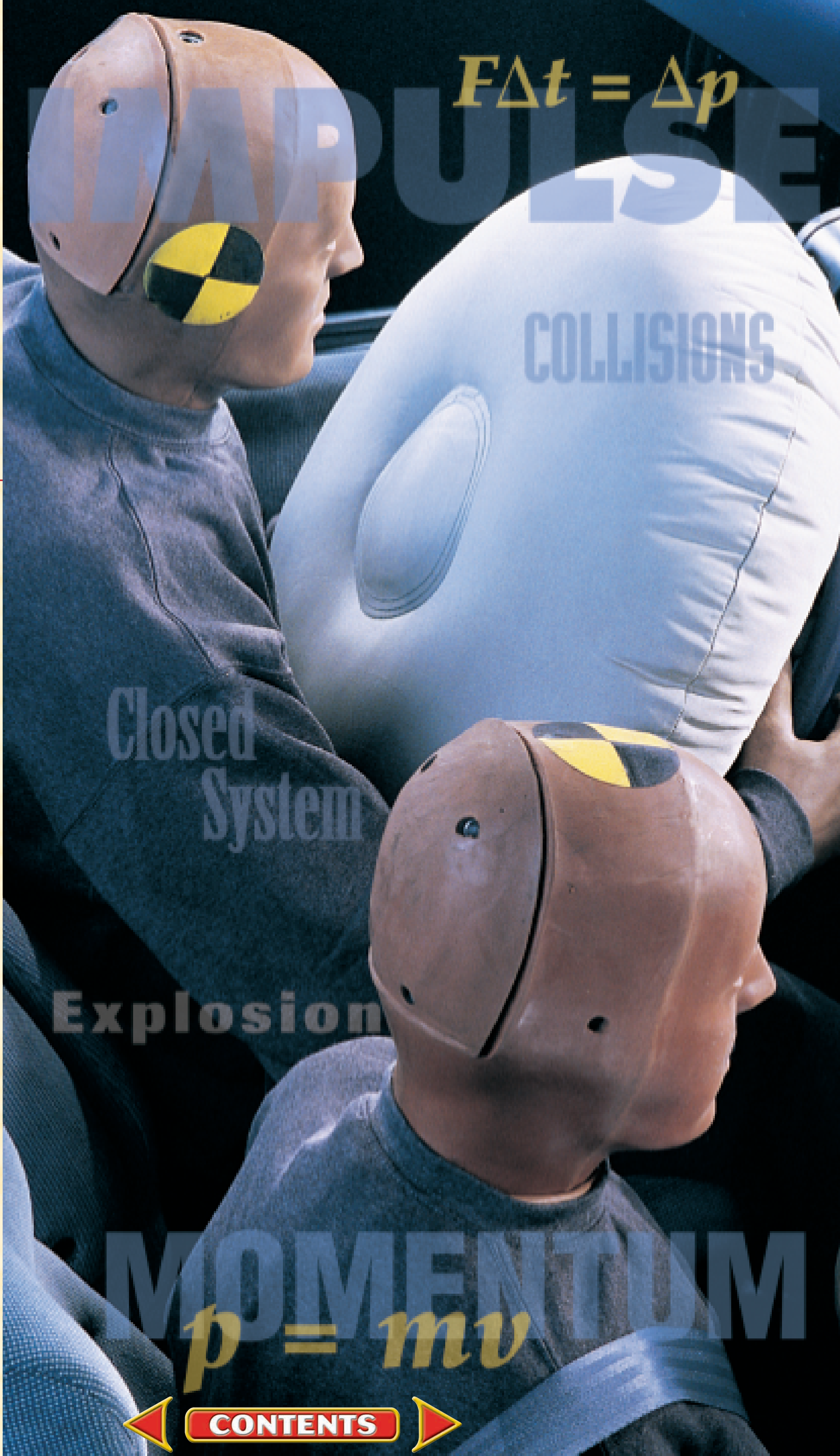
How Safe?

Many of today's cars have air bags. In a head-on crash of two cars equipped with air bags, both drivers walked away uninjured. How does an air bag help to reduce the injury to a person in an automobile accident?

Look at the text on page 203 for the answer.



CHAPTER

9 Momentum and Its Conservation

You've seen pictures of crashed cars. You might have even passed a crash scene. In many instances, you can see a round break or crack in the car's windshield. The break is usually caused by the impact of a person's head hitting the windshield. In the crash of a car moving at high speed, the car is brought to a stop quickly. However, the passengers continue to move until they are stopped by the windshield or some other part of the car. You may be surprised to learn that some of the same principles that explain why passengers hit the windshield and why the windshield cracks can explain how a major league baseball player can hit the ball out of the park!

So far in your study of physics, you have examined the causes of change, which are the part of physics called dynamics. You found that position is changed by velocity, and velocity is changed by acceleration, and that acceleration is caused by a net force. In most real-life situations, such as a car crash, the forces and accelerations change so rapidly that it would be nearly impossible to study them without technical tools such as strobe lights, slow-motion film, and computers.

However, you can learn more about forces by studying the properties of interacting bodies. In this chapter, you will examine some of the properties of objects before and after an interaction takes place, and you will discover how these properties are affected. You especially will look for properties that remain constant. Properties that remain constant can be described as being conserved.

WHAT YOU'LL LEARN

- You will describe momentum and impulse and apply them to the interaction of objects.
- You will relate Newton's third law of motion to conservation of momentum.

WHY IT'S IMPORTANT

- You will be able to explain how air bags can help reduce injuries and save lives in a car crash.
- You will understand how conservation of momentum explains the propulsion of rockets.

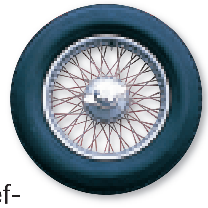
PHYSICS Online

To find out more about momentum and its conservation, visit the Glencoe Science Web site at **science.glencoe.com**

CLICK HERE

CONTENTS

9.1 Impulse and Momentum



The word *momentum* is used often in everyday speech. For example, a winning sports team is said to have momentum. In physics, however, momentum has its own definition. Newton wrote his three laws of motion in terms of momentum, which he called the quantity of motion.

OBJECTIVES

- **Compare** the system before and after an event in momentum problems.
- **Define** the momentum of an object.
- **Determine** the impulse given to an object.
- **Recognize** that impulse equals the change in momentum of an object.

Impulse and Momentum

A service ace in tennis is an exciting shot. The server lobs the ball overhead and swings the racket through a smooth arc to meet the ball. The ball explodes away from the racket at high speed. The first step in analyzing this interaction is to define "before," "during," and "after" and to sketch them as shown in **Figure 9–1.**

You can simplify the collision between the ball and the racket by assuming that all motion is in the horizontal direction. Before the hit, the ball is moving slowly. During the hit, the ball is squashed against the racket. After the hit, the ball moves at a higher velocity and the racket continues in its path, but at a slower velocity.

How is velocity affected by force? How are the velocities of the ball before and after the collision related to the force acting on it? According to Newton's first law of motion, if no net force acts on a body, its velocity is constant. Newton's second law of motion describes how the velocity of a body is changed by a net force acting on it.

