

Chapter 25

Electromagnetic Waves

Answers to Even-numbered Conceptual Questions

2. The electric and magnetic fields in an electromagnetic wave are proportional to one another, as we see in Equation 25-9. Therefore, doubling E results in a doubling of B . The intensity of such a wave depends on the square of the fields, however, as Equation 25-10 shows. It follows that the intensity of an electromagnetic field is quadrupled if its electric field is doubled.
4. We can tell if a weather system is approaching or receding by noting if the frequency of the reflected radar beam has been shifted up or down. The system is approaching if the frequency is higher; it is receding if the frequency is lower.
6. We note from Equation 25-12 that the radiation pressure depends on the intensity of a wave. The intensity, in turn, depends on the square of the fields, as Equation 25-10 shows. Therefore, the electric field in beam 2 has a magnitude given by $\sqrt{2} E_0$.
8. Ideally, the sails should be reflecting. Recall that there is a greater transfer of momentum when a beam is reflected than when it is merely absorbed.
10. If the incident light is unpolarized, the transmitted intensity is the same in both cases. Specifically, the first filter in both cases reduces the intensity of unpolarized light by a factor of 2. It also leaves the light polarized in the direction of its transmission axis, which is at an angle θ relative to the transmission axis of the second filter. The second filter then reduces the transmitted intensity by a further factor of $(\cos \theta)^2$.
12. Light reflected from a horizontal surface has a polarization in the horizontal direction. It follows that when you sit upright, with the transmission axis of your glasses in the vertical direction, they will block most of the reflected light. When you lie on your side, however, the transmission axis is horizontal. This allows most of the reflected light to enter your eyes.
14. View the light reflected from a horizontal surface, such as a tabletop. This light is polarized primarily in the horizontal direction. Therefore, if you rotate the sheet of polarizing material until you receive a maximum amount of reflected light, you will know that its transmission axis is horizontal.
16. The light from the sky is polarized at right angles to the direction of the Sun; therefore, the amount of light received by each of the two polarizing eyes will depend on the orientation of the spider relative to the Sun. By monitoring the amount of light received by each eye, the spider can maintain a course on a given heading relative to the Sun.
18. As mentioned in the answer to Question 14, the light reflected from a horizontal surface is polarized primarily in the horizontal direction. If the glasses are merely tinted, reflected light will have the same intensity no matter how the glasses are rotated. If they are Polaroid, however, you will notice a striking difference in reflected intensity as you rotate the glasses.

Solutions to Problems

1. According to the RHR, the wave is traveling in the positive x-direction.
2. (a) The electric field will oscillate in the x-direction.
 (b) The magnetic field will oscillate in the z-direction.
 (c) The electromagnetic wave will propagate in the positive y-direction.
3. (a) The electric field will oscillate in the z-direction.
 (b) The magnetic field will oscillate in the x-direction.
 (c) The electromagnetic wave will propagate in the positive y-direction.
4. (a) up
 (b) down
 (c) E
 (d) W
5. (a) +z
 (b) -z
 (c) -x
 (d) -x
6. (a) Since \vec{B} is perpendicular to the direction of propagation, the z component is zero.
 (b) By the right-hand rule, and by the fact that $E = cB$,

$$\begin{aligned}\vec{B} &= \frac{1}{c}(-E_y\hat{x} + E_x\hat{y}) \\ &= \frac{1}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} \left[\left(-2.87 \frac{\text{N}}{\text{C}} \right) \hat{x} + \left(6.22 \frac{\text{N}}{\text{C}} \right) \hat{y} \right] \\ &= \boxed{(-9.57 \times 10^{-9} \text{ T})\hat{x} + (2.07 \times 10^{-8} \text{ T})\hat{y}}\end{aligned}$$
7. (a) Since \vec{E} is perpendicular to the direction of propagation, the z component is zero.
 (b) By the right-hand rule, and by the fact that $E = cB$,

$$\begin{aligned}\vec{E} &= c(-B_y\hat{x} + B_x\hat{y}) \\ &= \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}} \right) [(4.06 \times 10^{-9} \text{ T})\hat{x} + (2.32 \times 10^{-9} \text{ T})\hat{y}] \\ &= \boxed{(1.22 \text{ N/C})\hat{x} + (0.696 \text{ N/C})\hat{y}}\end{aligned}$$

$$8. \text{ (a) light-year} = \left(3.00 \times 10^5 \frac{\text{km}}{\text{s}}\right)(365 \text{ d})\left(\frac{86,400 \text{ s}}{\text{d}}\right) = \boxed{9.46 \times 10^{12} \text{ km}}$$

$$\text{(b) } \boxed{c = 1.00 \text{ ly/y}}$$

$$\text{(c) } c = \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right)\left(\frac{1 \text{ s}}{10^9 \text{ ns}}\right)\left(\frac{1 \text{ ft}}{0.3048 \text{ m}}\right) = \boxed{0.984 \text{ ft/ns}}$$

$$9. \quad d = (4.3 \text{ ly})\left(\frac{9.46 \times 10^{15} \text{ m}}{1 \text{ ly}}\right) = \boxed{4.1 \times 10^{16} \text{ m}}$$

$$10. \quad d = ct = \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right)(12 \text{ min})\left(\frac{60 \text{ s}}{1 \text{ min}}\right) = \boxed{2.2 \times 10^{11} \text{ m}}$$

$$11. \quad f' = f\left(1 - \frac{u}{c}\right)$$

$$\frac{c}{\lambda'} = \frac{c}{\lambda}\left(1 - \frac{u}{c}\right)$$

$$\frac{\lambda'}{\lambda} = \frac{1}{1 - \frac{u}{c}}$$

$$= \frac{1}{1 - \frac{32,500 \times 10^3 \frac{\text{m}}{\text{s}}}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}}$$

$$= \boxed{1.12}$$

12. (a) Because the star is moving towards Earth, the frequencies of the electromagnetic waves are increased. But, since the wavelengths are inversely proportional to the frequencies, the measured wavelengths are **less than** what they would be if the star were at rest relative to us.

$$\text{(b) } f' = f\left(1 + \frac{u}{c}\right)$$

$$\frac{c}{\lambda'} = \frac{c}{\lambda}\left(1 + \frac{u}{c}\right)$$

$$\lambda' = \lambda\left(\frac{1}{1 + \frac{u}{c}}\right)$$

$$\frac{\lambda'}{\lambda} = \frac{c}{c + u}$$

$$= \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{3.00 \times 10^8 \frac{\text{m}}{\text{s}} + 32,500 \times 10^3 \frac{\text{m}}{\text{s}}}$$

$$= \boxed{0.902}$$

13. (a) According to the Doppler effect, the frequency of electromagnetic radiation as measured by an observer is less than what it was when emitted if the source is receding. So, the galaxy is moving away from the Earth.

