

CHAPTER 5

1. The centripetal acceleration is

$$a_R = v^2/r = (500 \text{ m/s})^2/(6.00 \times 10^3 \text{ m})(9.80 \text{ m/s}^2/g) = 4.25g \text{ up.}$$

2. (a) The centripetal acceleration is

$$a_R = v^2/r = (1.35 \text{ m/s})^2/(1.20 \text{ m}) = 1.52 \text{ m/s}^2 \text{ toward the center.}$$

- (b) The net horizontal force that produces this acceleration is

$$F_{\text{net}} = ma_R = (25.0 \text{ kg})(1.52 \text{ m/s}^2) = 38.0 \text{ N toward the center.}$$

3. The centripetal acceleration of the Earth is

$$a_R = v^2/r = (2\pi r/T)^2/r = 4\pi^2 r/T^2 \\ = 4\pi^2(1.50 \times 10^{11} \text{ m})/(3.16 \times 10^7 \text{ s})^2 = 5.93 \times 10^{-3} \text{ m/s}^2 \text{ toward the Sun.}$$

The net force that produces this acceleration is

$$F_{\text{net}} = m_E a_R = (5.98 \times 10^{24} \text{ kg})(5.93 \times 10^{-3} \text{ m/s}^2) = 3.55 \times 10^{22} \text{ N toward the Sun.}$$

This force is the gravitational attraction from the Sun.

4. The force on the discus produces the centripetal acceleration:

$$F = ma_R = mv^2/r; \\ 280 \text{ N} = (2.0 \text{ kg})v^2/(1.00 \text{ m}), \text{ which gives } v = 12 \text{ m/s.}$$

5. We write
- $\Sigma \mathbf{F} = m\mathbf{a}$
- from the force diagram for the stationary hanging mass, with down positive:

$$mg - F_T = ma = 0; \text{ which gives}$$

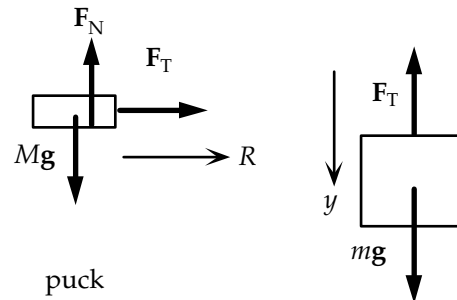
$$F_T = mg.$$

For the rotating puck, the tension provides the centripetal acceleration, $\Sigma F_R = Ma_R$:

$$F_T = Mv^2/R.$$

When we combine the two equations, we have

$$Mv^2/R = mg, \text{ which gives } v = (mgR/M)^{1/2}.$$



6. For the rotating ball, the tension provides the centripetal acceleration,
- $\Sigma F_R = Ma_R$
- :

$$F_T = Mv^2/R.$$

We see that the tension increases if the speed increases, so the maximum tension determines the maximum speed:

$$F_{T\text{max}} = Mv_{\text{max}}^2/R;$$

$$60 \text{ N} = (0.40 \text{ kg})v_{\text{max}}^2/(1.3 \text{ m}), \text{ which gives } v_{\text{max}} = 14 \text{ m/s.}$$

If there were friction, it would be kinetic opposing the motion of the ball around the circle. Because this is perpendicular to the radius and the tension, it would have no effect.

7. If the car does not skid, the friction is static, with $F_{\text{fr}} = \mu_s F_N$.

This friction force provides the centripetal acceleration.

We take a coordinate system with the x -axis in the direction of the centripetal acceleration.

We write $\sum \mathbf{F} = m\mathbf{a}$ from the force diagram for the auto:

$$x\text{-component: } F_{\text{fr}} = ma = mv^2/R;$$

$$y\text{-component: } F_N - mg = 0.$$

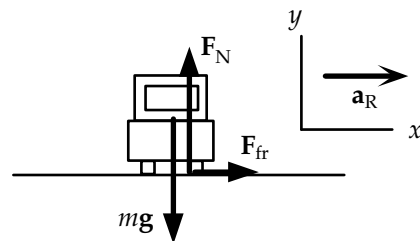
The speed is maximum when $F_{\text{fr}} = F_{\text{fr,max}} = \mu_s F_N$.

When we combine the equations, the mass cancels, and we get

$$\mu_s g = v_{\text{max}}^2/R;$$

$$(0.80)(9.80 \text{ m/s}^2) = v_{\text{max}}^2/(70 \text{ m}), \text{ which gives } v_{\text{max}} = 23 \text{ m/s}.$$

The mass canceled, so the result is independent of the mass.



8. At each position we take the positive direction in the direction of the acceleration.

- (a) At the top of the path, the tension and the weight are downward.

We write $\sum \mathbf{F} = m\mathbf{a}$ from the force diagram for the ball:

$$F_{T1} + mg = mv^2/R;$$

$$F_{T1} + (0.300 \text{ kg})(9.80 \text{ m/s}^2) = (0.300 \text{ kg})(4.15 \text{ m/s})^2/(0.850 \text{ m}),$$

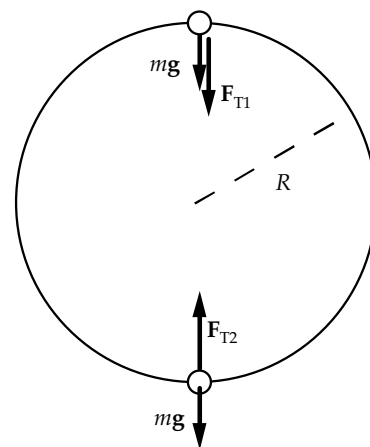
which gives $F_{T1} = 3.14 \text{ N}$.

- (b) At the bottom of the path, the tension is upward and the weight is downward. We write $\sum \mathbf{F} = m\mathbf{a}$ from the force diagram for the ball:

$$F_{T2} - mg = mv^2/R;$$

$$F_{T2} - (0.300 \text{ kg})(9.80 \text{ m/s}^2) = (0.300 \text{ kg})(4.15 \text{ m/s})^2/(0.850 \text{ m}),$$

which gives $F_{T2} = 9.02 \text{ N}$.



9. The friction force provides the centripetal acceleration.

We take a coordinate system with the x -axis in the direction of the centripetal acceleration.

We write $\sum \mathbf{F} = m\mathbf{a}$ from the force diagram for the auto:

$$x\text{-component: } F_{\text{fr}} = ma = mv^2/R;$$

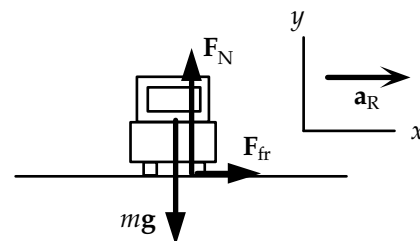
$$y\text{-component: } F_N - mg = 0.$$

If the car does not skid, the friction is static, with $F_{\text{fr}} = \mu_s F_N$.

Thus we have

$$mv^2/R = \mu_s mg, \text{ or}$$

$$\mu_s = v^2/gR = [(95 \text{ km/h})/(3.6 \text{ ks/h})]^2/(9.80 \text{ m/s}^2)(85 \text{ m}). \text{ Thus } \mu_s = 0.84.$$



10. The horizontal force on the astronaut produces the centripetal acceleration:

$$F = ma_R = mv^2/r;$$

$$(7.75)(2.0 \text{ kg})(9.80 \text{ m/s}^2) = (2.0 \text{ kg})v^2/(10.0 \text{ m}), \text{ which gives } v = 27.6 \text{ m/s}.$$

The rotation rate is

$$\text{Rate} = v/2\pi r = (27.6 \text{ m/s})/(2\pi(10.0 \text{ m})) = 0.439 \text{ rev/s}.$$

Note that the results are independent of mass, and thus are the same for all astronauts.

11. The static friction force provides the centripetal acceleration.

We write $\Sigma \mathbf{F} = m\mathbf{a}$ from the force diagram for the coin:

$$x\text{-component: } F_{\text{fr}} = mv^2/R;$$

$$y\text{-component: } F_N - mg = 0.$$

The highest speed without sliding requires $F_{\text{fr,max}} = \mu_s F_N$.

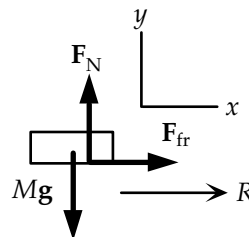
The maximum speed before sliding is

$$\begin{aligned} v_{\text{max}} &= 2\pi R/T_{\text{min}} = 2\pi R f_{\text{max}} \\ &= 2\pi(0.110 \text{ m})(36/\text{min})/(60 \text{ min/s}) = 0.415 \text{ m/s}. \end{aligned}$$

Thus we have

$$\mu_s mg = mv_{\text{max}}^2/R$$

$$\mu_s(9.80 \text{ m/s}^2) = (0.415 \text{ m/s})^2/(0.110 \text{ m}), \text{ which gives } \mu_s = 0.16.$$



12. At the top of the trip, both the normal force and the weight are downward.

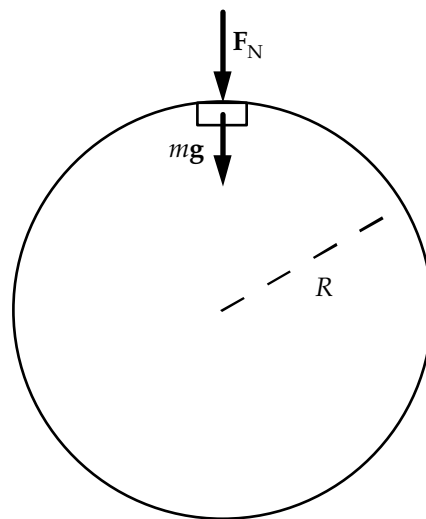
We write $\Sigma \mathbf{F} = m\mathbf{a}$ from the force diagram for the passenger:

$$y\text{-component: } F_N + mg = mv^2/R.$$

The speed v will be minimum when the normal force is minimum. The normal force can only push away from the seat, that is, with our coordinate system it must be positive, so $F_{N\text{min}} = 0$.

