frac{(1750 \text{ lm})(1.08 \text{ m})^2}{(1.25 \text{ m})^2} \\ = 1.31 \times 10^3 \text{ lm}$$

- 58.** Suppose that you wanted to measure the speed of light by putting a mirror on a distant mountain, setting off a camera flash, and measuring the time it takes the flash to reflect off the mirror and return to you, as shown in **Figure 16-24**. Without instruments, a person can detect a time interval of about 0.10 s. How many kilometers away would the mirror have to be? Compare this distance with that of some known distances.



■ Figure 16-24

$$d = vt \\ = (3.00 \times 10^8 \text{ m/s})(0.1 \text{ s}) \left(\frac{1 \text{ km}}{1000 \text{ m}} \right) \\ = 3 \times 10^4 \text{ km}$$

The mirror would be half this distance, or 15,000 km away. Earth is 40,000 km in circumference, so this is three-eighths of the way around Earth.

16.2 The Wave Nature of Light

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Level 1

- 59.** Convert 700 nm, the wavelength of red light, to meters.

$$(700 \text{ nm}) \left(\frac{1 \times 10^{-9} \text{ m}}{1 \text{ nm}} \right) = 7 \times 10^{-7} \text{ m}$$

Chapter 16 continued

- 60. Galactic Motion** How fast is a galaxy moving relative to Earth if a hydrogen spectral line of 486 nm is red-shifted to 491 nm?

Assume that the relative speed along the axis is much less than the speed of light. Thus, you can use the Doppler shift equation.

$$(\lambda_{\text{app}} - \lambda) = \pm \frac{v}{c} \lambda$$

The light is red-shifted, so the astronomer and the galaxy are moving away from each other. So use the positive form of the apparent light wavelength equation.

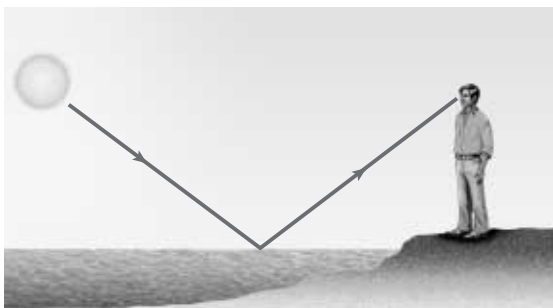
$$(\lambda_{\text{app}} - \lambda) = \pm \frac{v}{c} \lambda$$

Solve for the unknown variable.

$$\begin{aligned} v &= c \frac{(\lambda_{\text{app}} - \lambda)}{\lambda} \\ &= (3.00 \times 10^8 \text{ m/s}) \left(\frac{491 \text{ nm} - 486 \text{ nm}}{486 \text{ nm}} \right) \\ &= 3.09 \times 10^6 \text{ m/s} \end{aligned}$$

The original assumption was valid.

- 61.** Suppose that you are facing due east at sunrise. Sunlight is reflected off the surface of a lake, as shown in **Figure 16-25**. Is the reflected light polarized? If so, in what direction?



■ **Figure 16-25**

The reflected light is partially polarized in the direction parallel to the surface of the lake and perpendicular to the path of travel of the light from the lake to your eyes.

Level 2

- 62. Polarizing Sunglasses** In which direction should the transmission axis of polarizing sunglasses be oriented to cut the glare from the surface of a road: vertically or horizontally? Explain.

The transmission axis should be oriented vertically, since the light reflecting off the road will be partially polarized in the horizontal direction. A vertical transmission axis will filter horizontal waves.

- 63. Galactic Motion** A hydrogen spectral line that is known to be 434 nm is red-shifted by 6.50 percent in light coming from a distant galaxy. How fast is the galaxy moving away from Earth?

Assume that the relative speed along the axis is much less than the speed of light. Thus, you can use the Doppler shift equation.

$$(\lambda_{\text{app}} - \lambda) = \pm \frac{v}{c} \lambda$$

The light is red-shifted, so the astronomer and the galaxy are moving away from each other. So use the positive form of the apparent light wavelength equation.

$$(\lambda_{\text{app}} - \lambda) = \pm \frac{v}{c} \lambda$$

Solve for the unknown variable.

$$\begin{aligned} v &= c \frac{(\lambda_{\text{app}} - \lambda)}{\lambda} \\ &= (3.00 \times 10^8 \text{ m/s}) \\ &\quad \left(\frac{(1.065)(434 \text{ nm}) - 434 \text{ nm}}{434 \text{ nm}} \right) \\ &= 1.95 \times 10^7 \text{ m/s} \end{aligned}$$

The original assumption was valid.

Level 3

- 64.** For any spectral line, what would be an unrealistic value of the apparent wavelength for a galaxy moving away from Earth? Why?

