4

DYNAMICS: NEWTON'S LAWS OF MOTION

Responses to Questions

1. When you give the wagon a sharp pull forward, the force of friction between the wagon and the child acts on the child to move her forward. But the force of friction acts at the contact point between the child and the wagon—we assume the child is sitting in the wagon. The lower part of the child begins to move forward, while the upper part, following Newton's first law (the law of inertia), remains almost stationary, making it seem as if the child falls backward. The "backward" motion is relative to the wagon, not to the ground.

2. (*a*) Mary, standing on the ground beside the truck, will see the box remain motionless while the truck accelerates out from under it. Since there is no friction, there is no net horizontal force on the box and the box will not speed up. Thus Mary would describe the motion of the box in terms of Newton's first law—there is no force on the box, so it does not accelerate.

   (*b*) Chris, riding on the truck, will see the box appear to accelerate backward with respect to his frame of reference, which is not inertial. He might even say something about the box being "thrown" backward in the truck and try to invoke Newton's second law to explain the motion of the box. But the source of the force would be impossible to specify. (Chris had better hold on, though; if the truck bed is frictionless, he too will slide off if he is just standing!)

3. Yes, the net force can be zero on a moving object. If the net force is zero, then the object's *acceleration* is zero, but its *velocity* is not necessarily zero. [Instead of classifying objects as "moving" and "not moving," Newtonian dynamics classifies them as "accelerating" and "not accelerating." Both zero velocity and constant velocity fall in the "not accelerating" category.]

4. If the acceleration of an object is zero, the vector *sum* of the forces acting on the object is zero (Newton's second law), so there can be forces on an object that has no acceleration. For example, a book resting on a table is acted on by gravity and the normal force, but it has zero acceleration, because the forces are equal in magnitude and opposite in direction.

5. If only one force acts on an object, the net force cannot be zero, so the object cannot have zero acceleration, by Newton's second law. It *is* possible for the object to have zero velocity, but only for an instant. For example (if we neglect air resistance), a ball thrown upward into the air has only the force of gravity acting on it. Its speed will decrease while it travels upward, stops, then begins to fall back to the ground. At the instant the ball is at its highest point, its velocity is zero. However, the ball has a nonzero net force and a nonzero acceleration throughout its flight.

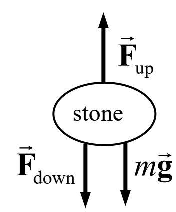
6. (*a*) A force is needed to bounce the ball back up, because the ball changes direction, so the ball accelerates. If the ball accelerates, there must be a force.
   (*b*) The pavement exerts the force on the golf ball.

$\boxed{7.}$ As you take a step on the log, your foot exerts a force on the log in the direction opposite to the direction in which *you* want to move, which pushes the log "backward." (The log exerts an equal and opposite force forward on you, by Newton's third law.) If the log had been on the ground, friction between the ground and the log would have kept the log from moving. However, the log is floating in water, which offers little resistance to the movement of the log as you push it backward.

8. (*a*) When you first start riding a bicycle you need to exert a strong force to accelerate the bike and yourself, as well as to overcome friction. Once you are moving at a constant speed, you need to exert a force that will just equal the opposing forces of friction and air resistance.
   (*b*) When the bike is moving at a constant speed, the *net* force on it is zero. Since friction and air resistance are present, you would slow down if you didn't pedal to keep the net force on the bike (and you) equal to zero.

9. When the person gives a sharp pull, the suddenness of application of the force is key. When a large, sudden force is applied to the bottom string, the bottom string will have a large tension in it. Because of the stone's inertia, the upper string does not immediately experience the large force. The bottom string must have more tension in it and will break first.

   If a slow and steady pull is applied, the tension in the bottom string increases. We approximate that condition as considering the stone to be in equilibrium until the string breaks. The free-body diagram for the stone would look like this diagram. While the stone is in equilibrium, Newton's second law states that $F_{\text{up}} = F_{\text{down}} + mg$. Thus the tension in the upper string is going to be larger than the tension in the lower string because of the weight of the stone, so the upper string will break first.



10. The acceleration of both rocks is found by dividing their weight (the force of gravity on them) by their mass. The 2-kg rock has a force of gravity on it that is twice as great as the force of gravity on the 1-kg rock, but also twice as great a mass as the 1-kg rock, so the acceleration is the same for both.

11. (*a*) When you pull the rope at an angle, only the horizontal component of the pulling force will be accelerating the box across the table. This is a smaller horizontal force than originally used, so the horizontal acceleration of the box will decrease.
    (*b*) We assume that the rope is angled upward, as in Fig. 4–21a. When there is friction, the problem is much more complicated. As the angle increases, there are two competing effects. The horizontal component of the pulling force gets smaller, as in part (*a*), which reduces the acceleration. But as the angle increases, the upward part of the pulling force gets larger, which reduces the normal force. As the normal force gets smaller, the force of friction also gets smaller, which would increase the acceleration. A detailed analysis shows that the acceleration increases initially, up to a certain angle, and then decreases for higher angles.

    If instead the rope is angled downward, then the normal force increases, which increases the force of friction, and for all angles, the acceleration will decrease.

12. Let us find the acceleration of the Earth, assuming the mass of the freely falling object is $m = 1$ kg. If the mass of the Earth is M, then the acceleration of the Earth would be found using Newton's third law and Newton's second law.

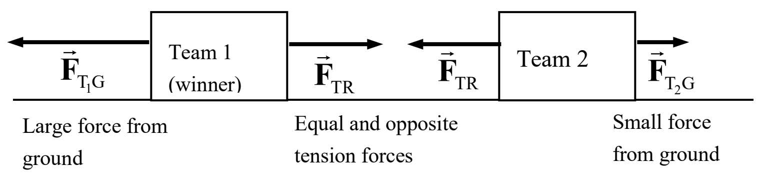
$$F_{\text{Earth}} = F_{\text{object}} \quad \rightarrow \quad Ma_{\text{Earth}} = mg \quad \rightarrow \quad a_{\text{Earth}} = g\, m / M$$

Since the Earth has a mass that is on the order of 10^{25} kg, the acceleration of the Earth is on the order of $10^{-25}\,g$, or about $10^{-24}\ \text{m/s}^2$. This tiny acceleration is undetectable.

13. Because the acceleration due to gravity on the Moon is less than it is on the Earth, an object with a mass of 10 kg will weigh less on the Moon than it does on the Earth. Therefore, it will be easier to lift on the Moon. (When you lift something, you exert a force to oppose its weight.) However, when throwing the object horizontally, the force needed to accelerate it to the desired horizontal speed is proportional to the object's mass, $F = ma$. Therefore, you would need to exert the same force to throw the 2-kg object with a given speed on the Moon as you would on Earth.

14. In a tug of war, the team that pushes hardest against the ground wins. It is true that both teams have the same force on them due to the tension in the rope. But the winning team pushes harder against the ground and thus the ground pushes harder on the winning team, making a net unbalanced force. The free-body diagram illustrates this.

The forces are $\vec{\mathbf{F}}_{\text{T}_1\text{G}}$, the force on team 1 from the ground, $\vec{\mathbf{F}}_{\text{T}_2\text{G}}$, the force on team 2 from the ground, and $\vec{\mathbf{F}}_{\text{TR}}$, the force on each team from the rope.



Thus the <u>net</u> force on the winning team $(\vec{\mathbf{F}}_{\text{T}_1\text{G}} - \vec{\mathbf{F}}_{\text{TR}})$ is in the "winning" direction.

15. If you are at rest, the net force on you is zero. Hence the ground exerts a force on you exactly equal to your weight. The two forces acting on you sum to zero, so you don't accelerate. If you squat down and then push with a larger force against the ground, the ground then pushes back on you with a larger force by Newton's third law, and you <u>can</u> then rise into the air.

16. The victim's head is not really thrown backward during the car crash. If the victim's car was initially at rest, or even moving forward, the impact from the rear suddenly pushes the car, the seat, and the person's body forward. The head, being attached by the somewhat flexible neck to the body, can momentarily remain where it was (inertia, Newton's first law), thus lagging behind the body. The neck muscles must eventually pull the head forward, and that causes the whiplash. To avoid this, use the car's headrests.

17. (*a*) The reaction force has a magnitude of 40 N.
(*b*) It points downward.
(*c*) It is exerted on Mary's hands and arms.
(*d*) It is exerted by the bag of groceries.

18. Both the father and daughter will have the same magnitude force acting on them as they push each other away, by consideration of Newton's third law. If we assume that the young daughter has less mass than the father, her acceleration should be greater ($a = F/m$). Both forces, and therefore both accelerations, act over the same time interval (while the father and daughter are in contact), so the daughter's final speed will be greater than her father's.

$\boxed{19.}$ Static friction between the crate and the truck bed causes the crate to accelerate.

20. On the way up, there are two forces on the block that are parallel to each other causing the deceleration—the component of weight parallel to the plane and the force of friction on the block. Since the forces are parallel to each other, both pointing down the plane, they add, causing a larger magnitude force and a larger acceleration. On the way down, those same two forces are opposite of each other, because the force of friction is now directed up the plane. With these two forces being opposite of each other, their net force is smaller, so the acceleration is smaller.

21. In a very simple analysis, the net force slowing the moving object is friction. If we consider that the moving object is on a level surface, then the normal force is equal to the weight. Combining these ideas, we get the following:

$$F_{\text{net}} = ma = \mu F_{\text{N}} = \mu mg \rightarrow a = \mu g$$

From Table 4–2, the "steel on steel (unlubricated)" coefficient of friction (applicable to the train) is smaller than the "rubber on dry concrete" coefficient of friction (applicable to the truck). Thus the acceleration of the train will be smaller than that of the truck, and therefore the truck's stopping distance will be smaller, from Eq. 2–11c.

22. Assume your weight is W. If you weighed yourself on an inclined plane that is inclined at angle θ, then the bathroom scale would read the magnitude of the normal force between you and the plane, which would be $W \cos \theta$.

Responses to MisConceptual Questions

1. (*a*) The crate does not accelerate up or down, so the net force cannot be vertical. The truck bed is frictionless and the crate is not in contact with any other surface, so there are no horizontal forces. Therefore, no net force acts on the crate. As the truck slows down, the crate continues to move forward at constant speed. (How did the crate stay on the truck in the first place to be able to travel on the truck bed?)

2. (*a*, *b*, *d*) The forces in (*a*), (*b*), and (*d*) are all equal to 400 N in magnitude.

   (*a*) You exert a force of 400 N on the car; by Newton's third law the force exerted by the car on you also has a magnitude of 400 N.

   (*b*) Since the car doesn't move and the only horizontal forces acting on the car are your pushing and the force of friction on the car from the road, Newton's second law requires these forces to have equal magnitudes (400 N) in the opposite direction. Since the road exerts a force of 400 N on the car by friction, Newton's third law requires that the friction force on the road from the car must also be 400 N.

   (*c*) The normal force exerted by the road on you will be equal in magnitude to your weight (assuming you are standing vertically and have no vertical acceleration). This force is not required to be 400 N.

(*d*) The car is exerting a 400-N horizontal force on you, and since you are not accelerating, and the only horizontal forces acting on you are the force from the car and the frictional force from the ground, Newton's second law requires that the ground must be exerting an equal and opposite horizontal force. Therefore, the magnitude of the friction force exerted on you by the road is 400 N.

3. (*d*) For Matt and the truck to move forward from rest, both of them must experience a positive horizontal acceleration. The horizontal forces acting on Matt are the friction force of the ground pushing him forward and the truck pulling him backward. The ground must push Matt forward with a stronger force than the truck is pulling him back. The horizontal forces on the truck are from Matt pulling the truck forward and the friction from the ground pulling the truck backward. For the truck to accelerate forward, the force from Matt must be greater than the backward force of friction from the ground. By Newton's third law, the force of the truck on Matt and the force of Matt on the truck are equal and opposite. Since the force of the ground on Matt is greater than the force of the truck on Matt, the force of the truck on Matt is equal to the force of Matt on the truck, and the force of Matt on the truck is greater than the friction force of the ground on the truck, the ground exerts a greater friction on Matt than on the truck.

4. (*d*) In order to hold the backpack up, the rope must exert a vertical force equal to the backpack's weight, so that the net vertical force on the backpack is zero. The force, F, exerted by the rope on each side of the pack is always along the length of the rope. The vertical component of this force is $F \sin \theta$, where θ is the angle the rope makes with the horizontal. The higher the pack goes, the smaller θ becomes and the larger F must be to hold the pack up there. No matter how hard you pull, the rope can never be horizontal because it must exert an upward (vertical) component of force to balance the pack's weight.

5. (*c*) The boat accelerates forward by horizontal forces acting on the boat. The force that the man exerts on the paddles pushes the paddles forward, but because he is part of the boat this force does not accelerate the boat, so (*a*) is not correct. As the paddle pushes on the water it causes the water to accelerate backward. This force acts to accelerate the water, not the boat, so (*b*) is incorrect. By Newton's third law, as the paddles push the water backward, the water pushes the paddles (and thus the boat) forward. With the force of the water on the paddles pushing the boat forward, the boat would move even when the water was still, so (*d*) is also incorrect.

6. (*c*) The person's apparent weight is equal to the normal force acting on him. When the elevator is at rest or moving at constant velocity, the net force on the person is zero, so the normal force is equal to his weight. When the elevator is accelerating downward, the net force is also downward, so the normal force is less than his weight. When the elevator is accelerating upward, the net force is upward, and the normal force (his apparent weight) is greater than his weight. Since his actual weight does not change, his apparent weight is greatest when he is accelerating upward.

7. (*c*) The weight of the skier can be broken into components parallel to and perpendicular to the slope. The normal force will be equal to the perpendicular component of the skier's weight. For a nonzero slope, this component is always less than the weight of the skier.

8. (*b*) The force of the golf club acting on the ball acts only when the two objects are in contact, not as the ball flies through the air. The force of gravity acts on the ball throughout its flight. Air resistance is to be neglected, so there is no force acting on the ball due to its motion through the air.

9. (*c*) Since the net force is now zero, Newton's first law requires that the object will move in a straight line at constant speed. A net force would be needed to bring the object to rest.

10. (*d*) By Newton's third law, the force you exert on the box must be equal in magnitude to the force the box exerts on you. The box accelerates forward because the force you exert on the box is greater than other forces (such as friction) that are also exerted on the box.

11. (*b*) The maximum static friction force is 25 N. Since the applied force is less than this maximum, the crate will not accelerate, Newton's second law can be used to show that the resulting friction force will be equal in magnitude but opposite in direction to the applied force.

12. (*b*, *d*) The normal force between the skier and the snow is a contact force preventing the skier from passing through the surface of the snow. The normal force requires contact with the surface and an external net force toward the snow. The normal force does not depend upon the speed of the skier. Any slope less than 90° will have a component of gravity that must be overcome by the normal force.

13. (*a*) If the two forces pulled in the same direction, then the net force would be the maximum and equal to the sum of the two individual forces, or 950 N. Since the forces are not parallel, the net force will be less than this maximum.

Solutions to Problems

1. Use Newton's second law to calculate the force.

$$\sum F = ma = (55\text{ kg})(1.4\text{ m/s}^2) = \boxed{77\text{ N}}$$

2. In all cases, $W = mg,$ where g changes with location.

(*a*) $W_{\text{Earth}} = mg_{\text{Earth}} = (68\text{ kg})(9.80\text{ m/s}^2) = \boxed{670\text{ N}}$

(*b*) $W_{\text{Moon}} = mg_{\text{Moon}} = (68\text{ kg})(1.7\text{ m/s}^2) = \boxed{120\text{ N}}$

(*c*) $W_{\text{Mars}} = mg_{\text{Mars}} = (68\text{ kg})(3.7\text{ m/s}^2) = \boxed{250\text{ N}}$

(*d*) $W_{\text{space}} = mg_{\text{space}} = (68\text{ kg})(0) = \boxed{0}$

3. Use Newton's second law to calculate the tension.

$$\sum F = F_{\text{T}} = ma = (1210\text{ kg})(1.20\text{ m/s}^2) = 1452\text{ N} \approx \boxed{1450\text{ N}}$$

4. The average acceleration of the blood is given by $a = \dfrac{\upsilon - \upsilon_0}{t} = \dfrac{0.35\text{ m/s} - 0.25\text{ m/s}}{0.10\text{ s}} = 1.0\text{ m/s}^2.$

The net force on the blood, exerted by the heart, is found from Newton's second law.

$$F = ma = (20 \times 10^{-3}\text{ kg})(1.0\text{ m/s}^2) = \boxed{0.02\text{ N}}$$

5. Find the average acceleration from Eq. 2–11c, and then find the force needed from Newton's second law. We assume the train is moving in the positive direction.

$$\upsilon = 0 \qquad \upsilon_0 = (120\text{ km/h})\left(\frac{1\text{ m/s}}{3.6\text{ km/h}}\right) = 33.33\text{ m/s} \qquad a_{\text{avg}} = \frac{\upsilon^2 - \upsilon_0^2}{2(x - x_0)}$$

$$F_{\text{avg}} = ma_{\text{avg}} = m\frac{\upsilon^2 - \upsilon_0^2}{2(x - x_0)} = (3.6 \times 10^5\text{ kg})\left[\frac{0 - (33.33\text{ m/s})^2}{2\ (150\text{ m})}\right] = -1.333 \times 10^6\text{ N} \approx \boxed{-1.3 \times 10^6\text{ N}}$$

The negative sign indicates the direction of the force, in the opposite direction to the initial velocity.