Color Conventions

- Displacement vectors are **green.**
- Velocity vectors are **red.**
- Acceleration vectors are **violet.**
- Force vectors are **blue.**
- Momentum and impulse vectors are **orange.**

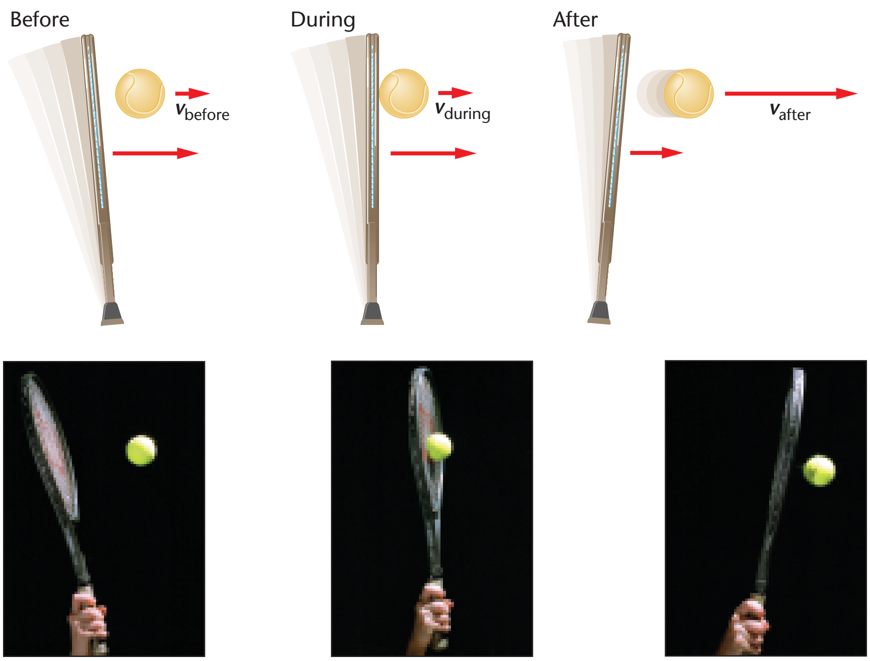


FIGURE 9–1 The motions of a tennis racket and ball are shown before, during, and after their interaction.

The change in velocity of the ball must have been caused by the force exerted by the racket on the ball. The force changes over time, as shown in **Figure 9–2.** Just after contact is made, the ball is squeezed, the racket strings are stretched, and the force increases. After the force reaches a maximum, the ball recovers its shape and snaps away from the strings of the racket. The force rapidly returns to zero. The maximum force is more than 1000 times greater than the weight of the ball! The whole event takes place within only a few thousandths of a second.

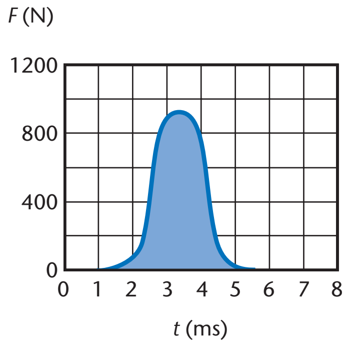


FIGURE 9–2 The force acting on a tennis ball increases, then rapidly decreases during a hit, as shown in this force-time graph.

Relating impulse and momentum Newton's second law of motion can help explain how the momentum of an object is changed by a net force acting on it. Newton's second law of motion, $\boldsymbol{F}=m\boldsymbol{a}$, can be rewritten by using the definition of acceleration as "the change in velocity divided by the time interval."

$$\boldsymbol{F} = m\boldsymbol{a} = m\frac{\Delta \boldsymbol{v}}{\Delta t}$$

Multiplying both sides of the equation by the time interval, Δt, results in the following equation.

$$\boldsymbol{F}\Delta t = m\Delta\boldsymbol{v}$$

The left-hand side, $\boldsymbol{F}\Delta t$, is the product of the average force and the time interval over which it acts. This product is called the **impulse,** and its unit of measurement is the newton-second (N·s). The magnitude of an impulse is found by determining the area under the curve of a force-time graph, such as the one shown in **Figure 9–2.**

The right-hand side of the equation, $m\Delta\boldsymbol{v}$, shows the change in velocity, $\Delta\boldsymbol{v} = \boldsymbol{v}_2 - \boldsymbol{v}_1$, which also can be stated as $m\boldsymbol{v}_2 - m\boldsymbol{v}_1$. The product of mass and velocity of an object such as a tennis ball is defined as the **linear momentum** (plural: momenta) of the object. The symbol for momentum is $\boldsymbol{p}$. Thus, $\boldsymbol{p} = m\boldsymbol{v}$. The right-hand side of the equation can be written $\boldsymbol{p}_2 - \boldsymbol{p}_1$, which expresses the change in momentum of the tennis ball. Thus, the impulse on an object is equal to the change in its momentum.

Impulse-Momentum Theorem $\boldsymbol{F}\Delta t = \boldsymbol{p}_2 - \boldsymbol{p}_1$

This equation is called the **impulse-momentum theorem.** The impulse on an object is equal to the change in momentum that it causes. If the force is constant, the impulse is simply the product of the force times the time interval over which it acts. Generally, the force is not constant, and the impulse is found by using an average force times the time interval, or by finding the area under the curve on a force-time graph.

Using the impulse-momentum theorem What is the change in momentum of the tennis ball? From the impulse-momentum theorem, you know that the change in momentum is equal to the impulse. The impulse on the tennis ball can be calculated by using the force-time graph. In **Figure 9–2,** the area under the curve is approximately 1.4 N·s.

F.Y.I.

Each time a runner's foot strikes the ground, it must absorb the force of two to four times the runner's weight. The goal of athletic shoe design is to reduce the stress on the foot. By using materials that lengthen the time of impact on the foot, the force of the impact on the foot is reduced.

Therefore, the change in momentum of the ball is also 1.4 N·s. Because one newton-second is equal to one kg·m/s, the momentum gained by the ball is 1.4 kg·m/s.

What is the momentum of the ball after the hit? Rearrange the impulse-momentum theorem to answer this question.

$$\boldsymbol{p}_2 = \boldsymbol{F}\Delta t + \boldsymbol{p}_1$$

You can see now that the ball's final momentum is the sum of the initial momentum and the impulse. If the tennis ball was at rest before it was hit, its final momentum is equal to the impulse, 1.4 kg·m/s.

$$p_2 = mv = 1.4 \text{ kg·m/s}$$

If the ball has a mass of 0.060 kg, then its velocity will be 23 m/s.

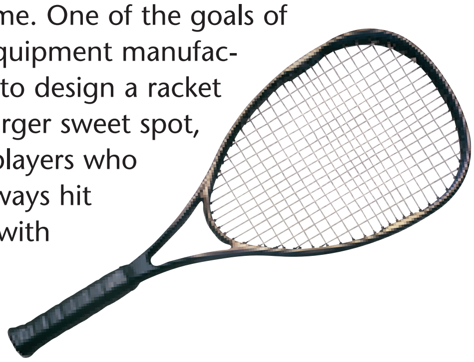
$$v = \frac{p_2}{m} = \frac{1.4 \text{ kg·m/s}}{0.060 \text{ kg}} = 23 \text{ m/s}$$

Physics & Technology

High-Tech Tennis Rackets

Strings along the outer edges of a tennis racket are less flexible than the strings at the center. The more flexible area at the center of a racket is known as the "sweet spot." Striking a tennis ball near the edge of the racket imparts greater momentum to the ball, but the shock of the impact is transferred to the player's arm. Hitting a ball at the sweet spot imparts less momentum, but the strings absorb more of the shock of impact, thereby increasing the player's control and reducing the risk of injury.

