CHAPTER 5

ANSWERS TO QUESTIONS

Q5.1. No. The book takes a shorter time in its upward motion. When it is sliding up the ramp its acceleration is larger in magnitude, $g(\sin\theta + \mu_k \cos\theta)$, than when the book is sliding down with acceleration $g(\sin\theta - \mu_k \cos\theta)$.

Q5.2 Kinetic friction is less than static friction.

Q5.3 Don't slam on the brakes, but gradually increase pressure to keep the car from skidding with the wheels locked. (This is especially important on wet roads.) With no relative sliding motion between rubber and road, static friction can stop the car, instead of weaker kinetic friction.

Q5.4 The car exerts the same force as *twenty* people. (This is twice as much as ten people on each end.)

Q5.5 A torque is exerted by the force of the water times the distance between the outlets.

Q5.6 Same principle as the centrifuge. All the material inside the cylinder tends to move along a straight-line path, but the walls of the cylinder exert an inward force to keep everything moving around in a circular path.

Q5.7 The ball would not behave as it would when dropped on the Earth. As the astronaut holds the ball, she and the ball are moving with the same angular velocity. The ball, however, being closer to the center of rotation, is moving with a slower tangential velocity. Once the ball is released, it acts according to Newton's first law, and simply drifts with constant velocity in the original direction of its velocity when released — it is no longer "attached" to the rotating space station. Since the ball follows a straight line and the astronaut follows a circular path, it will appear to the astronaut that the ball will "fall to the floor". But other dramatic effects will occur. Imagine that the ball is held so high that it is just slightly away from the center of rotation. Then, as the ball is released, it will move very slowly along a straight line. Thus, the astronaut may make several full rotations around the circular path before the ball strikes the floor. This will result in three obvious variations with the Earth drop. First, the time to fall will be much larger than that on the Earth, even though the feet of the astronaut are pressed into the floor with a force that suggests the same force of gravity as on Earth. Second, the ball may actually appear to bob up and down if several rotations are made while it "falls". As the ball moves in a straight line while the astronaut rotates, sometimes she is on the side of the circle on which the ball is moving toward her and other times she is on the other side, where the ball is moving away from her. The third effect is that the ball will not drop straight down to her feet. In the extreme case we have been imagining, it may actually strike the surface while she is on the opposite side, so it looks like it ended up "falling up". In the less extreme case, in which only a portion of a rotation is made before the ball strikes the surface, the ball will appear to move backward relative to the astronaut as it falls.

Q5.8 Inertial reaction. The water tends to move along a straight line, but the bucket pulls it in and around in a circle.

Q5.9 There is no such force. If the passenger slides outward across the slippery car seat, it is because the passenger is moving forward in a straight line while the car is turning under him. If the passenger pushes hard against the outside door, the door is exerting an inward force on him. No object is exerting an outward force on him, but he should still buckle his seatbelt.

Q5.10 Sometimes seatbelts do not help. Blood pressure cannot supply the force necessary both to balance the gravitational force and to provide the centripetal acceleration, to keep blood flowing up to the pilot's brain.

Q5.11. The speed changes. The tangential force component causes tangential acceleration.

Q5.12 Steeper. The acceleration of gravity is weaker on the moon. Replace **T** with **n** and Figure 5.11 becomes the free-body diagram for a car on a frictionless banked curve. The angle of banking is given by the equation $\tan\theta = v^2 / rg$ from Example 5.6.

Q5.13 Face area and drag coefficient change when a skydiver opens a parachute.

Q5.14 The larger drop has higher terminal speed. In the case of spheres, the text demonstrates that terminal speed is proportional to the square root of radius. When moving with terminal speed, an object is in equilibrium and has zero acceleration.

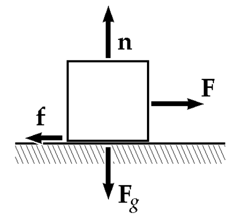
Q5.15 Lower air density reduces air resistance, so a tank-truck-load of fuel takes you farther.

Q5.16 If astronauts were indeed weightless, meaning that there were no gravitational force on them, they would move in a straight-line path tangent to the orbit rather than following the orbit around the Earth. In the space shuttle just above the atmosphere, gravity is only slightly weaker than at the Earth's surface. There is no way to get "beyond" a long-range force described by an inverse square law. Gravity does its job most clearly on an orbiting spacecraft, because the craft feels no other forces and is in free fall.

Q5.17. The thesis is false. The moment of decay of a radioactive atomic nucleus (for example) cannot be predicted. Quantum mechanics implies that the future is indeterminate. On the other hand, our sense of free will, of being able to make choices for ourselves that can appear to be random, may be an illusion. It may have nothing to do with the subatomic randomness described by quantum mechanics.

PROBLEM SOLUTIONS

5.1 For equilibrium: $f = F$ and $n = F_g$



Also, $f = \mu n$ i.e., $\mu = \frac{f}{n} = \frac{F}{F_g}$

$$\mu_s = \frac{75.0\text{ N}}{25.0(9.80)\text{ N}} = \boxed{0.306}$$

and $$\mu_k = \frac{60.0\text{ N}}{25.0(9.80)\text{ N}} = \boxed{0.245}$$

5.2 $\Sigma F_y = ma_y$: $+n - mg = 0$

$f_s \le \mu_s n = \mu_s mg$

This maximum magnitude of static friction acts so long as the tires roll without skidding.

$\Sigma F_x = ma_x$: $-f_s = ma$

The maximum acceleration is $a = -\mu_s g$

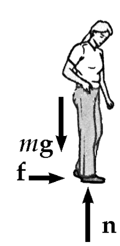
The initial and final conditions are: $x_i = 0$, $v_i = 50.0\text{ mi/h} = 22.4\text{ m/s}$, $v_f = 0$

$v_f^2 = v_i^2 + 2a\left(x_f - x_i\right)$: $-v_i^2 = -2\mu_s g x_f$

(a) $x_f = \dfrac{v_i^2}{2\mu g}$ $$x_f = \frac{(22.4\text{ m/s})^2}{2(0.100)\left(9.80\text{ m/s}^2\right)} = \boxed{256\text{ m}}$$

(b) $x_f = \dfrac{v_i^2}{2\mu g}$ $$x_f = \frac{(22.4\text{ m/s})^2}{2(0.600)\left(9.80\text{ m/s}^2\right)} = \boxed{42.7\text{ m}}$$

***5.3** (a) The person pushes backward on the floor. The floor pushes forward on the person with a force of friction. This is the only horizontal force on the person. If the person's shoe is on the point of slipping the static friction force has its maximum value.



$\Sigma F_x = ma_x$: $f = \mu_s n = ma_x$

$\Sigma F_y = ma_y$: $n - mg = 0$

$ma_x = \mu_s mg$ $a_x = \mu_s g = 0.5\left(9.8\text{ m/s}^2\right) = 4.9\text{ m/s}^2$

$x_f = x_i + v_{xi}t + \frac{1}{2}a_x t^2$ $3\text{ m} = 0 + 0 + \frac{1}{2}\left(4.9\text{ m/s}^2\right)t^2$ $t = \boxed{1.11\text{ s}}$

(b) $x_f = \frac{1}{2}\mu_s g t^2$ $$t = \sqrt{\frac{2x_f}{\mu_s g}} = \sqrt{\frac{2(3\text{ m})}{(0.8)(9.8\text{ m/s}^2)}} = \boxed{0.875\text{ s}}$$

***5.4** If all the weight is on the rear wheels,

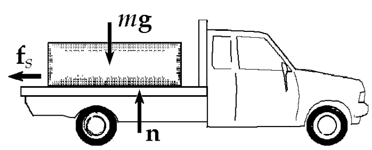
(a) $F = ma$: $\mu_s mg = ma$

But $\Delta x = \dfrac{at^2}{2} = \dfrac{\mu_s g t^2}{2}$

so $\mu_s = \dfrac{2\Delta x}{g t^2}$: $\mu_s = \dfrac{2(0.250\text{ mi})(1609\text{ m/mi})}{(9.80\text{ m/s}^2)(4.96\text{ s})^2} = \boxed{3.34}$

(b) Time would increase, as the wheels would skid and only kinetic friction would act; or perhaps the car would flip over.

***5.5** If the load is on the point of sliding forward on the bed of the slowing truck, static friction acts backward on the load with its maximum value, to give it the same acceleration as the truck



$\Sigma F_x = ma_x$: $-f = m_{\text{load}} a_x$

$\Sigma F_y = ma_y$: $n - m_{\text{load}} g = 0$

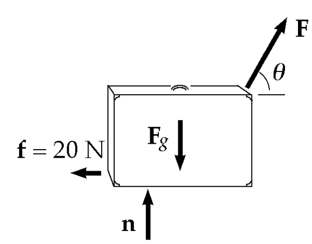
$-\mu_s mg = ma_x$ $a_x = -\mu_s g$

$v_{xf}^2 = v_{xi}^2 + 2a_x(x_f - x_i)$ $0 = v_{xi}^2 + 2(-\mu_s g)(x_f - 0)$

(a) $x_f = \dfrac{v_{xi}^2}{2\mu_s g} = \dfrac{(12\text{ m/s})^2}{2(0.5)(9.8\text{ m/s}^2)} = \boxed{14.7\text{ m}}$

(b) From the expression $x_f = v_{xi}^2/2\mu_s g$, $\boxed{\text{neither mass affects the answer}}$.

