

4

FORCES AND NEWTON'S LAWS OF MOTION

Q4.1. Reason: If friction and air resistance are negligible (as stated) then the net force on the puck is zero (the normal force and gravitational force are equal in magnitude and opposite in direction). If the net force on the puck is zero, then Newton's first law states that it will continue on with constant velocity. So no force is needed to keep the puck moving; it will naturally keep moving unless a force acts on it to change its velocity.

Assess: This question demonstrates the difference between Aristotelian thinking and Newtonian thinking. Objects do not need forces on them to keep them moving; forces are only required when we want to *change* the velocity of the object. The reason one has to normally keep pushing an object to keep it moving is because of friction; to keep it at constant velocity your pushing force must be equal in magnitude to the friction force. But in the case of this question, there is no friction, so there is no force needed to keep it moving.

Q4.2. Reason: Even if an object is not moving forces can be acting on it. However, the *net* force must be zero. As an example consider a book on a flat table. The forces that act on the book are the weight of the book (a long range force) and the normal force exerted by the table (a contact force). There are two forces acting on the book, but it is not moving because the net force on the book is zero.

Assess: The net force, which is the vector sum of the forces acting on an object, governs the acceleration of objects through Equation 4.4.

Q4.3. Reason: Newton's first law does *not* state that there can be no forces acting on an object moving with constant velocity—only that the *sum* of the forces must be zero (sometimes worded as “no unbalanced forces”). There can be forces acting on an object with constant velocity, but the vector sum of those forces must be zero.

Assess: When we say there is no *net* force on an object with constant velocity, we are not saying that there are no forces. Net force means the vector sum of the forces.

Q4.4. Reason: The ball is initially at rest and will stay at rest unless some unbalanced (net) force acts on it. As the wagon moves forward, static friction tries to pull the ball along with the wagon. This static friction causes the ball to roll backwards in the wagon.

Assess: Put a marble or some other small spherical object on your text and then push your text back and forth. The sphere will always roll in the direction opposite the direction you are moving the text.

Q4.5. Reason: No. If you know all of the forces then you know the direction of the acceleration, not the direction of the motion (velocity). For example, a car moving forward could have on it a net force forward if speeding up or backward if slowing down or no net force at all if moving at constant speed.

Assess: Consider carefully what Newton's second law says, and what it doesn't say. The net force must *always* be in the direction of the acceleration. This is also the direction of the *change* in velocity, although not necessarily in the direction of the velocity itself.

Q4.6. Reason: The arrows have been shot horizontally and air resistance is negligible. The only force on the arrows is due to gravity, which always points straight down. There is no component of a force in the horizontal direction. Each arrow has exactly the same magnitude of horizontal force on it, 0 N. No horizontal force is required to keep the arrows moving. Rather a horizontal force is required if we wish to change the horizontal motion of the arrows.

Assess: Weight always points vertically downward. Once the arrow has been fired, it is moving with a constant velocity, a force is required to change the velocity but not to maintain the velocity.

Q4.7. Reason: The picture on the left is more effective at tightening the head because of the greater inertia of the head. Once moving, the head will “want” to continue moving (Newton's first law) after the handle hits the

table, thus tightening the head, more so than in the second picture where the light handle has less inertia moving down than the head.

Assess: Newton's first law, the law of inertia, says the greater the mass of an object the more it will tend to continue with its previous velocity. One can assess this by trying it with a real hammer with a loose head.

Q4.8. Reason: (a) During the first collision a person in the car continues in their state of motion until a force acts to change their motion. This will happen when the seatbelt engages or when the person hits something on the inside of the car. Likewise, internal organs will continue in their state of motion until some force acts on them to change their motion. They continue moving due to Newton's first law.

(b) If there is no restraint on the body after the first collision, the body will be moving at 60 mph just before the second collision, and the organs will be traveling at this speed until just before the third collision.

Assess: Forces are required to change an object's state of motion.

Q4.9. Reason: Kinetic friction opposes the motion, but static friction is in the direction to prevent motion.

(a) Examples of motion where the frictional force on the object is directed opposite the motion would be a block sliding across a table top or the friction of the road on car tires in a skid.

(b) An example of motion in which the frictional force on the object is in the same direction as the motion would be a crate (not sliding) in the back of a pickup truck that is speeding up. The static frictional force of the truck bed on the crate is in the forward direction (the same direction as the motion) because it *is* the net force on the crate that accelerates it forward.

Assess: It is easy to think that the direction of the frictional force is *always* opposite the direction of motion, but static frictional forces are in the direction to prevent relative motion between the surfaces, and can be in various directions depending on the situation.

Q4.10. Reason: Since there is no source of gravity, you will not be able to feel the weight of the objects. However, Newton's second law is true even in an environment without gravity. Assuming you can exert a reproducible force in throwing both objects. You could throw each and note the acceleration each obtains.

Assess: Mass is independent of the force of gravity and exists even in environments with no sources of gravity.

Q4.11. Reason: Both objects (Jonathan and his daughter) experience the same acceleration (i.e. the acceleration of the car). However since the objects do not have the same mass, the forces required to accelerate them will be different. The object with the greater mass (Jonathan) will require the greater force.

Assess: This is a straightforward application of Newton's second law.

Q4.12. Reason: Since the box is at rest, the sum of the forces acting on it must be zero. Put another way, the upward forces must equal the downward forces. If the weight is the only downward force and the normal force is the only upward force, they will have the same magnitude. However, if some other force with a vertical component (such as you pushing down on the box) acts on the box, the weight and the normal force will not have the same magnitude.

Assess: For many objects in static equilibrium, the sum of the forces is equal to zero.

Q4.13. Reason: The book defines weight as the gravitational pull of the earth on an object, and that doesn't change when the ball is thrown straight up. That is, if the gravitational force of the earth on the ball is 2.0 N while it sits on the scale, then the gravitational force of the earth on the ball is still 2.0 N while it is in flight—even at the very top of its motion. The weight of the ball is 2.0 N all the time the ball is near the surface of the earth, regardless of its motion.

Assess: Hmm. . . . We previously distinguished between velocity, which *is* zero at the top of the trajectory (if the ball is thrown straight up), and acceleration, which is $-g$ all the while it is in free fall. But how do we explain the fact that the acceleration of the ball is $-g$ at the top of its trajectory but zero while sitting on the scale, if the gravitational force on it is the same in both cases? Doesn't $\vec{F}_{\text{net}} = m\vec{a}$? Yes, $\vec{F}_{\text{net}} = m\vec{a}$ is true, but in the case of the ball on the scale the net force is zero because the scale is pushing up on the ball with a force of 2.0 N; since the net force is zero the acceleration is zero. While the ball is in flight the scale isn't pushing up on it, so the acceleration is $-g$ because the net force (the weight) is 2.0 N.

It is also worth mentioning that not all physics texts define weight the same way. Some define weight as "what the scale reads," which would be different from the definition in our text because if the scale and ball are thrown up together they would both be in free fall and the scale would read zero. That is, some books would say the ball's weight *is* zero at the top of its motion (because that is what the scale would read). Both definitions have merit, and it is wise to understand the difference and be prepared in future situations if someone defines weight

differently than we have in this text. One way to avoid confusion is to always refer to “the gravitational force of the earth on the object” instead of the “weight.” Still, the definition in our textbook is very mainstream.

Q4.14. Reason: The initial force on each skater is the same and is the result of an action/reaction pair created as they push on each other. However, since Josh is more massive (bigger) than Taylor, his resulting acceleration during the push will be less and hence his final velocity after the push will be less.

Assess: This problem required a correct conceptual understanding of Newton's second and third laws. The third law allows us to conclude that each skater experiences the same force and the second law allows us to understand that the acceleration is inversely proportional to the mass being accelerated.

Q4.15. Reason: If the only forces acting on the person are the gravitational force of the earth, the normal force of the hill, and the (static) frictional force of the hill, then the frictional force must *always* point up the hill to prevent sliding down the hill.

However, if there were another agent (say, a second person) pushing or pulling up the hill on the person, then the static frictional force could be preventing a slide *up* the hill; in this case the direction of the static friction force would be down the hill.

Assess: It is a boon to understanding to stop and think about the exceptional cases that we might not have considered in our first encounter with a concept.

Looked at with the second law, if the second person is strongly pushing up the hill, then the static friction force might need to be down the hill to produce a zero net force and the required zero acceleration.

Q4.16. Reason: As your foot comes into contact with the floor the force of static friction acts in the direction necessary to prevent motion of the foot. The friction prevents your foot from slipping forward, so the direction of the force of the floor on your foot is backward.

Assess: Static friction acts in the direction necessary to prevent motion.

Q4.17. Reason: The force of the road on the tires is what accelerates the car forward, that is, when the acceleration is forward the net force must be forward. An example would be when the car is going forward and speeding up, Figure 4.31b.

However, if the car is accelerating backward (while going forward), that is, slowing down, then the force of the tires on the road must be in the direction of the acceleration, or backward.

Assess: Remember to apply Newton's second law. It doesn't answer every question in the universe, but at least it shouldn't be violated in problems like this. The acceleration must be in the same direction as the net force. This gives one a head start in answering this question.

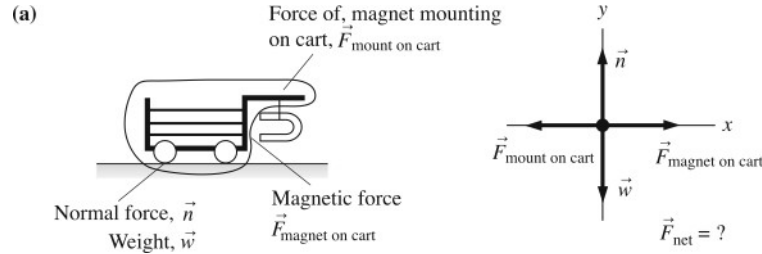
Q4.18. Reason: The two forces in question are both exerted on the same object, the filing cabinet. An action/reaction pair is exerted on two different objects. As Alyssa pushes to the right on the filing cabinet, the filing cabinet pushes on Alyssa an equal amount to the left. These two forces constitute an action/reaction pair – note that one force acts on Alyssa and the other force acts on the filing cabinet. The two forces of the action/reaction pair act on different objects. As the frictional force of the floor pushes on the filing cabinet to the left, the filing cabinet pushes on the floor an equal amount to the right. These two forces also constitute an action/reaction pair.

Assess: It is important to remember that the forces of an action/reaction pair act on different objects.

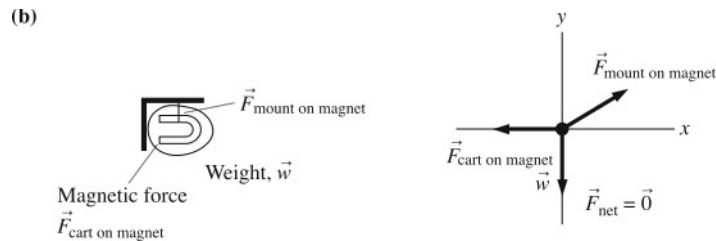
Q4.19. Reason: The force that you exert on the wagon will cause it to move forward if it is greater than all opposing forces *on the wagon*. That is, the wagon will accelerate if the net force *on the wagon* is not zero. This is a proper application of Newton's second law, but you cannot apply Newton's third law in this case. Newton's third law does not apply to the forces on a single object, but only to forces acting on two different objects. A Newton's third law pair of forces can never cancel because they are always acting on different (opposite) objects.

Assess: It is nice to have smart three-year-olds, but in this case she needs even more physics understanding, not less. Both Newton's second law and his third law are true (in classical physics), but they don't address the same forces. Newton's second law addresses all of the forces acting on a single object; Newton's third law addresses pairs of forces that act on opposite objects (these third law forces can't even be added up—let alone cancel—because they aren't on the same object).

Q4.20. Reason: Consider the cart to be the system. We will use the methods in Tactics Box 4.4, Tactics Box 4.3, and Integrated Example 4.11. Refer to the following diagram.



There are four forces on the cart. The contact forces are the normal force of the floor on the cart and the contact force of the magnet mounting on the cart. The long range forces are the weight of the cart and the force due to magnetic attraction of the cart to the magnet. The only horizontal forces on the cart are the force due to the magnet on the cart $\vec{F}_{\text{magnet on cart}}$, and the horizontal component of the force of the mount on the cart, $(\vec{F}_{\text{mount on cart}})_x$. We will find the relationship between these two horizontal forces to determine whether the cart will move. To do that, we will need to take a look at the forces on the magnet and the mount. See the following figure for the forces on the magnet.



