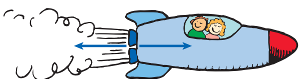
7 NEWTON'S THIRD LAW OF MOTION—ACTION AND REACTION



THE BIG IDEA For every force, there is an equal and opposite force.

If you lean over too far, you'll fall. But if you lean over with your hand outstretched and make contact with a wall, you can do so without falling. When you push against the wall, it pushes back on you. That's why you are supported. Ask your friends why you don't topple over. How many will answer, "Because the wall is pushing on you and holding you in place"? Probably not very many people, unless they're physics types, realize that walls can push on us every bit as much as we push on them.[7.0] Similarly, kayak paddles that push water backward are pushed forward by the water.

discover!

Can There Be Only One Force In an Interaction?

1. Connect the hooks of two spring balances. Have a tug of war with a classmate. Observe the reading on the scales during the tug of war. (Caution: Don't pull too hard!)
2. Try to have one person pull harder than the other. Note the scale readings again.
3. With your classmate, hold two bathroom scales back to back. Now push on the scales and share scale readings.

Analyze and Conclude

1. **Observing** How did readings on the spring balances compare throughout your tug of war?
2. **Predicting** Is there some way for one person to exert a force without causing the other person to interact? Explain.
3. **Making Generalizations** Why do we say forces occur only in pairs?

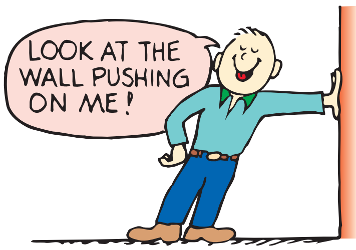


FIGURE 7.1 ▲
When you push on the wall, the wall pushes on you.

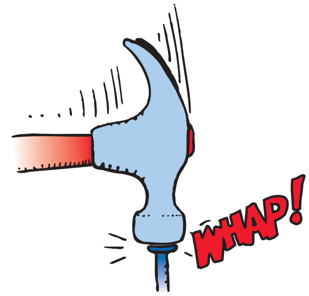


FIGURE 7.2 ▲
The interaction that drives the nail is the same as the one that halts the hammer.

7.1 Forces and Interactions

In the simplest sense, a force is a push or a pull. Looking closer, however, Newton realized that a force is not a thing in itself. **A force is always part of a mutual action that involves another force.** A mutual action is an **interaction** between one thing and another. For example, consider the interaction between a hammer and a nail, as shown in Figure 7.2. A hammer exerts a force on the nail and drives it into a board. But this force is only half the story, for there must also be a force exerted on the hammer to halt it in the process. What exerts this force? The nail does! Newton reasoned that while the hammer exerts a force on the nail, the nail exerts a force on the hammer. So, in the interaction between the hammer and the nail, there are a pair of forces, one acting on the nail and the other acting on the hammer. Such observations led Newton to his third law: the law of action and reaction.

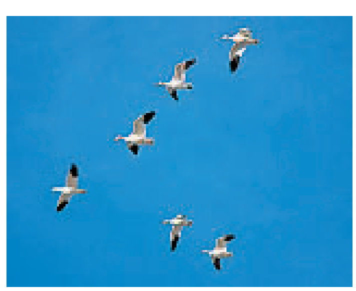
think!

Does a stick of dynamite contain force? Explain.
Answer: 7.1

CONCEPT CHECK Why do forces always occur in pairs?

Link to BIOLOGY

Action–Reaction in Action Why do migrating birds, such as geese, fly in a V formation? The answer is simple, physics! The bird's wings deflect air downward and the air pushes the bird upward. But the story doesn't end there. The downward-moving air meets the air below and swirls upward.



This upward-swirling air creates an updraft, which is strongest off to the side of the bird. A trailing bird positions itself to get added lift from the updraft, thus conserving its energy. This bird, in turn, creates an updraft for a following bird, and so on. The result is a flock flying in a V formation.

FIGURE 7.3 ▲
When the girl jumps to shore, the boat moves backward.

FIGURE 7.4 ▲
The dog wags the tail and the tail wags the dog.

7.2 Newton's Third Law

Newton's third law describes the relationship between two forces in an interaction. **Newton's third law states that whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first object.** One force is called the **action force.** The other force is called the **reaction force.** It doesn't matter which force we call *action* and which we call *reaction*. The important thing is that they are partners in a single interaction and that neither force exists without the other. They are equal in strength and opposite in direction. Newton's third law is often stated: "To every action there is always an equal opposing reaction."

Look at Figures 7.3 and 7.4. In every interaction, the forces always occur in pairs. For example, you interact with the floor when you walk on it. You push against the floor, and the floor simultaneously pushes against you. Likewise, the tires of a car interact with the road to produce the car's motion. The tires push against the road, and the road simultaneously pushes back on the tires. When swimming, you interact with the water. You push the water backward, and the water pushes you forward. Notice that the interactions in these examples depend on friction. For example, a person trying to walk on ice, where friction is minimal, may not be able to exert an action force against the ice. Without the action force there cannot be a reaction force, and thus there is no resulting forward motion.

CONCEPT CHECK **What happens when an object exerts a force on another object?**

7.3 Identifying Action and Reaction

Sometimes the identity of the pair of action and reaction forces in an interaction is not immediately obvious. For example, what are the action and reaction forces in the case of a falling boulder? You might say that Earth's gravitational force on the boulder is the action force, but can you identify the reaction force? Is it the weight of the boulder? No, weight is simply another name for the force of gravity. Is it caused by the ground where the boulder lands? No, the ground does not act on the boulder until the boulder hits it.

There is a simple recipe for treating action and reaction forces. First identify the interaction. Let's say one object, A, interacts with another object, B. The action and reaction forces are stated in this form:

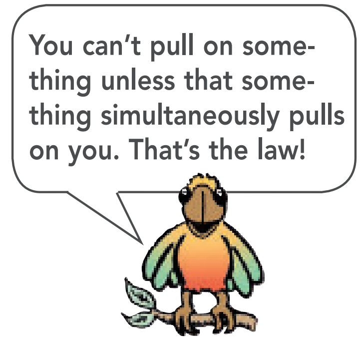
Action: Object A exerts a force on object B.

Reaction: Object B exerts a force on object A.

think!

