SECTION 3

Momentum

Imagine a compact car and a large truck traveling with the same velocity. The drivers of both vehicles put on the brakes at the same time. Which vehicle will stop first?

You would probably say that the compact car will stop first. You know that smaller objects are easier to stop than larger objects. But why? The answer is momentum (moh MEN tuhm).

What You Will Learn

- Calculate the momentum of moving objects.
- Explain the law of conservation of momentum.

Vocabulary

momentum

READING STRATEGY

Prediction Guide Before reading this section, write the title of each heading in this section. Next, under each heading, write what you think you will learn.

momentum a quantity defined as the product of the mass and velocity of an object

Momentum, Mass, and Velocity

The **momentum** of an object depends on the object's mass and velocity. The more momentum an object has, the harder it is to stop the object or change its direction. In the example above, the truck has more mass and more momentum than the car has. So, a larger force is needed to stop the truck. Similarly, a fast-moving car has a greater velocity and thus more momentum than a slow-moving car of the same mass. So, a fast-moving car is harder to stop than a slow-moving car. **Figure 1** shows another example of an object that has momentum.

Calculating Momentum

Momentum (p) can be calculated with the equation below:

$$p = m \times v$$

In this equation, m is the mass of an object in kilograms and v is the object's velocity in meters per second. The units of momentum are kilograms multiplied by meters per second, or kg•m/s. Like velocity, momentum has a direction. Its direction is always the same as the direction of the object's velocity.

Figure 1 *The teen on the right has less mass than the teen on the left. But, the teen on the right can have a large momentum by moving quickly when she kicks.*

MATH FOCUS

Momentum Calculations What is the momentum of an ostrich with a mass of 120 kg that runs with a velocity of 16 m/s north?

Step 1: Write the equation for momentum.

$$p = m \times v$$

Step 2: Replace m and v with the values given in the problem, and solve.

$$p = 120 \text{ kg} \times 16 \text{ m/s north}$$

$$p = 19{,}200 \text{ kg•m/s north}$$

Now It's Your Turn

1. What is the momentum of a 6 kg bowling ball that is moving at 10 m/s down the alley toward the pins?
2. An 85 kg man is jogging with a velocity of 2.6 m/s to the north. Nearby, a 65 kg person is skateboarding and is traveling with a velocity of 3 m/s north. Which person has greater momentum? Show your calculations.

The Law of Conservation of Momentum

When a moving object hits another object, some or all of the momentum of the first object is transferred to the object that is hit. If only some of the momentum is transferred, the rest of the momentum stays with the first object.

Imagine that a cue ball hits a billiard ball so that the billiard ball starts moving and the cue ball stops, as shown in **Figure 2.** The white cue ball had a certain amount of momentum before the collision. During the collision, all of the cue ball's momentum was transferred to the red billiard ball. After the collision, the billiard ball moved away with the same amount of momentum the cue ball had. This example shows the *law of conservation of momentum.* The law of conservation of momentum states that any time objects collide, the total amount of momentum stays the same. The law of conservation of momentum is true for any collision if no other forces act on the colliding objects. This law applies whether the objects stick together or bounce off each other after they collide.

Reading Check **What can happen to momentum when two objects collide?** (*See the Appendix for answers to Reading Checks.*)

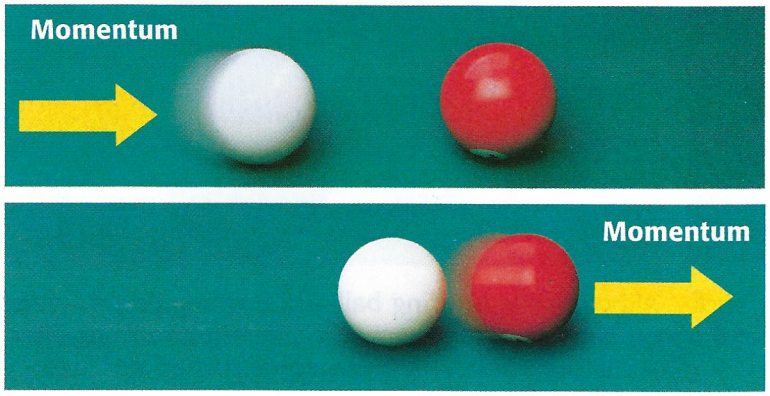


Figure 2 *The momentum before a collision is equal to the momentum after the collision.*

Objects Sticking Together

Sometimes, objects stick together after a collision. The football players shown in **Figure 3** are an example of such a collision. A dog leaping and catching a ball and a teen jumping on a skateboard are also examples. After two objects stick together, they move as one object. The mass of the combined objects is equal to the masses of the two objects added together. In a head-on collision, the combined objects move in the direction of the object that had the greater momentum before the collision. But together, the objects have a velocity that differs from the velocity of either object before the collision. The objects have a different velocity because momentum is conserved and depends on mass and velocity. So, when mass changes, the velocity must change, too.

