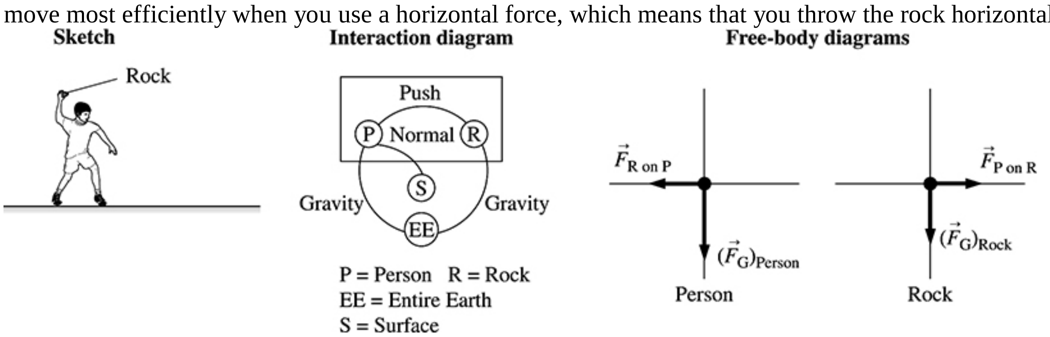
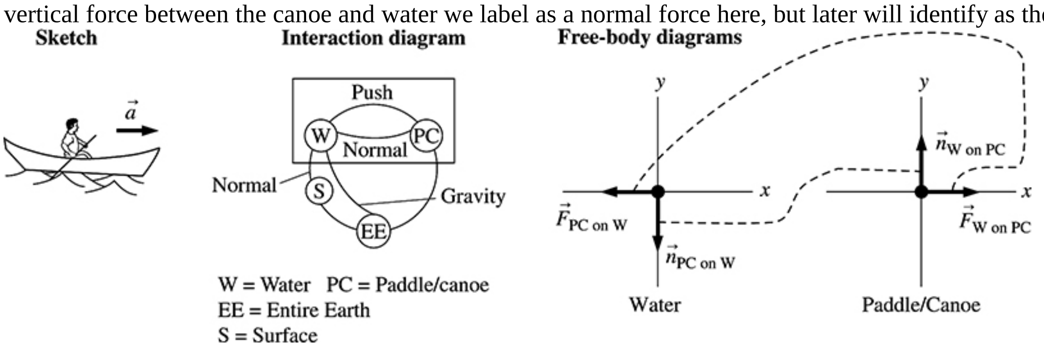
Chapter 7, Conceptual Questions

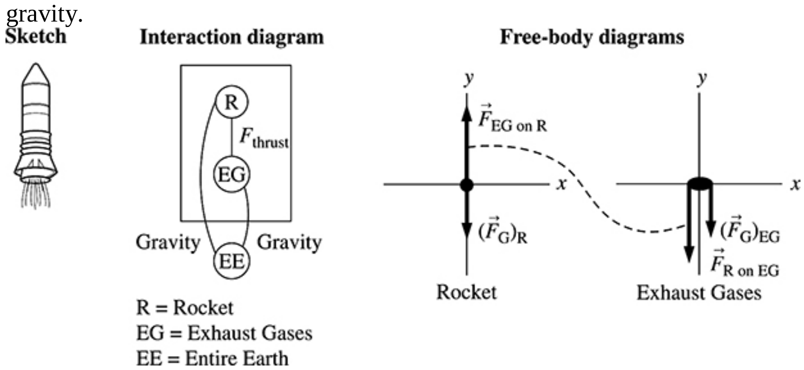
7.1. If you were to throw the rocks in the opposite direction you wanted to go, you would be pushed by the rocks in the right direction. Throwing the rocks requires a force to accelerate them (Newton's second law.) So you exert a force on the rock in one direction and the rock exerts an equal force on you in the opposite direction (Newton's third law.) This force will cause you to slide along the ice in the opposite direction that you threw the rock. Note that you will move most efficiently when you use a horizontal force, which means that you throw the rock horizontally.



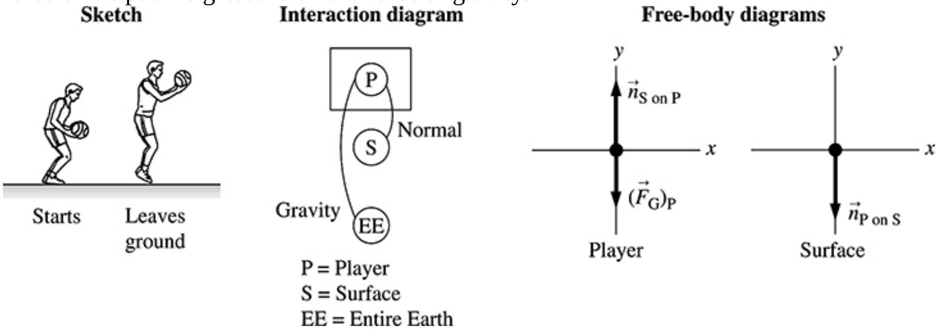
7.2. The paddle, you, and the canoe can be treated as a single object. You can push backward on the water with the paddle so that the water pushes forward on the paddle. The figure shows how the force of the paddle on the water backward and the force of the water on the paddle forward are action/reaction pairs. Since you hold the paddle while sitting in the canoe, the force of the water on the paddle causes the paddle-person-canoe object to move forward. The vertical force between the canoe and water we label as a normal force here, but later will identify as the buoyant force.



7.3. The rocket pushes down on the exhaust gases, which push up on the rocket. The two forces are a Newton's third law pair. The rocket accelerates upward because the force of the exhaust gases on the rocket is greater than the force of gravity.



7.4. The player pushes down on the floor, which pushes back up on him. The player accelerates upward because the force of his push is greater than the force of gravity.



7.5. Newton's third law tells us that the force of the mosquito on the car is equal to the force of the car on the mosquito.

7.6. The mosquito has a much smaller mass than the car, so the interaction force between the car and mosquito, while equal on each, causes the mosquito to have a much larger acceleration. In fact, usually the acceleration is fatal to the mosquito.

7.7. The forces are equal by Newton's third law. The motion of the truck and car are determined by the *net* force on each.

7.8. The force of the wagon on the girl is a force on the girl, while the force of the girl on the wagon is applied to the wagon. The wagon's motion is determined by the net force on it, and if the girl pulls hard enough to overcome any other opposing forces *on the wagon*, the wagon will move forward. So try saying, "But, my dear, the *net* force on the wagon allows it to move forward. The forces you mention act on different objects, so cannot cancel."

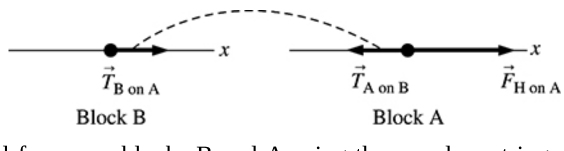
7.9. The *net* force on a team determines the team's motion. The net horizontal force on each team is the difference between the rope's tug and friction with the ground as the team digs in. So the team that wins a tug-of-war is the team that is best able to keep from sliding along the ground, not pull harder.

7.10. This technique will not work because the magnet is part of the cart, not external to it. The forces between the magnet and cart are equal and opposite, but because the two are solidly connected by the hanging bar, the magnet and cart make up one object.

7.11. The scale reads 5 kg. The left-hand mass performs a function no different than the ceiling would if the rope were attached to it. Both pull back with the force required to suspend 5 kg. The second mass provides the opposite force on the spring scale.

7.12. The scale reads 5 kg. The left-hand mass performs a function no different than the wall would if the rope were attached to it. Both pull back with the force required to suspend 5 kg. The second mass provides the opposite force on the spring scale.

7.13.



The figure shows the horizontal forces on blocks B and A using the massless string approximation in the absence of friction. The hand must accelerate both blocks A and B, so more force is required to accelerate the greater mass. Thus the force of the string on B is smaller than the force of the hand on A.