Thus we have $v_{\text{min}}^2 = gR$, or

$$\begin{aligned} v_{\text{min}} &= (gR)^{1/2} \\ &= [(9.80 \text{ m/s}^2)(8.6 \text{ m})]^{1/2} = 9.2 \text{ m/s}. \end{aligned}$$



13. At the top of the hill, the normal force is upward and the weight is downward, which we select as the positive direction.

(a) We write $\Sigma \mathbf{F} = m\mathbf{a}$ from the force diagram for the car:

$$m_{\text{car}}g - F_{N\text{car}} = mv^2/R;$$

$$(1000 \text{ kg})(9.80 \text{ m/s}^2) - F_{N\text{car}} = (1000 \text{ kg})(20 \text{ m/s})^2/(100 \text{ m}),$$

$$\text{which gives } F_{N\text{car}} = 5.8 \times 10^3 \text{ N}.$$

(b) When we apply a similar analysis to the driver, we have

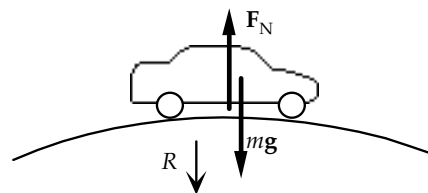
$$(70 \text{ kg})(9.80 \text{ m/s}^2) - F_{N\text{pass}} = (70 \text{ kg})(20 \text{ m/s})^2/(100 \text{ m}),$$

$$\text{which gives } F_{N\text{pass}} = 4.1 \times 10^2 \text{ N}.$$

(c) For the normal force to be equal to zero, we have

$$(1000 \text{ kg})(9.80 \text{ m/s}^2) - 0 = (1000 \text{ kg})v^2/(100 \text{ m}),$$

$$\text{which gives } v = 31 \text{ m/s} \quad (110 \text{ km/h or } 70 \text{ mi/h}).$$



14. To feel “weightless” the normal force will be zero and the only force acting on a passenger will be that from gravity, which provides the centripetal acceleration:

$$mg = mv^2/R, \text{ or } v^2 = gR;$$

$$v^2 = (9.80 \text{ m/s}^2)(50 \text{ ft})(0.305 \text{ m/ft}), \text{ which gives } v = 8.64 \text{ m/s}.$$

We find the rotation rate from

$$\text{Rate} = v/2\pi R = [(8.64 \text{ m/s})/2\pi(50 \text{ ft})(0.305 \text{ m/ft})](60 \text{ s/min}) = 11 \text{ rev/min}.$$

15. We check the form of $a_R = v^2/r$ by using the dimensions of each variable:

$$[a_R] = [v/t] = [d/t^2] = [L/T^2];$$

$$[v^2] = [(d/t)^2] = [(L/T)^2] = [L^2/T^2];$$

$$[r] = [d] = [L].$$

Thus we have $[v^2/r] = [L^2/T^2]/[L] = [L/T^2]$, which are the dimensions of a_R .

16. The masses will have different velocities:

$$v_1 = 2\pi r_1/T = 2\pi r_1 f; \quad v_2 = 2\pi r_2/T = 2\pi r_2 f.$$

We choose the positive direction toward the center of the circle.

For each mass we write $\Sigma F_r = ma_r$:

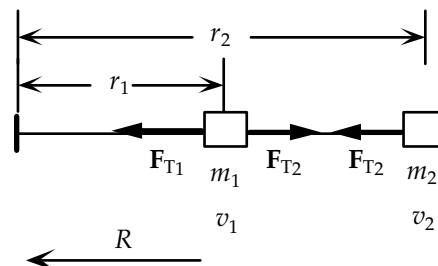
$$m_1: F_{T1} - F_{T2} = m_1 v_1^2/r_1 = 4\pi^2 m_1 r_1 f^2;$$

$$m_2: F_{T2} = m_2 v_2^2/r_2 = 4\pi^2 m_2 r_2 f^2.$$

When we use this in the first equation, we get

$$F_{T1} = F_{T2} + 4\pi^2 m_1 r_1 f^2; \text{ thus}$$

$$F_{T1} = 4\pi^2 f^2 (m_1 r_1 + m_2 r_2); \quad F_{T2} = 4\pi^2 f^2 m_2 r_2.$$



17. We convert the speed: $(90 \text{ km/h})/(3.6 \text{ ks/h}) = 25 \text{ m/s}$.

We take the x -axis in the direction of the centripetal acceleration. We find the speed when there is no need for a friction force.

We write $\Sigma F = ma$ from the force diagram for the car:

$$x\text{-component: } F_{N1} \sin \theta = ma_1 = mv_1^2/R;$$

$$y\text{-component: } F_{N1} \cos \theta - mg = 0.$$

Combining these, we get

$$v_1^2 = gR \tan \theta = (9.80 \text{ m/s}^2)(70 \text{ m}) \tan 12^\circ,$$

which gives $v_1 = 12.1 \text{ m/s}$. Because the speed is greater than this, a friction force is required. Because the car will tend to slide up the slope, the friction force will be down the slope. We write $\Sigma F = ma$ from the force diagram for the car:

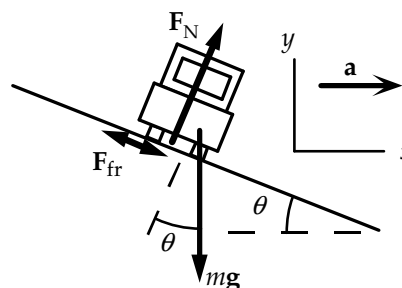
$$x\text{-component: } F_{N2} \sin \theta + F_{fr} \cos \theta = ma_2 = mv_2^2/R;$$

$$y\text{-component: } F_{N2} \cos \theta - F_{fr} \sin \theta - mg = 0.$$

We eliminate F_{N2} by multiplying the x -equation by $\cos \theta$, the y -equation by $\sin \theta$, and subtracting:

$$F_{fr} = m\{[(v_2^2/R) \cos \theta] - g \sin \theta\}$$

$$= (1200 \text{ kg})\{[(25 \text{ m/s})^2/(70 \text{ m})] \cos 12^\circ\} - (9.80 \text{ m/s}^2) \sin 12^\circ = 8.0 \times 10^3 \text{ N down the slope.}$$



18. The velocity of the people is

$$v = 2\pi R/T = 2\pi Rf = 2\pi(5.0 \text{ m/rev})(0.50 \text{ rev/s}) = 15.7 \text{ m/s}.$$

The force that prevents slipping is an upward friction force.

The normal force provides the centripetal acceleration.

We write $\Sigma F = ma$ from the force diagram for the person:

$$x\text{-component: } F_N = mv^2/R;$$

$$y\text{-component: } F_{fr} - mg = 0.$$

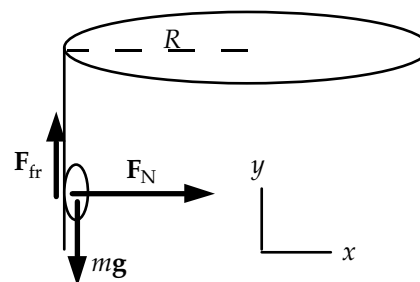
Because the friction is static, we have

$$F_{fr} \leq \mu_s F_N, \text{ or } mg \leq \mu_s mv^2/R.$$

Thus we have

$$\mu_s \geq gR/v^2 = (9.80 \text{ m/s}^2)(5.0 \text{ m})/(15.7 \text{ m/s})^2 = 0.20.$$

There is no force pressing the people against the wall. They feel the normal force and thus are applying



the reaction to this, which is an outward force on the wall. There is no horizontal force on the people except the normal force.