We compare the magnitude of this force to the weight of the train.

$$\frac{F_{\text{avg}}}{mg}=\frac{1.333\times10^{6}\,\text{N}}{(3.6\times10^{5}\text{ kg})(9.80\text{ m/s}^2)}=0.3886$$

Thus the force is $\boxed{\text{39\% of the weight}}$ of the train.

By Newton's third law, the train exerts the same magnitude of force on Superman that Superman exerts on the train, but in the opposite direction. So the train exerts a force of $\boxed{1.3\times10^{6}\text{ N}}$ in the forward direction on Superman.

6. We assume that 30 g's has 2 significant figures. The acceleration of a person having a 30 "g" deceleration is $a=(30g)\left(\frac{9.80\text{ m/s}^2}{1g}\right)=294\text{ m/s}^2$. The average force causing that acceleration is $F=ma=(65\text{ kg})(294\text{ m/s}^2)=\boxed{1.9\times10^{4}\text{ N}}$. Since the person is undergoing a deceleration, the acceleration and force would both be directed opposite to the direction of motion. Use Eq. 2–11c to find the distance traveled during the deceleration. Take the initial velocity to be in the positive direction, so that the acceleration will have a negative value, and the final velocity will be 0.

$$\upsilon_0=(95\text{ km/h})\left(\frac{1\text{ m/s}}{3.6\text{ km/h}}\right)=26.39\text{ m/s}$$

$$\upsilon^2-\upsilon_0^2=2a(x-x_0)\quad\rightarrow\quad(x-x_0)=\frac{\upsilon^2-\upsilon_0^2}{2a}=\frac{0-(26.39\text{ m/s})^2}{2(-294\text{ m/s}^2)}=1.18\text{ m}\approx\boxed{1.2\text{ m}}$$

7. Find the average acceleration from Eq. 2–4. The average force on the car is found from Newton's second law.

$$\upsilon=0\quad\upsilon_0=(95\text{ km/h})\left(\frac{1\text{ m/s}}{3.6\text{ km/h}}\right)=26.39\text{ m/s}\quad a_{\text{avg}}=\frac{\upsilon-\upsilon_0}{t}=\frac{0-26.39\text{ m/s}}{8.0\text{ s}}=-3.299\text{ m/s}^2$$

$$F_{\text{avg}}=ma_{\text{avg}}=(950\text{ kg})(-3.299\text{ m/s}^2)=-3134\text{ N}\approx\boxed{-3100\text{ N}}$$

The negative sign indicates the direction of the force, in the opposite direction to the initial velocity.

8. Find the average acceleration from Eq. 2–11c, and then find the force needed from Newton's second law.

$$a_{\text{avg}}=\frac{\upsilon^2-\upsilon_0^2}{2(x-x_0)}\quad\rightarrow$$

$$F_{\text{avg}}=ma_{\text{avg}}=m\frac{\upsilon^2-\upsilon_0^2}{2(x-x_0)}=(7.0\text{ kg})\left[\frac{(13\text{ m/s})^2-0}{2\,(2.8\text{ m})}\right]=211.25\,\text{N}\approx\boxed{210\,\text{N}}$$

9. The problem asks for the average force on the glove, which in a direct calculation would require knowledge about the mass of the glove and the acceleration of the glove. But no information about the glove is given. By Newton's third law, the force exerted by the ball on the glove is equal and opposite

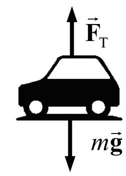
to the force exerted by the glove on the ball. So we calculate the average force on the ball, and then take the opposite of that result to find the average force on the glove. The average force on the ball is its mass times its average acceleration. Use Eq. 2–11c to find the acceleration of the ball, with $\upsilon = 0$, $\upsilon_0 = 35.0 \text{ m/s}$, and $x - x_0 = 0.110 \text{ m}$. The initial velocity of the ball is the positive direction.

$$a_{\text{avg}} = \frac{\upsilon^2 - \upsilon_0^2}{2(x - x_0)} = \frac{0 - (35.0 \text{ m/s})^2}{2(0.110 \text{ m})} = -5568 \text{ m/s}^2$$

$$F_{\text{avg}} = ma_{\text{avg}} = (0.140 \text{ kg})(-5568 \text{ m/s}^2) = -7.80 \times 10^2 \text{ N}$$

Thus the average force on the glove was $\boxed{\text{780 N, in the direction of the initial velocity of the ball.}}$

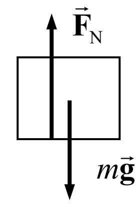
10. Choose up to be the positive direction. Write Newton's second law for the vertical direction, and solve for the tension force.



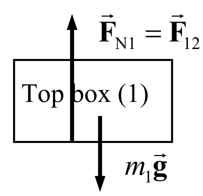
$$\sum F = F_T - mg = ma \quad \rightarrow \quad F_T = m(g + a)$$

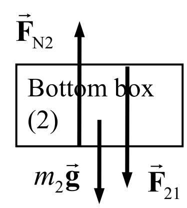
$$F_T = (1200 \text{ kg})(9.80 \text{ m/s}^2 + 0.70 \text{ m/s}^2) = \boxed{1.3 \times 10^4 \text{ N}}$$

11. (*a*) The 20.0-kg box resting on the table has the free-body diagram shown. Its weight is $mg = (20.0 \text{ kg})(9.80 \text{ m/s}^2) = \boxed{196 \text{ N}}$. Since the box is at rest, the net force on the box must be 0, so the normal force must also be $\boxed{196 \text{ N}}$.



(*b*) Free-body diagrams are shown for both boxes. $\vec{\mathbf{F}}_{12}$ is the force on box 1 (the top box) due to box 2 (the bottom box), and is the normal force on box 1. $\vec{\mathbf{F}}_{21}$ is the force on box 2 due to box 1, and has the same magnitude as $\vec{\mathbf{F}}_{12}$ by Newton's third law. $\vec{\mathbf{F}}_{N2}$ is the force of the table on box 2. That is the normal force on box 2. Since both boxes are at rest, the net force on each box must be 0. Write Newton's second law in the vertical direction for each box, taking the upward direction to be positive.





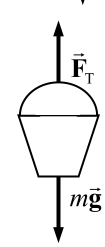
$$\sum F_1 = F_{N1} - m_1 g = 0$$

$$F_{N1} = m_1 g = (10.0 \text{ kg})(9.80 \text{ m/s}^2) = \boxed{98.0 \text{ N}} = F_{12} = F_{21}$$

$$\sum F_2 = F_{N2} - F_{21} - m_2 g = 0$$

$$F_{N2} = F_{21} + m_2 g = 98.0 \text{ N} + (20.0 \text{ kg})\left(9.80 \text{ m/s}^2\right) = \boxed{294 \text{ N}}$$

12. Choose up to be the positive direction. Write Newton's second law for the vertical direction, and solve for the acceleration.

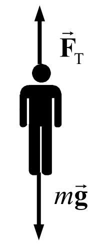


$$\sum F = F_T - mg = ma$$

$$a = \frac{F_T - mg}{m} = \frac{163 \text{ N} - (14.0 \text{ kg})(9.80 \text{ m/s}^2)}{14.0 \text{ kg}} = \boxed{1.8 \text{ m/s}^2}$$

Since the acceleration is positive, the bucket has an $\boxed{\text{upward}}$ acceleration.

13. If the thief were to hang motionless on the sheets, or descend at a constant speed, the sheets would not support him, because they would have to support the full 75 kg. But if he descends with an acceleration, the sheets will not have to support the total mass. A free-body diagram of the thief in descent is shown. If the sheets can support a mass of 58 kg, then the tension force that the sheets can exert is $F_T = (58 \text{ kg})(9.80 \text{ m/s}^2) = 568 \text{ N}$. Assume that is the tension in the sheets. Then write Newton's second law for the thief, taking the upward direction to be positive.

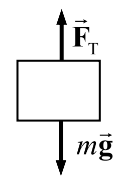


$$\sum F = F_T - mg = ma \quad \rightarrow \quad a = \frac{F_T - mg}{m} = \frac{568 \text{ N} - (75 \text{ kg})(9.80 \text{ m/s}^2)}{75 \text{ kg}} = -2.2 \text{ m/s}^2$$

The negative sign shows that the acceleration is downward.

$\boxed{\text{If the thief descends with an acceleration of } 2.2 \text{ m/s}^2 \text{ or greater, the sheets will support his descent.}}$

14. In both cases, a free-body diagram for the elevator would look like the adjacent diagram. Choose up to be the positive direction. To find the MAXIMUM tension, assume that the acceleration is up. Write Newton's second law for the elevator.



$$\sum F = ma = F_T - mg \quad \rightarrow$$
$$F_T = ma + mg = m(a+g) = m(0.0680g + g) = (4850 \text{ kg})(1.0680)(9.80 \text{ m/s}^2)$$
$$= \boxed{5.08 \times 10^4 \text{ N}}$$

To find the MINIMUM tension, assume that the acceleration is down. Then Newton's second law for the elevator becomes the following.

$$\sum F = ma = F_T - mg \quad \rightarrow \quad F_T = ma + mg = m(a+g) = m(-0.0680g + g)$$
$$= (4850 \text{ kg})(0.9320)(9.80 \text{ m/s}^2) = \boxed{4.43 \times 10^4 \text{ N}}$$

15. Use Eq. 2–11c to find the acceleration. The starting speed is $35 \text{ km/h}\left(\frac{1 \text{ m/s}}{3.6 \text{ km/h}}\right) = 9.72 \text{ m/s}$.

$$\upsilon^2 = \upsilon_0^2 + 2a(x - x_0) \quad \rightarrow \quad a = \frac{\upsilon^2 - \upsilon_0^2}{2(x - x_0)} = \frac{0 - (9.72 \text{ m/s})^2}{2(0.017 \text{ m})} = -2779 \text{ m/s}^2 \approx \boxed{-2800 \text{ m/s}^2}$$

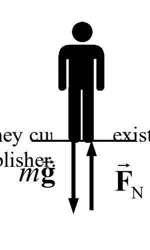
$$2779 \text{ m/s}^2 \left(\frac{1\, g}{9.80 \text{ m/s}^2}\right) = 284\ g\text{'s} \approx \boxed{280\ g\text{'s}}$$

The acceleration is negative because the car is slowing down. The required force is found by Newton's second law.

$$F = ma = (68 \text{ kg})(2779 \text{ m/s}^2) = \boxed{1.9 \times 10^5 \text{ N}}$$

This huge acceleration would not be possible unless the car hit some very heavy, stable object.

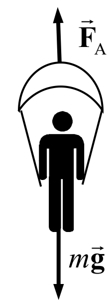
16. There will be two forces on the woman—her weight, and the normal force of the scales



pushing up on her. A free-body diagram for the woman is shown. Choose up to be the positive direction, and use Newton's second law to find the acceleration.

$$\sum F = F_N - mg = ma \quad \rightarrow \quad 0.75\,mg - mg = ma \quad \rightarrow$$
$$a = -0.25\,g = -0.25(9.8\text{ m/s}^2) = \boxed{-2.5\text{ m/s}^2}$$

Due to the sign of the result, the direction of the acceleration is $\boxed{\text{down.}}$ Thus the elevator must have started to move down since it had been motionless.



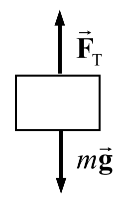
17. (*a*) There will be two forces on the sky divers—their combined weight and the upward force of air resistance, $\vec{\mathbf{F}}_A$. Choose up to be the positive direction. Write Newton's second law for the sky divers.

$$\sum F = F_A - mg = ma \quad \rightarrow \quad 0.25\,mg - mg = ma \quad \rightarrow$$
$$a = -0.75\,g = -0.75(9.80\text{ m/s}^2) = \boxed{-7.35\text{ m/s}^2}$$

Due to the sign of the result, the direction of the acceleration is down.

(*b*) If they are descending at constant speed, then the net force on them must be zero, so the force of air resistance must be equal to their weight.

$$F_A = mg = (132\text{ kg})(9.80\text{ m/s}^2) = \boxed{1290\text{ N}}$$



18. Choose UP to be the positive direction. Write Newton's second law for the elevator.

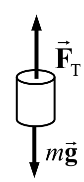
$$\sum F = F_T - mg = ma \quad \rightarrow$$
$$a = \frac{F_T - mg}{m} = \frac{21{,}750\text{ N} - (2125\text{ kg})(9.80\text{ m/s}^2)}{2125\text{ kg}} = 0.4353\text{ m/s}^2 \approx \boxed{0.44\text{ m/s}^2}$$

19. (*a*) Use Eq. 2–11c to find the speed of the person just before he strikes the ground. Take down to be the positive direction. For the person, $\upsilon_0 = 0$, $y - y_0 = 2.8$ m, and $a = 9.80\text{ m/s}^2$.

$$\upsilon^2 - \upsilon_0^2 = 2a(y - y_0) \rightarrow$$
$$\upsilon = \sqrt{2a(y - y_0)} = \sqrt{2(9.80\text{ m/s}^2)(2.8\text{ m})} = 7.408\text{ m/s} \approx \boxed{7.4\text{ m/s}}$$

(*b*) For the deceleration, use Eq. 2–11c to find the average deceleration, choosing down to be positive.

$$\upsilon_0 = 8.743\text{ m/s} \qquad \upsilon = 0 \qquad y - y_0 = 0.70\text{ m} \qquad \upsilon^2 - \upsilon_0^2 = 2a(y - y_0) \quad \rightarrow$$
$$a = \frac{-\upsilon_0^2}{2\Delta y} = \frac{-(7.408\text{ m/s})^2}{2(0.70\text{ m})} = -39.2\text{ m/s}^2$$

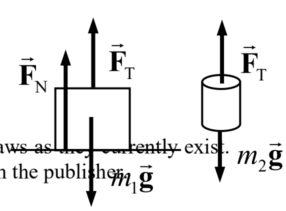


The average force on the torso (F_T) due to the legs is found from Newton's second law. See the free-body diagram. Down is positive.

$$F_{net} = mg - F_T = ma \quad \rightarrow$$
$$F_T = mg - ma = m(g - a) = (42\text{ kg})[9.80\text{ m/s}^2 - (-39.2\text{ m/s}^2)] = \boxed{2100\text{ N}}$$

The force is upward.

20. Free-body diagrams for the box and the weight are shown. The tension exerts



the same magnitude of force on both objects.

(*a*) If the weight of the hanging weight is less than the weight of the box, the objects will not move, and the tension will be the same as the weight of the hanging weight. The acceleration of the box will also be zero, so the sum of the forces on it will be zero. For the box,

$$F_N + F_T - m_1 g = 0 \quad \rightarrow \quad F_N = m_1 g - F_T = m_1 g - m_2 g = 77.0\ \text{N} - 30.0\ \text{N} = \boxed{47.0\ \text{N}}$$

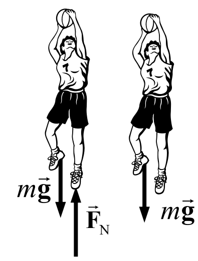
(*b*) The same analysis as for part (*a*) applies here.

$$F_N = m_1 g - m_2 g = 77.0\ \text{N} - 60.0\ \text{N} = \boxed{17.0\ \text{N}}$$

(*c*) Since the hanging weight has more weight than the box on the table, the box on the table will be lifted up off the table, and normal force of the table on the box will be $\boxed{0}$.

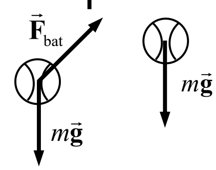
21. (*a*) Just before the player leaves the ground, the forces on the player are his weight and the floor pushing up on the player. If the player jumps straight up, then the force of the floor will be straight up—a normal force. See the first diagram. In this case, while touching the floor, $F_N > mg$.

(*b*) While the player is in the air, the only force on the player is his weight. See the second diagram.

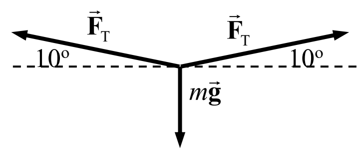


22. (*a*) Just as the ball is being hit, if we ignore air resistance, there are two main forces on the ball: the weight of the ball and the force of the bat on the ball.

(*b*) As the ball flies toward the outfield, the only force on it is its weight, if air resistance is ignored.



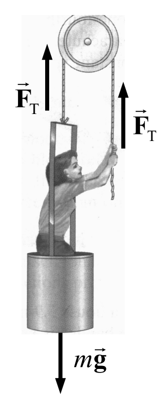
$\boxed{23.}$ Consider the point in the rope directly below Arlene. That point can be analyzed as having three forces on it—Arlene's weight, the tension in the rope toward the right point of connection, and the tension in the rope toward the left point of connection. Assuming the rope is massless, those two tensions will be of the same magnitude. Since the point is not accelerating, the sum of the forces must be zero. In particular, consider the sum of the vertical forces on that point, with UP as the positive direction.



$$\sum F = F_T \sin 10.0^\circ + F_T \sin 10.0^\circ - mg = 0 \quad \rightarrow$$

$$F_T = \frac{mg}{2 \sin 10.0^\circ} = \frac{(50.0\ \text{kg})(9.80\ \text{m/s}^2)}{2 \sin 10.0^\circ} = \boxed{1410\ \text{N}}$$

24. The window washer pulls down on the rope with her hands with a tension force F_T, so the rope pulls up on her hands with a tension force F_T. The tension in the rope is also applied at the other end of the rope, where it attaches to the bucket. Thus there is another force F_T pulling up on the bucket. The bucket–washer combination thus has a net force of $2F_T$ upward. See the adjacent free-body diagram, showing only forces on the bucket–washer combination, not forces exerted by the combination (the pull down on the rope by the person) or internal forces (normal force of bucket on person).