Objects Bouncing Off Each Other

In some collisions, the objects bounce off each other. The bowling ball and bowling pins shown in **Figure 3** are examples of objects that bounce off each other after they collide. Billiard balls and bumper cars are other examples. During these types of collisions, momentum is usually transferred from one object to another object. The transfer of momentum causes the objects to move in different directions at different speeds. However, the total momentum of all the objects will remain the same before and after the collision.

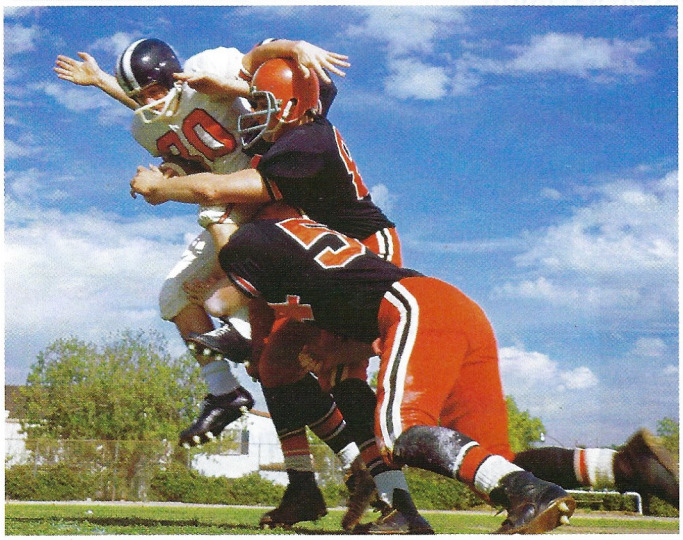
Reading Check **What are two ways that objects may interact after a collision?**

CONNECTION TO Language Arts

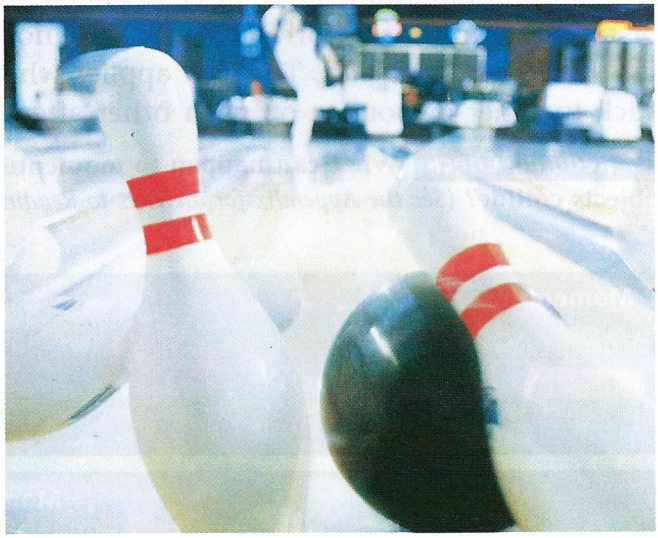
WRITING SKILL **Momentum and Language**

The word *momentum* is often used in everyday language. For example, a sports announcer may say that the momentum of a game has changed. Or you may read that an idea is gaining momentum. In your **science journal,** write a paragraph that explains how the everyday use of the word *momentum* differs from momentum in science.

Figure 3 **Examples of Conservation of Momentum**



When football players tackle another player, they stick together. The velocity of each player changes after the collision because of conservation of momentum.



Although the bowling ball and bowling pins bounce off each other and move in different directions after a collision, momentum is neither gained nor lost.

Conservation of Momentum and Newton's Third Law

Conservation of momentum can be explained by Newton's third law of motion. In the example of the billiard ball, the cue ball hit the billiard ball with a certain amount of force. This force was the action force. The reaction force was the equal but opposite force exerted by the billiard ball on the cue ball. The action force made the billiard ball start moving, and the reaction force made the cue ball stop moving, as shown in **Figure 4.** Because the action and reaction forces are equal and opposite, momentum is neither gained nor lost.

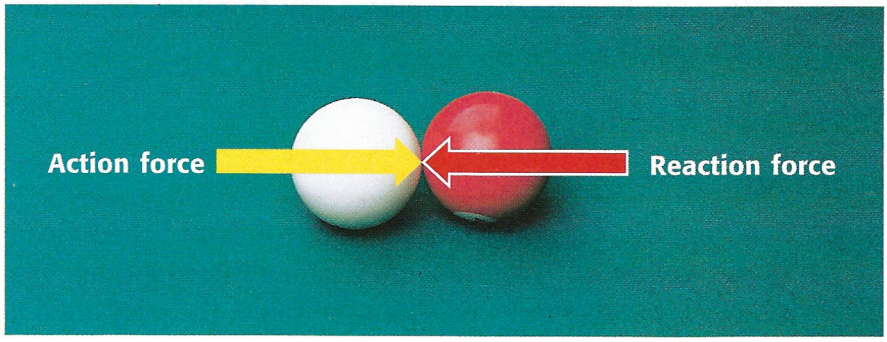


Figure 4 *The action force makes the billiard ball begin moving, and the reaction force stops the cue ball's motion.*

SECTION Review

Summary

- Momentum is a property of moving objects.
- Momentum is calculated by multiplying the mass of an object by the object's velocity.
- When two or more objects collide, momentum may be transferred, but the total amount of momentum does not change. This is the law of conservation of momentum.