5.6 $m_{\text{suitcase}} = 20.0\text{ kg}$, $F = 35.0\text{ N}$



$\Sigma F_x = ma_x$: $-20.0\text{ N} + F\cos\theta = 0$

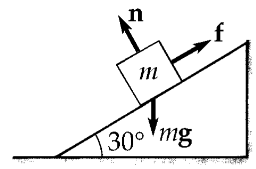
$\Sigma F_y = ma_y$: $+n + F\sin\theta - F_g = 0$

(a) $F\cos\theta = 20.0\text{ N}$ $\cos\theta = \dfrac{20.0\text{ N}}{35.0\text{ N}} = 0.571$

$\boxed{\theta = 55.2°}$

(b) $n = F_g - F\sin\theta = [196 - 35.0(0.821)]\text{ N}$ $\boxed{n = 167\text{ N}}$

5.7 $m = 3.00\text{ kg},\ \theta = 30.0°,\ x = 2.00\text{ m},\ t = 1.50\text{ s}$



(a) $x = \frac{1}{2}at^2$: $\qquad 2.00\text{ m} = \frac{1}{2}a(1.50\text{ s})^2$

$$a = \frac{4.00}{(1.50)^2} = \boxed{1.78\text{ m/s}^2}$$

$\Sigma\mathbf{F} = \mathbf{n} + \mathbf{f} + m\mathbf{g} = m\mathbf{a}$: $\qquad$ Along x: $\qquad 0 - f + mg\sin 30.0° = ma$

$$f = m(g\sin 30.0° - a)$$

Along y: $\qquad n + 0 - mg\cos 30.0° = 0$

$$n = mg\cos 30.0°$$

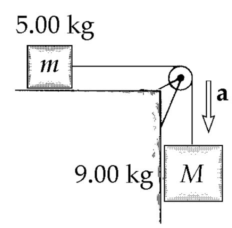
(b) $\mu_k = \frac{f}{n} = \frac{m(g\sin 30.0° - a)}{mg\cos 30.0°}$ $\qquad \mu_k = \tan 30.0° - \frac{a}{g\cos 30.0°} = \boxed{0.368}$

(c) $f = m(g\sin 30.0° - a)$ $\qquad f = 3.00(9.80\sin 30.0° - 1.78) = \boxed{9.37\text{ N}}$

(d) $v_f^2 = v_i^2 + 2a(x_f - x_i)$ $\qquad$ where $\qquad x_f - x_i = 2.00\text{ m}$

$v_f^2 = 0 + 2(1.78)(2.00) = 7.11\text{ m}^2/\text{s}^2$ $\qquad v_f = \sqrt{7.11\text{ m}^2/\text{s}^2} = \boxed{2.67\text{ m/s}}$

5.8 $T - f_k = 5.00a$ (for 5.00 kg mass)

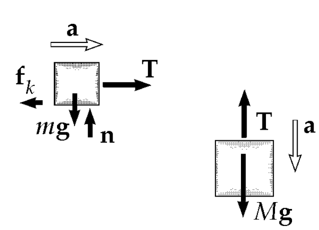


$9.00g - T = 9.00a$ (for 9.00 kg mass)

Adding these two equations gives:

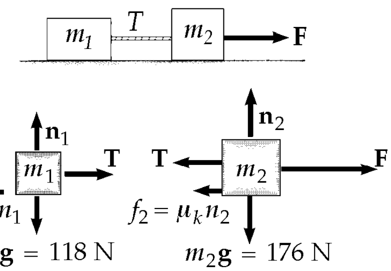
$$9.00(9.80) - 0.200(5.00)(9.80) = 14.0a$$

$$a = 5.60\text{ m/s}^2$$



$$\therefore\ T = 5.00(5.60) + 0.200(5.00)(9.80) = \boxed{37.8\text{ N}}$$

***5.9** (a) See Figure to the right



(b) $68.0 - T - \mu m_2 g = m_2 a$ (Block #2)

$T - \mu m_1 g = m_1 a$ (Block #1)

Adding, $68.0 - \mu(m_1 + m_2)g = (m_1 + m_2)a$

$$a = \frac{68.0}{(m_1 + m_2)} - \mu g = \boxed{1.29\ \text{m/s}^2}$$

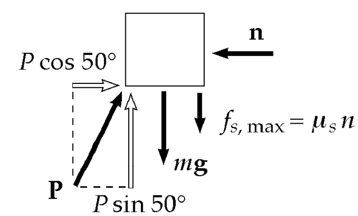
$$T = m_1 a + \mu m_1 g = \boxed{27.2\ \text{N}}$$

5.10 $-f + mg\sin\theta = 0$ and $+n - mg\cos\theta = 0$

with $f = \mu n$

yield $\mu_s = \tan\theta_c = \tan 36.0° = \boxed{0.727}$ $\mu_k = \tan\theta_c = \tan 30.0° = \boxed{0.577}$

***5.11** (Case 1, impending upward motion)



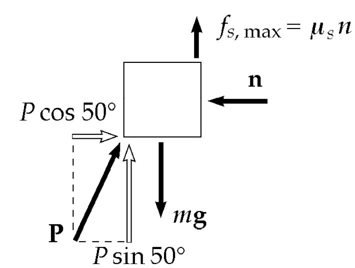
Setting $\Sigma F_x = 0$: $P\cos 50.0° - n = 0$

$f_{s,\max} = \mu_s n$: $f_{s,\max} = \mu_s P\cos 50.0° = 0.250(0.643)P = 0.161P$

Setting $\Sigma F_y = 0$: $P\sin 50.0° - 0.161P - 3.00(9.80) = 0$

$$P_{\max} = \boxed{48.6\ \text{N}}$$

(Case 2, impending downward motion)



As in Case 1, $f_{s,\max} = 0.161P$

Setting $\Sigma F_y = 0$: $P\sin 50.0° + 0.161P - 3.00(9.80) = 0$

$$P_{\min} = \boxed{31.7\ \text{N}}$$

5.12 (a) $$F = \frac{mv^2}{r} = \frac{9.11\times10^{-31}\ \text{kg}\left(2.20\times10^6\ \text{m/s}\right)^2}{0.530\times10^{-10}\ \text{m}} = \boxed{8.32\times10^{-8}\ \text{N inward}}$$

(b) $$a = \frac{v^2}{r} = \frac{\left(2.20\times10^6\ \text{m/s}\right)^2}{0.530\times10^{-10}\ \text{m}} = \boxed{9.13\times10^{22}\ \text{m/s}^2\ \text{inward}}$$

5.13 $m = 3.00 \text{ kg}$, $r = 0.800 \text{ m}$. The string will break if the tension exceeds the weight corresponding to 25.0 kg, so

$$T_{\max} = Mg = 25.0(9.80) = 245 \text{ N}$$

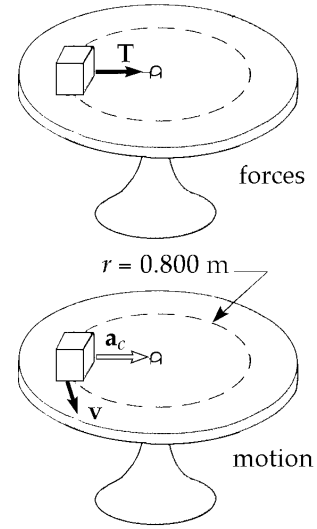
When the 3.00 kg mass rotates in a horizontal circle, the tension causes the centripetal acceleration,

so $$T = \frac{mv^2}{r} = \frac{(3.00)v^2}{0.800}$$

Then $$v^2 = \frac{rT}{m} = \frac{(0.800)T}{3.00} \le \frac{(0.800)T_{\max}}{3.00} = \frac{0.800(245)}{3.00} = 65.3 \text{ m}^2/\text{s}^2$$

and $$0 \le v \le \sqrt{65.3}$$

or $$\boxed{0 \le v \le 8.08 \text{ m/s}}$$



***5.14** $$v = \frac{2\pi r}{T} = \frac{2\pi(3.00 \text{ m})}{12.0 \text{ s}} = 1.57 \text{ m/s}$$

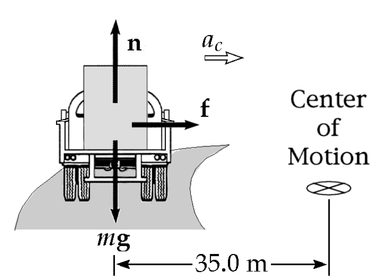
(a) $a = \dfrac{v^2}{r}$ $$a = \frac{(1.57 \text{ m/s})^2}{3.00 \text{ m}} = \boxed{0.822 \text{ m/s}^2 \text{ toward the center}}$$

(b) For no sliding motion, $$f_s = ma = 45.0 \text{ kg}\left(0.822 \text{ m/s}^2\right) = \boxed{37.0 \text{ N toward the center}}$$

(c) $f_s = \mu mg$ $$\mu = \frac{37.0 \text{ N}}{45.0 \text{ kg}\left(9.80 \text{ m/s}^2\right)} = \boxed{0.0839}$$

5.15 $n = mg$ since $a_y = 0$

The force causing the centripetal acceleration is the frictional force f.



