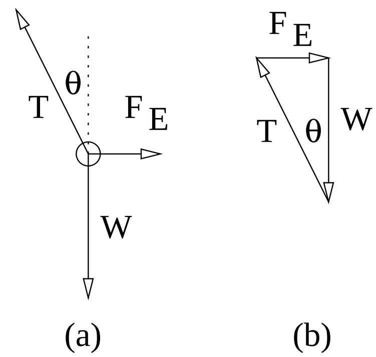
$\boxed{\textbf{E5-1}}$ There are three forces which act on the charged sphere— an electric force, F_E, the force of gravity, W, and the tension in the string, T. All arranged as shown in the figure on the right below.

(a) Write the vectors so that they geometrically show that the sum is zero, as in the figure on the left below. Now $W = mg = (2.8 \times 10^{-4}\ \text{kg})(9.8\ \text{m/s}^2) = 2.7 \times 10^{-3}$ N. The magnitude of the electric force can be found from the tangent relationship, so $F_E = W \tan\theta = (2.7 \times 10^{-3}\ \text{N}) \tan(33°) = 1.8 \times 10^{-3}$ N.



(b) The tension can be found from the cosine relation, so

$$T = W/\cos\theta = (2.7 \times 10^{-3}\,\text{N})/\cos(33°) = 3.2 \times 10^{-3}\,\text{N}.$$

E5-2 (a) The net force on the elevator is $F = ma = Wa/g = (6200\ \text{lb})(3.8\ \text{ft/s}^2)/(32\ \text{ft/s}^2) =$ 740 lb. Positive means up. There are two force on the elevator: a weight W down and a tension from the cable T up. Then $F = T - W$ or $T = F + W = (740\ \text{lb}) + (6200\ \text{lb}) = 6940$ lb.

(b) If the elevator acceleration is down then $F = -740$ lb; consequently $T = F+W = (-740\ \text{lb})+ (6200\ \text{lb}) = 5460$ lb.

E5-3 (a) The tension T is up, the weight W is down, and the net force F is in the direction of the acceleration (up). Then $F = T - W$. But $F = ma$ and $W = mg$, so

$$m = T/(a + g) = (89\,\text{N})/[(2.4\,\text{m/s}^2) + (9.8\,\text{m/s}^2)] = 7.3\,\text{kg}.$$

(b) $T = 89\,$N. The direction of velocity is unimportant. In both (a) and (b) the acceleration is up.

E5-4 The average speed of the elevator during deceleration is $v_{\text{av}} = 6.0\,\text{m/s}$. The time to stop the elevator is then $t = (42.0\,\text{m})/(6.0\,\text{m/s}) = 7.0\,\text{s}$. The deceleration is then $a = (12.0\,\text{m/s})/(7.0\,\text{s}) = 1.7\,\text{m/s}^2$. Since the elevator is moving downward but slowing down, then the acceleration is up, which will be positive.

The net force on the elevator is $F = ma$; this is equal to the tension T minus the weight W. Then

$$T = F + W = ma + mg = (1600\,\text{kg})[(1.7\,\text{m/s}^2) + (9.8\,\text{m/s}^2)] = 1.8\times 10^4\text{N}.$$

$\boxed{\textbf{E5-5}}$ (a) The magnitude of the man's acceleration is given by

$$a = \frac{m_2 - m_1}{m_2 + m_1} g = \frac{(110\ \text{kg}) - (74\ \text{kg})}{(110\ \text{kg}) + (74\ \text{kg})} g = 0.2g,$$

and is directed down. The time which elapses while he falls is found by solving $y = v_{0y}t + \frac{1}{2}a_y t^2$, or, with numbers, $(-12\ \text{m}) = (0)t + \frac{1}{2}(-0.2g)t^2$ which has the solutions $t = \pm 3.5$ s. The velocity with which he hits the ground is then $v = v_{0y} + a_y t = (0) + (-0.2g)(3.5\ \text{s}) = -6.9$ m/s.

(b) Reducing the speed can be accomplished by reducing the acceleration. We can't change Eq. 5-4 without also changing one of the assumptions that went into it. Since the man is hoping to reduce the speed with which he hits the ground, it makes sense that he might want to climb up the rope.

E5-6 (a) Although it might be the monkey which does the work, the upward force to lift him still comes from the tension in the rope. The minimum tension to lift the log is $T = W_\text{l} = m_\text{l}g$. The net force on the monkey is $T - W_\text{m} = m_\text{m}a$. The acceleration of the monkey is then

$$a = (m_\text{l} - m_\text{m})g/m_\text{m} = [(15\,\text{kg}) - (11\,\text{kg})](9.8\,\text{m/s}^2)/(11\,\text{kg}) = 3.6\,\text{m/s}^2.$$

(b) Atwood's machine!

$$a = (m_\text{l} - m_\text{m})g/(m_\text{l} + m_\text{m}) = [(15\,\text{kg}) - (11\,\text{kg})](9.8\,\text{m/s}^2)/[(15\,\text{kg}) + (11\,\text{kg})] = 1.5\,\text{m/s}.$$

(c) Atwood's machine!

$$T = 2m_\text{l}m_\text{m}g/(m_\text{l} + m_\text{m}) = 2(15\,\text{kg})(11\,\text{kg})(9.8\,\text{m/s}^2)/[(15\,\text{kg}) + (11\,\text{kg})] = 120\,\text{N}.$$

E5-7 The weight of each car has two components: a component parallel to the cables $W_{||} = W\sin\theta$ and a component normal to the cables $W_\perp$.. The normal component is "balanced" by the supporting cable. The parallel component acts with the pull cable.

In order to accelerate a car up the incline there must be a net force up with magnitude $F = ma$. Then $F = T_\text{above} - T_\text{below} - W_{||}$, or

$$\Delta T = ma + mg\sin\theta = (2800\,\text{kg})[(0.81\,\text{m/s}^2) + (9.8\,\text{m/s}^2)\sin(35°)] = 1.8\times10^4\text{N}.$$

E5-8 The tension in the cable is T, the weight of the man + platform system is $W = mg$, and the net force on the man + platform system is $F = ma = Wa/g = T - W$. Then

$$T = Wa/g + W = W(a/g + 1) = (180\text{ lb} + 43\text{ lb})[(1.2\text{ ft/s}^2)/(32\text{ ft/s}^2) + 1] = 231\text{ lb}.$$

$\boxed{\textbf{E5-9}}$ See Sample Problem 5-8. We need only apply the (unlabeled!) equation

$$\mu_s = \tan\theta$$

to find the egg angle. In this case $\theta = \tan^{-1}(0.04) = 2.3°$.

E5-10 (a) The maximum force of friction is $F = \mu_\text{s}N$. If the rear wheels support half of the weight of the automobile then $N = W/2 = mg/2$. The maximum acceleration is then

$$a = F/m = \mu_\text{s}N/m = \mu_\text{s}g/2.$$

(b) $a = (0.56)(9.8\,\text{m/s}^2)/2 = 2.7\,\text{m/s}^2$.

E5-11 The maximum force of friction is $F = \mu_\text{s}N$. Since there is no motion in the y direction the magnitude of the normal force must equal the weight, $N = W = mg$. The maximum acceleration is then

$$a = F/m = \mu_\text{s}N/m = \mu_\text{s}g = (0.95)(9.8\,\text{m/s}^2) = 9.3\,\text{m/s}^2.$$

E5-12 There is no motion in the vertical direction, so $N = W = mg$. Then $\mu_\text{k} = F/N = (470\,\text{N})/[(9.8\,\text{m/s}^2)(79\,\text{kg})] = 0.61$.

$\boxed{\textbf{E5-13}}$ A 75 kg mass has a weight of $W = (75\,\text{kg})(9.8\,\text{m/s}^2) = 735\,\text{N}$, so the force of friction on each end of the bar must be 368 N. Then

$$F \geq \frac{f_s}{\mu_s} = \frac{(368\,\text{N})}{(0.41)} = 900\,\text{N}.$$

E5-14 (a) There is no motion in the vertical direction, so $N = W = mg$.

To get the box moving you must overcome static friction and push with a force of $P \geq \mu_\text{s} N = (0.41)(240\,\text{N}) = 98\,\text{N}$.

(b) To keep the box moving at constant speed you must push with a force equal to the kinetic friction, $P = \mu_\text{k} N = (0.32)(240\,\text{N}) = 77\,\text{N}$.