(*a*) Write Newton's second law in the vertical direction, with up as positive. The net force must be zero if the bucket and washer have a constant speed.

$$\sum F = F_{\text{T}} + F_{\text{T}} - mg = 0 \rightarrow 2F_{\text{T}} = mg \rightarrow$$

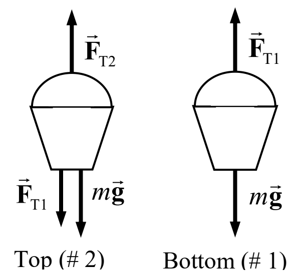
$$F_{\text{T}} = \frac{1}{2}mg = \frac{1}{2}(72\text{ kg})(9.80\text{ m/s}^2) = 352.8\text{ N} \approx \boxed{350\text{ N}}$$

(*b*) Now the force is increased by 15%, so $F_{\text{T}} = 358.2\text{ N}(1.15) = 405.72\text{ N}$. Again write Newton's second law, but with a nonzero acceleration.

$$\sum F = F_{\text{T}} + F_{\text{T}} - mg = ma \quad \rightarrow$$

$$a = \frac{2F_{\text{T}} - mg}{m} = \frac{2(405.72\text{ N}) - (72\text{ kg})(9.80\text{ m/s}^2)}{72\text{ kg}} = 1.47\text{ m/s}^2 \approx \boxed{1.5\text{ m/s}^2}$$

$\boxed{25.}$ We draw free-body diagrams for each bucket.



(*a*) Since the buckets are at rest, their acceleration is 0. Write Newton's second law for each bucket, calling UP the positive direction.

$$\sum F_1 = F_{\text{T1}} - mg = 0 \quad \rightarrow$$

$$F_{\text{T1}} = mg = (3.2\text{ kg})(9.80\text{ m/s}^2) = \boxed{31\text{ N}}$$

$$\sum F_2 = F_{\text{T2}} - F_{\text{T1}} - mg = 0 \quad \rightarrow$$

$$F_{\text{T2}} = F_{\text{T1}} + mg = 2\,mg = 2(3.2\text{ kg})(9.80\text{ m/s}^2) = \boxed{63\text{ N}}$$

(*b*) Now repeat the analysis, but with a nonzero acceleration. The free-body diagrams are unchanged.

$$\sum F_1 = F_{\text{T1}} - mg = ma \quad \rightarrow$$

$$F_{\text{T1}} = mg + ma = (3.2\text{ kg})(9.80\text{ m/s}^2 + 1.25\text{ m/s}^2) = 35.36\text{ N} \approx \boxed{35\text{ N}}$$

$$\sum F_2 = F_{\text{T2}} - F_{\text{T1}} - mg = ma \quad \rightarrow \quad F_{\text{T2}} = F_{\text{T1}} + mg + ma = 2F_{\text{T1}} = \boxed{71\text{ N}}$$

26. Choose the *y* direction to be the "forward" direction for the motion of the snowcats and the *x* direction to be to the right on the diagram in the textbook. Since the housing unit moves in the forward direction on a straight line, there is no acceleration in the *x* direction, so the net force in the *x* direction must be 0. Write Newton's second law for the *x* direction.

$$\sum F_x = F_{\text{A}x} + F_{\text{B}x} = 0 \quad \rightarrow \quad -F_{\text{A}}\sin 48^\circ + F_{\text{B}}\sin 32^\circ = 0 \quad \rightarrow$$

$$F_{\text{B}} = \frac{F_{\text{A}}\sin 48^\circ}{\sin 32^\circ} = \frac{(4500\text{ N})\sin 48^\circ}{\sin 32^\circ} = 6311\text{ N} \approx \boxed{6300\text{ N}}$$

Since the *x* components add to 0, the magnitude of the vector sum of the two forces will just be the sum of their *y* components.

$$\sum F_y = F_{\text{A}y} + F_{\text{B}y} = F_{\text{A}}\cos 48^\circ + F_{\text{B}}\cos 32^\circ = (4500\text{ N})\cos 48^\circ + (6311\text{ N})\cos 32^\circ$$

$$= 8363\text{ N} \approx \boxed{8400\text{ N}}$$

27. Since all forces of interest in this problem are horizontal, draw the free-body diagram showing only the horizontal forces. $\vec{\mathbf{F}}_{\text{T1}}$ is the tension in the coupling between the locomotive and the first car, and it pulls to the right on the first car. $\vec{\mathbf{F}}_{\text{T2}}$ is the tension in the coupling between the first car and the second car. It pulls to the right on car 2, labeled $\vec{\mathbf{F}}_{\text{T2R}}$ and to the left on car 1, labeled $\vec{\mathbf{F}}_{\text{T2L}}$. Both cars have the same mass *m* and the same acceleration *a*. Note that $|\vec{\mathbf{F}}_{\text{T2R}}| = |\vec{\mathbf{F}}_{\text{T2L}}| = F_{\text{T2}}$ by Newton's third law.

Write a Newton's second law expression for each car.

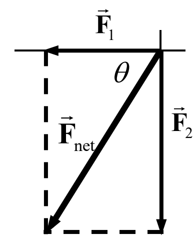
$$\sum F_1 = F_{T1} - F_{T2} = ma \qquad \sum F_2 = F_{T2} = ma$$

Substitute the expression for ma from the second expression into the first one.

$$F_{T1} - F_{T2} = ma = F_{T2} \;\rightarrow\; F_{T1} = 2F_{T2} \;\rightarrow\; \boxed{F_{T1}/F_{T2} = 2}$$

This can also be discussed in the sense that the tension between the locomotive and the first car is pulling two cars, while the tension between the cars is only pulling one car.

28. The net force in each case is found by vector addition with components.



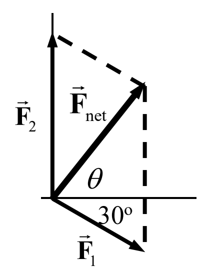
(*a*) $F_{\text{net}\,x} = -F_1 = -10.2\text{ N} \qquad F_{\text{net}\,y} = -F_2 = -16.0\text{ N}$

$$F_{\text{net}} = \sqrt{(-10.2)^2 + (-16.0)^2} = 19.0\text{ N} \qquad \theta = \tan^{-1}\frac{-16.0}{-10.2} = 57.48^\circ$$

The actual angle from the x axis is then 237.48°. Thus the net force is

$$F_{\text{net}} = \boxed{19.0\text{ N at }237^\circ}$$

$$a = \frac{F_{\text{net}}}{m} = \frac{19.0\text{ N}}{18.5\text{ kg}} = \boxed{1.03\text{ m/s}^2\text{ at }237^\circ}$$

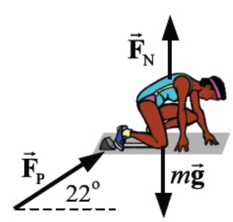


(*b*) $F_{\text{net}\,x} = F_1 \cos 30^\circ = 8.833\text{ N} \qquad F_{\text{net}\,y} = F_2 - F_1 \sin 30^\circ = 10.9\text{ N}$

$$F_{\text{net}} = \sqrt{(8.833\text{ N})^2 + (10.9\text{ N})^2} = 14.03\text{N} \approx \boxed{14.0\text{ N}}$$

$$\theta = \tan^{-1}\frac{10.9}{8.833} = \boxed{51.0^\circ} \qquad a = \frac{F_{\text{net}}}{m} = \frac{14.03\text{ N}}{18.5\text{ kg}} = \boxed{0.758\text{ m/s}^2\text{ at }51.0^\circ}$$

29. Since the sprinter exerts a force of 720 N on the ground at an angle of 22° below the horizontal, by Newton's third law the ground will exert a force of 720 N on the sprinter at an angle of 22° above the horizontal. A free-body diagram for the sprinter is shown.



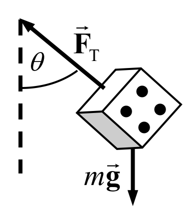
(*a*) The horizontal acceleration will be found from the net horizontal force. Using Newton's second law, we have the following:

$$\sum F_x = F_P \cos 22^\circ = ma_x \;\rightarrow$$

$$a_x = \frac{F_P \cos 22^\circ}{m} = \frac{(720\text{ N})\cos 22^\circ}{65\text{ kg}} = 10.27\text{ m/s}^2 \approx \boxed{1.0\times 10^1\text{ m/s}^2}$$

(*b*) Eq. 2–11a is used to find the final speed. The starting speed is 0.

$$\upsilon = \upsilon_0 + at \;\rightarrow\; \upsilon = 0 + at = (10.27\text{ m/s}^2)(0.32\text{ s}) = 3.286\text{ m/s} \approx \boxed{3.3\text{ m/s}}$$



30. (*a*) Consider a free-body diagram of the object. The car is moving to the right (the positive direction) and slowing down. Thus the acceleration and the net force are to the left. The acceleration of the object is found from Eq. 2–11a.

$$\upsilon = \upsilon_0 + = a_x t \quad \rightarrow \quad a_x = \frac{\upsilon - \upsilon_0}{t} = \frac{0 - 25\text{ m/s}}{6.0\text{ s}} = -4.17\text{ m/s}^2$$

Now write Newton's second law for both the vertical (y) and horizontal (x) directions.

$$\sum F_y = F_\text{T}\cos\theta - mg = 0 \quad \rightarrow \quad F_\text{T} = \frac{mg}{\cos\theta} \qquad \sum F_x = -F_\text{T}\sin\theta = ma_x$$

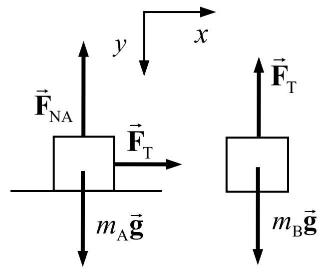
Substitute the expression for the tension from the y equation into the x equation.

$$ma_x = -F_\text{T}\sin\theta = -\frac{mg}{\cos\theta}\sin\theta = -mg\tan\theta \quad \rightarrow \quad a_x = -g\tan\theta$$

$$\theta = \tan^{-1}\frac{-a_x}{g} = \tan^{-1}\frac{4.17\text{ m/s}^2}{9.80\text{ m/s}^2} = \boxed{23^\circ}$$

(*b*) The angle is $\boxed{\text{toward}}$ the windshield.

31. (*a*) See the free-body diagrams included.



(*b*) For block A, since there is no motion in the vertical direction, we have $F_\text{NA} = m_\text{A}g$. We write Newton's second law for the x direction: $\sum F_{\text{A}x} = F_\text{T} = m_\text{A}a_{\text{A}x}$. For block B, we only need to consider vertical forces: $\sum F_{\text{B}y} = m_\text{B}g - F_\text{T} = m_\text{B}a_{\text{B}y}$. Since the two blocks are connected, the magnitudes of their accelerations will be the same, so let $a_{\text{A}x} = a_{\text{B}y} = a$. Combine the two force equations from above, and solve for a by substitution.

$$F_\text{T} = m_\text{A}a \qquad m_\text{B}g - F_\text{T} = m_\text{B}a \quad \rightarrow \quad m_\text{B}g - m_\text{A}a = m_\text{B}a \quad \rightarrow$$

$$m_\text{A}a + m_\text{B}a = m_\text{B}g \quad \rightarrow \quad \boxed{a = g\frac{m_\text{B}}{m_\text{A} + m_\text{B}} \qquad F_\text{T} = m_\text{A}a = g\frac{m_\text{A}m_\text{B}}{m_\text{A} + m_\text{B}}}$$

32. (*a*) From Problem 32, we have the acceleration of each block. Both blocks have the same acceleration.

$$a = g\frac{m_\text{B}}{m_\text{A} + m_\text{B}} = (9.80\text{ m/s}^2)\frac{5.0\text{ kg}}{(5.0\text{ kg} + 13.0\text{ kg})} = 2.722\text{ m/s}^2 \approx \boxed{2.7\text{ m/s}^2}$$

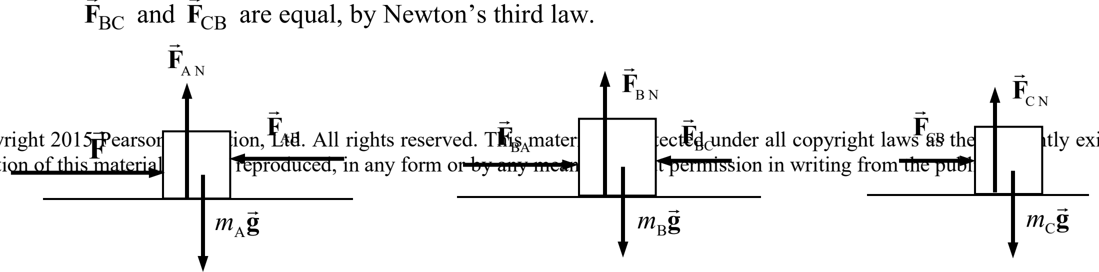
(*b*) Use Eq. 2–11b to find the time.

$$x - x_0 = \upsilon_0 t + \tfrac{1}{2}at^2 \quad \rightarrow \quad t = \sqrt{\frac{2(x - x_0)}{a}} = \sqrt{\frac{2(1.250\text{ m})}{(2.722\text{ m/s}^2)}} = \boxed{0.96\text{ s}}$$

(*c*) Again use the acceleration from Problem 32.

$$a = g\frac{m_\text{B}}{m_\text{A} + m_\text{B}} = \tfrac{1}{100}g \quad \rightarrow \quad \frac{m_\text{B}}{m_\text{A} + m_\text{B}} = \tfrac{1}{100} \quad \rightarrow \quad m_\text{A} = 99m_\text{B} = \boxed{99\text{ kg}}$$

33. (*a*) In the free-body diagrams below, $\vec{\mathbf{F}}_\text{AB}$ = force on block A exerted by block B, $\vec{\mathbf{F}}_\text{BA}$ = force on block B exerted by block A, $\vec{\mathbf{F}}_\text{BC}$ = force on block B exerted by block C, and $\vec{\mathbf{F}}_\text{CB}$ = force on block C exerted by block B. The magnitudes of $\vec{\mathbf{F}}_\text{BA}$ and $\vec{\mathbf{F}}_\text{AB}$ are equal, and the magnitudes of $\vec{\mathbf{F}}_\text{BC}$ and $\vec{\mathbf{F}}_\text{CB}$ are equal, by Newton's third law.



(*b*) All of the vertical forces on each block add up to zero, since there is no acceleration in the vertical direction. Thus, for each block, $F_N = mg$. For the horizontal direction, we have the following:

$$\sum F = F - F_{AB} + F_{BA} - F_{BC} + F_{CB} = F = (m_A + m_B + m_C)a \rightarrow \boxed{a = \frac{F}{m_A + m_B + m_C}}$$

(*c*) For each block, the net force must be ma by Newton's second law. Each block has the same acceleration since the blocks are in contact with each other.

$$\boxed{F_{A\,net} = F\frac{m_A}{m_A + m_B + m_C}} \qquad \boxed{F_{B\,net} = F\frac{m_B}{m_A + m_B + m_C}} \qquad \boxed{F_{C\,net} = F\frac{m_C}{m_A + m_B + m_C}}$$

(*d*) From the free-body diagram, we see that for m_C, $F_{CB} = F_{C\,net} = \boxed{F\frac{m_C}{m_A + m_B + m_C}}$. And by Newton's third law, $F_{BC} = F_{CB} = \boxed{F\frac{m_C}{m_A + m_B + m_C}}$. Of course, $\vec{\mathbf{F}}_{23}$ and $\vec{\mathbf{F}}_{32}$ are in opposite directions. Also from the free-body diagram, we use the net force on m_A.

$$F - F_{AB} = F_{A\,net} = F\frac{m_A}{m_A + m_B + m_C} \rightarrow F_{AB} = F - F\frac{m_A}{m_A + m_B + m_C} \rightarrow$$

$$\boxed{F_{AB} = F\frac{m_B + m_C}{m_A + m_B + m_C}}$$

By Newton's third law, $F_{BA} = F_{AB} = \boxed{F\frac{m_B + m_C}{m_A + m_B + m_C}}$.