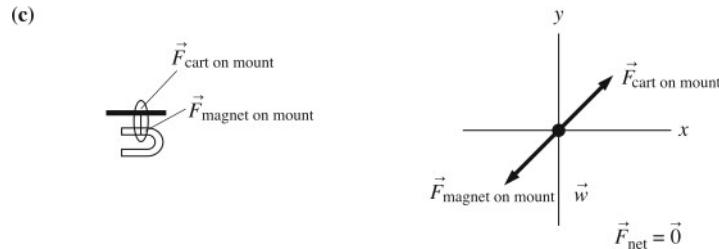
The long range forces are the magnet's weight and the magnetic attraction between the magnet and the cart. The force of the cart on the magnet is equal and opposite to the force of the magnet on the cart since these are action/reaction pairs.

$$\vec{F}_{\text{cart on magnet}} = -\vec{F}_{\text{magnet on cart}}$$

Since the magnet is not moving, Newton's second law gives that the net force on the magnet must be zero. We can see that the horizontal component of the force of the mount on the magnet must cancel the force of the cart on the magnet.

$$\vec{F}_{\text{cart on magnet}} = -(\vec{F}_{\text{mount on magnet}})_x$$

Consider the forces on the magnet mount in the figure below.



The magnet's mounting is what provides the force that keeps the magnet in place. The force of the magnet on the mount is equal and opposite to the force of the mount on the magnet, since these are action/reaction pairs. Using Newton's third law,

$$\vec{F}_{\text{magnet on mount}} = -\vec{F}_{\text{mount on magnet}}$$

From the free-body diagram, the x -components of the forces on the magnet mount must cancel.

$$(\vec{F}_{\text{magnet on mount}})_x = -(\vec{F}_{\text{cart on mount}})_x$$

From Newton's third law, the force of the cart on the mount must be equal and opposite to the force of the mount on the cart.

$$\vec{F}_{\text{cart on mount}} = -\vec{F}_{\text{mount on cart}}$$

We can now relate the two forces on the cart to each other. Using the first two equations above,

$$\vec{F}_{\text{magnet on cart}} = -\vec{F}_{\text{cart on magnet}} = -\left(-(\vec{F}_{\text{mount on magnet}})_x\right) = (\vec{F}_{\text{mount on magnet}})_x$$

Using the remaining basic equations above,

$$(\vec{F}_{\text{mount on magnet}})_x = -(\vec{F}_{\text{magnet on mount}})_x = -\left(-(\vec{F}_{\text{cart on mount}})_x\right) = +(\vec{F}_{\text{cart on mount}})_x = -(\vec{F}_{\text{mount on cart}})_x$$

Putting these last two equations together, we have

$$\vec{F}_{\text{magnet on cart}} = -(\vec{F}_{\text{mount on cart}})_x$$

The net horizontal force on the cart is zero. The cart will not move due to the magnet.

Assess: We could have arrived at this result if we had taken the cart, mount, and magnet as the system. The force between the magnet and the cart and the cart and the magnet are then internal forces. The net external force on the system is zero, so the system will not accelerate. Note the previous distinction between uses of Newton's second and third laws.

Q4.21. Reason: This is a very famous question, and one which many people miss until they understand Newton's laws.

Before the string snaps, it provides a tension force toward the center of the circle (centripetal), which keeps the puck going around in a circle; in other words, the net force is toward the center, so the acceleration is toward the center.

However, when the string snaps, that centripetal force disappears. There is now no net force acting on the puck, and Newton's first law tells us that its velocity must be constant (both in magnitude and direction) under those conditions. So the puck continues in the direction it was going at the instant the string snapped.

The answer is C.

Assess: Ask some friends, relatives, or roommates this question and then patiently explain to them the right answer.

Q4.22. Reason: Since the block glued on to the original block is identical to the original block, the mass of the two together must be twice as large as the mass of the original block. If the force applied is also twice as large, the acceleration will be the same. Explicitly applying Newton's second law to the two blocks glued together gives

$$a_{\text{new}} = \frac{2F}{2m} = \frac{F}{m} = a_{\text{old}}$$

The correct choice is C.

Assess: In Newton's second law, the acceleration is proportional to the net force and inversely proportional to the mass accelerated. As a result if you double both the mass and the force, the acceleration will remain the same.

Q4.23. Reason: We can apply Newton's second law twice to solve this problem. First to determine the force and second to determine the mass.

$$F = ma = (5.0 \text{ kg})(0.20 \text{ m/s}^2) = 1.0 \text{ N}$$

Then

$$m = F / a = 1.0 \text{ N} / 0.10 \text{ m/s}^2 = 10 \text{ kg}$$

The correct answer is A.

Assess: This problem is a straightforward application of Newton's Second Law.

Q4.24. Reason: Drag points opposite to the direction of motion. As the ball is going up, the drag force acts downward. As the ball comes down, the drag force acts upward. The correct choice is D.

Assess: Drag always acts opposite to the direction of motion of an object.

Q4.25. Reason: The direction of the kinetic friction force will be opposite the motion, so the friction points down while the box goes up, and the friction points up while the box slides down.

The answer is D.

Assess: Drawing a free-body diagram (with tilted axes) and applying Newton's second law will support this conclusion.

Q4.26. Reason: In order for the box to be moving with constant speed, the net force in the horizontal direction must be zero. This means that there must be some force acting in the direction opposite to the motion of the box. Otherwise the box would be accelerating in the direction the person was pushing. This force could be friction between the box and the floor. Once the person stops pushing, the box will immediately start slowing down and eventually stop due to friction. The correct choice is D.

Assess: The net force on a system must be zero for the system not to accelerate.

Q4.27. Reason: Since the box is moving at a constant velocity the net force on it must be zero. The friction force (which we are told is nonzero) must point in the direction opposite the direction of motion; thus, the friction force is in the same direction as Jon's pushing force. For the net force to be zero, the magnitude of Rachel's force must equal the magnitude of Jon's force plus the magnitude of the friction force, so Rachel's is greater than Jon's.

The correct choice is A.

Assess: A free-body diagram will help demonstrate this answer. If the box is moving to the right (in the direction of Rachel's force) then the arrows representing Jon's force and the friction force both point to the left, and their sum must be the same magnitude as Rachel's.

Q4.28. Reason: Since Thomas speeds up we know that the net force on him is not zero; the net force is in the same direction as the acceleration. Newton's second law guarantees this.

However, Newton's third law says that if Dave pushes on Thomas then Thomas pushes on Dave with a force equal in magnitude and opposite in direction.

The correct choice is C.

Assess: It is easy to use the wrong law to answer the question if one isn't sure what the question is asking. This is a Newton's third law question, not a second law question. Have faith in the third law.

Q4.29. Reason: Since block A rides without slipping, it, too, must be accelerating to the right. If it is accelerating to the right there must be a net force to the right, according to Newton's second law. The only object that can exert a force to the right is block B.

This static friction force is to the right to prevent slippage of block A to the left (relative to block B).

The correct choice is B.

Assess: This is one of those cases in which the static friction force can be in the same direction as the motion, to prevent slippage the other way. Verify with a free-body diagram of block A.

Problems

P4.1. Prepare: First note that time progresses to the right in each sequence of pictures. In one case the head is thrown back, and in the other, forward.

Solve: Using the principle of inertia, the head will tend to continue with the same velocity after the collision that it had before.

In the first series of sketches, the head is lagging behind because the car has been quickly accelerated forward (to the right). This is the result of a rear-end collision.

In the second series of sketches, the head is moving forward relative to the car because the car is slowing down and the head's inertia keeps it moving forward at the same velocity (although external forces do eventually stop the head as well). This is the result of a head-on collision.

Assess: Hopefully you haven't experienced either of these in an injurious way, but you have felt similar milder effects as the car simply speeds up or slows down.

It is for this reason that cars are equipped with headrests, to prevent the whiplash shown in the first series of sketches, because rear-end collisions are so common. The laws of physics tell us how wise it is to have the headrests properly positioned for our own height.

Air bags are now employed to prevent injury in the second scenario.

P4.2. Prepare: We can apply Newton's first law to determine the motion of the brain during the collision.

Solve: During the collision of the automobile, the passenger and the passenger's brain continue moving at the speed the car was moving just prior to the collision. When the passenger's head is stopped by a part of the inside of the car, such as an airbag or the windshield, the passenger's brain is traveling at the speed of the car before the collision. The brain continues to move forward, and comes to a rest as it compresses against the forward part of the skull. The frontal portion of the brain will be compressed.

Assess: Compare to the analysis in Question 4.8.

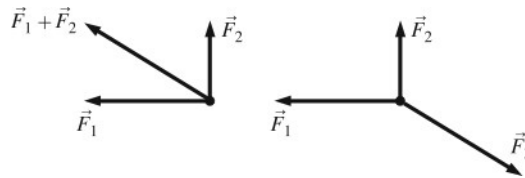
P4.3. Prepare: As background, look at question Q4.8 and problem P4.1. Also think about the design and orientation of the seat and how the child rides in the seat. Finally recall Newton's second law.

Solve: As the child rides in the seat, his/her head and back rest against the padded back of the seat. If the car is brought to a rapid stop (as in a head-on collision) the child will continue to move forward at the before-crash speed until he/she hits something. The object hit is the back of the seat (supporting the entire back and head) which is padded and as a result the force increases to the maximum value over a time interval. Granted this time interval may be small but that is considerable better than instantaneous. Also since the head is supported, there will be no whip-lash.

Assess: The fact the force acting on the child is spread over a small time interval is a critical factor. In later chapters you will learn to call this concept impulse.

P4.4. Prepare: Draw the vector sum $\vec{F}_1 + \vec{F}_2$ of the two forces \vec{F}_1 and \vec{F}_2 . Then look for a vector that will "balance" the force vector $\vec{F}_1 + \vec{F}_2$.

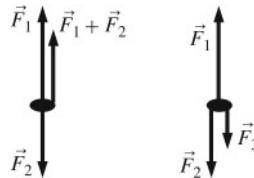
Solve: The object will be in equilibrium if \vec{F}_3 has the same magnitude as $\vec{F}_1 + \vec{F}_2$ but is in the opposite direction so that the sum of all the three forces is zero.



Assess: Adding the new force vector \vec{F}_3 with length and direction as shown will cause the object to be at rest.

P4.5. Prepare: Draw the vector sum $\vec{F}_1 + \vec{F}_2$ of the two forces \vec{F}_1 and \vec{F}_2 . Then look for a vector that will "balance" the force vector $\vec{F}_1 + \vec{F}_2$.

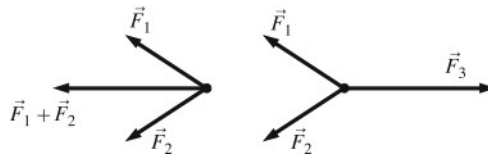
Solve: The object will be in equilibrium if \vec{F}_3 has the same magnitude as $\vec{F}_1 + \vec{F}_2$ but is in the opposite direction so that the sum of all three forces is zero.



Assess: Adding the new force vector \vec{F}_3 with length and direction as shown will cause the object to be at rest.

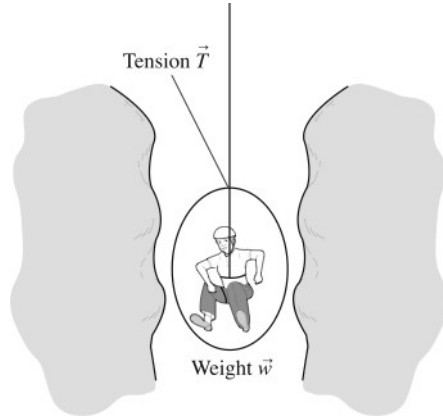
P4.6. Prepare: Draw the vector sum $\vec{F}_1 + \vec{F}_2$ of the two forces \vec{F}_1 and \vec{F}_2 . Then look for a vector that will "balance" the force vector $\vec{F}_1 + \vec{F}_2$.

Solve: The object will be in equilibrium if \vec{F}_3 has the same magnitude as $\vec{F}_1 + \vec{F}_2$ but is in the opposite direction so that the sum of all three forces is zero.



Assess: Adding the new force vector \vec{F}_3 with length and direction as shown will cause the object to be at rest.

P4.7. Prepare: Draw a picture of the situation, identify the system, in this case the mountain climber, and draw a closed curve around it. Name and label all relevant contact forces and long-range forces.

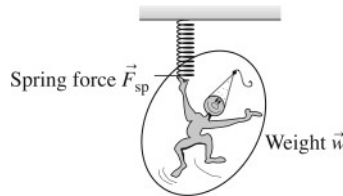


Solve: There are two forces acting on the mountain climber due to her interactions with the two agents earth and rope. One of the forces *on* the climber is the long-range weight force *by* the earth. The other force is the tension force exerted *by* the rope.

Assess: Note that the climber does not touch the sides of the crevasse so there are no forces from the crevasse walls.

P4.8. Prepare: We will follow the procedure in Tactics Box 4.2.

