Chapter 16: Light

Practice Problems

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1. What is the frequency of yellow light, λ = 556 nm?

   $c = \lambda f$, so
   $f = c/\lambda = (3.00 \times 10^8 \text{ m/s})/(556 \times 10^{-9} \text{ m})$
   $= 5.40 \times 10^{14}$ Hz

2. One nanosecond (ns) is 10^{-9} s. Laboratory workers often estimate the distance light travels in a certain time by remembering the approximation "light goes one foot in one nanosecond." How far, in meters, does light actually travel in 1.0 ns?

   $d = ct = (3.00 \times 10^8 \text{ m/s})(1.0 \times 10^{-9} \text{ s})$
   $= 0.30$ m

3. Modern lasers can create a pulse of light that lasts only a few femtoseconds (1 fs = 1×10^{-15} s).

   a. What is the length of a pulse of light that lasts 6.0 fs?

   $d = ct = (3.00 \times 10^8 \text{ m/s})(6.0 \times 10^{-15} \text{ s})$
   $= 1.8 \times 10^{-6}$ m

   b. How many wavelengths of violet light (λ = 400 nm) are included in such a pulse?

   $$\text{Number of wavelengths} = \frac{\text{pulse length}}{\lambda_{\text{violet}}} = \frac{1.8 \times 10^{-6}\text{ m}}{4.0 \times 10^{-7}\text{ m}} = 4.5$$

4. 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 defined velocity of light, calculate the distance to the moon.

   $d = ct = (299792458 \text{ m/s})(1/2)(2.562 \text{ s})$
   $= 3.840 \times 10^8$ m

Practice Problems

5. Use the correct time taken for light to cross Earth's orbit, 16 minutes, and the diameter of the orbit, 3.0×10^{11} m, to calculate the velocity of light using Roemer's method.

   $v = d/t = (3.0 \times 10^{11} \text{ m})/(16 \text{ min})(60 \text{ s/m})$
   $= 3.1 \times 10^8$ m/s

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

   $$\frac{E_{\text{after}}}{E_{\text{before}}} = \frac{P/4\pi d_{\text{after}}^2}{P/4\pi d_{\text{before}}^2} = \frac{d_{\text{before}}^2}{d_{\text{after}}^2} = \frac{(30\text{ cm})^2}{(90\text{ cm})^2} = \frac{1}{9}$$

7. What is the illumination on a surface 3.0 m below a 150–watt incandescent lamp that emits a luminous flux of 2275 lm?

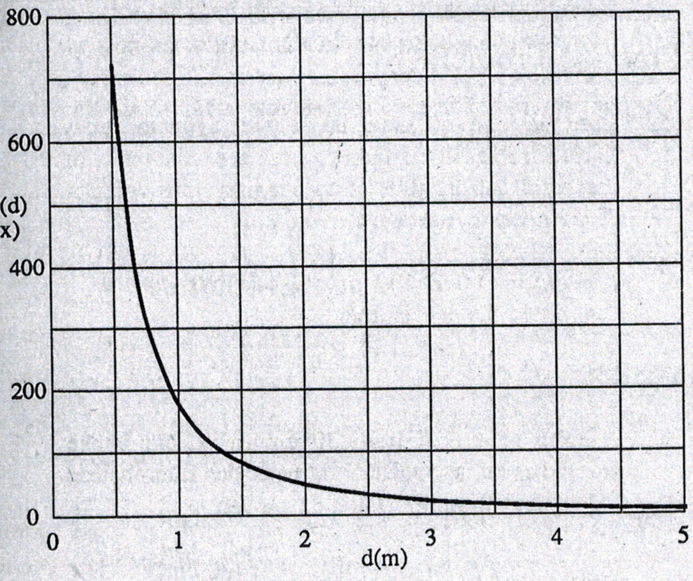
   $$E = \frac{P}{4\pi d^2} = \frac{2275\ lm}{4\pi(3.0\text{ m})^2} = 20\ lx$$

8. Draw a graph of the illuminance from a 150–watt incandescent lamp between 0.50 m and 5.0 m.

   Illuminance of a 150–watt bulb
   $P = 2275$, $d = 0.5, .75 \ldots 5$

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

Practice Problems



9. 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?

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

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

10. The illumination on a tabletop is 2.0×10^1 lx. The lamp providing the illumination is 4.0 m above the table. What is the intensity of the lamp?