Sports enthusiasts are always willing to try new technologies that could help improve their game. One of the goals of tennis equipment manufacturers is to design a racket with a larger sweet spot, so that players who don't always hit the ball with the center of the racket won't suffer arm injuries. Using information developed during research on how best to connect platforms in space, NASA researchers discovered that using strings that are thicker in the center and thinner near the edges of the racket enlarges the sweet spot. But racket makers found that implementing this idea is too complicated for practical use. The NASA researchers then developed a way to chemically treat strings so that they become more flexible as they are stretched tighter. In the manufacture of tennis rackets, these new strings enlarge the sweet spot.



The sweet spot can also be enlarged by widening the upper portion of the racket frame or using a thinner gauge string, more flexible string material, or less string tension.

Thinking Critically Why does striking a tennis ball with taut strings at the edge of the racket impart more speed to the ball than striking it at the sweet spot?

Because velocity is a vector, so is momentum. Similarly, because force is a vector, so is impulse. This means that signs are important for motion in one dimension. If you choose the positive direction to be to the right, then negative velocities, momenta, and impulses will be directed to the left.

Using the impulse-momentum theorem to save lives A large change in momentum occurs only when there is a large impulse. A large impulse, however, can result either from a large force acting over a short period of time, or from a smaller force acting over a longer period of time.

What happens to the driver when a crash suddenly stops a car? An impulse is needed to bring the driver's momentum to zero. The steering wheel can exert a large force during a short period of time. An air bag reduces the force exerted on the driver by greatly increasing the length of the time the force is exerted. If you refer back to the equation

$$\boldsymbol{F} = m\frac{\Delta \boldsymbol{v}}{\Delta t}$$

$\Delta \boldsymbol{v}$ is the same with or without the air bag. However, the air bag reduces $\boldsymbol{F}$ by increasing Δt. The product of the average force and the time interval of the crash would be the same for both kinds of crashes. Remember that mass has not changed and the change in velocity will not be any different regardless of the time needed to stop.

How Safe?

Answers question from page 198.

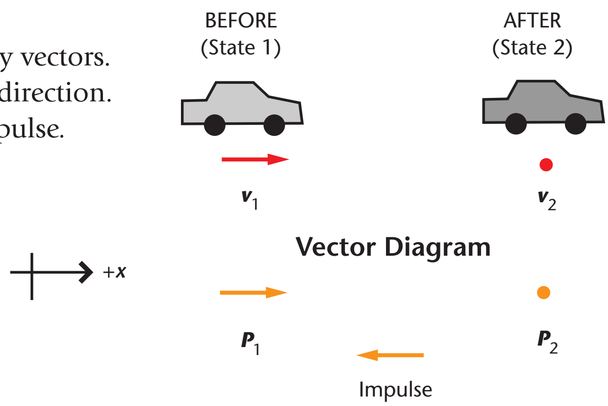
Example Problem

Stopping a Vehicle

A 2200-kg sport utility vehicle (SUV) traveling at 94 km/h (26 m/s) can be stopped in 21 s by gently applying the brakes, in 5.5 s in a panic stop, or in 0.22 s if it hits a concrete wall. What average force is exerted on the SUV in each of these stops?

Sketch the Problem

- Sketch the system before and after the event.
- Show the SUV coming to rest. Label the velocity vectors.
- Include a coordinate axis to select the positive direction.
- Draw a vector diagram for momentum and impulse.



Calculate Your Answer

Known:

$m = 2200$ kg

$v_1 = 26$ m/s

$v_2 = 0$ m/s

Δt: 21 s, 5.5 s, 0.22 s

Unknown:

$F = ?$

Continued on next page

Strategy:

Determine the momentum before, p_1, and after, p_2, the crash.

Calculations:

$p_1 = mv_1 = (2200 \text{ kg})(26 \text{ m/s})$
$= 5.7 \times 10^4 \text{ kg·m/s}$

$p_2 = mv_2 = 0.0$

Apply the impulse-momentum theorem to obtain the force needed to stop the SUV.

$F\Delta t = p_2 - p_1$
$F\Delta t = -5.7 \times 10^4 \text{ kg·m/s}$
$F = (-5.7 \times 10^4 \text{ kg·m/s})/\Delta t$

For gentle braking	$F = -2.7 \times 10^3$ N
For panic braking	$F = -1.0 \times 10^4$ N
When hitting the wall	$F = -2.6 \times 10^5$ N

Check Your Answer

- Are the units correct? Force is measured in newtons.
- Is the magnitude realistic? People weigh hundreds of newtons, so you would expect that the force to stop a car would be in the thousands of newtons. The impulse is the same for all three stops. So, as the stopping time is shortened by a factor of ten, the force is increased by a factor of ten.
- Does the direction make sense? Force is negative; it pushes back against the motion of the car.

Practice Problems

1. A compact car, mass 725 kg, is moving at 1.00×10^2 km/h toward the east. Sketch the moving car.
   a. Find the magnitude and direction of its momentum. Draw an arrow on your picture showing the momentum.
   b. A second car, mass 2175 kg, has the same momentum. What is its velocity?

2. The driver of the compact car suddenly applies the brakes hard for 2.0 s. As a result, an average force of 5.0×10^3 N is exerted on the car to slow it. Sketch the situation.
   a. What is the change in momentum, that is the magnitude and direction of the impulse, on the car?
   b. Complete the "before" and "after" diagrams, and determine the new momentum of the car.
   c. What is the velocity of the car now?

3. A 7.0-kg bowling ball is rolling down the alley with a velocity of 2.0 m/s. For each impulse, **a** and **b,** as shown in **Figure 9–3,** find the resulting speed and direction of motion of the bowling ball.

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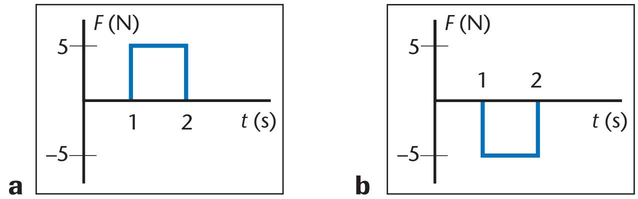


FIGURE 9–3

4. The driver accelerates a 240.0 kg snowmobile, which results in a force being exerted that speeds the snowmobile up from 6.00 m/s to 28.0 m/s over a time interval of 60.0 s.

- **a.** Sketch the event, showing the initial and final situations.
- **b.** What is the snowmobile's change in momentum? What is the impulse on the snowmobile?
- **c.** What is the magnitude of the average force that is exerted on the snowmobile?

5. A 0.144-kg baseball is pitched horizontally at 38.0 m/s. After it is hit by the bat, it moves at the same speed, but in the opposite direction.

- **a.** Draw arrows showing the ball's momentum before and after it hits the bat.
- **b.** What was the change in momentum of the ball?
- **c.** What was the impulse delivered by the bat?
- **d.** If the bat and ball were in contact for 0.80 ms, what was the average force the bat exerted on the ball?

6. A 60-kg person was in the car that hit the concrete wall in the example problem. The velocity of the person equals that of the car both before and after the crash, and the velocity changes in 0.20 s. Sketch the problem.

- **a.** What is the average force exerted on the person?
- **b.** Some people think that they can stop themselves rushing forward by putting their hands on the dashboard. Find the mass of the object that has a weight equal to the force you just calculated. Could you lift such a mass? Are you strong enough to stop yourself with your arms?