$$(b) f' = (1 - 0.15)f = f \left(1 - \frac{u}{c} \right)$$

$$0.85 = 1 - \frac{u}{c}$$

$$\frac{u}{c} = 1 - 0.85$$

$$u = \boxed{0.15c}$$

14. $\frac{2d}{t} = c$

$$\frac{2d}{t + \Delta t} = (1 - 0.15)c$$

$$\frac{2d}{\frac{2d}{c} + \Delta t} = 0.85c$$

$$\frac{2d}{2d + c\Delta t} = 0.85$$

$$2d + c\Delta t = \frac{2d}{0.85}$$

$$2d \left(1 - \frac{1}{0.85} \right) = -c\Delta t$$

$$\begin{aligned} d &= \frac{c\Delta t}{2 \left(\frac{1}{0.85} - 1 \right)} \\ &= \frac{(3.00 \times 10^8 \frac{\text{m}}{\text{s}})(0.2 \text{ s})}{2 \left(\frac{1}{0.85} - 1 \right)} \\ &= \boxed{2 \times 10^8 \text{ m}} \end{aligned}$$

15. $c = \frac{2d}{\Delta t} = \frac{2d\omega}{\Delta\theta} = \frac{(71.0 \times 10^3 \text{ m})(528 \frac{\text{rev}}{\text{s}})}{\frac{1}{8} \text{ rev}} = \boxed{3.00 \times 10^8 \text{ m/s}}$

16. $\Delta t = \frac{d}{c} = \frac{4.5 \times 10^{12} \text{ m}}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} = \boxed{1.5 \times 10^4 \text{ s}}$

17. $\Delta t_{\text{daughter}} = \frac{d}{v} = \frac{135 \text{ m}}{343 \frac{\text{m}}{\text{s}}} = 0.394 \text{ s}$

$$\Delta t_{\text{father}} = \frac{d}{c} = \frac{122 \times 10^3 \text{ m}}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} = 4.07 \times 10^{-4} \text{ s}$$

The father hears the home run first.

$$\begin{aligned}
 18. \quad (a) \quad \frac{1}{\lambda'} &= \frac{1}{\lambda} \left(1 + \frac{u}{c} \right) \\
 \lambda' &= \lambda \left(\frac{1}{1 + \frac{u}{c}} \right) \\
 1 + \frac{u}{c} &= \frac{\lambda}{\lambda'} \\
 u &= \left(\frac{\lambda}{\lambda'} - 1 \right) c \\
 &= \left(\frac{590 \text{ nm}}{550 \text{ nm}} - 1 \right) \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}} \right) \\
 &= \boxed{2 \times 10^7 \text{ m/s}}
 \end{aligned}$$

(b) The wavelength decreases if the motorist approaches the traffic light. So, the motorist should travel toward the traffic light.

$$19. \quad f' = f \left(1 - \frac{u}{c} \right) = (5.000 \times 10^{14} \text{ Hz}) \left(1 - \frac{3025 \times 10^3 \frac{\text{m}}{\text{s}}}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} \right) = \boxed{4.950 \times 10^{14} \text{ Hz}}$$

$$20. \quad \lambda = \lambda' \left(1 + \frac{u}{c} \right) = (670.3 \text{ nm}) \left(1 + \frac{722.5 \times 10^3 \frac{\text{m}}{\text{s}}}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} \right) = \boxed{671.9 \text{ nm}}$$

21. Δf at ball

$$f' - f = \frac{fu}{c} = \frac{(10.525 \times 10^9 \text{ Hz})(90.0 \text{ mph}) \left(\frac{0.447 \frac{\text{m}}{\text{s}}}{1 \text{ mph}} \right)}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} = 1410 \text{ Hz}$$

The waves are reflected, so at the gun, $\Delta f_g = 2\Delta f = \boxed{2820 \text{ Hz}}$

22. Δf at receding car

$$f' - f = \frac{fu}{c} = - \frac{(8.00 \times 10^9 \text{ Hz})(40.0 \frac{\text{m}}{\text{s}})}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} = -1070 \text{ Hz}$$

The waves are reflected, so at the highway patrol car, $\Delta f_{\text{hp}} = 2\Delta f = 2(-1067 \text{ Hz}) = \boxed{-2130 \text{ Hz}}$.

$$23. \quad (a) \quad f' = f \left(1 - \frac{u}{c} \right) = (8.230 \times 10^{14} \text{ Hz}) \left(1 - \frac{3.600 \times 10^5 \frac{\text{m}}{\text{s}} - 6.400 \times 10^5 \frac{\text{m}}{\text{s}}}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} \right) = \boxed{8.238 \times 10^{14} \text{ Hz}}$$

$$(b) \quad f' = (8.230 \times 10^{14} \text{ Hz}) \left(1 - \frac{3.600 \times 10^5 \frac{\text{m}}{\text{s}} + 6.400 \times 10^5 \frac{\text{m}}{\text{s}}}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} \right) = \boxed{8.203 \times 10^{14} \text{ Hz}}$$

24. (a) Observed frequencies decrease for receding objects. So, the car is moving away from the radar gun.

(b) Outgoing wave

$$f' = f \left(1 - \frac{u}{c} \right)$$

Return wave

$$f'' = f' \left(1 - \frac{u}{c} \right) = f \left(1 - \frac{u}{c} \right)^2 \approx f \left(1 - \frac{2u}{c} \right)$$

$$f'' - f = -\frac{2u}{c} f$$

$$\frac{2u}{c} f = f - f''$$

$$u = \frac{c}{2} \left(\frac{f - f''}{f} \right)$$

$$= \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{2} \left(\frac{5.04 \times 10^3 \text{ Hz}}{24.150 \times 10^9 \text{ Hz}} \right)$$

$$= \boxed{31.3 \text{ m/s}}$$

$$25. \quad f = \frac{c}{\lambda} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{0.30 \times 10^{-9} \text{ m}} = \boxed{1.0 \times 10^{18} \text{ Hz}}$$

$$26. \quad f = \frac{c}{\lambda} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{460 \times 10^{-9} \text{ m}} = \boxed{6.52 \times 10^{14} \text{ Hz}}$$

$$27. \quad \text{number of waves} = \frac{1.0 \times 10^{-3} \text{ m}}{590 \times 10^{-9} \text{ m}} = \boxed{1700 \text{ waves}}$$

