

4

Newton's Third Law

Reading Preview

Key Concepts

- What is Newton's third law of motion?
- How can you determine the momentum of an object?
- What is the law of conservation of momentum?

Key Terms

- momentum
- law of conservation of momentum

Target Reading Skill

Previewing Visuals Before you read, preview Figure 18. Then write two questions that you have about the diagram in a graphic organizer like the one below. As you read, answer your questions.

Conservation of Momentum

Q. What happens when two moving objects collide?

A.

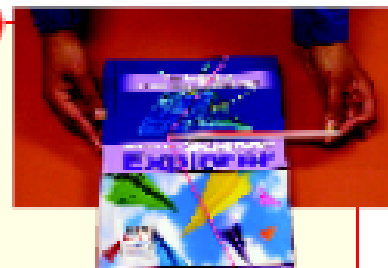
Q.

Lab
zone

Discover Activity

How Pushy Is a Straw?

1. Stretch a rubber band around the middle of the cover of a medium-size hardcover book.
2. Place four marbles in a small square on a table. Place the book on the marbles so that the cover with the rubber band is on top.
3. Hold the book steady by placing one index finger on the binding. Then, as shown, push a straw against the rubber band with your other index finger.
4. Push the straw until the rubber band stretches about 10 cm. Then let go of both the book and the straw at the same time.



Think It Over

Developing Hypotheses What did you observe about the motion of the book and the straw? Write a hypothesis to explain what happened in terms of the forces on the book and the straw.

Have you ever tried to teach a friend how to roller-skate? It's hard if you are both wearing skates. When your friend pushes against you to get started, you move too. And when your friend runs into you to stop, you both end up moving! To understand these movements you need to know Newton's third law of motion and the law of conservation of momentum.

Newton's Third Law of Motion

Newton proposed that whenever one object exerts a force on a second object, the second object exerts a force back on the first object. The force exerted by the second object is equal in strength and opposite in direction to the first force. Think of one force as the "action" and the other force as the "reaction." Newton's third law of motion states that if one object exerts a force on another object, then the second object exerts a force of equal strength in the opposite direction on the first object. Another way to state Newton's third law is that for every action there is an equal but opposite reaction.

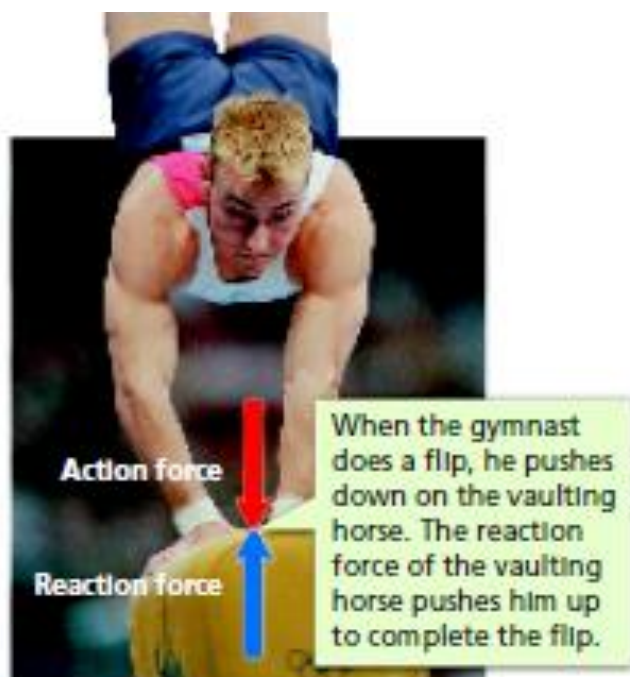


FIGURE 15

Action-Reaction Pairs

Action-reaction pairs explain how a gymnast can flip over a vaulting horse, how a kayaker can move through the water, and how a dog can leap off the ground. **Observing** Name some other action-reaction pairs that you have observed.

Action-Reaction Pairs You're probably familiar with many examples of Newton's third law. Pairs of action and reaction forces are all around you. When you jump, you push on the ground with your feet. This is an action force. The ground pushes back on your feet with an equal and opposite force. This is the reaction force. You move upward when you jump because the ground is pushing you! In a similar way, a kayaker moves forward by exerting an action force on the water with a paddle. The water pushes back on the paddle with an equal reaction force that propels the kayak forward.