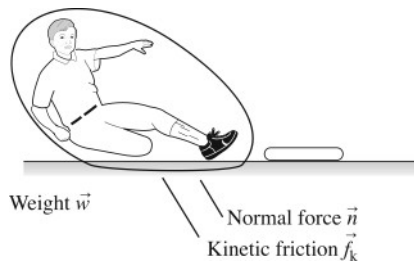
Solve: First identify the system. We are asked for forces acting on the clown, so we consider the clown as the system. A drawing of the situation is shown.



The environment touches the system at the clown's hand. The force on the clown at this point is due to the spring. The only long range force acting is gravity. There are no other contact or long range forces on the clown.

Assess: Use Tactics Box 4.2 along with Table 4.1 to identify forces on a system.

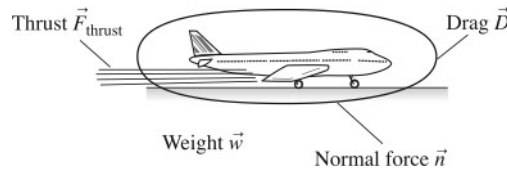
P4.9. Prepare: Draw a picture of the situation, identify the system, in this case the baseball player, and draw a closed curve around it. Name and label all relevant contact forces and long-range forces.



Solve: There are three forces acting *on* the baseball player due to his interactions with the two agents earth and ground. One of the forces *on* the player is the long-range weight force *by* the earth. Another force is the normal force exerted *by* the ground due to the contact between him and the ground. The third force is the kinetic friction force *by* the ground due to his sliding motion on the ground.

Assess: Note that the kinetic friction force would be *absent* if the baseball player were *not* sliding.

P4.10. Prepare: Draw a picture of the situation, identify the system, in this case the jet plane, and draw a closed curve around it. Name and label all relevant contact forces and long-range forces. Assume friction is negligible compared to other forces.



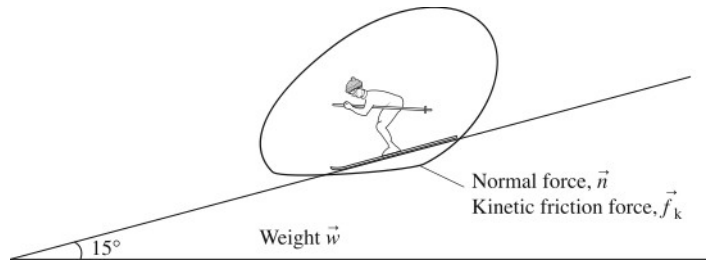
Solve: There are four forces acting *on* the jet plane due to its interactions with the four agents earth, ground, air, and the hot gases exhausted to the environment. One force *on* the plane is the long-range weight force *by* the earth. Second is the normal force exerted *by* the ground due to the plane's contact with ground. The third is the drag force *by* the air. The fourth is the thrust force exerted on the plane by the hot gas that is being let out to the environment.

Assess: Note that we left out friction force because we assumed it to be negligible.

P4.11. Prepare: We follow the outline in Tactics Box 4.2. See also Conceptual Example 4.2.

The exact angle of the slope is not critical in this problem; the answers would be very similar for any angle between 0° and 90°.

Solve: The system is the skier.



To identify forces, think of objects that are in contact with the object under consideration, as well as any long-range forces that might be acting on it. We are told to not ignore friction, but we will ignore air resistance.

The objects that are in contact with the skier are the snow-covered slope and . . . and that's all (although we will identify two forces exerted by this agent). The long-range force on the skier is the gravitational force of the earth on the skier.

One of the forces, then, is the gravitational force of the earth on the skier. This force points straight toward the center of the earth.

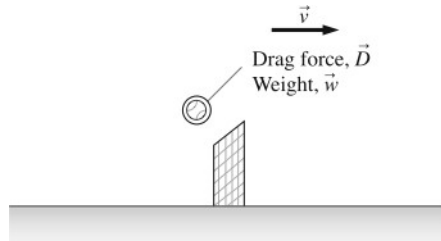
The slope, as we mentioned, exerts two forces on the skier: the normal force (directed perpendicularly to the slope) and the frictional force (directed parallel to the slope, backward from the downhill motion).

Assess: Since there are no other objects (agents) in contact with the skier (we are ignoring the air, remember?) and no other long-range forces we can identify (the gravitational force of the moon or the sun on the skier is also too small to be worth mentioning), then we have probably catalogued them all.

We are not told whether the skier has a constant velocity or is accelerating, and that factor would influence the relative lengths of the three arrows representing the forces. If the motion is constant velocity, then the vector sum of the three arrows must be zero.

P4.12. Prepare: The procedure in Tactics Box 4.2 can be used to identify all forces on the ball.

Solve: The tennis ball is the system. A picture of the situation is shown.



The environment touches the ball at the ball's surface. The force on the ball's surface is the drag force, and this is the only contact force on the system. The drag force is always opposite to the direction of motion of an object. The only long-range force acting is the ball's weight.

Assess: Tactics Box 4.2 along with Table 4.1 can be used to identify forces on a system.

P4.13. Prepare: Refer to Figure P4.13. From force = mass \times acceleration or mass = force/acceleration or mass = 1/(acceleration/force), mass is

$$m = \frac{1}{\text{slope of the acceleration-versus-force graph}}$$

A larger slope implies a smaller mass.

Solve: We know $m_2 = 0.20$ kg, and we can find the other masses relative to m_2 by comparing their slopes. Thus

$$\begin{aligned} \frac{m_1}{m_2} &= \frac{1/\text{slope 1}}{1/\text{slope 2}} = \frac{\text{slope 2}}{\text{slope 1}} = \frac{1}{5/2} = \frac{2}{5} = 0.40 \\ \Rightarrow m_1 &= 0.40 m_2 = 0.40 \times 0.20 \text{ kg} = 0.08 \text{ kg} \end{aligned}$$

Similarly,

$$\begin{aligned} \frac{m_3}{m_2} &= \frac{1/\text{slope 3}}{1/\text{slope 2}} = \frac{\text{slope 2}}{\text{slope 3}} = \frac{1}{2/5} = \frac{5}{2} = 2.50 \\ \Rightarrow m_3 &= 2.50 m_2 = 2.50 \times 0.20 \text{ kg} = 0.50 \text{ kg} \end{aligned}$$

Assess: From the initial analysis of the slopes, we had expected $m_3 > m_2$ and $m_1 < m_2$. This is consistent with our numerical answers.

P4.14. Prepare: We will use the particle model for the object and use Newton's second law.

Solve: (a) We are told that for an unknown force (call it F_0) acting on an unknown mass (call it m_A), the acceleration of the mass is 5 m/s^2 . The accelerations are 3 m/s^2 and 8 m/s^2 for objects B and C. According to Newton's second law,

$$F_0 = m_A(5 \text{ m/s}^2) = m_B(3 \text{ m/s}^2) = m_C(8 \text{ m/s}^2).$$

This means B has the largest mass.

(b) Object C has the smallest mass because it has the largest acceleration.

(c) From the equation in part (a) the ratio of mass A to mass B is $3/5$.

Assess: Since the force is constant and Newton's second law tells us the product of the mass and acceleration is equal to the force, given the accelerations finding the mass is relatively straightforward.

P4.15. Prepare: Note that an object's acceleration is linearly proportional to the net force.

Solve: (a) One rubber band produces a force F , two rubber bands produce a force $2F$, and so on. Because $F \propto a$ and two rubber bands (force $2F$) produce an acceleration of 1.2 m/s^2 , four rubber bands will produce an acceleration of 2.4 m/s^2 .

(b) Now, we have two rubber bands (force $2F$) pulling two glued objects (mass $2m$). Using $F = ma$, $2F = (2m)a \Rightarrow a = F/m = 0.60 \text{ m/s}^2$.

Assess: Newton's second law predicts that for the same mass, doubling the force doubles the acceleration. It also says that doubling mass alone halves the acceleration. These are consistent with parts (a) and (b), respectively.

P4.16. Prepare: The problem may be solved by applying Newton's second law to the present and the new situation.

Solve: (a) We are told that for an unknown force (call it F_0) acting on an unknown mass (call it m_0) the acceleration of the mass is 10 m/s^2 . According to Newton's second law

$$F_0 = m_0 (10 \text{ m/s}^2) \text{ or } F_0 / m_0 = 10 \text{ m/s}^2$$

For the new situation, the new force is $F_{\text{new}} = \frac{1}{2} F_0$, the mass is not changed ($m_{\text{new}} = m_0$) and we may find the acceleration by

$$F_{\text{new}} = m_{\text{new}} a_{\text{new}}$$

or

$$a_{\text{new}} = F_{\text{new}} / m_{\text{new}} = (F_o / 2) / m_o = (F_o / m_o) / 2 = (10 \text{ m/s}^2) / 2 = 5.0 \text{ m/s}^2$$

(b) For the new situation, the force is unchanged $F_{\text{new}} = F_o$, the new mass is $m_{\text{new}} = \frac{1}{2} m_o$ and we may find the acceleration by

$$F_{\text{new}} = m_{\text{new}} a_{\text{new}}$$

or

$$a_{\text{new}} = F_{\text{new}} / m_{\text{new}} = F_o / (m_o / 2) = 2(F_o / m_o) = 2(10 \text{ m/s}^2) = 20 \text{ m/s}^2$$

(c) A similar procedure gives $a = 10 \text{ m/s}^2$.

(d) A similar procedure gives $a = 2.5 \text{ m/s}^2$.

Assess: Knowing Newton's second law, one may obtain the answers in a qualitative manner. However the quantitative method used here usually results in fewer errors.

P4.17. Prepare: The problem may be solved by applying Newton's second law to the present and the new situation.

Solve: (a) We are told that for an unknown force (call it F_o) acting on an unknown mass (call it m_o) the acceleration of the mass is 8.0 m/s^2 . According to Newton's second law

$$F_o = m_o (8.0 \text{ m/s}^2) \text{ or } F_o / m_o = 8.0 \text{ m/s}^2$$

For the new situation, the new force is $F_{\text{new}} = 2F_o$, the mass is not changed ($m_{\text{new}} = m_o$) and we may find the acceleration by

$$F_{\text{new}} = m_{\text{new}} a_{\text{new}}$$

or

$$a_{\text{new}} = F_{\text{new}} / m_{\text{new}} = 2F_o / m_o = 2(F_o / m_o) = 2(8 \text{ m/s}^2) = 16 \text{ m/s}^2$$

(b) For the new situation, the force is unchanged $F_{\text{new}} = F_o$, the new mass is half the old mass ($m_{\text{new}} = m_o / 2$) and we may find the acceleration by

$$F_{\text{new}} = m_{\text{new}} a_{\text{new}}$$

or

$$a_{\text{new}} = F_{\text{new}} / m_{\text{new}} = F_o / 2m_o = (F_o / m_o) / 2 = (8.0 \text{ m/s}^2) / 2 = 4.0 \text{ m/s}^2$$

(c) A similar procedure gives $a = 8.0 \text{ m/s}^2$.

(d) A similar procedure gives $a = 32 \text{ m/s}^2$.

Assess: From the algebraic relationship $a = F / m$ we can see that when (a) the force is doubled, the acceleration is doubled; (b) the mass is doubled, the acceleration is halved; (c) both force and mass are doubled, the acceleration doesn't change; and (d) force is doubled and mass is halved, the acceleration will be four times larger.

P4.18. Prepare: We can use Newton's second law, Equation 4.4, to find the acceleration of the wagon with the child.

Solve: We do not know the mass of the wagon, but we do know that the same force is applied to the empty wagon as to the wagon with the child in it. We also know that the mass of the child is three times that of the wagon, so the child and wagon together have a mass of four times the mass of the empty wagon. Using Newton's second law for both the empty wagon and the wagon containing the child we have

$$a_{\text{empty wagon}} = \frac{F}{m} = 1.4 \text{ m/s}^2$$

$$a_{\text{wagon and child}} = \frac{F}{4m} = \frac{1}{4} \frac{F}{m} = \frac{1}{4} (1.4 \text{ m/s}^2) = 0.35 \text{ m/s}^2$$

Assess: We could have also used the fact that acceleration is inversely proportional to mass as discussed in Section 4.5. Since the mass is four times larger, the acceleration must be a quarter the original acceleration.

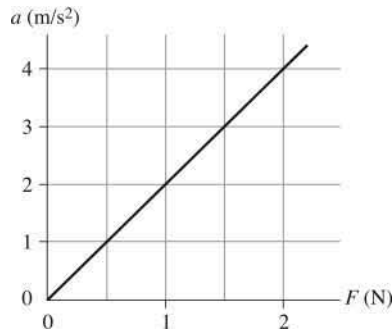
P4.19. Prepare: The principle involved is that “the acceleration is inversely proportional to the mass on which the force acts.” We will assume that the same maximum force accelerates the two-car system as was available to the one car alone.