28. Answers may vary. For a height of 6 ft:

$$\text{number of wavelengths} = \frac{(6 \text{ ft}) \left(\frac{0.3048 \text{ m}}{\text{ft}} \right)}{705 \times 10^{-9} \text{ m}} = \boxed{3 \times 10^6 \text{ wavelengths}}$$

$$29. \quad \lambda = \frac{c}{f} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{1.25 \times 10^8 \text{ Hz}} = \boxed{2.40 \text{ m}}$$

$$30. \quad (a) \quad f = \frac{c}{\lambda} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{9.0 \times 10^{-6} \text{ m}} = \boxed{3.3 \times 10^{13} \text{ Hz}}$$

(b) This frequency falls in the infrared range (10^{12} Hz to 4.3×10^{14} Hz).

$$31. f = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{\lambda}$$

λ (m)	f (Hz)
400×10^{-9}	7.50×10^{14}
320×10^{-9}	9.38×10^{14}
280×10^{-9}	1.07×10^{15}
100×10^{-9}	3.00×10^{15}

- (a) UV-A 7.50×10^{14} Hz to 9.38×10^{14} Hz
 UV-B 9.38×10^{14} Hz to 1.07×10^{15} Hz
 UC-C 1.07×10^{15} Hz to 3.00×10^{15} Hz

- (b) 7.9×10^{14} Hz is in the **UV-A** range.

$$32. \lambda = \frac{c}{f} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{10.0 \times 10^3 \text{ Hz}} = \boxed{30.0 \text{ km}}$$

33. (a) The wavelength of an electromagnetic wave is directly proportional to its speed. So, if the wave speed decreases, the wavelength **decreases**.

(b) $\lambda = \frac{c}{f}$
 $\lambda' = \frac{\frac{3}{4}c}{f} = \frac{3}{4}\lambda$
 $\frac{\lambda'}{\lambda} = \boxed{\frac{3}{4}}$

34. (a) Frequency varies inversely with wavelength. So, a shorter wavelength corresponds to a higher frequency. Since the wavelength of violet light is shorter than that for red light, **violet** light has the higher frequency.

(b) $f_{\text{blue}} = \frac{c}{\lambda_{\text{blue}}} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{470 \times 10^{-9} \text{ m}} = \boxed{6.4 \times 10^{14} \text{ Hz}}$

$$f_{\text{red}} = \frac{c}{\lambda_{\text{red}}} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{680 \times 10^{-9} \text{ m}} = \boxed{4.4 \times 10^{14} \text{ Hz}}$$

$$35. T = \frac{1}{f} = \frac{\lambda}{c} = \frac{29 \times 10^9 \text{ m}}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} = \boxed{97 \text{ s}}$$

$$36. L = \frac{1}{2}\lambda = \frac{c}{2f} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{2(6.60 \times 10^7 \text{ Hz})} = \boxed{2.27 \text{ m}}$$

$$37. \quad L = \frac{1}{4}\lambda = \frac{c}{4f} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{4(780 \times 10^3 \text{ Hz})} = \boxed{96.2 \text{ m}}$$

$$38. \quad f = \frac{c}{\lambda} = \frac{c}{4L} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{4(122 \text{ m})} = \boxed{615 \text{ kHz}}$$

$$39. \quad (\text{a}) \quad \lambda_1 - \lambda_2 = \frac{c}{f_1} - \frac{c}{f_2} = \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right) \left(\frac{1}{50 \times 10^3 \text{ Hz}} - \frac{1}{52 \times 10^3 \text{ Hz}} \right) = \boxed{200 \text{ m}}$$

$$(\text{b}) \quad \lambda_1 - \lambda_2 = \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right) \left(\frac{1}{500 \times 10^3 \text{ Hz}} - \frac{1}{502 \times 10^3 \text{ Hz}} \right) = \boxed{2 \text{ m}}$$

$$40. \quad (\text{a}) \quad f_1 - f_2 = \frac{c}{\lambda_1} - \frac{c}{\lambda_2} = \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right) \left(\frac{1}{300.0 \text{ m}} - \frac{1}{300.5 \text{ m}} \right) = \boxed{2 \text{ kHz}}$$

$$(\text{b}) \quad f_1 - f_2 = \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right) \left(\frac{1}{30.0 \text{ m}} - \frac{1}{30.5 \text{ m}} \right) = \boxed{200 \text{ kHz}}$$

$$41. \quad B_{\text{max}} = \frac{E_{\text{max}}}{c} = \frac{0.0400 \frac{\text{V}}{\text{m}}}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} = \boxed{1.33 \times 10^{-10} \text{ T}}$$

$$42. \quad E_{\text{rms}} = \frac{E_{\text{max}}}{\sqrt{2}} = \frac{65 \frac{\text{V}}{\text{m}}}{\sqrt{2}} = \boxed{46 \text{ V/m}}$$

$$43. \quad (\text{a}) \quad E = cB = \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right) (2.7 \times 10^{-6} \text{ T}) = \boxed{810 \text{ V/m}}$$

$$(\text{b}) \quad I = \frac{c}{\mu_0} B^2 = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{4\pi \times 10^{-7} \frac{\text{T} \cdot \text{m}}{\text{A}}} (2.7 \times 10^{-6} \text{ T})^2 = \boxed{1.7 \text{ kW/m}^2}$$

$$(\text{c}) \quad I_{\text{av}} = \frac{c}{\mu_0} B_{\text{rms}}^2 = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{4\pi \times 10^{-7} \frac{\text{T} \cdot \text{m}}{\text{A}}} \left(\frac{2.7 \times 10^{-6} \text{ T}}{\sqrt{2}} \right)^2 = \boxed{870 \text{ W/m}^2}$$

$$44. \quad I_{\text{max}} = c\epsilon_0 E_{\text{max}}^2$$

$$E_{\text{max}} = \sqrt{\frac{I_{\text{max}}}{c\epsilon_0}} = \sqrt{\frac{5.00 \frac{\text{W}}{\text{m}^2}}{\left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right) \left(8.85 \times 10^{-12} \frac{\text{C}^2}{\text{N} \cdot \text{m}^2}\right)}} = \boxed{43.4 \text{ V/m}}$$

$$45. I_{\text{av}} = \frac{1}{2} c \epsilon_0 E_{\text{max}}^2$$

$$E_{\text{max}} = \sqrt{\frac{2I_{\text{av}}}{c\epsilon_0}} = \sqrt{\frac{2\left(5.00 \frac{\text{W}}{\text{m}^2}\right)}{\left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right)\left(8.85 \times 10^{-12} \frac{\text{C}^2}{\text{N} \cdot \text{m}^2}\right)}} = \boxed{61.4 \text{ V/m}}$$

46. (a) For wave 2,

$$\begin{aligned} E_0 &= cB_0 \\ &= \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right)(1.5 \times 10^{-6} \text{ T}) \\ &= 4.5 \times 10^2 \frac{\text{V}}{\text{m}} > 52 \frac{\text{V}}{\text{m}} \end{aligned}$$

