CHAPTER 5 SOLUTIONS

PHYSICS 1a

5.3

Just before the pebble (of mass $m = 25\,\text{g} = 0.025\,\text{kg}$) flies out tangentially, it was undergoing circular motion under the influence of a centripetal force F_c (= 20 N). Thus its speed v as it flies out satisfies $F_c = mv^2/R$, where $R = \frac{1}{2}(28\,\text{in.}) = \frac{1}{2}(28\,\text{in.})(0.0254\,\text{m/in.}) = 0.3556\,\text{m}$. So

$$v = \sqrt{\frac{F_c R}{m}} = \sqrt{\frac{(20\,\text{N})(0.3556\,\text{m})}{0.025\,\text{kg}}} = 17\,\text{m/s}\,.$$

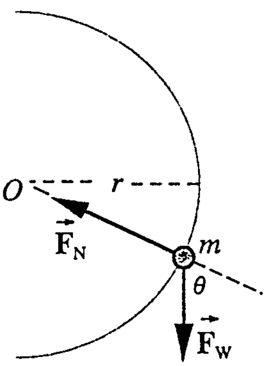
5.9

Each time the hammer travels once around a circle of radius r, it covers a distance of $2\pi r$; so in $T = 1.0\,\text{s}$ it covers a total distance of $l = 2.0(2\pi r) = 4.0\pi r$. Here $r = (6.0\,\text{ft})(0.3048\,\text{m/ft}) = 1.8288\,\text{m}$. The speed v of the hammer is $v = l/T = 4.0\pi r/T = (4.0\pi)(1.8288\,\text{m})/1.0\,\text{s} = 22.98\,\text{m/s}$. The mass m of the hammer can be obtained from its weight, F_W: $m = F_W/g = (16\,\text{lb})(4.448\,\text{N/lb})/(9.81\,\text{m/s}^2) = 7.255\,\text{kg}$. Hence

$$F_c = \frac{mv^2}{r} = \frac{(7.255\,\text{kg})(22.98\,\text{m/s})^2}{1.8288\,\text{m}} = 2.1 \times 10^3\,\text{N} = 2.1\,\text{kN}\,.$$

5.13

The Teddy bear (of mass m) is moving in a vertical circle of radius r. In addition to its weight, $F_W = mg$, it is also subject to F_N, the normal force from the wall of the washer. The net force exerted on the Teddy bear pointing into the center of the circle of radius R in which the Teddy bear moves is then $F_c = F_N - mg\cos\theta$. Let $F_c = mv^2/r$, where $v = 2\pi r/1.0\,\text{s} = 2\pi(0.40\,\text{m})/1.0\,\text{s} = 2.51\,\text{m/s}$, and solve for F_N: $F_N = m(v^2/r + g\cos\theta)$. To obtain the maximum value of F_c, set $\theta = 0$:



$$F_c(\text{max}) = m\left(\frac{v^2}{r} + g\right) = (4.5\,\text{kg})\left[\frac{(2.51\,\text{m/s})^2}{0.40\,\text{m}} + 9.81\,\text{m/s}^2\right] = 1.2 \times 10^2\,\text{N} = 0.12\,\text{kN}\,.$$

Lacking enough centripetal force to keep them in circular motion, the water drops fly out of the of the drum through the holes, leaving the clothes dry.

5.21

(a) The spin of the space station creates a centripetal acceleration, which simulates gravity. So $a_c = v^2/r = 1.0g$, where $r = \frac{1}{2}(1500\,\text{m}) = 750.0\,\text{m}$ and v is the speed of a point at the periphery. Suppose that the station spins once during time interval T, then $v = 2\pi r/T$ (since the distance covered per revolution by a point at the periphery is $2\pi r$). Substitute this expression for v into the equation for a_c: $a_c = (2\pi r/T)^2/r = 1.0g$. Solve for T:

$$T = 2\pi\sqrt{\frac{r}{1.0g}} = 2\pi\sqrt{\frac{750.0\,\text{m}}{1.0(9.81\,\text{m/s}^2)}} = 55\,\text{s},$$

i.e., the spin rate is $1\,\text{rev}/55\,\text{s} = 0.018\,\text{rev/s}$.