Solve: Doubling the mass halves the acceleration if the force is the same, so the new maximum acceleration would be

$$a' = \frac{a}{2} = \frac{5.0 \text{ m/s}^2}{2} = 2.5 \text{ m/s}^2$$

Assess: Hopefully the second law has had enough time to sink into your psyche so that this just feels right.

P4.20. Prepare: Inspect the graph carefully and read off some selected values of forces.



Solve: Newton’s second law is $F = ma$. When $F = 2 \text{ N}$, we have $2 \text{ N} = (0.5 \text{ kg})a$, hence $a = 4 \text{ m/s}^2$. After repeating this procedure at various points, the previous graph is obtained.

Assess: Because F and a are linearly related, we expected a force-versus-acceleration graph to be a straight line.

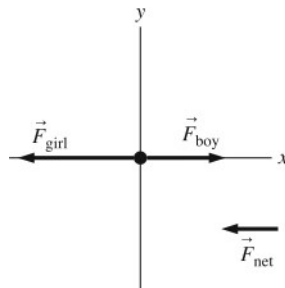
P4.21. Prepare: Refer to Figure P4.21.

Solve: Newton’s second law is $F = ma$. We can read a force and an acceleration from the graph, and hence find the mass. Choosing the force $F = 1 \text{ N}$ gives us $a = 4 \text{ m/s}^2$. Newton’s second law then yields $m = 0.25 \text{ kg}$.

Assess: Slope of the acceleration-versus-force graph is $4 \text{ m/N}\cdot\text{s}^2$, and therefore, the inverse of the slope will give the mass.

P4.22. Prepare: We can use Newton’s second law to find the acceleration of the bear.

Solve: The only forces on the bear are exerted by the girl and boy. A free-body diagram is shown.



(a) From the free-body diagram shown, the net force in the x -direction is

$$\vec{F}_{\text{Net}} = \vec{F}_{\text{Boy}} + \vec{F}_{\text{Girl}} = 15 \text{ N} - 17 \text{ N} = -2 \text{ N}$$

The net force acting on the bear is 2 N to the left. Since the net force on the bear is not zero, the bear is accelerating. Since at this instant, we know nothing about the rate at which the bear’s position is changing nothing can be said about the velocity of the bear.

(b) The bear is accelerating, since there is a net force on the bear. From part (a), the net force is 2 N to the left. We can use Newton’s second law to find the acceleration of the bear given the mass of the bear.

$$a = \frac{F_{\text{net}}}{m} = \frac{-2 \text{ N}}{0.2 \text{ kg}} = -10 \text{ m/s}^2$$

The acceleration is in the same direction as the force, to the left.

Assess: Knowing the mass of an object and the net force acting on it, Newton's second law may be used to determine its acceleration. The acceleration is always in the direction of the net force acting on an object.

P4.23. Prepare: We can use our knowledge of kinematics and our conceptual understanding of acceleration to determine the acceleration of the car and then Newton's second law to determine the force acting on the car.

Solve: First let's determine the acceleration of the car.

$$a = \Delta v / \Delta t = (v_f - v_i) / \Delta t = \left(21 \frac{\text{m}}{\text{s}} - 20 \frac{\text{m}}{\text{s}} \right) / 2.0 \text{ s} = 0.50 \text{ m/s}^2$$

Next, let's determine the force acting on the car.

$$F = ma = (1500 \text{ kg})(0.50 \text{ m/s}^2) = 7.5 \times 10^2 \text{ N}$$

Assess: It should be noted that even though we are in chapter 4 and dealing primarily with forces, it is critical that we stay up on the content of previous chapters.

P4.24. Prepare: We can use Newton's second law, Equation 4.4, to find the acceleration of the electron.

Solve: Applying Equation 4.4,

$$a = \frac{F}{m} = \frac{2.5 \times 10^{-2} \text{ N}}{9.1 \times 10^{-31} \text{ kg}} = 2.7 \times 10^{28} \text{ m/s}^2$$

Assess: As expected, this is a huge acceleration. The mass of the electron is numerically extremely small compared to the numerical value for the weight of a penny.

P4.25. Prepare: This is a straightforward application of Newton's second law: $\vec{F}_{\text{net}} = m\vec{a}$, where $m = 3.0 \times 10^8 \text{ kg}$, and $\vec{F}_{\text{net}} = \vec{F}_{\text{thrust}}$ (because we are told the supertanker is subject to no other forces), and $\vec{F}_{\text{thrust}} = 5 \times 10^6 \text{ N}$ (as given in Table 4.2).

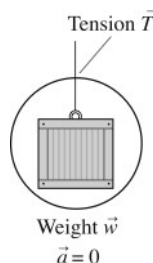
The vectors \vec{F}_{net} and \vec{a} must point in the same direction (because m is never negative), so we now compute the magnitude.

Solve: Solve the second law for a .

$$a = \frac{F_{\text{net}}}{m} = \frac{F_{\text{thrust}}}{m} = \frac{5 \times 10^6 \text{ N}}{3.0 \times 10^8 \text{ kg}} = 0.0167 \text{ m/s}^2 \approx 0.02 \text{ m/s}^2$$

Assess: It appears that there is only one significant figure in the data in Table 4.2, hence the rounding to 0.02 m/s^2 . If we assume one more significant figure in the table then we can report $a = 0.017 \text{ m/s}^2$. However, the point of the problem is clear: The rocket motor (the largest force in Table 4.2) was able to give the supertanker only an impressively small acceleration.

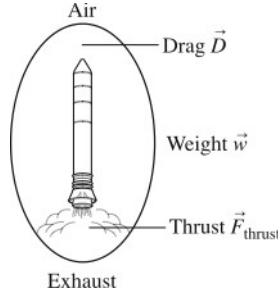
P4.26. Prepare: The free-body diagram shows two equal and opposite forces such that the net force is zero. The force directed down is labeled as a weight, and the force directed up is labeled as a tension. With zero net force the acceleration is zero. Draw as shown a picture of a real object with two forces to match the given free-body diagram.



Solve: A possible description is: “An object hangs from a rope and is at rest.” Or, “An object hanging from a rope is moving up or down with a constant speed.”

Assess: This problem and the following two problems make it clear how important it is to know all forces (and their direction) acting on an object in order to determine the net force acting on the object.

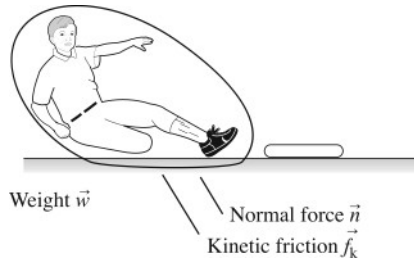
P4.27. Prepare: The free-body diagram shows three forces with a net force (and therefore net acceleration) upward. There is a force labeled \vec{w} directed down, a force \vec{F}_{thrust} directed up, and a force \vec{D} directed down. Now, draw a picture of a real object with three forces to match the given free-body diagram.



Solve: A possible description is, “A rocket accelerates upward.”

Assess: It is given that the net force is pointing up. Then, $\vec{F}_{\text{net}} = \vec{F}_{\text{thrust}} - \vec{w} - \vec{D}$ must be greater than zero. In other words, \vec{F}_{thrust} must be larger than $(\vec{w} + \vec{D})$.

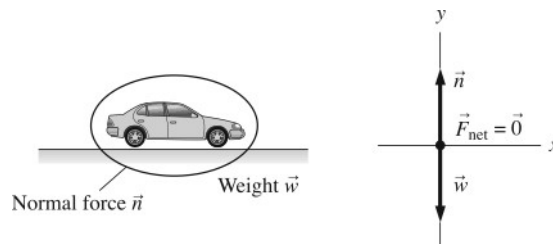
P4.28. Prepare: The free-body diagram shows three forces. There is a weight force \vec{w} , which is down. There is a normal force labeled \vec{n} , which is up. The forces \vec{w} and \vec{n} are shown with vectors of the same length so they are equal in magnitude and the net vertical force is zero. So we have an object on the ground that is not moving vertically. There is also a force \vec{f}_k to the left. This must be a frictional force and we need to decide whether it is static or kinetic friction. The frictional force is the only horizontal force, so the net horizontal force must be \vec{f}_k . This means there is a net force to the left producing an acceleration to the left. This all implies motion and therefore the frictional force is kinetic. Draw a picture of a real object with three forces to match the given free-body diagram.



Solve: A possible description is, “A baseball player is sliding into second base.”

Assess: On the free-body diagram, kinetic friction force is the only horizontal force, and it is pointing to the left. This tells us that the baseball player is sliding to the right.

P4.29. Prepare: Draw a picture of the situation, identify the system, in this case the car, and draw a closed curve around it. Name and label all relevant contact forces and long-range forces.

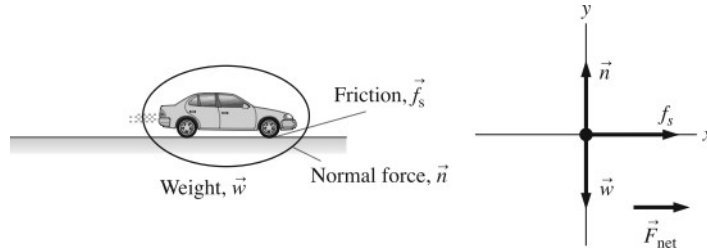


Solve: There are two forces acting *on* the car due to its interactions with the two agents the earth and the ground. One of the forces *on* the car is the long-range weight force *by* the earth. Another force is the normal force exerted *by* the ground due to the contact between the car and the ground. Since the car is sitting in the parking lot, acceleration is zero, and therefore the net force must also be zero. The free-body diagram is shown on the right.

Assess: It is implied that the car is sitting on a level parking lot, and therefore we need to consider only the vertical forces.

P4.30. Prepare: We will follow the procedures in Tactics Box 4.2 and Tactics Box 4.3.

Solve: Your car is the system. See the following diagram.



There are contact forces where the car touches the road. One of them is the normal force of the road on the car. The other is the force of static friction between the car's tires and the road, since the car is accelerating from a stop. The only long-range force acting is the weight of the car. Compare to Figure 4.31 and the discussion of propulsion in the text.

Assess: Tactics Box 4.2 and Tactics Box 4.3 give a systematic method for determining all forces on an object and drawing a free-body diagram.

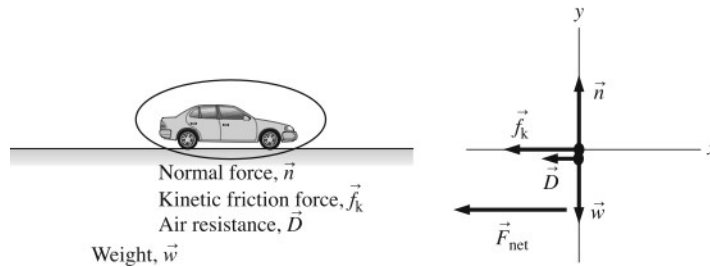
P4.31. Prepare: We follow the steps outlined in Tactics Boxes 4.2 and 4.3. We assume the road is level. We do not neglect air resistance, because at a "high speed" it is significant.

Solve: The system is your car.

(a) The objects in contact with your car are the air and the road. The road exerts two forces on the car: the normal force (directed up) and the kinetic friction force (directed horizontally back, parallel to the road). The air exerts a drag force (air resistance) on the car in the same direction as the friction force (i.e., opposite the velocity). The downward pull of the earth's gravitational force is the long-range force.

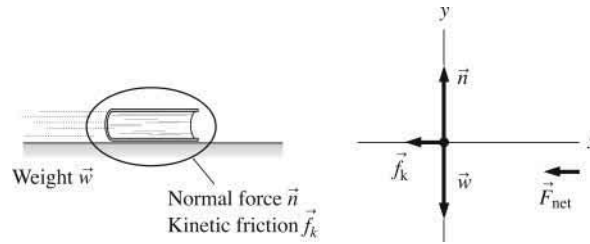
You could slow to a stop by air resistance alone if you are patient. You could also eventually slow to a stop by the friction of the road on the car (tires), but pressing on the brakes greatly increases the friction force and slows you down more quickly.

(b)



Assess: \vec{F}_{net} points to the left, as does the \vec{a} for a car that is moving to the right but slowing down.

P4.32. Prepare: Draw a picture of the situation, identify the system, in this case the physics textbook, and draw a closed curve around it. Name and label all relevant contact forces (the normal force and kinetic friction) and long-range forces (weight).