We know that Earth pulls on the moon. Does the moon also pull on Earth? If so, which pull is stronger?
Answer: 7.3

Look at Figure 7.5. ✅ **To identify a pair of action–reaction forces, first identify the interacting objects A and B, and if the action is A on B, the reaction is B on A.** So, in the case of the falling boulder, the interaction during the fall is the gravitational attraction between the boulder and Earth. If we call the *action* Earth exerting a force on the boulder, then the *reaction* is the boulder simultaneously exerting a force on Earth.



CONCEPT CHECK How do you identify the acton–reaction forces in an interaction?

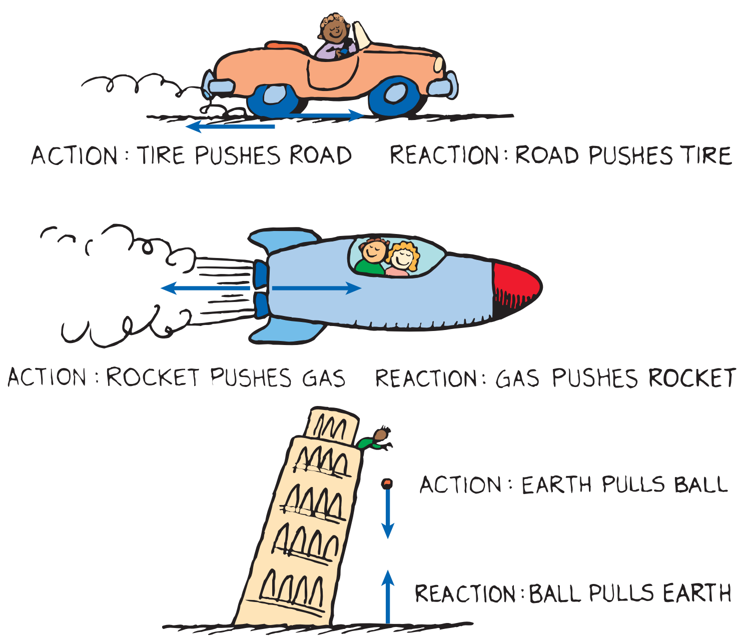
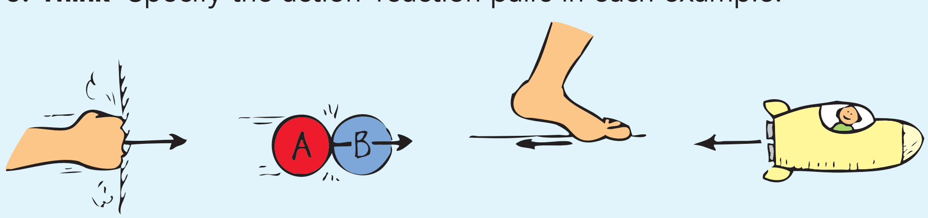


FIGURE 7.5 ▲
In the force-pair between object A and object B, note that when action is *A exerts force on B*, the reaction is simply *B exerts force on A*.

discover!

What are the action–reaction pairs?

1. Each of the drawings below shows the action force on an object. Recopy each of the drawings in your notebook.
2. Draw the appropriate vectors showing the reaction forces.
3. **Think** Specify the action–reaction pairs in each example.



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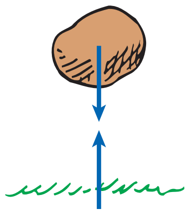


FIGURE 7.6 ▲
Earth is pulled up by the boulder with just as much force as the boulder is pulled down by Earth.

7.4 Action and Reaction on Different Masses

Interestingly enough, in the interaction between the boulder and Earth, shown in Figure 7.6, the boulder pulls up on Earth with as much force as Earth pulls down on the boulder. The forces are equal in strength and opposite in direction. We say the boulder falls to Earth. Could we also say Earth falls to the boulder? The answer is yes, but the distance Earth falls is much less. Although the pair of forces between the boulder and Earth are the same, the masses are quite unequal. Recall that Newton's second law states that acceleration is not only proportional to the net force, but it is also inversely proportional to the mass. Because Earth has a huge mass, we don't sense its infinitesimally small acceleration. Although Earth's acceleration is negligible, strictly speaking it does move up toward the falling boulder. So when you step off a curb, the street actually comes up a tiny bit to meet you!

Force and Mass A similar example occurs during the firing of a cannon, as shown in Figure 7.7. When the cannon is fired, there is an interaction between the cannon and the cannonball. The force the cannon exerts on the cannonball is exactly equal and opposite to the force the cannonball exerts on the cannon, so the cannon "kicks." On first consideration, you might expect the cannon to kick more than it does, or you might wonder why the cannonball moves so fast compared with the cannon. According to Newton's second law, we must also consider the masses.

Let F represent both the action and reaction forces; $\mathcal{M}$, the mass of the cannon; and m, the mass of the cannonball. Different-sized symbols indicate the differences in masses and the accelerations. The acceleration of the cannonball and cannon are

$$\text{Cannonball: } \frac{F}{m} = \mathcal{A} \qquad \text{Cannon: } \frac{F}{\mathcal{M}} = a$$

Do you see why the change in the velocity of the cannonball is great compared with the change in velocity of the cannon?

✅ **A given force exerted on a small mass produces a greater acceleration than the same force exerted on a large mass.**

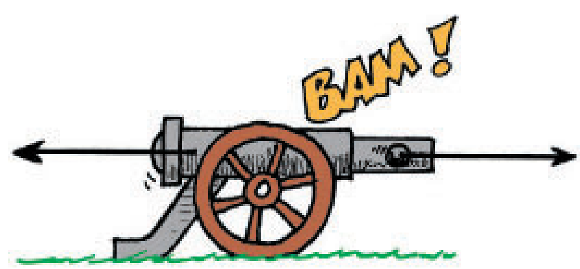


FIGURE 7.7 ▶
The cannonball undergoes more acceleration than the cannon because its mass is much smaller.

If we extend the basic idea of a cannon recoiling from the cannonball it launches, we can understand rocket propulsion. Consider air escaping from an untied, blown-up balloon. If the balloon is released and allowed to move as shown in Figure 7.8, it accelerates as the air comes out. A rocket accelerates in much the same way—it continually recoils from the exhaust gases ejected from its engine. Each molecule of exhaust gas acts like a tiny molecular cannonball shot downward from the rocket.