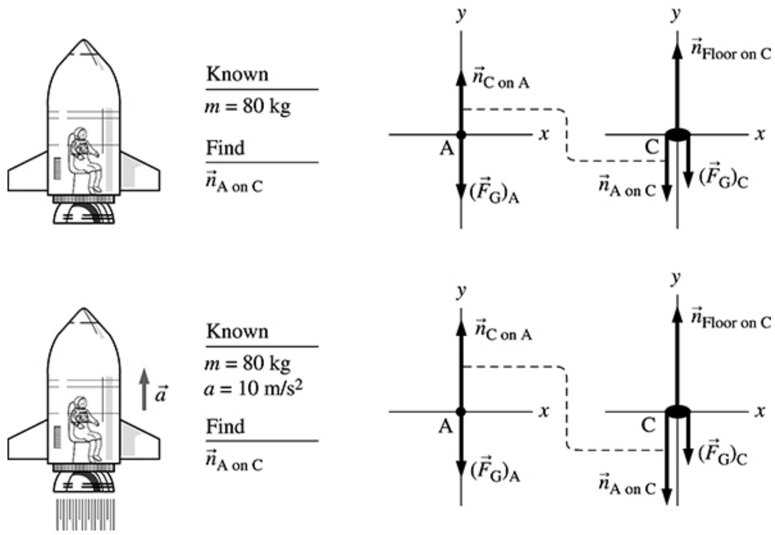
7.15. Block A's acceleration is greater in case b. In case a, the hanging 10 N must accelerate both the mass of A and its own mass, leading to a smaller acceleration than case b, where the entire 10 N force accelerates the mass of block A.

Case a	**Case b**
$10\text{ N} = (M_A + M_{10\text{ N}})a$	$10\text{ N} = M_A a$
$a = \dfrac{10\text{ N}}{(M_A + M_{10\text{ N}})}$	$a = \dfrac{10\text{ N}}{M_A}$

Chapter 7, Exercises and Problems

7.7. Model: We will model the astronaut and the chair as particles. The astronaut and the chair will be denoted by A and C, respectively, and they are separate systems. The launch pad is a part of the environment.
Visualize:

Pictorial representation



Solve: **(a)** Newton's second law for the astronaut is

$$\sum\left(F_{\text{on A}}\right)_y = n_{\text{C on A}} - \left(F_{\text{G}}\right)_{\text{A}} = m_{\text{A}} a_{\text{A}} = 0 \text{ N} \Rightarrow n_{\text{C on A}} = \left(F_{\text{G}}\right)_{\text{A}} = m_{\text{A}} g$$

By Newton's third law, the astronaut's force on the chair is

$$n_{\text{A on C}} = n_{\text{C on A}} = m_{\text{A}} g = (80 \text{ kg})\left(9.8 \text{ m/s}^2\right) = 7.8\times10^2 \text{ N}$$

(b) Newton's second law for the astronaut is:

$$\sum\left(F_{\text{on A}}\right)_y = n_{\text{C on A}} - \left(F_{\text{G}}\right)_{\text{A}} = m_{\text{A}} a_{\text{A}} \Rightarrow n_{\text{C on A}} = \left(F_{\text{G}}\right)_{\text{A}} + m_{\text{A}} a_{\text{A}} = m_{\text{A}}\left(g + a_{\text{A}}\right)$$

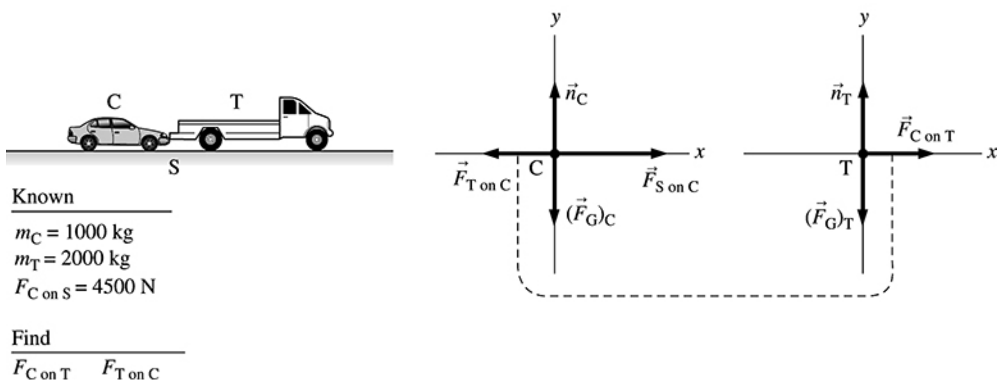
By Newton's third law, the astronaut's force on the chair is

$$n_{\text{A on C}} = n_{\text{C on A}} = m_{\text{A}}\left(g + a_{\text{A}}\right) = (80 \text{ kg})\left(9.8 \text{ m/s}^2 + 10 \text{ m/s}^2\right) = 1.6\times10^3 \text{ N}$$

Assess: This is a reasonable value because the astronaut's acceleration is more than *g*.

7.9. Model: The car and the truck will be modeled as particles and denoted by the symbols C and T, respectively. The surface of the ground will be denoted by the symbol S.
Visualize:

Pictorial representation



Solve: **(a)** The *x*-component of Newton's second law for the car is

$$\sum\left(F_{\text{on C}}\right)_x = F_{\text{S on C}} - F_{\text{T on C}} = m_{\text{C}} a_{\text{C}}$$

The *x*-component of Newton's second law for the truck is

$$\sum\left(F_{\text{on T}}\right)_x = F_{\text{C on T}} = m_{\text{T}}a_{\text{T}}$$

Using $a_{\text{C}} = a_{\text{T}} = a$ and $F_{\text{T on C}} = F_{\text{C on T}}$, we get

$$\left(F_{\text{C on S}} - F_{\text{C on T}}\right)\left(\frac{1}{m_{\text{C}}}\right) = a \quad \left(F_{\text{C on T}}\right)\left(\frac{1}{m_{\text{T}}}\right) = a$$

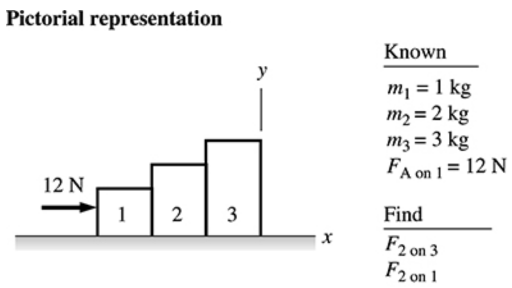
Combining these two equations,

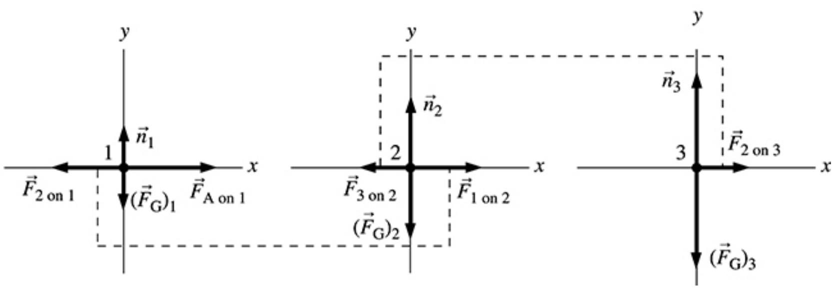
$$\left(F_{\text{C on S}} - F_{\text{C on T}}\right)\left(\frac{1}{m_{\text{C}}}\right) = \left(F_{\text{C on T}}\right)\left(\frac{1}{m_{\text{T}}}\right) \Rightarrow F_{\text{C on T}}\left(\frac{1}{m_{\text{C}}} + \frac{1}{m_{\text{T}}}\right) = \left(F_{\text{C on S}}\right)\left(\frac{1}{m_{\text{C}}}\right)$$

$$\Rightarrow F_{\text{C on T}} = \left(F_{\text{C on S}}\right)\left(\frac{m_{\text{T}}}{m_{\text{C}} + m_{\text{T}}}\right) = (4500\text{ N})\left(\frac{2000\text{ kg}}{1000\text{ kg} + 2000\text{ kg}}\right) = 3000\text{ N}$$