(*e*) Using the given values, $a = \frac{F}{m_A + m_B + m_C} = \frac{96.0\text{ N}}{30.0\text{ kg}} = \boxed{3.20\text{ m/s}^2}$. Since all three masses are the same value, the net force on each mass is $F_{net} = ma = (10.0\text{ kg})(3.20\text{ m/s}^2) = 32.0\text{ N}$. This is also the value of F_{CB} and F_{BC}. The value of F_{AB} and F_{BA} is found as follows:

$$F_{AB} = F_{BA} = (m_B + m_C)a = (20.0\text{ kg})(3.20\text{ m/s}^2) = 64.0\text{ N}$$

To summarize:

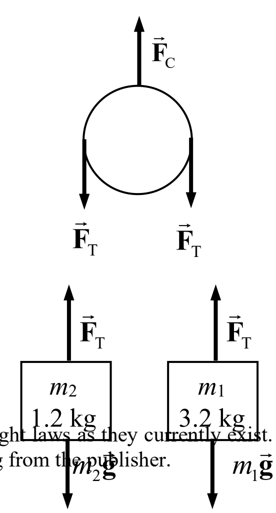
$$F_{A\,net} = F_{B\,net} = F_{C\,net} = \boxed{32.0\text{ N}} \qquad F_{AB} = F_{BA} = \boxed{64.0\text{ N}} \qquad F_{BC} = F_{CB} = \boxed{32.0\text{ N}}$$

The values make sense in that in order of magnitude, we should have $F > F_{BA} > F_{CB}$, since F is the net force pushing the entire set of blocks, F_{AB} is the net force pushing the right two blocks, and F_{BC} is the net force pushing the right block only.

$\boxed{34.}$ We draw a free-body diagram for each mass. We choose up to be the positive direction. The tension force in the cord is found from analyzing the two hanging masses. Notice that the same tension force is applied to each mass. Write Newton's second law for each of the masses.

$$F_T - m_1 g = m_1 a_1 \qquad F_T - m_2 g = m_2 a_2$$

Since the masses are joined together by the cord, their accelerations will have the same magnitude but opposite directions. Thus $a_1 = -a_2$. Substitute this into the force expressions and solve for the tension force.



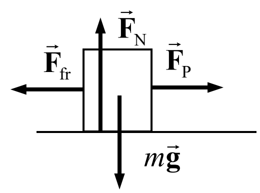
$$F_T - m_1 g = -m_1 a_2 \quad \to \quad F_T = m_1 g - m_1 a_2 \quad \to \quad a_2 = \frac{m_1 g - F_T}{m_1}$$

$$F_T - m_2 g = m_2 a_2 = m_2 \left(\frac{m_1 g - F_T}{m_1} \right) \quad \to \quad F_T = \frac{2 m_1 m_2 g}{m_1 + m_2}$$

Apply Newton's second law to the stationary pulley.

$$F_C - 2F_T = 0 \quad \to \quad F_C = 2F_T = \frac{4 m_1 m_2 g}{m_1 + m_2} = \frac{4(3.2\ \text{kg})(1.2\ \text{kg})(9.80\ \text{m/s}^2)}{4.4\ \text{kg}} = \boxed{34\ \text{N}}$$

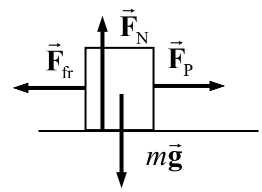
35. A free-body diagram for the crate is shown. The crate does not accelerate vertically, so $F_N = mg$. The crate does not accelerate horizontally, so $F_P = F_{fr}$.



$$F_P = F_{fr} = \mu_k F_N = \mu_k mg = (0.30)(22\ \text{kg})(9.80\ \text{m/s}^2) = \boxed{65\ \text{N}}$$

If the coefficient of kinetic friction is zero, then the horizontal force required is $\boxed{0}$, since there is no friction to counteract. Of course, it would take a force to START the crate moving, but once it was moving, no further horizontal force would be necessary to maintain the motion.

36. A free-body diagram for the box is shown. Since the box does not accelerate vertically, $F_N = mg$.



(*a*) To start the box moving, the pulling force must just overcome the force of static friction, and that means the force of static friction will reach its maximum value of $F_{fr} = \mu_s F_N$. Thus, we have for the starting motion,

$$\sum F_x = F_P - F_{fr} = 0 \quad \to$$

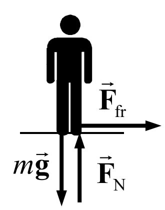
$$F_P = F_{fr} = \mu_s F_N = \mu_s mg \quad \to \quad \mu_s = \frac{F_P}{mg} = \frac{35.0\ \text{N}}{(6.0\ \text{kg})(9.80\ \text{m/s}^2)} = \boxed{0.60}$$

(*b*) The same force diagram applies, but now the friction is kinetic friction, and the pulling force is NOT equal to the frictional force, since the box is accelerating to the right.

$$\sum F = F_P - F_{fr} = ma \quad \to \quad F_P - \mu_k F_N = ma \quad \to \quad F_P - \mu_k mg = ma \quad \to$$

$$\mu_k = \frac{F_P - ma}{mg} = \frac{35.0\ \text{N} - (6.0\ \text{kg})(0.60\ \text{m/s}^2)}{(6.0\ \text{kg})(9.80\ \text{m/s}^2)} = \boxed{0.53}$$

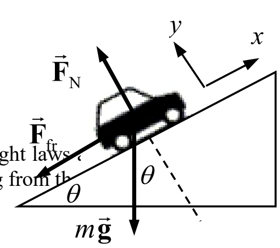
37. A free-body diagram for you as you stand on the train is shown. You do not accelerate vertically, so $F_N = mg$. The maximum static frictional force is $\mu_s F_N$, and that must be greater than or equal to the force needed to accelerate you in order for you not to slip.



$$F_{fr} \geq ma \quad \to \quad \mu_s F_N \geq ma \quad \to \quad \mu_s mg \geq ma \quad \to \quad \mu_s \geq a/\cancel{g} = 0.20\cancel{g}/\cancel{g} = \boxed{0.20}$$

The static coefficient of friction must be at least 0.20 for you not to slide.

38. See the adjacent free-body diagram. To find the maximum angle, assume that the car is just ready to slide, so that the force of static friction is a

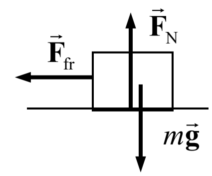


maximum. Write Newton's second law for both directions. Note that for both directions, the net force must be zero since the car is not accelerating.

$$\sum F_y = F_N - mg\cos\theta = 0 \;\rightarrow\; F_N = mg\cos\theta$$
$$\sum F_x = mg\sin\theta - F_{fr} = 0 \;\rightarrow\; mg\sin\theta = F_{fr} = \mu_s F_N = \mu_s mg\cos\theta$$

$$\mu_s = \frac{mg\sin\theta}{mg\cos\theta} = \tan\theta = 0.90 \;\rightarrow\; \theta = \tan^{-1}0.90 = \boxed{42^\circ}$$

39. The force of static friction is what decelerates the crate if it is not sliding on the truck bed. If the crate is not to slide, but the maximum deceleration is desired, then the maximum static frictional force must be exerted, so $F_{fr} = \mu_s F_N$. The direction of travel is to the right. It is apparent that $F_N = mg$ since there is no acceleration in the y direction. Write Newton's second law for the truck in the horizontal direction.



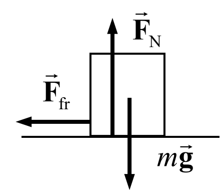
$$\sum F_x = -F_{fr} = ma \;\rightarrow\; -\mu_s mg = ma \;\rightarrow\; a = -\mu_s g = -(0.75)(9.80\text{ m/s}^2) = \boxed{-7.4\text{ m/s}^2}$$

The negative sign indicates the direction of the acceleration, as opposite to the direction of motion.

40. Since the drawer moves with the applied force of 9.0 N, we assume that the maximum static frictional force is essentially 9.0 N. This force is equal to the coefficient of static friction times the normal force. The normal force is assumed to be equal to the weight, since the drawer is horizontal.

$$F_{fr} = \mu_s F_N = \mu_s mg \;\rightarrow\; \mu_s = \frac{F_{fr}}{mg} = \frac{9.0\text{ N}}{(2.0\text{ kg})(9.80\text{ m/s}^2)} = \boxed{0.46}$$

41. A free-body diagram for the box is shown, assuming that it is moving to the right. The "push" is not shown on the free-body diagram because as soon as the box moves away from the source of the pushing force, the push is no longer applied to the box. It is apparent from the diagram that $F_N = mg$ for the vertical direction. We write Newton's second law for the horizontal direction, with positive to the right, to find the acceleration of the box.

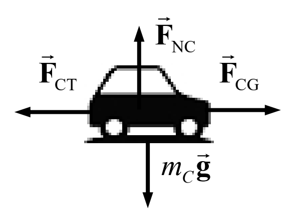


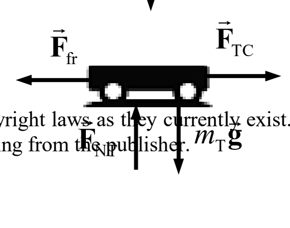
$$\sum F_x = -F_{fr} = ma \;\rightarrow\; ma = -\mu_k F_N = -\mu_k mg \;\rightarrow$$
$$a = -\mu_k g = -0.15(9.80\text{ m/s}^2) = -1.47\text{ m/s}^2$$

Eq. 2–11c can be used to find the distance that the box moves before stopping. The initial speed is 4.0 m/s, and the final speed will be 0.

$$\upsilon^2 - \upsilon_0^2 = 2a(x - x_0) \;\rightarrow\; x - x_0 = \frac{\upsilon^2 - \upsilon_0^2}{2a} = \frac{0 - (3.5\text{ m/s})^2}{2(-1.47\text{ m/s}^2)} = 4.17\text{ m} \approx \boxed{4.2\text{ m}}$$

42. We draw three free-body diagrams—one for the car, one for the trailer, and then "add" them for the combination of car and trailer. Note that since the car pushes against the ground, the ground will push against the car with an equal but oppositely directed force. $\vec{F}_{CG}$ is the force on the car due to the ground, $\vec{F}_{TC}$ is the force on the trailer due to the car, and $\vec{F}_{CT}$ is the force

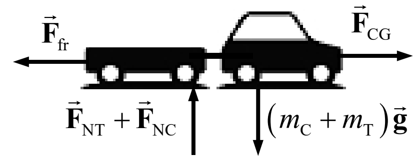




on the car due to the trailer. Note that by Newton's third law, $|\vec{\mathbf{F}}_{\text{CT}}| = |\vec{\mathbf{F}}_{\text{TC}}|$.

From consideration of the vertical forces in the individual free-body diagrams, it is apparent that the normal force on each object is equal to its weight. This leads to the conclusion that

$$F_{\text{fr}} = \mu_{\text{k}} F_{\text{NT}} = \mu_{\text{k}} m_{\text{T}} g = (0.15)(350\ \text{kg})(9.80\ \text{m/s}^2) = 514.5\ \text{N}.$$



Now consider the combined free-body diagram. Write Newton's second law for the horizontal direction. This allows the calculation of the acceleration of the system.

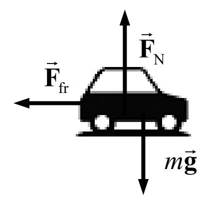
$$\sum F = F_{\text{CG}} - F_{\text{fr}} = (m_{\text{C}} + m_{\text{T}})a \quad \rightarrow \quad a = \frac{F_{\text{CG}} - F_{\text{fr}}}{m_{\text{C}} + m_{\text{T}}} = \frac{3600\ \text{N} - 514.5\ \text{N}}{1630\ \text{kg}} = 1.893\ \text{m/s}^2$$

Finally, consider the free-body diagram for the trailer alone. Again write Newton's second law for the horizontal direction, and solve for F_{TC}.

$$\sum F = F_{\text{TC}} - F_{\text{fr}} = m_{\text{T}} a \quad \rightarrow$$

$$F_{\text{TC}} = F_{\text{fr}} + m_{\text{T}} a = 514.5\ \text{N} + (350\ \text{kg})(1.893\ \text{m/s}^2) = 1177\ \text{N} \approx \boxed{1200\ \text{N}}$$

43. Assume that kinetic friction is the net force causing the deceleration. See the free-body diagram for the car, assuming that the right is the positive direction and the direction of motion of the skidding car. There is no acceleration in the vertical direction, so $F_{\text{N}} = mg$. Applying Newton's second law to the x direction gives the following.



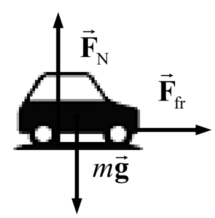
$$\sum F = -F_{\text{f}} = ma \quad \rightarrow \quad -\mu_{\text{k}} F_{\text{N}} = -\mu_{\text{k}} mg = ma \quad \rightarrow \quad a = -\mu_{\text{k}} g$$

Use Eq. 2–11c to determine the initial speed of the car, with the final speed of the car being zero.

$$\upsilon^2 - \upsilon_0^2 = 2a(x - x_0) \quad \rightarrow$$

$$\upsilon_0 = \sqrt{\upsilon^2 - 2a(x - x_0)} = \sqrt{0 - 2(-\mu_{\text{k}} g)(x - x_0)} = \sqrt{2(0.80)(9.80\ \text{m/s}^2)(72\ \text{m})} = \boxed{34\ \text{m/s}}$$

44. Assume that the static frictional force is the only force accelerating the racer. Then consider the free-body diagram for the racer as shown. It is apparent that the normal force is equal to the weight, since there is no vertical acceleration. It is also assumed that the static frictional force is at its maximum. Thus



$$F_{\text{fr}} = ma \quad \rightarrow \quad \mu_{\text{s}} mg = ma \quad \rightarrow \quad \mu_{\text{s}} = a/g.$$

The acceleration of the racer can be calculated from Eq. 2–11b, with an initial speed of 0.

$$x - x_0 = \upsilon_0 t + \tfrac{1}{2} a t^2 \quad \rightarrow \quad a = 2(x - x_0)/t^2$$

$$\mu_{\text{s}} = \frac{a}{g} = \frac{2(x - x_0)}{g t^2} = \frac{2(1000\ \text{m})}{(9.80\ \text{m/s}^2)(12\ \text{s})^2} = \boxed{1.4}$$

45. The analysis of the blocks at rest can be done exactly the same as that presented in Example 4–20, up to the equation for the acceleration, $a = \dfrac{m_B g - F_{fr}}{m_A + m_B}$. Now, for the stationary case, the force of friction is static friction. To find the minimum value of m_A, we assume the maximum static frictional force. Thus $a = \dfrac{m_B g - \mu_s m_A g}{m_A + m_B}$. Finally, for the system to stay at rest, the acceleration must be zero. Thus

$$m_B g - \mu_s m_A g = 0 \quad \rightarrow \quad m_A = m_B / \mu_s = 2.0 \text{ kg}/0.30 = \boxed{6.7 \text{ kg}}$$

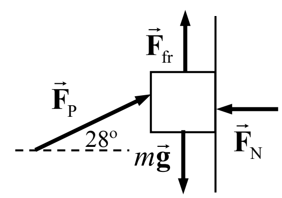
46. (*a*) For m_B not to move, the tension must be equal to $m_B g$, so $m_B g = F_T$. For m_A not to move, the tension must be equal to the force of static friction, so $F_{fr} = F_T$. Note that the normal force on m_A is equal to its weight. Use these relationships to solve for m_A.

$$m_B g = F_T = F_{fr} \le \mu_s m_A g \quad \rightarrow \quad m_A \ge \frac{m_B}{\mu_s} = \frac{2.0 \text{ kg}}{0.40} = 5.0 \text{ kg} \quad \rightarrow \quad m_A \ge \boxed{5.0 \text{ kg}}$$

(*b*) For m_B to move with constant velocity, the tension must be equal to $m_B g$. For m_A to move with constant velocity, the tension must be equal to the force of kinetic friction. Note that the normal force on m_A is equal to its weight. Use these relationships to solve for m_A.

$$m_B g = F_{fr} = \mu_k m_A g \quad \rightarrow \quad m_A = \frac{m_B}{\mu_k} = \frac{2.0 \text{ kg}}{0.20} = \boxed{10 \text{ kg}} \text{(2 significant figures)}$$

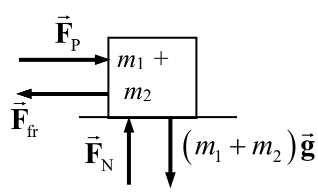
47. Consider a free-body diagram for the box, showing force on the box. When $F_P = 23\,\text{N}$, the block does not move. Thus in that case, the force of friction is static friction, and must be at its maximum value, given by $F_{fr} = \mu_s F_N$. Write Newton's second law in both the *x* and *y* directions. The net force in each case must be 0, since the block is at rest.



$$\sum F_x = F_P \cos\theta - F_N = 0 \quad \rightarrow \quad F_N = F_P \cos\theta$$
$$\sum F_y = F_{fr} + F_P \sin\theta - mg = 0 \quad \rightarrow \quad F_{fr} + F_P \sin\theta = mg$$
$$\mu_s F_N + F_P \sin\theta = mg \quad \rightarrow \quad \mu_s F_P \cos\theta + F_P \sin\theta = mg$$

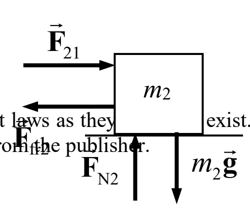
$$m = \frac{F_P}{g}(\mu_s \cos\theta + \sin\theta) = \frac{23 \text{ N}}{9.80 \text{ m/s}^2}(0.40 \cos 28^\circ + \sin 28^\circ) = \boxed{1.9 \text{ kg}}$$

48. (*a*) Since the two blocks are in contact, they can be treated as a single object as long as no information is needed about internal forces (like the force of one block pushing on the other block). Since there is no motion in the vertical direction, it is apparent that $F_N = (m_1 + m_2)g$, so $F_{fr} = \mu_k F_N = \mu_k (m_1 + m_2)g$. Write Newton's second law for the horizontal direction.



$$\sum F_x = F_P - F_{fr} = (m_1 + m_2)a \quad \rightarrow$$
$$a = \frac{F_P - F_{fr}}{m_1 + m_2} = \frac{F_P - \mu_k (m_1 + m_2)g}{m_1 + m_2} = \frac{650 \text{ N} - (0.18)(190 \text{ kg})(9.80 \text{ m/s}^2)}{190 \text{ kg}}$$
$$= 1.657 \text{ m/s}^2 \approx \boxed{1.7 \text{ m/s}^2}$$

(*b*) To solve for the contact forces between the blocks, an individual block

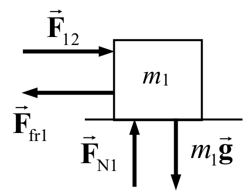


must be analyzed. Look at the free-body diagram for the second block. $\vec{\mathbf{F}}_{21}$ is the force of the first block pushing on the second block. Again, it is apparent that $F_{\mathrm{N2}} = m_2 g$, so $F_{\mathrm{fr2}} = \mu_{\mathrm{k}} F_{\mathrm{N2}} = \mu_{\mathrm{k}} m_2 g$. Write Newton's second law for the horizontal direction.

$$\sum F_x = F_{21} - F_{\mathrm{fr2}} = m_2 a \quad \rightarrow$$

$$F_{21} = \mu_{\mathrm{k}} m_2 g + m_2 a = (0.18)(125\text{ kg})(9.80\text{ m/s}^2) + (125\text{ kg})(1.657\text{ m/s}^2) = \boxed{430\text{ N}}$$

By Newton's third law, there will also be a 430-N force to the left on block # 1 due to block # 2.