A common misconception is that a rocket, like the one shown in Figure 7.9, is propelled by the impact of exhaust gases against the atmosphere. In fact, before the advent of rockets, it was commonly thought that sending a rocket to the moon was impossible because of the absence of an atmosphere for the rocket to push against. This is like saying a cannon won't recoil unless the cannonball has air to push against. This is not true! Both the rocket and recoiling cannon accelerate because of the reaction forces created by the "cannonballs" they fire—air or no air. In fact, rockets work better above the atmosphere where there is no air resistance.

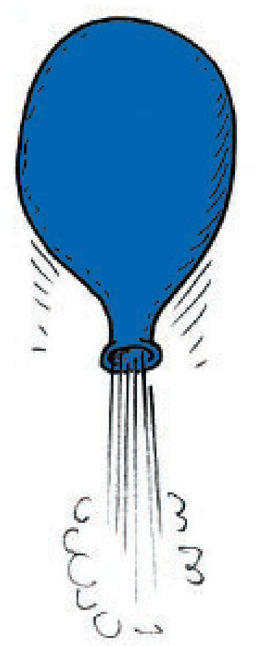


FIGURE 7.8 ▲
The balloon recoils from the escaping air and climbs upward.

Lift Using Newton's third law, we can understand how a helicopter gets its lifting force. The whirling blades are shaped to force air particles downward (action), and the air forces the blades upward (reaction). This upward reaction force is called lift. When lift equals the weight of the craft, the helicopter hovers in midair. When lift is greater, the helicopter climbs upward.

Birds and airplanes also fly because of action and reaction forces. When a bird is soaring, the shape of its wings deflects air downward. The air in turn pushes the bird up. The slightly tilted wings of an airplane also deflect oncoming air downward and produce lift. Airplanes must continuously push air downward to maintain lift and remain airborne. This continuous supply of air is produced by the forward motion of the aircraft, which results from jets or propellers that push air backward. When the engines push air back, the air in turn pushes the engines and the plane forward. We will learn later how the curved surface of an airplane wing enhances the lifting force.

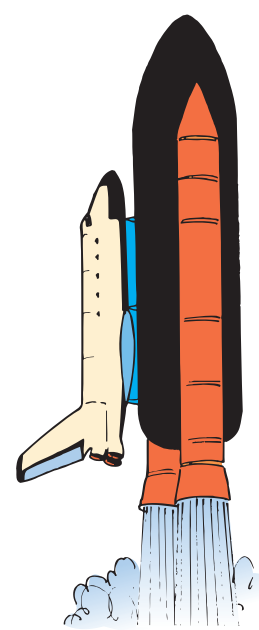
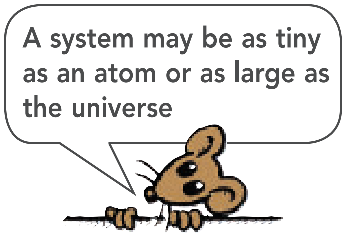


FIGURE 7.9 ▲
The rocket recoils from the "molecular cannonballs" it fires and climbs upward.

CONCEPT CHECK **Why do objects that experience the same amount of force accelerate at different rates?**

think!

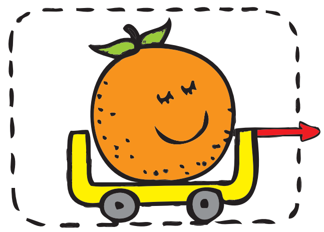
A tug of war occurs between boys and girls on a polished floor that's somewhat slippery. If the boys are wearing socks and the girls are wearing rubber-soled shoes, who will surely win, and why?
Answer: 7.4



7.5 Defining Systems

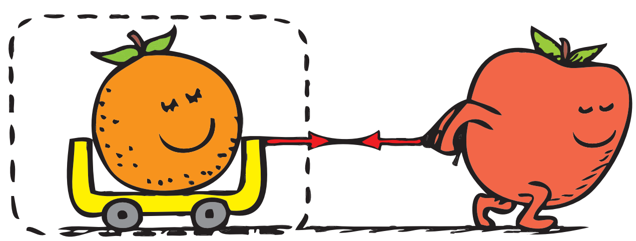
An interesting question often arises: since action and reaction forces are equal and opposite, why don't they cancel to zero? To answer this question, we must consider the system involved. Consider, for example, a system consisting of a single orange, as in Figure 7.10. The dashed line surrounding the orange encloses and defines the system. The vector that pokes outside the dashed line represents an external force on the system. The system (that is, the orange) accelerates in accord with Newton's second law.

FIGURE 7.10 ▶
A force acts on the orange, and the orange accelerates to the right.

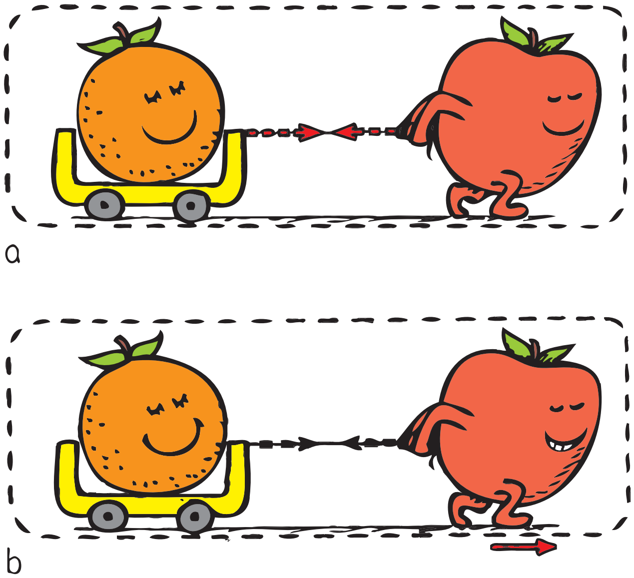


In Figure 7.11 we see that this force is provided by an apple, which doesn't change our analysis. The apple is outside the system. The fact that the orange simultaneously exerts a force on the apple, which is external to the system, may affect the apple (another system), but not the orange. You can't cancel a force on the orange with a force on the apple. So in this case the action and reaction forces don't cancel. **Action and reaction forces do not cancel each other when either of the forces is external to the system being considered.**

FIGURE 7.11 ▶
The force on the orange, provided by the apple, is not cancelled by the reaction force on the apple. The orange still accelerates.