(b) Due to Newton's third law, $F_{\text{T on C}} = 3000\text{ N}.$

7.10. Model: The blocks are to be modeled as particles and denoted as 1, 2, and 3. The surface is frictionless and along with the earth it is a part of the environment. The three blocks are our three systems of interest.
Visualize:





The force applied on block 1 is $F_{\text{A on 1}} = 12\text{ N}.$ The acceleration for all the blocks is the same and is denoted by *a*.
Solve: (a) Newton's second law for the three blocks along the *x*-direction is

$$\sum\left(F_{\text{on 1}}\right)_x = F_{\text{A on 1}} - F_{\text{2 on 1}} = m_1 a \quad \sum\left(F_{\text{on 2}}\right)_x = F_{\text{1 on 2}} - F_{\text{3 on 2}} = m_2 a \quad \sum\left(F_{\text{on 3}}\right)_x = F_{\text{2 on 3}} = m_3 a$$

Adding these three equations and using Newton's third law $(F_{\text{2 on 1}} = F_{\text{1 on 2}}$ and $F_{\text{3 on 2}} = F_{\text{2 on 3}})$, we get

$$F_{\text{A on 1}} = \left(m_1 + m_2 + m_3\right)a \Rightarrow (12\text{ N}) = (1\text{ kg} + 2\text{ kg} + 3\text{ kg})a \Rightarrow a = 2\text{ m/s}^2$$

Using this value of *a*, the force equation on block 3 gives

$$F_{\text{2 on 3}} = m_3 a = (3\text{ kg})\left(2\text{ m/s}^2\right) = 6\text{ N}$$

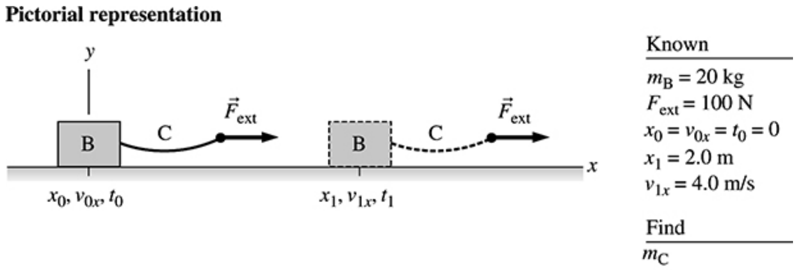
(b) Substituting into the force equation on block 1,

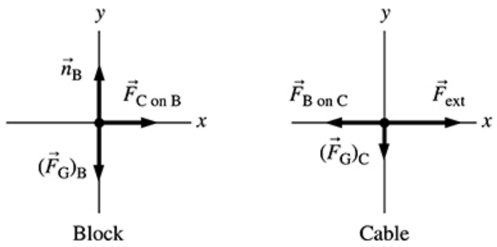
$$12\text{ N} - F_{\text{2 on 1}} = (1\text{ kg})\left(2\text{ m/s}^2\right) \Rightarrow F_{\text{2 on 1}} = 10\text{ N}$$

Assess: Because all three blocks are pushed forward by a force of 12 N, the value of 10 N for the force that the 2 kg block exerts on the 1 kg block is reasonable.

7.11. Model: The block (B) and the steel cable (C), the two objects of interest to us, are treated like particles. The motion of these objects is governed by the constant-acceleration kinematic equations.

Visualize:





Solve: Using $v_{1x}^2 = v_{0x}^2 + 2a_x(x_1 - x_0)$,

$$(4.0\text{ m/s})^2 = 0\text{ m}^2/\text{s}^2 + 2a_x(2.0\text{ m}) \Rightarrow a_x = 4.0\text{ m/s}^2$$

From the free-body diagram on the block:

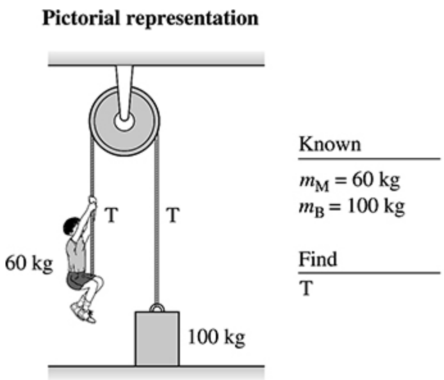
$$\sum(F_{\text{on B}})_x = F_{\text{C on B}} = m_B a_x \Rightarrow F_{\text{C on B}} = (20\text{ kg})(4.0\text{ m/s}^2) = 80\text{ N}$$

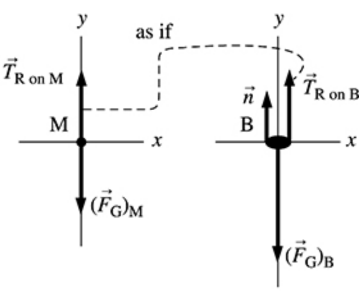
Also, according to Newton's third law $F_{\text{B on C}} = F_{\text{C on B}} = 80$ N. Newton's second law on the cable is:

$$\sum(F_{\text{on C}})_x = F_{\text{ext}} - F_{\text{B on C}} = m_C a_x \Rightarrow 100\text{ N} - 80\text{ N} = m_C(4.0\text{ m/s}^2) \Rightarrow m_C = 5\text{ kg}$$

7.12. Model: The man (M) and the block (B) are interacting with each other through a rope. We will assume the pulley to be frictionless. This assumption implies that the tension in the rope is the same on both sides of the pulley. The system is the man and the block.

Visualize:



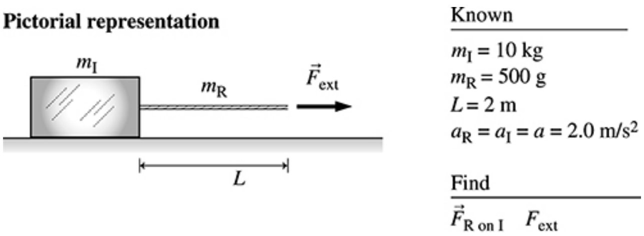


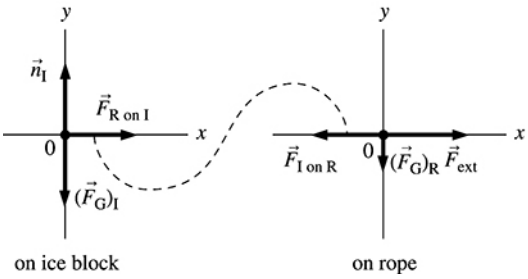
Solve: Clearly the entire system remains in equilibrium since $m_B > m_M$. The block would move downward but it is already on the ground. From the free-body diagrams, we can write down Newton's second law in the vertical direction as

$$\sum(F_{\text{on M}})_y = T_{\text{R on M}} - (F_G)_M = 0\text{ N} \Rightarrow T_{\text{R on M}} = (F_G)_M = (60\text{ kg})(9.8\text{ m/s}^2) = 588\text{ N}$$

Since the tension is the same on both sides, $T_{\text{B on R}} = T_{\text{M on R}} = T = 588$ N.