From Newton's second law $$f = ma_c = \frac{mv^2}{r}$$

But the friction condition is $$f \le \mu_s n$$

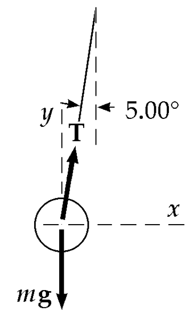
i.e., $$\frac{mv^2}{r} \le \mu_s mg$$

$$v \le \sqrt{\mu_s r g} = \sqrt{0.600(35.0 \text{ m})\left(9.80 \text{ m/s}^2\right)} \qquad v \le \boxed{14.3 \text{ m/s}}$$

5.16 $T\cos 5.00° = mg = (80.0\text{ kg})(9.80\text{ m/s}^2)$

(a) $T = 787\text{ N}$: $\quad T = \boxed{(68.6\text{ N})\mathbf{i} + (784\text{ N})\mathbf{j}}$

(b) $T\sin 5.00° = ma_c$: $\quad \boxed{a_c = 0.857\text{ m/s}^2}$ toward the center of the circle.



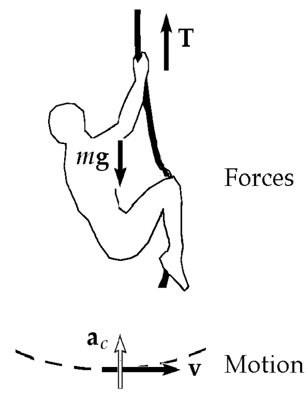
The length of the wire is unnecessary information. We could, on the other hand, use it to find the radius of the circle, the speed of the bob, and the period of the motion.

5.17 Let the tension at the lowest point be T.

$\Sigma F = ma$: $\quad T - mg = ma_c = \dfrac{mv^2}{r}$

$$T = m\left(g + \frac{v^2}{r}\right)$$

$$T = 85.0\text{ kg}\left[9.80\text{ m/s}^2 + \frac{(8.00\text{ m/s})^2}{10.0\text{ m}}\right] = 1.38\text{ kN} > 1000\text{N}$$



$\boxed{\text{He doesn't make it across the river because the vine breaks.}}$

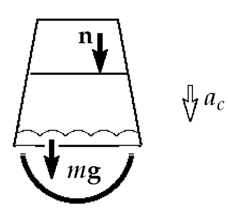
5.18 (a) $\Sigma F_y = ma_y = \dfrac{mv^2}{R}$

$mg - n = \dfrac{mv^2}{R}$ $\qquad n = \boxed{mg - \dfrac{mv^2}{R}}$

(b) When $n = 0$, $\qquad mg = \dfrac{mv^2}{R}$

Then, $\qquad v = \boxed{\sqrt{gR}}$

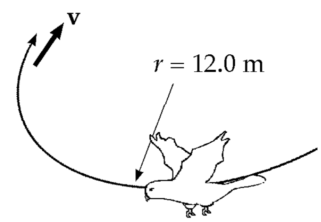
5.19 $\Sigma F_y = \dfrac{mv^2}{r} = mg + n$



But $n = 0$ at this minimum speed condition, so

$$\frac{mv^2}{r} = mg \Rightarrow v = \sqrt{gr} = \sqrt{(9.80\text{ m/s}^2)(1.00\text{ m})} = \boxed{3.13\text{ m/s}}$$

***5.20** (a) $a_c = \frac{v^2}{r} = \frac{(4.00 \text{ m/s})^2}{12.0 \text{ m}} = \boxed{1.33 \text{ m/s}^2}$

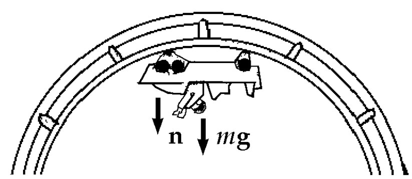


(b) $a = \sqrt{a_c{}^2 + a_t{}^2}$

$a = \sqrt{(1.33)^2 + (1.20)^2} = \boxed{1.79 \text{ m/s}^2}$

at an angle $\theta = \tan^{-1}\left(\frac{a_c}{a_t}\right) = \boxed{47.9° \text{ inward}}$

5.21 (a) $a_c = \frac{v^2}{r}$ $\qquad r = \frac{v^2}{a_c} = \frac{(13.0 \text{ m/s})^2}{2(9.80 \text{ m/s}^2)} = \boxed{8.62 \text{ m}}$



(b) Let n be the force exerted by the rail.

Newton's law gives $\qquad Mg + n = \frac{Mv^2}{r}$

$$n = M\left(\frac{v^2}{r} - g\right) = M(2g - g) = \boxed{Mg, \text{ downward}}$$

(c) $a_c = \frac{v^2}{r}$ $\qquad a_c = \frac{(13.0 \text{ m/s})^2}{20.0 \text{ m}} = \boxed{8.45 \text{ m/s}^2}$

If the force exerted by the rail is n_1,

then $\qquad n_1 + Mg = \frac{Mv^2}{r} = Ma_c$

$n_1 = M(a_c - g)$ $\qquad$ which is < 0, since $\qquad a_c = 8.45 \text{ m/s}^2$

Thus, the normal force would have to point away from the center of the curve. Unless they have belts, the riders will fall from the cars. To be safe we must require n_1 to be positive. Then $a_c > g$. We need

$$\frac{v^2}{r} > g \qquad \text{or} \qquad v > \sqrt{rg} = \sqrt{(20.0 \text{ m})(9.80 \text{ m/s}^2)} \qquad v > 14.0 \text{ m/s}$$

5.22 (a) $a = g - bv$

When $v = v_T$, $a = 0$ and $g = bv_T$ $\qquad b = \dfrac{g}{v_T}$

The Styrofoam falls 1.50 m at constant speed v_T in 5.00 s.

Thus, $\qquad v_T = \dfrac{y}{t} = \dfrac{1.50\text{ m}}{5.00\text{ s}} = 0.300\text{ m/s}$

Then $\qquad b = \dfrac{9.80\text{ m/s}^2}{0.300\text{ m/s}} = \boxed{32.7\text{ s}^{-1}}$

(b) At $t = 0$, $v = 0$ and $\qquad a = g = \boxed{9.80\text{ m/s}^2}$ down

(c) When $v = 0.150\text{ m/s}$, $\qquad a = g - bv = 9.80\text{ m/s}^2 - \left(32.7\text{ s}^{-1}\right)(0.150\text{ m/s}) = \boxed{4.90\text{ m/s}^2}$ down

***5.23** (a) At terminal velocity, $\qquad R = v_T b = mg$

$$\therefore\ b = \frac{mg}{v_T} = \frac{3.00\times10^{-3}\text{ kg}\left(9.80\text{ m/s}^2\right)}{2.00\times10^{-2}\text{ m/s}} = \boxed{1.47\text{ N}\cdot\text{s/m}}$$

(b) From Equation 5.6, the velocity of the bead is

$v = v_T\left(1 - e^{-bt/m}\right)$ $\qquad v = 0.632\ v_T$ when $e^{-bt/m} = 0.368$

or at time $\qquad t = -\left(\dfrac{m}{b}\right)\ln(0.368) = \boxed{2.04\times10^{-3}\text{ s}}$

(c) At terminal velocity, $\qquad R = v_T b = mg = \boxed{2.94\times10^{-2}\text{ N}}$

5.24 (a) $\rho = \dfrac{m}{V}$, $A = 0.0201\text{ m}^2$, $\qquad R = \frac{1}{2}\rho_{\text{air}} A D v_T^{\,2} = mg$

$$m = \rho_{\text{bead}} V = 0.830\text{ g/cm}^3\left[\frac{4}{3}\pi(8.00\text{ cm})^3\right] = 1.78\text{ kg}$$

Assuming a drag coefficient of $D = 0.500$ for this spherical object, and taking the density of air at 20°C from the endpapers, we have

$$v_T = \sqrt{\frac{2(1.78\text{ kg})\left(9.80\text{ m/s}^2\right)}{0.500\left(1.20\text{ kg/m}^3\right)\left(0.0201\text{ m}^2\right)}} = \boxed{53.8\text{ m/s}}$$

(b) $v_f^{\,2} = v_i^{\,2} + 2gh = 0 + 2gh$: $\qquad h = \dfrac{v_f^{\,2}}{2g} = \dfrac{(53.8\text{ m/s})^2}{2\left(9.80\text{ m/s}^2\right)} = \boxed{148\text{ m}}$