Wave 2 has the greater intensity.

$$\begin{aligned} \text{(b)} \quad I_1 &= c\epsilon_0 E^2 \\ &= \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right)\left(8.85 \times 10^{-12} \frac{\text{C}^2}{\text{N} \cdot \text{m}^2}\right)\left(52 \frac{\text{V}}{\text{m}}\right)^2 \\ &= \boxed{7.2 \frac{\text{W}}{\text{m}^2}} \end{aligned}$$

$$\begin{aligned} I_2 &= \frac{c}{\mu_0} B^2 \\ &= \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{4\pi \times 10^{-7} \frac{\text{T} \cdot \text{m}}{\text{A}}} (1.5 \times 10^{-6} \text{ T})^2 \\ &= \boxed{5.4 \times 10^2 \frac{\text{W}}{\text{m}^2}} \end{aligned}$$

$$47. \text{(a)} \quad I_{\text{av}} = \frac{P_{\text{av}}}{A} = \frac{P_{\text{av}}}{4\pi r^2} = \frac{55 \times 10^3 \text{ W}}{4\pi (250 \text{ m})^2} = \boxed{70 \text{ mW/m}^2}$$

$$\text{(b)} \quad I_{\text{av}} = \frac{55 \times 10^3 \text{ W}}{4\pi (2500 \text{ m})^2} = \boxed{0.70 \text{ mW/m}^2}$$

48. Set $I_{75} = I_{120}$.

$$\begin{aligned} \frac{P_{75}}{4\pi r_{75}^2} &= \frac{P_{120}}{4\pi r_{120}^2} \\ r_{75} &= r_{120} \sqrt{\frac{P_{75}}{P_{120}}} = (25 \text{ m}) \sqrt{\frac{75 \text{ W}}{120 \text{ W}}} = \boxed{20 \text{ m}} \end{aligned}$$

$$49. \quad \frac{I_{\text{Pluto}}}{I_{\text{Earth}}} = \frac{\frac{P_{\text{Sun}}}{4\pi r_{\text{P}}^2}}{\frac{P_{\text{Sun}}}{4\pi r_{\text{E}}^2}} = \left(\frac{r_{\text{E}}}{r_{\text{P}}}\right)^2 = \left(\frac{1}{39}\right)^2 = \boxed{6.6 \times 10^{-4}}$$

50. (a) $I = \frac{P}{4\pi r^2} = \frac{0.050(120 \text{ W})}{4\pi(2.0 \text{ m})^2} = \boxed{0.12 \text{ W/m}^2}$

(b) The intensity of light from sources of equal power is **the same** regardless of the differing sources' wavelengths.

(c) $I = \frac{0.050(120 \text{ W})}{4\pi(2.0 \text{ m})^2} = \boxed{0.12 \text{ W/m}^2}$

51. The time it takes the laser to travel 1.0 m is $\Delta t = (1.0 \text{ m})/c$.

$$E = P\Delta t = P \frac{1.0 \text{ m}}{c} = \frac{(5.0 \times 10^{-3} \text{ W})(1.0 \text{ m})}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} = \boxed{1.7 \times 10^{-11} \text{ J}}$$

52. $\text{length} = c\Delta t = c \frac{E}{P} = \frac{(3.00 \times 10^8 \frac{\text{m}}{\text{s}})(7.5 \text{ mJ})}{5.0 \text{ mW}} = \boxed{4.5 \times 10^8 \text{ m}}$

53. $F_{\text{av}} = P_{\text{av}} A = \frac{I_{\text{av}} A}{c} = \frac{(1.0 \times 10^3 \frac{\text{W}}{\text{m}^2})(15 \text{ m})(45 \text{ m})}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} = \boxed{2.3 \text{ mN}}$

54. (a) $u_{\text{av}} = \epsilon_0 \left(\frac{E}{\sqrt{2}} \right)^2$

$$E = \sqrt{\frac{2u_{\text{av}}}{\epsilon_0}} = \sqrt{\frac{2(1.0 \frac{\text{J}}{\text{m}^3})}{8.85 \times 10^{-12} \frac{\text{C}^2}{\text{N} \cdot \text{m}^2}}} = \boxed{480 \text{ kV/m}}$$

$$u_{\text{av}} = \frac{1}{\mu_0} \left(\frac{B}{\sqrt{2}} \right)^2$$

$$B = \sqrt{2\mu_0 u_{\text{av}}} = \sqrt{2 \left(4\pi \times 10^{-7} \frac{\text{T} \cdot \text{m}}{\text{A}} \right) \left(1.0 \frac{\text{J}}{\text{m}^3} \right)} = \boxed{1.6 \text{ mT}}$$

(b) Since the energy density is proportional to the square of the field amplitudes, the field amplitudes must be increased by a factor of $\boxed{\sqrt{2}}$ to double the energy density.

55. (a) Since $3.00 \text{ MJ} > 40.0 \text{ kJ}$, the **NIF** laser produces more energy in each pulse.

(b) $P_{\text{NOVA}} = \frac{40.0 \times 10^3 \text{ J}}{2.50 \times 10^{-9} \text{ s}} = 1.60 \times 10^{13} \text{ W}$

$$P_{\text{NIF}} = \frac{3.00 \times 10^6 \text{ J}}{10.0 \times 10^{-9} \text{ s}} = 3.00 \times 10^{14} \text{ W}$$

The **NIF** laser produces the greater power during each pulse.

$$(c) \frac{I_{\text{NIF}}}{I_{\text{NOVA}}} = \frac{\frac{P_{\text{NIF}}}{A_{\text{NIF}}}}{\frac{P_{\text{NOVA}}}{A_{\text{NOVA}}}} = \frac{P_{\text{NIF}} A_{\text{NOVA}}}{P_{\text{NOVA}} A_{\text{NIF}}}$$

Since $A_{\text{NOVA}} = A_{\text{NIF}}$, and since $P_{\text{NIF}} > P_{\text{NOVA}}$, the **NIF** laser produces the greatest intensity.

$$56. (a) P = P_{\text{bulb}} \frac{A_{\text{pupil}}}{A} = P_{\text{bulb}} \frac{\frac{1}{4}\pi d^2}{4\pi r^2} = \frac{1}{16} P_{\text{bulb}} \left(\frac{d}{r}\right)^2 = \frac{1}{16} (0.050)(150 \text{ W}) \left(\frac{5.0 \times 10^{-3} \text{ m}}{2.5 \text{ m}}\right)^2 = \boxed{1.9 \mu\text{W}}$$

(b) Since the entire beam enters the pupil, the energy that enters the eye per second is **0.5 mW**.