An unrealistic value would make the galaxy seem to be moving away from us at a speed close to or greater than the speed of light, or $v \sim c$. If this were the

Chapter 16 continued

case, use of the low-speed Doppler shift equation would give a wavelength difference of $(\lambda_{\text{app}} - \lambda) = +\frac{c}{c}\lambda$. When solved, this would give an apparent wavelength of $\lambda_{\text{app}} = 2\lambda$. It would be twice as large as the actual wavelength. So any apparent wavelength close to or greater than twice the actual wavelength would be unrealistic.

Mixed Review

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Level 1

65. **Streetlight Illumination** A streetlight contains two identical bulbs that are 3.3 m above the ground. If the community wants to save electrical energy by removing one bulb, how far from the ground should the streetlight be positioned to have the same illumination on the ground under the lamp?

$$E = \frac{P}{4\pi d^2}$$

If P is reduced by a factor of 2, so must d^2 .

Thus, d is reduced by a factor of $\sqrt{2}$, becoming

$$\frac{(3.3 \text{ m})}{\sqrt{2}} = 2.3 \text{ m}$$

66. An octave in music is a doubling of frequency. Compare the number of octaves that correspond to the human hearing range to the number of octaves in the human vision range.

Humans hear over a range of about nine or ten octaves (20 Hz to 10,240 or 20,480 Hz); however, human vision is less than one “octave.”

Level 2

67. A 10.0-cd point-source lamp and a 60.0-cd point-source lamp cast equal intensities on a wall. If the 10.0-cd lamp is 6.0 m from the wall, how far from the wall is the 60.0-cd lamp?

$E = \frac{I}{d^2}$ and since the intensities on the wall are equal, the wall is equally

illuminated and

$$E_1 = E_2$$

$$\text{So } \frac{I_1}{d_1^2} = \frac{I_2}{d_2^2}$$

$$\text{or } d_2 = d_1 \sqrt{\frac{I_2}{I_1}} = (6.0 \text{ m}) \sqrt{\frac{60.0 \text{ cd}}{10.0 \text{ cd}}} \\ = 15 \text{ m}$$

68. **Thunder and Lightning** Explain why it takes 5 s to hear thunder when lightning is 1.6 km away.

The time for light to travel 1.6 km is a small fraction of a second (5.3 μ s). The sound travels about 340 m/s, which is about one-fifth of the 1.6 km every second, and takes about 4.7 s to travel 1.6 km.

Level 3

69. **Solar Rotation** Because the Sun rotates on its axis, one edge of the Sun moves toward Earth and the other moves away. The Sun rotates approximately once every 25 days, and the diameter of the Sun is 1.4×10^9 m. Hydrogen on the Sun emits light of frequency 6.16×10^{14} Hz from the two sides of the Sun. What changes in wavelength are observed?

Speed of rotation is equal to circumference times period of rotation.

$$v_{\text{rot}} = \frac{(1.4 \times 10^9 \text{ m})\pi}{(25 \text{ days})(24 \text{ h/day})(3600 \text{ s/h})} \\ = 2.04 \times 10^3 \text{ m/s}$$

$$\lambda = \frac{c}{f} \\ = \frac{3.00 \times 10^8 \text{ m/s}}{6.16 \times 10^{14} \text{ Hz}} \\ = 4.87 \times 10^{-7} \text{ m}$$

$$\Delta\lambda = \pm \frac{v}{c} \lambda$$

$$\Delta\lambda = \pm \frac{v_{\text{rot}}}{c} \lambda \\ = \pm \frac{(2.04 \times 10^3 \text{ m/s})}{(3.00 \times 10^8 \text{ m/s})} (4.87 \times 10^{-7} \text{ m}) \\ = \pm 3.3 \times 10^{-12} \text{ m}$$

Chapter 16 continued

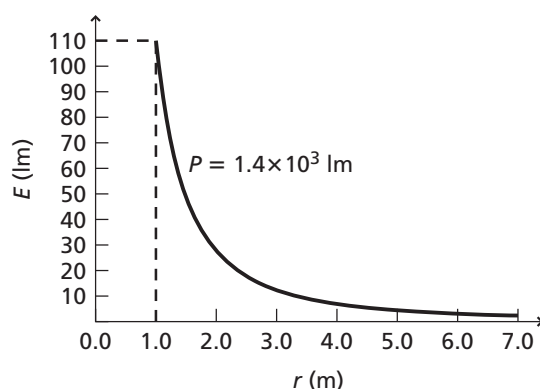
Thinking Critically

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70. Research Why did Galileo's method for measuring the speed of light not work?

It was not precise enough. He was not able to measure the small time intervals involved in a terrestrial measurement.

71. Make and Use Graphs A 110-cd light source is 1.0 m from a screen. Determine the illumination on the screen originally and for every meter of increasing distance up to 7.0 m. Graph the data.