19. The mass moves in a circle of radius r and has a centripetal acceleration.

We write $\mathbf{F} = m\mathbf{a}$ from the force diagram for the mass:

$$x\text{-component: } F_T \cos \theta = mv^2/r;$$

$$y\text{-component: } F_T \sin \theta - mg = 0.$$

Combining these, we get

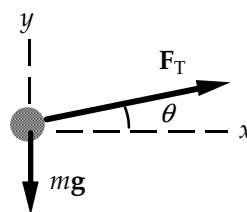
$$rg = v^2 \tan \theta,$$

$$(0.600 \text{ m})(9.80 \text{ m/s}^2) = (7.54 \text{ m/s})^2 \tan \theta, \text{ which gives}$$

$$\tan \theta = 0.103, \text{ or } \theta = 5.91^\circ.$$

We find the tension from

$$F_T = mg / \sin \theta = (0.150 \text{ kg})(9.80 \text{ m/s}^2) / \sin 5.91^\circ = 14.3 \text{ N}.$$



20. We convert the speeds:

$$(70 \text{ km/h}) / (3.6 \text{ ks/h}) = 19.4 \text{ m/s};$$

$$(90 \text{ km/h}) / (3.6 \text{ ks/h}) = 25.0 \text{ m/s}.$$

At the speed for which the curve is banked perfectly, there is no need for a friction force. We take the x -axis in the direction of the centripetal acceleration.

We write $\mathbf{F} = m\mathbf{a}$ from the force diagram for the car:

$$x\text{-component: } F_{N1} \sin \theta = ma_1 = mv_1^2/R;$$

$$y\text{-component: } F_{N1} \cos \theta - mg = 0.$$

Combining these, we get $v_1^2 = gR \tan \theta$.

$$(19.4 \text{ m/s})^2 = (80 \text{ m})(9.80 \text{ m/s}^2) \tan \theta, \text{ which gives}$$

$$\tan \theta = 0.482, \text{ or } \theta = 25.7^\circ.$$

At a higher speed, there is need for a friction force, which will be down the incline. If the automobile does not skid, the friction is static, with $F_{fr} \leq \mu_s F_N$.

We write $\mathbf{F} = m\mathbf{a}$ from the force diagram for the car:

$$x\text{-component: } F_{N2} \sin \theta + F_{fr} \cos \theta = ma_2 = mv_2^2/R;$$

$$y\text{-component: } F_{N2} \cos \theta - F_{fr} \sin \theta - mg = 0.$$

We eliminate F_{fr} by multiplying the x -equation by $\sin \theta$, the y -equation by $\cos \theta$, and adding:

$$F_{N2} = m \{ [(v_2^2/R) \sin \theta] + g \cos \theta \}.$$

By reversing the trig multipliers and subtracting, we eliminate F_{N2} to get

$$F_{fr} = m \{ [(v_2^2/R) \cos \theta] - g \sin \theta \}.$$

If the automobile does not skid, the friction is static, with $F_{fr} \leq \mu_s F_N$:

$$m \{ [(v_2^2/R) \cos \theta] - g \sin \theta \} \leq \mu_s m \{ [(v_2^2/R) \sin \theta] + g \cos \theta \}, \text{ or}$$

$$\mu_s \{ [(v_2^2/R) \cos \theta] - g \sin \theta \} \leq \{ [(v_2^2/R) \sin \theta] + g \cos \theta \} = [(v_2^2/gR)] - \tan \theta / \{ [(v_2^2/gR) \tan \theta] + 1 \}.$$

When we express $\tan \theta$ in terms of the design speed, we get

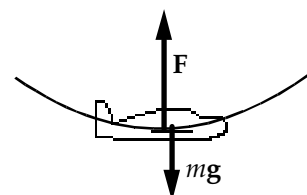
$$\begin{aligned} \mu_s \{ [(v_2^2/gR) - (v_1^2/gR)] / \{ [(v_2^2/gR)(v_1^2/gR)] + 1 \} \} &= (1/gR)(v_2^2 - v_1^2) / \{ [(v_1 v_2 / gR)^2 + 1] \} \\ &= [1 / (9.80 \text{ m/s}^2)(80 \text{ m})] \{ (25.0)^2 - (19.4 \text{ m/s})^2 \} / \{ [(19.4 \text{ m/s})(25.0 \text{ m/s}) / (9.80 \text{ m/s}^2)(80 \text{ m})]^2 + 1 \} \\ &= 0.23. \end{aligned}$$

21. At the bottom of the dive, the normal force is upward, which we select as the positive direction, and the weight is downward. The pilot experiences the upward centripetal acceleration at the bottom of the dive. We find the minimum radius of the circle from the maximum acceleration:

$$a_{\max} = v^2 / R_{\min};$$

$$(9.0)(9.80 \text{ m/s}^2) = (310 \text{ m/s})^2 / R_{\min}, \text{ which gives } R_{\min} = 1.1 \times 10^3 \text{ m}.$$

Because the pilot is diving vertically, he must begin to pull out at an altitude equal to the minimum



radius: 1.1 km.

22. For the components of the net force we have

$$F_{\tan} = ma_{\tan} = (1000 \text{ kg})(3.2 \text{ m/s}^2) = 3.2 \times 10^3 \text{ N};$$

$$F_R = ma_R = (1000 \text{ kg})(1.8 \text{ m/s}^2) = 1.8 \times 10^3 \text{ N}.$$

23. We find the constant tangential acceleration from the motion around the turn:

$$v_{\tan}^2 = v_0^2 + 2a_{\tan}(x_{\tan} - x_0)$$

$$[(320 \text{ km/h})/(3.6 \text{ ks/h})]^2 = 0 + 2a_{\tan}[1(200 \text{ m}) - 0], \text{ which gives } a_{\tan} = 6.29 \text{ m/s}^2.$$

The centripetal acceleration depends on the speed, so it will increase around the turn. We find the speed at the halfway point from

$$v_1^2 = v_0^2 + 2a_{\tan}(x_1 - x_0)$$

$$= 0 + 2(6.29 \text{ m/s}^2)[1(100 \text{ m}) - 0], \text{ which gives } v_1 = 62.8 \text{ m/s}.$$

The radial acceleration is

$$a_R = v_1^2/R = (62.8 \text{ m/s})^2/(200 \text{ m}) = 19.7 \text{ m/s}^2.$$

The magnitude of the acceleration is

$$a = (a_{\tan}^2 + a_R^2)^{1/2} = [(6.29 \text{ m/s}^2)^2 + (19.7 \text{ m/s}^2)^2]^{1/2} = 20.7 \text{ m/s}^2.$$

On a flat surface, $F_N = Mg$; and the friction force must provide the acceleration: $F_{\text{fr}} = ma$.

With no slipping the friction is static, so we have

$$F_{\text{fr}} \leq \mu_s F_N, \text{ or } Ma \leq \mu_s Mg.$$

Thus we have

$$\mu_s \geq a/g = (20.7 \text{ m/s}^2)/(9.80 \text{ m/s}^2) = 2.11.$$

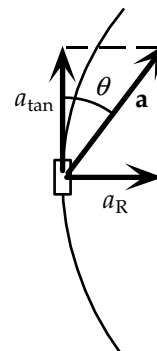
24. (a) We find the speed from the radial component of the acceleration:

$$a_R = a \cos \theta = v_1^2/R;$$

$$(1.05 \text{ m/s}^2) \cos 32.0^\circ = v_1^2/(2.70 \text{ m}), \text{ which gives } v_1 = 1.23 \text{ m/s}.$$

- (b) Assuming constant tangential acceleration, we find the speed from

$$v_2 = v_1 + a_{\tan}t = (1.23 \text{ m/s}) + (1.05 \text{ m/s}^2)(\sin 32.0^\circ)(2.00 \text{ s}) = 3.01 \text{ m/s}.$$



25. Because the spacecraft is 2 Earth radii above the surface, it is 3 Earth radii from the center.

The gravitational force on the spacecraft is

$$F = GMm/r^2$$

$$= (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(5.98 \times 10^{24} \text{ kg})(1400 \text{ kg})/[3(6.38 \times 10^6 \text{ m})]^2 = 1.52 \times 10^3 \text{ N}.$$

26. The acceleration due to gravity on the surface of a planet is

$$g = F/m = GM/R^2.$$

For the Moon we have

$$g_{\text{Moon}} = (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(7.35 \times 10^{22} \text{ kg})/(1.74 \times 10^6 \text{ m})^2 = 1.62 \text{ m/s}^2.$$

27. The acceleration due to gravity on the surface of a planet is

$$g = F/m = GM/R^2.$$

If we form the ratio of the two accelerations, we have

$$g_{\text{planet}}/g_{\text{Earth}} = (M_{\text{planet}}/M_{\text{Earth}})/(R_{\text{planet}}/R_{\text{Earth}})^2, \text{ or}$$
$$g_{\text{planet}} = g_{\text{Earth}}(M_{\text{planet}}/M_{\text{Earth}})/(R_{\text{planet}}/R_{\text{Earth}})^2 = (9.80 \text{ m/s}^2)(1)/(2.5)^2 = 1.6 \text{ m/s}^2.$$

28. The acceleration due to gravity on the surface of a planet is

$$g = F/m = GM/R^2.$$

If we form the ratio of the two accelerations, we have

$$g_{\text{planet}}/g_{\text{Earth}} = (M_{\text{planet}}/M_{\text{Earth}})/(R_{\text{planet}}/R_{\text{Earth}})^2, \text{ or}$$

$$g_{\text{planet}} = g_{\text{Earth}}(M_{\text{planet}}/M_{\text{Earth}})/(R_{\text{planet}}/R_{\text{Earth}})^2 = (9.80 \text{ m/s}^2)(2.5)/(1)^2 = 24.5 \text{ m/s}^2.$$

29. (a) The mass does not depend on the gravitational force, so it is 2.10 kg on both.