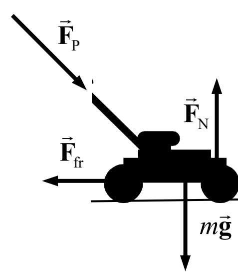


(*c*) If the crates are reversed, the acceleration of the system will remain the same—the analysis from part (*a*) still applies. We can also repeat the analysis from part (*b*) to find the force of one block on the other, if we simply change m_1 to m_2 in the free-body diagram and the resulting equations.

$$a = \boxed{1.7\text{ m/s}^2}; \ \sum F_x = F_{12} - F_{\mathrm{fr1}} = m_1 a \quad \rightarrow$$

$$F_{12} = \mu_{\mathrm{k}} m_1 g + m_1 a = (0.18)(65\text{ kg})(9.80\text{ m/s}^2) + (65\text{ kg})(1.657\text{ m/s}^2) = \boxed{220\text{ N}}$$

49. (*a*) We assume that the mower is being pushed to the right. $\vec{\mathbf{F}}_{\mathrm{fr}}$ is the friction force, and $\vec{\mathbf{F}}_{\mathrm{p}}$ is the pushing force along the handle.



(*b*) Write Newton's second law for the horizontal direction. The forces must sum to 0 since the mower is not accelerating.

$$\sum F_x = F_{\mathrm{p}} \cos 45.0° - F_{\mathrm{fr}} = 0 \quad \rightarrow$$

$$F_{\mathrm{fr}} = F_{\mathrm{p}} \cos 45.0° = (88.0\text{ N}) \cos 45.0° = \boxed{62.2\text{ N}}$$

(*c*) Write Newton's second law for the vertical direction. The forces must sum to 0 since the mower is not accelerating in the vertical direction.

$$\sum F_y = F_{\mathrm{N}} - mg - F_{\mathrm{p}} \sin 45.0° = 0 \quad \rightarrow$$

$$F_{\mathrm{N}} = mg + F_{\mathrm{p}} \sin 45° = (14.0\text{ kg})(9.80\text{ m/s}^2) + (88.0\text{ N}) \sin 45.0° = \boxed{199\text{ N}}$$

(*d*) First use Eq. 2–11a to find the acceleration.

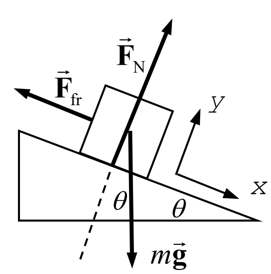
$$\upsilon - \upsilon_0 = at \quad \rightarrow \quad a = \frac{\upsilon - \upsilon_0}{t} = \frac{1.5\text{ m/s} - 0}{2.5\text{ s}} = 0.60\text{ m/s}^2$$

Now use Newton's second law for the *x* direction to find the necessary pushing force.

$$\sum F_x = F_{\mathrm{p}} \cos 45.0° - F_{\mathrm{f}} = ma \quad \rightarrow$$

$$F_{\mathrm{p}} = \frac{F_{\mathrm{f}} + ma}{\cos 45.0°} = \frac{62.2\text{ N} + (14.0\text{ kg})(0.60\text{ m/s}^2)}{\cos 45.0°} = \boxed{99.9\text{ N}}$$

50. A free-body diagram for the bar of soap is shown. There is no motion in the *y* direction and thus no acceleration in the *y* direction. Write Newton's second law for both directions, and use those expressions to find the acceleration of the soap.

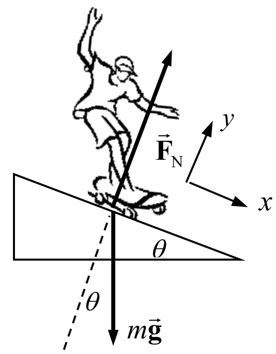


$$\sum F_y = F_N - mg\cos\theta = 0 \quad \rightarrow \quad F_N = mg\cos\theta$$
$$\sum F_x = mg\sin\theta - F_{fr} = ma$$
$$ma = mg\sin\theta - \mu_k F_N = mg\sin\theta - \mu_k mg\cos\theta$$
$$a = g(\sin\theta - \mu_k\cos\theta)$$

Now use Eq. 2–11b, with an initial velocity of 0, to find the final velocity.

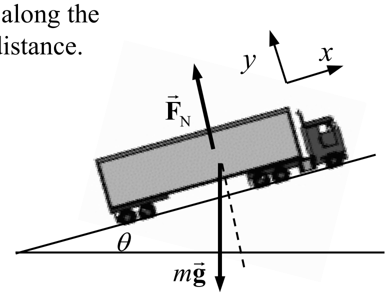
$$x = x_0 + \upsilon_0 t + \tfrac{1}{2}at^2 \quad \rightarrow$$
$$t = \sqrt{\frac{2x}{a}} = \sqrt{\frac{2x}{g(\sin\theta - \mu_k\cos\theta)}} = \sqrt{\frac{2(9.0\text{ m})}{(9.80\text{ m/s}^2)(\sin 8.0^\circ - (0.060)\cos 8.0^\circ)}} = \boxed{4.8\text{ s}}$$

51. From the free-body diagram, the net force along the plane on the skateboarder is $mg\sin\theta$, so the acceleration along the plane is $g\sin\theta$. We use the kinematical data and Eq. 2–11b to write an equation for the acceleration, and then solve for the angle.



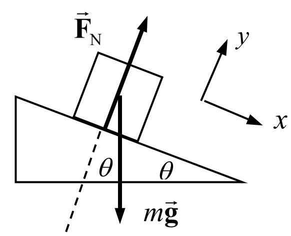
$$x - x_0 = \upsilon_0 t + \tfrac{1}{2}at^2 = \upsilon_0 t + \tfrac{1}{2}gt^2\sin\theta \quad \rightarrow$$
$$\theta = \sin^{-1}\left(\frac{2\Delta x - \upsilon_0 t}{gt^2}\right) = \sin^{-1}\left(\frac{2(18\text{ m}) - 2(2.0\text{ m/s})(3.3\text{ s})}{(9.80\text{ m/s}^2)(3.3\text{ s})^2}\right) = \boxed{12^\circ}$$

52. For a simple ramp, the decelerating force is the component of gravity along the ramp. See the free-body diagram, and use Eq. 2–11c to calculate the distance.



$$\sum F_x = -mg\sin\theta = ma \quad \rightarrow \quad a = -g\sin\theta$$
$$x - x_0 = \frac{\upsilon^2 - \upsilon_0^2}{2a} = \frac{0 - \upsilon_0^2}{2(-g\sin\theta)} = \frac{\upsilon_0^2}{2g\sin\theta}$$
$$= \frac{\left[(140\text{ km/h})\left(\dfrac{1\text{ m/s}}{3.6\text{ km/h}}\right)\right]^2}{2(9.80\text{ m/s}^2)\sin 11^\circ} = \boxed{4.0\times 10^2\text{ m}}$$

53. (*a*) Consider the free-body diagram for the block on the frictionless surface. There is no acceleration in the *y* direction. Use Newton's second law for the *x* direction to find the acceleration.



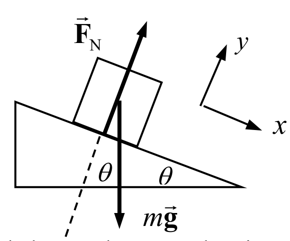
$$\sum F_x = mg\sin\theta = ma \quad \rightarrow$$
$$a = g\sin\theta = (9.80\text{ m/s}^2)\sin 22.0^\circ = \boxed{3.67\text{ m/s}^2}$$

(*b*) Use Eq. 2–11c with $\upsilon_0 = 0$ to find the final speed.

$$\upsilon^2 - \upsilon_0^2 = 2a(x - x_0) \quad \rightarrow \quad \upsilon = \sqrt{2a(x - x_0)} = \sqrt{2(3.67\text{ m/s}^2)(12.0\text{ m})} = \boxed{9.39\text{ m/s}}$$

54. (*a*) Consider the free-body diagram for the block on the frictionless surface. There is no acceleration in the *y* direction. Write Newton's second law for the *x* direction.

$$\sum F_x = mg\sin\theta = ma \quad \rightarrow \quad a = g\sin\theta$$



Use Eq. 2–11c with $\upsilon_0 = -4.5\text{ m/s}$ and $\upsilon = 0$ to find the distance that it slides before stopping.

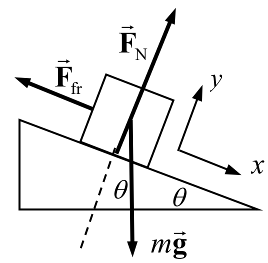
$$\upsilon^2 - \upsilon_0^2 = 2a(x - x_0) \quad \rightarrow$$

$$(x - x_0) = \frac{\upsilon^2 - \upsilon_0^2}{2a} = \frac{0 - (-4.5\text{ m/s})^2}{2(9.80\text{ m/s}^2)\sin 22.0^\circ} = -2.758\text{ m} \approx \boxed{2.8\text{ m up the plane}}$$

(*b*) The time for a round trip can be found from Eq. 2–11a. The free-body diagram (and thus the acceleration) is the same whether the block is rising or falling. For the entire trip, $\upsilon_0 = -4.5\text{ m/s}$ and $\upsilon = +4.5\text{ m/s}$.

$$\upsilon = \upsilon_0 + at \quad \rightarrow \quad t = \frac{\upsilon - \upsilon_0}{a} = \frac{(4.5\text{ m/s}) - (-4.5\text{ m/s})}{(9.80\text{ m/s}^2)\sin 22^\circ} = 2.452\text{ s} \approx \boxed{2.5\text{ s}}$$

55. (*a*) Consider the free-body diagram for the crate on the surface. There is no motion in the *y* direction and thus no acceleration in the *y* direction. Write Newton's second law for both directions.



$$\sum F_y = F_{\mathrm{N}} - mg\cos\theta = 0 \quad \rightarrow \quad F_{\mathrm{N}} = mg\cos\theta$$

$$\sum F_x = mg\sin\theta - F_{\mathrm{fr}} = ma$$

$$ma = mg\sin\theta - \mu_{\mathrm{k}}F_{\mathrm{N}} = mg\sin\theta - \mu_{\mathrm{k}}mg\cos\theta$$

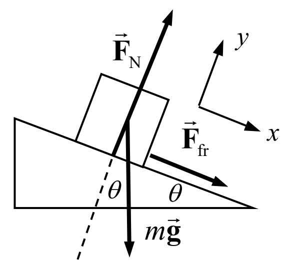
$$a = g(\sin\theta - \mu_{\mathrm{k}}\cos\theta)$$

$$= (9.80\text{ m/s}^2)(\sin 25.0^\circ - 0.19\cos 25.0^\circ) = 2.454\text{ m/s}^2 \approx \boxed{2.5\text{ m/s}^2}$$

(*b*) Now use Eq. 2–11c, with an initial velocity of 0, to find the final velocity.

$$\upsilon^2 - \upsilon_0^2 = 2a(x - x_0) \quad \rightarrow \quad \upsilon = \sqrt{2a(x - x_0)} = \sqrt{2(2.454\text{ m/s}^2)(8.15\text{ m})} = \boxed{6.3\text{ m/s}}$$

56. (*a*) Consider the free-body diagram for the crate on the surface. There is no acceleration in the *y* direction. Write Newton's second law for both directions, and find the acceleration.



$$\sum F_y = F_{\mathrm{N}} - mg\cos\theta = 0 \quad \rightarrow \quad F_{\mathrm{N}} = mg\cos\theta$$

$$\sum F_x = mg\sin\theta + F_{\mathrm{fr}} = ma$$

$$ma = mg\sin\theta + \mu_{\mathrm{k}}F_{\mathrm{N}} = mg\sin\theta + \mu_{\mathrm{k}}mg\cos\theta$$

$$a = g(\sin\theta + \mu_{\mathrm{k}}\cos\theta)$$

Now use Eq. 2–11c, with an initial velocity of -3.0 m/s and a final velocity of 0 to find the distance the crate travels up the plane.

$$\upsilon^2 - \upsilon_0^2 = 2a(x - x_0) \quad \rightarrow$$

$$x - x_0 = \frac{-\upsilon_0^2}{2a} = \frac{-(-3.0\text{ m/s})^2}{2(9.80\text{ m/s}^2)(\sin 25.0^\circ + 0.12\cos 25.0^\circ)} = -0.864\text{ m}$$

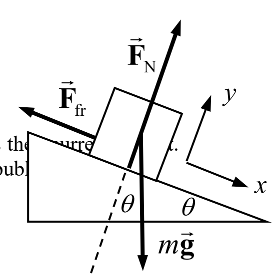
The crate travels $\boxed{0.86\text{ m}}$ up the plane.

(*b*) We use the acceleration found above with the initial velocity in Eq. 2–11a to find the time for the crate to travel up the plane.

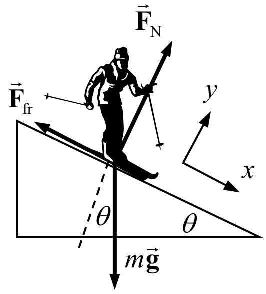
$$\upsilon = \upsilon_0 + at \quad \rightarrow \quad t_{\mathrm{up}} = 2\,\frac{\upsilon_0}{a_{\mathrm{up}}} = -\frac{(-3.0\text{ m/s})}{(9.80\text{ m/s}^2)(\sin 25.0^\circ + 0.12\cos 25.0^\circ)} = 0.5761\text{ s}$$

The total time is NOT just twice the time to travel up the plane, because the acceleration of the block is different for the two parts of the motion.

The second free-body diagram applies to the block sliding down the plane. A



similar analysis will give the acceleration, and then Eq. 2–11b with an initial velocity of 0 is used to find the time to move down the plane.



$$\sum F_y = F_{\mathrm{N}} - mg\cos\theta = 0 \quad\rightarrow\quad F_{\mathrm{N}} = mg\cos\theta$$

$$\sum F_x = mg\sin\theta - F_{\mathrm{fr}} = ma$$

$$ma = mg\sin\theta - \mu_{\mathrm{k}}F_{\mathrm{N}} = mg\sin\theta - \mu_{\mathrm{k}}mg\cos\theta$$

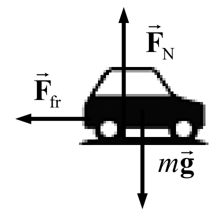
$$a = g(\sin\theta - \mu_{\mathrm{k}}\cos\theta)$$

$$x - x_0 = \upsilon_0 t + \tfrac{1}{2}at^2 \quad\rightarrow$$

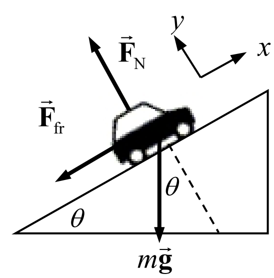
$$t_{\mathrm{down}} = \sqrt{\frac{2(x-x_0)}{a_{\mathrm{down}}}} = \sqrt{\frac{2(0.864\ \mathrm{m})}{(9.80\ \mathrm{m/s^2})(\sin 25.0^\circ - 0.12\cos 25.0^\circ)}} =$$

$$t = t_{\mathrm{up}} + t_{\mathrm{down}} = 0.5761\ \mathrm{s} + 0.7495\ \mathrm{s} = 1.3256\ \mathrm{s} \approx \boxed{1.33\ \mathrm{s}}$$

It is worth noting that the final speed is about 2.3 m/s, significantly less than the 3.0 m/s original speed.