7.14. Model: The block of ice (I) is a particle and so is the rope (R) because it is not massless. We must therefore consider both the block of ice and the rope as objects in the system.
Visualize:





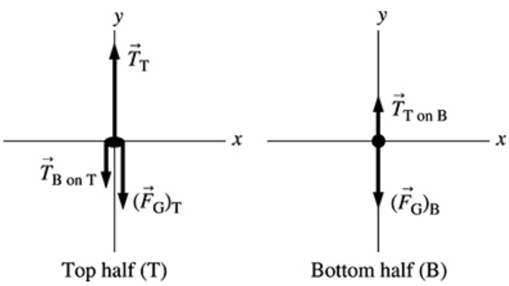
Solve: The force $\vec{F}_{ext}$ acts only on the rope. Since the rope and the ice block move together, they have the same acceleration. Also because the rope has mass, F_{ext} on the front end of the rope is not the same as $F_{I\ on\ R}$ that acts on the rear end of the rope.
Newton's second law along the *x*-axis for the ice block and the rope is

$$\sum\left(F_{on\ I}\right)_x = F_{R\ on\ I} = m_I a = (10\ \text{kg})\left(2.0\ \text{m/s}^2\right) = 20\ \text{N}$$

$$\sum\left(F_{on\ R}\right)_x = F_{ext} - F_{I\ on\ R} = m_R a \Rightarrow F_{ext} - F_{R\ on\ I} = m_R a$$

$$\Rightarrow F_{ext} = F_{R\ on\ I} + m_R a = 20\ \text{N} + (0.500\ \text{kg})\left(2.0\ \text{m/s}^2\right) = 21\ \text{N}$$

7.16. Visualize:



Solve: The rope is treated as two 1.0-kg interacting objects. At the midpoint of the rope, the rope has a tension $T_{B\ on\ T} = T_{T\ on\ B} \equiv T.$ Apply Newton's first law to the bottom half of the rope to find *T*.

$$\left(F_{net}\right)_y = 0 = T - \left(F_G\right)_B$$

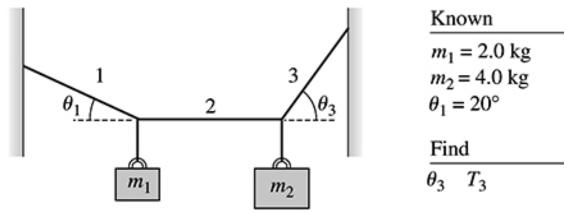
$$\Rightarrow T = m_B g = (1.0\ \text{kg})\left(9.80\ \text{m/s}^2\right) = 9.8\ \text{N}$$

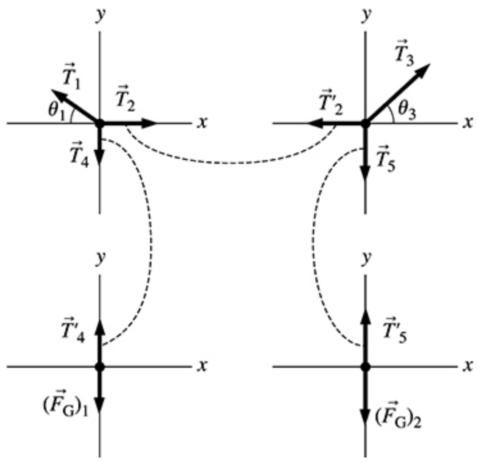
Assess: 9.8 N is half the gravitational force on the whole rope. This is reasonable since the top half is holding up the bottom half of the rope against gravity.

7.17. Model: The two hanging blocks, which can be modeled as particles, together with the two knots where rope 1 meets with rope 2 and rope 2 meets with rope 3 form a system. All the four objects in the system are in static equilibrium. The ropes are assumed to be massless.

Visualize:

Pictorial representation





Solve: **(a)** We will consider both the two hanging blocks *and* the two knots. The blocks are in static equilibrium with $\vec{F}_{\text{net}} = 0$ N. Note that there are three action/reaction pairs. For Block 1 and Block 2, $\vec{F}_{\text{net}} = 0$ N and we have

$$T'_4 = (F_G)_1 = m_1 g \quad T'_5 = (F_G)_2 = m_2 g$$

Then, by Newton's third law:

$$T_4 = T'_4 = m_1 g \quad T_5 = T'_5 = m_2 g$$

The knots are also in equilibrium. Newton's law applied to the left knot is

$$(F_{\text{net}})_x = T_2 - T_1\cos\theta_1 = 0 \text{ N} \quad (F_{\text{net}})_y = T_1\sin\theta_1 - T_4 = T_1\sin\theta_1 - m_1 g = 0 \text{ N}$$

The y-equation gives $T_1 = m_1 g/\sin\theta_1$. Substitute this into the x-equation to find

$$T_2 = \frac{m_1 g\cos\theta_1}{\sin\theta_1} = \frac{m_1 g}{\tan\theta_1}$$

Newton's law applied to the right knot is

$$(F_{\text{net}})_x = T_3\cos\theta_3 - T'_2 = 0 \text{ N} \quad (F_{\text{net}})_y = T_3\sin\theta_3 - T_5 = T_3\sin\theta_3 - m_2 g = 0 \text{ N}$$

These can be combined just like the equations for the left knot to give

$$T'_2 = \frac{m_2 g\cos\theta_3}{\sin\theta_3} = \frac{m_2 g}{\tan\theta_3}$$

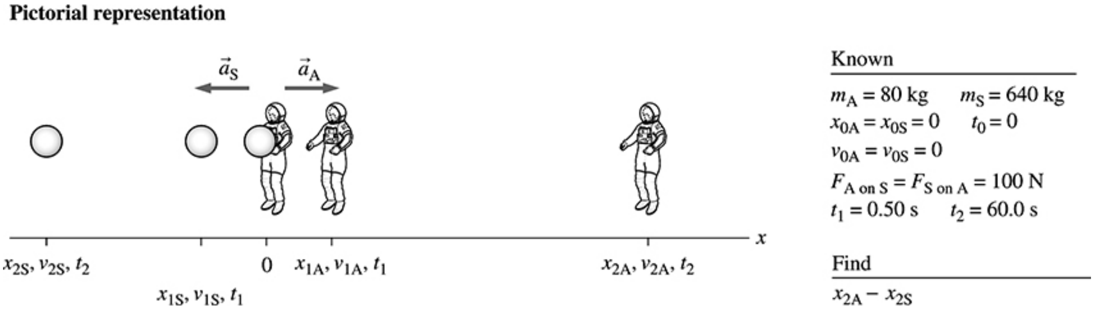
But the forces $\vec{T}_2$ and $\vec{T}'_2$ are an action/reaction pair, so $T_2 = T'_2$. Therefore,

$$\frac{m_1 g}{\tan\theta_1} = \frac{m_2 g}{\tan\theta_3} \Rightarrow \tan\theta_3 = \frac{m_2}{m_1}\tan\theta_1 \Rightarrow \theta_3 = \tan^{-1}(2\tan 20°) = 36°$$

We can now use the y-equation for the right knot to find $T_3 = m_2 g/\sin\theta_3 = 67$ N.