(b) From part (a) above we see that

$$a_c = \frac{(2\pi r/T)^2}{r} \propto r,$$

so the simulated gravity, which is equal to a_c, is directly proportional to r, decreasing linearly with the distance "up" from the floor.

5.25

According to Eq. (5.7) the weight F_W of an object of mass m placed at a distance r from the center of the Earth is given by $F_W = mg_\oplus = GmM_\oplus/r^2$. If both m and r are doubled, then its new weight is

$$F'_W = \frac{G(2m)M_\oplus}{(2r)^2} = \frac{1}{2}\left(\frac{GmM_\oplus}{r^2}\right) = \frac{1}{2}F_W.$$

5.27

Put $m = M$ in Eq. (5.5) to obtain $F_G = Gm^2/r^2$. Solve for m, the mass of each sphere:

$$m = r\sqrt{\frac{F_G}{G}} = (1.00\,\text{m})\sqrt{\frac{1.00\,\text{N}}{6.67\times10^{-11}\,\text{N}\cdot\text{m}^2/\text{kg}^2}} = 1.22\times10^5\,\text{kg}.$$

5.31

The gravitational attraction between Uranus (U) and Neptune (N) is given by

$$F_G = \frac{GM_UM_N}{r_{UN}^2} = \frac{G(14.6M_\oplus)(17.3M_\oplus)}{r_{UN}^2}$$
$$= \frac{(6.67\times10^{-11}\,\text{N}\cdot\text{m}^2/\text{kg}^2)(14.6)(17.3)(5.975\times10^{24}\,\text{kg})^2}{(4.9\times10^{12}\,\text{m})^2}$$
$$= 2.5\times10^{16}\,\text{N}.$$

5.37

The acceleration of gravity on the surface of Mars (M) is given by $g_M = GM_M/R_M^2$. Solve for M_M:

$$M_M = \frac{g_M R_M^2}{G} = \frac{(3.7\,\text{m/s}^2)(6.8 \times 10^6\,\text{m}/2)^2}{6.67 \times 10^{-11}\,\text{N}\cdot\text{m}^2/\text{kg}^2} = 6.4 \times 10^{23}\,\text{kg}\,.$$

In terms of $M_\oplus$, this is $(6.4 \times 10^{23}\,\text{kg})(M_\oplus/5.975 \times 10^{24}\,\text{kg}) = 0.11 M_\oplus$.

5.41

The mass of Venus (V) is given by $M_V = \rho_V V_V = \rho_V(4\pi R_V^3/3) = (5.2 \times 10^3\,\text{kg/m}^3)[4\pi(12.1 \times 10^6\,\text{m}/2)^3/3] = 4.82 \times 10^{24}\,\text{kg}$. Thus the acceleration of gravity at the surface of Venus is given by

$$g_V = \frac{GM_V}{R_V}^2 = \frac{(6.67 \times 10^{-11}\,\text{N}\cdot\text{m}^2/\text{kg}^2)(4.82 \times 10^{24}\,\text{kg})}{(12.1 \times 10^6\,\text{m}/2)^2} = 8.79\,\text{m/s}^2\,.$$

From $s = \frac{1}{2}gt^2$ we then find s, the distance an apple would fall in $t = 1.0\,\text{s}$ at its surface:

$$s = \frac{1}{2}gt^2 = \frac{1}{2}(8.79\,\text{m/s}^2)(1.0\,\text{s})^2 = 4.4\,\text{m}\,.$$

5.49

The volume V of a spherical neutron star of radius R is $V = 4\pi R^3/3$. Therefore its mass M_n is given by $M_n = \rho_n V = 4\pi\rho_n R^3/3$. Let $M_n = M_\odot$ and solve for R:

$$R = \left(\frac{3M_\odot}{4\pi\rho_n}\right)^{1/3} = \left[\frac{3(2.0 \times 10^{30}\,\text{kg})}{4\pi(3 \times 10^{17}\,\text{kg/m}^3)}\right]^{1/3} = 1.168 \times 10^4\,\text{m} = 11.68\,\text{km}\,.$$