Now let's consider a larger system, enclosing both the orange and the apple. We see the system bounded by the dashed line in Figure 7.12a. Notice that the force pair is internal to the orange–apple system. Therefore these forces do cancel each other. They play no role in accelerating the system. A force external to the system is needed for acceleration. That's where friction with the floor comes in, as in Figure 7.12b. When the apple pushes against the floor, the floor simultaneously pushes on the apple—an external force on the system. The system accelerates to the right.



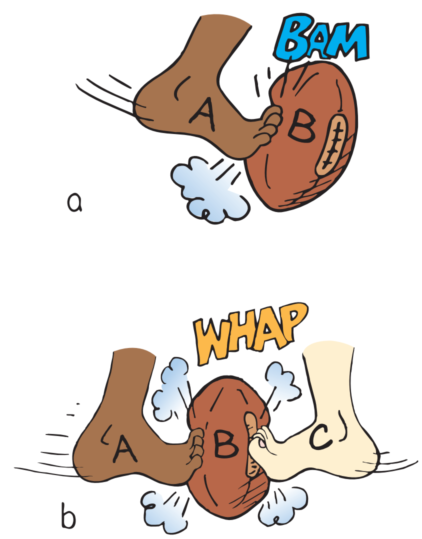
a

b

◀ **FIGURE 7.12**
Consider the larger system of orange + apple. **a.** Action and reaction forces cancel. **b.** When the floor pushes on the apple (reaction to the apple's push on the floor), the orange–apple system accelerates.

Inside a baseball are trillions and trillions of interatomic forces at play. They hold the ball together but play no role in accelerating the ball. Although every one of the interatomic forces is part of an action–reaction pair within the ball, they combine to zero, no matter how many of them there are. A force external to the ball, such as a swinging bat provides, is needed to accelerate the ball. If the action–reaction forces are internal to the system, then they cancel and the system does not accelerate.

Consider the football in Figure 7.13a. There is one interaction between the foot and the football, and the ball accelerates. But when two kicks act on the ball as in Figure 7.13b, no acceleration occurs. In this case there are two interactions occurring. If the two kicks on the ball are simultaneous, equal, and opposite, then the net force on the ball is zero. It is important to notice that the opposing forces act on the same object, not on different objects, so they do not make up an action–reaction pair.[7.5]



a

b

FIGURE 7.13 ▲
A football is kicked. **a.** A acts on B and B accelerates. **b.** Both A and C act on B. They can cancel each other so B does not accelerate.

CONCEPT CHECK **Why don't action–reaction forces cancel each other?**

think!

Suppose a friend who hears about Newton's third law says that you can't move a football by kicking it because the reaction force by the kicked ball would be equal and opposite to your kicking force. The net force would be zero, so no matter how hard you kick, the ball won't move! What do you say to your friend?
Answer: 7.5

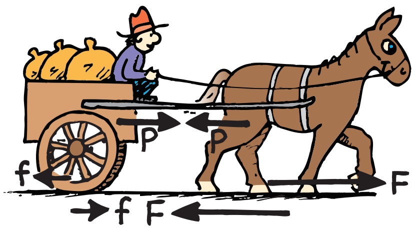


FIGURE 7.14 ▲
All the pairs of forces that act on the horse and cart are shown. The acceleration of the horse–cart system is due to the net force $F - f$.

7.6 The Horse–Cart Problem

A situation similar to the kicked football is shown in the comic strip "Horse Sense." Look at Figure 7.14. Here we think of the horse as believing its pull on the cart will be canceled by the opposite and equal pull by the cart on the horse, thus making acceleration impossible. This is a classic problem that stumps many college students. By thinking carefully, you can understand it.

The horse–cart problem can be looked at from three different points of view. First, consider the point of view of the farmer, who is concerned with getting his cart (the cart system) to market. Then, there is the point of view of the horse (the horse system). Finally, there is the point of view of the horse and cart together (the horse–cart system).

From the farmer's point of view, the only concern is with the force that is exerted on the cart system. The net force on the cart, divided by the mass of the cart, will produce a very real acceleration. The farmer doesn't care about the reaction on the horse.

Now look at the horse system. It's true that the opposite reaction force by the cart on the horse restrains the horse. Without this force, the horse could freely gallop to the market. This force tends to hold the horse back. So how does the horse move forward? The horse moves forward by interacting with the ground. When the horse pushes backward on the ground, the ground simultaneously pushes forward on the horse. ✓ **If the horse in the horse–cart system pushes the ground with a greater force than it pulls on the cart, there is a net force on the horse, and the horse–cart system accelerates.** When the cart is up to speed, the horse need only push against the ground with enough force to offset the friction between the cart wheels and the ground.

Finally, look at the horse–cart system as a whole. From this viewpoint, the pull of the horse on the cart and the reaction of the cart on the horse are internal forces, or forces that act and react within the system. They contribute nothing to the acceleration of the horse–cart system. They cancel and can be neglected. To move across the ground, there must be an interaction between the horse–cart system and the ground. For example, if your car is stalled, you can't get it moving by sitting inside and pushing on the dashboard. You must interact with the ground outside. You must get outside and make the ground push the car. The horse–cart system is similar. It is the outside reaction by the ground that pushes the system.

think!

What is the net force that acts on the cart in Figure 7.14? On the horse? On the ground?
Answer: 7.6

CONCEPT CHECK How does a horse–cart system accelerate?


HORSE SENSE
GIDDIUP! PULL THE CART SO WE CAN GET GOING.
FOR ME TO PULL THE CART WOULD BE A FUTILE EFFORT.
YOU SEE, IF I PULL ON THE CART, THE CART WILL PULL BACK ON ME. BY NEWTON'S 3rd LAW, THE FORCES ARE EQUAL AND OPPOSITE- SO THEY'LL CANCEL OUT. A ZERO NET FORCE WON'T GET US MOVING.
PHYSICS PHYSICS PHYSICS
a CART = F CART / m CART
PHYSICS PHYSICS
I DON'T CARE ABOUT THE FORCE EXERTED ON YOU. I'M INTERESTED IN THE FORCE YOU EXERT ON THE CART! YOU PULL THE CART AND I GUARANTEE IT WILL MOVE!
BUT HOW CAN I MOVE FORWARD WHEN THE CART PULLS BACKWARD ON ME?
PHYSICS PHYSICS PHYSICS
JUST PUSH BACKWARD ON THE GROUND. BY NEWTON'S 3rd LAW, THE GROUND WILL PUSH FORWARD EQUALLY ON YOU --- THEN I'LL SIMPLY FOLLOW ALONG!
THAT GROUND IS DOING A VERY GOOD JOB!
PHYSICS GRUMBLE PHYSICS
Hewitt Drew it!