Using Key Terms

1. Use the following term in a sentence: *momentum*.

Understanding Key Ideas

2. Which of the following has the smallest amount of momentum?
   - **a.** a loaded truck driven at highway speeds
   - **b.** a track athlete running a race
   - **c.** a baby crawling on the floor
   - **d.** a jet airplane being towed toward an airport
3. Explain the law of conservation of momentum.
4. How is Newton's third law of motion related to the law of conservation of momentum?

Math Skills

5. Calculate the momentum of a 2.5 kg puppy that is running with a velocity of 4.8 m/s south.

Critical Thinking

6. **Applying Concepts** A car and a train are traveling with the same velocity. Do the two objects have the same momentum? Explain your answer.
7. **Analyzing Ideas** When you catch a softball, your hand and glove move in the same direction that the ball is moving. Analyze the motion of your hand and glove in terms of momentum.

SCILINKS® NSTA
Developed and maintained by the National Science Teachers Association
For a variety of links related to this chapter, go to www.scilinks.org
Topic: Momentum
SciLinks code: HSM0988

Chapter Review

USING KEY TERMS

Complete each of the following sentences by choosing the correct term from the word bank.

free fall	projectile motion
inertia	terminal velocity
momentum	

1. An object in motion has ___, so it tends to stay in motion.
2. An object is falling at its ___ if it falls at a constant velocity.
3. ___ is the path that a thrown object follows.
4. ___ is a property of moving objects that depends on mass and velocity.
5. ___ occurs only when air resistance does not affect the motion of a falling object.

UNDERSTANDING KEY IDEAS

Multiple Choice

6. When a soccer ball is kicked, the action and reaction forces do not cancel each other out because
   - **a.** the forces are not equal in size.
   - **b.** the forces act on different objects.
   - **c.** the forces act at different times.
   - **d.** All of the above
7. An object is in projectile motion if it
   - **a.** is thrown with a horizontal push.
   - **b.** is accelerated downward by gravity.
   - **c.** does not accelerate horizontally.
   - **d.** All of the above
8. Newton's first law of motion applies to
   - **a.** moving objects.
   - **b.** objects that are not moving.
   - **c.** objects that are accelerating.
   - **d.** Both (a) and (b)
9. To accelerate two objects at the same rate, the force used to push the object that has more mass should be
   - **a.** smaller than the force used to push the object that has less mass.
   - **b.** larger than the force used to push the object that has less mass.
   - **c.** the same as the force used to push the object that has less mass.
   - **d.** equal to the object's weight.
10. A golf ball and a bowling ball are moving at the same velocity. Which of the two has more momentum?
    - **a.** The golf ball has more momentum because it has less mass.
    - **b.** The bowling ball has more momentum because it has more mass.
    - **c.** They have the same momentum because they have the same velocity.
    - **d.** There is not enough information to determine the answer.

Short Answer

11 Give an example of an object that is in free fall.

12 Describe how gravity and air resistance are related to an object's terminal velocity.

13 Why can friction make observing Newton's first law of motion difficult?

Math Skills

14 A 12 kg rock falls from rest off a cliff and hits the ground in 1.5 s.

a. Without considering air resistance, what is the rock's velocity just before it hits the ground?

b. What is the rock's momentum just before it hits the ground?

CRITICAL THINKING

15 **Concept Mapping** Use the following terms to create a concept map: *gravity, free fall, terminal velocity, projectile motion,* and *air resistance.*

16 **Identifying Relationships** During a space shuttle launch, about 830,000 kg of fuel is burned in 8 min. The fuel provides the shuttle with a constant thrust, or forward force. How does Newton's second law of motion explain why the shuttle's acceleration increases as the fuel is burned?

17 **Analyzing Processes** When using a hammer to drive a nail into wood, you have to swing the hammer through the air with a certain velocity. Because the hammer has both mass and velocity, it has momentum. Describe what happens to the hammer's momentum after the hammer hits the nail.

18 **Applying Concepts** Suppose you are standing on a skateboard or on in-line skates and you toss a backpack full of heavy books toward your friend. What do you think will happen to you? Explain your answer in terms of Newton's third law of motion.

INTERPRETING GRAPHICS

19 The picture below shows a common desk toy. If you pull one ball up and release it, it hits the balls at the bottom and comes to a stop. In the same instant, the ball on the other side swings up and repeats the cycle. How does conservation of momentum explain how this toy works?