(c) If you push with a force of 98 N on a box that experiences a (kinetic) friction of 77 N, then the net force on the box is 21 N. The box will accelerate at

$$a = F/m = Fg/W = (21\,\text{N})(9.8\,\text{m/s}^2)/(240\,\text{N}) = 0.86\,\text{m/s}^2.$$

E5-15 (a) The maximum braking force is $F = \mu_\text{s} N$. There is no motion in the vertical direction, so $N = W = mg$. Then $F = \mu_\text{s} mg = (0.62)(1500\,\text{kg})(9.8\,\text{m/s}^2) = 9100\,\text{N}$.

(b) Although we still use $F = \mu_\text{s} N$, $N \neq W$ on an incline! The weight has two components; one which is parallel to the surface and the other which is perpendicular. Since there is no motion perpendicular to the surface we must have $N = W_\perp = W \cos\theta$. Then

$$F = \mu_\text{s} mg \cos\theta = (0.62)(1500\,\text{kg})(9.8\,\text{m/s}^2)\cos(8.6^\circ) = 9000\,\text{N}.$$

E5-16 $\mu_s = \tan\theta$ is the condition for an object to sit without slipping on an incline. Then $\theta = \arctan(0.55) = 29^\circ$. The angle should be reduced by 13°.

$\boxed{\textbf{E5-17}}$ (a) The force of static friction is less than $\mu_s N$, where N is the normal force. Since the crate isn't moving up or down, $\sum F_y = 0 = N - W$. So in this case $N = W = mg =$ (136 kg)(9.81 m/s^2) = 1330 N. The force of static friction is less than or equal to $(0.37)(1330\,\text{N}) = 492\,\text{N}$; moving the crate will require a force greater than or equal to 492 N.

(b) The second worker could lift upward with a force L, reducing the normal force, and hence reducing the force of friction. If the first worker can move the block with a 412 N force, then $412 \geq \mu_s N$. Solving for N, the normal force needs to be less than 1110 N. The crate doesn't move off the table, so then $N + L = W$, or $L = W - N =$ (1330 N) $-$ (1110 N) $=$ 220 N.

(c) Or the second worker can help by adding a push so that the total force of both workers is equal to 492 N. If the first worker pushes with a force of 412 N, the second would need to push with a force of 80 N.

E5-18 The coefficient of static friction is $\mu_\text{s} = \tan(28.0^\circ) = 0.532$. The acceleration is $a = 2(2.53\,\text{m})/(3.92\,\text{s})^2 = .329\,\text{m/s}^2$. We will need to insert a negative sign since this is downward.

The weight has two components: a component parallel to the plane, $W_{||} = mg\sin\theta$; and a component perpendicular to the plane, $W_\perp = mg\cos\theta$. There is no motion perpendicular to the plane, so $N = W_\perp$. The kinetic friction is then $f = \mu_\text{k} N = \mu_\text{k} mg\cos\theta$. The net force parallel to the plane is $F = ma = f - W_{||} = \mu_\text{k} mg\cos\theta - mg\sin\theta$. Solving this for μ_k,

$$\begin{aligned} \mu_\text{k} &= (a + g\sin\theta)/(g\cos\theta), \\ &= [(-0.329\,\text{m/s}^2) + (9.81\,\text{m/s}^2)\sin(28.0^\circ)]/[((9.81\,\text{m/s}^2)\cos(28.0^\circ)] = 0.494. \end{aligned}$$

E5-19 The acceleration is $a = -2d/t^2$, where $d = 203\,\text{m}$ is the distance down the slope and t is the time to make the run.

The weight has two components: a component parallel to the incline, $W_{||} = mg\sin\theta$; and a component perpendicular to the incline, $W_\perp = mg\cos\theta$. There is no motion perpendicular tot he plane, so $N = W_\perp$. The kinetic friction is then $f = \mu_\text{k}N = \mu_\text{k}mg\cos\theta$. The net force parallel to the plane is $F = ma = f - W_{||} = \mu_\text{k}mg\cos\theta - mg\sin\theta$. Solving this for μ_k,

$$\begin{aligned} \mu_\text{k} &= (a + g\sin\theta)/(g\cos\theta), \\ &= (g\sin\theta - 2d/t^2)/(g\cos\theta). \end{aligned}$$

If $t = 61\,\text{s}$, then

$$\mu_\text{k} = \frac{(9.81\,\text{m/s}^2)\sin(3.0^\circ) - 2(203\,\text{m})/(61\,\text{s})^2}{(9.81\,\text{m/s}^2)\cos(3.0^\circ)} = 0.041;$$

if $t = 42\,\text{s}$, then

$$\mu_\text{k} = \frac{(9.81\,\text{m/s}^2)\sin(3.0^\circ) - 2(203\,\text{m})/(42\,\text{s})^2}{(9.81\,\text{m/s}^2)\cos(3.0^\circ)} = 0.029.$$

E5-20 (a) If the block slides down with constant velocity then $a = 0$ and $\mu_\text{k} = \tan\theta$. Not only that, but the force of kinetic friction must be equal to the parallel component of the weight, $f = W_{||}$. If the block is projected up the ramp then the net force is now $2W_{||} = 2mg\sin\theta$. The deceleration is $a = 2g\sin\theta$; the block will travel a time $t = v_0/a$ before stopping, and travel a distance

$$d = -at^2/2 + v_0t = -a(v_0/a)^2/2 + v_0(v_0/a) = v_0^2/(2a) = v_0^2/(4g\sin\theta)$$

before stopping.

(b) Since $\mu_\text{k} < \mu_\text{s}$, the incline is *not* steep enough to get the block moving again once it stops.

$\boxed{\textbf{E5-21}}$ Let a_1 be acceleration down frictionless incline of length l, and t_1 the time taken. The a_2 is acceleration down "rough" incline, and $t_2 = 2t_1$ is the time taken. Then

$$l = \frac{1}{2}a_1t_1^2 \text{ and } l = \frac{1}{2}a_2(2t_1)^2.$$

Equate and find $a_1/a_2 = 4$.

There are two force which act on the ice when it sits on the frictionless incline. The normal force acts perpendicular to the surface, so it doesn't contribute any components parallel to the surface. The force of gravity has a component parallel to the surface, given by

$$W_{||} = mg\sin\theta,$$

and a component perpendicular to the surface given by

$$W_\perp = mg\cos\theta.$$

The acceleration down the frictionless ramp is then

$$a_1 = \frac{W_{||}}{m} = g\sin\theta.$$

When friction is present the force of kinetic friction is $f_k = \mu_kN$; since the ice doesn't move perpendicular to the surface we also have $N = W_\perp$; and finally the acceleration down the ramp is

$$a_2 = \frac{W_{||} - f_k}{m} = g(\sin\theta - \mu\cos\theta).$$

Previously we found the ratio of a_1/a_2, so we now have

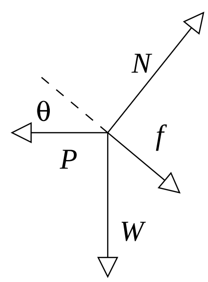
$$\begin{aligned}
\sin\theta &= 4\sin\theta - 4\mu\cos\theta,\\
\sin 33^\circ &= 4\sin 33^\circ - 4\mu\cos 33^\circ,\\
\mu &= 0.49.
\end{aligned}$$

E5-22 (a) The static friction between A and the table must be equal to the weight of block B to keep A from sliding. This means $m_B g = \mu_\mathrm{s}(m_A + m_C)g$, or $m_c = m_B/\mu_\mathrm{s} - m_A = (2.6\,\mathrm{kg})/(0.18) - (4.4\,\mathrm{kg}) = 10\,\mathrm{kg}$.

(b) There is no up/down motion for block A, so $f = \mu_\mathrm{k} N = \mu_\mathrm{k} m_A g$. The net force on the system containing blocks A and B is $F = W_B - f = m_B g - \mu_\mathrm{k} m_A g$; the acceleration of this system is then

$$a = g\frac{m_B - \mu_\mathrm{k} m_A}{m_A + m_B} = (9.\,\mathrm{m/s^2})\frac{(2.6\,\mathrm{kg}) - (0.15)(4.4\,\mathrm{kg})}{(2.6\,\mathrm{kg}) + (4.4\,\mathrm{kg})} = 2.7\,\mathrm{m/s^2}.$$

$\boxed{\textbf{E5-23}}$ There are four forces on the block— the force of gravity, $W = mg$; the normal force, N; the horizontal push, P, and the force of friction, f. Choose the coordinate system so that components are either parallel (x-axis) to the plane or perpendicular (y-axis) to it. $\theta = 39^\circ$. Refer to the figure below.



The magnitudes of the x components of the forces are $W_x = W\sin\theta$, $P_x = P\cos\theta$ and f; the magnitudes of the y components of the forces are $W_y = W\cos\theta$, $P_y = P\sin\theta$.