- What is the shape of the graph?
hyperbola
- What is the relationship between illumination and distance shown by the graph?
inverse square

72. Analyze and Conclude If you were to drive at sunset in a city filled with buildings that have glass-covered walls, the setting Sun reflected off the building's walls might temporarily blind you. Would polarizing glasses solve this problem?

Yes. Light reflected off glass is partially polarized, so polarizing sunglasses will reduce much of the glare, if the sunglasses are aligned correctly.

Writing in Physics

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73. Write an essay describing the history of human understanding of the speed of light. Include significant individuals and the contribution that each individual made.

Answers will vary.

74. Look up information on the SI unit *candela*, cd, and explain in your own words the standard that is used to set the value of 1 cd.

Answers will vary. Begin with the element thorium. Heat it to the melting point of platinum. At this temperature, the thorium will glow. Surround the thorium with an opaque material that can take the high temperature. Leave an opening that is one-sixtieth of a square centimeter in size. The candela is defined as the amount of steady flow of light energy that is emitted by the thorium through the opening under these conditions.

Cumulative Review

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75. A 2.0-kg object is attached to a 1.5-m long string and swung in a vertical circle at a constant speed of 12 m/s. (Chapter 7)

a. What is the tension in the string when the object is at the bottom of its path?

$$F_{\text{net}} = \frac{mv^2}{r} = \frac{(2.0 \text{ kg})(12 \text{ m/s})^2}{1.5 \text{ m}}$$

$$= 1.9 \times 10^1 \text{ N}$$

$$F_g = mg = (2.0 \text{ kg})(9.80 \text{ m/s}^2)$$

$$= 2.0 \times 10^2 \text{ N}$$

$$F_{\text{net}} = T - F_g$$

$$T = F_{\text{net}} + F_g$$

$$= 1.9 \times 10^2 \text{ N} + 0.20 \times 10^2 \text{ N}$$

$$= 2.1 \times 10^2 \text{ N}$$

b. What is the tension in the string when the object is at the top of its path?

$$F_{\text{net}} = T + F_g$$

$$T = F_{\text{net}} - F_g$$

$$= 1.9 \times 10^2 \text{ N} - 0.20 \times 10^2 \text{ N}$$

$$= 1.7 \times 10^2 \text{ N}$$

Chapter 16 continued

76. A space probe with a mass of 7.600×10^3 kg is traveling through space at 125 m/s. Mission control decides that a course correction of 30.0° is needed and instructs the probe to fire rockets perpendicular to its present direction of motion. If the gas expelled by the rockets has a speed of 3.200 km/s, what mass of gas should be released? (Chapter 9)

$$\tan 30.0^\circ = \frac{m_g \Delta v_g}{m_p v_{p1}}$$

$$m_g = \frac{m_p v_{p1} (\tan 30.0^\circ)}{\Delta v_g}$$

$$= \frac{(7.600 \times 10^3 \text{ kg})(125 \text{ m/s})(\tan 30.0^\circ)}{3.200 \times 10^3 \text{ m/s}}$$

$$= 171 \text{ kg}$$

77. When a 60.0-cm-long guitar string is plucked in the middle, it plays a note of frequency 440 Hz. What is the speed of the waves on the string? (Chapter 14)

$$\lambda = 2L = 2(0.600 \text{ m}) = 1.20 \text{ m}$$

$$v = \lambda f = (1.20 \text{ m})(440 \text{ Hz}) = 530 \text{ m/s}$$

78. What is the wavelength of a sound wave with a frequency of 17,000 Hz in water at 25°C ? (Chapter 15)

$$\lambda = \frac{v}{f} = \frac{1493 \text{ m/s}}{17,000 \text{ Hz}} = 0.0878 \text{ m} = 8.8 \text{ cm}$$

Challenge Problem

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You place an analyzer filter between the two cross-polarized filters, such that its polarizing axis is not parallel to either of the two filters, as shown in the figure to the right.

1. You observe that some light passes through filter 2, though no light passed through filter 2 previous to inserting the analyzer filter. Why does this happen?

The analyzer filter allows some light to pass through, since its polarizing axis is not perpendicular to the polarizing axis of the first filter. The last polarizing filter now can pass light from the analyzer filter, since the polarizing axis of the analyzer filter is not perpendicular to the polarizing axis of the last polarizing filter.

2. The analyzer filter is placed at an angle of θ relative to the polarizing axes of filter 1. Derive an equation for the intensity of light coming out of filter 2 compared to the intensity of light coming out of filter 1.

I_1 is the light intensity out of the first filter, I_{analyzer} is the light intensity out of the analyzer filter, and I_2 is the light intensity out of the last filter.

$$I_{\text{analyzer}} = I_1 \cos^2 \theta$$

$$I_2 = I_{\text{analyzer}} \cos^2(90^\circ - \theta)$$

$$I_2 = I_1 \cos^2(\theta) \cos^2(90^\circ - \theta)$$