57. The direction of travel for the car is to the right, and that is also the positive horizontal direction. Using the free-body diagram, write Newton's second law in the x direction for the car on the level road. We assume that the car is just on the verge of skidding, so that the magnitude of the friction force is $F_{\mathrm{fr}} = \mu_{\mathrm{s}}F_{\mathrm{N}}$.



$$\sum F_x = -F_{\mathrm{fr}} = ma \qquad F_{\mathrm{fr}} = -ma = -\mu_{\mathrm{s}}mg \quad\rightarrow\quad \mu_{\mathrm{s}} = \frac{a}{g} = \frac{3.80\ \mathrm{m/s^2}}{9.80\ \mathrm{m/s^2}} = 0.38$$

Now put the car on an inclined plane. Newton's second law in the x-direction for the car on the plane is used to find the acceleration. We again assume the car is on the verge of slipping, so the static frictional force is at its maximum.

$$\sum F_x = -F_{\mathrm{fr}} - mg\sin\theta = ma \quad\rightarrow$$

$$a = \frac{-F_{\mathrm{fr}} - mg\sin\theta}{m} = \frac{-\mu_{\mathrm{s}}mg\cos\theta - mg\sin\theta}{m} = -g(\mu_{\mathrm{s}}\cos\theta + \sin\theta)$$

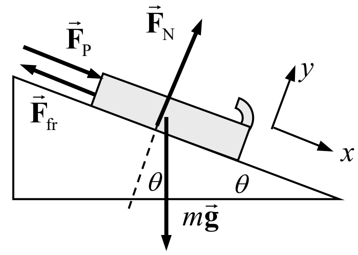
$$= -(9.80\ \mathrm{m/s^2})(0.3878\cos 9.3^\circ + \sin 9.3^\circ) = \boxed{-5.3\ \mathrm{m/s^2}}$$

58. Since the skier is moving at a constant speed, the net force on the skier must be 0. See the free-body diagram, and write Newton's second law for both the x and y directions.

$$mg\sin\theta = F_{\mathrm{fr}} = \mu_{\mathrm{s}}F_{\mathrm{N}} = \mu_{\mathrm{s}}mg\cos\theta \quad\rightarrow$$

$$\mu_{\mathrm{s}} = \tan\theta = \tan 12^\circ = \boxed{0.21}$$

59. A free-body diagram for the bobsled is shown. The acceleration of the sled is found from Eq. 2–11c. The final velocity also needs to be converted to m/s.



$$\upsilon = (60 \text{ km/h})\left(\frac{1 \text{ m/s}}{3.6 \text{ km/h}}\right) = 16.667 \text{ m/s}$$

$$\upsilon^2 - \upsilon_0^2 = 2a_x(x - x_0) \quad \rightarrow$$

$$a_x = \frac{\upsilon^2 - \upsilon_0^2}{2(x - x_0)} = \frac{(16.667 \text{ m/s})^2 - 0}{2(75 \text{ m})} = 1.852 \text{ m/s}^2$$

Now write Newton's second law for both directions. Since the sled does not accelerate in the y direction, the net force on the y direction must be 0. Then solve for the pushing force.

$$\sum F_y = F_N - mg \cos\theta = 0 \quad \rightarrow \quad F_N = mg \cos\theta$$

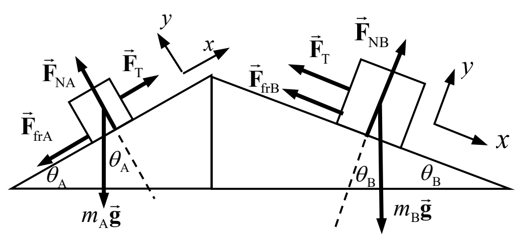
$$\sum F_x = mg \sin\theta + F_P - F_{fr} = ma_x$$

$$F_P = ma_x - mg \sin\theta + F_{fr} = ma_x - mg \sin\theta + \mu_k F_N$$

$$= ma_x - mg \sin\theta + \mu_k mg \cos\theta = m[a_x + g(\mu_k \cos\theta - \sin\theta)]$$

$$= (22 \text{ kg})[1.852 \text{ m/s}^2 + (9.80 \text{ m/s}^2)(0.10 \cos 6.0° - \sin 6.0°)] = 39.6 \text{ N} \approx \boxed{40 \text{ N}}$$

60. We define the positive x direction to be the direction of motion for each block. See the free-body diagrams. Write Newton's second law in both dimensions for both objects. Add the two x equations to find the acceleration.



Block A:

$$\sum F_{yA} = F_{NA} - m_A g \cos\theta_A = 0 \rightarrow F_{NA} = m_A g \cos\theta_A$$

$$\sum F_{xA} = F_T - m_A g \sin\theta - F_{frA} = m_A a$$

Block B:

$$\sum F_{yB} = F_{NB} - m_B g \cos\theta_B = 0 \quad \rightarrow \quad F_{NB} = m_B g \cos\theta_B$$

$$\sum F_{xB} = m_B g \sin\theta_B - F_{frB} - F_T = m_B a$$

Add the final equations together from both analyses and solve for the acceleration, noting that in both cases the friction force is found as $F_{fr} = \mu F_N$.

$$m_A a = F_T - m_A g \sin\theta_A - \mu_A m_A g \cos\theta_A; \quad m_B a = m_B g \sin\theta_B - \mu_B m_B g \cos\theta_B - F_T$$

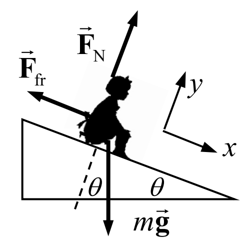
$$m_A a + m_B a = F_T - m_A g \sin\theta_A - \mu_A m_A g \cos\theta_A + m_B g \sin\theta_B - \mu_B m_B g \cos\theta_B - F_T \quad \rightarrow$$

$$a = g\left[\frac{-m_A(\sin\theta_A + \mu_A \cos\theta_A) + m_B(\sin\theta_B - \mu_B \cos\theta_B)}{(m_A + m_B)}\right]$$

$$= (9.80 \text{ m/s}^2)\left[\frac{-(2.0 \text{ kg})(\sin 51° + 0.30 \cos 51°) + (5.0 \text{ kg})(\sin 21° - 0.30 \cos 21°)}{(7.0 \text{ kg})}\right]$$

$$= \boxed{-2.2 \text{ m/s}^2}$$

61. We assume that the child starts from rest at the top of the slide, and then slides a distance $x - x_0$ along the slide. A force diagram is shown for the child on the slide. First, ignore the frictional force and consider the no-friction case. All of the motion is in the x direction, so we will only consider Newton's second law for the x direction.



$$\sum F_x = mg \sin\theta = ma \quad \rightarrow \quad a = g\sin\theta$$

Use Eq. 2–11c to calculate the speed at the bottom of the slide.

$$\upsilon^2 - \upsilon_0^2 = 2a(x - x_0) \quad \rightarrow \quad \upsilon_{(\text{No friction})} = \sqrt{\upsilon_0^2 + 2a(x - x_0)} = \sqrt{2g\sin\theta(x - x_0)}$$

Now include kinetic friction. We must consider Newton's second law in both the x and y directions now. The net force in the y direction must be 0 since there is no acceleration in the y direction.

$$\sum F_y = F_{\mathrm{N}} - mg\cos\theta = 0 \quad \rightarrow \quad F_{\mathrm{N}} = mg\cos\theta$$
$$\sum F_x = ma = mg\sin\theta - F_{\mathrm{fr}} = mg\sin\theta - \mu_{\mathrm{k}}F_{\mathrm{N}} = mg\sin\theta - \mu_{\mathrm{k}}mg\cos\theta$$
$$a = \frac{mg\sin\theta - \mu_{\mathrm{k}}mg\cos\theta}{m} = g(\sin\theta - \mu_{\mathrm{k}}\cos\theta)$$

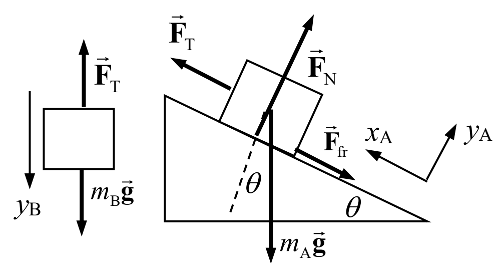
With this acceleration, we can again use Eq. 2–11c to find the speed after sliding a certain distance.

$$\upsilon^2 - \upsilon_0^2 = 2a(x - x_0) \quad \rightarrow \quad \upsilon_{(\text{friction})} = \sqrt{\upsilon_0^2 + 2a(x - x_0)} = \sqrt{2g(\sin\theta - \mu_{\mathrm{k}}\cos\theta)(x - x_0)}$$

Now let the speed with friction be half the speed without friction, and solve for the coefficient of friction. Square the resulting equation and divide by $g\cos\theta$ to get the result.

$$\upsilon_{(\text{friction})} = \frac{1}{2}\upsilon_{(\text{No friction})} \quad \rightarrow \quad \sqrt{2g(\sin\theta - \mu_{\mathrm{k}}\cos\theta)(x - x_0)} = \frac{1}{2}\sqrt{2g(\sin\theta)(x - x_0)}$$
$$2g(\sin\theta - \mu_{\mathrm{k}}\cos\theta)(x - x_0) = \frac{1}{4}2g(\sin\theta)(x - x_0)$$
$$\mu_{\mathrm{k}} = \frac{3}{4}\tan\theta = \frac{3}{4}\tan 34^\circ = \boxed{0.51}$$

$\boxed{62.}$ (*a*) Given that m_{B} is moving down, m_{A} must be moving up the incline, so the force of kinetic friction on m_{A} will be directed down the incline. Since the blocks are tied together, they will both have the same acceleration, so $a_{y\mathrm{B}} = a_{x\mathrm{A}} = a$. Write Newton's second law for each mass.



$$\sum F_{y\mathrm{B}} = m_{\mathrm{B}}g - F_{\mathrm{T}} = m_{\mathrm{B}}a \quad \rightarrow \quad F_{\mathrm{T}} = m_{\mathrm{B}}g - m_{\mathrm{B}}a$$
$$\sum F_{x\mathrm{A}} = F_{\mathrm{T}} - m_{\mathrm{A}}g\sin\theta - F_{\mathrm{fr}} = m_{\mathrm{A}}a$$
$$\sum F_{y\mathrm{A}} = F_{\mathrm{N}} - m_{\mathrm{A}}g\cos\theta = 0 \quad \rightarrow \quad F_{\mathrm{N}} = m_{\mathrm{A}}g\cos\theta$$

Take the information from the two y equations and substitute into the x equation to solve for the acceleration.

$$m_{\mathrm{B}}g - m_{\mathrm{B}}a - m_{\mathrm{A}}g\sin\theta - \mu_{\mathrm{k}}m_{\mathrm{A}}g\cos\theta = m_{\mathrm{A}}a \quad \rightarrow$$

$$a = \frac{m_{\mathrm{B}}g - m_{\mathrm{A}}g\sin\theta - m_{\mathrm{A}}g\mu_{\mathrm{k}}\cos\theta}{(m_{\mathrm{A}} + m_{\mathrm{B}})} = \tfrac{1}{2}g\,(1 - \sin\theta - \mu_{\mathrm{k}}\cos\theta)$$

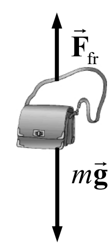
$$= \tfrac{1}{2}(9.80\ \mathrm{m/s^2})(1 - \sin 34° - 0.15\cos 34°) = \boxed{1.6\ \mathrm{m/s^2}}$$

(*b*) To have an acceleration of zero, the expression for the acceleration must be zero.

$$a = \tfrac{1}{2}g(1 - \sin\theta - \mu_{\mathrm{k}}\cos\theta) = 0 \quad \rightarrow \quad 1 - \sin\theta - \mu_{\mathrm{k}}\cos\theta = 0 \quad \rightarrow$$

$$\mu_{\mathrm{k}} = \frac{1 - \sin\theta}{\cos\theta} = \frac{1 - \sin 34°}{\cos 34°} = \boxed{0.53}$$

63. See the free-body diagram for the falling purse. Assume that down is the positive direction, and that the air resistance force $\vec{\mathbf{F}}_{\mathrm{fr}}$ is constant. Write Newton's second law for the vertical direction.



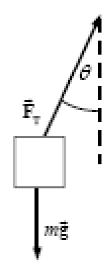
$$\sum F = mg - F_{\mathrm{fr}} = ma \quad \rightarrow \quad F_{\mathrm{fr}} = m(g - a)$$

Now obtain an expression for the acceleration from Eq. 2–11c with $\upsilon_0 = 0$, and substitute back into the friction force.

$$\upsilon^2 - \upsilon_0^2 = 2a(x - x_0) \quad \rightarrow \quad a = \frac{\upsilon^2}{2(x - x_0)}$$

$$F_{\mathrm{fr}} = m\left(g - \frac{\upsilon^2}{2(x - x_0)}\right) = (2.0\ \mathrm{kg})\left(9.80\ \mathrm{m/s^2} - \frac{(27\ \mathrm{m/s})^2}{2(55\ \mathrm{m})}\right) = \boxed{6.3\ \mathrm{N}}$$

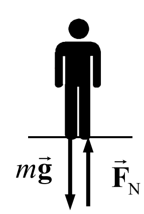
64. See the free-body diagram for the load. The vertical component of the tension force must be equal to the weight of the load, and the horizontal component of the tension accelerates the load. The angle is exaggerated in the picture.



$$F_{\underset{x}{\mathrm{net}}} = F_{\mathrm{T}}\sin\theta = ma \quad \rightarrow \quad a = \frac{F_{\mathrm{T}}\sin\theta}{m}; \quad F_{\underset{y}{\mathrm{net}}} = F_{\mathrm{T}}\cos\theta - mg = 0 \quad \rightarrow$$

$$F_{\mathrm{T}} = \frac{mg}{\cos\theta} \quad \rightarrow \quad a_{\mathrm{H}} = \frac{mg}{\cos\theta}\frac{\sin\theta}{m} = g\tan\theta = (9.80\ \mathrm{m/s^2})\tan 5.0° = \boxed{0.86\ \mathrm{m/s^2}}$$

65. A free-body diagram for the person in the elevator is shown. The scale reading is the magnitude of the normal force. Choosing up to be the positive direction, Newton's second law for the person says that $\sum F = F_{\mathrm{N}} - mg = ma \rightarrow F_{\mathrm{N}} = m(g + a)$. The kilogram reading of the scale is the apparent weight, F_{N}, divided by g, which gives $F_{\mathrm{N\text{-}kg}} = \frac{F_{\mathrm{N}}}{g} = \frac{m(g + a)}{g}$.



(*a*) $a = 0 \quad \rightarrow \quad F_{\mathrm{N}} = mg = (75.0\ \mathrm{kg})(9.80\ \mathrm{m/s^2}) = \boxed{7.35 \times 10^2\ \mathrm{N}}$

$$F_{\mathrm{N\text{-}kg}} = \frac{mg}{g} = m = \boxed{75.0\ \mathrm{kg}}$$

(*b*) $a = 0 \quad \rightarrow \quad F_{\mathrm{N}} = \boxed{7.35 \times 10^2\ \mathrm{N}},\ F_{\mathrm{N\text{-}kg}} = \boxed{75.0\ \mathrm{kg}}$

(*c*) $a = 0 \rightarrow F_N = \boxed{7.35 \times 10^2\text{ N}}, F_{\text{N-kg}} = \boxed{75.0\text{ kg}}$

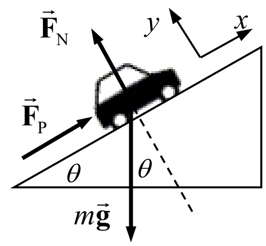
(*d*) $F_N = m(g + a) = (75.0\text{ kg})(9.80\text{ m/s}^2 + 3.0\text{ m/s}^2) = \boxed{9.60 \times 10^2\text{ N}}$

$$F_{\text{N-kg}} = \frac{F_N}{g} = \frac{960\text{ N}}{9.80\text{ m/s}^2} = \boxed{98.0\text{ kg}}$$

(*e*) $F_N = m(g + a) = (75.0\text{ kg})(9.80\text{ m/s}^2 - 3.0\text{ m/s}^2) = \boxed{5.1 \times 10^2\text{ N}}$

$$F_{\text{N-kg}} = \frac{F_N}{g} = \frac{510\text{ N}}{9.80\text{ m/s}^2} = \boxed{52\text{ kg}}$$

66. The given data can be used to calculate the force with which the road pushes against the car, which in turn is equal in magnitude to the force the car pushes against the road. The acceleration of the car on level ground is found from Eq. 2–11a.



$$\upsilon - \upsilon_0 = at \rightarrow a = \frac{\upsilon - \upsilon_0}{t} = \frac{21\text{ m/s} - 0}{12.5\text{ s}} = 1.68\text{ m/s}^2$$

The force pushing the car in order to have this acceleration is found from Newton's second law.