Now you can understand what happens when you teach your friend to roller-skate. Your friend exerts an action force when he pushes against you to start. You exert a reaction force in the opposite direction. As a result, both of you move in opposite directions.

Detecting Motion Can you always detect motion when paired forces are in action? The answer is no. For example, when Earth's gravity pulls on an object, you cannot detect Earth's equal and opposite reaction. Suppose you drop your pencil. Gravity pulls the pencil downward. At the same time, the pencil pulls Earth upward with an equal and opposite reaction force. You don't see Earth accelerate toward the pencil because Earth's inertia is so great that its acceleration is too small to notice.

Do Action-Reaction Forces Cancel? Earlier you learned that if two equal forces act in opposite directions on an object, the forces are balanced. Because the two forces add up to zero, they cancel each other out and produce no change in motion. Why then don't the action and reaction forces in Newton's third law of motion cancel out as well? After all, they are equal and opposite.

The action and reaction forces do not cancel out because they are acting on different objects. Look at the volleyball player on the left in Figure 16. She exerts an upward action force on the ball. In return, the ball exerts an equal but opposite downward reaction force back on her wrists. The action and reaction forces act on different objects.

On the other hand, the volleyball players on the right are both exerting a force on the *same* object—the volleyball. When they hit the ball from opposite directions, each of their hands exerts a force on the ball equal in strength but opposite in direction. The forces on the volleyball are balanced and the ball does not move either to the left or to the right.



Why don't action and reaction forces cancel each other?

Forces

[Video Preview](#)

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[Video Assessment](#)



FIGURE 16

Action-Reaction Forces

In the photo on the left, the player's wrists exert the action force. In the photo below, the ball exerts reaction forces on both players.

Interpreting Diagrams In the photo below, forces cancel each other out? What force is cancelled? What will happen to the ball?



Momentum

All moving objects have what Newton called a “quantity of motion.” What is this quantity of motion? Today we call it momentum. **Momentum** (moh MEN tum) is a characteristic of a moving object that is related to the mass and the velocity of the object. The momentum of a moving object can be determined by multiplying the object’s mass and velocity.

$$\text{Momentum} = \text{Mass} \times \text{Velocity}$$

Since mass is measured in kilograms and velocity is measured in meters per second, the unit for momentum is kilogram-meters per second (kg·m/s). Like velocity, acceleration, and force, momentum is described by its direction as well as its quantity. The momentum of an object is in the same direction as its velocity.



Math Practice

1. Calculating Momentum

A golf ball travels at 16 m/s, while a baseball moves at 7 m/s. The mass of the golf ball is 0.045 kg and the mass of the baseball is 0.14 kg. Which has greater momentum?

2. Calculating Momentum

What is the momentum of a bird with a mass of 0.018 kg flying at 15 m/s?

Math Sample Problem

Calculating Momentum

Which has more momentum: a 3.0-kg sledgehammer swung at 1.5 m/s, or a 4.0-kg sledgehammer swung at 0.9 m/s?

1 Read and Understand

What information are you given?

Mass of smaller sledgehammer = 3.0 kg

Velocity of smaller sledgehammer = 1.5 m/s

Mass of larger sledgehammer = 4.0 kg

Velocity of larger sledgehammer = 0.9 m/s

2 Plan and Solve

What quantities are you trying to calculate?

The momentum of each sledgehammer = ■

What formula contains the given quantities and the unknown quantity?

Momentum = **Mass** × **Velocity**

Perform the calculations.

Smaller sledgehammer: 3.0 kg × 1.5 m/s = 4.5 kg·m/s

Larger sledgehammer: 4.0 kg × 0.9 m/s = 3.6 kg·m/s

3 Look Back and Check

Does your answer make sense?

The 3.0-kg hammer has more momentum than the 4.0-kg one. This answer makes sense because it is swung at a greater velocity.



FIGURE 17

Momentum

An object's momentum depends on velocity and mass.