7.19. Model: The astronaut and the satellite, the two objects in our system, will be treated as particles.

Visualize:



Solve: The astronaut and the satellite accelerate in opposite directions for 0.50 s. The force on the satellite and the force on the astronaut are an action/reaction pair, so both are 100 N. Newton's second law for the satellite along the *x*-direction is

$$\sum\left(F_{\text{on S}}\right)_x = F_{\text{A on S}} = m_\text{S}a_\text{S} \Rightarrow a_\text{S} = \frac{F_{\text{A on S}}}{m_\text{S}} = \frac{-(100\ \text{N})}{640\ \text{kg}} = -0.156\ \text{m/s}^2$$

Newton's second law for the astronaut along the *x*-direction is

$$\sum\left(F_{\text{on A}}\right)_x = F_{\text{S on A}} = m_\text{A}a_\text{A} \Rightarrow a_\text{A} = \frac{F_{\text{S on A}}}{m_\text{A}} = \frac{F_{\text{A on S}}}{m_\text{A}} = \frac{100\ \text{N}}{80\ \text{kg}} = 1.25\ \text{m/s}^2$$

Let us first calculate the positions and velocities of the astronaut and the satellite at $t_1 = 0.50$ s under the accelerations a_A and a_S:

$$x_{1\text{A}} = x_{0\text{A}} + v_{0\text{A}}(t_1 - t_0) + \tfrac{1}{2}a_\text{A}(t_1 - t_0)^2 = 0\ \text{m} + 0\ \text{m} + \tfrac{1}{2}(1.25\ \text{m/s}^2)(0.50\ \text{s} - 0\ \text{s})^2 = 0.156\ \text{m}$$

$$x_{1\text{S}} = x_{0\text{S}} + v_{0\text{S}}(t_1 - t_0) + \tfrac{1}{2}a_\text{S}(t_1 - t_0)^2 = 0\ \text{m} + 0\ \text{m} + \tfrac{1}{2}(-0.156\ \text{m/s}^2)(0.50\ \text{s} - 0\ \text{s})^2 = -0.020\ \text{m}$$

$$v_{1\text{A}} = v_{0\text{A}} + a_\text{A}(t_1 - t_0) = 0\ \text{m/s} + (1.25\ \text{m/s}^2)(0.50\ \text{s} - 0\ \text{s}) = 0.625\ \text{m/s}$$

$$v_{1\text{S}} = v_{0\text{S}} + a_\text{S}(t_1 - t_0) = 0\ \text{m/s} + (-0.156\ \text{m/s}^2)(0.5\ \text{s} - 0\ \text{s}) = -0.078\ \text{m/s}$$

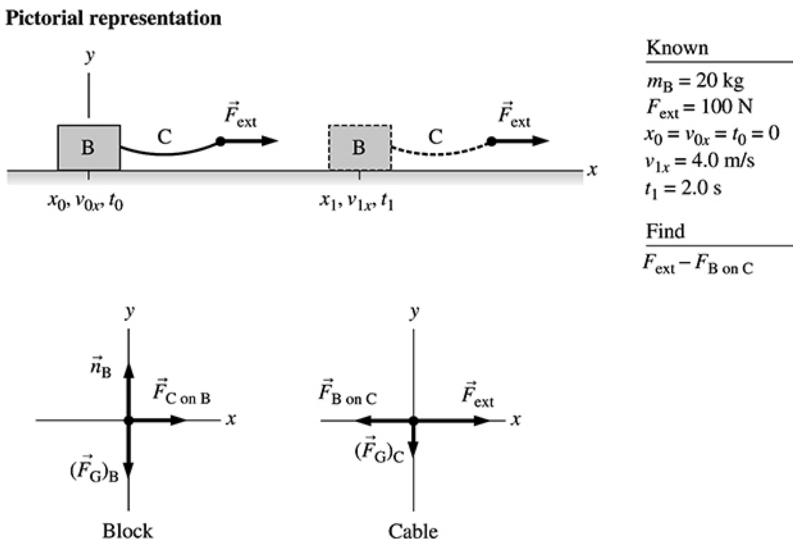
With $x_{1\text{A}}$ and $x_{1\text{S}}$ as initial positions, $v_{1\text{A}}$ and $v_{1\text{S}}$ as initial velocities, and zero accelerations, we can now obtain the new positions at $(t_2 - t_1) = 59.5$ s:

$$x_{2\text{A}} = x_{1\text{A}} + v_{1\text{A}}(t_2 - t_1) = 0.156\ \text{m} + (0.625\ \text{m/s})(59.5\ \text{s}) = 37.34\ \text{m}$$

$$x_{2\text{S}} = x_{1\text{S}} + v_{1\text{S}}(t_2 - t_1) = -0.02\ \text{m} + (-0.078\ \text{m/s})(59.5\ \text{s}) = -4.66\ \text{m}$$

Thus the astronaut and the satellite are $x_{2\text{A}} - x_{2\text{S}} = (37.34\ \text{m}) - (-4.66\ \text{m}) = 42\ \text{m}$ apart.

7.20. Model: The block (B) and the steel cable (C), the two objects in the system, are considered particles, and their motion is determined by the constant-acceleration kinematic equations.
Visualize:



Solve: Using $v_{1x} = v_{0x} + a_x(t_1 - t_0)$,

$$4.0 \text{ m/s} = 0 \text{ m/s} + a_x(2.0 \text{ s} - 0 \text{ s}) \Rightarrow a_x = 2.0 \text{ m/s}^2$$

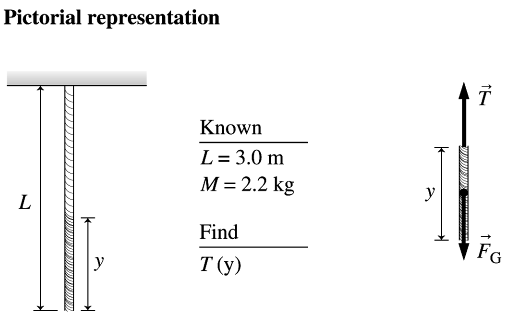
Newton's second law along the *x*-direction for the block is

$$\sum(F_{\text{on B}})_x = F_{\text{C on B}} = m_\text{B}a_x = (20 \text{ kg})(2.0 \text{ m/s}^2) = 40 \text{ N}$$

F_{ext} acts on the right end of the cable and $F_{\text{B on C}}$ acts on the left end. According to Newton's third law, $F_{\text{B on C}} = F_{\text{C on B}} =$ 40 N. The difference in tension between the two ends of the cable is thus

$$F_{\text{ext}} - F_{\text{B on C}} = 100 \text{ N} - 40 \text{ N} = 60 \text{ N}$$

7.22. Visualize: Consider a segment of the rope of length *y*, starting from the bottom of the rope. The weight of this segment of rope is a downward force. It is balanced by the tension force at height *y*.



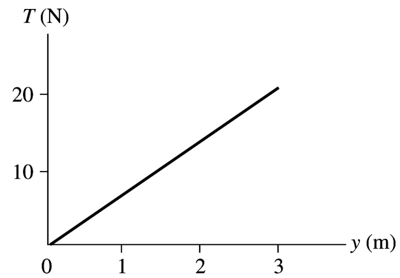
Solve: The mass *m* of this segment of rope is the same fraction of the total mass $M = 2.2$ kg as length *y* is a fraction of the total length $L = 3.0$ m. That is, $m/M = y/L$, from which we can write the mass of the rope segment

$$m = \frac{M}{L}y$$

This segment of rope is in static equilibrium, so the tension force pulling up on it is

$$T = F_\text{G} = mg = \frac{Mg}{L}y = \frac{(2.2 \text{ kg})(9.8 \text{ m/s}^2)}{3.0 \text{ m}}y = 7.19y \text{ N}$$

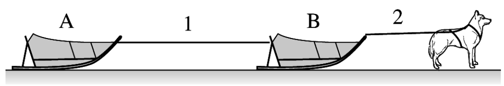
where *y* is in m. The tension increases linearly from 0 N at the bottom $(y = 0 \text{ m})$ to 21.6 N at the top $(y = 3 \text{ m})$. This is shown in the graph.



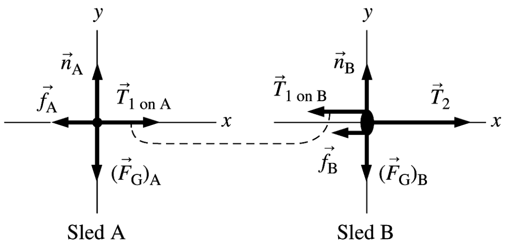
7.23. Model: Sled A, sled B, and the dog (D) are treated like particles in the model of kinetic friction.