(a) We consider the first the case of the block moving up the ramp; then f is directed down. Newton's second law for each set of components then reads as

$$\begin{aligned}
\sum F_x &= P_x - f - W_x = P\cos\theta - f - W\sin\theta = ma_x,\\
\sum F_y &= N - P_y - W_y = N - P\sin\theta - W\cos\theta = ma_y
\end{aligned}$$

Then the second equation is easy to solve for N

$$N = P\sin\theta + W\cos\theta = (46\text{ N})\sin(39^\circ) + (4.8\text{ kg})(9.8\text{ m/s}^2)\cos(39^\circ) = 66\text{ N}.$$

The force of friction is found from $f = \mu_k N = (0.33)(66\text{ N}) = 22$ N. This is directed down the incline while the block is moving up. We can now find the acceleration in the x direction.

$$\begin{aligned}
ma_x &= P\cos\theta - f - W\sin\theta,\\
&= (46\,\mathrm{N})\cos(39^\circ) - (22\,\mathrm{N}) - (4.8\,\mathrm{kg})(9.8\,\mathrm{m/s^2})\sin(39^\circ) = -16\,\mathrm{N}.
\end{aligned}$$

So the block is slowing down, with an acceleration of magnitude 3.3 m/s^2.

(b) The block has an initial speed of $v_{0x} = 4.3$ m/s; it will rise until it stops; so we can use $v_y = 0 = v_{0y} + a_y t$ to find the time to the highest point. Then $t = (v_y - v_{0y})/a_y = -(-4.3\text{ m/s})/(3.3$ m/s^2 = 1.3 s. Now that we know the time we can use the other kinematic relation to find the distance

$$y = v_{0y}t + \frac{1}{2}a_y t^2 = (4.3\text{ m/s})(1.3\text{ s}) + \frac{1}{2}(-3.3\text{ m/s}^2)(1.3\text{ s})^2 = 2.8\text{ m}$$

(c) When the block gets to the top it *might* slide back down. But in order to do so the frictional force, which is now directed up the ramp, must be sufficiently small so that $f + P_x \le W_x$. Solving for f we find $f \le W_x - P_x$ or, using our numbers from above, $f \le -6$ N. Is this possible? No, so the block will not slide back down the ramp, *even if the ramp were frictionless,* while the horizontal force is applied.

E5-24 (a) The horizontal force needs to overcome the maximum static friction, so $P \ge \mu_s N = \mu_s mg = (0.52)(12\,\text{kg})(9.8\,\text{m/s}^2) = 61\,\text{N}$.

(b) If the force acts upward from the horizontal then there are two components: a horizontal component $P_x = P\cos\theta$ and a vertical component $P_y = P\sin\theta$. The normal force is now given by $W = P_y + N$; consequently the maximum force of static friction is now $\mu_s N = \mu_s(mg - P\sin\theta)$. The block will move only if $P\cos\theta \ge \mu_s(mg - P\sin\theta)$, or

$$P \ge \frac{\mu_s mg}{\cos\theta + \mu_s\sin\theta} = \frac{(0.52)(12\,\text{kg})(9.8\,\text{m/s}^2)}{\cos(62^\circ) + (0.52)\sin(62^\circ)} = 66\,\text{N}.$$

(c) If the force acts downward from the horizontal then $\theta = -62^\circ$, so

$$P \ge \frac{\mu_s mg}{\cos\theta + \mu_s\sin\theta} = \frac{(0.52)(12\,\text{kg})(9.8\,\text{m/s}^2)}{\cos(-62^\circ) + (0.52)\sin(-62^\circ)} = 5900\,\text{N}.$$

E5-25 (a) If the tension acts upward from the horizontal then there are two components: a horizontal component $T_x = T\cos\theta$ and a vertical component $T_y = T\sin\theta$. The normal force is now given by $W = T_y + N$; consequently the maximum force of static friction is now $\mu_s N = \mu_s(W - T\sin\theta)$. The crate will move only if $T\cos\theta \ge \mu_s(W - T\sin\theta)$, or

$$P \ge \frac{\mu_s W}{\cos\theta + \mu_s\sin\theta} = \frac{(0.52)(150\text{ lb})}{\cos(17^\circ) + (0.52)\sin(17^\circ)} = 70\text{ lb}.$$

(b) Once the crate starts to move then the net force on the crate is $F = T_x - f$. The acceleration is then

$$\begin{aligned} a &= \frac{g}{W}[T\cos\theta - \mu_k(W - T\sin\theta)], \\ &= \frac{(32\text{ ft/s}^2)}{(150\text{ lb})}\{(70\text{ lb})\cos(17^\circ) - (0.35)[(150\text{ lb}) - (70\text{ lb})\sin(17^\circ)]\}, \\ &= 4.6\text{ ft/s}^2. \end{aligned}$$

E5-26 If the tension acts upward from the horizontal then there are two components: a horizontal component $T_x = T\cos\theta$ and a vertical component $T_y = T\sin\theta$. The normal force is now given by $W = T_y + N$; consequently the maximum force of static friction is now $\mu_s N = \mu_s(W - T\sin\theta)$. The crate will move only if $T\cos\theta \ge \mu_s(W - T\sin\theta)$, or

$$W \le T\cos\theta/\mu_s + T\sin\theta.$$

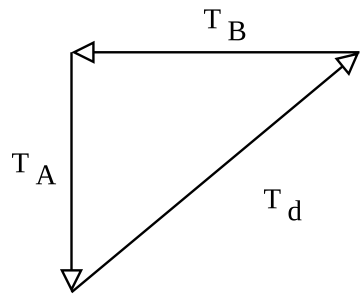
We want the maximum, so we find $dW/d\theta$,

$$dW/d\theta = -(T/\mu_s)\sin\theta + T\cos\theta,$$

which equals zero when $\mu_s = \tan\theta$. For this problem $\theta = \arctan(0.35) = 19^\circ$, so

$$W \le (1220\,\text{N})\cos(19^\circ)/(0.35) + (1220\,\text{N})\sin(19^\circ) = 3690\,\text{N}.$$

E5-27 The three force on the know above A must add to zero. Construct a vector diagram: $\vec{\mathbf{T}}_A + \vec{\mathbf{T}}_B + \vec{\mathbf{T}}_d = 0$, where $\vec{\mathbf{T}}_d$ refers to the diagonal rope. T_A and T_B must be related by $T_A = T_B \tan\theta$, where $\theta = 41°$.



There is no up/down motion of block B, so $N = W_B$ and $f = \mu_s W_B$. Since block B is at rest $f = T_B$. Since block A is at rest $W_A = T_A$. Then

$$W_A = W_B(\mu_s \tan\theta) = (712\,\mathrm{N})(0.25)\tan(41°) = 155\,\mathrm{N}.$$

E5-28 (a) Block 2 doesn't move up/down, so $N = W_2 = m_2 g$ and the force of friction on block 2 is $f = \mu_k m_2 g$. Block 1 is on a frictionless incline; only the component of the weight parallel to the surface contributes to the motion, and $W_{||} = m_1 g \sin\theta$. There are two relevant forces on the two mass system. The effective net force is the of magnitude $W_{||} - f$, so the acceleration is

$$a = g\frac{m_1 \sin\theta - \mu_k m_2}{m_1 + m_2} = (9.81\,\mathrm{m/s^2})\frac{(4.20\,kg)\sin(27°) - (0.47)(2.30\,\mathrm{kg})}{(4.20\,\mathrm{kg}) + (2.30\,\mathrm{kg})} = 1.25\,\mathrm{m/s^2}.$$

The blocks accelerate down the ramp.

(b) The net force on block 2 is $F = m_2 a = T - f$. The tension in the cable is then

$$T = m_2 a + \mu_k m_2 g = (2.30\,\mathrm{kg})[(1.25\,\mathrm{m/s^2}) + (0.47)(9.81\,\mathrm{m/s^2})] = 13.5\,\mathrm{N}.$$

$\boxed{\textbf{E5-29}}$ This problem is similar to Sample Problem 5-7, except now there is friction which can act on block B. The relevant equations are now for block B

$$N - m_B g\cos\theta = 0$$

and

$$T - m_B g \sin\theta \pm f = m_B a,$$

where the sign in front of f depends on the direction in which block B is moving. If the block is moving up the ramp then friction is directed down the ramp, and we would use the negative sign. If the block is moving down the ramp then friction will be directed up the ramp, and then we will use the positive sign. Finally, if the block is stationary then friction we be in such a direction as to make $a = 0$.