(b) For the weights we have

$$w_{\text{Earth}} = mg_{\text{Earth}} = (2.10 \text{ kg})(9.80 \text{ m/s}^2) = 20.6 \text{ N};$$

$$w_{\text{planet}} = mg_{\text{planet}} = (2.10 \text{ kg})(12.0 \text{ m/s}^2) = 25.2 \text{ N}.$$

30. The acceleration due to gravity at a distance r from the center of the Earth is

$$g = F/m = GM_{\text{Earth}}/r^2.$$

If we form the ratio of the two accelerations for the different distances, we have

$$g_h/g_{\text{surface}} = [(R_{\text{Earth}})/(R_{\text{Earth}} + h)]^2 = [(6400 \text{ km})/(6400 \text{ km} + 300 \text{ km})]^2$$

which gives $g_h = 0.91g_{\text{surface}}$.

31. The acceleration due to gravity on the surface of the neutron star is

$$g = F/m = GM/R^2 = (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(5)(2.0 \times 10^{30} \text{ kg})/(10 \times 10^3 \text{ m})^2 = 6.7 \times 10^{12} \text{ m/s}^2.$$

32. The acceleration due to gravity at a distance r from the center of the Earth is

$$g = F/m = GM_{\text{Earth}}/r^2.$$

If we form the ratio of the two accelerations for the different distances, we have

$$g/g_{\text{surface}} = (R_{\text{Earth}}/R)^2;$$

$$1/10 = [(6400 \text{ km})/R]^2, \text{ which gives } R = 2.0 \times 10^7 \text{ m}.$$

33. The acceleration due to gravity on the surface of the white dwarf star is

$$g = F/m = GM/R^2 = (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(2.0 \times 10^{30} \text{ kg})/(1.74 \times 10^6 \text{ m})^2 = 4.4 \times 10^7 \text{ m/s}^2.$$

34. The acceleration due to gravity at a distance r from the center of the Earth is

$$g = F/m = GM_{\text{Earth}}/r^2.$$

If we form the ratio of the two accelerations for the different distances, we have

$$g/g_{\text{surface}} = [(R_{\text{Earth}})/(R_{\text{Earth}} + h)]^2;$$

$$(a) \quad g = (9.80 \text{ m/s}^2)[(6400 \text{ km})/(6400 \text{ km} + 3.2 \text{ km})]^2 = 9.8 \text{ m/s}^2.$$

$$(b) \quad g = (9.80 \text{ m/s}^2)[(6400 \text{ km})/(6400 \text{ km} + 3200 \text{ km})]^2 = 4.3 \text{ m/s}^2.$$

35. We choose the coordinate system shown in the figure and find the force on the mass in the lower left corner.

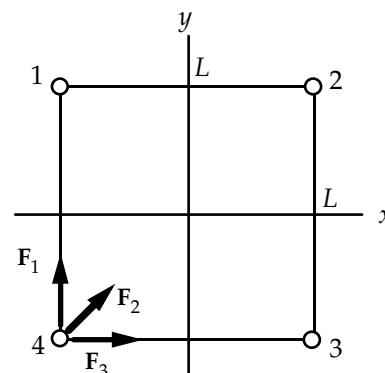
Because the masses are equal, for the magnitudes of the forces from the other corners we have

$$\begin{aligned} F_1 = F_3 &= Gmm/r_1^2 \\ &= (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(7.5 \text{ kg})(7.5 \text{ kg})/(0.60 \text{ m})^2 \\ &= 1.04 \times 10^{-8} \text{ N}; \end{aligned}$$

$$\begin{aligned} F_2 &= Gmm/r_2^2 \\ &= (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(7.5 \text{ kg})(7.5 \text{ kg})/[(0.60 \text{ m})/\cos 45^\circ]^2 \\ &= 5.21 \times 10^{-9} \text{ N}. \end{aligned}$$

From the symmetry of the forces we see that the resultant will be along the diagonal. The resultant force is

$$\begin{aligned} F &= 2F_1 \cos 45^\circ + F_2 \\ &= 2(1.04 \times 10^{-8} \text{ N}) \cos 45^\circ + 5.21 \times 10^{-9} \text{ N} = \quad \mathbf{2.0 \times 10^{-8} \text{ N toward center of the square.}} \end{aligned}$$



36. For the magnitude of each attractive gravitational force, we have

$$\begin{aligned} F_V &= GM_E M_V / r_V^2 = G f_V M_E^2 / r_V^2 \\ &= (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(0.815)(5.98 \times 10^{24} \text{ kg})^2 / [(108 - 150) \times 10^9 \text{ m}]^2 \\ &= 1.10 \times 10^{18} \text{ N}; \end{aligned}$$

$$\begin{aligned} F_J &= GM_E M_J / r_J^2 = G f_J M_E^2 / r_J^2 \\ &= (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(318)(5.98 \times 10^{24} \text{ kg})^2 / [(778 - 150) \times 10^9 \text{ m}]^2 \\ &= 1.92 \times 10^{18} \text{ N}; \end{aligned}$$

$$\begin{aligned} F_S &= GM_E M_S / r_S^2 = G f_S M_E^2 / r_S^2 \\ &= (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(95.1)(5.98 \times 10^{24} \text{ kg})^2 / [(1430 - 150) \times 10^9 \text{ m}]^2 \\ &= 1.38 \times 10^{17} \text{ N}. \end{aligned}$$

The force from Venus is toward the Sun; the forces from Jupiter and Saturn are away from the Sun. For the net force we have

$$F_{\text{net}} = F_J + F_S - F_V = 1.92 \times 10^{18} \text{ N} + 1.38 \times 10^{17} \text{ N} - 1.10 \times 10^{18} \text{ N} = \quad \mathbf{9.6 \times 10^{17} \text{ N away from the Sun.}}$$



Sun



Venus Earth



Jupiter Saturn



37. The acceleration due to gravity on the surface of a planet is

$$g = F/m = GM/R^2.$$

If we form the ratio of the two accelerations, we have

$$\begin{aligned} g_{\text{Mars}}/g_{\text{Earth}} &= (M_{\text{Mars}}/M_{\text{Earth}})/(R_{\text{Mars}}/R_{\text{Earth}})^2; \\ 0.38 &= [M_{\text{Mars}}/(6.0 \times 10^{24} \text{ kg})]/(3400 \text{ km}/6400 \text{ km})^2, \text{ which gives } M_{\text{Mars}} = \quad \mathbf{6.4 \times 10^{23} \text{ kg.}} \end{aligned}$$

38. We relate the speed of the Earth to the period of its orbit from

$$v = 2\pi R/T.$$

The gravitational attraction from the Sun must provide the centripetal acceleration for the circular orbit:

$$GM_E M_S / R^2 = M_E v^2 / R = M_E (2\pi R/T)^2 / R = M_E 4\pi^2 R / T^2, \text{ so we have}$$

$$GM_S = 4\pi^2 R^3 / T^2;$$

$$(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2) M_S = 4\pi^2 (1.50 \times 10^{11} \text{ m})^3 / (3.16 \times 10^7 \text{ s})^2, \text{ which gives } M_S = \quad \mathbf{2.0 \times 10^{30} \text{ kg.}}$$

This is the same as found in Example 5-17.

39. The gravitational attraction must provide the centripetal acceleration for the circular orbit:

$$GM_E m / R^2 = mv^2 / R, \text{ or}$$

$$v^2 = GM_E / (R_E + h)$$

$$= (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2 / \text{kg}^2)(5.98 \times 10^{24} \text{ kg}) / (6.38 \times 10^6 \text{ m} + 3.6 \times 10^6 \text{ m}),$$

which gives $v = 6.3 \times 10^3 \text{ m/s}$.

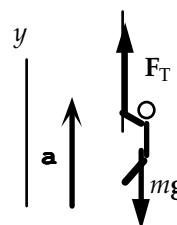
40. The greater tension will occur when the elevator is accelerating upward, which we take as the positive direction. We write $\Sigma \mathbf{F} = m\mathbf{a}$ from the force diagram for the monkey:

$$F_T \cos \theta - mg = ma;$$

$$220 \text{ N} - (17.0 \text{ kg})(9.80 \text{ m/s}^2) = (17.0 \text{ kg})a, \text{ which gives}$$

$$a = 3.14 \text{ m/s}^2 \text{ upward.}$$

Because the rope broke, the tension was at least 220 N, so this is the minimum acceleration.



41. We relate the speed of rotation to the period of rotation from

$$v = 2\pi R / T.$$

For the required centripetal acceleration, we have

$$a_R = v^2 / R = (2\pi R / T)^2 / R = 4\pi^2 R / T^2;$$

$$(9.80 \text{ m/s}^2) = 4\pi^2 (16 \text{ m}) / T^2, \text{ which gives } T = 11 \text{ s.}$$

42. We relate the speed to the period of revolution from

$$v = 2\pi R / T.$$

For the required centripetal acceleration, we have

$$a_R = v^2 / R = (2\pi R / T)^2 / R = 4\pi^2 R / T^2;$$

$$9.80 \text{ m/s}^2 = 4\pi^2 (6.38 \times 10^6 \text{ m}) / T^2, \text{ which gives } T = 5.07 \times 10^3 \text{ s (1.41 h).}$$

The result is independent of the mass of the satellite.