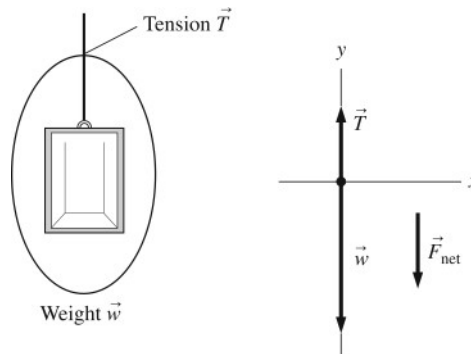


Solve: There are three forces acting *on* the physics textbook due to its interactions with the two agents the earth and the table. One of the forces *on* the book is the long-range weight force *by* the earth. Forces exerted *on* the book by the table are the normal force and the force of kinetic friction. The normal force exerted *by* the surface of the table is due to the contact between the book and the table. The force of kinetic friction exerted *by* the surface of the table is due to the sliding contact between the book and the table. Since the textbook is slowing down, it has an acceleration and hence net force. The free-body diagram is shown on the right.

Assess: The problem uses the word “sliding.” Any real sliding situation involves kinetic friction with the surface the object is sliding over. The force of kinetic friction always opposes the motion of the object.

P4.33. Prepare: Follow the steps outlined in Tactics Boxes 4.2 and 4.3. Draw a picture of the situation, identify the system, in this case the elevator, and draw a closed curve around it. Name and label all relevant contact forces (the tension) and long-range forces (weight).

Solve:

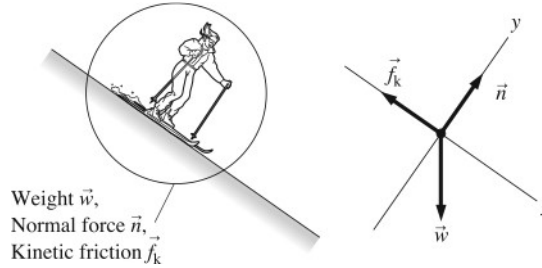


There are two forces acting *on* the elevator due to its interactions with the two agents earth and the cable. One of the forces *on* the elevator is the long-range weight force *by* the earth. Another force is the tension force exerted *by* the cable due to the contact between the elevator and the cable. Since the elevator is coming to a stop while ascending, it has a negative acceleration, hence a negative net force. As a result, we know that the length of the vector representing the weight of the elevator must be greater than the length of the vector representing the tension in the cable. The free-body diagram is shown in the previous diagram on the right.

Assess: There are only two forces on the elevator. The weight is directed down and the tension in the cable is directed up. Since the elevator is slowing down (has a negative acceleration) the tension must be less than the weight.

P4.34. Prepare: Follow the steps outlined in Tactics Boxes 4.2 and 4.3. Draw a picture of the situation, identify the system, in this case the skier, and draw a closed curve around it. Name and label all relevant contact forces (normal and kinetic friction) and long-range forces (weight). For the force diagram, identify an appropriate coordinate system (parallel and perpendicular to the motion of the skier), draw and label all forces and then the net force acting on the skier.

Solve:



There are three forces acting *on* the skier due to interactions with the two agents earth and the snow. One of the forces is the long-range weight force *by* the earth. Forces exerted on the skier by the snow are the normal force and the force of kinetic friction. The normal force exerted *by* the snow is due to the contact between the snow and the skier. The force of kinetic friction exerted *by* the snow is due to the sliding contact between the snow and skier. Since the skier is traveling down the slope at a constant speed, there is no acceleration and hence no net force. The free-body diagram is shown on the right.

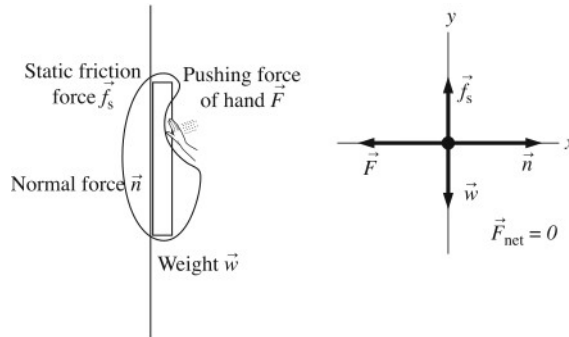
Assess: There is a lot more to this problem than we are presently able to appreciate. After you master the content of chapter 5, you will be able to appreciate your physics growth by looking at this problem again. The language and the ideas you will use then as opposed to now will be considerably more sophisticated.

P4.35. Prepare: We follow the steps outlined in Tactics Boxes 4.2 and 4.3.

Solve: The system is the picture.

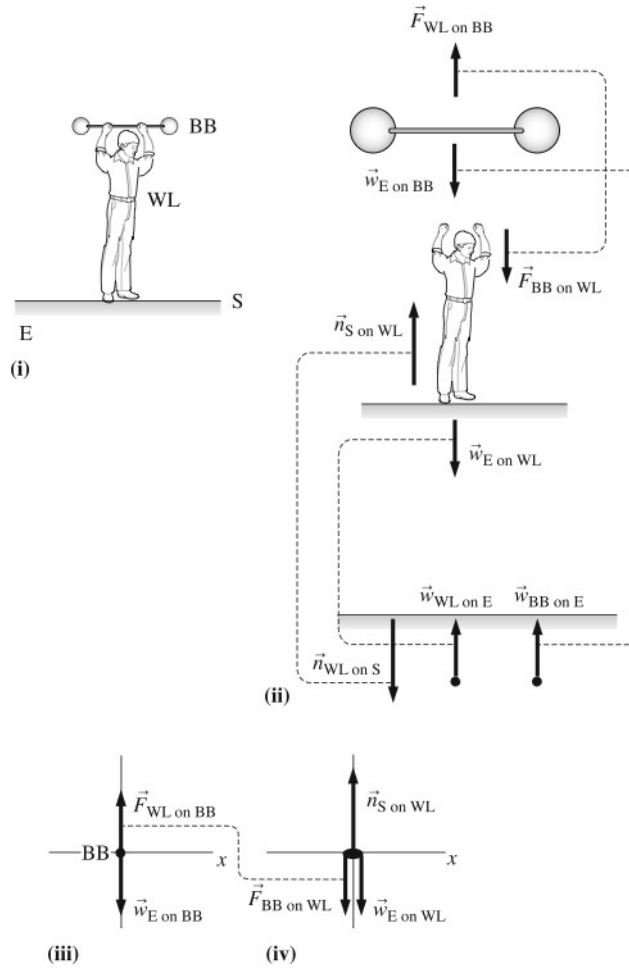
The objects in contact with the picture are the wall and your hand. The wall exerts a normal force (opposite the pushing force of the hand) and a static friction force, which is directed upward and prevents the picture from falling down.

The important long-range force is the gravitational force of the earth on the picture (i.e., the weight).



Assess: The net force is zero, as it should be for an object which is motionless (isn't accelerating).

P4.36. Prepare: Draw a picture of the situation, identify the objects and agents, and the pair-wise interactions between them. There are four objects, namely the weightlifter, a barbell, a rough surface (floor), and the earth. Name and label all relevant contact forces and long-range forces.



Solve: Figure (i) shows a weightlifter (WL) holding a heavy barbell (BB) across his shoulders. He is standing on a rough surface (S) that is a part of the earth (E). We distinguish between the surface (S), which exerts a contact force, and the earth, which exerts the long range force of gravity. Figure (ii) shows the barbell, the weightlifter, and the earth separated from one another. This separation helps to indicate the forces acting on each object. Figures (iii) and (iv) are free-body diagrams for the barbell and the weightlifter, respectively.

Altogether there are four interactions. There is the interaction between the barbell and the weightlifter, the weightlifter and the surface of the earth (contact force), the barbell and the earth, and the weightlifter and the earth. The interaction between the barbell and the weightlifter leads to two forces: $\vec{F}_{\text{WL on BB}}$ and $\vec{F}_{\text{BB on WL}}$. This is an action/reaction pair of forces. The interaction between the weightlifter and the surface of the earth is a contact interaction leading to $\vec{n}_{\text{S on WL}}$ and $\vec{n}_{\text{WL on S}}$. These two forces also constitute an action/reaction pair. The weight force $\vec{w}_{\text{E on BB}}$ has its action/reaction force $\vec{w}_{\text{BB on E}}$, and the weight force $\vec{w}_{\text{E on WL}}$ has its action/reaction pair force $\vec{w}_{\text{WL on E}}$.

Assess: Note that if we are studying a particular object, say the weightlifter, all the other three objects (barbell, rough surface, and earth) will be the agents interacting with the chosen object (in this case the weightlifter). In other words, the terms “object” and “agent” are interchangeable depending on which one is chosen to be the object.

P4.37. Prepare: Knowing that for every action there is an equal and opposite reaction and that these forces are exerted on different objects, we can identify, draw and label all the action-reaction pairs. Knowing all the forces acting on skater 2, we can construct a free-body diagram for skater 2.

Solve:

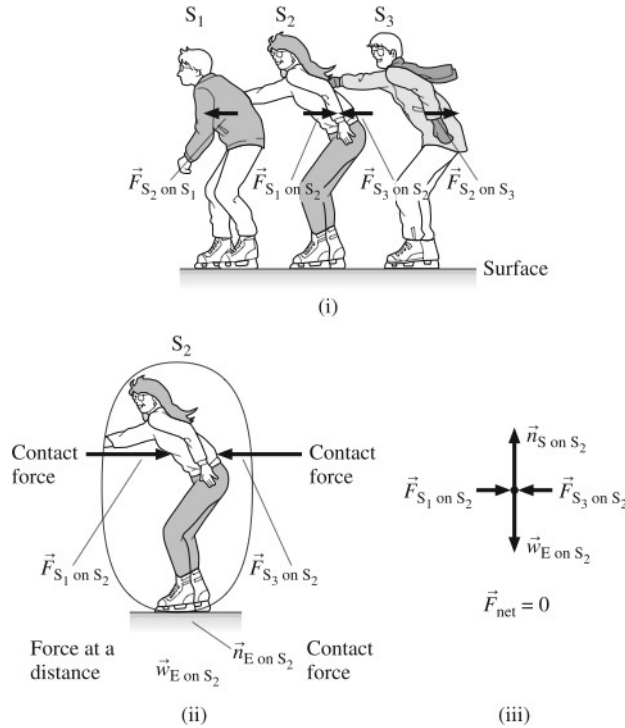


Figure (i) shows all three skater and the pair-wise interactions (connected by the dashed line) between them. Figure (ii) identifies skater 2 as the object of interest, shows the three contact forces that act on her, and the one long-range force that acts on her. Finally Figure (iii) shows a free body diagram for skater 2.

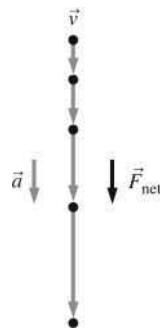
Assess: We have been informed that there is no friction and that the skaters are standing. If this is the case the net force acting on skater 2 should be zero. Also note that the action reaction pairs act on different objects.

P4.38. Prepare: Knowing that for every action there is an equal and opposite reaction and that these forces are exerted on different objects, we can identify all the action-reaction pairs.

Solve: When the girl stands on the sofa there is only one action-reaction pair of forces acting between the girl and the sofa. This action pair consist of the force the girl exerts on the sofa and the force the sofa exerts on the girl.

Assess: The two forces involved in an action pair act on two different objects. The girl exerts a force on the sofa (one object) and the sofa exerts a force on the girl (the other object).

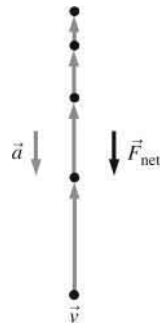
P4.39. Prepare: Redraw the motion diagram as shown.



Solve: The previous figure shows velocity as downward, so the object is moving down. The length of the vector increases showing that the speed is increasing (like a dropped ball). Thus, the acceleration is directed down. Since $\vec{F} = m\vec{a}$, the force is in the same direction as the acceleration and must be directed down.

Assess: Since the object is speeding up, the acceleration vector must be parallel to the velocity vector and the net force must be parallel to the acceleration. In order to determine the net force, we had to combine our knowledge of motion diagrams, kinematics, and dynamics.

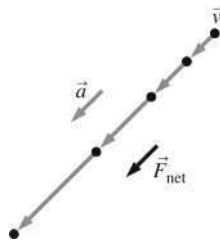
P4.40. Prepare: Redraw the motion diagram as shown.



Solve: The previous figure shows the velocity as upward, so the object is moving upward. But the length of the vector decreases with each step showing that the speed is decreasing (like a ball thrown up). Thus, the acceleration is directed down. Since $\vec{F} = m\vec{a}$, the force is in the same direction as the acceleration and must be directed down.

Assess: Since the object is slowing down, the acceleration vector must be antiparallel to the velocity vector and the net force must be parallel to the acceleration. In order to determine the net force, we had to combine our knowledge of motion diagrams, kinematics, and dynamics.