$$57. (a) E = P\Delta t = (0.75 \times 10^{-3} \text{ W})(0.2 \text{ s}) = \boxed{0.2 \text{ mJ}}$$

$$(b) I = \frac{P}{A} = \frac{0.75 \times 10^{-3} \text{ W}}{\pi \left(\frac{5.0 \times 10^{-4} \text{ cm}}{2}\right)^2} = \boxed{3.8 \text{ kW/cm}^2}$$

$$(c) f = \frac{3800 \frac{\text{W}}{\text{cm}^2}}{1.0 \times 10^{-2} \frac{\text{W}}{\text{cm}^2}} = \boxed{380,000}$$

$$58. E_{\text{rms}} = \sqrt{\frac{I_{\text{av}}}{c\epsilon_0}} = \sqrt{\frac{P_{\text{av}}}{Ac\epsilon_0}} = \sqrt{\frac{20.0 \text{ W}}{4\pi(3.50 \text{ m})^2 \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right) \left(8.85 \times 10^{-12} \frac{\text{C}^2}{\text{N}\cdot\text{m}^2}\right)}} = \boxed{7.00 \text{ V/m}}$$

$$B_{\text{rms}} = \sqrt{\frac{\mu_0 I_{\text{av}}}{c}} = \sqrt{\frac{\mu_0 P_{\text{av}}}{Ac}} = \sqrt{\frac{\left(4\pi \times 10^{-7} \frac{\text{T}\cdot\text{m}}{\text{A}}\right)(20.0 \text{ W})}{4\pi(3.50 \text{ m})^2 \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right)}} = \boxed{2.33 \times 10^{-8} \text{ T}}$$

$$59. (a) I_{\text{av}} = \frac{P_{\text{av}}}{A} = \frac{0.50 \times 10^{-3} \text{ W}}{\pi \left(\frac{1.5 \times 10^{-3} \text{ m}}{2}\right)^2} = \boxed{280 \text{ W/m}^2}$$

$$(b) \frac{P_{\text{bulb}}}{4\pi d^2} = \frac{P_{\text{laser}}}{\pi r^2}$$

$$d = \frac{r}{2} \sqrt{\frac{P_{\text{bulb}}}{P_{\text{laser}}}} = \frac{1.5 \times 10^{-3} \text{ m}}{4} \sqrt{\frac{0.050(150 \text{ W})}{0.50 \times 10^{-3} \text{ W}}} = \boxed{4.6 \text{ cm}}$$

$$60. I_{\text{av}} = \frac{P_{\text{av}}}{A} = c\epsilon_0 E_{\text{rms}}^2$$

$$E_{\text{rms}} = \sqrt{\frac{P_{\text{av}}}{Ac\epsilon_0}} = \sqrt{\frac{2.8 \times 10^{-3} \text{ W}}{\pi \left(\frac{2.4 \times 10^{-3} \text{ m}}{2}\right)^2 \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right) \left(8.85 \times 10^{-12} \frac{\text{C}^2}{\text{N}\cdot\text{m}^2}\right)}} = \boxed{480 \text{ V/m}}$$

$$61. \text{ (a) } E = P_{\text{av}} \Delta t = (2.8 \times 10^{-3} \text{ W})(12 \text{ s}) = \boxed{34 \text{ mJ}}$$

$$\text{ (b) radiation pressure} = \frac{I_{\text{av}}}{c} = \frac{P_{\text{av}}}{Ac} = \frac{2.8 \times 10^{-3} \text{ W}}{\pi \left(\frac{2.4 \times 10^{-3} \text{ m}}{2} \right)^2 \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}} \right)} = \boxed{2.1 \mu\text{Pa}}$$

$$62. \text{ (a) } P = \frac{E}{\Delta t} = \frac{2.50 \times 10^{-3} \text{ J}}{10.0 \times 10^{-9} \text{ s}} = \boxed{250 \text{ kW}}$$

$$\text{ (b) } I = \frac{P}{A} = \frac{250 \times 10^3 \text{ W}}{\pi \left(\frac{0.850 \times 10^{-3} \text{ m}}{2} \right)^2} = \boxed{4.41 \times 10^{11} \text{ W/m}^2}$$

$$\text{ (c) } P_{\text{av}} = \frac{55(2.50 \times 10^{-3} \text{ J})}{1 \text{ s}} = \boxed{138 \text{ mW}}$$

$$63. \text{ (a) } P_{\text{av}} = \frac{E}{\Delta t} = \frac{0.350 \text{ J}}{225 \times 10^{-15} \text{ s}} = \boxed{1.56 \times 10^{12} \text{ W}}$$

$$\text{ (b) } I_{\text{av}} = \frac{P_{\text{av}}}{A} = \frac{E}{A \Delta t} = \frac{0.350 \text{ J}}{\pi \left(\frac{2.00 \times 10^{-3} \text{ m}}{2} \right)^2 (225 \times 10^{-15} \text{ s})} = \boxed{4.95 \times 10^{17} \text{ W/m}^2}$$

$$\begin{aligned} \text{ (c) } E_{\text{rms}} &= \sqrt{\frac{I_{\text{av}}}{c \epsilon_0}} = \sqrt{\frac{E}{A \Delta t c \epsilon_0}} \\ &= \sqrt{\frac{0.350 \text{ J}}{\pi \left(\frac{2.00 \times 10^{-3} \text{ m}}{2} \right)^2 (225 \times 10^{-15} \text{ s}) \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}} \right) \left(8.85 \times 10^{-12} \frac{\text{C}^2}{\text{N} \cdot \text{m}^2} \right)}} \\ &= \boxed{1.37 \times 10^{10} \text{ V/m}} \end{aligned}$$

$$64. \quad I = I_0 \cos^2 \theta = \left(0.55 \frac{\text{W}}{\text{m}^2} \right) \cos^2 25.0^\circ = \boxed{0.45 \text{ W/m}^2}$$

$$65. \quad \frac{I}{I_0} = \cos^2 \theta = \cos^2 60.0^\circ = \boxed{0.250}$$

$$66. \quad I_1 = \frac{1}{2} I_0$$

$$I_2 = I_1 \cos^2 \theta = \frac{1}{2} I_0 \cos^2 \theta$$

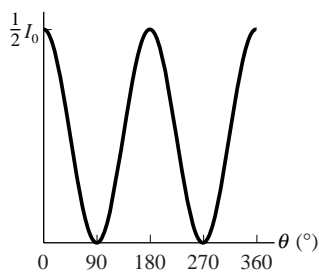
$$\frac{I_2}{I_0} = \frac{1}{2} \cos^2 30.0^\circ = \boxed{0.375}$$

