it serves as the centripetal force. The maximum centripetal force occurs when $F_c = f_s^{MAX}$. Therefore, the maximum speed v the car can have without slipping is related to f_s^{MAX} by

$$F_c = f_s^{MAX} = \frac{mv^2}{r} \quad (2)$$

Substituting Equation (2) into Equation (1) yields

$$\mu_s = \frac{\frac{mv^2}{r}}{F_N} \quad (3)$$

In part *a* the car is subject to two downward-pointing forces, its weight W and the downforce D. The vertical acceleration of the car is zero, so the upward normal force must balance the two downward forces: $F_N = W + D$. Combining this relation with Equation (3), we obtain an expression for the coefficient of static friction:

$$\mu_s = \frac{\frac{mv^2}{r}}{F_N} = \frac{\frac{mv^2}{r}}{W+D} = \frac{mv^2}{r(mg+D)} \quad (4)$$

SOLUTION

a. Since the downforce is D = 11 000 N, Equation (4) gives the coefficient of static friction as

$$\mu_s = \frac{mv^2}{r(mg+D)} = \frac{(830\text{ kg})(58\text{ m/s})^2}{(160\text{ m})\left[(830\text{ kg})(9.80\text{ m/s}^2)+11\,000\text{ N}\right]} = \boxed{0.91}$$

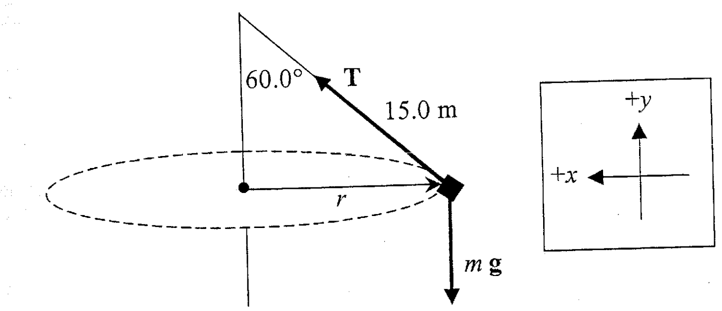
b. The downforce is now absent (D = 0 N). Solving Equation (4) for the speed of the car, we find that

$$v = \sqrt{\frac{\mu_s r(mg+D)}{m}} = \sqrt{\frac{\mu_s r(mg+0\text{ N})}{m}} = \sqrt{\frac{\mu_s r(\not{m}g)}{\not{m}}}$$

$$= \sqrt{\mu_s rg} = \sqrt{(0.91)(160\text{ m})(9.80\text{ m/s}^2)} = \boxed{38\text{ m/s}}$$

REASONING

a. The free body diagram shows the swing ride and the two forces that act on a chair: the tension **T** in the cable, and the weight $m\mathbf{g}$ of the chair and its occupant. We note that the chair does not accelerate vertically, so the net force $\sum F_y$ in the vertical direction must be zero, $\sum F_y = 0$. The net force consists of the upward vertical component of the tension and the downward weight of the chair. The fact that the net force is zero will allow us to determine the magnitude of the tension.



b. According to Newton's second law, the net force $\sum F_x$ in the horizontal direction is equal to the mass m of the chair and its occupant times the centripetal acceleration $(a_c = v^2/r)$, so that $\sum F_x = ma_c = mv^2/r$. There is only one force in the horizontal direction, the horizontal component of the tension, so it is the net force. We will use Newton's second law to find the speed v of the chair.

SOLUTION

a. The vertical component of the tension is $+T\cos 60.0°$, and the weight is $-mg$, where we have chosen "up" as the + direction. Since the chair and its occupant have no vertical acceleration, we have that $\sum F_y = 0$, so

$$\underbrace{+T\cos 60.0° - mg}_{\sum F_y} = 0 \quad (1)$$

Solving for the magnitude T of the tension gives

$$T = \frac{mg}{\cos 60.0°} = \frac{(179\text{ kg})(9.80\text{ m/s}^2)}{\cos 60.0°} = \boxed{3510\text{ N}}$$

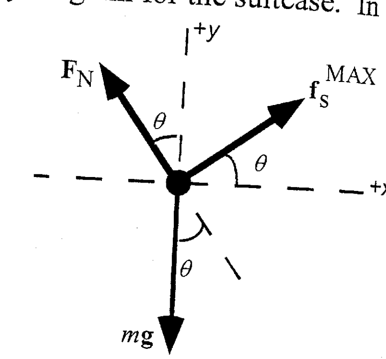
b. The horizontal component of the tension is $+T\sin 60.0°$, where we have chosen the direction to the left in the diagram as the + direction. Since the chair and its occupant have a centripetal acceleration in this direction, we have

30. ***REASONING*** The centripetal force F_c required to keep an object of mass m that moves with speed v on a circle of radius r is $F_c = mv^2/r$ (Equation 5.3). From Equation 5.1, we know that $v = 2\pi r/T$, where T is the period or the time for the suitcase to go around once. Therefore, the centripetal force can be written as

$$F_c = \frac{m(2\pi r/T)^2}{r} = \frac{4m\pi^2 r}{T^2} \quad (1)$$

This expression can be solved for T. However, we must first find the centripetal force that acts on the suitcase.