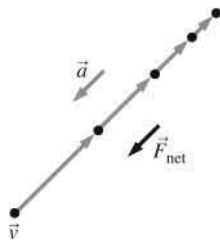
P4.41. Prepare: Redraw the motion diagram as shown.



Solve: The velocity vector in the previous figure is shown downward and to the left. So movement is downward and to the left. The velocity vectors get successively longer which means the speed is increasing. Therefore the acceleration is downward and to the left. By Newton's second law $\vec{F} = m\vec{a}$, the net force must be in the same direction as the acceleration. Thus, the net force is downward and to the left.

Assess: Since the object is speeding up, the acceleration vector must be parallel to the velocity vector. This means the acceleration vector must be pointing along the direction of velocity. Therefore the net force must also be downward and to the left.

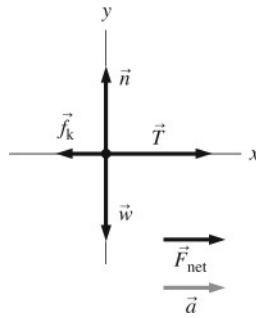
P4.42. Prepare: Redraw the motion diagram as shown.



Solve: The velocity vector shown is upward and to the right. So movement is upward and to the right. The velocity vector gets successively shorter which means the speed is decreasing. Therefore the acceleration is downward and to the left. By Newton's second law $\vec{F} = m\vec{a}$, the net force must be in the same direction as the acceleration. Thus, the net force is downward and to the left.

Assess: Since the object is slowing down, the acceleration vector must be antiparallel to the velocity vector. This means the acceleration vector must be pointing in the opposite direction of velocity. Therefore the net force must also be pointing in the opposite direction of velocity. In other words, the net force must be downward and to the left.

P4.43. Prepare: Redraw the motion diagram as shown.

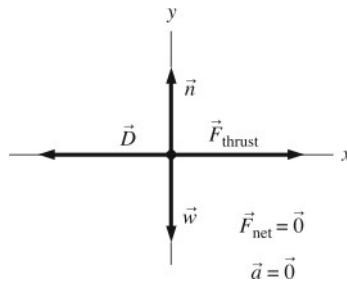


Solve: (a)–(c) Since the net force is to the right, the acceleration will also be to the right.

(d) There is a normal force and a weight, which are equal and opposite, so this is an object on a horizontal surface. The description could be, “A tow truck pulls a stuck car out of the mud.”

Assess: Our scenario seems to fit the free-body diagram. Check by doing the last part of the problem first: Start with the scenario and then draw a free-body diagram. Make sure it matches the original.

P4.44. Prepare: Redraw the motion diagram as shown.

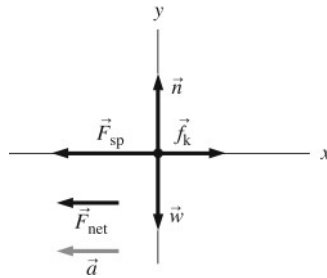


Solve: (a)–(c) Since the net force is zero, the acceleration will also be zero.

(d) There is a normal force and a weight, which are equal and opposite, so this is an object on a horizontal surface. The description of this free-body diagram could be, “A jet plane is flying at constant speed.”

Assess: The scenario fits the free-body diagram. Check by doing the last part of the problem first: Start with the scenario and then draw a free-body diagram. Make sure it matches the original.

P4.45. Prepare: Redraw the motion diagram as shown.

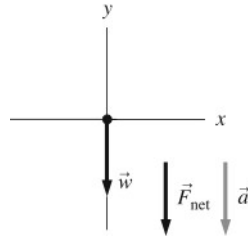


Solve: (a)–(c) The net force is to the left. Therefore acceleration will also be to the left.

(d) This is an object on a surface because $w = n$. It must be moving to the left because the kinetic friction is to the right. The description of the free-body diagram could be, “A compressed spring is shooting a plastic block to the left.”

Assess: The scenario fits the free-body diagram. Check by doing the last part of the problem first: Start with the scenario and then draw a free-body diagram. Make sure it matches the original.

P4.46. Prepare: Redraw the motion diagram as shown.

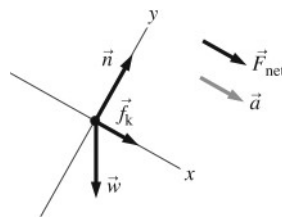


Solve: (a)–(c) The net force is pointing down. Therefore acceleration will also be pointing down.

(d) The description is, “Galileo has dropped a ball from the Leaning Tower of Pisa and we are ignoring friction.”

Assess: The scenario fits the free-body diagram. Check by doing the last part of the problem first: Start with the scenario and then draw a free-body diagram. Make sure it matches the original.

P4.47. Prepare: Redraw the motion diagram as shown.

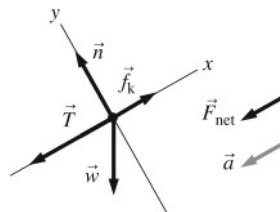


Solve: (a)–(c) There is an object on an inclined surface. The net force is down the plane so the acceleration is down the plane. The net force includes both the frictional force and a component of the weight. Since kinetic friction opposes the motion, the object must be traveling up the incline.

(d) The description could be, “A crate is sliding up a ramp.”

Assess: We must look at all the forces and the nature of these forces to accurately determine what will happen to the object.

P4.48. Prepare: Redraw the motion diagram as shown.

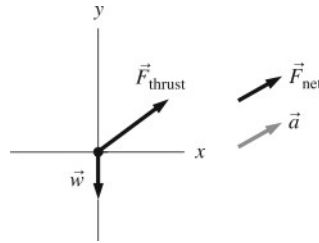


Solve: (a)–(c) There is an object on an inclined surface with a tension force down the surface. There is a small frictional force up the surface implying that the object is sliding down the slope. The force vector and the acceleration vector are in the same direction.

(d) A description could be, “A sled is being pulled down a slope with a rope that is parallel to the slope.”

Assess: Knowing that kinetic friction opposes the motion of an object, we are able to establish that the sled is travelling down the slope. It is essential that we look at all the forces and the nature of these forces to accurately determine what will happen to the object.

P4.49. Prepare: Redraw the motion diagram as shown.



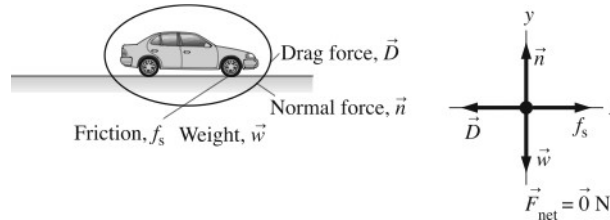
Solve: (a)–(c) There is a thrust at an angle to the horizontal and a weight. There is no normal force so the object is not on a surface. Adding the thrust and the weight we obtain a net force that acts as shown in the figure. The acceleration acts in the direction of the net force.

(d) The description could be, “A rocket is fired at an angle to the horizontal and there is no drag force.”

Assess: It is essential that we look at all the forces and the nature of these forces to accurately determine what will happen to the object.

P4.50. Prepare: Refer to Tactics Box 4.2 and Tactics Box 4.3 for identification of forces and for drawing free-body diagrams. We will draw a correct free-body diagram and compare.

Solve: Your car is the system. See the following diagram.



There are contact forces where the car touches the road. One of them is the normal force of the road on the car. The other is the force of static friction between the car's tires and the road since the car is moving. Compare to Figure 4.32 and the discussion of propulsion in the text.

In addition to this there must be a force in the opposite direction to the car's motion, since the car is moving at constant speed. If only the frictional force acted in the horizontal direction, the car would be accelerating! The diagram omits one of the forces. A possible force that acts in this direction is the force of air drag on the car, which is indicated on the diagram.

The only long-range force acting is the weight of the car.

The diagram also identifies the weight of the car and the normal force on the car as an action/reaction pair. This isn't possible, since both these forces act on the same object, while action/reaction pairs always act on *different* objects. The normal force on an object and its weight are *never* action/reaction pairs.

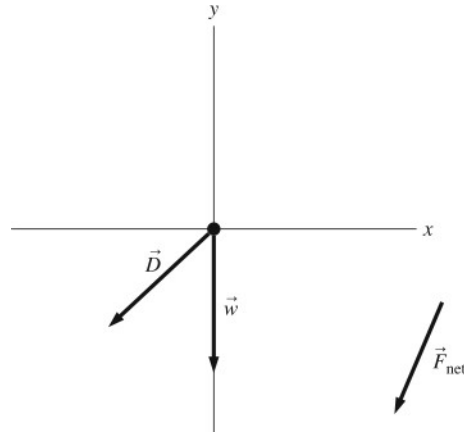
Assess: In order for an object to be moving at constant velocity, the net force on it must be zero. Action/reaction pairs always act on two different objects.

P4.51. Prepare: Review Tactics Box 4.3 about drawing free-body diagrams.

Solve: One error is that there isn't a force along the direction of motion in this case; \vec{F}_{motion} should be erased completely.

Another error is that the drag force should be opposite the direction of the velocity, not straight left.

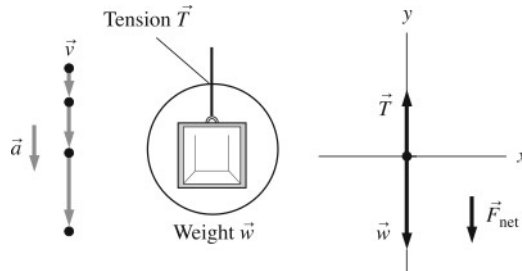
A correct free-body diagram would be



The acceleration (not shown) is in the same direction as \vec{F}_{net} . The velocity (not shown) is up to the right, opposite the drag force.

Assess: Motion is not a force. To draw a free-body diagram you must simply consider all of the forces acting *on* the object of interest. Do this by considering which objects are in contact with the object of interest, and which long-range forces act on the object.

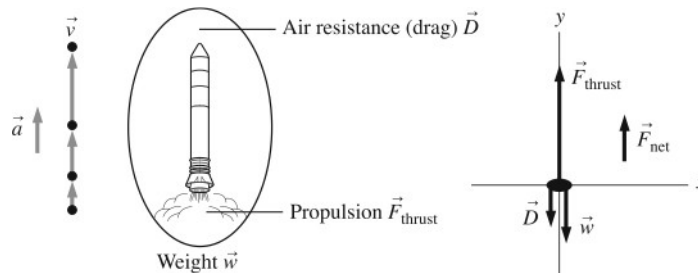
P4.52. Prepare: There are two forces acting *on* the elevator due to its interactions with the two agents the earth and the cable. One of the forces *on* the elevator is the long-range weight force *by* the earth. Another force is the tension force exerted *by* the cable due to the contact between the elevator and the cable. Since the elevator is speeding up as it descends its acceleration is pointing downward. Tension is the only contact force. The downward acceleration implies that $w > T$. Therefore the net force on the elevator must also point downward.



Solve: A force-identification diagram, a motion diagram, and a free-body diagram are shown.

Assess: You now have three important tools in your “Physics Toolbox,” motion diagrams, force diagrams, and free-body diagrams. Careful use of these tools will give you an excellent conceptual understanding of a situation.

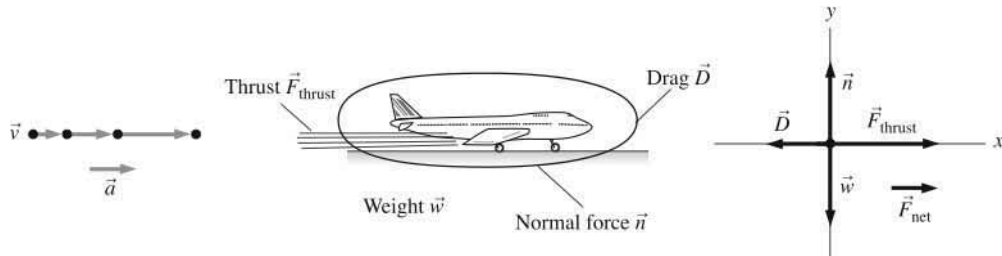
P4.53. Prepare: There are three forces acting *on* the rocket due to its interactions with the three agents the earth, the air, and the hot gases exhausted to the environment. One force on the rocket is the long-range weight force *by* the earth. The second force is the drag force *by* the air. The third is the thrust force exerted on the rocket *by* the hot gas that is being let out to the environment. Since the rocket is being launched upward, it is being accelerated upward. Therefore, the net force on the rocket must also point upward. Draw a picture of the situation, identify the system, in this case the rocket, and draw a motion diagram. Draw a closed curve around the system, and name and label all relevant contact forces and long-range forces.



Solve: A force-identification diagram, a motion diagram, and a free-body diagram are shown.