43. We relate the speed to the period of revolution from

$$v = 2\pi R / T.$$

The required centripetal acceleration is provided by the gravitational attraction:

$$GM_M m / R^2 = mv^2 / R = m(2\pi R / T)^2 / R = 4\pi^2 m R / T^2, \text{ so we have}$$

$$GM_M = 4\pi^2 (R_M + h)^3 / T^2;$$

$$(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2 / \text{kg}^2)(7.4 \times 10^{22} \text{ kg}) = 4\pi^2 (1.74 \times 10^6 \text{ m} + 1.00 \times 10^5 \text{ m})^3 / T^2,$$

which gives $T = 7.06 \times 10^3 \text{ s} = 2.0 \text{ h}$.

44. We take the positive direction upward. The spring scale reads the normal force expressed as an effective mass: F_N/g . We write $\sum \mathbf{F} = m\mathbf{a}$ from the force diagram:

$$F_N - mg = ma, \text{ or } m_{\text{effective}} = F_N/g = m(1 + a/g).$$

- (a) For a constant speed, there is no acceleration, so we have

$$m_{\text{effective}} = m(1 + a/g) = m = \mathbf{58 \text{ kg}}.$$

- (b) For a constant speed, there is no acceleration, so we have

$$m_{\text{effective}} = m(1 + a/g) = m = \mathbf{58 \text{ kg}}.$$

- (c) For the upward (positive) acceleration, we have

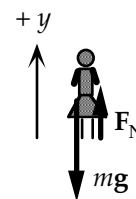
$$m_{\text{effective}} = m(1 + a/g) = m(1 + 0.33g/g) = 1.33(58 \text{ kg}) = \mathbf{77 \text{ kg}}.$$

- (d) For the downward (negative) acceleration, we have

$$m_{\text{effective}} = m(1 + a/g) = m(1 - 0.33g/g) = 0.67(58 \text{ kg}) = \mathbf{39 \text{ kg}}.$$

- (e) In free fall the acceleration is $-g$, so we have

$$m_{\text{effective}} = m(1 + a/g) = m(1 - g/g) = \mathbf{0}.$$



45. We relate the orbital speed to the period of revolution from

$$v = 2\pi R/T.$$

The required centripetal acceleration is provided by the gravitational attraction:

$$GM_S m/R^2 = mv^2/R = m(2\pi R/T)^2/R = m4\pi^2 R/T^2, \text{ so we have}$$

$$GM_S = 4\pi^2 R^3/T^2.$$

For the two extreme orbits we have

$$(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(5.69 \times 10^{26} \text{ kg}) = 4\pi^2(7.3 \times 10^7 \text{ m})^3/T_{\text{inner}}^2,$$

which gives $T_{\text{inner}} = 2.01 \times 10^4 \text{ s} = \mathbf{5 \text{ h } 35 \text{ min}};$

$$(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(5.69 \times 10^{26} \text{ kg}) = 4\pi^2(17 \times 10^7 \text{ m})^3/T_{\text{outer}}^2,$$

which gives $T_{\text{outer}} = 7.15 \times 10^4 \text{ s} = \mathbf{19 \text{ h } 50 \text{ min}}.$

Because the mean rotation period of Saturn is between the two results, with respect to a point on the surface of Saturn, the edges of the rings are moving in opposite directions.

46. The centripetal acceleration has a magnitude of

$$a_R = v^2/R = (2\pi R/T)^2/R = 4\pi^2 R/T^2 \\ = 4\pi^2(12.0 \text{ m})/(12.5 \text{ s})^2 = 3.03 \text{ m/s}^2.$$

At each position we take the positive direction in the direction of the acceleration. Because the seat swings, the normal force from the seat is upward and the weight is downward. The apparent weight is measured by the normal force.

- (a) At the top, we write $\sum \mathbf{F} = m\mathbf{a}$ from the force diagram:

$$-F_{\text{Ttop}} + mg = ma_R, \text{ or } F_{\text{Ttop}} = mg(1 - a_R/g).$$

For the fractional change we have

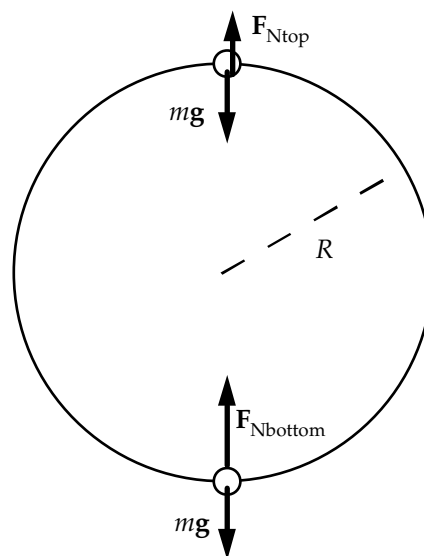
$$\text{Fractional change} = (F_{\text{Ttop}} - mg)/mg = -a_R/g \\ = -(3.03 \text{ m/s}^2)/(9.80 \text{ m/s}^2) = \mathbf{-0.309 (-30.9\%).}$$

- (b) At the bottom, we write $\sum \mathbf{F} = m\mathbf{a}$ from the force diagram:

$$F_{\text{Tbottom}} - mg = ma_R, \text{ or } F_{\text{Tbottom}} = mg(1 + a_R/g).$$

For the fractional change we have

$$\text{Fractional change} = (F_{\text{Tbottom}} - mg)/mg = +a_R/g \\ = +(3.03 \text{ m/s}^2)/(9.80 \text{ m/s}^2) = \mathbf{+0.309 (+30.9\%).}$$



47. The acceleration due to gravity is

$$g = F_{\text{grav}}/m = GM/R^2 \\ = (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(7.4 \times 10^{22} \text{ kg})/(4.2 \times 10^6 \text{ m})^2 = 0.28 \text{ m/s}^2.$$

We take the positive direction toward the Moon. The apparent weight is measured by the normal force. We write $\Sigma \mathbf{F} = m\mathbf{a}$ from the force diagram:

$$-F_N + mg = ma,$$

- (a) For a constant velocity, there is no acceleration, so we have

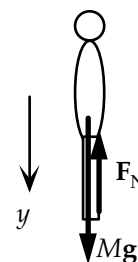
$$-F_N + mg = 0, \text{ or}$$

$$F_N = mg = (70 \text{ kg})(0.28 \text{ m/s}^2) = \mathbf{20 \text{ N (toward the Moon)}}.$$

- (b) For an acceleration toward the Moon, we have

$$-F_N + mg = ma, \text{ or}$$

$$F_N = m(g - a) = (70 \text{ kg})(0.28 \text{ m/s}^2 - 2.9 \text{ m/s}^2) = \mathbf{-1.8 \times 10^2 \text{ N (away from the Moon)}}.$$



48. We determine the period
- T
- and radius
- r
- of the satellite's orbit, and relate the orbital speed to the period of revolution from

$$v = 2\pi r/T.$$

We know that the gravitational attraction provides the centripetal acceleration:

$$GM_{\text{planet}}m/r^2 = mv^2/r = m(2\pi r/T)^2/r = m4\pi^2 r/T^2, \text{ so we have}$$

$$M_{\text{planet}} = 4\pi^2 r^3/GT^2.$$

49. We relate the speed to the period of revolution from

$$v = 2\pi r/T, \text{ where } r \text{ is the distance to the midpoint.}$$

The gravitational attraction provides the centripetal acceleration:

$$Gmm/(2r)^2 = mv^2/r = m(2\pi r/T)^2/r = m4\pi^2 r/T^2, \text{ so we have}$$

$$m = 16\pi^2 r^3/GT^2$$

$$= 16\pi^2 (180 \times 10^9 \text{ m})^3 / (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2) [(5.0 \text{ yr})(3.16 \times 10^7 \text{ s/yr})]^2 = \mathbf{5.5 \times 10^{29} \text{ kg}}.$$

50. (a) We relate the speed of rotation to the period of revolution from

$$v = 2\pi R/T.$$

We know that the gravitational attraction provides the centripetal acceleration:

$$GM_{\text{planet}}m/R^2 = mv^2/R = m(2\pi R/T)^2/R = m4\pi^2 R/T^2, \text{ so we have}$$

$$M_{\text{planet}} = 4\pi^2 R^3/GT^2.$$

Thus the density is

$$\rho = M_{\text{planet}}/V = [4\pi^2 R^3/GT^2]/\frac{4}{3}\pi R^3 = 3/GT^2.$$

- (b) For the Earth we have

$$\rho = 3/GT^2 = 3/(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2) [(90 \text{ min})(60 \text{ s/min})]^2 = \mathbf{4.8 \times 10^3 \text{ kg/m}^3}.$$

Note that the density of iron is $7.8 \times 10^3 \text{ kg/m}^3$.

