**Name:**

# Skill Sheet 12.1 Momentum

This exercise will help you solve problems that involve momentum. The momentum of an object is equal to its mass times its velocity. When two objects collide, their momentum before the collision is equal to their momentum after the collision. This statement is called the law of conservation of momentum.

## 1. What is momentum?

A baseball bat and a ball are a pair of objects that collide with each other. Because of Newton's third law of motion, we know that the force the bat has on the baseball is equal, but opposite in direction, to the force of the ball on the bat. The bat and the baseball illustrate that action and reaction forces come in pairs.

Similarly, the momentum of the bat before it hits the ball will affect how much momentum the ball has after it and the bat collide. Likewise, the momentum of the ball coming toward the bat determines how much force you must use when swinging the bat if you are to hit a home run. What is *momentum*?

The momentum (kg-m/sec) of an object is its mass (in kilograms) multiplied by its velocity (m/sec). The equation for momentum where $p$ equals momentum, $m$ equals mass, and $v$ equals velocity, is:

$$\vec{p} = m\vec{v}$$

$$\vec{p} = \text{mass in kilograms} \times \text{velocity in m/sec}$$

## 2. The law of conservation of momentum

The *law of conservation of momentum* states that momentum is conserved. This means that the momentum of the bat and ball before their collision is equal to the momentum of the bat and ball after their collision.

Two colliding objects represent a *system*. The formula below can be used to find the new velocities of objects if both keep moving after the collision.

$$\text{the momentum of a system before a collision} = \text{the momentum of a system after a collision}$$

$$m_1\vec{v}_{1(\text{ initial})} + m_2\vec{v}_{2\text{ (initial)}} = m_1\vec{v}_{3\text{ (final)}} + m_2\vec{v}_{4\text{ (final)}}$$

If two objects are initially at rest, the total momentum of the system is zero. For the final momentum to be zero, the objects must have equal momenta in opposite directions.

For example, if you are standing on ice skates and throw a bowling ball, the ball's forward momentum will be equal to your backward momentum.

$$\text{the momentum of a system before a collision} = 0$$

$$0 = \text{the momentum of a system after a collision}$$

$$0 = m_1\vec{v}_3 + m_2\vec{v}_4$$

$$m_1\vec{v}_3 = -(m_2\vec{v}_4)$$

If a collision is inelastic and the objects stick together, both have the same final velocity.

$$m_1\vec{v}_{1(\text{inital})} + m_2\vec{v}_{2(\text{intial})} = (m_1 + m_2)\vec{v}_{3(\text{final})}$$

## 3. Solving momentum problems

Find the momentum of the following objects. The first two problems have been done for you.

1. A 0.2-kilogram steel ball that is rolling at a velocity of 3.0 m/sec.

$$\text{momentum} = m \times \vec{v} = 0.2 \text{ kg} \times \frac{3 \text{ m}}{\text{sec}} = 0.6 \text{ kg} \cdot \frac{m}{\text{sec}}$$

2. A 0.005-kilogram bullet with a velocity of 500 m/sec.

$$\text{momentum} = m \times \vec{v} = 0.005 \text{ kg} \times \frac{500 \text{ m}}{\text{sec}} = 2.5 \text{ kg} \cdot \frac{m}{\text{sec}}$$

3. A 100-kilogram fullback carrying a football on a play at a velocity of 3.5 m/sec.

4. A 75-kilogram defensive back chasing the fullback at a velocity of 5 m/sec.

5. In questions 3 and 4 above, if the fullback collided with the defensive back, who would get thrown backward? Explain your answer.

6. If a ball is rolling at a velocity of 1.5 m/sec and has a momentum of 10.0 kg-m/sec, what is the mass of the ball?

7. What is the velocity of an object that has a mass of 2.5 kilogram and a momentum of 1,000 kg-m/sec?

## 4. Problems involving the law of conservation of momentum

Use the law of conservation of momentum formulas to answer the following problems. The first problem has been done for you.

1. You and a friend stand facing each other on ice skates. Your mass is 50 kilograms and your friend's mass is 60 kilograms. As the two of you push off each other, you move with a velocity of 4 m/sec to the right. What is your friend's velocity?

$$m_1\vec{v}_3 = -(m_2\vec{v}_4)$$

$$(50\text{ kg})(4\text{ m/sec}) = -(60\text{ kg})(v_4)$$

   The answer is: $v_4$ = - 3.33 m/sec or 3.33 m/sec to the left.

2. A 400-kilogram cannon fires a 10-kilogram cannonball at 20 m/sec. If the cannon is on wheels, at what velocity does it move backward? (This backward motion is called recoil velocity.)

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3. You stand on a skateboard at rest and throw a rock at 5 m/sec. You move back at 0.5 m/sec. What is the combined mass of you and the skateboard?

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4. A 2,000-kilogram railroad car moving at 5 m/sec collides with a 6,000-kilogram railroad car at rest. If the cars coupled together, what is their velocity after the collision?

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5. A 2,000-kilogram railroad car moving at 5 m/sec to the east collides with a 6,000-kilogram railroad car moving at 3 m/sec to the west. If the cars couple together, what is their velocity after the collision?

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6. A 4-kilogram ball moving at 8 m/sec to the right collides with a 1-kilogram ball at rest. After the collision, the 4-kilogram ball moves at 4.8 m/sec to the right. What is the velocity of the 1-kilogram ball?

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