For block A the relevant equation is

$$m_A g - T = m_A a.$$

Combine the first two equations with $f = \mu N$ to get

$$T - m_B g\sin\theta \pm \mu m_B g\cos\theta = m_B a.$$

Take some care when interpreting friction for the static case, since the static value of μ yields the maximum possible static friction force, which is not necessarily the actual static frictional force.

Combine this last equation with the block A equation,

$$m_A g - m_A a - m_B g \sin\theta \pm \mu m_B g \cos\theta = m_B a,$$

and then rearrange to get

$$a = g\frac{m_A - m_B \sin\theta \pm \mu m_B \cos\theta}{m_A + m_B}.$$

For convenience we will use metric units; then the masses are $m_A = 13.2\,\mathrm{kg}$ and $m_B = 42.6\,\mathrm{kg}$. In addition, $\sin 42^\circ = 0.669$ and $\cos 42^\circ = 0.743$.

(a) If the blocks are originally at rest then

$$m_A - m_B \sin\theta = (13.2\,\mathrm{kg}) - (42.6\,\mathrm{kg})(0.669) = -15.3\,\mathrm{kg}$$

where the negative sign indicates that block B would slide downhill if there were no friction.

If the blocks are originally at rest we need to consider static friction, so the last term can be as large as

$$\mu m_B \cos\theta = (.56)(42.6\,\mathrm{kg})(0.743) = 17.7\,\mathrm{kg}.$$

Since this quantity is larger than the first static friction would be large enough to stop the blocks from accelerating if they are at rest.

(b) If block B is moving up the ramp we use the negative sign, and the acceleration is

$$a = (9.81\,\mathrm{m/s^2})\frac{(13.2\,\mathrm{kg}) - (42.6\,\mathrm{kg})(0.669) - (.25)(42.6\,\mathrm{kg})(0.743)}{(13.2\,\mathrm{kg}) + (42.6\,\mathrm{kg})} = -4.08\,\mathrm{m/s^2}.$$

where the negative sign means down the ramp. The block, originally moving up the ramp, will slow down and stop. Once it stops the static friction takes over and the results of part (a) become relevant.

(c) If block B is moving down the ramp we use the positive sign, and the acceleration is

$$a = (9.81\,\mathrm{m/s^2})\frac{(13.2\,\mathrm{kg}) - (42.6\,\mathrm{kg})(0.669) + (.25)(42.6\,\mathrm{kg})(0.743)}{(13.2\,\mathrm{kg}) + (42.6\,\mathrm{kg})} = -1.30\,\mathrm{m/s^2}.$$

where the negative sign means down the ramp. This means that if the block is moving down the ramp it will continue to move down the ramp, faster and faster.

E5-30 The weight can be resolved into a component parallel to the incline, $W_{||} = W\sin\theta$ and a component that is perpendicular, $W_\perp = W\cos\theta$. There are two normal forces on the crate, one from each side of the trough. By symmetry we expect them to have equal magnitudes; since they both act perpendicular to their respective surfaces we expect them to be perpendicular to each other. They must add to equal the perpendicular component of the weight. Since they are at right angles and equal in magnitude, this yields $N^2 + N^2 = {W_\perp}^2$, or $N = W_\perp/\sqrt{2}$.

Each surface contributes a frictional force $f = \mu_\mathrm{k} N = \mu_\mathrm{k} W_\perp/\sqrt{2}$; the total frictional force is then twice this, or $\sqrt{2}\mu_\mathrm{k} W_\perp$. The net force on the crate is $F = W\sin\theta - \sqrt{2}\mu_\mathrm{k} W\cos\theta$ down the ramp. The acceleration is then

$$a = g(\sin\theta - \sqrt{2}\mu_\mathrm{k}\cos\theta).$$

E5-31 The normal force between the top slab and the bottom slab is $N = W_{\rm t} = m_{\rm t}g$. The force of friction between the top and the bottom slab is $f \leq \mu N = \mu m_{\rm t} g$. We don't yet know if the slabs slip relative to each other, so we don't yet know what kind of friction to consider.

The acceleration of the top slab is

$$a_{\rm t} = (110\,{\rm N})/(9.7\,{\rm kg}) - \mu(9.8\,{\rm m/s^2}) = 11.3\,{\rm m/s^2} - \mu(9.8\,{\rm m/s^2}).$$

The acceleration of the bottom slab is

$$a_{\rm b} = \mu(9.8\,{\rm m/s^2})(9.7,{\rm kg})/(42\,{\rm kg}) = \mu(2.3\,{\rm m/s^2}).$$

Can these two be equal? Only if $\mu \geq 0.93$. Since the static coefficient is less than this, the block slide. Then $a_{\rm t} = 7.6\,{\rm m/s^2}$ and $a_{\rm b} = 0.87\,{\rm m/s^2}$.

E5-32 (a) Convert the speed to ft/s: $v = 88$ ft/s. The acceleration is

$$a = v^2/r = (88\text{ ft/s})^2/(25\text{ ft}) = 310\text{ ft/s}^2.$$

(b) $a = 310\text{ ft/s}^2 g/(32\text{ ft/s}^2) = 9.7g$.

$\boxed{\textbf{E5-33}}$ (a) The force required to keep the car in the turn is $F = mv^2/r = Wv^2/(rg)$, or

$$F = (10700\,{\rm N})(13.4\,{\rm m/s})^2/[(61.0\,{\rm m})(9.81\,{\rm m/s^2})] = 3210\,{\rm N}.$$

(b) The coefficient of friction required is $\mu_{\rm s} = F/W = (3210\,{\rm N})/(10700\,{\rm N}) = 0.300$.

E5-34 (a) The proper banking angle is given by

$$\theta = \arctan\frac{v^2}{Rg} = \arctan\frac{(16.7\,{\rm m/s})^2}{(150\,{\rm m})(9.8\,{\rm m/s^2})} = 11^\circ.$$

(b) If the road is not banked then the force required to keep the car in the turn is $F = mv^2/r = Wv^2/(Rg)$ and the required coefficient of friction is

$$\mu_{\rm s} = F/W = \frac{v^2}{Rg} = \frac{(16.7\,{\rm m/s})^2}{(150\,{\rm m})(9.8\,{\rm m/s^2})} = 0.19.$$

E5-35 (a) This conical pendulum makes an angle $\theta = \arcsin(0.25/1.4) = 10^\circ$ with the vertical. The pebble has a speed of

$$v = \sqrt{Rg\tan\theta} = \sqrt{(0.25\,{\rm m})(9.8\,{\rm m/s^2})\tan(10^\circ)} = 0.66\,{\rm m/s}.$$

(b) $a = v^2/r = (0.66\,{\rm m/s})^2/(0.25\,{\rm m}) = 1.7\,{\rm m/s^2}$.
(c) $T = mg/cos\theta = (0.053\,{\rm kg})(9.8\,{\rm m/s^2})/\cos(10^\circ) = 0.53\,{\rm N}$.

E5-36 Ignoring air friction (there must be a forward component to the friction!), we have a normal force upward which is equal to the weight: $N = mg = (85\,{\rm kg})(9.8\,{\rm m/s^2}) = 833\,{\rm N}$. There is a sideways component to the friction which is equal tot eh centripetal force, $F = mv^2/r = (85\,{\rm kg})(8.7\,{\rm m/s})^2/(25\,{\rm m}) = 257\,{\rm N}$. The magnitude of the net force of the road on the person is

$$F = \sqrt{(833\,{\rm N})^2 + (257\,{\rm N})^2} = 870\,{\rm N},$$

and the direction is $\theta = \arctan(257/833) = 17^\circ$ off of vertical.

E5-37 (a) The speed is $v = 2\pi rf = 2\pi(5.3\times10^{-11}\,\mathrm{m})(6.6\times10^{15}/\mathrm{s}) = 2.2\times10^{6}\mathrm{m/s}$.

(b) The acceleration is $a = v^2/r = (2.2\times10^{6}\mathrm{m/s})^2/(5.3\times10^{-11}\mathrm{m}) = 9.1\times10^{22}\,\mathrm{m/s^2}$.

(c) The net force is $F = ma = (9.1\times10^{-31}\,\mathrm{kg})(9.1\times10^{22}\,\mathrm{m/s^2}) = 8.3\times10^{-8}\mathrm{N}$.

