chapter 1

# Motion and Momentum

## section 3 Momentum

### What You'll Learn

- how mass and inertia are related
- what momentum is
- to use the law of conservation of momentum to predict motion

## Before You Read

What happens if you are riding in a car and the driver slams on the brakes? Explain on the lines below.

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Study Coach

**Identify the Main Point** When you read each paragraph, look for the main point or main idea. Highlight it or write it down. When you finish reading, make sure you understand each main point.

## Read to Learn

### Mass and Inertia

One important property of objects is mass. The **mass** of an object is the amount of matter in the object. The SI unit for mass is the kilogram. Mass is related to weight. Objects with more mass weigh more than objects with less mass. A bowling ball has more mass than a pillow. So, it weighs more. But a pillow is larger. The size of an object is not the same as its mass.

Think about what happens when you try to stop someone who is running toward you. It is easier to stop a small child than an adult. The more mass an object has, the harder it is to start moving, stop moving, slow down, speed up, or turn. **Inertia** is the tendency of an object to resist a change in its motion. The more inertia an object has, the harder it is to change its motion.

Think it Over

1. **Determine** Which has more inertia, a soccer ball or a bowling ball?

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### Momentum

You know that the faster a bicycle moves, the harder it is to stop. The **momentum** of an object is the measure of how hard it is to stop the object. It depends on the object's mass and velocity. Momentum is usually symbolized by $p$.

**momentum** (in kg • m/s) = **mass** (in kg) × **velocity** (in m/s)

$$p = mv$$



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Mass is measured in kilograms. Velocity is measured in meters per second. So, the unit of momentum is kilograms multiplied by meters per second (kg • m/s). Momentum has a direction that is the same as the direction of the velocity.

## Conservation of Momentum

When you play billiards, you knock the cue ball into other balls. When a cue ball hits another ball, the motion of both balls changes. The cue ball slows down and may change direction. So its momentum decreases. The other ball starts moving. So its momentum increases.

### What happens to lost momentum?

The momentum lost by the cue ball is moved to the other ball. It is gained by the other ball. This means that the total momentum of the two balls was the same just before and just after the collision. This is true for any collision, but only as long as no outside forces like friction act on the objects. The **law of conservation of momentum** states that the total momentum of objects that collide is the same before and after the collision. This is true for the collision of the billiard balls. It is also true for collisions of atoms, cars, football players, or any other matter. ☑

## Using Momentum Conservation

Outside forces are almost always acting on objects that are colliding. These are forces like friction and gravity. But sometimes, these forces are very small and can be ignored. Then the law of conservation of mass can be used to predict how the motions of objects will change after a collision.

### What happens after objects collide?

There are many ways that collisions can happen. Sometimes the objects that collide will bounce off each other. In another type of collision, objects stick to each other after they collide.

**Bounce Off** What happens when you knock down bowling pins with a bowling ball? Picture a bowling ball rolling down the alley and hitting some bowling pins. The bowling ball and pins bounce off each other. When the ball hits the pins, some of the ball's momentum is transferred to the pins. The ball slows down and the pins speed up. The speeds change, but the total momentum does not. Momentum is conserved.

**Applying Math**

**2. Use Formulas** Calculate the momentum of a 14-kg bicycle traveling north at 2 m/s. Show all your work.

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**✔ Reading Check**

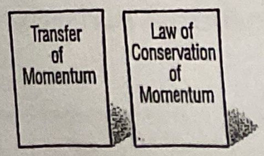
**3. Identify** The law of conservation of momentum affects objects that

**a.** rotate.
**b.** turn.
**c.** collide.
**d.** roll.

**FOLDABLES™**

**C Organize Informati**

Make the following Foldable help you organize informatio about how momentum is transferred and the law of conservation of momentum



**Stick together** Suppose you're watching a football game when one player tackles another. The two players collide, but instead of bouncing apart, they stick together. The speeds of both players change, but the total momentum does not. In this type of collision, momentum also is conserved. In both of these types of collisions, you can use the law of conservation of momentum to find the speeds of the objects after they collide.

## How do you calculate the momentum of two objects that stick together?

Imagine you are standing still on a pair of skates. You are not moving. Then someone standing in front of you throws you a backpack. You catch the backpack and begin to move backwards. You and the backpack move in the same direction that the backpack was moving before the collision.