Assess: You now have three important tools in your "Physics Toolbox," motion diagrams, force diagrams, and free-body diagrams. Careful use of these tools will give you an excellent conceptual understanding of a situation.

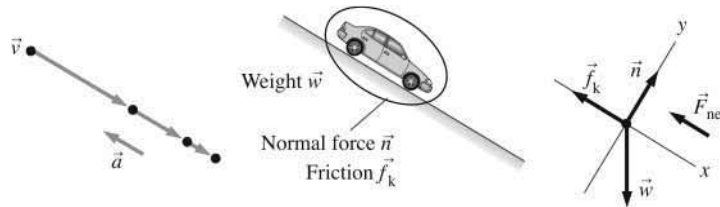
P4.54. Prepare: The normal force is perpendicular to the ground. The thrust force is parallel to the ground and in the direction of acceleration. The drag force is opposite to the direction of motion. There are four forces acting *on* the jet plane due to its interactions with the four agents the earth, the air, the ground, and the hot gases exhausted to the environment. One force on the rocket is the long-range weight force *by* the earth. The second force is the drag force *by* the air. Third is the normal force on the rocket *by* the ground. The fourth is the thrust force exerted on the jet plane *by* the hot gas that is being let out to the environment. Since the jet plane is speeding down the runway, its acceleration is pointing to the right. Therefore, the net force on the jet plane must also point to the right. Now, draw a picture of the situation, identify the system, in this case the jet plane, and draw a motion diagram. Draw a closed curve around the system, and name and label all relevant contact forces and long-range forces.



Solve: A force-identification diagram, a motion diagram, and a free-body diagram are shown.

Assess: You now have three important tools in your "Physics Toolbox," motion diagrams, force diagrams, and free-body diagrams. Careful use of these tools will give you an excellent conceptual understanding of a situation.

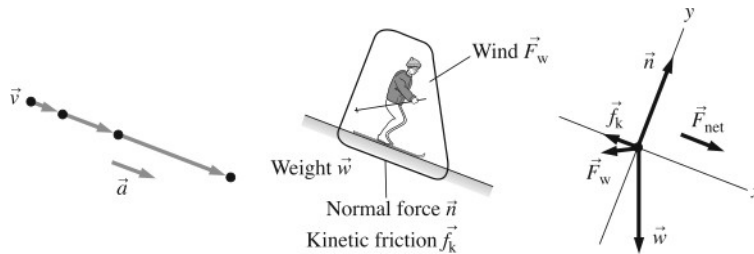
P4.55. Prepare: The normal force is perpendicular to the hill. The frictional force is parallel to the hill.



Solve: A force-identification diagram, a motion diagram, and a free-body diagram are shown.

Assess: You now have three important tools in your "Physics Toolbox," motion diagrams, force diagrams, and free-body diagrams. Careful use of these tools will give you an excellent conceptual understanding of a situation.

P4.56. Prepare: There are four forces acting *on* the skier due to his interactions with the three agents: the slope, the earth, and the wind. One force on the skier is the long-range weight force *by* the earth. A second force is the normal force on the skier *by* the slope. A third is the kinetic friction on the skier by the slope. And the fourth force is due to the wind on the skier. We will assume that the horizontal force due to the wind is not too large to cause significant deceleration. Since the friction is small and the sloping angle is reasonably large, we will argue that the skier is accelerating down the slope. The net force on the skier thus points downward along the slope. Now, draw a picture of the situation, identify the system, in this case the skier, and draw a motion diagram. Draw a closed curve around the system, and name and label all relevant contact forces and long-range forces.

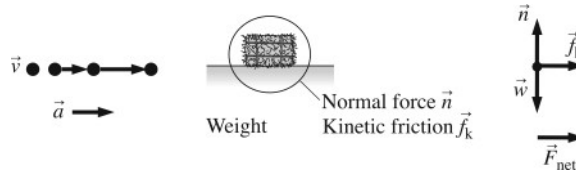


Solve: A force-identification diagram, a motion diagram, and a free-body diagram are shown.

Assess: Since the skier's acceleration is down the slope, the sum of the kinetic friction and the component of the wind force up the slope must be smaller than the weight component pointing down along the slope.

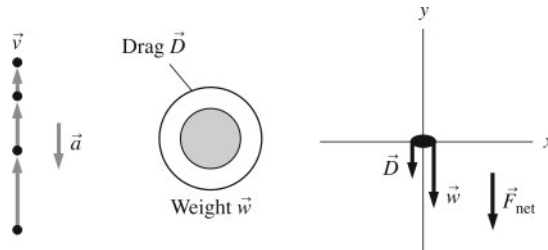
P4.57. Prepare: There are three forces acting on the bale of hay due to its interactions with the two agents: the earth and the bed of the truck. The two contact forces between the bale of hay and the bed of the truck are the normal force and the force of kinetic friction which is dragging the bale of hay forward (even though it is sliding backward). The force at a distance is the force the earth exerts on the bale of hay (the weight). Since the normal force and the weight are equal in magnitude and opposite in direction, there is no net vertical force. Since the force of kinetic friction provides a net horizontal force, the net force acting on the bale of hay and hence the acceleration of the bale of hay is in the direction of the force of kinetic friction. Now, draw a picture of the situation, identify the system, in this case the bale of hay, and draw a motion diagram. Draw a closed curve around the system, and name and label all relevant contact forces and long-range forces.

Solve:



Assess: Since there is a net or unbalanced force acting on the bale of hay, it will experience an acceleration in the direction of this force.

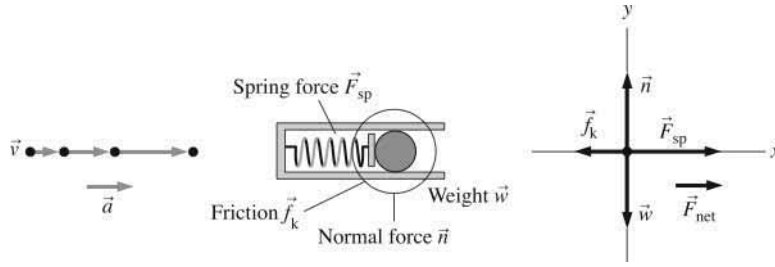
P4.58. Prepare: There are two forces acting on the Styrofoam ball due to its interactions with the two agents: the earth and the air. One force on the ball is the long-range weight force by the earth. A second force is the downward air drag force on the ball by the air. Since the ball is slowing down while going up, the ball's acceleration points downward. Therefore, the net force on the ball must also point downward. Now draw a picture of the situation, identify the system, in this case the Styrofoam ball, and draw a free-body diagram. Draw a closed curve around the system, and name and label all relevant contact forces and long-range forces.



Solve: A force-identification diagram, a motion diagram, and a free-body diagram are shown.

Assess: The drag force due to the air is opposite the motion.

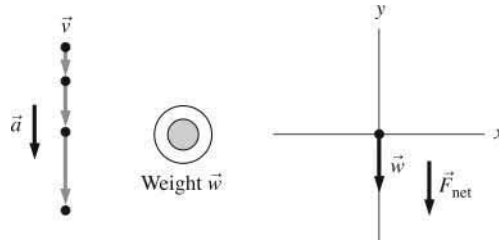
P4.59. Prepare: The ball rests on the floor of the barrel because the weight is equal to the normal force. There is a force of the spring to the right, which causes acceleration. The force of kinetic friction is smaller than the spring force. Now, draw a picture of the situation, identify the system, in this case the plastic ball, and draw a motion diagram. Draw a closed curve around the system, and name and label all relevant contact forces and long-range forces.



Solve: A force-identification diagram, a motion diagram, and a free-body diagram are shown.

Assess: Since the normal force acting on the ball and the weight of the ball are equal in magnitude and opposite in direction, the ball experiences no vertical motion. Since the spring exerts a greater force on the ball than kinetic friction, the ball accelerates out the barrel of the gun.

P4.60. Prepare: There are no contact forces on the rock. There is only one force acting *on* the rock due to its interaction with one agent, the earth. Since weight force points down, the acceleration must also point downward. Now, draw a picture of the situation, identify the system, in this case the rock, and draw a motion diagram. Draw a closed curve around the system, and name and label all relevant contact forces and long-range forces.

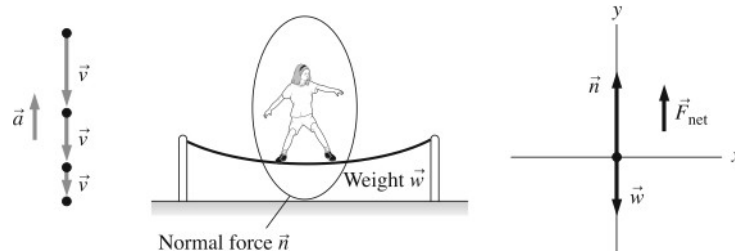


Solve: A force-identification diagram, a motion diagram, and a free-body diagram are shown.

Assess: If there is only one force acting on an object, that will be the net force.

P4.61. Prepare: The gymnast experiences the long range force of weight. There is also a contact force from the trampoline, which is the normal force of the trampoline on the gymnast. The gymnast is moving downward and the trampoline is decreasing her speed, so the acceleration is upward and there is a net force upward. Thus the normal force must be larger than the weight. The actual behavior of the normal force will be complicated as it involves the stretching of the trampoline and therefore tensions.

Now, draw a picture of the situation, identify the system, in this case the gymnast, and draw a motion diagram. Draw a closed curve around the system, and name and label all relevant contact forces and long-range forces.

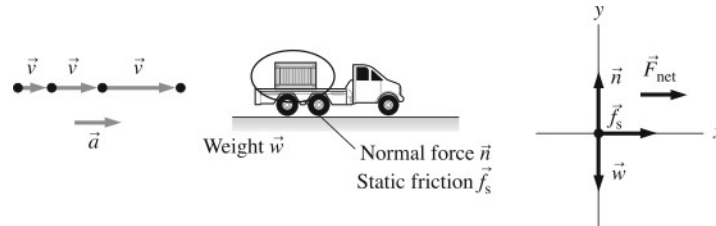


Solve: A force-identification diagram, a motion diagram, and a free-body diagram are shown.

Assess: There are only two forces on the gymnast. The weight force is directed downward and the normal force is directed upward. Since the gymnast is slowing down right after after making contact with the trampoline, upward normal force must be larger than the downward weight force.

P4.62. Prepare: You can see from the motion diagram that the box accelerates to the right along with the truck. According to Newton's second law, $\vec{F} = m\vec{a}$, there must be a force to the *right* acting on the box. This is friction, but not kinetic friction. The box is not sliding against the truck. Instead, it is static friction, the force that prevents slipping. Were it not for static friction, the box would slip off the back of the truck. Static friction acts in the direction needed to prevent slipping. In this case, friction must act in the forward (toward the right) direction.

Now, draw a picture of the situation, identify the system, in this case the heavy box, and draw a motion diagram. Draw a closed curve around the system, and name and label all relevant contact forces and long-range forces.



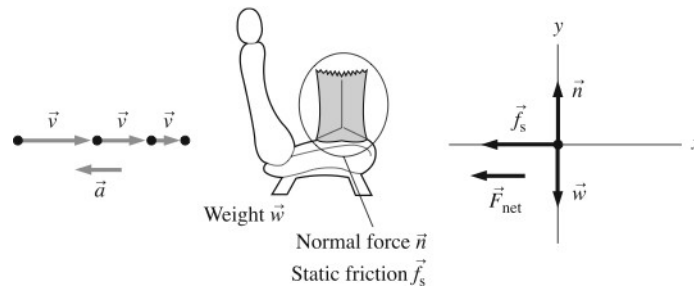
Solve: There are three forces acting on the heavy box due to its interactions with the two agents the earth and the truck's floor. One force on the box is the long-range weight force *by* the earth. A second force is the static friction force *by* the truck's floor. A third is the normal force on the box *by* the truck's floor. Since the box is not sliding on the truckbed, its acceleration will be the same as the truck's acceleration, which is pointing to the right. Therefore, the net force on the box must also be pointing to the right.

A force-identification diagram, a motion diagram, and a free-body diagram are shown.

Assess: There is only one horizontal force, the static friction force, acting on the heavy box. Since the box is moving on a level ground, weight force must equal normal force.

P4.63. Prepare: You can see from the motion diagram that the bag accelerates to the left along with the car as the car slows down. According to Newton's second law, $\vec{F} = m\vec{a}$, there must be a force to the *left* acting on the bag. This is friction, but not kinetic friction. The bag is not sliding across the seat. Instead, it is static friction, the force that prevents slipping. Were it not for static friction, the bag would slide off the seat as the car stops. Static friction acts in the direction needed to prevent slipping. In this case, friction must act in the backward (toward the left) direction.

Now, draw a picture of the situation, identify the system, in this case the bag of groceries, and draw a motion diagram. Draw a closed curve around the system, and name and label all relevant contact forces and long-range forces.