5.25 (a) $v(t) = v_i e^{-ct}$ $\quad v(20.0\text{ s}) = 5.00 = v_i e^{-20.0c}, \quad v_i = 10.0\text{ m/s}$

So $\quad 5.00 = 10.0e^{-20.0c}$ and $\quad -20.0c = \ln\left(\frac{1}{2}\right)$ $\quad c = -\dfrac{\ln\left(\frac{1}{2}\right)}{20.0} = \boxed{3.47\times10^{-2}\text{ s}^{-1}}$

(b) At $t = 40.0$ s $\quad v = (10.0\text{ m/s})e^{-40.0c} = (10.0\text{ m/s})(0.250) = \boxed{2.50\text{ m/s}}$

(c) $v = v_i e^{-ct}$ $\quad a = \dfrac{dv}{dt} = -cv_i e^{-ct} = \boxed{-cv}$

5.26 $\Sigma F_x = ma_x$: $\quad -kmv^2 = ma_x = m\dfrac{dv}{dt}$

$$-k\int_0^t dt = \int_{v_f}^{v} v^{-2}dv \qquad -k(t-0) = \left.\frac{v^{-1}}{-1}\right|_{v_f}^{v} = -\frac{1}{v} + \frac{1}{v_f} \qquad v = \boxed{\frac{v_f}{1+ktv_f}}$$

5.27 (a) When $v = v_T$, $a = 0$, $\Sigma F = -mg + Cv_T^{\,2} = 0$

$$v_T = -\sqrt{\frac{mg}{C}} = -\sqrt{\frac{(4.80\times10^{-4}\text{ kg})(9.80\text{ m/s}^2)}{2.50\times10^{-5}\text{ kg/m}}} = \boxed{-13.7\text{ m/s}}$$

(b)

t(s)	x(m)	v(m/s)	F(mN)	a(m/s^2)
0	0	0	– 4.704	–9.8
0.2	0	–1.96	– 4.608	–9.5999
0.4	–0.392	–3.88	– 4.3276	–9.0159
0.6	–1.168	–5.6832	–3.8965	–8.1178
0.8	–2.30	–7.3068	–3.3693	–7.0193
1.0	–3.77	–8.7107	–2.8071	–5.8481
1.2	–5.51	–9.8803	–2.2635	–4.7156
1.4	–7.48	–10.823	–1.7753	–3.6986
1.6	–9.65	–11.563	–1.3616	–2.8366
1.8	–11.96	–12.13	–1.03	–2.14
2	–14.4	–12.56	–0.762	–1.59
... listing results after each fifth step				
3	–27.4	–13.49	–0.154	–0.321
4	–41.0	–13.67	–0.0291	–0.0606
5	–54.7	–13.71	–0.00542	–0.0113

The hailstone reaches 99.95% of v_T after 5.0 s, 99.99% of v_T after 6.0 s, 99.999% of v_T after 7.4 s.

5.28 (a) At $v = v_T$, $a = 0$, $-mg + bv_T = 0$ $\quad v_T = \frac{mg}{b} = \frac{(3.00\times10^{-3}\text{ kg})(9.80\text{ m/s}^2)}{3.00\times10^{-2}\text{ kg/s}} = \boxed{0.980\text{ m/s}}$

(b)

t(s)	x(m)	v(m/s)	F(mN)	a (m/s^2)
0	2	0	–29.4	–9.8
0.005	2	–0.049	–27.93	–9.31
0.01	1.999755	–0.09555	–26.534	–8.8445
0.015	1.9993	–0.13977	–25.2	–8.40
. . . we list the result after each tenth iteration				
0.5	1.990	–0.393	–17.6	–5.87
0.1	1.965	–0.629	–10.5	–3.51
0.15	1.930	–0.770	–6.31	–2.10
0.2	1.889	–0.854	–3.78	–1.26
0.25	1.845	–0.904	–2.26	–0.754
0.3	1.799	–0.935	–1.35	–0.451
0.35	1.752	–0.953	–0.811	–0.270
0.4	1.704	–0.964	–0.486	–0.162
0.45	1.65	–0.970	–0.291	–0.0969
0.5	1.61	–0.974	–0.174	–0.0580
0.55	1.56	–0.977	–0.110	–0.0347
0.6	1.51	–0.978	–0.0624	–0.0208
0.65	1.46	–0.979	–0.0374	–0.0125

Terminal velocity is never reached. The leaf is at 99.9% of v_T after 0.67 s. The fall to the ground takes about 2.14 s. Repeating with $\Delta t = 0.001$ s, we find the fall takes 2.14 s.

***5.29** (a) At terminal velocity, $\Sigma F = 0 = -mg + Cv_T^{\,2}$.

$$C = \frac{mg}{v_T^{\,2}} = \frac{(0.142\text{ kg})(9.80\text{ m/s}^2)}{(42.5\text{ m/s})^2} = \boxed{7.70\times10^{-4}\text{ kg/m}}$$

(b) $Cv^2 = (7.70\times10^{-4}\text{ kg/m})(36.0\text{ m/s})^2 = \boxed{0.998\text{ N}}$

(c)

Elapsed Time (s)	Altitude (m)	Speed (m/s)	Resistance Force (N)	Net Force (N)	Acceleration (m/s^2)
0.00000	0.00000	36.00000	–0.99849	–2.39009	–16.83158
0.05000	1.75792	35.15842	–0.95235	–2.34395	–16.50667
…					
2.95000	48.62327	0.82494	–0.00052	–1.39212	–9.80369
3.00000	48.64000	0.33476	–0.00009	–1.39169	–9.80061
3.05000	48.63224	–0.15527	0.00002	–1.39158	–9.79987
…					
6.25000	1.25085	–26.85297	0.55555	–0.83605	–5.88769
6.30000	–0.10652	–27.14736	0.56780	–0.82380	–5.80144

Maximum height is about $\boxed{49\text{ m}}$. It returns to the ground after about $\boxed{6.3\text{ s}}$ with a speed of approximately $\boxed{27\text{ m/s}}$.

5.30 (a)

time(s)	x(m)	y(m)
0	0	0
0.100	7.81	5.43
0.200	14.9	10.2
0.400	27.1	18.3
1.00	51.9	32.7
1.92	70.0	38.5
2.00	70.9	38.5
4.00	80.4	26.7
5.00	81.4	17.7
6.85	81.8	0

with θ	we find range
30.0°	86.410 m
35.0°	81.8 m
25.0°	90.181 m
20.0°	92.874 m
15.0°	93.812 m
10.0°	90.965 m
17.0°	93.732 m
16.0°	93.8398 m
15.5°	93.829 m
15.8°	93.839 m
16.1°	93.838 m
15.9°	93.8402 m

(b) range = $\boxed{81.8 \text{ m}}$

(c) So we have maximum range at $\theta = \boxed{15.9°}$

5.31 $$F = \frac{Gm_1m_2}{r^2} = \frac{(6.672 \times 10^{-11})(2)(2)}{(0.30)^2} = \boxed{2.97 \times 10^{-9} \text{ N}}$$

5.32 $$F = k_e \frac{q_1q_2}{(r_{12})^2} = (8.99 \times 10^9)\frac{(+40)(-40)}{(2000)^2} = -3.60 \times 10^6 \text{ N (attractive)} = \boxed{3.60 \times 10^6 \text{ N downward}}$$

5.33 For two 70–kg persons, modeled as spheres,

$$F_g = \frac{Gm_1m_2}{r^2} = \frac{(6.67 \times 10^{-11} \text{ N} \cdot \text{m}^2/\text{kg}^2)(70 \text{ kg})(70 \text{ kg})}{(2 \text{ m})^2} \boxed{\sim 10^{-7} \text{ N}}$$

***5.34** (a) $$v = \frac{2\pi r}{T} = \frac{2\pi(3.84 \times 10^8 \text{ m})}{27.3 \text{ d}}\left(\frac{1 \text{ d}}{86\,400 \text{ s}}\right) = \boxed{1.02 \times 10^3 \text{ m/s}}$$

(b) $$a_c = \frac{v^2}{r} = \frac{(1.02 \times 10^3 \text{ m/s})^2}{3.84 \times 10^8 \text{ m}} = \boxed{2.72 \times 10^{-3} \text{ m/s}^2 \text{ toward Earth}}$$

(c) $\mathbf{g} = -\frac{GM_E}{r^2}\hat{\mathbf{r}}$. Newton did not know the value of G or M_E. To follow his logic about the inverse-square law, we make a ratio relating the surface gravitational field $g_{\text{surf}} = GM_E/R_E^2$ and that at the Moon $g_r = GM_E/r^2$.

$$\frac{g_r}{g_{\text{surf}}} = \frac{GM_E}{r^2}\frac{R_E^2}{GM_E}$$

$$g_r = g_{\text{surf}}\frac{R_E^2}{r^2} = 9.8 \text{ m/s}^2\left(\frac{6.37 \times 10^6 \text{ m}}{3.84 \times 10^8 \text{ m}}\right)^2 = \boxed{2.70 \times 10^{-3} \text{ m/s}^2 \text{ toward Earth}}$$

The two values agree within 1%.