From $E = \dfrac{P}{4\pi d^2}$,

$P = 4\pi d^2 E = 4\pi(4.0\text{ m})^2(2.0 \times 10^1\ lx)$
$= 1280\pi\ lm$

so $I = \dfrac{P}{4\pi} = \dfrac{1280\pi\ lm}{4\pi} = 320\text{ cd}$

Chapter Review Problems

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1. Convert 700 nm, the wavelength of red light, to meters.

$$\frac{700\text{ nm}}{1}\left[\frac{1 \times 10^{-9}\text{ m}}{1\text{ nm}}\right] = 7.00 \times 10^{-7}\text{ m}$$

2. Light takes 1.28 s to travel from the moon to Earth. What is the distance between them?

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

3. The sun is 1.5×10^8 km from Earth. How long does it take for its light to reach us?

$d = vt$, so

$t = \dfrac{d}{v} = \dfrac{(1.5 \times 10^8\text{ km})(10^3\text{ m/km})}{(3.00 \times 10^8\text{ m/s})}$
$= 5.0 \times 10^2\text{ s}$

4. Ole Roemer found that the maximum increased delay in the appearance of Io from one orbit to the next was 14 s.

a. How far does light travel in 14 s?

$d = vt = (3.00 \times 10^8\text{ m/s})(14\text{ s})$
$= 4.2 \times 10^9\text{ m}$

b. Each orbit of Io is 42.5 h. Earth traveled the distance calculated above in 42.5 h. Find the speed of Earth in km/s.

$v = \dfrac{d}{t} = \dfrac{(4.2 \times 10^9\text{ m})}{(42.5\text{ h})}$
$= 28\text{ km/s}$

c. See if your answer for part b is reasonable. Calculate Earth's speed in orbit using the orbital radius, 1.5×10^8 km, and the period, one year.

$v = \dfrac{d}{t} = \dfrac{2\pi(1.5 \times 10^8\text{ km})}{(365\text{ d})}$
$= 30\text{ km/s}$

Chapter Review Problems

5. Radio stations are usually identified by their frequency. One radio station in the middle of the FM band has a frequency of 99.0 MHz. What is its wavelength?

$c = f\lambda$, so

$$\lambda = \frac{c}{f} = \frac{3.00 \times 10^8 \text{ m/s}}{99.0 \text{ MHz}}$$

$$= \frac{3.00 \times 10^8 \text{ m/s}}{99.0 \times 10^6 \ \frac{1}{\text{s}}}$$

$$= 3.03 \text{ m}$$

6. Suppose 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. Without instruments, a person can detect a time interval of about 0.1 s. How many kilometers away would the mirror have to be? Compare this size with that of some known objects.

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

The mirror would be half this distance, or 15,000 km away. Earth is 40,000 km in circumference, so this is 3/8 of the way around Earth!

7. What is the frequency of a microwave that has a wavelength of 3.0 cm?

$c = \lambda f$, so

$$f = \frac{c}{\lambda} = \frac{3.00 \times 10^8 \text{ m/s}}{0.030 \text{ m}} = 1.0 \times 10^{10} \text{ Hz}$$

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

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

9. A public school law requires a minimum illumination of 160 lx on 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 the lights must deliver?

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

$$P = 4\pi E d^2 = 4\pi(160 \text{ lm/m}^2)(2.0 \text{ m})^2$$
$$= 8.0 \times 10^3 \text{ lm}$$

10. A 3-way bulb uses 50–100–150 W of electrical 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 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.

11. A streetlight contains two identical bulbs 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

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

12. A student wants to compare the luminous flux from a bulb with that of a 1750–ℓm lamp. The two bulbs equally illuminate a sheet of paper. The 1750–ℓm lamp is 1.25 m away; the unknown bulb is 1.08 m away. What is its luminous flux?

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

Since the illumination is equal, $E_1 = E_2$, so

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

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

$$= 1.31 \times 10^3 \text{ ℓm}$$

13. A screen is placed between two lamps so that they illuminate the screen equally. 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?

Since the illumination is equal, $E_1 = E_2$, so

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

$$d_2 = d_1\sqrt{(P_2/P_1)} = (2.5 \text{ m})\sqrt{(2375/1445)} = 3.2 \text{ m}$$

14. Two lamps illuminate a screen equally. The first lamp has an intensity of 101 cd and is 5.0 m from the screen. The second lamp is 3.0 m from the screen. What is the intensity of the second lamp?

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

Since the illumination is equal,

$E_1 = E_2$, so

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

$$I_2 = \frac{(I_1)({d_2}^2)}{({d_1}^2)}$$

$$I_2 = \frac{(101 \text{ cd})(3.0 \text{ m})^2}{(5.0 \text{ m})^2} = 36 \text{ cd}$$

Chapter Review Problems

15. A 10–cd point source lamp and a 60–cd point source lamp cast equal intensities on a wall. If the 10–cd lamp is 6.0 m from the wall, how far is the 60–cd lamp?

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

$E_1 = E_2$, so

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

$$d_2 = d_1\sqrt{I_2/I_1} = (6.0 \text{ m})\sqrt{\frac{60 \text{ cd}}{10 \text{ cd}}} = 15 \text{ m}$$

Supplemental Problems (Appendix B)

1. The wavelength of blue light is about 4.5×10^{-7} m. Convert this to nm.

$$(4.5 \times 10^{-7} \text{ m})\left[\frac{\text{nm}}{10^{-7} \text{ m}}\right] = 4.5 \times 10^2 \text{ nm}$$

2. As a spacecraft passes directly over Cape Kennedy, radar pulses are transmitted toward the craft and are then reflected back toward the ground. If the total time interval was 3.00×10^{-3} s, how far above the ground was the spacecraft when it passed over Cape Kennedy?

