SOLUTIONS : PROBLEM SET 9

4. The wavelength of light traveling in water would decrease, since the wavelength of light in a medium is given by $\lambda = \lambda_0/n$, where λ_0 is the wavelength in vacuum and n is the index of refraction of the medium. Since the positions of the bright and dark fringes are proportional to the wavelength, the fringe separations would decrease.

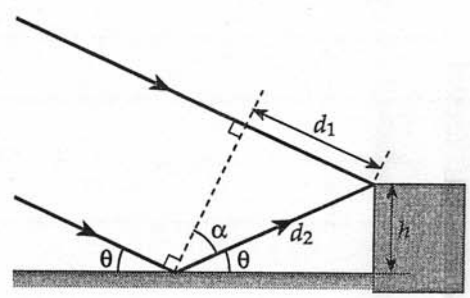
24.4 From $\left.y_{dark}\right| = \frac{\lambda L}{d}\left(m+\frac{1}{2}\right)$, the spacing between the first and second dark fringes is $\Delta y = \frac{\lambda L}{d}\left(\frac{3}{2}-\frac{1}{2}\right) = \frac{\lambda L}{d}$. Thus, the required distance to the screen is

$$L = \frac{(\Delta y)d}{\lambda} = \frac{\left(4.00\times10^{-3}\text{ m}\right)\left(0.300\times10^{-3}\text{ m}\right)}{460\times10^{-9}\text{ m}} = \boxed{2.61\text{ m}}$$

24.11 The distance between the central maximum (position of A) and the first minimum is $y = \left.\frac{\lambda L}{d}\left(m+\frac{1}{2}\right)\right|_{m=0} = \frac{\lambda L}{2d}$.

Thus, $d = \frac{\lambda L}{2y} = \frac{(3.00\text{ m})(150\text{ m})}{2(20.0\text{ m})} = \boxed{11.3\text{ m}}$

24.13 As shown in the figure at the right, the path difference in the waves reaching the telescope is $\delta = d_2 - d_1 = d_2(1-\sin\alpha)$. If the first minimum $(\delta = \lambda/2)$ occurs when $\theta = 25.0°$, then



$$\alpha = 180° - (\theta + 90.0° + \theta) = 40.0°\text{, and}$$

$$d_2 = \frac{\delta}{1-\sin\alpha} = \frac{(250\text{ m}/2)}{1-\sin 40.0°} = 350\text{ m}$$

Thus, $h = d_2 \sin 25.0° = \boxed{148\text{ m}}$

6. The speed of light in a vacuum is the same for all observers regardless the relative motion of the observers. Therefore the three observers must agree on the speed of the light pulse emitted by the rocket.

10. The clock in orbit will run more slowly. The extra centripetal acceleration of the orbiting clock makes its history fundamentally different from that of the clock on Earth.

26.6 (a) The time for 70 beats, as measured by the astronaut and any observer at rest with respect to the astronaut, is $\Delta t_p = 1.0\text{ min}$. The observer in the ship then measures a rate of $\boxed{70\text{ beats/min}}$.

(b) The observer on Earth moves at $v = 0.90c$ relative to the astronaut and measures the time for 70 beats as

$$\Delta t = \gamma \Delta t_p = \frac{\Delta t_p}{\sqrt{1-(v/c)^2}} = \frac{1.0\text{ min}}{\sqrt{1\text{-}(0.90)^2}} = 2.3\text{ min}$$

This observer then measures a beat rate of $\frac{70\text{ beats}}{2.3\text{ min}} = \boxed{31\text{ beats/min}}$

26.11 The proper length of the faster ship is three times that of the slower ship $\left(L_{pf} = 3L_{ps}\right)$, yet they both appear to have the same contracted length, L. Thus,

$$L = L_{ps}\sqrt{1-(v_s/c)^2} = (3L_{ps})\sqrt{1-(v_f/c)^2}\text{, or } 1-(v_s/c)^2 = 9-9(v_f/c)^2$$

This gives $v_f = \frac{c\sqrt{8+(v_s/c)^2}}{3} = \frac{\sqrt{8+(0.350)^2}}{3}c = 0.950c$

26.16 (a) $\Delta t = \gamma \Delta t_p = \frac{\Delta t_p}{\sqrt{1-(v/c)^2}} = \frac{15.0\text{ yr}}{\sqrt{1-(0.700)^2}} = \boxed{21.0\text{ yr}}$

(b) $d = v(\Delta t) = [0.700c](21.0\text{ yr}) = [(0.700)(1.00\text{ ly/yr})](21.0\text{ yr}) = \boxed{14.7\text{ ly}}$

(c) The astronauts see Earth flying out the back window at $0.700c$:

$$d = v(\Delta t_p) = [0.700c](15.0\text{ yr}) = [(0.700)(1.00\text{ ly/yr})](15.0\text{ yr}) = \boxed{10.5\text{ ly}}$$

(d) Mission control gets signals for 21.0 yr while the battery is operating, and then for 14.7 yr after the battery stops powering the transmitter, 14.7 ly away:
$21.0\text{ yr} + 14.7\text{ yr} = \boxed{35.7\text{ yr}}$

16. The electron behaves like a particle as it follows a circular orbit in a magnetic field or as it is ejected from a metal surface in the photoelectric effect. It behaves like a wave in forming an interference pattern.

27.37 (a) The momentum of the electron would be

$$p = \frac{h}{\lambda} \geq \frac{6.63\times10^{-34}\ \text{J}\cdot\text{s}}{10^{-14}\ \text{m}} \sim 7\times10^{-20}\ \text{kg}\cdot\text{m/s}$$

If the electron is nonrelativistic, then its speed would be

$$v = \frac{p}{m_e} \sim \frac{7\times10^{-20}\ \text{kg}\cdot\text{m/s}}{9.11\times10^{-31}\ \text{kg}} \sim 8\times10^{10}\ \text{m/s} \gg c$$

which is impossible. Thus, a relativistic calculation is required.

With a rest energy of $E_R = 0.511\ \text{MeV} \approx 8\times10^{-14}\ \text{J}$, its kinetic energy is

$$KE = E - E_R = \sqrt{p^2c^2 + E_R^2} - E_R$$

Thus, $KE \sim \sqrt{\left(7\times10^{-20}\ \text{kg}\cdot\text{m/s}\right)^2\left(3\times10^8\ \text{m/s}\right)^2 + \left(8\times10^{-14}\ \text{J}\right)^2} - 8\times10^{-14}\ \text{J}$

or $KE \sim 2\times10^{-11}\ \text{J}\left(\frac{1\ \text{MeV}}{1.60\times10^{-13}\ \text{J}}\right) \rightarrow \boxed{\sim 10^2\ \text{MeV}}$ or more

27.44 (a) With uncertainty Δx in position, the minimum uncertainty in the speed is

$$\Delta v = \frac{\Delta p}{m} \geq \frac{h}{4\pi m(\Delta x)} = \frac{2\pi\ \text{J}\cdot\text{s}}{4\pi(2.00\ \text{kg})(1.00\ \text{m})} = \boxed{0.250\ \text{m/s}}$$

(b) Fuzzy might move by $(0.250\ \text{m/s})(5.00\ \text{s}) = 1.25\ \text{m}$. With original uncertainty of 1.00 m, we can think of Δx growing to

$$1.00\ \text{m} + 1.25\ \text{m} = \boxed{2.25\ \text{m}}$$