Problem Solving If both dogs have the same velocity, which one has the greater momentum?

The more momentum a moving object has, the harder it is to stop. The mass of an object affects the amount of momentum the object has. For example, you can catch a baseball moving at 20 m/s, but you cannot stop a car moving at the same speed. The car has more momentum because it has a greater mass. The velocity of an object also affects the amount of momentum an object has. For example, an arrow shot from a bow has a large momentum because, although it has a small mass, it travels at a high velocity.



Reading Checkpoint

What must you know to determine an object's momentum?

Conservation of Momentum

The word *conservation* has a special meaning in physical science. In everyday language, conservation means saving resources. You might conserve water or fossil fuels, for example. In physical science, conservation refers to the conditions before and after some event. An amount that is conserved is the same amount after an event as it was before.

The amount of momentum objects have is conserved when they collide. Momentum may be transferred from one object to another, but none is lost. This fact is called the law of conservation of momentum.

The law of conservation of momentum states that, in the absence of outside forces, the total momentum of objects that interact does not change. The amount of momentum is the same before and after they interact. The total momentum of any group of objects remains the same, or is conserved, unless outside forces act on the objects. Friction is an example of an outside force.

Lab Zone

Try This Activity

Colliding Cars

Momentum is always conserved—even by toys!

1. Find two nearly identical toy cars that roll easily.
2. Make two loops out of masking tape (sticky side out). Put one loop on the front of one of the cars and the other loop on the back of the other car.
3. Place on the floor the car that has tape on the back. Then gently roll the other car into the back of the stationary car. Was momentum conserved? How do you know?

Predicting What will happen if you put masking tape on the fronts of both cars and roll them at each other with equal speeds? Will momentum be conserved in this case? Test your prediction.



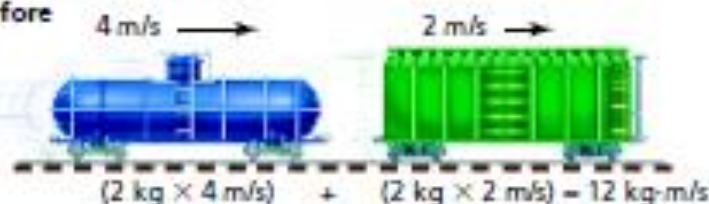
FIGURE 18

Conservation of Momentum

In the absence of friction, momentum is conserved when two train cars collide. **Interpreting Diagrams** In which diagram is all of the momentum transferred from the blue car to the green car?

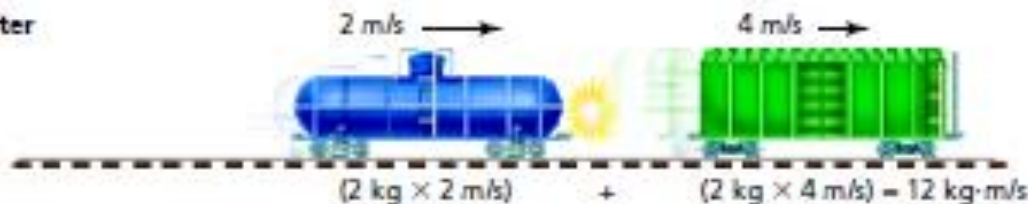
A Two Moving Objects

Before



Before the collision, the blue car moves faster than the green car. Afterward, the green car moves faster. The total momentum stays the same.

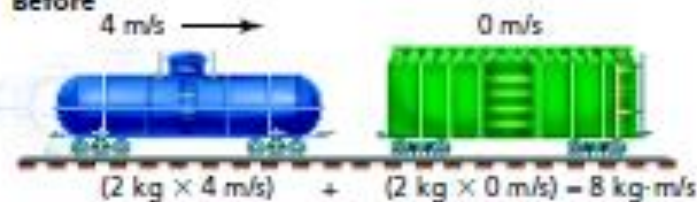
After



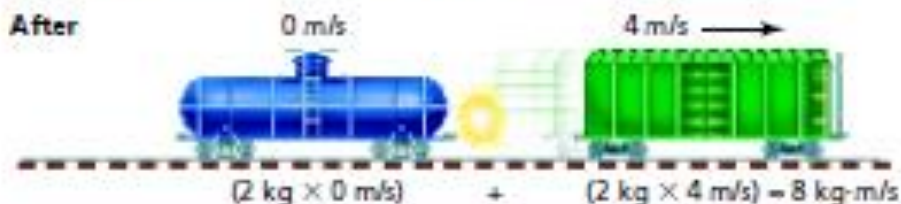
B One Moving Object

When the green car is at rest before the collision, all of the blue car's momentum is transferred to it. Momentum is conserved.