FIGURE 7.15 ▲
If you hit the wall, it will hit you equally hard.

7.7 Action Equals Reaction

This chapter began with a discussion of how a wall pushes back on you when you push against it. Suppose that for some reason, you punch the wall. Bam! Your hand is hurt. Look at the cartoon in Figure 7.15. Your friends see your damaged hand and ask what happened. What can you say truthfully? You can say that the wall hit your hand. How hard did the wall hit your hand? It hit just as hard as you hit the wall. You cannot hit the wall any harder than the wall can hit you back.

Hold a sheet of paper in midair and tell your friends that the heavyweight champion of the world could not strike the paper with a force of 200 N (45 pounds). You are correct, because a 200-N interaction between the champ's fist and the sheet of paper in midair isn't possible. The paper is not capable of exerting a reaction force of 200 N, and you cannot have an action force without a reaction force. Now, if you hold the paper against the wall, that's a different story. The wall will easily assist the paper in providing 200 N of reaction force, and more if needed!

For every interaction between things, there is always a pair of oppositely directed forces that are equal in strength. If you push hard on the world, for example, the world pushes hard on you. If you touch the world gently, the world will touch you gently in return. The way you touch others is the way others touch you, as shown in Figure 7.16.

CONCEPT CHECK What must occur in every interaction between things?

FIGURE 7.16 ▶
The author and his wife demonstrate that you cannot touch without being touched—Newton's third law.

7 REVIEW

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Concept Summary

- A force is always part of a mutual action that involves another force.
- Newton's third law states, that whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first object.
- To identify a pair of action–reaction forces, first identify the interacting objects A and B, and if the action is A on B, the reaction is B on A.
- A given force exerted on a small mass produces a greater acceleration than the same force exerted on a large mass.
- Action and reaction forces do not cancel each other when either of the forces is external to the system being considered.
- If the horse in the horse–cart system pushes on the ground with a greater force than it pulls on the cart, there is a net force on the horse, and the horse–cart system accelerates.
- For every interaction between things, there is always a pair of oppositely directed forces that are equal in strength.

Key Terms

interaction *(p.107)*

Newton's third law *(p.108)*

action force *(p.108)*

reaction force *(p.108)*

think! Answers

7.1 No. Force is not something an object has, like mass. Force is an interaction between one object and another. An object may possess the capability of exerting a force on another object, but it cannot possess force as a thing in itself. Later we will see that something like a stick of dynamite possesses *energy.*

7.3 Asking which pull is stronger is like asking which distance is greater—between New York and San Francisco, or between San Francisco and New York. The distances either way are the same. It is the same with force pairs. Both Earth and moon pull on each other with equal and opposite forces.

7.4 The girls will win. The force of friction is greater between the girls' feet and the floor than between the boys' feet and the floor. When both the girls and the boys exert action forces on the floor, the floor exerts a greater reaction force on the girls' feet. As a result, the girls stay at rest and the boys slide towards the girls.

7.5 Tell your friend that if you kick a football, it will accelerate. No other force has been applied to the ball. What about the reaction force? Aha! That force doesn't act on the ball; it acts on your foot. Tell your friend that you can't cancel a force on the ball with a force on your foot.

7.6 The net force on the cart is $P - f$; on the horse, $F - P$; on the ground, $F - f$.

7 ASSESS

Check Concepts

Section 7.1

1. Can an action force exist without a reaction force?
2. When a hammer exerts a force on a nail, how does this amount of force compare with that of the nail on the hammer?

Section 7.2

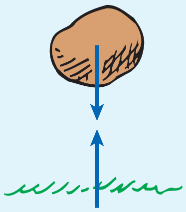
3. When you walk on a floor, what pushes you along?
4. State Newton's third law of motion.

Section 7.3

5. Consider hitting a baseball with a bat. If we call the force the bat exerts against the ball the action force, identify the reaction force.
6. If a bat hits a ball with 1000 N of force, can the ball exert less than 1000 N of force on the bat? More than 1000 N?

Section 7.4

7. If the world pulls you downward against your chair, what is the reaction force?



8. When a cannon is fired, are the forces on the cannonball and on the cannon equal in magnitude? Are the accelerations of the two equal?
9. When a cannon is fired, why do the cannonball and cannon have very different accelerations?
10. Identify the force that propels a rocket.
11. How does a helicopter get its lifting force?

Section 7.5

12. True or false: When a net force is exerted on a system, the system will accelerate, but when an applied force and its reaction are within a system, the system as a whole does not accelerate.
13. When can two kicks on a soccer ball produce a net force of zero on the ball?
14. Why don't the enormous number of interatomic forces inside a baseball accelerate the baseball?

Section 7.6

15. Referring to Figure 7.14, how many horizontal forces are exerted on the cart? What is the horizontal net force on the cart?
16. How many horizontal forces are exerted on the horse in Figure 7.14? What is the horizontal net force on the horse?
17. How many horizontal forces are exerted on the horse–cart system in Figure 7.14? What is the horizontal net force on the horse–cart system?

Section 7.7

18. If you hit a wall with a force of 200 N, how much force does the wall exert on you?

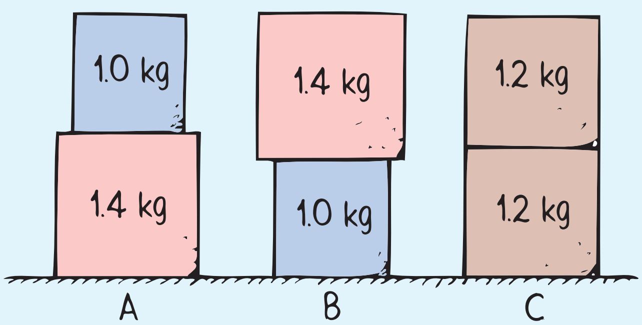
19. Can you physically touch another person without that person touching you with the same magnitude of force?