SOLUTION Three forces act on the suitcase. They are the weight mg of the suitcase, the force of static friction $\mathbf{f}_s^{MAX}$, and the normal force $\mathbf{F}_N$ exerted on the suitcase by the surface of the carousel. The following figure shows the free body diagram for the suitcase. In this diagram, the y axis is along the vertical direction. The force of gravity acts, then, in the $-y$ direction. The centripetal force that causes the suitcase to move on its circular path is provided by the net force in the $+x$ direction in the diagram. From the diagram, we can see that only the forces $\mathbf{F}_N$ and $\mathbf{f}_s^{MAX}$ have horizontal components. Thus, we have $F_c = f_s^{MAX}\cos\theta - F_N\sin\theta$, where the minus sign indicates that the x component of $\mathbf{F}_N$ points to the left in the diagram. Using Equation 4.7 for the maximum static frictional force, we can write this result as in equation (2).



$$F_c = \mu_s F_N\cos\theta - F_N\sin\theta = F_N(\mu_s\cos\theta - \sin\theta) \quad (2)$$

If we apply Newton's second law in the y direction, we see from the diagram that

$$F_N\cos\theta + f_s^{MAX}\sin\theta - mg = ma_y = 0 \quad \text{or} \quad F_N\cos\theta + \mu_s F_N\sin\theta - mg = 0$$

where we again have used Equation 4.7 for the maximum static frictional force. Solving for the normal force, we find

$$F_N = \frac{mg}{\cos\theta + \mu_s\sin\theta}$$

Using this result in equation (2), we obtain the magnitude of the centripetal force that acts on the suitcase:

$$F_c = F_N(\mu_s\cos\theta - \sin\theta) = \frac{mg(\mu_s\cos\theta - \sin\theta)}{\cos\theta + \mu_s\sin\theta}$$

With this expression for the centripetal force, equation (1) becomes

$$\frac{mg(\mu_s\cos\theta - \sin\theta)}{\cos\theta + \mu_s\sin\theta} = \frac{4m\pi^2 r}{T^2}$$

Solving for the period T, we find

$$T = \sqrt{\frac{4\pi^2 r(\cos\theta + \mu_s\sin\theta)}{g(\mu_s\cos\theta - \sin\theta)}} = \sqrt{\frac{4\pi^2(11.0\ \text{m})(\cos 36.0° + 0.760\sin 36.0°)}{(9.80\ \text{m/s}^2)(0.760\cos 36.0° - \sin 36.0°)}} = \boxed{45\ \text{s}}$$

31. ***REASONING*** The speed v of a satellite in circular orbit about the earth is given by $v = \sqrt{GM_E/r}$ (Equation 5.5), where G is the universal gravitational constant, M_E is the mass of the earth, and r is the radius of the orbit. The radius is measured from the center of the earth, not the surface of the earth, to the satellite. Therefore, the radius is found by adding the height of the satellite above the surface of the earth to the radius of the earth (6.38×10^6 m).

SOLUTION First we add the orbital heights to the radius of the earth to obtain the orbital radii. Then we use Equation 5.5 to calculate the speeds.

Satellite A $r_A = 6.38\times10^6\ \text{m} + 360\times10^3\ \text{m} = 6.74\times10^6\ \text{m}$

$$v = \sqrt{\frac{GM_E}{r_A}} = \sqrt{\frac{(6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2)(5.98\times10^{24}\ \text{kg})}{6.74\times10^6\ \text{m}}} = \boxed{7690\ \text{m/s}}$$

Satellite B $r_A = 6.38\times10^6\ \text{m} + 720\times10^3\ \text{m} = 7.10\times10^6\ \text{m}$

$$v = \sqrt{\frac{GM_E}{r_A}} = \sqrt{\frac{(6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2)(5.98\times10^{24}\ \text{kg})}{7.10\times10^6\ \text{m}}} = \boxed{7500\ \text{m/s}}$$

32. ***REASONING AND SOLUTION*** We have for Jupiter $v^2 = GM_J/r$, where

$$r = 6.00\times10^5\ \text{m} + 7.14\times10^7\ \text{m} = 7.20\times10^7\ \text{m}$$

Thus,

$$v = \sqrt{\frac{(6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2)(1.90\times10^{27}\ \text{kg})}{7.20\times10^7\ \text{m}}} = \boxed{4.20\times10^4\ \text{m/s}}$$

Since an angle of 90° corresponds to one fourth of the circumference of a circle, the distance is $\frac{1}{4}(2\pi r)$.