5.35 $a = \frac{MG}{(4R_E)^2} = \frac{9.8 \text{ m/s}^2}{16} = \boxed{0.613 \text{ m/s}^2}$ toward the earth

***5.36** (a) We require that $\frac{GM_E m}{r^2} = \frac{mv^2}{r}$, but $g = \frac{M_E G}{R_E^{\,2}}$

In this case $r = 2R_E$ therefore, $\frac{g}{4} = \frac{v^2}{2R_E}$

or $v = \sqrt{\frac{gR_E}{2}} = \sqrt{\frac{9.80 \text{ m/s}^2 (6.37 \times 10^6 \text{ m})}{2}} = \boxed{5.59 \times 10^3 \text{ m/s}}$

(b) $T = \frac{2\pi r}{v} = \frac{2\pi(2)(6.37 \times 10^6 \text{ m})}{5.59 \times 10^3 \text{ m/s}} = \boxed{239 \text{ min}}$

(c) $F = \frac{GM_E m}{(2R_E)^2} = \frac{mg}{4} = \frac{(300 \text{ kg})(9.80 \text{ m/s}^2)}{4} = \boxed{735 \text{ N}}$

***5.37** The orbit radius is $r = 1.70 \times 10^6 \text{ m} + 100 \text{ km} = 1.80 \times 10^6 \text{ m}$.

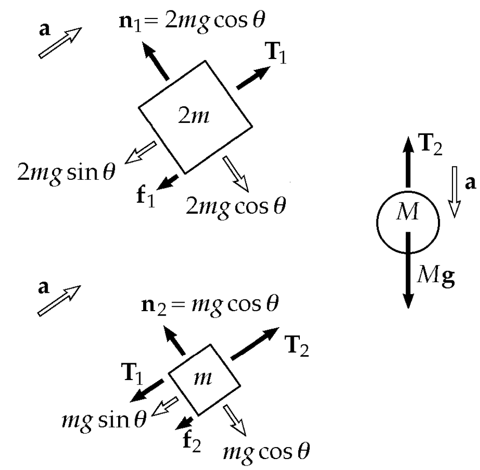
$\Sigma F = m_s a$: $\frac{GM_m m_s}{r^2} = \frac{m_s 2^2 \pi^2 r^2}{rT^2} = m_s a$

(a) $a = \frac{GM_m}{r^2} = \frac{(6.67 \times 10^{-11})(7.40 \times 10^{22})}{(1.80 \times 10^6 \text{ m})^2} = \boxed{1.52 \text{ m/s}^2}$

(b) $a = \frac{v^2}{r}$ $v = \sqrt{(1.52 \text{ m/s}^2)(1.80 \times 10^6 \text{ m})} = \boxed{1.66 \text{ km/s}}$

(c) $v = \frac{2\pi r}{T}$ $T = \frac{2\pi(1.80 \times 10^6)}{1.66 \times 10^3} = \boxed{6820 \text{ s}}$

***5.38** Applying Newton's second law to each object gives:



(1) $T_1 = f_1 + 2m(g\sin\theta + a)$

(2) $T_2 - T_1 = f_2 + m(g\sin\theta + a)$

(3) $T_2 = M(g - a)$

Parts (a) and (b): Equilibrium $(a = 0)$
and frictionless incline $(f_1 = f_2 = 0)$

Under these conditions, the equations reduce to

(1′) $\boxed{T_1 = 2mg\sin\theta}$

(2′) $T_2 - T_1 = mg\sin\theta$

(3′) $T_2 = Mg$

Substituting (1′) and (3′) into equation (2′) then gives $\boxed{M = 3m\sin\theta}$

so equation (3′) becomes $\boxed{T_2 = 3mg\sin\theta}$

Parts (c) and (d): $M = 6m\sin\theta$ (double the value found above), and $f_1 = f_2 = 0$. With these conditions present, the equations become

$$T_1 = 2m(g\sin\theta + a) \quad T_2 - T_1 = m(g\sin\theta + a) \text{ and } T_2 = 6m\sin\theta(g - a)$$

Solved simultaneously, these yield

$$\boxed{a = \frac{g\sin\theta}{1+2\sin\theta}}, \quad \boxed{T_1 = 4mg\sin\theta\left(\frac{1+\sin\theta}{1+2\sin\theta}\right)} \quad \text{and} \quad \boxed{T_2 = 6mg\sin\theta\left(\frac{1+\sin\theta}{1+2\sin\theta}\right)}$$

Part (e): Equilibrium $(a = 0)$ and impending motion up the incline so $M = M_{\max}$ while $f_1 = 2\mu_s mg\cos\theta$ and $f_2 = \mu_s mg\cos\theta$, both directed down the incline. Under these conditions, the equations become

$$T_1 = 2mg(\sin\theta + \mu_s\cos\theta),\ T_2 - T_1 = mg(\sin\theta + \mu_s\cos\theta), \text{ and } T_2 = M_{\max}g,$$

which yield $\boxed{M_{\max} = 3m(\sin\theta + \mu_s\cos\theta)}$

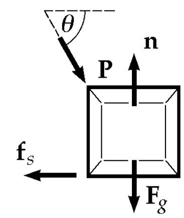
Part (f): Equilibrium $(a = 0)$ and impending motion **down** the incline so $M = M_{\min}$, while $f_1 = 2\mu_s mg\cos\theta$ and $f_2 = \mu_s mg\cos\theta$, both directed **up** the incline. Under these conditions, the equations are

$$T_1 = 2mg(\sin\theta - \mu_s\cos\theta),\ T_2 - T_1 = mg(\sin\theta - \mu_s\cos\theta), \text{ and } T_2 = M_{\min}g,$$

which yield $\boxed{M_{\min} = 3m(\sin\theta - \mu_s\cos\theta)}$

Part (g): $\boxed{T_{2,\max} - T_{2,\min} = M_{\max}g - M_{\min}g = 6\mu_s mg\cos\theta}$

5.39 (a) The crate is in equilibrium, just before it starts to move. Let the normal force acting on it be n and the friction force, f_s.



Resolving vertically: $n = F_g + P\sin\theta$

Horizontally: $P\cos\theta = f_s$

But, $f_s \le \mu_s n$

i.e., $P\cos\theta \le \mu_s\left(F_g + P\sin\theta\right)$

or $P\left(\cos\theta - \mu_s\sin\theta\right) \le \mu_s F_g$

Divide by $\cos\theta$: $P\left(1-\mu_s\tan\theta\right) \le \mu_s F_g\sec\theta$

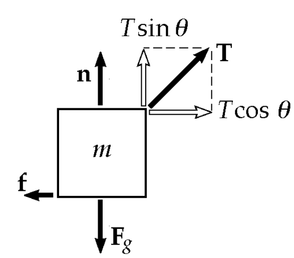
Then $\boxed{P_{\text{minimum}} = \dfrac{\mu_s F_g\sec\theta}{1-\mu_s\tan\theta}}$

(b) $P = \dfrac{0.400(100\text{ N})\sec\theta}{1-0.400\tan\theta}$

θ (deg)	0.00	15.0	30.0	45.0	60.0
P (N)	40.0	46.4	60.1	94.3	260

If the angle were 68.2° or more, the expression for P would go to infinity and motion would become impossible.

5.40 With motion impending, $n + T\sin\theta - mg = 0$



$f = \mu_s\left(mg - T\sin\theta\right)$

and $T\cos\theta - \mu_s mg + \mu_s T\sin\theta = 0$

so $T = \dfrac{\mu_s mg}{\cos\theta + \mu_s\sin\theta}$

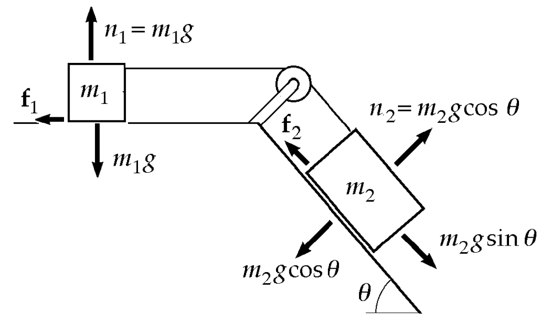
To minimize T, we maximize $\cos\theta + \mu_s\sin\theta$

$$\frac{d}{d\theta}\left(\cos\theta + \mu_s\sin\theta\right) = 0 = -\sin\theta + \mu_s\cos\theta$$

(a) $\theta = \tan^{-1}\mu_s = \tan^{-1}0.350 = \boxed{19.3°}$

(b) $T = \dfrac{0.350(1.30\text{ kg})\left(9.80\text{ m/s}^2\right)}{\cos 19.3° + 0.350\sin 19.3°} = \boxed{4.21\text{ N}}$

***5.41** For the system to start to move when released, the force tending to move m_2 down the incline, $m_2 g\sin\theta$, must exceed the maximum friction force which can retard the motion:



$$f_{\max} = f_{1,\max} + f_{2,\max} = \mu_{s,1}n_1 + \mu_{s,2}n_2$$

$$f_{\max} = \mu_{s,1}m_1g + \mu_{s,2}m_2g\cos\theta$$

From Table 5.1, $\mu_{s,1} = 0.610$ (aluminum on steel)

and $\mu_{s,2} = 0.530$ (copper on steel).