20. Fill in the blanks: Newton's first law is often called the law of ________; Newton's second law highlights the concepts of force, mass, and ________________; and Newton's third law is the law of _______ and _________.

Think and Rank

Rank each of the following sets of scenarios in order of the quantity or property involved. List them from left to right. If scenarios have equal rankings, then separate them with an equal sign. (e.g., A = B)

21. Three sets of double boxes rest on a table.

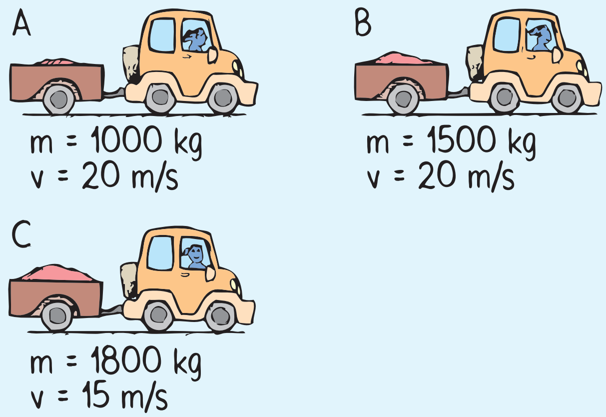


Rank the following from greatest to least.

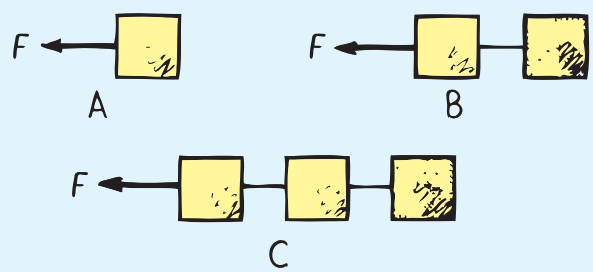
a. the normal force that the table exerts on the sets

b. the normal force exerted by the bottom block on the top block

22. A van exerts a force on trailers of different masses m. All velocities v are constant. Compared with the force exerted on the trailer, rank the magnitude of force the trailer exerts on the van. Or are all pairs of forces equal in magnitude?



23. Each of these boxes is pulled by the same force F to the left. All boxes have the same mass and slide on a friction-free surface.



Rank the following from greatest to least.

a. the acceleration of the boxes

b. the tension in the rope connected to the boxes on the right in B and in C

7 ASSESS *(continued)*

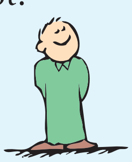
Think and Explain

24. When you rub your hands together, can you push harder on one hand than the other?

25. Your weight is the result of the gravitational force of Earth on your body. What is the corresponding reaction force?

26. Why can you exert greater force on the pedals of a bicycle if you pull up on the handlebars?

27. Consider the two forces acting on a person who stands still, namely, the downward pull of gravity and the upward support of the floor. Are these forces equal and opposite? Do they comprise an action–reaction pair? Why or why not?



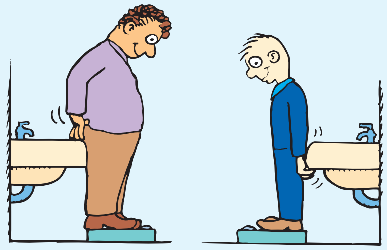
28. If you walk on a log that is floating in the water, the log moves backward. Why?

29. Why is it easier to walk on a carpeted floor than on a smooth, polished floor?

30. If you step off a ledge, you accelerate noticeably toward Earth. Does Earth accelerate toward you as well? Explain.

31. When a racquet hits a tennis ball, action and reaction forces occur between the racquet and ball. What other action–reaction pair of forces occur for the ball both before and after interaction with the racquet? Neglect air resistance.

32. Suppose you're weighing yourself while standing next to the bathroom sink. Using the idea of action and reaction, explain why the scale reading will be less when you push down on the top of the sink. Why will the scale reading be more if you pull up on the bottom of the sink?

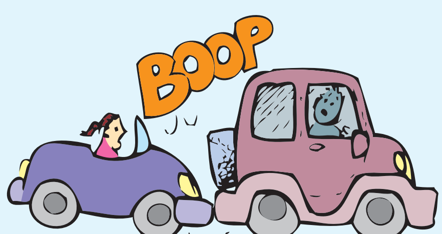


33. When a high jumper leaves the ground, what is the source of the upward force that accelerates her? What force acts after her feet are no longer in contact with the ground?

34. What is the reaction force to an action force of 1000 N exerted by Earth on an orbiting communications satellite?

35. If action equals reaction, why isn't Earth pulled into orbit around a communications satellite?

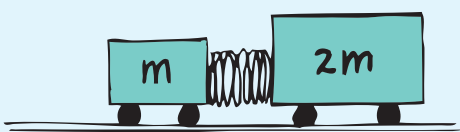
36. A small car bumps into a van at rest in a parking lot. Upon which vehicle is the force of impact greater? Which vehicle undergoes the greater change in acceleration? Defend your answer.



37. Does your answer to question 36 depend on the relative speeds of the vehicles?

38. A speeding bus makes contact with a bug that splatters onto the windshield. Because of the sudden force, the unfortunate bug undergoes a sudden deceleration. Is the corresponding force that the bug exerts against the windshield greater, less, or the same? Is the resulting deceleration of the bus greater than, less than, or the same as that of the bug?

39. Consider two carts, one twice as massive as the other, that fly apart when the compressed spring squeezed between them is released. How fast does the heavier cart roll compared with the lighter cart?



40. Some people used to think that a rocket could not travel to the moon because it would have no air to push against once it left Earth's atmosphere. We now know that idea was mistaken. What force propels a rocket when it is in a vacuum?

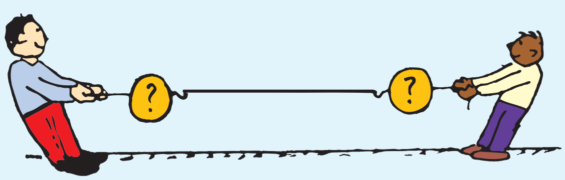
41. Since the force that acts on a cannonball when a cannon is fired is equal and opposite to the force that acts on the cannon, does this imply a zero net force and therefore the impossibility of an accelerating cannonball? Explain.