E5-38 The basket has speed $v = 2\pi r/t$. The basket experiences a frictional force $F = mv^2/r = m(2\pi r/t)^2/r = 4\pi^2 mr/t^2$. The coefficient of static friction is $\mu_\mathrm{s} = F/N = F/W$. Combining,

$$\mu_\mathrm{s} = \frac{4\pi^2 r}{gt^2} = \frac{4\pi^2(4.6\,\mathrm{m})}{(9.8\,\mathrm{m/s^2})(24\,\mathrm{s})^2} = 0.032.$$

$\boxed{\textbf{E5-39}}$ There are two forces on the hanging cylinder: the force of the cord pulling up T and the force of gravity $W = Mg$. The cylinder is at rest, so these two forces must balance, or $T = W$. There are three forces on the disk, but only the force of the cord on the disk T is relevant here, since there is no friction or vertical motion.

The disk undergoes circular motion, so $T = mv^2/r$. We want to solve this for v and then express the answer in terms of m, M, r, and G.

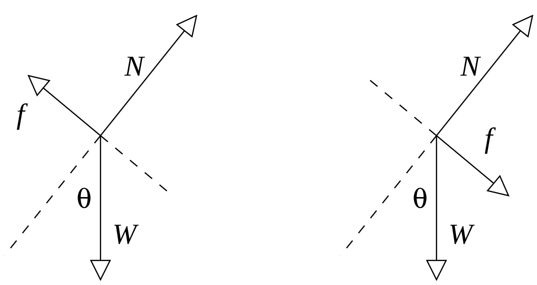
$$v = \sqrt{\frac{Tr}{m}} = \sqrt{\frac{Mgr}{m}}.$$

E5-40 (a) The frictional force stopping the car is $F = \mu_\mathrm{s}N = \mu_\mathrm{s}mg$. The deceleration of the car is then $a = \mu_\mathrm{s}g$. If the car is moving at $v = 13.3\,\mathrm{m/s}$ then the average speed while decelerating is half this, or $v_\mathrm{av} = 6.7\,\mathrm{m/s}$. The time required to stop is $t = x/v_\mathrm{av} = (21\,\mathrm{m})/(6.7\,\mathrm{m/s}) = 3.1\,\mathrm{s}$. The deceleration is $a = (13.3\,\mathrm{m/s})/(3.1\,\mathrm{s}) = 4.3\,\mathrm{m/s^2}$. The coefficient of friction is $\mu_\mathrm{s} = a/g = (4.3\,\mathrm{m/s^2})/(9.8\,\mathrm{m/s^2}) = 0.44$.

(b) The acceleration is the same as in part (a), so $r = v^2/a = (13.3\,\mathrm{m/s})^2/(4.3\,\mathrm{m/s^2}) = 41\,\mathrm{m}$.

$\boxed{\textbf{E5-41}}$ There are three forces to consider: the normal force of the road on the car N; the force of gravity on the car W; and the frictional force on the car f. The acceleration of the car in circular motion is toward the center of the circle; this means the *net* force on the car is horizontal, toward the center. We will arrange our coordinate system so that r is horizontal and z is vertical. Then the components of the normal force are $N_r = N\sin\theta$ and $N_z = N\cos\theta$; the components of the frictional force are $f_r = f\cos\theta$ and $f_z = f\sin\theta$.

The direction of the friction depends on the speed of the car. The figure below shows the two force diagrams.



The turn is designed for 95 km/hr, at this speed a car should require *no* friction to stay on the road. Using Eq. 5-17 we find that the banking angle is given by

$$\tan\theta_b = \frac{v^2}{rg} = \frac{(26\ \mathrm{m/s})^2}{(210\ \mathrm{m})(9.8\ \mathrm{m/s^2})} = 0.33,$$

for a bank angle of $\theta_b = 18°$.

(a) On the rainy day traffic is moving at 14 m/s. This is slower than the rated speed, so any frictional force must be directed up the incline. Newton's second law is then

$$\begin{aligned}\sum F_r &= N_r - f_r = N\sin\theta - f\cos\theta = \frac{mv^2}{r},\\ \sum F_z &= N_z + f_z - W = N\cos\theta + f\sin\theta - mg = 0.\end{aligned}$$

We can substitute $f = \mu_s N$ to find the minimum value of μ_s which will keep the cars from slipping. There will then be two equations and two unknowns, μ_s and N. Solving for N,

$$N\left(\sin\theta - \mu_s\cos\theta\right) = \frac{mv^2}{r} \text{ and } N\left(\cos\theta + \mu_s\sin\theta\right) = mg.$$

Combining,

$$\left(\sin\theta - \mu_s\cos\theta\right) mg = \left(\cos\theta + \mu_s\sin\theta\right)\frac{mv^2}{r}$$

Rearrange,

$$\mu_s = \frac{gr\sin\theta - v^2\cos\theta}{gr\cos\theta + v^2\sin\theta}.$$

We know all the numbers. Put them in and we'll find $\mu_s = 0.22$

(b) Now the frictional force will point the other way, so Newton's second law is now

$$\begin{aligned}\sum F_r &= N_r + f_r = N\sin\theta + f\cos\theta = \frac{mv^2}{r},\\ \sum F_z &= N_z - f_z - W = N\cos\theta - f\sin\theta - mg = 0.\end{aligned}$$

The bottom equation can be rearranged to show that

$$N = \frac{mg}{\cos\theta - \mu_s\sin\theta}.$$

This can be combined with the top equation to give

$$mg\frac{\sin\theta + \mu_s\cos\theta}{\cos\theta - \mu_s\sin\theta} = \frac{mv^2}{r}.$$

We can solve this final expression for v using all our previous numbers and get $v = 35$ m/s. That's about 130 km/hr.

E5-42 (a) The net force on the person at the top of the Ferris wheel is $mv^2/r = W - N_\mathrm{t}$, pointing down. The net force on the bottom is still mv^2/r, but this quantity now equals $N_\mathrm{b} - W$ and is point up. Then $N_\mathrm{b} = 2W - N_\mathrm{t} = 2(150 \text{ lb}) - (125 \text{ lb}) = 175$ lb.

(b) Doubling the speed would quadruple the net force, so the new scale reading at the top would be (150 lb) − 4[(150 lb) − (125 lb)] = 50 lb. Wee!

E5-43 The net force on the object when it is *not* sliding is $F = mv^2/r$; the speed of the object is $v = 2\pi rf$ (f is rotational frequency here), so $F = 4\pi^2 mrf^2$. The coefficient of friction is then at least $\mu_\mathrm{s} = F/W = 4\pi^2 rf^2/g$. If the object stays put when the table rotates at $33\frac{1}{3}$ rev/min then

$$\mu_\mathrm{s} \geq 4\pi^2(0.13\,\mathrm{m})(33.3/60\,/\mathrm{s})^2/(9.8\,\mathrm{m/s^2}) = 0.16.$$

If the object slips when the table rotates at 45.0 rev/min then

$$\mu_\mathrm{s} \leq 4\pi^2(0.13\,\mathrm{m})(45.0/60\,/\mathrm{s})^2/(9.8\,\mathrm{m/s^2}) = 0.30.$$

E5-44 This is effectively a banked highway problem if the pilot is flying correctly.

$$r = \frac{v^2}{g\tan\theta} = \frac{(134\,\mathrm{m/s})^2}{(9.8\,\mathrm{m/s^2})\tan(38.2^\circ)} = 2330\,\mathrm{m}.$$

E5-45 (a) Assume that frigate bird flies as well as a pilot. Then this is a banked highway problem. The speed of the bird is given by $v^2 = gr\tan\theta$. But there is also $vt = 2\pi r$, so $2\pi v^2 = gvt\tan\theta$, or

$$v = \frac{gt\tan\theta}{2\pi} = \frac{(9.8\,\mathrm{m/s^2})(13\,\mathrm{s})\tan(25^\circ)}{2\pi} = 9.5\,\mathrm{m/s}.$$

(b) $r = vt/(2\pi) = (9.5\,\mathrm{m/s})(13\,\mathrm{s})/(2\pi) = 20\,\mathrm{m}$.

E5-46 (a) The radius of the turn is $r = \sqrt{(33\,\mathrm{m})^2 - (18\,\mathrm{m})^2} = 28\,\mathrm{m}$. The speed of the plane is $v = 2\pi rf = 2\pi(28\,\mathrm{m})(4.4/60\,/\mathrm{s}) = 13\,\mathrm{m/s}$. The acceleration is $a = v^2/r = (13\,\mathrm{m/s})^2/(28\,\mathrm{m}) = 6.0\,m/\mathrm{s}^2$.