You can use the law of conservation of momentum to find your velocity after you catch the backpack. Suppose the backpack has a mass of 2 kg and is tossed at a velocity of 5 m/s. Your mass is 48 kg and you have no velocity because you are standing still. So, your velocity before the collision is 0 m/s.

First, find the total momentum of you and the backpack. Remember, momentum equals mass times velocity.

$$\begin{aligned}\text{total momentum} &= \text{your momentum} + \text{backpack momentum}\\ &= (48\ \text{kg} \times 0\ \text{m/s}) + (2\ \text{kg} \times 5\ \text{m/s})\\ &= 0\ \text{kg} \cdot \text{m/s} + 10\ \text{kg} \cdot \text{m/s}\\ &= 10\ \text{kg} \cdot \text{m/s}\end{aligned}$$

The law of conservation of momentum tells you that the total momentum before the collision is the same as the total momentum after the collision. After the collision, the total momentum does not change. You and the backpack have become one object and are moving at the same velocity. You can use the equation for momentum to find the final velocity.

$$\begin{aligned}\text{total momentum} &= (\text{mass of backpack} + \text{your mass}) \times \text{velocity}\\ 10\ \text{kg} \cdot \text{m/s} &= (2\ \text{kg} + 48\ \text{kg}) \times \text{velocity}\\ 10\ \text{kg} \cdot \text{m/s} &= (50\ \text{kg}) \times \text{velocity}\\ \frac{10\ \text{kg} \cdot \text{m/s}}{(50\ \text{kg})} &= \text{velocity}\\ 0.2\ \text{m/s} &= \text{velocity}\end{aligned}$$

Your velocity right after you catch the backpack is 0.2 m/s.

**Think it Over**

4. **Predict** Will the velocity of the student and the backpack together be faster or slower than the velocity of the backpack by itself?

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**Applying Math**

5. **Calculate** Find the velocity of the student and the backpack if the backpack's mass is 3 kg, it was tossed at a velocity of 4 m/s, and the mass of the student is 57 kg. Show all your work.

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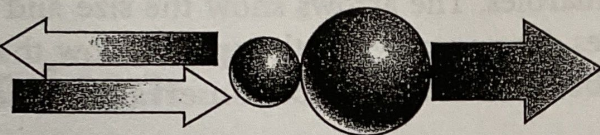
**Stopping** Friction between your skates and the ground will slow you down as you move on your skates. The momentum of you and the backpack will continue to decrease until you stop because of friction.

## How can mass predict motion after collisions?

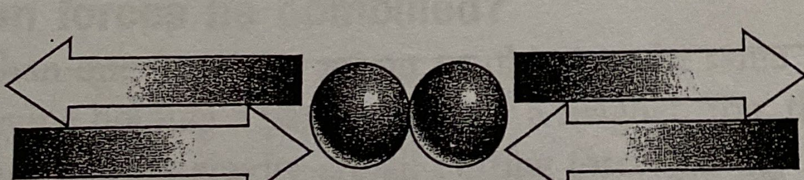
You can use the law of conservation of momentum to predict collisions between two objects. What happens when one marble hits another marble that is at rest? It depends on the masses of the marbles that collide. The figure shows a marble with a smaller mass hitting a marble with a larger mass. The larger marble is at rest. After the collision, the marble with a smaller mass bounces off in the opposite direction. The larger marble moves in the same direction that the small marble was moving.



What if the larger marble hits a smaller marble that is not moving? Both marbles will move in the same direction. But the marble with the smaller mass always moves faster than the marble with the greater mass.

## How does bouncing affect momentum?

Two objects can also bounce off of each other. The two marbles in the figure have the same mass and are moving at the same speed. They bounce off each other when they collide. Before the collision, the momentum of each marble was the same but in opposite directions. So the total momentum was zero. That means that the total momentum after the collision has to be zero too. The two marbles must move in opposite directions with the same speed after the collision. Then the total momentum is zero again.



**Picture This**

**6. Describe** From which marble to which marble was momentum moved?

**Applying Math**

**7. Analyze** Would the total momentum still be zero if one marble had greater mass than the other marble?