Visualize:

Pictorial representation



Known
$m_A = 100$ kg
$m_B = 80$ kg
$\mu_k = 0.10$
$T_1 = 150$ N
Find
T_2



Solve: The acceleration constraint is $(a_A)_x = (a_B)_x = a_x$. Newton's second law on sled A is

$$\sum(\vec{F}_{\text{on A}})_y = n_A - (F_G)_A = 0\text{ N} \Rightarrow n_A = (F_G)_A = m_A g \quad \sum(\vec{F}_{\text{on A}})_x = T_{1\text{ on A}} - f_A = m_A a_x$$

Using $f_A = \mu_k n_A$, the x-equation yields

$$T_{1\text{ on A}} - \mu_k n_A = m_A a_x \Rightarrow 150\text{ N} - (0.1)(100\text{ kg})(9.8\text{ m/s}^2) = (100\text{ kg})a_x \Rightarrow a_x = 0.52\text{ m/s}^2$$

On sled B:

$$\sum(\vec{F}_{\text{on B}})_y = n_B - (F_G)_B = 0\text{ N} \Rightarrow n_B = (F_G)_B = m_B g \quad \sum(\vec{F}_{\text{on B}})_x = T_2 - T_{1\text{ on B}} - f_B = m_B a_x$$

$T_{1\text{ on B}}$ and $T_{1\text{ on A}}$ act as if they are an action/reaction pair, so $T_{1\text{ on B}} = 150$ N. Using $f_B = \mu_k n_B = (0.10)(80\text{ kg})(9.8\text{ m/s}^2) = 78.4$ N, we get

$$T_2 - 150\text{ N} - 78.4\text{ N} = (80\text{ kg})(0.52\text{ m/s}^2) \Rightarrow T_2 = 270\text{ N}$$

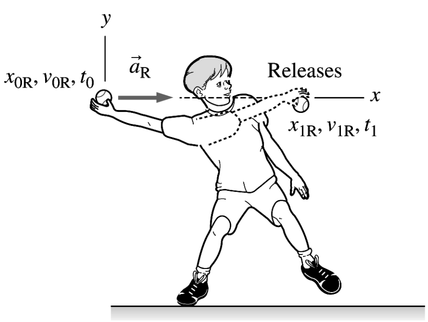
Thus the tension $T_2 = 2.7\times10^2$ N.

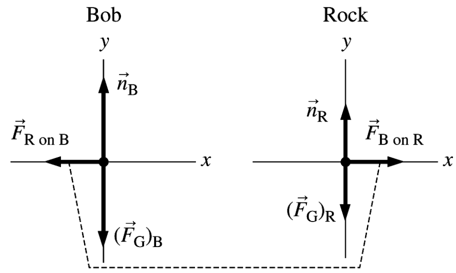
7.27. Model: The rock (R) and Bob (B) are the two objects in our system, and will be treated as particles. We will also use the constant-acceleration kinematic equations.

Visualize:

Pictorial representation

Known
$m_B = 75$ kg
$m_R = 500$ g
$v_{0R} = v_{0B} = 0$
$v_{1R} = 30$ m/s
$x_1 - x_0 = \Delta x = 1.0$ m
Find
$F_{B\text{ on R}}$ and v_{B1}





Solve: **(a)** Bob exerts a forward force $\vec{F}_{B\text{ on R}}$ on the rock to accelerate it forward. The rock's acceleration is calculated as follows:

$$v_{1R}^2 = v_{0R}^2 + 2a_{0R}\Delta x \Rightarrow a_R = \frac{v_{1R}^2}{2\Delta x} = \frac{(30\text{ m/s})^2}{2(1.0\text{ m})} = 450\text{ m/s}^2$$

The force is calculated from Newton's second law:

$$F_{B\text{ on R}} = m_R a_R = (.500\text{ kg})(450\text{ m/s}^2) = 225\text{ N}$$

Bob exerts a force of 2.3×10^2 N on the rock.

(b) Because Bob pushes on the rock, the rock pushes back on Bob with a force $\vec{F}_{\text{R on B}}$. Forces $\vec{F}_{\text{R on B}}$ and $\vec{F}_{\text{B on R}}$ are an action/reaction pair, so $F_{\text{R on B}} = F_{\text{B on R}} = 225\ \text{N}$. The force causes Bob to accelerate backward with an acceleration equal to

$$a_{\text{B}} = \frac{(F_{\text{net on B}})_x}{m_{\text{B}}} = -\frac{F_{\text{R on B}}}{m_{\text{B}}} = -\frac{225\ \text{N}}{75\ \text{kg}} = -3.0\ \text{m/s}^2$$

This is a rather large acceleration, but it lasts only until Bob releases the rock. We can determine the time interval by returning to the kinematics of the rock:

$$v_{1\text{R}} = v_{0\text{R}} + a_{\text{R}}\Delta t = a_{\text{R}}\Delta t \Rightarrow \Delta t = \frac{v_{1\text{R}}}{a_{\text{R}}} = 0.0667\ \text{s}$$

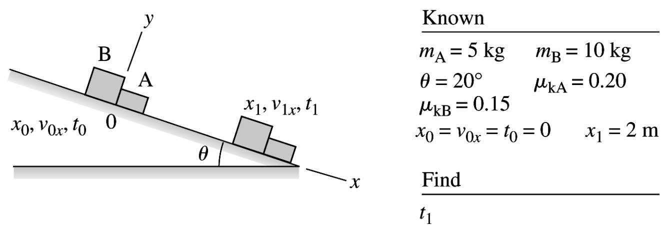
At the end of this interval, Bob's velocity is

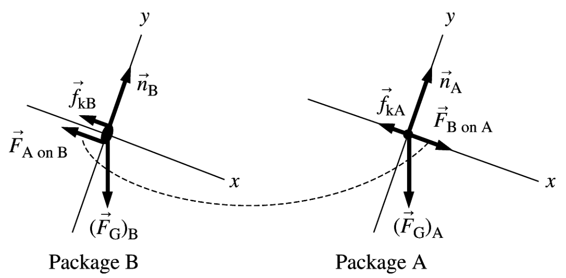
$$v_{1\text{B}} = v_{0\text{B}} + a_{\text{B}}\Delta t = a_{\text{B}}\Delta t = -0.20\ \text{m/s}$$

Thus his recoil speed is 0.20 m/s.

7.29. Model: Assume package A and package B are particles. Use the model of kinetic friction and the constant-acceleration kinematic equations.
Visualize:

Pictorial representation





Solve: Package B has a smaller coefficient of friction. It will try to overtake package A and push against it. Package A will push back on B. The acceleration constraint is $(a_{\text{A}})_x = (a_{\text{B}})_x = a$.

Newton's second law for each package is

$$\sum (F_{\text{on A}})_x = F_{\text{B on A}} + (F_{\text{G}})_{\text{A}} \sin\theta - f_{\text{kA}} = m_{\text{A}} a$$

$$\Rightarrow F_{\text{B on A}} + m_{\text{A}} g \sin\theta - \mu_{\text{kA}} (m_{\text{A}} g \cos\theta) = m_{\text{A}} a$$

$$\sum (F_{\text{on B}})_x = -F_{\text{A on B}} - f_{\text{kB}} + (F_{\text{G}})_{\text{B}} \sin\theta = m_{\text{B}} a$$

$$\Rightarrow -F_{\text{A on B}} - \mu_{\text{kB}} (m_{\text{B}} g \cos\theta) + m_{\text{B}} g \sin\theta = m_{\text{B}} a$$