(b) The tension has two components: $T_x = T\cos\theta$ and $T_y = T\sin\theta$. In this case $\theta = \arcsin(18/33) = 33^\circ$. All of the centripetal force is provided for by T_x, so

$$T = (0.75\,\mathrm{kg})(6.0\,\mathrm{m/s^2})/\cos(33^\circ) = 5.4\,\mathrm{N}.$$

(c) The lift is balanced by the weight and T_y. The lift is then

$$T_y + W = (5.4\,\mathrm{N})\sin(33^\circ) + (0.75\,\mathrm{kg})(9.8\,\mathrm{m/s^2}) = 10\,\mathrm{N}.$$

E5-47 (a) The acceleration is $a = v^2/r = 4\pi^2 r/t^2 = 4\pi^2(6.37\times10^6\mathrm{m})/(8.64\times10^4\mathrm{s})^2 = 3.37\times10^{-2}\mathrm{m/s^2}$. The centripetal force on the standard kilogram is $F = ma = (1.00\,\mathrm{kg})(3.37{\times}10^{-2}\mathrm{m/s^2}) = 0.0337\,\mathrm{N}$.

(b) The tension in the balance would be $T = W - F = (9.80\,\mathrm{N}) - (0.0337\,\mathrm{N}) = 9.77\,\mathrm{N}$.

E5-48 (a) $v = 4(0.179\,\mathrm{m/s^4})(7.18\,\mathrm{s})^3 - 2(2.08\,\mathrm{m/s^2})(7.18\,\mathrm{s}) = 235\,\mathrm{m/s}$.

(b) $a = 12(0.179\,\mathrm{m/s^4})(7.18\,\mathrm{s})^2 - 2(2.08\,\mathrm{m/s^2}) = 107\,\mathrm{m/s^2}$.

(c) $F = ma = (2.17\,\mathrm{kg})(107\,\mathrm{m/s^2}) = 232\,\mathrm{N}$.

$\boxed{\textbf{E5-49}}$ The force only has an x component, so we can use Eq. 5-19 to find the velocity.

$$v_x = v_{0x} + \frac{1}{m}\int_0^t F_x\,dt = v_0 + \frac{F_0}{m}\int_0^t (1 - t/T)\ dt$$

Integrating,

$$v_x = v_0 + a_0\left(t - \frac{1}{2T}t^2\right)$$

Now put this expression into Eq. 5-20 to find the position as a function of time

$$x = x_0 + \int_0^t v_x\,dt = \int_0^t \left(v_{0x} + a_0\left(t - \frac{1}{2T}t^2\right)\right)\ dt$$

Integrating,

$$x = v_0T + a_0\left(\frac{1}{2}T^2 - \frac{1}{6T}T^3\right) = v_0T + a_0\frac{T^2}{3}.$$

Now we can put $t = T$ into the expression for v.

$$v_x = v_0 + a_0\left(T - \frac{1}{2T}T^2\right) = v_0 + a_0T/2.$$

P5-1 (a) There are two forces which accelerate block 1: the tension, T, and the parallel component of the weight, $W_{||,1} = m_1 g \sin\theta_1$. Assuming the block accelerates to the right,

$$m_1 a = m_1 g \sin\theta_1 - T.$$

There are two forces which accelerate block 2: the tension, T, and the parallel component of the weight, $W_{||,2} = m_2 g \sin\theta_2$. Assuming the block 1 accelerates to the right, block 2 must also accelerate to the right, and

$$m_2 a = T - m_2 g \sin\theta_2.$$

Add these two equations,

$$(m_1 + m_2)a = m_1 g \sin\theta_1 - m_2 g \sin\theta_2,$$

and then rearrange:

$$a = \frac{m_1 g \sin\theta_1 - m_2 g \sin\theta_2}{m_1 + m_2}.$$

Or, take the two net force equations, divide each side by the mass, and set them equal to each other:

$$g \sin\theta_1 - T/m_1 = T/m_2 - g \sin\theta_2.$$

Rearrange,

$$T\left(\frac{1}{m_1} + \frac{1}{m_2}\right) = g \sin\theta_1 + g \sin\theta_2,$$

and then rearrange again:

$$T = \frac{m_1 m_2 g}{m_1 + m_2}(\sin\theta_1 + \sin\theta_2).$$

(b) The negative sign we get in the answer means that block 1 accelerates up the ramp.

$$a = \frac{(3.70\,\text{kg})\sin(28^\circ) - (4.86\,\text{kg})\sin(42^\circ)}{(3.70\,\text{kg}) + (4.86\,\text{kg})}(9.81\,\text{m/s}^2) = -1.74\,\text{m/s}^2.$$

$$T = \frac{(3.70\,\text{kg})(4.86\,\text{kg})(9.81\,\text{m/s}^2)}{(3.70\,\text{kg}) + (4.86\,\text{kg})}[\sin(28^\circ) + \sin(42^\circ)] = 23.5\,\text{N}.$$

(c) No acceleration happens when $m_2 = (3.70\,\text{kg})\sin(28^\circ)/\sin(42^\circ) = 2.60\,\text{kg}$. If m_2 is more massive than this m_1 will accelerate up the plane; if m_2 is less massive than this m_1 will accelerate down the plane.

P5-2 (a) Since the pulley is massless, $F = 2T$. The largest value of T that will allow block 2 to remain on the floor is $T \leq W_2 = m_2 g$. So $F \leq 2(1.9\,\text{kg})(9.8\,\text{m/s}^2) = 37\,\text{N}$.

(b) $T = F/2 = (110\,\text{N})/2 = 55\,\text{N}$.

(c) The net force on block 1 is $T - W_1 = (55\,\text{N}) - (1.2\,\text{kg})(9.8\,\text{m/s}^2) = 43\,\text{N}$. This will result in an acceleration of $a = (43\,\text{N})/(1.2\,\text{kg}) = 36\,\text{m/s}^2$.

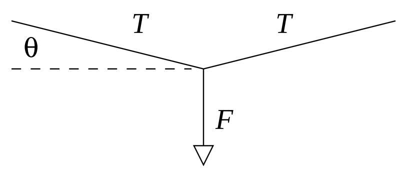
$\boxed{\textbf{P5-3}}$ As the string is pulled the two masses will move together so that the configuration will look like the figure below. The point where the force is applied to the string is massless, so $\sum F = 0$ at that point. We can take advantage of this fact and the figure below to find the tension in the cords, $F/2 = T\cos\theta$. The factor of $1/2$ occurs because only $1/2$ of F is contained in the right triangle that has T as the hypotenuse. From the figure we can find the x component of the force on one mass to be $T_x = T\sin\theta$. Combining,

$$T_x = \frac{F}{2}\frac{\sin\theta}{\cos\theta} = \frac{F}{2}\tan\theta.$$

But the tangent is equal to

$$\tan\theta = \frac{\text{Opposite}}{\text{Adjacent}} = \frac{x}{\sqrt{L^2 - x^2}}$$

And now we have the answer in the book.



What happens when $x = L$? Well, a_x is infinite according to this expression. Since that could only happen if the tension in the string were infinite, then there must be some other physics that we had previously ignored.

P5-4 (a) The force of static friction can be as large as $f \le \mu_s N = (0.60)(12 \text{ lb}) = 7.2$ lb. That is more than enough to hold the block up.

(b) The force of static friction is actually only large enough to hold up the block: $f = 5.0$ lb. The magnitude of the force of the wall on the block is then $F_{\text{bw}} = \sqrt{(5.0)^2 + (12.0)^2}\text{lb} = 13$ lb.

P5-5 (a) The weight has two components: normal to the incline, $W_\perp = mg\cos\theta$ and parallel to the incline, $W_{||} = mg\sin\theta$. There is no motion perpendicular to the incline, so $N = W_\perp = mg\cos\theta$. The force of friction on the block is then $f = \mu N = \mu mg\cos\theta$, where we use whichever μ is appropriate. The net force on the block is $F - f - W_{||} = F \pm \mu mg\cos\theta - mg\sin\theta$.