Round trip distance

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

$= 9.00 \times 10^5$ m,

so distance is 4.50×10^5 m.

3. It takes 4.0 years for light from a star to reach Earth. How far away is this star from Earth?

$$d = vt = (3.00 \times 10^8 \text{ m/s})(4.0 \text{ yr})\left[\frac{365 \text{ days}}{\text{yr}}\right]\left[\frac{24 \text{ h}}{\text{day}}\right]\left[\frac{3600 \text{ s}}{\text{h}}\right]$$

$$= 3.8 \times 10^{16} \text{ m}$$

4. The planet Venus is sometimes a very bright object in the night sky. Venus is 4.1×10^{10} m away from Earth when it is closest to Earth. How long would we have to wait for a radar signal to return from Venus and be detected?

Round trip distance
$d = 2(4.1 \times 10^{10}\ \text{m}) = 8.2 \times 10^{10}\ \text{m}$
$t = d/v = (8.2 \times 10^{10}\ \text{m})/(3.00 \times 10^{8}\ \text{m/s})$
$= 2.7 \times 10^{2}\ \text{s}$

5. The distance from Earth to the moon is about 3.8×10^{8} m. A beam of light is sent to the moon and, after it reflects, returns to Earth. How long did it take to make the round trip?

Round trip distance
$d = 2(3.8 \times 10^{8}\ \text{m}) = 7.6 \times 10^{8}\ \text{m}$
$t = d/v = (7.6 \times 10^{8}\ \text{m})/(3.00 \times 10^{8}\ \text{m/s})$
$= 2.5\ \text{s}$

6. A baseball fan in a ball park is 101 m away from the batter's box when the batter hits the ball. How long after the batter hits the ball does the fan see it occur?

$t = d/v = (101\ \text{m})/(3.00 \times 10^{8}\ \text{m/s})$
$= 3.37 \times 10^{-7}\ \text{s}$

7. A radio station on the AM band has an assigned frequency of 825 kHz (kilohertz). What is the wavelength of the station?

$\lambda = c/f = (3.00 \times 10^{8}\ \text{m/s})/(825 \times 10^{3}\ \text{Hz})$
$= 364\ \text{m}$

8. A short-wave, HAM, radio operator uses the 5-meter band. On what frequency does the HAM operate?

$f = c/\lambda = (3.00 \times 10^{8}\ \text{m/s})/(5\ \text{m})$
$= 6 \times 10^{7}\ \text{Hz} = 60\ \text{MHz}$

9. Find the illumination 8.0 m below a 405-ℓm lamp.

$E = P/4\pi d^2 = (405\ \ell\text{m})/4\pi(8.0\ \text{m})^2$
$= 0.50\ \ell\text{m/m}^2 = 0.50\ \ell\text{x}$

10. Two lamps illuminate a screen equally. The first lamp has an intensity of 12.5 cd and is 3.0 m from the screen. The second lamp is 9.0 m from the screen. What is its intensity?

Since $P/4\pi = I$, $E = P/4\pi d^2 = I/d^2$
$E_1 = E_2$, or $I_1/d_1^2 = I_2/d_2^2$, so
$I_2 = I_1(d_2/d_1)^2 = (12.5\ \text{cd})(9.0\ \text{m}/3.0\ \text{m})^2$
$= (12.5\ \text{cd})(9.0)$
$= 1.1 \times 10^{2}\ \text{cd}$

11. A 15-cd point source lamp and a 45-cd point source lamp cast equal illuminations on a wall. If the 45-cd lamp is 12 m away from the wall, how far from the wall is the 15-cd lamp?

$E = I/d^2$ and $E_1 = E_2$, so $I_1/d_1^2 = I_2/d_2^2$, or

$$d_1^2 = \frac{I_1 d_2^2}{I_2} = \frac{(15\ \text{cd})(12\ \text{m})^2}{45\ \text{cd}} = 48\ \text{m}^2$$

$d_1 = 6.9\ \text{m}$

12. What is the name given to the electromagnetic radiation that has a wavelength slightly longer than visible light?

Infrared.

13. What is the name given to the electromagnetic radiation that has a wavelength slightly shorter than visible light?

Ultraviolet.

14. If a black object absorbs all light ray incident on it, how can we see it?

The black object stands out from other objects that are not black. It is also illuminated by some diffuse reflection.

15. What is the appearance of a red dress in a closed room illuminated only by green light?

The dress appears black, since red pigment absorbs green light.

16. A shirt that is the color of a primary color is illuminated with the complement of that primary color. What color do you see?

Black.