Angular Momentum

As you have seen in Chapter 7, if an object rotates, its speed changes only if torque is applied to it. This is a statement of Newton's law for rotating objects. The quantity of angular motion that is used with rotating objects is called angular momentum. **Angular momentum** is the quantity of motion used with objects rotating about a fixed axis. Just as the linear momentum of an object changes when force acts on the object, the angular momentum of an object changes when torque acts on the object.

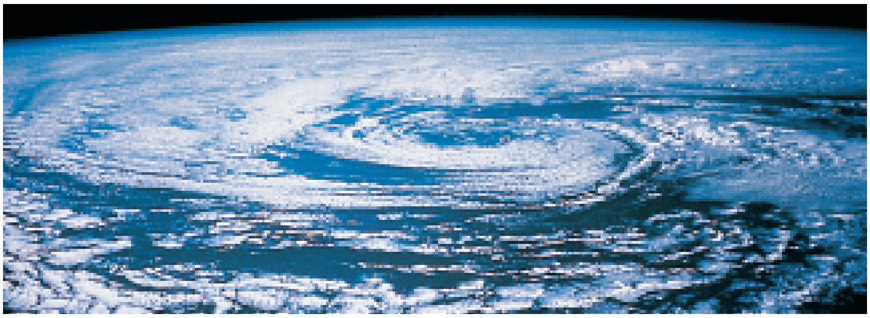
Pocket Lab

Cart Momentum

Attach a spring scale to a laboratory cart. First, pull the cart for 1.0 s while exerting 1.0 N of force. Next, pull the cart for 2.0 s while exerting about 0.50 N of force. Predict which trial will give the cart more acceleration. Explain. Predict which trial will give the cart more velocity. Explain. Then try it.

Recognizing Cause and Effect Which factor, F or Δt, seems to be more important in changing the velocity of the cart?

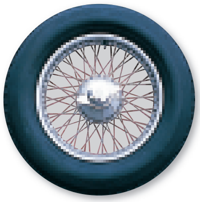
FIGURE 9–4 This hurricane was photographed from space. The huge, rotating mass of air possesses a large angular momentum.



Linear momentum is a product of an object's mass and velocity $\boldsymbol{p} = m\boldsymbol{v}$. Angular momentum is a product of the object's mass, displacement from the center of rotation, and the component of velocity perpendicular to that displacement, as illustrated by **Figure 9–4.** If angular momentum is constant and the distance to the center of rotation decreases, then velocity increases. For example, the torque on the planets orbiting the sun is zero because the gravitational force is directly toward the sun. Therefore, each planet's angular momentum is constant. Thus, when a planet's distance from the sun becomes smaller, the planet moves faster. This is an explanation of Kepler's second law of planetary motion based on Newton's laws of motion.

9.1 Section Review

1. Is the momentum of a car traveling south different from that of the same car when it travels north at the same speed? Draw the momentum vectors to support your answer.
2. A basketball is dribbled. If its speed while going toward the floor is the same as it is when it rises from the floor, is the ball's change in momentum equal to zero when it hits the floor? If not, in which direction is the change in momentum? Draw the ball's momentum vectors before and after it hits the floor.
3. Which has more momentum, a supertanker tied to a dock or a raindrop falling?
4. If you jump off a table, you let your legs bend at the knees as your feet hit the floor. Explain why you do this in terms of the physics concepts introduced in this chapter.
5. **Critical Thinking** An archer shoots arrows at a target. Some arrows stick in the target, while others bounce off. Assuming that their masses and velocities are the same, which arrows give a bigger impulse to the target? **Hint:** Draw a diagram to show the momentum of the arrows before and after hitting the target for the two cases.



The Conservation of Momentum

9.2

You have seen how a force applied during a time interval changes the momentum of a tennis ball. But in the discussion of Newton's third law of motion, you learned that forces are the result of interactions between objects moving in opposite directions. The force of a tennis racket on the ball is accompanied by an equal and opposite force of the ball on the racket. Is the momentum of the racket, therefore, also changed?

OBJECTIVES

- **Relate** Newton's third law of motion to conservation of momentum in collisions and explosions.
- **Recognize** the conditions under which the momentum of a system is conserved.
- **Apply** conservation of momentum to explain the propulsion of rockets.
- **Solve** conservation of momentum problems in two dimensions by using vector analysis.

Two-Particle Collisions

Although it would be simple to consider the tennis racket as a single object, the racket, the hand of the player, and the ground on which the player is standing are all objects that interact when the tennis player hits the ball. To begin your study of interactions in collisions, examine the much simpler system, shown in **Figure 9–5.**

During the collision of two balls, each briefly exerts a force on the other. Despite the differences in sizes and velocities of the balls, the forces they exert on each other are equal and opposite, according to Newton's third law of motion. These forces are represented by the following equation.

$$\boldsymbol{F}_{\text{B on A}} = -\boldsymbol{F}_{\text{A on B}}$$

Because the time intervals over which the forces are exerted are the same, how do the impulses received by both balls compare? They must be equal in magnitude but opposite in direction. How do the momenta of the balls compare after the collision?

According to the impulse-momentum theorem, the final momentum is equal to the initial momentum plus the impulse. Compare the momenta of the two balls.

For ball A: $\boldsymbol{p}_{\text{A2}} = \boldsymbol{F}_{\text{B on A}}\Delta t + \boldsymbol{p}_{\text{A1}}$

For ball B: $\boldsymbol{p}_{\text{B2}} = \boldsymbol{F}_{\text{A on B}}\Delta t + \boldsymbol{p}_{\text{B1}}$

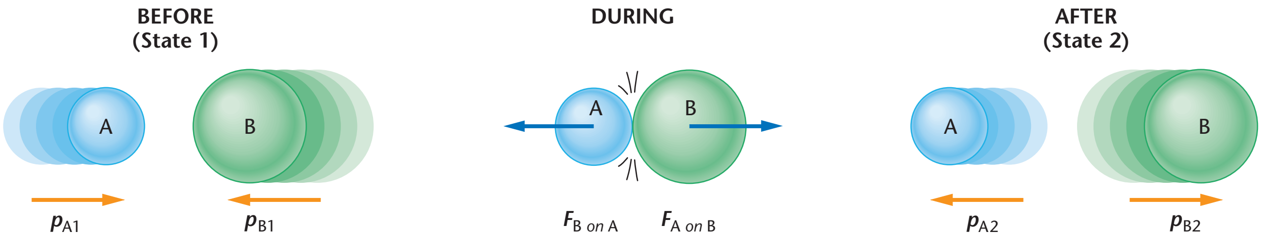


FIGURE 9–5 When two balls collide, they exert forces on each other, changing their momenta.

Use the result of Newton's third law of motion $-\boldsymbol{F}_{\text{A on B}} = \boldsymbol{F}_{\text{B on A}}$.

$$\boldsymbol{p}_{\text{A2}} = -\boldsymbol{F}_{\text{A on B}}\Delta t + \boldsymbol{p}_{\text{A1}}$$

Add the momenta of the two balls.

$$\boldsymbol{p}_{\text{A2}} = -\boldsymbol{F}_{\text{A on B}}\Delta t + \boldsymbol{p}_{\text{A1}} \text{ and } \boldsymbol{p}_{\text{B2}} = \boldsymbol{F}_{\text{A on B}}\Delta t + \boldsymbol{p}_{\text{B1}} \text{ yield:}$$

Conserved Momentum $\boldsymbol{p}_{\text{A2}} + \boldsymbol{p}_{\text{B2}} = \boldsymbol{p}_{\text{A1}} + \boldsymbol{p}_{\text{B1}}$

This shows that the sum of the momenta of the balls is the same before and after the collision. That is, the momentum gained by ball 2 is equal to the momentum lost by ball 1. If the system is defined as the two balls, the momentum of the system is constant. For the system, momentum is conserved.