To hold the block in place we use μ_s and friction will point *up* the ramp so the $\pm$ is $+$, and

$$F = (7.96\,\text{kg})(9.81\,\text{m/s}^2)[\sin(22.0^\circ) - (0.25)\cos(22.0^\circ)] = 11.2\,\text{N}.$$

(b) To find the minimum force to begin sliding the block up the ramp we still have static friction, but now friction points *down*, so

$$F = (7.96\,\text{kg})(9.81\,\text{m/s}^2)[\sin(22.0^\circ) + (0.25)\cos(22.0^\circ)] = 47.4\,\text{N}.$$

(c) To keep the block sliding up at constant speed we have kinetic friction, so

$$F = (7.96\,\text{kg})(9.81\,\text{m/s}^2)[\sin(22.0^\circ) + (0.15)\cos(22.0^\circ)] = 40.1\,\text{N}.$$

P5-6 The sand will slide if the cone makes an angle greater than θ where $\mu_s = \tan\theta$. But $\tan\theta = h/R$ or $h = R\tan\theta$. The volume of the cone is then

$$Ah/3 = \pi R^2 h/3 = \pi R^3 \tan\theta/3 = \pi\mu_s R^3/3.$$

$\boxed{\textbf{P5-7}}$ There are four forces on the broom: the force of gravity $W = mg$; the normal force of the floor N; the force of friction f; and the applied force from the person P (the book calls it F). Then

$$\begin{aligned}\sum F_x &= P_x - f = P\sin\theta - f = ma_x,\\ \sum F_y &= N - P_y - W = N - P\cos\theta - mg = ma_y = 0\end{aligned}$$

Solve the second equation for N,

$$N = P\cos\theta + mg.$$

(a) If the mop slides at constant speed $f = \mu_k N$. Then

$$P\sin\theta - f = P\sin\theta - \mu_k\,(P\cos\theta + mg) = 0.$$

We can solve this for P (which was called F in the book);

$$P = \frac{\mu mg}{\sin\theta - \mu_k\cos\theta}.$$

This is the force required to push the broom at constant speed.

(b) Note that P becomes negative (or infinite) if $\sin\theta \le \mu_k\cos\theta$. This occurs when $\tan\theta_c \le \mu_k$. If this happens the mop stops moving, to get it started again you must overcome the static friction, but this is impossible if $\tan\theta_0 \le \mu_s$

P5-8 (a) The condition to slide is $\mu_\mathrm{s} \le \tan\theta$. In this case, $(0.63) > \tan(24^\circ) = 0.445$.

(b) The normal force on the slab is $N = W_\perp = mg\cos\theta$. There are *three* forces parallel to the surface: friction, $f = \mu_\mathrm{s}N = \mu_\mathrm{s}mg\cos\theta$; the parallel component of the weight, $W_{||} = mg\sin\theta$, and the force F. The block will slide if these don't balance, or

$$F > \mu_\mathrm{s}mg\cos\theta - mg\sin\theta = (1.8\times10^7\mathrm{kg})(9.8\,\mathrm{m/s^2})[(0.63)\cos(24^\circ) - \sin(24^\circ)] = 3.0\times10^7\mathrm{N}.$$

$\boxed{\textbf{P5-9}}$ To hold up the smaller block the frictional force between the larger block and smaller block must be as large as the weight of the smaller block. This can be written as $f = mg$. The normal force of the larger block on the smaller block is N, and the frictional force is given by $f \le \mu_s N$. So the smaller block won't fall if $mg \le \mu_s N$.

There is only one horizontal force on the large block, which is the normal force of the small block on the large block. Newton's third law says this force has a magnitude N, so the acceleration of the large block is $N = Ma$.

There is only one horizontal force on the two block system, the force F. So the acceleration of this system is given by $F = (M + m)a$. The two accelerations are equal, otherwise the blocks won't stick together. Equating, then, gives $N/M = F/(M + m)$.

We can combine this last expression with $mg \le \mu_s N$ and get

$$mg \le \mu_s F\frac{M}{M+m}$$

or

$$F \ge \frac{g(M+m)m}{\mu_s M} = \frac{(9.81\,\mathrm{m/s^2})(88\,\mathrm{kg} + 16\,\mathrm{kg})(16\,\mathrm{kg})}{(0.38)(88\,\mathrm{kg})} = 490\,\mathrm{N}$$

P5-10 The normal force on the ith block is $N_i = m_i g\cos\theta$; the force of friction on the ith block is then $f_i = \mu_i m_i g\cos\theta$. The parallel component of the weight on the ith block is $W_{||,i} = m_i g\sin\theta$.

(a) The net force on the system is

$$F = \sum_i m_i g(\sin\theta - \mu_i\cos\theta).$$

Then

$$\begin{aligned} a &= (9.81\,\mathrm{m/s^2})\frac{(1.65\,\mathrm{kg})(\sin 29.5^\circ - 0.226\cos 29.5^\circ) + (3.22\,\mathrm{kg})(\sin 29.5^\circ - 0.127\cos 29.5^\circ)}{(1.65\,\mathrm{kg}) + (3.22\,\mathrm{kg})}, \\ &= 3.46\,\mathrm{m/s^2}. \end{aligned}$$

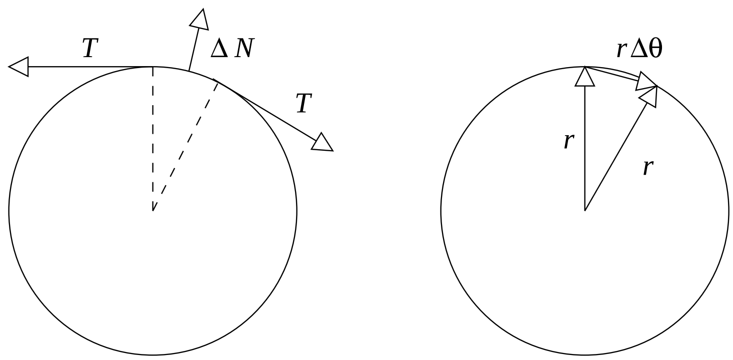
(b) The net force on the lower mass is $m_2 a = W_{||,2} - f_2 - T$, so the tension is

$$T = (9.81\,\mathrm{m/s^2})(3.22\,\mathrm{kg})(\sin 29.5^\circ - 0.127\cos 29.5^\circ) - (3.22\,\mathrm{kg})(3.46\,\mathrm{m/s^2}) = 0.922\,\mathrm{N}.$$

(c) The acceleration will stay the same, since the system is still the same. Reversing the order of the masses can only result in a reversing of the tension: it is still 0.992 N, but is now negative, meaning compression.

$\boxed{\textbf{P5-11}}$ The rope wraps around the dowel and there is a contribution to the frictional force Δf from each small segment of the rope where it touches the dowel. There is also a normal force ΔN at each point where the contact occurs. We can find ΔN much the same way that we solve the circular motion problem.

In the figure on the left below we see that we can form a triangle with long side T and short side ΔN. In the figure on the right below we see a triangle with long side r and short side $r\Delta\theta$. These triangles are similar, so $r\Delta\theta/r = \Delta N/T$.



Now $\Delta f = \mu\Delta N$ and $T(\theta) + \Delta f \approx T(\theta + \Delta\theta)$. Combining, and taking the limit as $\Delta\theta \to 0$, $dT = df$

$$\int \frac{1}{\mu}\frac{dT}{T} = \int d\theta$$

integrating both sides of this expression,

$$\begin{aligned} \int \frac{1}{\mu}\frac{dT}{T} &= \int d\theta, \\ \frac{1}{\mu}\ln T|_{T_1}^{T_2} &= \pi, \\ T_2 &= T_1 e^{\pi\mu}. \end{aligned}$$

In this case T_1 is the weight and T_2 is the downward force.

P5-12 Answer this out of order!

(b) The maximum static friction between the blocks is 12.0 N; the maximum acceleration of the top block is then $a = F/m = (12.0\,\mathrm{N})/(4.40\,\mathrm{kg}) = 2.73\,\mathrm{m/s^2}$.

(a) The net force on a system of two blocks that will accelerate them at $2.73\,\mathrm{m/s^2}$ is $F = (4.40\,\mathrm{kg} + 5.50\,\mathrm{kg})(2.73\,\mathrm{m/s^2}) = 27.0\,\mathrm{N}$.

(c) The coefficient of friction is $\mu_\mathrm{s} = F/N = F/mg = (12.0\,\mathrm{N})/[(4.40\,\mathrm{kg})(9.81\,\mathrm{m/s^2})] = 0.278$.

P5-13 The speed is $v = 23.6\,\mathrm{m/s}$.

(a) The average speed while stopping is half the initial speed, or $v_\mathrm{av} = 11.8\,\mathrm{m/s}$. The time to stop is $t = (62\,\mathrm{m})/(11.8\,\mathrm{m/s}) = 5.25\,\mathrm{s}$. The rate of deceleration is $a = (23.6\,\mathrm{m/s})/(5.25\,\mathrm{s}) = 4.50\,\mathrm{m/s^2}$. The stopping force is $F = ma$; this is related to the frictional force by $F = \mu_\mathrm{s} mg$, so $\mu_\mathrm{s} = a/g = (4.50\,\mathrm{m/s^2})/(9.81\,\mathrm{m/s^2}) = 0.46$.