51. From Kepler's third law,
- $T^2 = 4\pi^2 R^3/GM_E$
- , we can relate the periods of the satellite and the Moon:

$$(T/T_{\text{Moon}})^2 = (R/R_{\text{Moon}})^3;$$

$$(T/27.4 \text{ d})^2 = [(6.38 \times 10^6 \text{ m})/(3.84 \times 10^8 \text{ m})]^3, \text{ which gives } T = \mathbf{0.0587 \text{ days (1.41 h)}}.$$

52. From Kepler's third law,
- $T^2 = 4\pi^2 R^3/GM_S$
- , we can relate the periods of Icarus and the Earth:

$$(T_{\text{Icarus}}/T_{\text{Earth}})^2 = (R_{\text{Icarus}}/R_{\text{Earth}})^3;$$

$$(410 \text{ d}/365 \text{ d})^2 = [R_{\text{Icarus}}/(1.50 \times 10^{11} \text{ m})]^3, \text{ which gives } \mathbf{R_{\text{Icarus}} = 1.62 \times 10^{11} \text{ m}}.$$

53. From Kepler's third law, $T^2 = 4\pi^2 R^3 / GM_S$, we can relate the periods of the Earth and Neptune:

$$(T_{\text{Neptune}}/T_{\text{Earth}})^2 = (R_{\text{Neptune}}/R_{\text{Earth}})^3;$$

$$(T_{\text{Neptune}}/1 \text{ yr})^2 = [(4.5 \times 10^{12} \text{ m})/(1.50 \times 10^{11} \text{ m})]^3, \text{ which gives } T_{\text{Neptune}} = 1.6 \times 10^2 \text{ yr.}$$

54. We use Kepler's third law, $T^2 = 4\pi^2 R^3 / GM_E$, for the motion of the Moon around the Earth:

$$T^2 = 4\pi^2 R^3 / GM_E;$$

$$[(27.4 \text{ d})(86,400 \text{ s/d})]^2 = 4\pi^2 (3.84 \times 10^8 \text{ m})^3 / (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2) M_E,$$

$$\text{which gives } M_E = 5.97 \times 10^{24} \text{ kg.}$$

55. From Kepler's third law, $T^2 = 4\pi^2 R^3 / GM_S$, we can relate the periods of Halley's comet and the Earth to find the mean distance of the comet from the Sun:

$$(T_{\text{Halley}}/T_{\text{Earth}})^2 = (R_{\text{Halley}}/R_{\text{Earth}})^3;$$

$$(76 \text{ yr}/1 \text{ yr})^2 = [R_{\text{Halley}}/(1.50 \times 10^{11} \text{ m})]^3, \text{ which gives } R_{\text{Halley}} = 2.68 \times 10^{12} \text{ m.}$$

If we take the nearest distance to the Sun as zero, the farthest distance is

$$d = 2R_{\text{Halley}} = 2(2.68 \times 10^{12} \text{ m}) = 5.4 \times 10^{12} \text{ m.}$$

It is still orbiting the Sun and thus is **in the Solar System**. The planet nearest it is **Pluto**.

56. We relate the speed to the period of revolution from

$v = 2\pi r/T$, where r is the distance to the center of the Milky Way.

The gravitational attraction provides the centripetal acceleration:

$$GM_{\text{galaxy}}M_S/r^2 = M_S v^2/r = M_S (2\pi r/T)^2/r = M_S 4\pi^2 r/T^2, \text{ so we have}$$

$$M_{\text{galaxy}} = 4\pi^2 r^3 / GT^2$$

$$= 4\pi^2 [(30,000 \text{ ly})(9.5 \times 10^{15} \text{ m/ly})]^3 / [(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)[(200 \times 10^6 \text{ yr})(3.16 \times 10^7 \text{ s/yr})]^2] = 3.4 \times 10^{41} \text{ kg.}$$

The number of stars ("Suns") is

$$(3.4 \times 10^{41} \text{ kg}) / (2.0 \times 10^{30} \text{ kg}) = 1.7 \times 10^{11}.$$

57. From Kepler's third law, $T^2 = 4\pi^2 R^3 / GM_{\text{Jupiter}}$, we have

$$M_{\text{Jupiter}} = 4\pi^2 R^3 / GT^2.$$

$$(a) \ M_{\text{Jupiter}} = 4\pi^2 R_{\text{Io}}^3 / GT_{\text{Io}}^2 = 4\pi^2 (422 \times 10^6 \text{ m})^3 / (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)[(1.77 \text{ d})(86,400 \text{ s/d})]^2 = 1.90 \times 10^{27} \text{ kg.}$$

$$(b) \ M_{\text{Jupiter}} = 4\pi^2 R_{\text{Europa}}^3 / GT_{\text{Europa}}^2 = 4\pi^2 (671 \times 10^6 \text{ m})^3 / (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)[(3.55 \text{ d})(86,400 \text{ s/d})]^2 = 1.90 \times 10^{27} \text{ kg;}$$

$$M_{\text{Jupiter}} = 4\pi^2 R_{\text{Ganymede}}^3 / GT_{\text{Ganymede}}^2 = 4\pi^2 (1070 \times 10^6 \text{ m})^3 / (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)[(7.16 \text{ d})(86,400 \text{ s/d})]^2 = 1.89 \times 10^{27} \text{ kg;}$$

$$M_{\text{Jupiter}} = 4\pi^2 R_{\text{Callisto}}^3 / GT_{\text{Callisto}}^2 = 4\pi^2 (1883 \times 10^6 \text{ m})^3 / (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)[(16.7 \text{ d})(86,400 \text{ s/d})]^2 = 1.89 \times 10^{27} \text{ kg.}$$

The results are consistent.

58. From Kepler's third law, $T^2 = 4\pi^2 R^3 / GM_{\text{Jupiter}}$, we can relate the distances of the moons:

$$(R/R_{\text{Io}})^3 = (T/T_{\text{Io}})^2.$$

Thus we have

$$(R_{\text{Europa}}/422 \times 10^3 \text{ km})^3 = (3.55 \text{ d}/1.77 \text{ d})^2, \text{ which gives } R_{\text{Europa}} = 6.71 \times 10^5 \text{ km.}$$

$$(R_{\text{Ganymede}}/422 \times 10^3 \text{ km})^3 = (7.16 \text{ d}/1.77 \text{ d})^2, \text{ which gives } R_{\text{Ganymede}} = 1.07 \times 10^6 \text{ km.}$$

$(R_{\text{Callisto}}/422 \times 10^3 \text{ km})^3 = (16.7 \text{ d}/1.77 \text{ d})^2$, which gives $R_{\text{Callisto}} = 1.88 \times 10^6 \text{ km}$.
All values agree with the table.

59. (a) From Kepler's third law, $T^2 = 4\pi^2 R^3 / GM_S$, we can relate the periods of the assumed planet and the Earth:

$$(T_{\text{planet}}/T_{\text{Earth}})^2 = (R_{\text{planet}}/R_{\text{Earth}})^3;$$

$$(T_{\text{planet}}/1 \text{ yr})^2 = (3)^3, \text{ which gives } T_{\text{planet}} = 5.2 \text{ yr.}$$

- (b) No, the radius and period are independent of the mass of the orbiting body.

60. (a) In a short time interval t , the planet will travel a distance vt along its orbit. This distance has been exaggerated on the diagram. Kepler's second law states that the area swept out by a line from the Sun to the planet in time t is the same anywhere on the orbit. If we take the areas swept out at the nearest and farthest points, as shown on the diagram, and approximate the areas as triangles (which is a good approximation for very small t), we have

$$\frac{1}{2}d_N(v_N t) = \frac{1}{2}d_F(v_F t), \text{ which gives } v_N/v_F = d_F/d_N.$$

- (b) For the average velocity we have

$$v = 2\pi[(d_N + d_F)]/T = (1.47 \times 10^{11} \text{ m} + 1.52 \times 10^{11} \text{ m})/(3.16 \times 10^7 \text{ s}) = 2.97 \times 10^4 \text{ m/s}.$$

From the result for part (a), we have

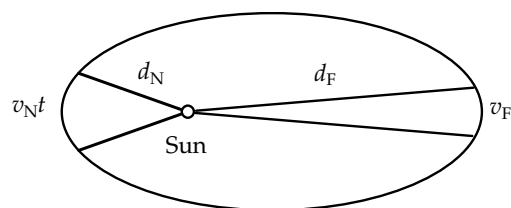
$$v_N/v_F = d_F/d_N = 1.52/1.47 = 1.034, \text{ or } v_N \text{ is } 3.4\% \text{ greater than } v_F.$$

For this small change, we can take each of the extreme velocities to be $\pm 1.7\%$ from the average.