Momentum in a Closed System

Under what conditions is the momentum of the system of two balls conserved? The first and most obvious condition is that at all times only two balls collide. No balls are lost, and none are gained. A system that doesn't gain or lose mass is said to be a **closed system.** All the forces within a closed system are **internal forces.** The second condition required to conserve momentum of the system is that the only forces involved are internal forces. All the forces outside the system are **external forces.** When the net external force on a closed system is zero, it is described as an **isolated system.** No system on Earth can be said to be absolutely closed and isolated. That is, there will always be some interaction between a system and its environment. Often, these interactions are small and can be ignored when solving physics problems.

Systems can contain any number of objects, and the objects can stick together or come apart in the collision. Under these conditions, the **law of conservation of momentum** states that the momentum of any closed system with no net external force does not change. This law will enable you to make a connection between conditions before and after an interaction without knowing any of the details of the interaction.

A flask filled with gas and closed with a stopper, as shown in **Figure 9–6,** is a system with many particles. The gas molecules are in constant, random motion at all temperatures above absolute zero, and they are constantly colliding with each other and with the walls of the flask. The momenta of the particles are changing with every collision. In a two-particle collision, the momentum gained by one particle is equal to that lost by the other. Momentum is also conserved in collisions between particles and the flask wall. Although the wall's velocity might change very slightly in each collision, there are as many momenta of particles to the right as to the left, and as many up as down, so the net change in the momentum of the flask is zero. The total momentum of the system doesn't change; it is conserved.

Pocket Lab

Skateboard Fun

Have two students sit facing each other on skateboards approximately 3 to 5 meters apart. Place a rope in their hands. Predict what will happen when one student pulls on the rope while the other just holds his or her end. Explain your prediction. Which person is exerting more force on the rope? Compare the amount of time that the force is acting on each person. Which person will have a greater change in momentum? Explain. Then try it. Describe what really happened.

Design An Experiment Can you devise a method to pull only one student to the other so that the other student doesn't move?

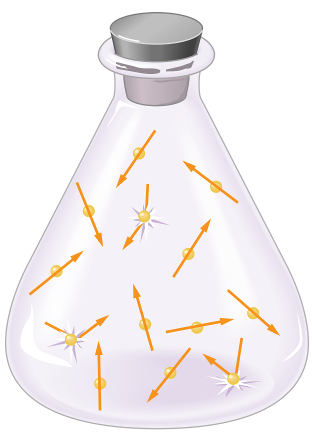


FIGURE 9–6 The total momentum of a closed, isolated system is constant.

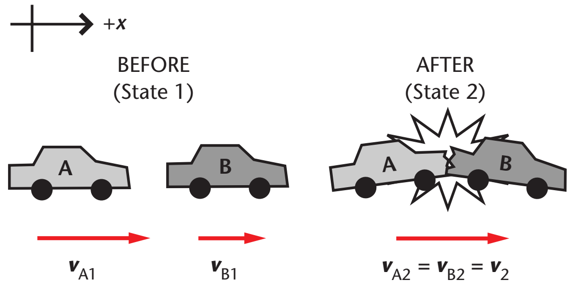
Example Problem

Car Collisions

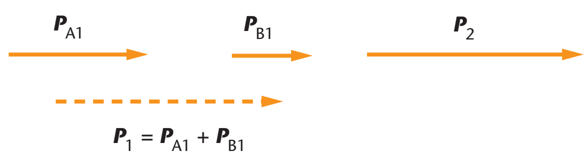
A 2275-kg car going 28 m/s rear-ends an 875-kg compact car going 16 m/s on ice in the same direction. The two cars stick together. How fast does the wreckage move immediately after the collision?

Sketch the Problem

- Establish a coordinate axis.
- Show the before and after states.
- Label car A and car B and include velocities.
- Draw a vector diagram for the momentum.
- The length of the arrow representing the momentum after the collision equals the sum of the lengths of the arrows for the momenta before the collision.



Vector Diagram



Calculate Your Answer

Known:

$m_A = 2275$ kg
$v_{A1} = 28$ m/s
$m_B = 875$ kg
$v_{B1} = 16$ m/s

Unknown:

$v_2 = ?$

Strategy:

The law of conservation of momentum can be used because the ice makes total external force on the cars nearly zero.

Calculations:

$$p_1 = p_2$$
$$p_{A1} + p_{B1} = p_{A2} + p_{B2}$$
$$m_A v_{A1} + m_B v_{B1} = m_A v_{A2} + m_B v_{B2}$$

Because the two cars stick together, their velocities after the collision, denoted as v_2, are equal.

$$v_{A2} = v_{B2} = v_2$$
$$m_A v_{A1} + m_B v_{B1} = (m_A + m_B)\, v_2$$
$$v_2 = \frac{m_A v_{A1} + m_B v_{B1}}{m_A + m_B}$$
$$v_2 = \frac{(2275 \text{ kg})(28 \text{ m/s}) + (875 \text{ kg})(16 \text{ m/s})}{2275 \text{ kg} + 875 \text{ kg}}$$
$$v_2 = 25 \text{ m/s}$$

Check Your Answer

- Are the units correct? The correct unit for speed is m/s.
- Does the direction make sense? All the initial speeds are in the positive direction. You would, therefore, expect v_2 to be positive.
- Is the magnitude realistic? The magnitude of v_2 is between the initial speeds of the two cars, so it is reasonable.

USING A CALCULATOR

Using Parentheses

Using the parentheses functions of your calculator can simplify the evaluation of complex expressions.

$$v_2 = \frac{m_A v_{A1} + m_B v_{B1}}{m_A + m_B}$$

Keys	Display
2275 × 28 =	63700
+ (875 × 16) =	77700
÷ (2275 + 875) =	24.67

Answer
v_2 = 25 m/s

Practice Problems

7. Two freight cars, each with a mass of 3.0×10^5 kg, collide. One was initially moving at 2.2 m/s; the other was at rest. They stick together. What is their final speed?

8. A 0.105-kg hockey puck moving at 24 m/s is caught and held by a 75-kg goalie at rest. With what speed does the goalie slide on the ice?

9. A 35.0-g bullet strikes a 5.0-kg stationary wooden block and embeds itself in the block. The block and bullet fly off together at 8.6 m/s. What was the original speed of the bullet?

10. A 35.0-g bullet moving at 475 m/s strikes a 2.5-kg wooden block that is at rest. The bullet passes through the block, leaving at 275 m/s. How fast is the block moving when the bullet leaves?

11. Glider A, with a mass of 0.355 kg, moves along a frictionless air track with a velocity of 0.095 m/s, as in **Figure 9–7.** It collides with glider B, with a mass of 0.710 kg and a speed of 0.045 m/s in the same direction. After the collision, glider A continues in the same direction at 0.035 m/s. What is the speed of glider B?

FIGURE 9–7

12. A 0.50-kg ball traveling at 6.0 m/s collides head-on with a 1.00-kg ball moving in the opposite direction at a speed of 12.0 m/s. The 0.50-kg ball bounces backward at 14 m/s after the collision. Find the speed of the second ball after the collision.