(b) Turning,

$$a = v^2/r = (23.6\,\mathrm{m/s})^2/(62\,\mathrm{m}) = 8.98\,\mathrm{m/s^2}.$$

Then $\mu_\mathrm{s} = a/g = (8.98\,\mathrm{m/s^2})/(9.81\,\mathrm{m/s^2}) = 0.92$.

P5-14 (a) The net force on car as it travels at the top of a circular hill is $F_\mathrm{net} = mv^2/r = W - N$; in this case we are told $N = W/2$, so $F_\mathrm{net} = W/2 = (16000\,\mathrm{N})/2 = 8000\,\mathrm{N}$. When the car travels through the bottom valley the net force at the bottom is $F_\mathrm{net} = mv^2/r = N - W$. Since the magnitude of v, r, and hence F_net is the same in both cases,

$$N = W/2 + W = 3W/2 = 3(16000\,\mathrm{N})/2 = 24000\,\mathrm{N}$$

at the bottom of the valley.

(b) You leave the hill when $N = 0$, or

$$v = \sqrt{rg} = \sqrt{(250\,\mathrm{m})(9.81\,\mathrm{m/s^2})} = 50\,\mathrm{m/s}.$$

(c) At this speed $F_\mathrm{net} = W$, so at the bottom of the valley $N = 2W = 32000\,\mathrm{N}$.

P5-15 (a) $v = 2\pi r/t = 2\pi(0.052\,\mathrm{m})(3/3.3\,\mathrm{s}) = 0.30\,\mathrm{m/s}$.

(b) $a = v^2/r = (0.30\,\mathrm{m/s})^2/(0.052\,\mathrm{m}) = 1.7\,\mathrm{m/s^2}$, toward center.

(c) $F = ma = (0.0017\,\mathrm{kg})(1.7\,\mathrm{m/s^2}) = 2.9\times10^{-3}\mathrm{N}$.

(d) If the coin can be as far away as r before slipping, then

$$\mu_\mathrm{s} = F/mg = (2\pi r/t)^2/(rg) = 4\pi^2 r/(t^2 g) = 4\pi^2(0.12\,\mathrm{m})/[(3/3.3\,\mathrm{s})^2(9.8\,\mathrm{m/s^2})] = 0.59.$$

P5-16 (a) Whether you assume constant speed or constant energy, the tension in the string must be the greatest at the bottom of the circle, so that's where the string will break.

(b) The net force on the stone at the bottom is $T - W = mv^2/r$. Then

$$v = \sqrt{rg[T/W - 1]} = \sqrt{(2.9\text{ ft})(32\text{ ft/s}^2)[(9.2\text{ lb})/(0.82\text{ lb}) - 1]} = 31\text{ ft/s}.$$

P5-17 (a) In order to keep the ball moving in a circle there must be a net centripetal force F_c directed horizontally toward the rod. There are only *three* forces which act on the ball: the force of gravity, $W = mg = (1.34\,\mathrm{kg})(9.81\,\mathrm{m/s^2}) = 13.1\,\mathrm{N}$; the tension in the top string $T_1 = 35.0\,\mathrm{N}$, and the tension in the bottom string, T_2.

The components of the force from the tension in the top string are

$$T_{1,x} = (35.0\,\mathrm{N})\cos 30^\circ = 30.3\,\mathrm{N} \text{ and } T_{1,y} = (35.0\,\mathrm{N})\sin 30^\circ = 17.5\,\mathrm{N}.$$

The vertical components *do* balance, so

$$T_{1,y} + T_{2,y} = W,$$

or $T_{2,y} = (13.1\,\mathrm{N}) - (17.5\,\mathrm{N}) = -4.4\,\mathrm{N}$. From this we can find the tension in the bottom string,

$$T_2 = T_{2,y}/\sin(-30^\circ) = 8.8\,\mathrm{N}.$$

(b) The net force on the object will be the sum of the two horizontal components,

$$F_c = (30.3\,\mathrm{N}) + (8.8\,\mathrm{N})\cos 30^\circ = 37.9\,\mathrm{N}.$$

(c) The speed will be found from

$$\begin{aligned} v &= \sqrt{a_c r} = \sqrt{F_c r/m}, \\ &= \sqrt{(37.9\,\mathrm{m})(1.70\,\mathrm{m})\sin 60^\circ/(1.34\,\mathrm{kg})} = 6.45\,\mathrm{m/s}. \end{aligned}$$

P5-18 The net force on the cube is $F = mv^2/r$. The speed is $2\pi r\omega$. (Note that we are using ω in a non-standard way!) Then $F = 4\pi^2 mr\omega^2$. There are three forces to consider: the normal force of the funnel on the cube N; the force of gravity on the cube W; and the frictional force on the cube f. The acceleration of the cube in circular motion is toward the center of the circle; this means the *net* force on the cube is horizontal, toward the center. We will arrange our coordinate system so that r is horizontal and z is vertical. Then the components of the normal force are $N_r = N\sin\theta$ and $N_z = N\cos\theta$; the components of the frictional force are $f_r = f\cos\theta$ and $f_z = f\sin\theta$.

The direction of the friction depends on the speed of the cube; it will point up if ω is small and down if ω is large.

(a) If ω is small, Newton's second law is

$$\begin{aligned}\sum F_r &= N_r - f_r = N\sin\theta - f\cos\theta = 4\pi^2 mr\omega^2,\\ \sum F_z &= N_z + f_z - W = N\cos\theta + f\sin\theta - mg = 0.\end{aligned}$$

We can substitute $f = \mu_s N$. Solving for N,

$$N(\cos\theta + \mu_s\sin\theta) = mg.$$

Combining,

$$4\pi^2 r\omega^2 = g\frac{\sin\theta - \mu_s\cos\theta}{\cos\theta + \mu_s\sin\theta}.$$

Rearrange,

$$\omega = \frac{1}{2\pi}\sqrt{\frac{g}{r}\,\frac{\sin\theta - \mu_s\cos\theta}{\cos\theta + \mu_s\sin\theta}}.$$

This is the minimum value.

(b) Now the frictional force will point the other way, so Newton's second law is now

$$\begin{aligned}\sum F_r &= N_r + f_r = N\sin\theta + f\cos\theta = 4\pi^2 mr\omega^2,\\ \sum F_z &= N_z - f_z - W = N\cos\theta - f\sin\theta - mg = 0.\end{aligned}$$

We've swapped + and - signs, so

$$\omega = \frac{1}{2\pi}\sqrt{\frac{g}{r}\,\frac{\sin\theta + \mu_s\cos\theta}{\cos\theta - \mu_s\sin\theta}}$$

is the maximum value.

P5-19 (a) The radial distance from the axis of rotation at a latitude L is $R\cos L$. The speed in the circle is then $v = 2\pi R\cos L/T$. The net force on a hanging object is $F = mv^2/(R\cos L) = 4\pi^2 mR\cos L/T^2$. This net force is *not* directed toward the center of the earth, but is instead directed toward the axis of rotation. It makes an angle L with the Earth's vertical. The tension in the cable must then have two components: one which is vertical (compared to the Earth) and the other which is horizontal. If the cable makes an angle θ with the vertical, then $T_{||} = T\sin\theta$ and $T_\perp = T\cos\theta$. Then $T_{||} = F_{||}$ and $W - T_\perp = F_\perp$. Written with a little more detail,

$$T\sin\theta = 4\pi^2 mR\cos L\,\sin L/T^2 \approx T\theta,$$

and

$$T\cos\theta = 4\pi^2 mR\cos^2 L/T^2 + mg \approx T.$$

But $4\pi^2 R\cos^2 L/T^2 \ll g$, so it can be ignored in the last equation compared to g, and $T \approx mg$. Then from the first equation,

$$\theta = 2\pi^2 R \sin 2L/(gT^2).$$

(b) This is a maximum when $\sin 2L$ is a maximum, which happens when $L = 45°$. Then

$$\theta = 2\pi^2(6.37\times 10^6\mathrm{m})/[(9.8\,\mathrm{m/s^2})(86400\,\mathrm{s})^2] = 1.7\times 10^{-3}\ \mathrm{rad}.$$

(c) The deflection at both the equator and the poles would be zero.

P5-20 $a = (F_0/m)e^{-t/T}$. Then $v = \int_0^t a\,dt = (F_0 T/m)e^{-t/T}$, and $x = \int_0^t v\,dt = (F_0 T^2/m)e^{-t/T}$.
(a) When $t = T$ $v = (F_0 T/m)e^{-1} = 0.368(F_0 T/m)$.
(b) When $t = T$ $x = (F_0 T^2/m)e^{-1} = 0.368(F_0 T^2/m)$.