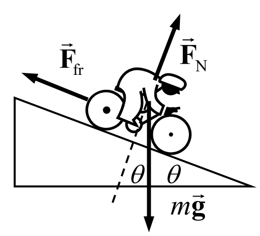
$$F_P = ma = (920\text{ kg})(1.68\text{ m/s}^2) = 1546\text{ N}$$

We assume that this is the force pushing the car on the incline as well. Consider a free-body diagram for the car climbing the hill. We assume that the car will have a constant speed on the maximum incline. Write Newton's second law for the *x* direction, with a net force of zero since the car is not accelerating.

$$\sum F_x = F_P - mg\sin\theta = 0 \rightarrow \sin\theta = \frac{F_P}{mg}$$

$$\theta = \sin^{-1}\frac{F_P}{mg} = \sin^{-1}\frac{1546\text{ N}}{(920\text{ kg})(9.80\text{ m/s}^2)} = \boxed{9.9^\circ}$$

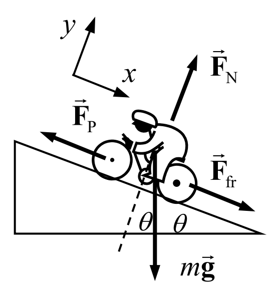
67. Consider a free-body diagram for the cyclist coasting downhill at a constant speed. Since there is no acceleration, the net force in each direction must be zero. Write Newton's second law for the *x* direction (down the plane).



$$\sum F_x = mg\sin\theta - F_{fr} = 0 \rightarrow F_{fr} = mg\sin\theta$$

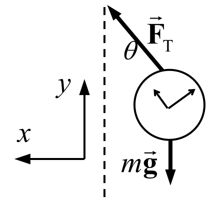
This establishes the size of the air friction force at 6.0 km/h, which can be used in the next part.

Now consider a free-body diagram for the cyclist climbing the hill. F_P is the force pushing the cyclist uphill. Again, write Newton's second law for the *x* direction, with a net force of 0.



$$\sum F_x = F_{fr} + mg\sin\theta - F_P = 0 \rightarrow$$
$$F_P = F_{fr} + mg\sin\theta = 2mg\sin\theta$$
$$= 2(65\text{ kg})(9.80\text{ m/s}^2)(\sin 6.5^\circ) = \boxed{140\text{ N}}$$

68. Consider the free-body diagram for the watch. Write Newton's second law for both the x and y directions. Note that the net force in the y direction is 0 because there is no acceleration in the y direction.



$$\sum F_y = F_\mathrm{T} \cos\theta - mg = 0 \quad\rightarrow\quad F_\mathrm{T} = \frac{mg}{\cos\theta}$$

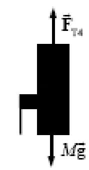
$$\sum F_x = F_\mathrm{T} \sin\theta = ma \quad\rightarrow\quad \frac{mg}{\cos\theta}\sin\theta = ma$$

$$a = g\tan\theta = (9.80\ \mathrm{m/s^2})\tan 25^\circ = 4.57\ \mathrm{m/s^2}$$

Use Eq. 2–11a with $\upsilon_0 = 0$ to find the final velocity (takeoff speed).

$$\upsilon - \upsilon_0 = at \quad\rightarrow\quad \upsilon = \upsilon_0 + at = 0 + (4.57\ \mathrm{m/s^2})(16\ \mathrm{s}) = \boxed{73\ \mathrm{m/s}}$$

69. (*a*) To find the minimum force, assume that the piano is moving with a constant velocity. Since the piano is not accelerating, $F_{\mathrm{T}4} = Mg$. For the lower pulley, since the tension in a rope is the same throughout, and since the pulley is not accelerating, it is seen that $F_{\mathrm{T}1} + F_{\mathrm{T}2} = 2F_{\mathrm{T}1} = Mg \quad\rightarrow\quad F_{\mathrm{T}1} = F_{\mathrm{T}2} = Mg/2$. It also can be seen that since $F = F_{\mathrm{T}2}$, $\boxed{F = Mg/2}$.

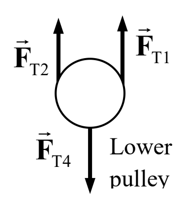


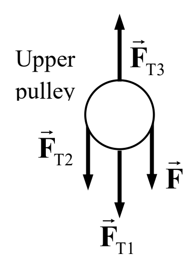
(*b*) Draw a free-body diagram for the upper pulley. From that diagram, we see that

$$F_{\mathrm{T}3} = F_{\mathrm{T}1} + F_{\mathrm{T}2} + F = \frac{3Mg}{2}.$$

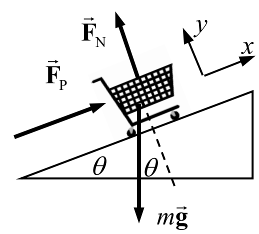
To summarize:

$$\boxed{F_{\mathrm{T}1} = F_{\mathrm{T}2} = Mg/2 \qquad F_{\mathrm{T}3} = 3Mg/2 \qquad F_{\mathrm{T}4} = Mg}$$





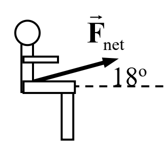
70. Consider a free-body diagram for a grocery cart being pushed up an incline. Assuming that the cart is not accelerating, we write Newton's second law for the x direction.

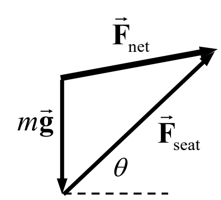


$$\sum F_x = F_\mathrm{P} - mg\sin\theta = 0 \quad\rightarrow\quad \sin\theta = \frac{F_\mathrm{P}}{mg}$$

$$\theta = \sin^{-1}\frac{F_\mathrm{P}}{mg} = \sin^{-1}\frac{18\ \mathrm{N}}{(25\ \mathrm{kg})(9.80\ \mathrm{m/s^2})} = \boxed{4.2^\circ}$$

71. The acceleration of the pilot will be the same as that of the plane, since the pilot is at rest with respect to the plane. Consider first a free-body diagram of the pilot, showing only the net force. By Newton's second law, the net force MUST point in the direction of the acceleration, and its magnitude is ma. That net force is the sum of ALL forces on the pilot. If we assume that the force of gravity and the force of the cockpit seat on the pilot are the only forces on the pilot, then in terms of vectors, $\vec{\mathbf{F}}_\mathrm{net} = m\vec{\mathbf{g}} + \vec{\mathbf{F}}_\mathrm{seat} = m\vec{\mathbf{a}}$. Solve this equation for the force of the seat to find $\vec{\mathbf{F}}_\mathrm{seat} = \vec{\mathbf{F}}_\mathrm{net} - m\vec{\mathbf{g}} = m\vec{\mathbf{a}} - m\vec{\mathbf{g}}$. A vector diagram of that equation is shown. Solve for the force of the seat on the pilot using components.





$$F_{x\text{ seat}} = F_{x\text{ net}} = ma\cos 18^\circ = (75\,\text{kg})(3.8\text{ m/s}^2)\cos 18^\circ = 271.1\text{ N}$$

$$F_{y\text{ seat}} = mg + F_{y\text{ net}} = mg + ma\sin 18^\circ$$

$$= (75\text{ kg})(9.80\text{ m/s}^2) + (75\text{ kg})(3.8\text{ m/s}^2)\sin 18^\circ = 823.2\text{ N}$$

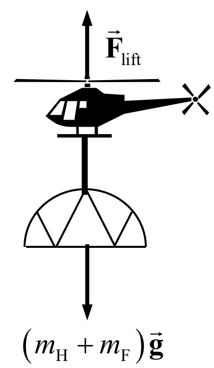
The magnitude of the cockpit seat force is as follows:

$$F = \sqrt{F_{x\text{ seat}}^2 + F_{y\text{ seat}}^2} = \sqrt{(271.1\text{ N})^2 + (823.2\text{ N})^2} = 866.7\text{ N} \approx \boxed{870\text{ N}}$$

The angle of the cockpit seat force is as follows:

$$\theta = \tan^{-1}\frac{F_{y\text{ seat}}}{F_{x\text{ seat}}} = \tan^{-1}\frac{823.2\text{ N}}{271.1\text{ N}} = \boxed{72^\circ}\text{ above the horizontal}$$

72. (*a*) Both the helicopter and frame will have the same acceleration and can be treated as one object if no information about internal forces (like the cable tension) is needed. A free-body diagram for the helicopter–frame combination is shown. Write Newton's second law for the combination, calling UP the positive direction.

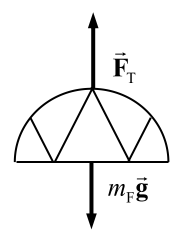


$$\sum F = F_{\text{lift}} - (m_{\text{H}} + m_{\text{F}})g = (m_{\text{H}} + m_{\text{F}})a \quad \rightarrow$$

$$F_{\text{lift}} = (m_{\text{H}} + m_{\text{F}})(g + a) = (7180\text{ kg} + 1080\text{ kg})(9.80\text{ m/s}^2 + 0.80\text{ m/s}^2)$$

$$= 87{,}556\text{ N} \approx \boxed{8.76\times 10^4\text{ N}}$$

(*b*) Now draw a free-body diagram for the frame alone, in order to find the tension in the cable. Again use Newton's second law.



$$\sum F = F_{\text{T}} - m_{\text{F}}g = m_{\text{F}}a \quad \rightarrow$$

$$F_{\text{T}} = m_{\text{F}}(g + a) = (1080\text{ kg})(9.80\text{ m/s}^2 + 0.80\text{ m/s}^2)$$

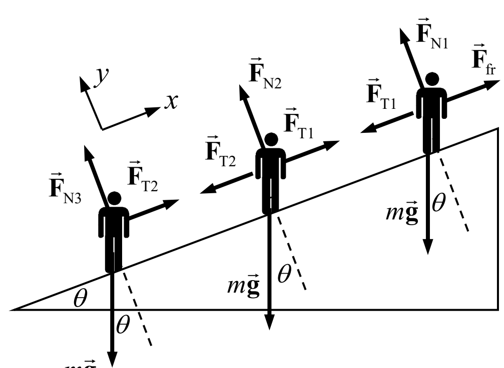
$$= 11{,}448\text{ N} \approx \boxed{1.14\times 10^4\text{ N}}$$

(*c*) The tension in the cable is the same at both ends, so the cable exerts a force of $\boxed{1.14\times 10^4\text{ N}}$ downward on the helicopter.

73. Use Newton's second law.

$$F = ma = m\frac{\Delta v}{\Delta t} \quad \rightarrow \quad \Delta t = \frac{m\Delta v}{F} = \frac{(1.0\times 10^{10}\text{ kg})(2.0\times 10^{-3}\text{ m/s})}{(2.5\text{ N})} = \boxed{8.0\times 10^6\text{ s}} = 93\text{ d}$$

74. Since the climbers are on ice, the frictional force for the lower two climbers is negligible. Consider the free-body diagram as shown. Note that all the masses are the same. Write Newton's second law in the x direction for the lowest climber, assuming he is at rest.

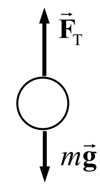


$$\sum F_x = F_{T2} - mg\sin\theta = 0$$
$$F_{T2} = mg\sin\theta = (75\text{ kg})(9.80\text{ m/s}^2)\sin 31.0° = \boxed{380\text{ N}}$$

Write Newton's second law in the *x* direction for the middle climber, assuming he is at rest.

$$\sum F_x = F_{T1} - F_{T2} - mg\sin\theta = 0 \;\rightarrow\; F_{T1} = F_{T2} + mg\sin\theta = 2F_{T2}g\sin\theta = \boxed{760\text{ N}}$$

75. For each object, we have the free-body diagram shown, assuming that the string doesn't break. Newton's second law is used to get an expression for the tension. Since the string broke for the 2.10 kg mass, we know that the required tension to accelerate that mass was more than 22.2 N. Likewise, since the string didn't break for the 2.05-kg mass, we know that the required tension to accelerate that mass was less than 22.2 N. These relationships can be used to get the range of accelerations.



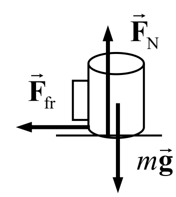
$$\sum F = F_T - mg = ma \;\rightarrow\; F_T = m(a+g)$$

$$F_{T_{max}} < m_{2.10}(a+g);\quad F_{T_{max}} > m_{2.05}(a+g) \;\rightarrow\; \frac{F_{T_{max}}}{m_{2.10}} - g < a;\quad \frac{F_{T_{max}}}{m_{2.05}} - g > a \;\rightarrow$$

$$\frac{F_{T_{max}}}{m_{2.10}} - g < a < \frac{F_{T_{max}}}{m_{2.05}} - g \;\rightarrow\; \frac{22.2\text{ N}}{2.10\text{ kg}} - 9.80\text{ m/s}^2 < a < \frac{22.2\text{ N}}{2.05\text{ kg}} - 9.80\text{ m/s}^2 \;\rightarrow$$

$$0.77\text{ m/s}^2 < a < 1.03\text{ m/s}^2 \;\rightarrow\; \boxed{0.8\text{ m/s}^2 < a < 1.0\text{ m/s}^2}$$

76. A free-body diagram for the coffee cup is shown. Assume that the car is moving to the right, so the acceleration of the car (and cup) will be to the left. The deceleration of the cup is caused by friction between the cup and the dashboard. For the cup not to slide on the dash and to have the minimum deceleration time means the largest possible static frictional force is acting, so $F_{fr} = \mu_s F_N$. The normal force on the cup is equal to its weight, since there is no vertical acceleration. The horizontal acceleration of the cup is found from Eq. 2–11a, with a final velocity of zero.



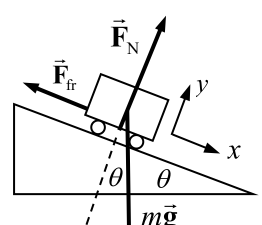
$$\upsilon_0 = (45\text{ km/h})\left(\frac{1\text{ m/s}}{3.6\text{ km/h}}\right) = 12.5\text{ m/s}$$

$$\upsilon - \upsilon_0 = at \;\rightarrow\; a = \frac{\upsilon - \upsilon_0}{t} = \frac{0 - 12.5\text{ m/s}}{3.5\text{ s}} = -3.57\text{ m/s}^2$$

Write Newton's second law for the horizontal forces, considering to the right to be positive.

$$\sum F_x = -F_{fr} = ma \;\rightarrow\; ma = -\mu_s F_N = -\mu_s mg \;\rightarrow\; \mu_s = -\frac{a}{g} = -\frac{(-3.57\text{ m/s}^2)}{9.80\text{ m/s}^2} = \boxed{0.36}$$

77. See the free-body diagram for the descending roller coaster. It starts its descent with $\upsilon_0 = (6.0\text{ km/h})\left(\frac{1\text{ m/s}}{3.6\text{ km/h}}\right) = 1.667\text{ m/s}$. The total displacement in the *x* direction is $x - x_0 = 45.0\text{ m}$. Write Newton's second law for both the *x* and *y* directions.



$$\sum F_y = F_N - mg\cos\theta = 0 \quad\rightarrow\quad F_N = mg\cos\theta$$

$$\sum F_x = ma = mg\sin\theta - F_{fr} = mg\sin\theta - \mu_k F_N = mg\sin\theta - \mu_k mg\cos\theta$$

$$a = \frac{mg\sin\theta - \mu_k mg\cos\theta}{m} = g(\sin\theta - \mu_k\cos\theta)$$

Now use Eq. 2–11c to solve for the final velocity.