Thus we have

$$v_N = 1.017(2.97 \times 10^4 \text{ m/s}) = 3.02 \times 10^4 \text{ m/s};$$

$$v_F = 0.983(2.97 \times 10^4 \text{ m/s}) = 2.92 \times 10^4 \text{ m/s}.$$



61. An apparent gravity of one g means that the normal force from the band is mg , where

$$g = GM_E/R_E^2.$$

The normal force and the gravitational attraction from the Sun provide the centripetal acceleration:

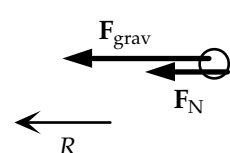
$$GM_S m/R_{SE}^2 + mGM_E/R_E^2 = mv^2/R_{SE}, \text{ or}$$

$$v^2 = G[(M_S/R_{SE}) + (M_E R_{SE}/R_E^2)]$$

$$= (6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)[(1.99 \times 10^{30} \text{ kg})/(1.50 \times 10^{11} \text{ m}) + (5.98 \times 10^{24} \text{ kg})(1.50 \times 10^{11} \text{ m})/(6.38 \times 10^6 \text{ m})^2], \text{ which gives } v = 1.2 \times 10^6 \text{ m/s}.$$

For the period of revolution we have

$$T = 2\pi R_{SE}/v = [2\pi(1.50 \times 10^{11} \text{ m})/(1.2 \times 10^6 \text{ m/s})]/(86,400 \text{ s/day}) = 9.0 \text{ Earth-days}.$$



62. The acceleration due to gravity at a distance r from the center of the Earth is

$$g = F/m = GM_{\text{Earth}}/r^2.$$

If we form the ratio of the two accelerations for the different distances, we have

$$g/g_{\text{surface}} = [R_{\text{Earth}}/(R_{\text{Earth}} + h)]^2;$$

$$1/2 = [(6.38 \times 10^3 \text{ km})/(6.38 \times 10^3 \text{ km} + h)]^2, \text{ which gives } h = 2.6 \times 10^3 \text{ km}.$$

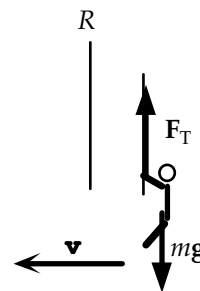
63. The net force on Tarzan will provide his centripetal acceleration, which we take as the positive direction.

We write $\Sigma \mathbf{F} = m\mathbf{a}$ from the force diagram for Tarzan:

$$F_T - mg = ma = mv^2/R.$$

The maximum speed will require the maximum tension that Tarzan can create:

$$1400 \text{ N} - (80 \text{ kg})(9.80 \text{ m/s}^2) = (80 \text{ kg})v^2/(4.8 \text{ m}), \text{ which gives } v = 6.1 \text{ m/s}.$$

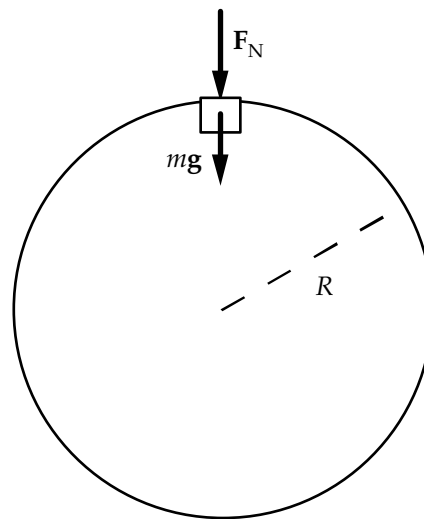


64. Yes. If the bucket is traveling fast enough at the top of the circle, in addition to the weight of the water a force from the bucket, similar to a normal force, is required to provide the necessary centripetal acceleration to make the water go in the circle. From the force diagram, we write

$$F_N + mg = ma = mv_{\text{top}}^2/R.$$

The minimum speed is that for which the normal force is zero:

$$0 + mg = mv_{\text{top,min}}^2/R, \text{ or } v_{\text{top,min}} = (gR)^{1/2}.$$



65. We find the speed of the skaters from the period of rotation:

$$v = 2\pi r/T = 2\pi(0.80 \text{ m})/(3.0 \text{ s}) = 1.68 \text{ m/s}.$$

The pull or tension in their arms provides the centripetal acceleration:

$$F_T = mv^2/R; \\ = (60.0 \text{ kg})(1.68 \text{ m/s})^2/(0.80 \text{ m}) = 2.1 \times 10^2 \text{ N}.$$

66. If we consider a person standing on a scale, the apparent weight is measured by the normal force. The person is moving with the rotational speed of the surface of the Earth:

$$v = 2\pi R_E/T = 2\pi(6.38 \times 10^6 \text{ m})/(86,400 \text{ s}) = 464 \text{ m/s}.$$

We take down as positive and write $\Sigma \mathbf{F} = m\mathbf{a}$:

$$-F_N + mg = ma = mv^2/R_E, \text{ or } F_N = mg_{\text{effective}} = mg - mv^2/R_E.$$

$$\text{Thus } g_{\text{effective}} - g = -v^2/R_E = -(464 \text{ m/s})^2/(6.38 \times 10^6 \text{ m}) = -0.0337 \text{ m/s}^2 \text{ (0.343\% of } g).$$

67. Because the gravitational force is always attractive, the two forces will be in opposite directions. If we call the distance from the Earth to the Moon D and let x be the distance from the Earth where the magnitudes of the forces are equal, we have

$$GM_M m/(D-x)^2 = GM_E m/x^2, \text{ which becomes } M_M x^2 = M_E (D-x)^2.$$

$$(7.35 \times 10^{22} \text{ kg})x^2 = (5.98 \times 10^{24} \text{ kg})[(3.84 \times 10^8 \text{ m}) - x]^2, \text{ which gives}$$

$$x = 3.46 \times 10^8 \text{ m from Earth's center}.$$

68. (a) People will be able to walk on the **inside surface farthest from the center**, so the normal force can provide the centripetal acceleration.

(b) The centripetal acceleration must equal g :

$$g = v^2/R = (2\pi R/T)^2/R = 4\pi^2 R/T^2;$$

$$9.80 \text{ m/s}^2 = (0.55 \times 10^3 \text{ m})^2/T^2, \text{ which gives } T = 47.1 \text{ s.}$$

For the rotation speed we have

$$\text{revolutions/day} = (86,400 \text{ s/day})/(47.1 \text{ s/rev}) = \mathbf{1.8 \times 10^3 \text{ rev/day.}}$$

69. We take the positive direction upward. The spring scale reads the normal force expressed as an effective mass: F_N/g .

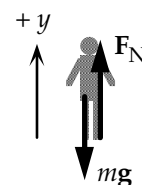
We write $\Sigma \mathbf{F} = m\mathbf{a}$ from the force diagram:

$$F_N - mg = ma, \text{ or } m_{\text{effective}} = F_N/g = m(1 + a/g);$$

$$80 \text{ kg} = (60 \text{ kg})[1 + a/(9.80 \text{ m/s}^2)],$$

which gives $a = \mathbf{3.3 \text{ m/s}^2 \text{ upward.}}$

The direction is given by the sign of the result.



70. At each position we take the positive direction in the direction of the acceleration.

(a) The centripetal acceleration is

$a_R = v^2/R$, so we see that the radius is minimum for a maximum centripetal acceleration:

$$(6.0)(9.80 \text{ m/s}^2) = [(1500 \text{ km/h})/(3.6 \text{ ks/h})]^2/R_{\text{min}},$$

which gives $\mathbf{R_{\text{min}} = 3.0 \times 10^3 \text{ m} = 3.0 \text{ km.}}$

(b) At the bottom of the circle, the normal force is upward and the weight is downward. We write $\Sigma \mathbf{F} = m\mathbf{a}$ from the force diagram for the ball:

$$F_{\text{Nbottom}} - mg = mv^2/R = m(6.0g);$$

$$F_{\text{Nbottom}} - (80 \text{ kg})(9.80 \text{ m/s}^2) = (80 \text{ kg})(6.0)(9.80 \text{ m/s}^2),$$

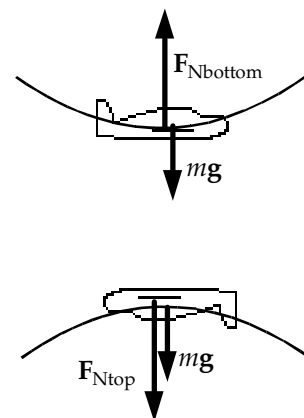
which gives $\mathbf{F_{\text{Nbottom}} = 5.5 \times 10^3 \text{ N.}}$

(c) At the top of the path, both the normal force and the weight are downward. We write $\Sigma \mathbf{F} = m\mathbf{a}$ from the force diagram for the ball:

$$F_{\text{Ntop}} + mg = mv^2/R;$$

$$F_{\text{Ntop}} + (80 \text{ kg})(9.80 \text{ m/s}^2) = (80 \text{ kg})(6.0)(9.80 \text{ m/s}^2),$$

which gives $\mathbf{F_{\text{Ntop}} = 3.9 \times 10^3 \text{ N.}}$



71. The acceleration due to gravity on the surface of a planet is

$$g_P = F_{\text{grav}}/m = GM_P/r^2, \text{ so we have}$$

$$\mathbf{M_P = g_P r^2 / G.}$$

72. (a) The attractive gravitational force on the plumb bob is

$$F_M = GmM_M/D_M^2.$$

Because $\Sigma \mathbf{F} = 0$, we see from the force diagram:

$$\tan \theta = F_M/mg = (GmM_M/D_M^2)/(mGM_E/R_E^2),$$

where we have used GM_E/R_E^2 for g .