Solve: A force-identification diagram, a motion diagram, and a free-body diagram are shown.

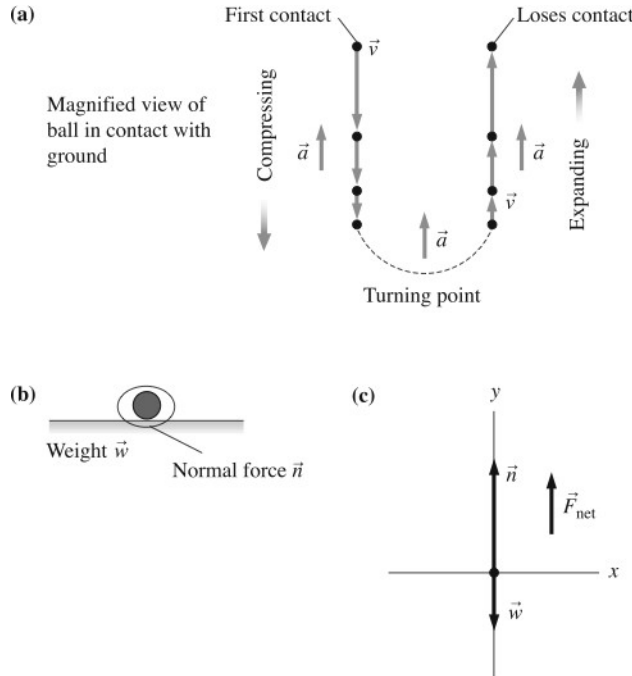
Assess: Since the normal force acting on the bag of groceries and the weight of the groceries are equal in magnitude and opposite in direction, the bag experiences no vertical motion. The only horizontal force acting on the bag of groceries is static friction, and it provides the net force acting on the bag which results in the acceleration of the bag.

P4.64. Prepare: Draw a picture of the situation, identify the system, in this case the rubber ball, and draw a motion diagram. Draw a closed curve around the system, and name and label all relevant contact forces and long-range forces.

Solve: (a) During the brief time interval that the rubber ball is in contact with the floor, there are two forces acting on the ball due to its interactions with the two agents the earth and the floor. One force on the ball is the long-range weight force *by* the earth. A second force is the normal force *by* the horizontal surface of the floor. During compression of the ball, it moves downward with steadily decreasing speed, reaches zero velocity at the instant of maximum compression, then its speed increases steadily while expanding. The ball rises up at increasing speed, and begins to slow down at the point where it loses contact with the floor.

(b) The forces are identified as the weight force and normal force.

(c) The free-body diagram is shown below during the time the ball is in contact with the floor (ground). During this time there is a net force acting on the ball pointing in the upward direction.

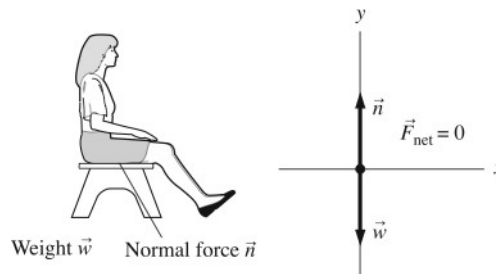


(d) The ball accelerates downward until the instant when it makes contact with the ground. Once it makes contact, it begins to compress and to slow down. The compression takes a short but nonzero distance, as shown in the motion diagram. The point of maximum compression is the turning point, where the ball has an instantaneous speed of $v = 0$ m/s and reverses direction. The ball then expands and speeds up until it loses contact with the ground. The motion diagram shows that the acceleration vector \vec{a} points *upward* the entire time that the ball is in contact with the ground. An upward acceleration implies that there is a net upward force \vec{F}_{net} on the ball. The only two forces on the ball are its weight downward and the normal force of the ground upward. To have a net force upward requires $n > w$. So the ball bounces because the normal force of the ground *exceeds* the weight, causing a net upward force during the entire time that the ball is in contact with the ground. This net upward force slows the ball, turns it, and accelerates it upward until it loses contact with the ground. Once contact with the ground is lost, the normal force vanishes and the ball is simply in free fall.

Assess: The normal force acts on the ball only while it is in contact with the floor. Since the normal force is larger than the weight of the ball, it first slows the ball to an instantaneous stop and then accelerates the ball vertically upward until it loses contact with the ball.

P4.65. Prepare: To solve this problem, we will need to think carefully about the forces acting on the object of interest (the passenger in the car). It will also be important to determine what is meant by a *very* slippery bench.

Solve:

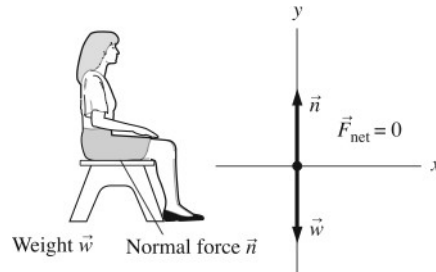


(a) The passenger is sitting on a *very* slippery bench in a car that is traveling to the right. Both the passenger and the seat are moving with a constant speed. There is a force on the passenger due to her weight, which is directed down. There is a contact force (the normal force) between the passenger and the seat, which is directed

up. Since the passenger is not accelerating up or down, the net vertical force on her is zero, which means the two vertical forces are equal in magnitude. The statement of the problem gives no indication of any other contact forces. Specifically, we are told that the seat is *very slippery*. We can take this to mean there is no frictional force. So our force diagram includes only the normal force up, the weight down, but no horizontal force.

(b) The above considerations lead to the free-body diagram shown in the previous figure.

(c) The car (and therefore the *very slippery* seat) begins to slow down. Since the seat cannot exert a force of friction (either static or kinetic) on the passenger, the passenger cannot slow down as fast as the seat which is attached to the car. As a result the passenger continues to move forward with the initial speed of the car. Since the forces acting on the passenger remain the same, the free-body diagram is unchanged but the pictorial representation of the passenger is changed. These are shown in the following diagram.



(d) The car slows down because of some new contact force on the car (maybe the brakes lock the wheels and the road exerts a force on the tires). But there is no new contact force on you *the passenger*. The force diagram for the passenger remains unchanged, there are no horizontal forces on you. You do not slow down, but rather continue at an unchanged velocity until something in the picture changes for you (for example, you slide off the seat or hit the windshield). (e) The net force on you has remained zero because the net vertical force is zero and there are no horizontal forces. According to Newton's first law, if the net force on you is zero, then you continue to move in a straight line with a constant velocity. That is what happens to you when the car slows down. You continue to move forward with a constant velocity. The statement that you are "thrown forward" is misleading and incorrect. To be "thrown" there would need to be a net force on you and there is none. It might be correct to say that the car has been "thrown backward" leaving you to continue onward (until you part company with the seat).

Assess: Careful thinking and precise language, aided by a good diagram and understanding of Newton's first and second laws, are needed to articulate the solution of this problem.

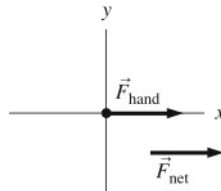
P4.66. Prepare: Assume the ball undergoes constant acceleration during the pitch so we can use the kinematic equations in Table 2.4.

$$(v_x)_f^2 = (v_x)_i^2 + 2a_x \Delta x$$

Use coordinates where $+x$ is in the direction the ball is thrown. We are given $\Delta x = 1.0$ m, $(v_x)_f = 46$ m/s, and $m = 0.145$ kg. Assume $(v_x)_i = 0.0$ m/s.

We'll first solve for a_x and then use Newton's second law to find the average force.

Solve: (a)



(b) Solve the equation for a_x .

$$a_x = \frac{(v_x)_f^2 - (v_x)_i^2}{2\Delta x} = \frac{(46 \text{ m/s})^2 - (0.0 \text{ m/s})^2}{2(1.0 \text{ m})} = 1060 \text{ m/s}^2$$

$$F_x = ma_x = (0.145 \text{ kg})(1060 \text{ m/s}^2) = 150 \text{ N}$$

(c) Say a typical pitcher weighs 170 lbs.

$$170 \text{ lb} \left(\frac{4.45 \text{ N}}{1 \text{ lb}} \right) \approx 760 \text{ N}$$

Now divide the force from part (b) by this weight to see the fraction.

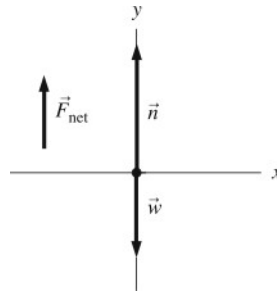
$$150 \text{ N} \div 760 \text{ N} \approx \frac{1}{5}$$

So the force the pitcher exerted on the ball is about 1/5 his weight.

Assess: The answer to each part seems reasonable. The units also work out.

P4.67. Prepare: The jump itself occurs while the froghopper is still in contact with the ground, but pushing off. During that time the froghopper must be accelerating upward, so the net force is upward.

Solve: (a)

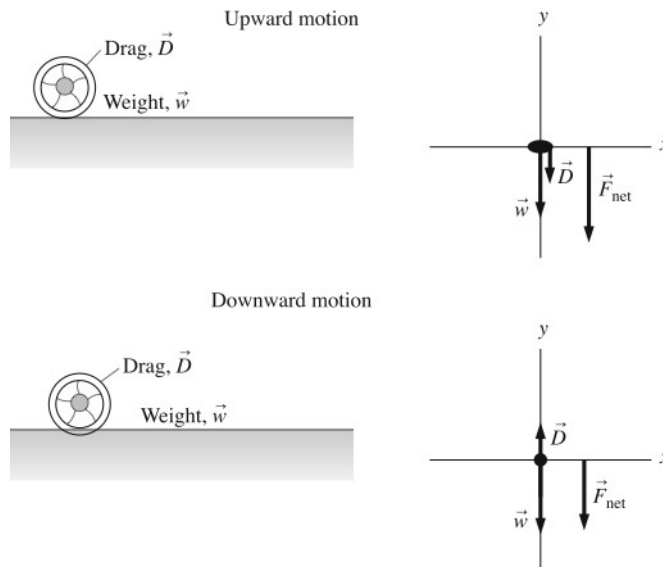


(b) Since the froghopper is accelerating upward the net force is upward; hence, the upward force of the ground on the froghopper is greater than the downward gravitational force (the froghopper's weight).

Assess: Once the froghopper leaves the ground it is accelerating down since it is slowing down; this is due to a net downward force (mainly the gravitational force). But before it leaves the ground it is accelerating upward.

P4.68. Prepare: We will identify all forces on the beach ball and draw a free-body diagram to consider the magnitude of the net force on the ball.

Solve: The beach ball is our system. See the diagram below.



The only contact force is the force of air drag on the ball. The only long-range force is the weight of the ball. Drag always points in the direction opposite to the motion. From the free-body diagram, the net force will always be greater when the beach ball is moving upward compared to downward. There the weight of the ball and the drag force always reinforce each other.

Assess: Note that in the downward portion there is a possibility of the net force equaling zero. The ball will not accelerate downward and fall with constant velocity if this happens, in contrast to the case where there is no drag.

P4.69. Prepare: Think of Newton's first two laws of motion.

Solve: When we assume the vector sum of the forces on an object is zero, it is usually because we know the acceleration of the object is zero.

The correct choice is C.

Assess: The other choices don't really have much to do with whether the vector sum of the forces on an object is zero.

P4.70. Prepare: Tension force is discussed in Section 4.2. We will use Newton's third law to find the force on the rope.

Solve: In the diagram in the problem, the force the left part of the rope exerts on you is mostly in the westerly direction, with a small component to the south. The force that you exert on the left portion of the rope is the reaction force to this force and would be in the exact opposite direction, mostly to the east and a little to the north. The rope is connected directly to the tree. As explained in Section 4.2, the tension force is "transmitted" through the rope by the molecular bonds in the rope. So the force on the tree is directly mostly to the east with a small component to the north. The correct choice is C.

Assess: Tension is "transmitted" along a rope by the molecular bonds in the rope.

P4.71. Prepare: If the car is not moving then its acceleration is zero.

Solve: If the acceleration on an object is zero then the sum of the forces on the object is zero. In the horizontal direction, the rope is pulling on the car approximately west, and therefore the mud must exert a force on the car approximately east.

The answer is C.

Assess: If there are only two horizontal forces on a stationary object, they must be in opposite directions.

P4.72. Prepare: Newton's third law should help us solve this problem.

Solve: The rope exerts a force on the car and the car exerts a force on the rope. According to Newton's third law, these two forces constitute an action pair and as such they are equal in magnitude and opposite in direction. Hence the force the car exerts on the rope is equal to the force the rope exerts on the car. The correct answer is C.

Assess: Newton's third law informs us that the two forces in an action-pair are equal in magnitude and opposite in direction.