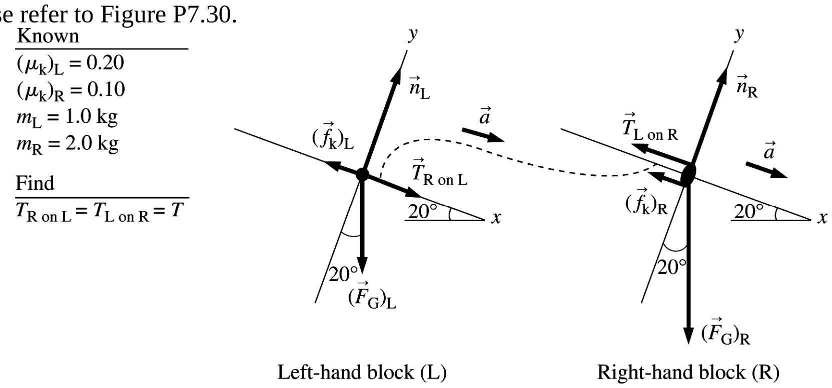
where we have used $n_{\text{A}} = m_{\text{A}} \cos\theta g$ and $n_{\text{B}} = m_{\text{B}} \cos\theta g$. Adding the two force equations, and using $F_{\text{A on B}} = F_{\text{B on A}}$ because they are an action/reaction pair, we get

$$a = g\sin\theta - \frac{(\mu_{\text{kA}} m_{\text{A}} + \mu_{\text{kB}} m_{\text{B}})(g\cos\theta)}{m_{\text{A}} + m_{\text{B}}} = 1.82\ \text{m/s}^2$$

Finally, using $x_1 = x_0 + v_{0x}(t_1 - t_0) + \frac{1}{2} a (t_1 - t_0)^2$,

$$2.0\ \text{m} = 0\ \text{m} + 0\ \text{m} + \tfrac{1}{2}(1.82\ \text{m/s}^2)(t_1 - 0\ \text{s})^2 \Rightarrow t_1 = 1.48\ \text{s}$$

7.30. Model: The two blocks form a system of interacting objects.
Visualize: Please refer to Figure P7.30.



Solve: It is possible that the left-hand block (Block L) is accelerating down the slope faster than the right-hand block (Block R), causing the string to be slack (zero tension). If that were the case, we would get a zero or negative answer for the tension in the string.
Newton's first law applied to the y-direction on Block L yields

$$\left(\sum F_L\right)_y = 0 = n_L - (F_G)_L \cos 20° \Rightarrow n_L = m_L g \cos 20°$$

Therefore

$$(f_k)_L = (\mu_k)_L m_L g \cos 20° = (0.20)(1.0 \text{ kg})(9.80 \text{ m/s}^2)\cos 20° = 1.84 \text{ N}$$

A similar analysis of the vertical forces on Block R gives $(f_k)_R = 1.84$ N as well. Using Newton's second law in the x-direction for Block L,

$$\left(\sum F_L\right)_x = m_L a = T_{R\text{ on }L} - (f_k)_L + (F_G)_L \sin 20° \;\; \Rightarrow m_L a = T_{R\text{ on }L} - 1.84 \text{ N} + m_L g \sin 20°.$$

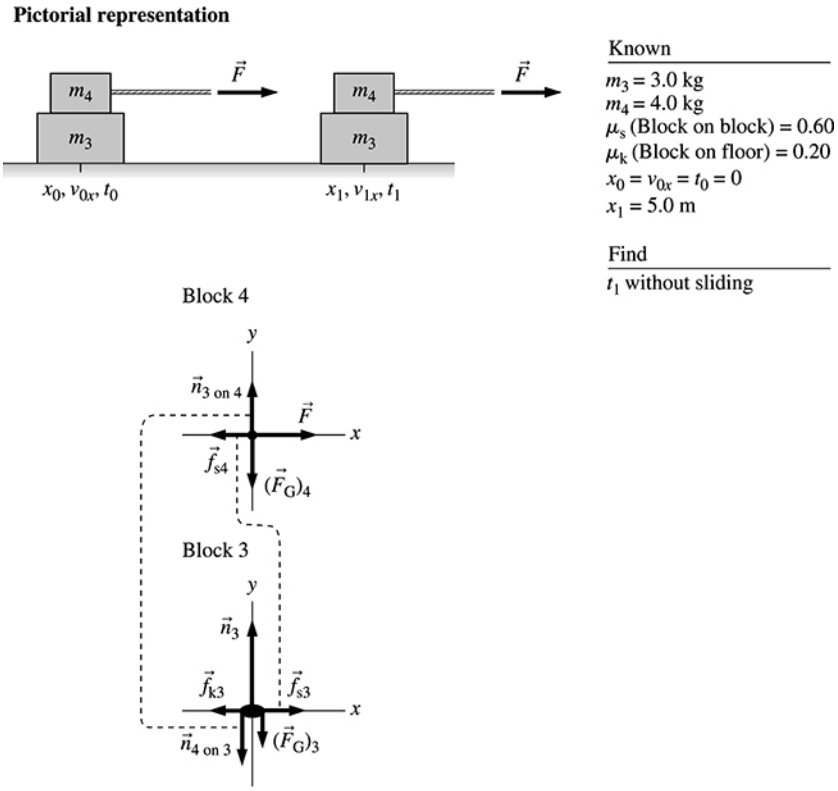
For Block R,

$$\left(\sum F_R\right)_x = m_R a = (F_G)_R \sin 20° - 1.84 \text{ N} - T_{L\text{ on }R} \;\; \Rightarrow m_R a = m_R g \sin 20° - 1.84 \text{ N} - T_{L\text{ on }R}$$

These are two equations in the two unknowns a and $T_{L\text{ on }R} = T_{R\text{ on }L} \equiv T$. Solving them, we obtain $a = 2.12 \text{ m/s}^2$ and $T = 0.61$ N.
Assess: The tension in the string is positive, and is about 1/3 of the kinetic friction force on each of the blocks, which is reasonable.

7.33. Model: The 3-kg and 4-kg blocks are to be treated as particles. The models of kinetic and static friction and the constant-acceleration kinematic equations will be used.

Visualize:



Solve: Minimum time will be achieved when static friction is at its maximum possible value. Newton's second law for the 4-kg block is

$$\sum (F_{\text{on }4})_y = n_{3\text{ on }4} - (F_G)_4 = 0\text{ N} \Rightarrow n_{3\text{ on }4} = (F_G)_4 = m_4 g = (4.0\text{ kg})(9.8\text{ m/s}^2) = 39.2\text{ N}$$

$$\Rightarrow f_{s4} = (f_s)_{\max} = \mu_s n_{3\text{ on }4} = (0.60)(39.2\text{ N}) = 23.52\text{ N}$$

Newton's second law for the 3-kg block is

$$\sum (F_{\text{on }3})_y = n_3 - n_{4\text{ on }3} - (F_G)_3 = 0\text{ N} \Rightarrow n_3 = n_{4\text{ on }3} + (F_G)_3 = 39.2\text{ N} + (3.0\text{ kg})(9.8\text{ m/s}^2) = 68.6\text{ N}$$

Friction forces f_{s3} and f_{s4} are an action/reaction pair. Thus

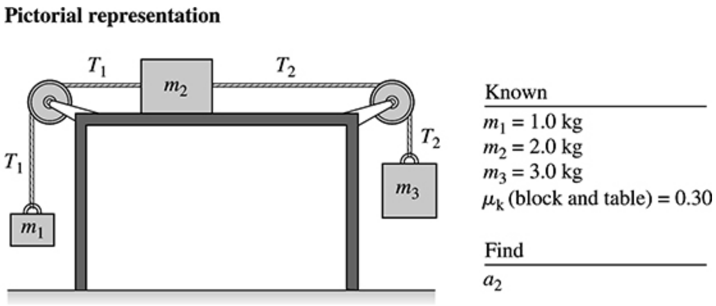
$$\sum (F_{\text{on }3})_x = f_{s3} - f_{k3} = m_3 a_3 \Rightarrow f_{s4} - \mu_k n_3 = m_3 a_3 \Rightarrow 23.52\text{ N} - (0.20)(68.6\text{ N}) = (3.0\text{ kg})a_3 \Rightarrow a_3 = 3.267\text{ m/s}^2$$