42. Suppose you exert 200 N on your refrigerator and push it across the kitchen floor at constant velocity. What friction force acts between the refrigerator and the floor? Is the friction force equal and opposite to your 200-N push? Does the friction force make up the reaction force to your push?

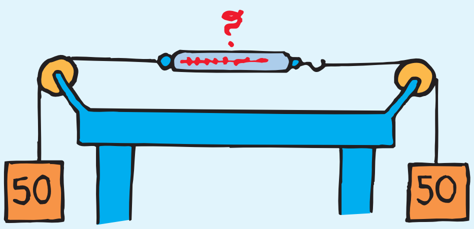
43. The photo shows Steve Hewitt and his daughter Gretchen. Is Gretchen touching Steve, or is Steve touching her? Explain.

44. Hold your hand like a flat wing outside the window of a moving vehicle. Then tilt it slightly upward and your hand will rise. Explain this in terms of Newton's third law.

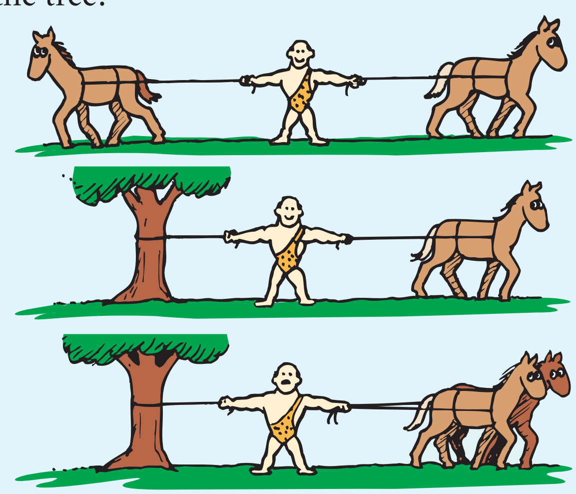
45. Your teacher challenges you and your best friend to each pull on a pair of scales attached to the ends of a horizontal rope, in tug-of-war fashion, so that the readings on the scales will differ. Can this be done? Explain.



46. A pair of 50-N weights are attached to a spring scale as shown. Does the spring scale read 0, 50, or 100 N? (*Hint:* Would it read any differently if one of the strings were held by your hand instead of being attached to the 50-N weight?)



47. The strong man can withstand the tension force exerted by the two horses pulling in opposite directions. How would the tension compare if only one horse pulled and the left rope were tied to a tree? How would the tension compare if the two horses pulled in the same direction, with the left rope tied to the tree?



48. A balloon floats motionless in the air. A balloonist begins climbing up the supporting cable. In which direction does the balloon move as the balloonist climbs? Explain.

49. When you get up from a sitting position, do your feet push against the floor with a force equal to, more than, or less than your weight? Explain.

50. When a weightlifter jerks a barbell over his head, is the force exerted on the barbell more than, less than, or equal to the barbell's weight? Explain.

51. Identify two pairs of action-reaction forces that exist when you stand on a scale.

52. A car of mass m cruises along the highway at a constant velocity v. The tires push backward on the road with a force f. The reaction to this force provides the forward force on the car. Wind resistance against the car is R.
   a. Using symbols, what is the net force on the car?
   b. Using symbols, what is the acceleration of the car?
   c. A friend says that since the car is moving forward, there must be a net forward force, which means f must be greater than R, even at constant velocity. What do you say to enlighten your friend?

Think and Solve

53. What will be the acceleration of recoil when a 60-kg person on rollerskates pushes against a wall with a force of 30 N?

54. Two people attempt a tug-of-war on low-friction ice. One person has four times the mass of the other. Relative to the acceleration of the heavier person, what will be the acceleration of the lighter person?

55. Two blocks, one three times as massive as the other, are connected by a compressed spring. When the spring is released, both blocks fly apart. Relative to the acceleration of the heavier block, what is the acceleration of the lighter block?

56. What is the net force on a falling 100-N barrel hitting a pavement with 5000 N of force?

57. Amanda looks at a 1.0-kg bag of jellybeans resting on a table.

a. Calculate the amount of force that the table exerts on the bag of jellybeans.

b. How does this compare with the force that the bag of jellybeans exerts on the table?

58. When 56-kg Diane on rollerskates pushes against a wall with a force of 28 N, she accelerates away from the wall. Show that Diane's recoil acceleration is 0.50 m/s^2.

59. A 7.00-kg bowling ball moving at 8.0 m/s strikes a 1.0-kg bowling pin and slows to 7.0 m/s in 0.040 s.

a. Show that the force of impact on the bowling ball is 175 N.

b. How much force acts on the bowling pin?

60. A 70-kg skydiver is falling at her terminal speed. Show that she exerts a 700-N downward force on the air as she falls.

61. Gymnast Gracie of weight *mg* is suspended by a pair of vertical ropes attached to the ceiling.

a. In terms of Gracie's weight, what is the tension in each rope?

b. If Gracie's mass is 30 kg, show that the tension in each rope is 150 N.

More Problem-Solving Practice
Appendix F

sample problem

With all his might, a boxer punches a sheet of tissue paper of mass m in midair. The punch brings the paper from rest up to a speed v in time t. (a) Using Newton's second law, write an equation showing how much force the boxer exerts on the tissue paper. (b) By Newton's third law, what amount of force does the tissue paper exert on the boxer? (c) Assume the paper has mass of 0.001 kg and gains a speed of 30.0 m/s in an impact time of 0.050 s. Show that the force of impact is only 0.6 N.

▶ **Step 1** $F = ?$

▶ **Step 2** From Newton's second law:

$$a = \frac{F_{net}}{m}$$

$$F_{net} = ma = m\frac{\theta v}{\theta t} = m\frac{v}{t}$$

(a) All the terms above are known quantities, so the solution is complete.

(b) By Newton's third law, the magnitude of the force the tissue paper exerts on the boxer and the force the boxer exerts on the tissue paper is the same:

$$F = ma = m\frac{v}{t}$$

$$F = m\frac{v}{t} = 0.001\ \text{kg}\left(\frac{30.0\frac{\text{m}}{\text{s}}}{0.050\ \text{s}}\right) = 0.6\ \text{N}.$$

(c) This is about a 2-ounce tap —hence the origin of the expression about not being able to fight your way out of a paper bag!