SOLUTION Since $a_c = v^2/r$ and $v = \frac{1}{4}(2\pi r)/t = \pi r/(2t)$, the magnitude of the centripetal acceleration of the blade tip is

$$a_c = \frac{v^2}{r} = \frac{\left(\frac{\pi r}{2t}\right)^2}{r} = \frac{\pi^2 r}{4t^2} = \frac{\pi^2(0.45\text{ m})}{4(0.40\text{ s})^2} = \boxed{6.9\text{ m/s}^2}$$

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52. ***REASONING AND SOLUTION***

a. In terms of the period of the motion, the centripetal force is written as

$$F_C = 4\pi^2 mr/T^2 = 4\pi^2\,(0.0120\text{ kg})(0.100\text{ m})/(0.500\text{ s})^2 = \boxed{0.189\text{ N}}$$

b. The centripetal force varies as the square of the speed. Thus, doubling the speed would increase the centripetal force by a factor of $\boxed{2^2 = 4}$.

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53. ***REASONING*** The astronaut in the chamber is subjected to a centripetal acceleration a_c that is given by $a_c = v^2/r$ (Equation 5.2). In this expression v is the speed at which the astronaut in the chamber moves on the circular path of radius r. We can solve this relation for the speed.

SOLUTION Using Equation 5.2, we have

$$a_c = \frac{v^2}{r} \quad \text{or} \quad v = \sqrt{a_c r} = \sqrt{\left[7.5\left(9.80\text{ m/s}^2\right)\right](15\text{ m})} = \boxed{33\text{ m/s}}$$

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54. ***REASONING*** The person feels the centripetal force acting on his back. This force is $F_c = mv^2/r$, according to Equation 5.3. This expression can be solved directly to determine the radius r of the chamber.

SOLUTION Solving Equation 5.3 for the radius r gives

$$r = \frac{mv^2}{F_C} = \frac{(83\text{ kg})(3.2\text{ m/s})^2}{560\text{ N}} = \boxed{1.5\text{ m}}$$

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55. SSM ***REASONING*** As the motorcycle passes over the top of the hill, it will experience a centripetal force, the magnitude of which is given by Equation 5.3: $F_C = mv^2/r$. The centripetal force is provided by the net force on the cycle + driver system. At that instant, the net force on the system is composed of the normal force, which points upward, and the weight, which points downward. Taking the direction toward the center of the circle (downward) as the positive direction, we have $F_C = mg - F_N$. This expression can be solved for F_N, the normal force.

SOLUTION

a. The magnitude of the centripetal force is

$$F_C = \frac{mv^2}{r} = \frac{(342\text{ kg})(25.0\text{ m/s})^2}{126\text{ m}} = \boxed{1.70\times10^3\text{ N}}$$

b. The magnitude of the normal force is

$$F_N = mg - F_C = (342\text{ kg})(9.80\text{ m/s}^2) - 1.70\times10^3\text{ N} = \boxed{1.66\times10^3\text{ N}}$$

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56. ***REASONING*** The speed of the satellite is given by Equation 5.1 as $v = 2\pi r/T$. Since we are given that the period is $T = 1.20 \times 10^4$ s, it will be possible to determine the speed from Equation 5.1 if we can determine the radius r of the orbit. To find the radius, we will use Equation 5.6, which relates the period to the radius according to $T = 2\pi r^{3/2}/\sqrt{GM_E}$, where G is the universal gravitational constant and M_E is the mass of the earth.