67. $I_1 = \frac{1}{2} I_0$

$$I_2 = I_1 \cos^2 \theta = \frac{1}{2} I_0 \cos^2 \theta$$

$$\theta = \cos^{-1} \sqrt{\frac{2I_2}{I_0}} = \cos^{-1} \sqrt{2\left(\frac{1}{10}\right)} = \boxed{\cos^{-1} \frac{1}{\sqrt{5}}}$$

68. $I \text{ (W/m}^2\text{)}$



69. $I_1 = I_0 \cos^2 \theta_1$

$$I_2 = I_1 \cos^2 \theta_2 = I_0 \cos^2 \theta_1 \cos^2 \theta_2$$

(a) $\frac{I_2}{I_0} = \cos^2 45^\circ \cos^2 (90^\circ - 45^\circ) = \cos^4 45^\circ = 0.25$

(b) $\frac{I_2}{I_0} = \cos^2 45^\circ \cos^2 (0^\circ - 45^\circ) = \cos^4 45^\circ = 0.25$

(c) $\frac{I_2}{I_0} = \cos^2 45^\circ \cos^2 (45^\circ + 45^\circ) = \cos^2 45^\circ \cos^2 90^\circ = 0$

(c) is the smallest; (a) and (b) tie.

(b) (a) $I = \left(37.0 \frac{\text{W}}{\text{m}^2} \right) \cos^2 45^\circ \cos^2 (90^\circ - 45^\circ) = 9.25 \text{ W/m}^2$

(b) $I = \left(37.0 \frac{\text{W}}{\text{m}^2} \right) \cos^2 45^\circ \cos^2 (0^\circ - 45^\circ) = 9.25 \text{ W/m}^2$

(c) $I = \left(37.0 \frac{\text{W}}{\text{m}^2} \right) \cos^2 45^\circ \cos^2 (45^\circ + 45^\circ) = 0$

(c) is the smallest (0); (a) and (b) tie (9.25 W/m²). The results verify part (a).

70. $I_1 = I_0 \cos^2 \theta_1$

$$I_2 = I_1 \cos^2 \theta_2 = I_0 \cos^2 \theta_1 \cos^2 \theta_2$$

(a) $\frac{I_2}{I_0} = \cos^2 22.5^\circ \cos(90^\circ - 22.5^\circ) = \cos^2 22.5^\circ \cos^2 67.5^\circ = 0.125$

(b) $\frac{I_2}{I_0} = \cos^2 22.5^\circ \cos(0^\circ - 22.5^\circ) = \cos^4 22.5^\circ = 0.729$

(c) $\frac{I_2}{I} = \cos^2 22.5^\circ \cos(45^\circ + 22.5^\circ) = \cos^2 22.5^\circ \cos^2 67.5^\circ = 0.125$

(a) and (c) tie; (b) is the largest.

(b) (a) $I = \left(37.0 \frac{\text{W}}{\text{m}^2} \right) \cos^2 22.5^\circ \cos(90^\circ - 22.5^\circ) = 4.63 \text{ W/m}$

(b) $I = \left(37.0 \frac{\text{W}}{\text{m}^2} \right) \cos^2 22.5^\circ \cos(0^\circ - 22.5^\circ) = 27.0 \text{ W/m}$

(c) $I = \left(37.0 \frac{\text{W}}{\text{m}^2} \right) \cos^2 22.5^\circ \cos(45^\circ + 22.5^\circ) = 4.63 \text{ W/m}$

(a) and (c) tie (4.63 W/m); (b) is the largest (27.0 W/m). The results verify part (a).

71. (a) The greater intensity will be transmitted by the solution that rotates the polarization most nearly by 90° —that is, the d-glutamic acid solution.

(b) $I_l = \left(12.5 \frac{\text{W}}{\text{m}^2} \right) \left(\frac{1}{2} \right) \cos^2 (90.00^\circ + 0.550^\circ) = \boxed{0.576 \text{ mW/m}^2}$

$I_b = \left(12.5 \frac{\text{W}}{\text{m}^2} \right) \left(\frac{1}{2} \right) \cos^2 (90.00^\circ - 0.620^\circ) = \boxed{0.732 \text{ mW/m}^2}$

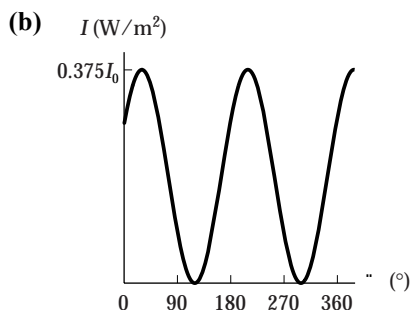
72. (a) $I = \boxed{\frac{1}{2} I_0}$

(b) $I = \frac{1}{2} I_0 \cos^2 30.0^\circ = \boxed{0.375 I_0}$

(c) $I = 0.375 I_0 \cos^2 (90.0^\circ - 30.0^\circ) = \boxed{0.0938 I_0}$

(d) $I = \frac{1}{2} I_0 \cos^2 90.0^\circ = \boxed{0}$

73. (a) $I = \frac{1}{2} I_0 \cos^2 30.0^\circ \cos^2 (\theta - 30.0^\circ) = \boxed{0.375 I_0 \cos^2 (\theta - 30.0^\circ)}$



The maximum value of $\cos^2 (\theta - 30.0^\circ)$ is 1.

So, $I_{\max} = \boxed{0.375 I_0}$.

(c) I is at its maximum when $\theta - 30.0^\circ = 0^\circ$ or 180.0° . So, $\theta_{\max} = \boxed{30.0^\circ \text{ or } 210.0^\circ}$.

74. $E_{\text{rms}} = \sqrt{\frac{I_{\text{av}}}{c\epsilon_0}} = \sqrt{\frac{1.00 \times 10^3 \frac{\text{W}}{\text{m}^2}}{(3.00 \times 10^8 \frac{\text{m}}{\text{s}})(8.85 \times 10^{-12} \frac{\text{C}^2}{\text{N}\cdot\text{m}^2})}} = \boxed{614 \text{ V/m}}$

$B_{\text{rms}} = \sqrt{\frac{\mu_0 I_{\text{av}}}{c}} = \sqrt{\frac{(4\pi \times 10^{-7} \frac{\text{T}\cdot\text{m}}{\text{A}})(1.00 \times 10^3 \frac{\text{W}}{\text{m}^2})}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}} = \boxed{2.05 \mu\text{T}}$

75. $\lambda = \frac{c}{f} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{1.50 \times 10^{19} \text{ Hz}} = \boxed{2.00 \times 10^{-11} \text{ m}}$

76. number of hydrogen atoms $= \frac{410 \text{ nm}}{0.10 \text{ nm}} = \boxed{4.1 \times 10^3}$

77. $\Delta x = c\Delta t = \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right)(0.030 \times 10^{-9} \text{ s}) = \boxed{9.0 \text{ mm}}$

78. $\lambda' = \lambda \left(1 - \frac{u}{c}\right)^{-1}$
 $\frac{\lambda}{\lambda'} = 1 - \frac{u}{c}$
 $u = c \left(1 - \frac{\lambda}{\lambda'}\right)$
 $= \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right) \left(1 - \frac{486 \text{ nm}}{486 \text{ nm} + 20.0 \text{ nm}}\right)$
 $= \boxed{1.2 \times 10^7 \text{ m/s away from Earth}}$

79. (a) $c = \frac{2d}{\Delta t}$ where $\Delta t = \frac{1}{\omega}$ rev, so $c = 16d\omega$

If d decreases, ω must increase.