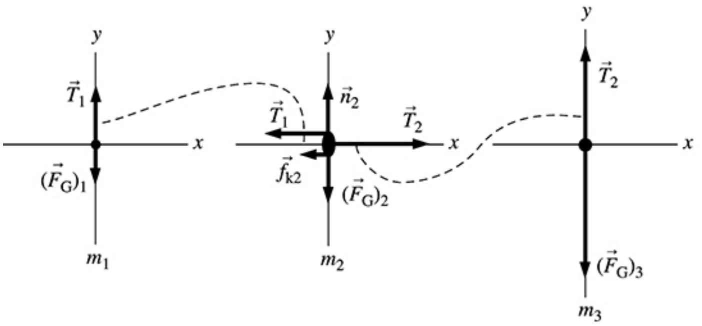
Since block 3 does not slip, this is also the acceleration of block 4. The time is calculated as follows:

$$x_1 = x_0 + v_{0x}(t_1 - t_0) + \tfrac{1}{2}a(t_1 - t_0)^2 \Rightarrow 5.0\text{ m} = 0\text{ m} + 0\text{ m} + \tfrac{1}{2}(3.267\text{ m/s}^2)(t_1 - 0\text{ s})^2 \Rightarrow t_1 = 1.75\text{ s}$$

7.38. Model: Assume the particle model for m_1, m_2, and m_3, and the model of kinetic friction. Assume the ropes to be massless, and the pulleys to be frictionless and massless.

Visualize:





Solve: Newton's second law for m_1 is $T_1 - (F_G)_1 = m_1 a_1$. Newton's second law for m_2 is

$$\sum\left(F_{\text{on } m_2}\right)_y = n_2 - \left(F_G\right)_2 = 0 \text{ N} \Rightarrow n_2 = (2.0 \text{ kg})\left(9.8 \text{ m/s}^2\right) = 19.6 \text{ N}$$

$$\sum(F_{\text{on } m_2})_x = T_2 - f_{k2} - T = m_2 a_2 \Rightarrow T_2 - \mu_k n_2 - T_1 = (2.0 \text{ kg})a_2$$

Newton's second law for m_3 is

$$\sum\left(F_{\text{on } m_3}\right)_y = T_2 - \left(F_G\right)_3 = m_3 a_3$$

Since m_1, m_2, and m_3 move together, $a_1 = a_2 = -a_3 = a$. The equations for the three masses thus become

$$T_1 - \left(F_G\right)_1 = m_1 a = (1.0 \text{ kg})a \quad T_2 - \mu_k n_2 - T_1 = m_2 a = (2.0 \text{ kg})a \quad T_2 - \left(F_G\right)_3 = -m_3 a = -(3.0 \text{ kg})a$$

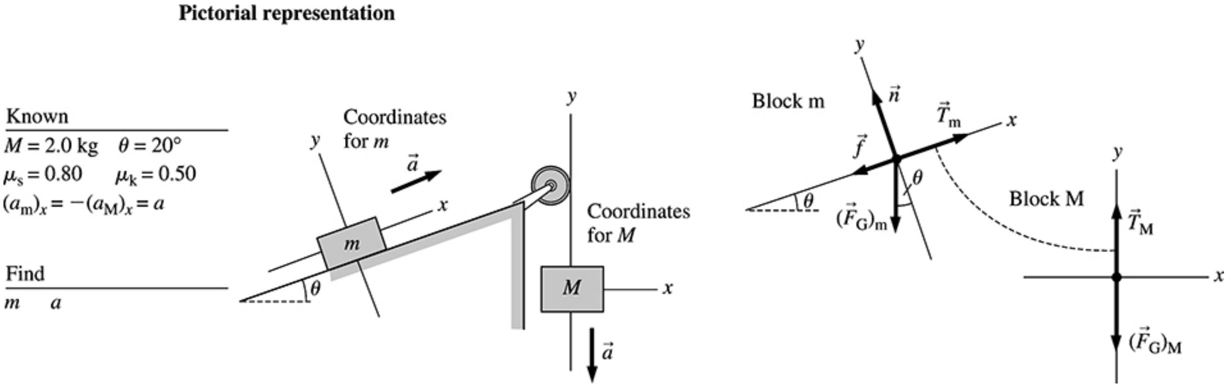
Subtracting the third equation from the sum of the first two equations yields:

$$-\left(F_G\right)_1 - \mu_k n_2 + \left(F_G\right)_3 = (6.0 \text{ kg})a$$

$$\Rightarrow -(1.0 \text{ kg})\left(9.8 \text{ m/s}^2\right) - (0.30)(19.6 \text{ N}) + (3.0 \text{ kg})\left(9.8 \text{ m/s}^2\right) = (6.0 \text{ kg})a \Rightarrow a = 2.3 \text{ m/s}^2$$

7.39. Model: Assume the particle model for the two blocks, and the model of kinetic and static friction.

Visualize:



Solve: (a) If the mass *m* is too small, the hanging 2.0 kg mass will pull it up the slope. We want to find the smallest mass that will stick because of friction. The smallest mass will be the one for which the force of static friction is at its maximum possible value: $f_s = (f_s)_{max} = \mu_s n$. As long as the mass *m* is stuck, both blocks are at rest with $\vec{F}_{net} = 0$ N. Newton's second law for the hanging mass *M* is

$$(F_{net})_y = T_M - Mg = 0 \text{ N} \Rightarrow T_M = Mg = 19.6 \text{ N}$$

For the smaller mass *m*,

$$(F_{net})_x = T_m - f_s - mg\sin\theta = 0 \text{ N} \quad (F_{net})_y = n - mg\cos\theta \Rightarrow n = mg\cos\theta$$

For a massless string and frictionless pulley, forces $\vec{T}_m$ and $\vec{T}_M$ act as if they are an action/reaction pair. Thus $T_m = T_M$. Mass *m* is a minimum when $(f_s)_{max} = \mu_s n = \mu_s mg\cos\theta$. Substituting these expressions into the *x*-equation,

$$T_M - \mu_s mg\cos\theta - mg\sin\theta = 0 \text{ N} \Rightarrow m = \frac{T_M}{(\mu_s\cos\theta + \sin\theta)g} = 1.83 \text{ kg}$$

(b) Because $\mu_k < \mu_S$ the 1.83 kg block will begin to slide up the ramp, and the 2.0 kg mass will begin to fall, if the block is nudged ever so slightly. Now the net force and the acceleration are *not* zero. Notice how, in the pictorial representation, we chose different coordinate systems for the two masses. This gives block M an acceleration with only a *y*-component and block m an acceleration with only an *x*-component. The magnitudes of the accelerations are the same because the blocks are tied together. But block M has a negative acceleration component a_y (vector $\vec{a}$ points down) whereas block m has a positive a_x. Thus the acceleration constraint is $(a_m)_x = -(a_M)_y = a$, where *a* will have a positive value. Newton's second law for block M is

$$(F_{net})_y = T - Mg = M(a_M)_y = -Ma$$

For block m we have

$$(F_{net})_x = T - f_k - mg\sin\theta = T - \mu_k mg\cos\theta - mg\sin\theta = m(a_m)_x = ma$$

In writing these equations, we used Newton's third law to write $T_m = T_M = T$. Also, we noticed that the *y*-equation and the friction model for block m don't change, except for μ_s becoming μ_k, so we already know f_k from part (a). Notice that the tension in the string is *not* the gravitational force *Mg*. We have two equations in the two unknowns *T* and *a*:

$$T - Mg = -Ma \quad T - (\mu_k\cos\theta + \sin\theta)mg = ma$$

Subtracting the second equation from the first to eliminate *T*,

$$-Mg + (\mu_k\cos\theta + \sin\theta)mg = -Ma - ma = -(M+m)a$$

$$\Rightarrow a = \frac{M - (\mu_k\cos\theta + \sin\theta)m}{M+m}g = 1.32 \text{ m/s}^2$$