SOLUTION According to Equation 5.1, the orbital speed is

$$v = \frac{2\pi r}{T}$$

To find a value for the radius, we begin with Equation 5.6:

$$T = \frac{2\pi r^{3/2}}{\sqrt{GM_E}} \quad \text{or} \quad r^{3/2} = \frac{T\sqrt{GM_E}}{2\pi}$$

Next, we square both sides of the result for $r^{3/2}$:

$$\left(r^{3/2}\right)^2 = \left(\frac{T\sqrt{GM_E}}{2\pi}\right)^2 \quad \text{or} \quad r^3 = \frac{T^2 GM_E}{4\pi^2}$$

We can now take the cube root of both sides of the expression for r^3 in order to determine r:

$$r=\sqrt[3]{\frac{T^2GM_E}{4\pi^2}}=\sqrt[3]{\frac{\left(1.20\times10^4\ \text{s}\right)^2\left(6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2\right)\left(5.98\times10^{24}\ \text{kg}\right)}{4\pi^2}}=1.13\times10^7\ \text{m}$$

With this value for the radius, we can use Equation 5.1 to obtain the speed:

$$v=\frac{2\pi r}{T}=\frac{2\pi\left(1.13\times10^7\ \text{m}\right)}{1.20\times10^4\ \text{s}}=\boxed{5.92\times10^3\ \text{m/s}}$$

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57. SSM **_REASONING AND SOLUTION_** The centripetal acceleration for any point on the blade a distance r from center of the circle, according to Equation 5.2, is $a_c = v^2/r$. From Equation 5.1, we know that $v = 2\pi r/T$ where T is the period of the motion. Combining these two equations, we obtain

$$a_c=\frac{(2\pi r/T)^2}{r}=\frac{4\pi^2 r}{T^2}$$

a. Since the turbine blades rotate at 617 rev/s, all points on the blades rotate with a period of $T = (1/617)\ \text{s} = 1.62\times10^{-3}\ \text{s}$. Therefore, for a point with $r = 0.020\ \text{m}$, the magnitude of the centripetal acceleration is

$$a_c=\frac{4\pi^2(0.020\ \text{m})}{(1.62\times10^{-3}\ \text{s})^2}=\boxed{3.0\times10^5\ \text{m/s}^2}$$

b. Expressed as a multiple of g, this centripetal acceleration is

$$a_c=\left(3.0\times10^5\ \text{m/s}^2\right)\left(\frac{1.00\ g}{9.80\ \text{m/s}^2}\right)=\boxed{3.1\times10^4\ g}$$

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58. **_REASONING_** The centripetal acceleration for any point that is a distance r from the center of the disc is, according to Equation 5.2, $a_c = v^2/r$. From Equation 5.1, we know that $v = 2\pi r/T$ where T is the period of the motion. Combining these two equations, we obtain

$$a_c=\frac{(2\pi r/T)^2}{r}=\frac{4\pi^2 r}{T^2}$$

SOLUTION Using the above expression for a_c, the ratio of the centripetal accelerations of the two points in question is

$$\frac{a_2}{a_1}=\frac{4\pi^2 r_2/T_2^2}{4\pi^2 r_1/T_1^2}=\frac{r_2/T_2^2}{r_1/T_1^2}$$

Since the disc is rigid, all points on the disc must move with the same period, so $T_1 = T_2$. Making this cancellation and solving for a_2, we obtain

$$a_2=a_1\frac{r_2}{r_1}=\left(120\ \text{m/s}^2\right)\left(\frac{0.050\ \text{m}}{0.030\ \text{m}}\right)=\boxed{2.0\times10^2\ \text{m/s}^2}$$

Note that even though $T_1 = T_2$, it is not true that $v_1 = v_2$. Thus, the simplest way to approach this problem is to express the centripetal acceleration in terms of the period T which cancels in the final step.

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59. SSM WWW **_REASONING_** Let v_0 be the initial speed of the ball as it begins its projectile motion. Then, the centripetal force is given by Equation 5.3: $F_C = mv_0^2/r$. We are given the values for m and r; however, we must determine the value of v_0 from the details of the projectile motion after the ball is released.

In the absence of air resistance, the x component of the projectile motion has zero acceleration, while the y component of the motion is subject to the acceleration due to gravity. The horizontal distance traveled by the ball is given by Equation 3.5a (with $a_x = 0\ \text{m/s}^2$):

$$x = v_{0x}t = (v_0\cos\theta)t$$

with t equal to the flight time of the ball while it exhibits projectile motion. The time t can be found by considering the vertical motion. From Equation 3.3b,

$$v_y = v_{0y} + a_y t$$

After a time t, $v_y = -v_{0y}$. Assuming that up and to the right are the positive directions, we have

$$t=\frac{-2v_{0y}}{a_y}=\frac{-2v_0\sin\theta}{a_y}$$

and

$$x=(v_0\cos\theta)\left(\frac{-2v_0\sin\theta}{a_y}\right)$$

Using the fact that $2\sin\theta\cos\theta = \sin 2\theta$, we have