Explosions You have seen how important it is to define each system carefully. The momentum of the tennis ball changed when the external force of the racket was exerted on it. The tennis ball was not an isolated system. On the other hand, the total momentum of the two colliding balls within the isolated system didn't change because all forces were between objects within the system.

Can you find the final velocities of the two in-line skaters in **Figure 9–8?** Assume that they are skating on such a smooth surface that there are no external forces. They both start at rest one behind the other.

FIGURE 9–8 The internal forces exerted by these in-line skaters cannot change the total momentum of the system.

Skater A gives skater B a push. Now both skaters are moving, making this situation similar to that of an explosion. Because the push was an internal force, you can use the law of conservation of momentum to find the skaters' relative velocities. The total momentum of the system was zero before the push. Therefore, it also must be zero after the push.

$$\begin{array}{llcl} & \text{BEFORE (State 1)} & & \text{AFTER (State 2)} \\ & \boldsymbol{p}_{A1} + \boldsymbol{p}_{B1} & = & \boldsymbol{p}_{A2} + \boldsymbol{p}_{B2} \\ & 0 & = & \boldsymbol{p}_{A2} + \boldsymbol{p}_{B2} \\ \textit{or:} & \boldsymbol{p}_{A2} & = & -\boldsymbol{p}_{B2} \\ & m_A\boldsymbol{v}_{A2} & = & -m_B\boldsymbol{v}_{B2} \end{array}$$

The momenta of the skaters after the push are equal in magnitude but opposite in direction. The backward motion of skater A is an example of recoil. Are the skaters' velocities equal and opposite? Solve the last equation for the velocity of skater A.

$$\boldsymbol{v}_{A2} = -\left(\frac{m_B}{m_A}\right)\boldsymbol{v}_{B2}$$

The velocities depend on the skaters' relative masses. If skater A has a mass of 45.0 kg and skater B's mass is 60.0 kg, then the ratio of their velocities will be 60/45 or 1.33. The less massive skater moves at the greater velocity. But, without more information about how hard they pushed, you can't find the velocity of each skater.

Explosions in space How does a rocket in space change its velocity? The rocket carries both fuel and oxidizer. They are combined chemically in the rocket motor, and the resulting hot gases leave the exhaust nozzle at high speed. If the rocket and chemicals are the system, then the system is closed. The forces that expel the gases are internal forces, so the system is also isolated. Therefore, the law of conservation of momentum can be applied to this situation. The movement of an astronaut in space can be used to demonstrate an isolated system.

F.Y.I.

Forensic investigations frequently involve the study of momentum. Careful analysis of skid marks, bullet tracks, wounds, and cracks in fragile materials can indicate the initial velocities of moving objects and provide important evidence about crimes.

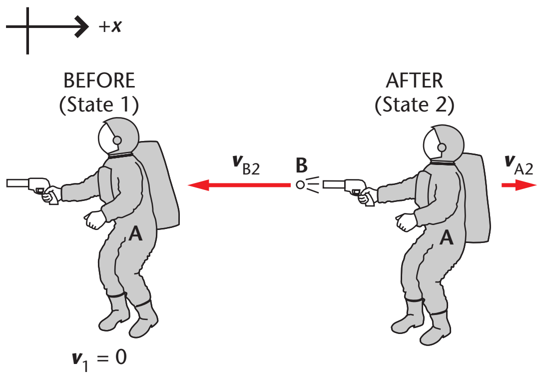
Example Problem

Recoil of an Astronaut

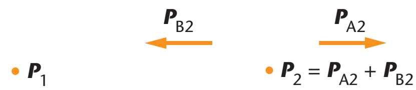
An astronaut at rest in space fires a thruster pistol that expels 35 g of hot gas at 875 m/s. The combined mass of the astronaut and pistol is 84 kg. How fast and in what direction is the astronaut moving after firing the pistol?

Sketch the Problem

- Establish a coordinate axis.
- Show the before and after conditions.
- Label the astronaut A and the expelled gas B, and include their velocities.
- Draw a vector diagram including all momenta.



Vector Diagram



Calculate Your Answer

Known:

$m_A = 84$ kg

$m_B = 0.035$ kg

$v_{A1} = v_{B1} = 0$ m/s

$v_{B2} = -875$ m/s

Unknown:

$v_{A2} = ?$

Strategy:

Before the firing, both parts of the system are at rest, thus, initial momentum is zero.

The momentum of the astronaut is equal in magnitude but opposite in direction to that of the gas leaving the pistol.

Use the law of conservation of momentum to find p_2 and solve for the final velocity of the astronaut, v_{A2}

Calculations:

$p_1 = p_{A1} + p_{B1} = 0$

$p_{A1} + p_{B1} = p_{A2} + p_{B2}$
$0 = p_{A2} + p_{B2}$
$p_{A2} = -p_{B2}$
$m_A v_{A2} = -m_B v_{B2}$ or $v_{A2} = \left(\dfrac{-m_B v_{B2}}{m_A}\right)$

$$v_{A2} = \frac{-(0.035\text{ kg})(-875\text{ m/s})}{84\text{ kg}} = +0.36\text{ m/s}$$

Check Your Answer

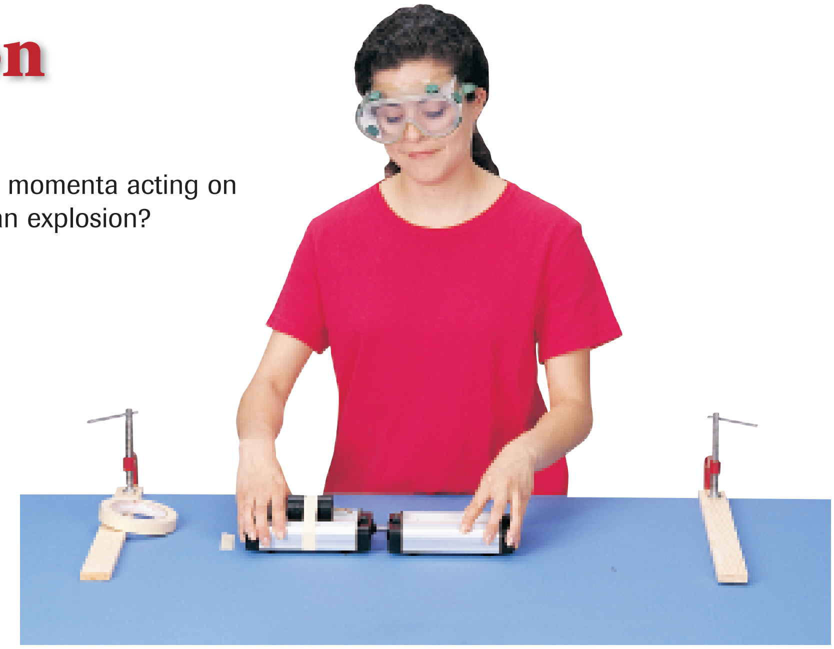
- Are the units correct? The correct unit for velocity is m/s.
- Do the direction and magnitude make sense? The astronaut's mass is much larger than that of the gas. So the velocity of the astronaut is much less than that of the expelled gas, and opposite in direction.

Have you ever wondered how a rocket can accelerate in space? In this example, you see that the astronaut didn't push on anything external. According to Newton's third law, the pistol pushes the gases out, and the gases in turn push on the pistol and the astronaut. All the system's forces are internal.

The Explosion

Problem

How do the forces and changes in momenta acting on different masses compare during an explosion?