In Newtonian mechanics, the acceleration of gravity at the surface of the star is then

$$g_n = \frac{GM_\odot}{R^2} = \frac{(6.67 \times 10^{-11}\,\text{N}\cdot\text{m}^2/\text{kg}^2)(2.0 \times 10^{30}\,\text{kg})}{(1.168 \times 10^4\,\text{m})^2} = 1 \times 10^{12}\,\text{m/s}^2\,.$$

5.66

From Eq. (5.10) (Kepler's Third Law), we may solve for $M_\odot$:

$$M_\odot = \frac{4\pi^2 r_\odot^3}{T^2 G} = \frac{4\pi^2(1.495 \times 10^{11}\,\text{m})^3}{(3.16 \times 10^7\,\text{s})^2(6.67 \times 10^{-11}\,\text{m}^3/\text{kg}\cdot\text{s}^2)} = 2.00 \times 10^{30}\,\text{kg}\,,$$

where we used the data for the Earth-Sun distance $(1.495 \times 10^{11}\,\text{m})$ and one Earth-year $(365.25\,\text{d} = 3.16 \times 10^7\,\text{s})$.

5.70

The radius of the orbital of *Sputnik I*, in meters, was $r_\oplus = 6950\,\text{km} = 6.950 \times 10^6\,\text{m}$. Thus from the result of the previous problem

$$T = 3.15 \times 10^{-7} \left(r_\oplus\right)^{3/2} = (3.15 \times 10^{-7})\left(6.950 \times 10^6\right)^{3/2}\,\text{s} = 5.77 \times 10^3\,\text{s},$$

or 96.2 min.

5.82

Apply Newton's Law of Universal Gravitation to the orbital motion of the star (of mass m) about M31, whose mass is denoted as M: $F_G = GmM/r^2 = F_c = mv^2/r$. Here $r = (5 \times 10^9\,\text{AU})(1.495 \times 10^{11}\,\text{m/AU}) = 7.475 \times 10^{20}\,\text{m}$ is the orbital radius of the star, and $v = 200\,\text{km/s} = 2 \times 10^5\,\text{m/s}$. Solve for M:

$$M = \frac{v^2 r}{G} = \frac{(2 \times 10^5\,\text{m/s})^2 (7.475 \times 10^{20}\,\text{m})}{6.67 \times 10^{-11}\,\text{m}^3/\text{kg}\cdot\text{s}^2} = 4 \times 10^{41}\,\text{kg},$$

which is equivalent to about 2×10^{11} (two hundred billion) solar masses.

5.86

The respective distances r_A and r_B of stars A and B to their barycenter satisfy $r_A + r_B = 2.99 \times 10^{12}\,\text{m}$ and $r_B = 2r_A$, so the result of Problem (5.79) reads

$$\frac{m_B}{m_A} = \frac{r_A}{r_B} = \frac{1}{2};$$

and that of Problem (5.80) reads

$$\begin{aligned} m_A + m_B &= \frac{4\pi^2 (r_A + r_B)^3}{GT^2} \\ &= \frac{4\pi^2 (2.99 \times 10^{12}\,\text{m})^3}{(6.67 \times 10^{-11}\,\text{m}^3/\text{kg}\cdot\text{s}^2)\left[(50\,\text{y})(3.16 \times 10^7\,\text{s/y})\right]^2} \\ &= 6.35 \times 10^{30}\,\text{kg}. \end{aligned}$$

Solve for m_A and m_B: $m_A = 4.2 \times 10^{30}\,\text{kg}$, $m_B = 2.1 \times 10^{30}\,\text{kg}$. In terms of solar masses ($M_\odot = 2.0 \times 10^{30}\,\text{kg}$), $m_A \approx 2M_\odot$ and $m_B \approx 1M_\odot$.