1. When a boxer in the gym punches a heavy bag of mass 60 kg, the bag moves from rest to a speed of 2.0 m/s in 0.50 second. Show that the force of impact on the bag is about 240 N. (Neglect the fact that the bag is suspended, and is not really a freely-moving body.)
2. A boxer punches a sheet of paper in midair, and brings it from rest up to a speed of 25 m/s in 0.050 second. The mass of the paper is 0.0030 kg. Show that the force of impact on the paper is merely 1.5 N.
3. Gymnast Gracie of weight mg is suspended by a pair of vertical ropes attached to the ceiling. (a) In terms of Gracie's weight, what is the tension in each rope? (b) If Gracie's mass is 30 kg, show that the tension in each rope is 150 N. **4.** When Abigail swims to the end of the pool she wants to increase her speed after turning around by pushing against the pool wall with force F. Her mass is m, and during her push the average force of water resistance is R. (a) Write an equation showing her average acceleration. (b) Is it possible for Abigail to push against the wall *without* the wall simultaneously pushing on her?

5. A 65-kg astronaut in the space station kicks a soccer ball with a force of 13 N. Show that the astronaut accelerates backwards at 0.20 m/s^2.

6. A water skier of mass m is pulled at a constant velocity v by a boat of mass M. Tension in the rope held horizontally by the skier is T. (a) Defend the fact that the amount of resistive force from the water and air on the skier is T. (b) Defend the fact that the upward force the water exerts on the skier is mg.

7. Two ninth-graders, one with three times the mass of the other, attempt a tug-of-war on frictionless ice. Show that the heavier person will gain a speed one-third that of the lighter person.

8. Carts A and B are connected by a compressed spring on an air table. Cart A has a mass of 0.25 kg and Cart B has a mass of 0.75 kg. The spring is then released. Show that Cart A ends up moving at three times the speed of Cart B.

9. When two identical air pucks with repelling magnets are held together on an air table and released, they end up moving in opposite directions at the same speed v. Assume the mass of one of the pucks is doubled and the procedure is repeated. (a) How does the final speed of the double-mass puck compare with the speed of the single puck? (b) Calculate the speed of the double-mass puck if the single puck moves away at 0.4 m/s.

10. Daniel (mass 40 kg) and Justin (mass 30 kg) face each other at rest while wearing roller blades. Daniel pushes Justin and accelerates him at 1.6 m/s^2. Show that Daniel accelerates in the other direction at 1.2 m/s^2.

11. Manuel, mass M, and Caillen, mass m, put on their ice skates and meet near the center of a frozen pond. While facing each other Manuel pushes Caillen away with force F, giving her an acceleration a. Assume that friction between their ice skates and the ice is negligible. (a) During the contact with Caillen, show that Manuel's acceleration is $\frac{m}{M}a$. What is the direction of his acceleration? (b) Assume Manuel's mass is 66 kg, and Caillen of mass 44 kg accelerates at 2.4 m/s^2. Show that Manuel accelerates at 1.6 m/s^2.

12. Ryan observes a tug-of-war between Jose (mass M) and Juanita (mass m), taking place on a quite slippery floor. Jose pulls on the rope and imparts an acceleration a to Juanita. (a) Write an equation for the tension in the rope. (b) Assume Jose's mass is 80 kg, Juanita's mass is 60 kg, and that Ryan observes Juanita accelerate across the floor at 0.10 m/s^2. Show that the rope tension is 6.0 N.

13. Two cars of mass m traveling with crash dummies at the same speed v have a head-on collision and slam to a halt. The collision occurs in a brief time t. (a) Show that the average deceleration of each car is $\frac{v}{t}$. (b) Assume each car's mass is 958 kg, initial speed is 15 m/s, and impact time is 0.20 s. Show that the magnitude of deceleration for each car is 75 m/s^2. (c) Show that during collision the magnitude of the average force acting on each car is 72,000 N. (d) If you simulate this with smaller carts in lab, each with a force sensor at its "front bumper," how will the force readings for both carts compare during the collision?

Chapter 5

5.2.1 Whenever a pair of vectors are at right angles (90°), their resultant can be found by the Pythagorean Theorem, a well-known tool of geometry. It states that the square of the hypotenuse of a right-angle triangle is equal to the sum of the squares of the other two sides. Note that two right triangles are present in the rectangle in Figure 5.3. From either one of these triangles we get

$$\begin{aligned} \text{resultant}^2 &= (60\text{ km/h})^2 + (80\text{ km/h})^2 \\ &= 3600\ (\text{km/h})^2 + 6400\ (\text{km/h})^2 \\ &= 10{,}000\ (\text{km/h})^2 \end{aligned}$$

The square root of 10,000 $(\text{km/h})^2$ is 100 km/h, as expected.

5.2.2 An important property of vectors is that they can be moved around as long as their length and direction are not changed. Vectors can be rearranged into a chain, tail-to-head in any order. A vector drawn from the tail of the first vector to the head of the last vector represents the resultant of the entire chain of vectors.

Chapter 7

7.0 The terms *push* and *pull* usually invoke the idea of a living thing exerting a force. So, strictly speaking, to say "the wall pushes on you" is to say "the wall exerts a force as though it were pushing on you." As far as these mutual forces are concerned, there is no observable difference between the force exerted by you, a living being, and the force exerted by a wall, a nonliving object.

7.5 In both cases we consider the football to be the system. In the first case the foot (A) exerts a force on the ball (B). The force exerted by A is the net force on the system (the ball), so the ball accelerates. In the second case there are two forces on the ball—A on B, and C on B. Note two things: A doesn't interact with C and vice versa—so A and C do not make up an action-reaction pair of forces. Also note there are three objects involved, not just two. Read on to the horse-cart problem, which may make this clearer.

Chapter 8

8.2 This relationship is derived by rearranging Newton's second law to make the time factor more evident. If we equate the formula for acceleration, $a = F/m$, with what acceleration actually is, $a = \Delta v/\Delta t$, we get $F/m = \Delta v/\Delta t$. From this we derive $F\Delta t = \Delta(mv)$.

Chapter 9

9.1 For the more general case, work is the product of the *component of force* acting in the direction of motion and the distance moved. (No work is done when force and distance are perpendicular to each other.)