Materials

two laboratory carts
  (one with a spring mechanism)
two C-clamps
two blocks of wood
20-N spring balance
0.50-kg mass
stopwatch
masking tape
meterstick

Procedure

1. Securely tape the 0.50-kg mass to cart 2 and then use the balance to determine the mass of each cart.
2. Use the C-clamps to secure the two blocks of wood to the laboratory table. Position the blocks at least 1 meter apart.
3. Arrange the equipment as shown in the diagram.
4. Predict the starting position so that the carts will hit the blocks at the same instant when the spring mechanism is released.
5. Place pieces of tape on the table at the front of the carts to mark starting positions.
6. Depress the mechanism to release the spring and explode the carts.
7. Notice which cart hits the block first.
8. Adjust the starting position for the carts until they hit the wood blocks at the same time. Be sure to mark the starting position of each cart for each trial. Measure the time it takes for the carts to reach the blocks.
9. Dispose of the masking tape, and put the other materials away.

Data and Observations

1. Which cart moved farther? How do you know?
2. Which cart moved faster? Explain.

Analyze and Conclude

1. **Analyzing** Which data will help you estimate the velocity of each cart? Explain.
2. **Estimating** Which cart had the greater velocity?
3. **Comparing** Compare the change in momentum of each cart.
4. **Applying** Suppose that the spring pushed on cart 1 for 0.05 s. How long did cart 2 push on the spring? Explain.
5. **Comparing** Using $\boldsymbol{F}\Delta t = m\Delta\boldsymbol{v}$, which cart had the greater impulse?

Apply

1. Based on your data, explain why a target shooter might prefer to shoot a more massive gun.

HELP WANTED

PARAMEDIC TRAINEE

Trainee position open to Emergency Medical Technicians certified in basic life support. Will complete up to 2000 hours of advanced training and work with patients in hospital and field settings. Must be skilled in communicating with both medical staff and injured, frightened patients. Position requires strength, endurance, coordination, high tolerance for stress, and excellent driving skills. Must also pass state exam. For information, contact:

American Ambulance Association
1255 Twenty-Third Street, N.W.
Washington, D.C. 20037 or
National Registry of Emergency Medical Technicians
Box 29233
6610 Busch Blvd.
Columbus, OH 43229

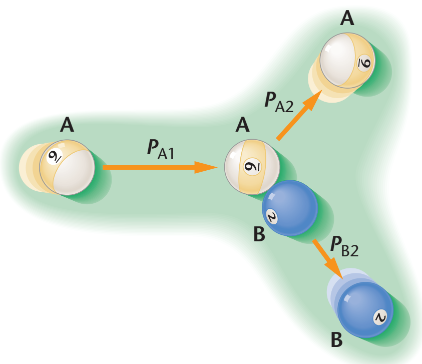


FIGURE 9–10 The law of conservation of momentum holds for all isolated, closed systems, regardless of the directions of objects before and after collision.

Practice Problems

13. A 4.00-kg model rocket is launched, shooting 50.0 g of burned fuel from its exhaust at a speed of 625 m/s. What is the velocity of the rocket after the fuel has burned? **Hint:** Ignore the external forces of gravity and air resistance.

14. A thread holds two carts together, as shown in **Figure 9–9.** After the thread is burned, a compressed spring pushes the carts apart, giving the 1.5-kg cart a speed of 27 cm/s to the left. What is the velocity of the 4.5-kg cart?

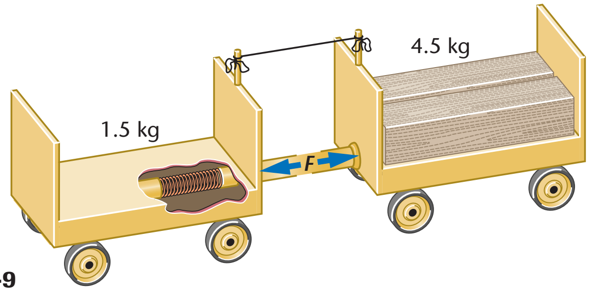


FIGURE 9–9

15. Two campers dock a canoe. One camper has a mass of 80.0 kg and moves forward at 4.0 m/s as she leaves the boat to step onto the dock. With what speed and direction do the canoe and the other camper move if their combined mass is 115 kg?

16. A colonial gunner sets up his 225-kg cannon at the edge of the flat top of a high tower. It shoots a 4.5-kg cannonball horizontally. The ball hits the ground 215 m from the base of the tower. The cannon also moves on frictionless wheels, falls off the back of the tower, and lands on the ground.

a. What is the horizontal distance of the cannon's landing, measured from the base of the back of the tower?

b. Why don't you need to know the width of the tower?

Two-Dimensional Collisions

Up until now, you have looked at momentum in one dimension only. The law of conservation of momentum holds for all closed systems with no external forces. It is valid regardless of the directions of the particles before or after they interact.

Now you will look at momentum in two dimensions. **Figure 9–10** shows the result of billiard ball A striking stationary ball B. Consider the two balls to be the system. The original momentum of the moving ball is $\boldsymbol{p}_{A1}$; the momentum of the stationary ball is zero. Therefore, the momentum of the system before the collision is equal to $\boldsymbol{p}_{A1}$.

After the collision, both balls are moving and have momenta. According to the law of conservation of momentum, the initial momentum equals the vector sum of the final momenta, so $\boldsymbol{p}_{A1} = \boldsymbol{p}_{A2} + \boldsymbol{p}_{B2}$.

The equality of the momentum before and after the collision also means that the sum of the components of the vectors before and after the collision must be equal. If you define the *x*-axis to be in the direction of the initial momentum, the *y*-component of the initial momentum is zero. Therefore, the sum of the final *y*-components must be zero.

$$p_{A2y} + p_{B2y} = 0$$

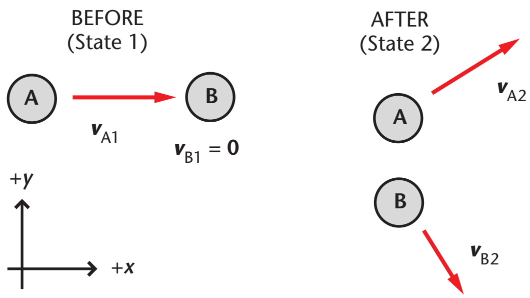
They are equal in magnitude but have opposite signs. The sum of the horizontal components is also equal.

$$p_{A1} = p_{A2x} + p_{B2x}$$

Example Problem

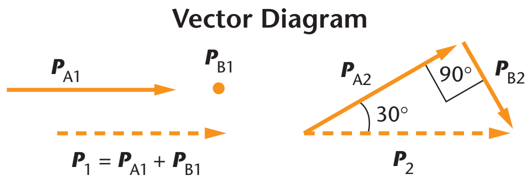
Two-Dimensional Collision

A 2.00-kg ball, A, is moving at a speed of 5.00 m/s. It collides with a stationary ball, B, of the same mass. After the collision, A moves off in a direction 30.0° to the left of its original direction. Ball B moves off in a direction 90.0° to the right of ball A's final direction. How fast are they moving after the collision?



Sketch the Problem

- Sketch the before and after states.
- Establish the coordinate axis with the *x*-axis in the original direction of ball A.
- Draw a momentum vector diagram. Note that p_{A2} and p_{B2} form a 90° angle.



Calculate Your Answer

Known:

$m_A = m_B = 2.00$ kg

$v_{A1} = 5.00$ m/s

$v_{B1} = 0$

Unknowns:

$v_{A2} = ?$

$v_{B2} = ?$

Strategy:

Determine the initial momenta.