Before

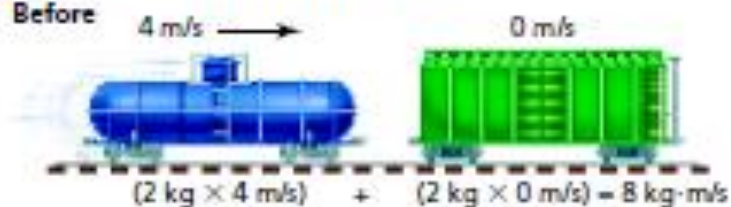


After



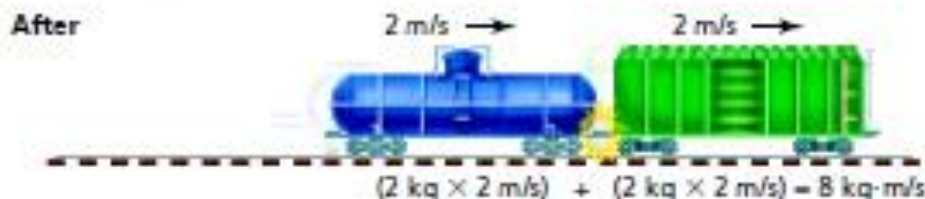
C Two Connected Objects

Before



If the two cars lock together, momentum is still conserved. Together, the cars move slower than the blue car did before the collision.

After



Collisions With Two Moving Objects In Figure 18A, a train car is traveling at 4 m/s down the same track as another train car traveling only 2 m/s. Eventually, the blue car will catch up with the green car and bump into it. During the collision, the speed of each car changes. The blue car slows down to 2 m/s, and the green car speeds up to 4 m/s. Momentum is conserved—the momentum of one train car decreases while the momentum of the other increases.

Collisions With One Moving Object In Figure 18B, the blue car travels at 4 m/s but the green car is not moving. Eventually the blue car hits the green car. After the collision, the blue car is no longer moving, but the green car travels at 4 m/s. Even though the situation has changed, momentum is conserved. All of the momentum has been transferred from the blue car to the green car.

Collisions With Connected Objects Suppose that, instead of bouncing off each other, the two train cars couple together when they hit. Is momentum still conserved in Figure 18C? After the collision, the coupled train cars make one object with twice the mass. The velocity of the coupled trains is 2 m/s—half the velocity of the blue car before the collision. Since the mass is doubled and the velocity is divided in half, the total momentum remains the same.



What happens to the momentum of two objects after they collide?

Section 4 Assessment

- **Target Reading Skill Previewing Visuals** Refer to your questions and answers about Figure 18 to help you answer Question 3 below.

Reviewing Key Concepts

- Reviewing** State Newton's third law of motion.
 - Summarizing** According to Newton's third law of motion, how are action and reaction forces related?
 - Applying Concepts** What would happen if you tried to catch a ball when you were standing on roller skates?
- Defining** What is momentum?
 - Predicting** What is the momentum of a parked car?
 - Relating Cause and Effect** Why is it important for drivers to allow more distance between their cars when they travel at faster speeds?

- Identifying** What is conservation of momentum?
 - Inferring** The total momentum of two marbles before a collision is 0.06 kg·m/s. No outside forces act on the marbles. What is the total momentum of the marbles after the collision?

Math Practice

- Calculating Momentum** What is the momentum of a 920-kg car moving at a speed of 25 m/s?
- Calculating Momentum** Which has more momentum: a 250-kg dolphin swimming at 4 m/s, or a 350-kg manatee swimming at 2 m/s?