With $m_1 = 2.00$ kg, $m_2 = 6.00$ kg, $\theta = 30.0°$,

the maximum friction force is found to be $f_{\max} = 38.9$ N.

This exceeds the force tending to cause the system to move,

$$m_2g\sin\theta = 6.00\text{ kg}\left(9.80\text{ m/s}^2\right)\sin 30° = 29.4\text{ N}$$

Hence, $\boxed{\text{the system will not start to move when released}}$.

The friction forces increase in magnitude until the total friction force retarding the motion, $f = f_1 + f_2$, equals the force tending to set the system in motion. That is, until $\boxed{f = m_2g\sin\theta = 29.4\text{ N}}$.

***5.42** $\Sigma F_1 = m_1a$: $\quad -m_1g\sin 35.0° - f_{k,1} + T = m_1a$

$$-(3.50)(9.80)\sin 35.0° - \mu_s(3.50)(9.80)\cos 35.0° + T = 3.50(1.50) \qquad (1)$$

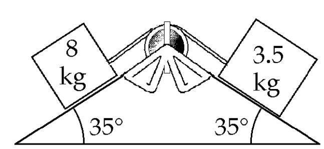
$\Sigma F_2 = m_2a$: $\quad +m_2g\sin 35.0° - f_{k,2} - T = m_2a$

$$+(8.00)(9.80)\sin 35.0° - \mu_s(8.00)(9.80)\cos 35.0° - T = 8.00(1.50) \qquad (2)$$

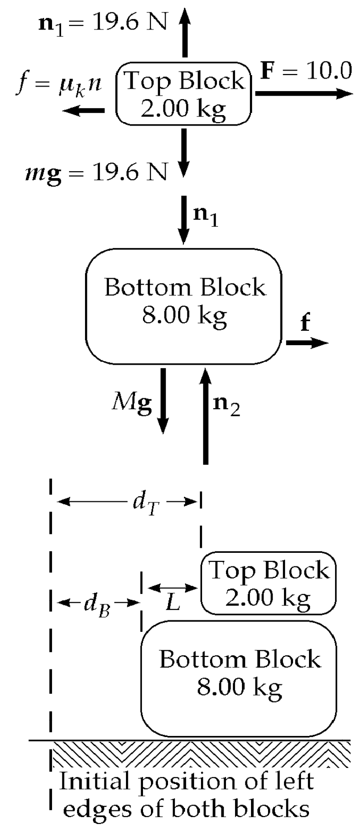
Solving equations (1) and (2) simultaneously gives

(a) $\boxed{\mu_k = 0.0871}$

(b) $\boxed{T = 27.4\text{ N}}$



***5.43** (a) First, draw a free-body diagram, (top figure) of the top block.



Since $a_y = 0$, $\quad n_1 = 19.6$ N

And $\quad f_k = \mu_k n_1 = 0.300(19.6\text{ N}) = 5.88$ N

$\Sigma F_x = ma_T \quad 10.0\text{ N} - 5.88\text{ N} = (2.00\text{ kg})a_T$

or $\quad a_T = 2.06\text{ m/s}^2$ (for top block)

Now draw a free-body diagram (middle figure) of the bottom block and observe that

$\Sigma F_x = Ma_B$ gives $\quad f = 5.88\text{ N} = (8.00\text{ kg})a_B$

or $\quad a_B = 0.735\text{ m/s}^2$ (for the bottom block)

In time t, the distance each block moves (starting from rest) is

$$d_T = \frac{1}{2}a_T t^2$$

and

$$d_B = \frac{1}{2}a_B t^2$$

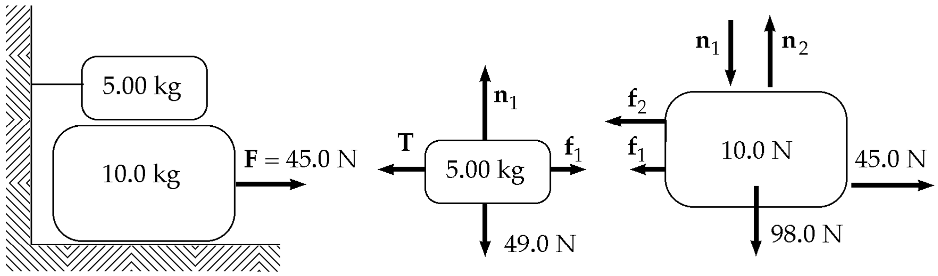
For the top block to reach the right edge of the bottom block, (see bottom figure) it is necessary that

$d_T = d_B + L \quad$ or $\quad \frac{1}{2}(2.06\text{ m/s}^2)t^2 = \frac{1}{2}(0.735\text{ m/s}^2)t^2 + 3.00\text{ m}$

which gives: $\quad t = \boxed{2.13\text{ s}}$

(b) From above, $\quad d_B = \frac{1}{2}(0.735\text{ m/s}^2)(2.13\text{ s})^2 = \boxed{1.67\text{ m}}$

***5.44** (a)



f_1 and n_1 appear in both diagrams as action-reaction pairs

(b) 5.00 kg: $\Sigma F_x = ma$: $n_1 = m_1 g = 5.00(9.80) = 49.0\text{ N}$ $\qquad f_1 - T = 0$

$$T = f_1 = \mu mg = 0.200(5.00)(9.80) = \boxed{9.80\text{ N}}$$

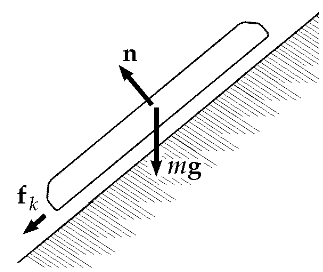
10.0 kg: $\Sigma F_x = ma$: $45.0 - f_1 - f_2 = 10.0a$

$\Sigma F_y = 0$: $n_2 - n_1 - 98.0 = 0$

$$f_2 = \mu n_2 = \mu(n_1 + 98.0) = 0.20(49.0 + 98.0) = 29.4\text{ N}$$

$$45.0 - 9.80 - 29.4 = 10.0a \qquad a = \boxed{0.580\text{ m/s}^2}$$

***5.45** We must consider separately the disk when it is in contact with the roof and when it has gone over the top into free fall. In the first case, we take x and y as parallel and perpendicular to the surface of the roof:



$\Sigma F_y = ma_y$: $+n - mg\cos\theta = 0$ $\qquad n = mg\cos\theta$

then friction is $f_k = \mu_k n = \mu_k mg\cos\theta$

$\Sigma F_x = ma_x$: $-f_k - mg\sin\theta = ma_x$

$$a_x = -\mu_k g\cos\theta - g\sin\theta = (-0.4\cos 37° - \sin 37°)9.8\text{ m/s}^2 = -9.03\text{ m/s}^2$$

The Frisbee goes ballistic with speed given by

$$v_{xf}^2 = v_{xi}^2 + 2a_x(x_f - x_i) = (15\text{ m/s})^2 + 2(-9.03\text{ m/s}^2)(10\text{ m} - 0) = 44.4\text{ m}^2/\text{s}^2$$

$$v_{xf} = 6.67\text{ m/s}$$

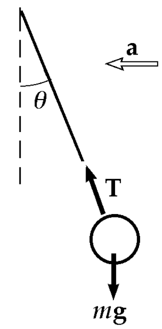
For the free fall, we take x and y horizontal and vertical:

$$v_{yf}^2 = v_{yi}^2 + 2a_y(y_f - y_i)$$

$$0 = (6.67\text{ m/s }\sin 37°)^2 + 2(-9.8\text{ m/s}^2)(y_f - 10\text{ m }\sin 37°)$$

$$y_f = 6.02\text{ m} + \frac{(4.01\text{ m/s})^2}{19.6\text{ m/s}^2} = \boxed{6.84\text{ m}}$$

5.46 (a) While the car negotiates the curve, the accelerometer is at the angle θ.



Horizontally: $$T\sin\theta = \frac{mv^2}{r}$$

Vertically: $$T\cos\theta = mg$$

where r is the radius of the curve, and v is the speed of the car.

By division, $$\tan\theta = \frac{v^2}{rg}$$

Then $a_c = \dfrac{v^2}{r} = g\tan\theta$: $$a_c = \left(9.80\text{ m/s}^2\right)\tan 15.0°$$

$$a_c = \boxed{2.63\text{ m/s}^2}$$

(b) $r = \dfrac{v^2}{a_c}$ $$r = \frac{(23.0\text{ m/s})^2}{2.63\text{ m/s}^2} = \boxed{201\text{ m}}$$

(c) $v^2 = rg\tan\theta = (201\text{ m})\left(9.80\text{ m/s}^2\right)\tan 9.00°$ $$v = \boxed{17.7\text{ m/s}}$$

***5.47** (a) Since the object of mass m_2 is in equilibrium, $$\Sigma F_y = T - m_2 g = 0,$$

or $$T = \boxed{m_2 g}$$

(b) The tension in the string provides the required centripetal acceleration of the puck.