(b) $\omega = \frac{c}{16d} = \frac{3.00 \times 10^8 \frac{\text{m}}{\text{s}}}{16(22.5 \times 10^3 \text{ m})} = \boxed{833 \text{ rev/s}}$

80. (a) Both arms show a red shift, because both arms have net motion away from Earth.

(b) $f' = f \left(1 - \frac{u}{c} \right) = (8.230 \times 10^{14} \text{ Hz}) \left(1 - \frac{3.600 \times 10^6 \frac{\text{m}}{\text{s}} - 6.400 \times 10^5 \frac{\text{m}}{\text{s}}}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} \right) = \boxed{8.149 \times 10^{14} \text{ Hz}}$

(c) $f' = (8.230 \times 10^{14} \text{ Hz}) \left(1 - \frac{3.600 \times 10^6 \frac{\text{m}}{\text{s}} + 6.400 \times 10^5 \frac{\text{m}}{\text{s}}}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} \right) = \boxed{8.114 \times 10^{14} \text{ Hz}}$

81. (a) Since the incident beam is not focused on a tiny spot, its intensity and therefore its E_{rms} are less than where the beam hits the retina.

(b) $E_{\text{rms}} = \sqrt{\frac{I_{\text{av}}}{c\epsilon_0}} = \sqrt{\frac{1.0 \times 10^2 \frac{\text{W}}{\text{m}^2}}{\left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right) \left(8.85 \times 10^{-12} \frac{\text{C}^2}{\text{N} \cdot \text{m}^2}\right)}} = \boxed{0.19 \text{ kV/m}}$

Notice the unit conversion for I_{av} .

(c) The area of the spot is reduced by a factor of four, and the intensity correspondingly increases by a factor of four. E_{rms} increases by the square root of that factor, namely by a factor of two.

82. (a) $I_1 = I_0 \cos^2 \theta_1$

$$\theta_1 = \cos^{-1} \sqrt{\frac{I_1}{I_0}} = \cos^{-1} \sqrt{\frac{212 \frac{\text{W}}{\text{m}^2}}{825 \frac{\text{W}}{\text{m}^2}}} = 59.54^\circ = \boxed{59.5^\circ}$$

(b) $I_2 = I_0 \cos^2(90^\circ - \theta_1) = I_0 \sin^2 \theta_1 = \left(825 \frac{\text{W}}{\text{m}^2}\right) \sin^2 59.54^\circ = \boxed{613 \frac{\text{W}}{\text{m}^2}}$

83. $f' = f \left(1 + \frac{u}{c} \right)$

$$f' - f = \frac{fu}{c} = \frac{(9.00 \times 10^9 \text{ Hz}) \left(35.0 \frac{\text{m}}{\text{s}}\right)}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} = \boxed{1050 \text{ Hz}}$$

$$f'' - f' = \frac{f'u}{c}$$

$$\begin{aligned}
 f'' - (f + 1050 \text{ Hz}) &= \frac{(f + 1050 \text{ Hz})u}{c} \\
 f'' - f' &= \frac{(f + 1050 \text{ Hz})u}{c} + 1050 \text{ Hz} \\
 &= \frac{(9.00 \times 10^9 \text{ Hz} + 1050 \text{ Hz})(35.0 \frac{\text{m}}{\text{s}})}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} + 1050 \text{ Hz} \\
 &= \boxed{2.10 \text{ kHz}}
 \end{aligned}$$

$$84. P_{\text{Sun}} = I_{\text{M}}(4\pi r_{\text{M}}^2) = I_{\text{E}}(4\pi r_{\text{E}}^2)$$

$$\frac{I_{\text{M}}}{I_{\text{E}}} = \left(\frac{r_{\text{E}}}{r_{\text{M}}}\right)^2 = \left(\frac{1}{0.39}\right)^2 = \boxed{6.6}$$

$$85. P = 0.800IA$$

$$A = \frac{P}{0.800I} = \frac{10.0 \times 10^3 \text{ W}}{0.800(1.00 \times 10^3 \frac{\text{W}}{\text{m}^2})} = \boxed{12.5 \text{ m}^2}$$

$$86. \text{ (a) } F = mg = (\text{Pressure}_{\text{av}})(\text{cross-sectional area of the sphere}) = \frac{I_{\text{av}}A}{c}$$

$$I_{\text{av}} = \frac{cmg}{A} = \frac{(3.00 \times 10^8 \frac{\text{m}}{\text{s}})(1.6 \times 10^{-15} \text{ kg})(9.81 \frac{\text{m}}{\text{s}^2})}{\pi(0.5 \times 10^{-6} \text{ m})^2} = \boxed{6 \text{ MW/m}^2}$$

Although a laser of this intensity can be built, the sphere may be destroyed by the laser.

(b) Since the intensity is inversely proportional to the square of the radius, doubling the radius while holding the mass fixed requires a minimum intensity which is less than that found in part (a).

$$\text{ (c) } I_{\text{av}} = \frac{(3.00 \times 10^8 \frac{\text{m}}{\text{s}})(1.6 \times 10^{-15} \text{ kg})(9.81 \frac{\text{m}}{\text{s}^2})}{\pi(1 \times 10^{-6} \text{ m})^2} = \boxed{1 \text{ MW/m}^2}$$

$$87. I_1 = \frac{1}{2}I_0$$

$$I_2 = I_1 \cos^2 \theta_2 = \frac{1}{2}I_0 \cos^2 \theta_2$$

$$I_3 = I_2 \cos^2(\theta_3 - \theta_2) = \frac{1}{2}I_0 \cos^2 \theta_2 \cos^2(\theta_3 - \theta_2)$$

$$\text{ (a) } I_3 = \frac{1}{2} \left(1.60 \frac{\text{W}}{\text{m}^2} \right) \cos^2 25.0^\circ \cos^2 25.0^\circ = \boxed{540 \text{ mW/m}^2}$$