Thus we have

$$\theta = \tan^{-1} (M_M R_E^2 / M_E D_M^2).$$

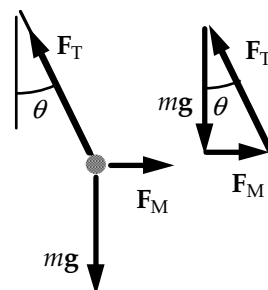
- (b) For the mass of a cone with apex half-angle
- α
- , we have

$$\begin{aligned} M_M &= \rho V = \rho \frac{1}{3} \pi r^2 h \tan^2 \alpha \\ &= (3 \times 10^3 \text{ kg/m}^3) \frac{1}{3} \pi (4 \times 10^3 \text{ m})^2 \tan^2 30^\circ = 7 \times 10^{13} \text{ kg}. \end{aligned}$$

- (c) Using the result from part (a) for the angle, we have

$$\begin{aligned} \tan \theta &= M_M R_E^2 / M_E D_M^2 \\ &= (7 \times 10^{13} \text{ kg})(6.4 \times 10^6 \text{ m})^2 / (56 \times 10^{24} \text{ kg})(5 \times 10^3 \text{ m})^2 = 2 \times 10^{-5}, \end{aligned}$$

which gives $\theta \approx (1 \times 10^{-3})^\circ$.



73. We convert the speed:
- $(100 \text{ km/h}) / (3.6 \text{ ks/h}) = 27.8 \text{ m/s}$
- .

At the speed for which the curve is banked perfectly, there is no need for a friction force. We take the x -axis in the direction of the centripetal acceleration.

We write $\Sigma \mathbf{F} = m\mathbf{a}$ from the force diagram for the car:

$$x\text{-component: } F_{N1} \sin \theta = ma_1 = mv_1^2/R;$$

$$y\text{-component: } F_{N1} \cos \theta - mg = 0.$$

Combining these, we get $v_1^2 = gR \tan \theta$.

$$(27.8 \text{ m/s})^2 = (60 \text{ m})(9.80 \text{ m/s}^2) \tan \theta, \text{ which gives}$$

$$\tan \theta = 1.31, \text{ or } \theta = 52.7^\circ.$$

At a higher speed, there is need for a friction force, which will be down the incline to help provide the greater centripetal acceleration. If the automobile does not skid, the friction is static, with $F_{fr} \leq \mu_s F_N$.

At the maximum speed, $F_{fr} = \mu_s F_N$. We write $\Sigma \mathbf{F} = m\mathbf{a}$ from the force diagram for the car:

$$x\text{-component: } F_{N2} \sin \theta + \mu_s F_{N2} \cos \theta = ma_2 = mv_{\max}^2/R;$$

$$y\text{-component: } F_{N2} \cos \theta - \mu_s F_{N2} \sin \theta - mg = 0, \text{ or } F_{N2}(\cos \theta - \mu_s \sin \theta) = mg.$$

When we eliminate F_{N2} by dividing the equations, we get

$$\begin{aligned} v_{\max}^2 &= gR[(\sin \theta + \mu_s \cos \theta)/(\sin \theta - \mu_s \cos \theta)] \\ &= (9.80 \text{ m/s}^2)(60 \text{ m})[(\sin 52.7^\circ + 0.30 \cos 52.7^\circ)/(\sin 52.7^\circ - 0.30 \cos 52.7^\circ)], \end{aligned}$$

which gives $v_{\max} = 39.5 \text{ m/s} = 140 \text{ km/h}$.

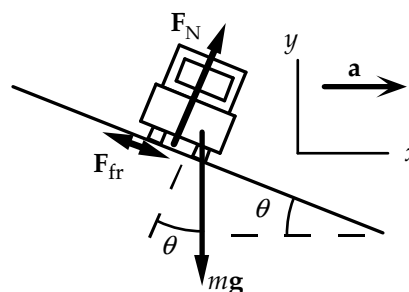
At a lower speed, there is need for a friction force, which will be up the incline to prevent the car from sliding down the incline. If the automobile does not skid, the friction is static, with $F_{fr} \leq \mu_s F_N$.

At the minimum speed, $F_{fr} = \mu_s F_N$. The reversal of the direction of F_{fr} can be incorporated in the above equations by changing the sign of μ_s , so we have

$$\begin{aligned} v_{\min}^2 &= gR[(\sin \theta - \mu_s \cos \theta)/(\sin \theta + \mu_s \cos \theta)] \\ &= (9.80 \text{ m/s}^2)(60 \text{ m})[(\sin 52.7^\circ - 0.30 \cos 52.7^\circ)/(\sin 52.7^\circ + 0.30 \cos 52.7^\circ)], \end{aligned}$$

which gives $v_{\min} = 20.7 \text{ m/s} = 74 \text{ km/h}$.

Thus the range of permissible speeds is $74 \text{ km/h} < v < 140 \text{ km/h}$.



74. We relate the speed to the period from

$$v = 2\pi R/T.$$

To be apparently weightless, the acceleration of gravity must be the required centripetal acceleration, so we have

$$a_R = g = v^2/R = (2\pi R/T)^2/R = 4\pi^2 R/T^2;$$

$$9.80 \text{ m/s}^2 = 4\pi^2(6.38 \times 10^6 \text{ m})/T^2, \text{ which gives } T = 5.07 \times 10^3 \text{ s (1.41 h)}.$$

75. (a) The attractive gravitational force between the stars is providing the required centripetal acceleration for the circular motion.

- (b) We relate the orbital speed to the period of revolution from

$$v = 2\pi r/T, \text{ where } r \text{ is the distance to the midpoint.}$$

The gravitational attraction provides the centripetal acceleration:

$$Gmm/(2r)^2 = mv^2/r = m(2\pi r/T)^2/r = m4\pi^2 r/T^2, \text{ so we have}$$

$$m = 16\pi^2 r^3/GT^2$$

$$= 16\pi^2(4.0 \times 10^{10} \text{ m})^3/(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)[(12.6 \text{ yr})(3.16 \times 10^7 \text{ s/yr})]^2 = 9.6 \times 10^{26} \text{ kg}.$$

76. The chandelier swings out until the tension in the suspension provides the centripetal acceleration, which is the centripetal acceleration of the train. The forces are shown in the diagram.

We write $\Sigma F = ma$ from the force diagram for the chandelier:

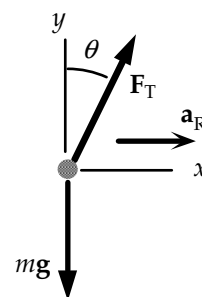
$$x\text{-component: } F_T \sin \theta = mv^2/r;$$

$$y\text{-component: } F_T \cos \theta - mg = 0.$$

When these equations are combined, we get

$$\tan \theta = v^2/rg;$$

$$\tan 17.5^\circ = v^2/(275 \text{ m})(9.80 \text{ m/s}^2), \text{ which gives } v = 29.2 \text{ m/s}.$$



77. The acceleration due to gravity on the surface of a planet is

$$g_P = F_{\text{grav}}/m = GM_P/R^2.$$

If we form the ratio of the expressions for Jupiter and the Earth, we have

$$g_{\text{Jupiter}}/g_{\text{Earth}} = (M_{\text{Jupiter}}/M_{\text{Earth}})(R_{\text{Earth}}/R_{\text{Jupiter}})^2;$$

$$g_{\text{Jupiter}}/g_{\text{Earth}} = [(1.9 \times 10^{27} \text{ kg})/(6.0 \times 10^{24} \text{ kg})][(6.38 \times 10^6 \text{ m})/(7.1 \times 10^7 \text{ m})]^2,$$

which gives $g_{\text{Jupiter}} = 2.56g_{\text{Earth}}$.

This has not taken into account the centripetal acceleration. We ignore the small contribution on Earth.

The centripetal acceleration on the equator of Jupiter is

$$a_R = v^2/R = (2\pi R/T)^2/R = 4\pi^2 R/T^2$$

$$= 4\pi^2(7.1 \times 10^7 \text{ m})/[(595 \text{ min})(60 \text{ s/min})]^2 = 2.2 \text{ m/s}^2 = 0.22g_{\text{Earth}}.$$

The centripetal acceleration reduces the effective value of g :

$$g'_{\text{Jupiter}} = g_{\text{Jupiter}} - a_R = 2.56g_{\text{Earth}} - 0.22g_{\text{Earth}} = 2.3g_{\text{Earth}}.$$

78. The gravitational attraction from the core must provide the centripetal acceleration for the orbiting stars:

$$GM_{\text{star}}M_{\text{core}}/R^2 = M_{\text{star}}v^2/R, \text{ so we have}$$

$$M_{\text{core}} = v^2 R/G$$

$$= (780 \text{ m/s})^2(5.7 \times 10^{17} \text{ m})/(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2) = 5.2 \times 10^{33} \text{ kg}.$$

If we compare this to our Sun, we get

$$M_{\text{core}}/M_{\text{Sun}} = (5.2 \times 10^{33} \text{ kg})/(2.0 \times 10^{30} \text{ kg}) = 2.6 \times 10^3 \times.$$