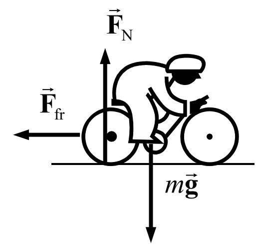
$$\upsilon^2 - \upsilon_0^2 = 2a(x - x_0) \quad\rightarrow$$

$$\upsilon = \sqrt{\upsilon_0^2 + 2a(x - x_0)} = \sqrt{\upsilon_0^2 + 2g(\sin\theta - \mu_k\cos\theta)(x - x_0)}$$

$$= \sqrt{(1.667\text{ m/s})^2 + 2(9.80\text{ m/s}^2)[\sin 45^\circ - (0.12)\cos 45^\circ](45.0\text{ m})}$$

$$= 23.49\text{ m/s} \approx \boxed{23\text{ m/s}} \approx 85\text{ km/h}$$

78. Consider the free-body diagram for the cyclist in the sand, assuming that the cyclist is traveling to the right. It is apparent that $F_N = mg$ since there is no vertical acceleration. Write Newton's second law for the horizontal direction, positive to the right.



$$\sum F_x = -F_{fr} = ma \quad\rightarrow\quad -\mu_k mg = ma \quad\rightarrow\quad a = -\mu_k g$$

Use Eq. 2–11c to determine the distance the cyclist could travel in the sand before coming to rest.

$$\upsilon^2 - \upsilon_0^2 = 2a(x - x_0) \quad\rightarrow\quad (x - x_0) = \frac{\upsilon^2 - \upsilon_0^2}{2a} = \frac{-\upsilon_0^2}{-2\mu_k g} = \frac{(20.0\text{ m/s})^2}{2(0.70)(9.80\text{ m/s}^2)} = 29\text{ m}$$

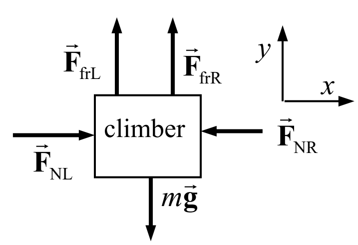
Since there is only 15 m of sand, $\boxed{\text{the cyclist will emerge from the sand}}$. The speed upon emerging is found from Eq. 2–11c.

$$\upsilon^2 - \upsilon_0^2 = 2a(x - x_0) \quad\rightarrow$$

$$\upsilon = \sqrt{\upsilon_0^2 + 2a(x - x_0)} = \sqrt{\upsilon_0^2 - 2\mu_k g(x - x_0)} = \sqrt{(20.0\text{ m/s})^2 - 2(0.70)(9.80\text{ m/s}^2)(15\text{ m})}$$

$$= \boxed{14\text{ m/s}}$$

79. Since the walls are vertical, the normal forces are horizontal, away from the wall faces. We assume that the frictional forces are at their maximum values, so $F_{fr} = \mu_s F_N$ applies at each wall. We assume that the rope in the diagram is not under any tension and does not exert any forces. Consider the free-body diagram for the climber. F_{NR} is the normal force on the climber from the right wall, and F_{NL} is the normal force on the climber from the left wall. The static frictional forces are $F_{frL} = \mu_{sL} F_{NL}$ and $F_{frR} = \mu_{sR} F_{NR}$. Write Newton's second law for both the x and y directions. The net force in each direction must be zero if the climber is stationary.



$$\sum F_x = F_{NL} - F_{NR} = 0 \quad\rightarrow\quad F_{NL} = F_{NR} \qquad \sum F_y = F_{frL} + F_{frR} - mg = 0$$

Substitute the information from the x equation into the y equation.

$$F_{\text{frL}} + F_{\text{frR}} = mg \quad \to \quad \mu_{\text{sL}} F_{\text{NL}} + \mu_{\text{sR}} F_{\text{NR}} = mg \quad \to \quad (\mu_{\text{sL}} + \mu_{\text{sR}})F_{\text{NL}} = mg$$

$$F_{\text{NL}} = \frac{mg}{(\mu_{\text{sL}} + \mu_{\text{sR}})} = \frac{(70.0\text{ kg})(9.80\text{ m/s}^2)}{1.40} = 4.90\times 10^2\text{ N}$$

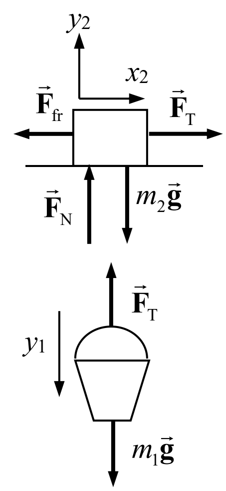
So $\boxed{F_{\text{NL}} = F_{\text{NR}} = 4.90\times 10^2\text{ N}}$. These normal forces arise as Newton's third law reaction forces to the climber pushing on the walls. Thus the climber must exert a force of at least 490 N against each wall.

80. (*a*) Consider the free-body diagrams for both objects, initially stationary. As sand is added, the tension will increase, and the force of static friction on the block will increase until it reaches its maximum, $F_{\text{fr}} = \mu_{\text{s}} F_{\text{N}}$. Then the system will start to move. Write Newton's second law for each object, when the static frictional force is at its maximum, but the objects are still stationary.

$$\sum F_{y\text{ bucket}} = m_1 g - F_{\text{T}} = 0 \quad \to \quad F_{\text{T}} = m_1 g$$

$$\sum F_{y\text{ block}} = F_{\text{N}} - m_2 g = 0 \quad \to \quad F_{\text{N}} = m_2 g$$

$$\sum F_{x\text{ block}} = F_{\text{T}} - F_{\text{fr}} = 0 \quad \to \quad F_{\text{T}} = F_{\text{fr}}$$



Equate the two expressions for tension, and substitute in the expression for the normal force to find the masses.

$$m_1 g = F_{\text{fr}} \quad \to \quad m_1 g = \mu_{\text{s}} F_{\text{N}} = \mu_{\text{s}} m_2 g \quad \to$$

$$m_1 = \mu_{\text{s}} m_2 = (0.45)(28.0\text{ kg}) = 12.6\text{ kg}$$

Thus $12.6\text{ kg} - 2.00\text{ kg} = 10.6\text{ kg} \approx \boxed{11\text{ kg}}$ of sand was added.

(*b*) The same free-body diagrams can be used, but now the objects will accelerate. Since they are tied together, $a_{y1} = a_{x2} = a$. The frictional force is now kinetic friction, given by $F_{\text{fr}} = \mu_{\text{k}} F_{\text{N}} = \mu_{\text{k}} m_2 g$. Write Newton's second law for the objects in the direction of their acceleration.

$$\sum F_{y\text{ bucket}} = m_1 g - F_{\text{T}} = m_1 a \quad \to \quad F_{\text{T}} = m_1 g - m_1 a$$

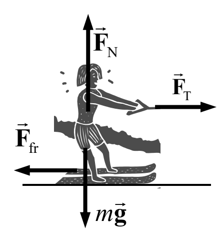
$$\sum F_{x\text{ block}} = F_{\text{T}} - F_{\text{fr}} = m_2 a \quad \to \quad F_{\text{T}} = F_{\text{fr}} + m_2 a$$

Equate the two expressions for tension, and solve for the acceleration.

$$m_1 g - m_1 a = \mu_{\text{k}} m_2 g + m_2 a \quad \to$$

$$a = g\frac{(m_1 - \mu_{\text{k}} m_2)}{(m_1 + m_2)} = (9.80\text{ m/s}^2)\frac{(12.6\text{ kg} - (0.32)(28.0\text{ kg}))}{(12.6\text{ kg} + 28.0\text{ kg})} = \boxed{0.88\text{ m/s}^2}$$

81. (*a*) See the free-body diagram for the skier when the tow rope is horizontal. Use Newton's second law for both the vertical and horizontal directions in order to find the acceleration.

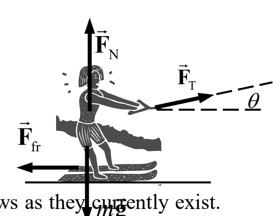


$$\sum F_y = F_{\text{N}} - mg = 0 \quad \to \quad F_{\text{N}} = mg$$

$$\sum F_x = F_{\text{T}} - F_{\text{fr}} = F_{\text{T}} - \mu_{\text{k}} F_{\text{N}} = F_{\text{T}} - \mu_{\text{k}} mg = ma$$

$$a = \frac{F_{\text{T}} - \mu_{\text{k}} mg}{m} = \frac{(240\text{ N}) - 0.25(72\text{ kg})(9.80\text{ m/s}^2)}{(72\text{ kg})} = 0.8833\text{ m/s}^2 \approx \boxed{0.9\text{ m/s}^2}$$

(*b*) Now see the free-body diagram for the skier when the tow rope has an upward component.

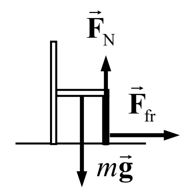


$$\sum F_y = F_N + F_T \sin\theta - mg = 0 \quad\to\quad F_N = mg - F_T \sin\theta$$
$$\sum F_x = F_T \cos\theta - F_{fr} = F_T \cos\theta - \mu_k F_N$$
$$= F_T \cos\theta - \mu_k(mg - F_T \sin\theta) = ma$$

$$a = \frac{F_T(\cos\theta + \mu_k \sin\theta) - \mu_k mg}{m}$$
$$= \frac{(240\text{ N})(\cos 12° + 0.25 \sin 12°) - 0.25(72\text{ kg})(9.80\text{ m/s}^2)}{(72\text{ kg})} = \boxed{0.98\text{ m/s}^2}$$

(*c*) The acceleration is greater in part (*b*) because the upward tilt of the tow rope reduces the normal force, which then reduces the friction. The reduction in friction is greater than the reduction in horizontal applied force, so the horizontal acceleration increases.

82. (*a*) Assume that the earthquake is moving the Earth to the right. If an object is to "hold its place," then the object must also be accelerating to the right with the Earth. The force that will accelerate that object will be the static frictional force, which would also have to be to the right. If the force were not large enough, the Earth would move out from under the chair somewhat, giving the appearance that the chair were being "thrown" to the left. Consider the free-body diagram shown for a chair on the floor. It is apparent that the normal force is equal to the weight since there is no motion in the vertical direction. Newton's second law says that $F_{fr} = ma$. We also assume that the chair is just on the verge of slipping, which means that the static frictional force has its maximum value of $F_{fr} = \mu_s F_N = \mu_s mg$. Equate the two expressions for the frictional force to find the coefficient of friction.

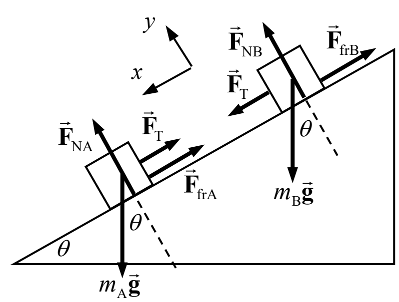


$$ma = \mu_s mg \quad\to\quad \boxed{\mu_s = a/g}$$

If the static coefficient is larger than this, then there will be a larger maximum frictional force, and the static frictional force will be more than sufficient to hold the chair in place on the floor.

(*b*) For the 1989 quake, $\dfrac{a}{g} = \dfrac{4.0\text{ m/s}^2}{9.80\text{ m/s}^2} = 0.41$. Since $\mu_s = 0.25$, $\boxed{\text{the chair would slide.}}$

83. Since the upper block has a higher coefficient of friction, that block will "drag behind" the lower block. Thus there will be tension in the cord, and the blocks will have the same acceleration. From the free-body diagrams for each block, we write Newton's second law for both the *x* and *y* directions for each block, and then combine those equations to find the acceleration and tension.



(*a*) Block A:

$$\sum F_{yA} = F_{NA} - m_A g \cos\theta = 0 \quad\to\quad F_{NA} = m_A g \cos\theta$$
$$\sum F_{xA} = m_A g \sin\theta - F_{frA} - F_T = m_A a$$
$$m_A a = m_A g \sin\theta - \mu_A F_{NA} - F_T = m_A g \sin\theta - \mu_A m_A g \cos\theta - F_T$$

Block B:

$$\sum F_{yB} = F_{NB} - m_B g \cos\theta = 0 \quad\to\quad F_{NB} = m_B g \cos\theta$$
$$\sum F_{xB} = m_A g \sin\theta - F_{frA} + F_T = m_B a$$
$$m_B a = m_B g \sin\theta - \mu_B F_{NB} + F_T = m_B g \sin\theta - \mu_B m_B g \cos\theta + F_T$$

Add the final equations together from both analyses and solve for the acceleration.

$$m_A a = m_A g \sin\theta - \mu_A m_A g \cos\theta - F_T; \quad m_B a = m_B g \sin\theta - \mu_B m_B g \cos\theta + F_T$$

$$m_A a + m_B a = m_A g \sin\theta - \mu_A m_A g \cos\theta - F_T + m_B g \sin\theta - \mu_B m_B g \cos\theta + F_T \rightarrow$$

$$a = g\left[\frac{m_A(\sin\theta - \mu_A \cos\theta) + m_B(\sin\theta - \mu_B \cos\theta)}{(m_A + m_B)}\right]$$

$$= (9.80 \text{ m/s}^2)\left[\frac{(5.0 \text{ kg})(\sin 32^\circ - 0.20 \cos 32^\circ) + (5.0 \text{ kg})(\sin 32^\circ - 0.30 \cos 32^\circ)}{(10.0 \text{ kg})}\right]$$

$$= 3.1155 \text{ m/s}^2 \approx \boxed{3.1 \text{ m/s}^2}$$

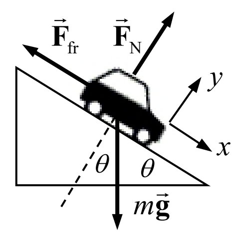
(*b*) Solve one of the equations for the tension force.

$$m_A a = m_A g \sin\theta - \mu_A m_A g \cos\theta - F_T \rightarrow$$

$$F_T = m_A(g \sin\theta - \mu_A g \cos\theta - a)$$

$$= (5.0 \text{ kg})[(9.80 \text{ m/s}^2)(\sin 32^\circ - 0.20 \cos 32^\circ) - 3.1155 \text{ m/s}^2] = \boxed{2.1 \text{ N}}$$

84. We include friction from the start, and then for the no-friction result, set the coefficient of friction equal to 0. Consider a free-body diagram for the car on the hill. Write Newton's second law for both directions. Note that the net force on the y direction will be zero, since there is no acceleration in the y direction.



$$\sum F_y = F_N - mg \cos\theta = 0 \rightarrow F_N = mg \cos\theta$$

$$\sum F_x = mg \sin\theta - F_{\text{fr}} = ma \rightarrow$$

$$a = g \sin\theta - \frac{F_{\text{fr}}}{m} = g \sin\theta - \frac{\mu_k mg \cos\theta}{m} = g(\sin\theta - \mu_k \cos\theta)$$

Use Eq. 2–11c to determine the final velocity, assuming that the car starts from rest.

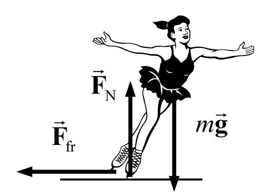
$$\upsilon^2 - \upsilon_0^2 = 2a(x - x_0) \rightarrow \upsilon = \sqrt{0 + 2a(x - x_0)} = \sqrt{2g(x - x_0)(\sin\theta - \mu_k \cos\theta)}$$

The angle is given by $\sin\theta = 1/4 \rightarrow \theta = \sin^{-1} 0.25 = 14.5^\circ$.

(*a*) $\mu_k = 0 \rightarrow \upsilon = \sqrt{2g(x - x_0)x \sin\theta} = \sqrt{2(9.80 \text{ m/s}^2)(55 \text{ m}) \sin 14.5^\circ} = \boxed{16 \text{ m/ s}}$

(*b*) $\mu_k = 0.10 \rightarrow \upsilon = \sqrt{2(9.80 \text{ m/s}^2)(55 \text{ m})(\sin 14.5^\circ - 0.10 \cos 14.5^\circ)} = \boxed{13 \text{ m/s}}$

85. Consider the free-body diagram for the decelerating skater, moving to the right. It is apparent that $F_N = mg$ since there is no acceleration in the vertical direction. From Newton's second law in the horizontal direction, we have



$$\sum F = F_{\text{fr}} = ma \rightarrow -\mu_k mg = ma \rightarrow a = -\mu_k g.$$

Now use Eq. 2–11c to find the starting speed.

$$\upsilon^2 - \upsilon_0^2 = 2a(x - x_0) \rightarrow$$

$$\upsilon_0 = \sqrt{\upsilon^2 - 2a(x - x_0)} = \sqrt{0 + 2\mu_k g(x - x_0)} = \sqrt{2(0.10)(9.80 \text{ m/s}^2)(75 \text{ m})} = \boxed{12 \text{ m/s}}$$

Solutions to Search and Learn Problems

1. The static friction force is the force that prevents two objects from moving relative to one another. The "less than" sign (<) in the static friction force tells you that the actual force may be any value less than

that given by the equation. Typically you use Newton's second law to determine the value of the static friction force. You then verify that the force calculated is in the allowed range given by the static friction equation. The equals sign in the equation is used when you are searching for the maximum force of static friction. For example, if an object is "on the verge" of moving away from a static configuration, you would use the equals sign.

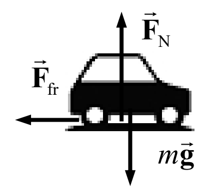
2. As the skier travels down the slope at constant speed, her acceleration parallel to the slope must be zero. Newton's second law can then be written in component form as:

$$\sum F_x = mg \sin\theta - \mu_k F_N = 0 \qquad \sum F_y = F_N - mg\cos\theta = 0$$

The vertical equation can be solved for the normal force, which can then be inserted into the horizontal equation. The horizontal equation can then be solved for the coefficient of kinetic friction.

$$F_N = mg\cos\theta; \quad mg\sin\theta - \mu_k(mg\cos\theta) = 0 \;\rightarrow\; \mu_k = \frac{mg\sin\theta}{mg\cos\theta} = \tan\theta$$

3. (*a*) A free-body diagram for the car is shown, assuming that it is moving to the right. It is apparent from the diagram that $F_N = mg$ for the vertical direction. Write Newton's second law for the horizontal direction, with positive to the right, to find the acceleration of the car. Since the car is assumed NOT to be sliding, use the maximum force of static friction.



$$\sum F_x = -F_{fr} = ma \;\rightarrow\; ma = -\mu_s F_N = -\mu_s mg \;\rightarrow\; a = -\mu_s g$$

Eq. 2–11c can be used to find the distance that the car moves before stopping. The initial speed is given as υ, and the final speed will be 0.

$$\upsilon^2 - \upsilon_0^2 = 2a(x - x_0) \;\rightarrow\; (x - x_0) = \frac{\upsilon^2 - \upsilon_0^2}{2a} = \frac{0 - \upsilon^2}{2(-\mu_s g)} = \boxed{\frac{\upsilon^2}{2\mu_s g}}$$

(*b*) Using the given values:

$$\upsilon = (95\text{ km/h})\left(\frac{1\text{ m/s}}{3.6\text{ km/h}}\right) = 26.38\text{ m/s} \qquad (x - x_0) = \frac{\upsilon^2}{2\mu_s g} = \frac{(26.38\text{ m/s})^2}{2(0.65)(9.80\text{ m/s}^2)} = \boxed{55\text{ m}}$$

(*c*) From part (*a*), we see that the distance is inversely proportional to *g*, so if *g* is reduced by a factor of 6, the distance is increased by a factor of 6 to $\boxed{330\text{ m}}$.