$$\text{ (b) } I_3 = \frac{1}{2} \left(1.60 \frac{\text{W}}{\text{m}^2} \right) \cos^2 50.0^\circ \cos^2 (-25.0^\circ) = \boxed{272 \text{ mW/m}^2}$$

$$88. I_1 = I_0 \cos^2 \theta_1 = I_0 \cos^2 0^\circ = I_0$$

$$I_2 = I_1 \cos^2 \theta_2 = I_0 \cos^2 \theta_2$$

$$I_3 = I_2 \cos^2 (\theta_3 - \theta_2) = I_0 \cos^2 \theta_2 \cos^2 (\theta_3 - \theta_2)$$

$$(a) I_3 = \left(1.60 \frac{\text{W}}{\text{m}^2}\right) \cos^2 25.0^\circ \cos^2 25.0^\circ = \boxed{1.08 \text{ W/m}^2}$$

$$(b) I_3 = \left(1.60 \frac{\text{W}}{\text{m}^2}\right) \cos^2 50.0^\circ \cos^2 (-25.0^\circ) = \boxed{0.543 \text{ W/m}^2}$$

$$89. P_{\text{av}} = I_{\text{av}} A = c \epsilon_0 E_{\text{rms}}^2 A = \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right) \left(8.85 \times 10^{-12} \frac{\text{C}^2}{\text{N} \cdot \text{m}^2}\right) \left(18.0 \frac{\text{N}}{\text{C}}\right)^2 4\pi (1.85 \text{ m})^2 = \boxed{37.0 \text{ W}}$$

90. (a) If I_u equaled zero, setting the polarizer at an angle in the neighborhood of 45° would cut the transmitted intensity roughly in half. Since what actually happens is not too far from this, we can surmise that I_u is, if not zero, then at least less than I_p .

- (b) Solve the system.

$$\frac{1}{2} I_u + I_p \cos(0^\circ) = 16.8 \text{ W/m}^2$$

$$\frac{1}{2} I_u + I_p \cos(55.0^\circ) = 8.68 \text{ W/m}^2$$

to obtain

$$I_u = \boxed{9.4 \frac{\text{W}}{\text{m}^2}}$$

$$I_p = \boxed{12.1 \frac{\text{W}}{\text{m}^2}}$$

This confirms our conclusion in part (a).

$$91. (a) I_1 = I_0 \cos^2 \theta_1 \text{ and } I_2 = I_0 \cos^2 (90^\circ - \theta_1) = I_0 \sin^2 \theta_1.$$

$$I_1 + I_2 = I_0 (\cos^2 \theta_1 + \sin^2 \theta_1) = I_0$$

$$(b) I_0 = I_1 + I_2 = 183 \frac{\text{W}}{\text{m}^2} + 669 \frac{\text{W}}{\text{m}^2} = 852 \frac{\text{W}}{\text{m}^2}$$

$$\theta_1 = \cos^{-1} \sqrt{\frac{I_1}{I_0}} = \sqrt{\frac{183 \frac{\text{W}}{\text{m}^2}}{852 \frac{\text{W}}{\text{m}^2}}} = 62.4^\circ$$

To make $\theta_1 = 45.0^\circ$, the spider must rotate through $62.4^\circ - 45.0^\circ = \boxed{17.4^\circ}$.

$$92. E = 0.25 I A \Delta t$$

$$A = \frac{E}{0.25 I \Delta t} = \frac{2.00 \times 10^6 \text{ W} \cdot \text{h}}{0.25 \left(1.00 \times 10^3 \frac{\text{W}}{\text{m}^2}\right) (25 \text{ d}) \left(\frac{8.0 \text{ h}}{1 \text{ d}}\right)} = \boxed{40 \text{ m}^2}$$

$$93. P = IA = \left(1360 \frac{\text{W}}{\text{m}^2}\right) 4\pi(1.50 \times 10^{11} \text{ m})^2 = \boxed{3.85 \times 10^{26} \text{ W}}$$

$$94. \text{ (a) } I_{\text{av}} = \frac{P_{\text{av}}}{A} = \frac{0.75 \times 10^{-3} \text{ W}}{\pi \left(\frac{1.0 \times 10^{-3} \text{ m}}{2}\right)^2} = \boxed{950 \text{ W/m}^2}$$

$$\text{ (b) } I_{\text{peak}} = 2I_{\text{av}} = \boxed{1900 \text{ W/m}^2}$$

$$\text{ (c) } u_{\text{av}} = \frac{I_{\text{av}}}{c} = \frac{P_{\text{av}}}{Ac} = \frac{0.75 \times 10^{-3} \text{ W}}{\pi(0.50 \times 10^{-3} \text{ m})^2 \left(3.00 \times 10^8 \frac{\text{m}}{\text{s}}\right)} = \boxed{3.2 \mu\text{J/m}^3}$$

$$\text{ (d) } F_{\text{max}} = \frac{2I_{\text{peak}} A}{c} = \frac{4P_{\text{av}}}{c} = \frac{4(0.75 \times 10^{-3} \text{ W})}{3.00 \times 10^8 \frac{\text{m}}{\text{s}}} = \boxed{1.0 \times 10^{-11} \text{ N}}$$

$$\text{ (e) } \boxed{\text{The laser beam must be normal to the plane of the mirror.}}$$

$$95. I_1 = \frac{1}{2} I_0$$

$$I_2 = I_1 \cos^2 \theta = \frac{1}{2} I_0 \cos^2 \theta$$

$$I_3 = I_2 \cos^2 \theta = \frac{1}{2} I_0 \cos^4 \theta$$

$$I_4 = I_3 \cos^2 \theta = \frac{1}{2} I_0 \cos^6 \theta = \frac{1}{25} I_0$$

$$\cos^6 \theta = \frac{2}{25}$$

$$\theta = \cos^{-1} \left(\frac{2}{25} \right)^{1/6}$$

$$= \boxed{49^\circ}$$

$$96. \text{ (a) } I = \frac{1}{2} I_0 \text{ for the unpolarized incident light. So, } \boxed{50\%} \text{ will pass through the first filter.}$$

$$\text{ (b) } I = I_0 \cos^2 90^\circ = 0, \text{ so } \boxed{0\%} \text{ will pass through the second filter.}$$

$$\text{ (c) } 0.400 I_0 = 0.500 I_0 \cos^2 (90^\circ - \theta)$$

$$\cos^2 (90^\circ - \theta) = 0.800$$

$$\theta = 90^\circ - \cos^{-1} \sqrt{0.800}$$

$$= 90^\circ - 26.6^\circ$$

$$= \boxed{63.4^\circ}$$

$$\text{ (d) } I = \frac{1}{2} I_0 \cos^2 \left(90^\circ - \frac{63.4^\circ}{2} \right) = \boxed{0.138 I_0}$$