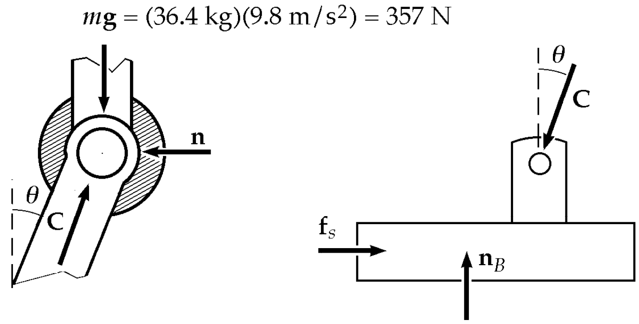
Thus, $$F_c = T = \boxed{m_2 g}$$

(c) From $$F_c = \frac{m_1 v^2}{R}$$

we have $$v = \sqrt{\frac{RF_c}{m_1}} = \boxed{\sqrt{\left(\frac{m_2}{m_1}\right)gR}}$$

***5.48** (a) See Figure (a) to the right.

(b) See Figure (b) to the right.



(a) (b)

(c) For the pin,

$$\Sigma F_y = ma_y: \quad C\cos\theta - 357\text{ N} = 0$$

$$C = 357\text{ N}/\cos\theta$$

For the foot,

$$\Sigma F_y = ma_y: \quad +n_B - C\cos\theta = 0$$

$$n_B = \boxed{357\text{ N}}$$

(d) For the foot with motion impending,

$$\Sigma F_x = ma_x: \quad +f_s - C\sin\theta_s = 0$$

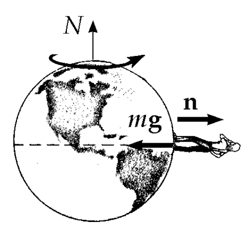
$$\mu_s n_B = C\sin\theta_s$$

$$\mu_s = \frac{C\sin\theta_s}{n_B} = \frac{(357\text{ N}/\cos\theta_s)\sin\theta_s}{357\text{ N}} = \tan\theta_s$$

(e) The maximum coefficient is

$$\mu_s = \tan\theta_s = \tan 50.2° = \boxed{1.20}$$

5.49 (a) Since the centripetal acceleration of a person is downward (toward the axis of the earth), it is equivalent to the effect of a falling elevator. Therefore,

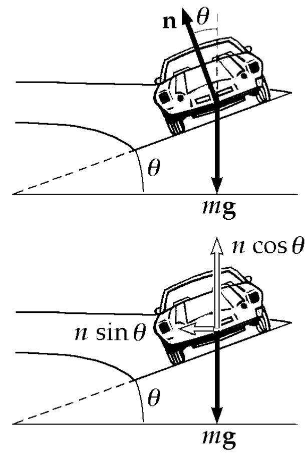


$$F_g' = F_g - \frac{mv^2}{r} \qquad \text{or} \qquad \boxed{F_g > F_g'}$$

(b) At the poles $v = 0$, and $F_g' = F_g = mg = 75.0(9.80) = \boxed{735\text{ N}}$ down.

At the equator, $F_g' = F_g - ma_c = 735\text{ N} - 75.0(0.0337)\text{ N} = \boxed{732\text{ N}}$ down.

5.50 On the level road, the centripetal acceleration must be provided by a force of friction between car and road. However, if the road is banked at an angle θ, the normal force, n, has a horizontal component $n \sin \theta$ pointing toward the center of the circular path followed by the car. We assume that only the component $n \sin \theta$ causes the centripetal acceleration. Therefore, the banking angle we calculate will be one for which *no frictional force is required*. In other words, a car moving at the correct speed (13.4 m/s) can negotiate the curve even on an icy surface. Newton's second law written for the radial direction gives



$$n \sin \theta = \frac{mv^2}{r} \qquad (1)$$

The car is in equilibrium in the vertical direction.

Thus, from $\Sigma F_y = 0$, we have $\qquad n \cos \theta = mg \qquad (2)$

Dividing (1) by (2) gives $\qquad \tan \theta = v^2 / rg$

$$\theta = \tan^{-1}\left[\frac{(13.4 \text{ m/s})^2}{(50 \text{ m})(9.80 \text{ m/s}^2)}\right] = \boxed{20.1°}$$

If a car rounds the curve at a speed lower than 13.4 m/s, the driver will have to rely on friction to keep from sliding down the incline. A driver who attempts to negotiate the curve at a speed higher than 13.4 m/s will have to depend on friction to keep from sliding up the ramp.

5.51 Standing on the inner surface of the rim, and moving with it, each person will feel a normal force exerted by the rim. This inward force causes the 3.00 m/s^2 centripetal acceleration:

$a_c = \dfrac{v^2}{r}$: $\qquad v = \sqrt{a_c r} = \sqrt{(3.00 \text{ m/s}^2)(60.0 \text{ m})} = 13.4 \text{ m/s}$

The period of rotation comes from $v = \dfrac{2\pi r}{T}$: $\qquad T = \dfrac{2\pi r}{v} = \dfrac{2\pi(60.0 \text{ m})}{13.4 \text{ m/s}} = 28.1 \text{ s}$

so the frequency of rotation is $\qquad f = \dfrac{1}{T} = \dfrac{1}{28.1 \text{ s}} = \dfrac{1}{28.1 \text{ s}}\left(\dfrac{60 \text{ s}}{1 \text{ min}}\right) = \boxed{2.14 \text{ rev/min}}$

5.52 $v = \left(\frac{mg}{b}\right)\left[1 - \exp\left(\frac{-bt}{m}\right)\right]$ where $\exp(x) = e^x$ is the exponential function.

At $t \to \infty$, $v \to v_T = \frac{mg}{b}$

At $t = 5.54$ s, $0.500 v_T = v_T\left[1 - \exp\left(\frac{-b(5.54 \text{ s})}{9.00 \text{ kg}}\right)\right]$

$$\exp\left(\frac{-b(5.54 \text{ s})}{9.00 \text{ kg}}\right) = 0.500;$$

$$\frac{-b(5.54 \text{ s})}{9.00 \text{ kg}} = \ln 0.500 = -0.693;$$

$$b = \frac{(9.00 \text{ kg})(0.693)}{5.54 \text{ s}} = 1.13 \text{ m/s}$$

(a) $v_T = \frac{mg}{b}$ $\quad v_T = \frac{(9.00 \text{ kg})(9.80 \text{ m/s}^2)}{1.13 \text{ kg/s}} = \boxed{78.3 \text{ m/s}}$

(b) $0.750\, v_T = v_T\left[1 - \exp\left(\frac{-1.13t}{9.00 \text{ s}}\right)\right]$ $\quad \exp\left(\frac{-1.13t}{9.00 \text{ s}}\right) = 0.250$

$$t = \frac{9.00(\ln 0.250)}{-1.13} \text{ s} = \boxed{11.1 \text{ s}}$$

(c) $\frac{dx}{dt} = \left(\frac{mg}{b}\right)\left[1 - \exp\left(-\frac{bt}{m}\right)\right]$; $\quad \int_{x_0}^{x} dx = \int_0^t \left(\frac{mg}{b}\right)\left[1 - \exp\left(\frac{-bt}{m}\right)\right]dt$

$$x - x_0 = \frac{mgt}{b} + \left(\frac{m^2 g}{b^2}\right)\exp\left(\frac{-bt}{m}\right)\Big|_0^t = \frac{mgt}{b} + \left(\frac{m^2 g}{b^2}\right)\left[\exp\left(\frac{-bt}{m}\right) - 1\right]$$

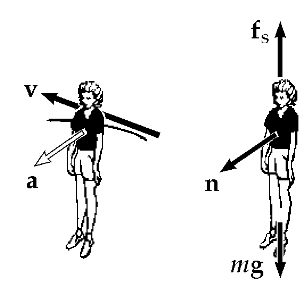
At $t = 5.54$ s, $x = 9.00 \text{ kg}\left(9.80 \text{ m/s}^2\right)\frac{5.54 \text{ s}}{1.13 \text{ kg/s}} + \left(\frac{(9.00 \text{ kg})^2\left(9.80 \text{ m/s}^2\right)}{(1.13 \text{ m/s})^2}\right)\left[\exp(-0.693) - 1\right]$

$$x = 434 \text{ m} + 626 \text{ m}(-0.500) = \boxed{121 \text{ m}}$$

5.53 (a) $n = \frac{mv^2}{R}$ $\quad f - mg = 0$

$f = \mu_s n$ $\quad v = \frac{2\pi R}{T}$

$$T = \boxed{\sqrt{\frac{4\pi^2 R \mu_s}{g}}}$$



motion forces

(b) $T = \boxed{2.54 \text{ s}}$

$$\omega = \frac{1 \text{ rev}}{2.54 \text{ s}}\left(\frac{60 \text{ s}}{\text{min}}\right) = \boxed{23.6 \text{ rev/min}}$$

5.54 At terminal velocity, the accelerating force of gravity is balanced by frictional drag:

$$mg = arv + br^2v^2$$

(a) $mg = \left(3.10\times10^{-9}\right)v + \left(0.870\times10^{-10}\right)v^2$

For water, $m = \rho V = 1000\ \text{kg/m}^3\left[\frac{4}{3}\pi\left(10^{-5}\ \text{m}\right)^3\right]$

$$4.11\times10^{-11} = \left(3.10\times10^{-9}\right)v + \left(0.870\times10^{-10}\right)v^2$$

Assuming v is small, ignore the second term on the right hand side: $\boxed{v = 0.0132\ \text{m/s}}$

(b) $mg = \left(3.10\times10^{-8}\right)v + \left(0.870\times10^{-8}\right)v^2$

Here we cannot ignore the second term because the coefficients are of nearly equal magnitude.

$$4.11\times10^{-8} = \left(3.10\times10^{-8}\right)v + \left(0.870\times10^{-8}\right)v^2$$

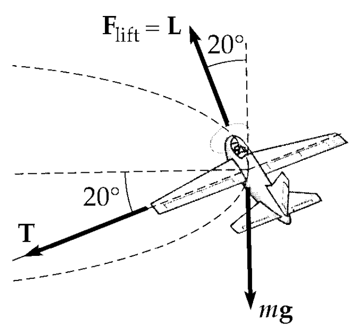
$$v = \frac{-3.10 \pm \sqrt{(3.10)^2 + 4(0.870)(4.11)}}{2(0.870)} = \boxed{1.03\ \text{m/s}}$$

(c) $mg = \left(3.10\times10^{-7}\right)v + \left(0.870\times10^{-6}\right)v^2$

Assuming $v > 1\ \text{m/s}$, and ignoring the first term:

$$4.11\times10^{-5} = \left(0.870\times10^{-6}\right)v^2 \qquad v = \boxed{6.87\ \text{m/s}}$$

5.55 $\Sigma F_y = L_y - T_y - mg = L\cos 20.0° - T\sin 20.0° - 7.35\ \text{N} = ma_y = 0$



$$\Sigma F_x = L_x + T_x = L\sin 20.0° + T\cos 20.0° = m\frac{v^2}{r}$$

$$m\frac{v^2}{r} = 0.750\ \text{kg}\frac{(35.0\ \text{m/s})^2}{(60.0\ \text{m})\cos 20.0°} = 16.3\ \text{N}$$

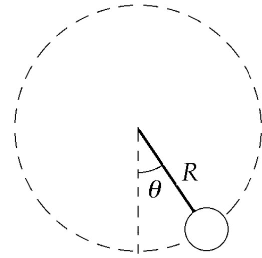
$$\therefore\ L\sin 20.0° + T\cos 20.0° = 16.3\ \text{N}$$

$$L\cos 20.0° - T\sin 20.0° = 7.35\ \text{N}$$

$$L + T\frac{\cos 20.0°}{\sin 20.0°} = \frac{16.3\ \text{N}}{\sin 20.0°} \qquad L - T\frac{\sin 20.0°}{\cos 20.0°} = \frac{7.35\ \text{N}}{\cos 20.0°}$$

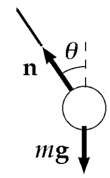
$$T\left(\cot 20.0° + \tan 20.0°\right) = \frac{16.3\ \text{N}}{\sin 20.0°} - \frac{7.35\ \text{N}}{\cos 20.0°} \qquad T(3.11) = 39.8\ \text{N} \qquad T = \boxed{12.8\ \text{N}}$$

***5.56** (a) The bead moves in a circle with radius $r = R\sin\theta$ at a speed of



$$v = \frac{2\pi r}{T} = \frac{2\pi R\sin\theta}{T}$$

The normal force has
an inward radial component of $n\sin\theta$
and an upward component of $n\cos\theta$.



$\Sigma F_y = ma_y$: $\quad n\cos\theta - mg = 0$

or $\quad n = \dfrac{mg}{\cos\theta}$

Then $\Sigma F_x = n\sin\theta = m\dfrac{v^2}{r}$ becomes $\quad \left(\dfrac{mg}{\cos\theta}\right)\sin\theta = \dfrac{m}{R\sin\theta}\left(\dfrac{2\pi R\sin\theta}{T}\right)^2$

which reduces to $\quad \dfrac{g\sin\theta}{\cos\theta} = \dfrac{4\pi^2 R\sin\theta}{T^2}$.

This has two solutions: $\quad \sin\theta = 0 \Rightarrow \theta = 0°$ (1)

and $\quad \cos\theta = \dfrac{gT^2}{4\pi^2 R}$ (2)

If $R = 15.0$ cm and $T = 0.450$ s, the second solution yields

$$\cos\theta = \frac{(9.80\ \text{m/s}^2)(0.450\ \text{s})^2}{4\pi^2(0.150\ \text{m})} = 0.335 \qquad \text{and} \qquad \theta = 70.4°$$

Thus, in this case, the bead can ride at two positions $\boxed{\theta = 70.4°}$ and $\boxed{\theta = 0°}$.

(b) At this slower rotation, solution (2) above becomes

$$\cos\theta = \frac{(9.80\ \text{m/s}^2)(0.850\ \text{s})^2}{4\pi^2(0.150\ \text{m})} = 1.20, \text{ which is impossible.}$$

In this case, the bead can ride only at the bottom of the loop, $\boxed{\theta = 0°}$. The loop's rotation must be faster than a certain threshold value in order for the bead to move away from the lowest position.

***5.57** $v = v_i - kx$ implies the acceleration is $\quad a = \dfrac{dv}{dt} = 0 - k\dfrac{dx}{dt} = -kv$

Then the total force is $\quad \Sigma F = ma = m(-kv)$

The resistive force is opposite to the velocity: $\boxed{\Sigma \mathbf{F} = -km\mathbf{v}}$

ANSWERS TO EVEN NUMBERED PROBLEMS

2. (a) 256 m (b) 42.7 m

4. (a) 3.34
(b) Time would increase, as the wheels would skid and only kinetic friction would act; or perhaps the car would flip over.

6. (a) 55.2° (b) 167 N (See the solution for free body diagram.)

8. 37.8 N

10. $\mu_s = 0.727$, $\mu_k = 0.577$

12. (a) 8.32×10^{-8} N inward, toward the nucleus (b) 9.13×10^{22} m/s^2 inward

14. (a) 0.822 m/s^2 toward the center (b) 37.0 N toward the center (c) 0.083 9

16. (a) 68.6 N toward the center of the circle and 784 N up (b) 0.857 m/s^2

18. (a) $mg - mv^2 / R$ upward (b) $\sqrt{gR}$

20. (a) 1.33 m/s^2 radially inward (b) 1.79 m/s^2 at 47.9° inward from the tangent

22. (a) 32.7 s^{-1} (b) 9.80 m/s^2 down (c) 4.90 m/s^2 down

24. (a) 53.8 m/s (b) 148 m

26. See the solution.

28. (a) 0.980 m/s (b) See the solution.

30. (a) See the solution. (b) 81.8 m (c) 15.9°

32. 3.60×10^6 N downward

34. (a) 1.02 km/s (b) $0.00272\ \text{m/s}^2$ toward the Earth
(c) $0.00270\ \text{m/s}^2$ toward Earth

36. (a) $5.59 \times 10^3\ \text{m/s}$ (b) 239 min (c) 735 N downward

38. (a) $M = 3m \sin\theta$ (b) $T_1 = 2mg\sin\theta$, $T_2 = 3mg\sin\theta$
(c) $a = \dfrac{g\sin\theta}{1 + 2\sin\theta}$ (d) $T_1 = 4mg\sin\theta\left(\dfrac{1+\sin\theta}{1+2\sin\theta}\right)$, $T_2 = 6mg\sin\theta\left(\dfrac{1+\sin\theta}{1+2\sin\theta}\right)$
(e) $M_{\text{max}} = 3m(\sin\theta + \mu_s\cos\theta)$ (f) $M_{\text{min}} = 3m(\sin\theta - \mu_s\cos\theta)$
(g) $T_{2,\text{max}} - T_{2,\text{min}} = (M_{\text{max}} - M_{\text{min}})g = 6\mu_s mg\cos\theta$

40. (a) 19.3° (b) 4.21 N

42. (a) 0.087 1 (b) 27.4 N

44. (a) See the solution. (b) $T = 9.80$ N, $a = 0.580\ \text{m/s}^2$

46. (a) $2.63\ \text{m/s}^2$ (b) 201 m (c) 17.7 m/s

48. (a) and (b) See the solution. (c) 357 N (e) 1.20

50. 20.1°

52. (a) 78.3 m/s (b) 11.1 s (c) 121 m

54. (a) 0.013 2 m/s (b) 1.03 m/s (c) 6.87 m/s

56. (a) either 70.4° or 0° (b) 0°