Calculations:

$p_{A1} = m_A v_{A1} = (2.00 \text{ kg})(5.00 \text{ m/s}) = 10.0 \text{ kg·m/s}$

$p_{B1} = 0.0$

$p_1 = p_{A1} + p_{B1} = 10.0 \text{ kg·m/s}$

Use conservation of momentum to find p_2.

$p_2 = p_1 = 10.0 \text{ kg·m/s}$

Use the diagram to set up equations for p_{A2} and p_{B2}.

$$\begin{aligned} p_{A2} &= p_2 \cos 30.0° \\ &= (10.0 \text{ kg·m/s})(\cos 30.0°) \\ &= 8.66 \text{ kg·m/s} \end{aligned}$$

$$\begin{aligned} p_{B2} &= p_2 \sin 30.0° \\ &= (10.0 \text{ kg·m/s})(\sin 30.0°) \\ &= 5.00 \text{ kg·m/s} \end{aligned}$$

Continued on next page

Determine the final speeds: $v_{A2} = \frac{p_{A2}}{m_A}$ $\qquad v_{B2} = \frac{p_{B2}}{m_B}$

$$= \frac{8.66 \text{ kg·m/s}}{2.00 \text{ kg}} = 4.33 \text{ m/s} \qquad = \frac{5.00 \text{ kg·m/s}}{2.00 \text{ kg}} = 2.50 \text{ m/s}$$

Check Your Answer

- Are the units correct? The correct unit for speed is m/s.
- Does the sign make sense? Answers are both positive and at the appropriate angles.
- Is the magnitude realistic? In this system in which two equal masses collide, v_{A2} and v_{B2} must be smaller than v_{A1}.

Practice Problems

17. A 1325-kg car moving north at 27.0 m/s collides with a 2165-kg car moving east at 17.0 m/s. They stick together. In what direction and with what speed do they move after the collision?

18. A stationary billiard ball, mass 0.17 kg, is struck by an identical ball moving at 4.0 m/s. After the collision, the second ball moves off at 60° to the left of its original direction. The stationary ball moves off at 30° to the right of the moving ball's original direction. What is the velocity of each ball after the collision?

Math Handbook

To review **Trigonometric Ratios,** see the Math Handbook, Appendix A, page 745.

9.2 Section Review

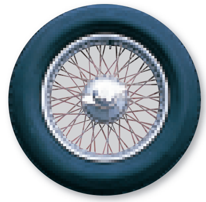
1. Two soccer players come from opposite directions and collide when trying to head the ball. They come to rest in midair and fall to the ground. What can you say about their initial momenta?

2. During a tennis serve, the racket continues forward after hitting the ball. Is momentum conserved in the collision? Explain, making sure you are careful in defining the system.

3. A pole-vaulter runs toward the launch point with horizontal momentum. Where does the vertical momentum come from as the athlete vaults over the crossbar?

4. Critical Thinking You catch a heavy ball while you are standing on a skateboard, and roll backward. If you were standing on the ground, however, you would be able to avoid moving. Explain both results using the law of conservation of momentum. Explain the system you use in each case.

CHAPTER 9 REVIEW



Key Terms

9.1

- impulse
- linear momentum
- impulse-momentum theorem
- angular momentum

9.2

- closed system
- internal force
- external force
- isolated system
- law of conservation of momentum

Summary

9.1 Impulse and Momentum

- When doing a momentum problem, first examine the system before and after the event.
- The momentum of an object is the product of its mass and velocity and is a vector quantity.
- The impulse given an object is the average net force exerted on the object multiplied by the time interval over which the force acts.
- The impulse given an object is equal to the change in momentum of the object.

9.2 The Conservation of Momentum

- Newton's third law of motion explains momentum conservation in a collision because the forces that the colliding objects exert on each other are equal in magnitude and opposite in direction.
- The momentum is conserved in a closed, isolated system.
- Conservation of momentum is used to explain the propulsion of rockets.
- Vector analysis is used to solve momentum-conservation problems in two dimensions.

Key Equations

9.1

$$\boldsymbol{p} = m\boldsymbol{v} \qquad \boldsymbol{F}\Delta t = \boldsymbol{p}_2 - \boldsymbol{p}_1$$

9.2

$$\boldsymbol{p}_{A2} + \boldsymbol{p}_{B2} = \boldsymbol{p}_{A1} + \boldsymbol{p}_{B1}$$

Reviewing Concepts

Section 9.1

1. Can a bullet have the same momentum as a truck? Explain.
2. A pitcher throws a fastball to the catcher. Assuming that the speed of the ball doesn't change in flight,
   a. which player exerts the larger impulse on the ball?
   b. which player exerts the larger force on the ball?
3. Newton's second law of motion states that if no net force is exerted on a system, no acceleration is possible. Does it follow that no change in momentum can occur?
4. Why are cars made with bumpers that can be pushed in during a crash?

Section 9.2

5. What is meant by an isolated system?
6. A spacecraft in outer space increases its velocity by firing its rockets. How can hot gases escaping from its rocket engine change the velocity of the craft when there is nothing in space for the gases to push against?
7. The cue ball travels across the pool table and collides with the stationary eight-ball. The two balls have equal mass. After the collision, the cue ball is at rest. What must be true regarding the speed of the eight-ball?
8. Consider a ball falling toward Earth.
   a. Why is the momentum of the ball not conserved?

b. In what system that includes the falling ball is the momentum conserved?

9. A falling ball hits the floor. Just before it hits, the momentum is in the downward direction, and the momentum is in the upward direction after it hits.
a. The bounce is a collision, so why isn't the momentum of the ball conserved?
b. In what system is it conserved?

10. Only an external force can change the momentum of a system. Explain how the internal force of a car's brakes brings the car to a stop.

Applying Concepts

11. Explain the concept of impulse using physical ideas rather than mathematics.

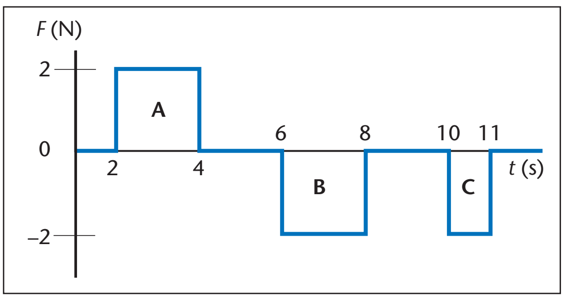
12. Is it possible for an object to obtain a larger impulse from a smaller force than it does from a larger force? How?

13. You are sitting at a baseball game when a foul ball comes in your direction. You prepare to catch it barehanded. In order to catch it safely, should you move your hands toward the ball, hold them still, or move them in the same direction as the moving ball? Explain.

14. A 0.11-g bullet leaves a pistol at 323 m/s, while a similar bullet leaves a rifle at 396 m/s. Explain the difference in exit speeds of the two bullets assuming that the forces exerted on the bullets by the expanding gases have the same magnitude.

15. An object initially at rest experiences the impulses described by the graph in **Figure 9–11.** Describe the object's motion after impulses A, B, and C.

FIGURE 9–11



16. During a space walk, the tether connecting an astronaut to the spaceship breaks. Using a gas pistol, the astronaut manages to get back to the ship. Explain why this method was effective, using the language of the impulse-momentum theorem and a diagram.

17. As a tennis ball bounces off a wall, its momentum is reversed. Explain this action in terms of the law of conservation of momentum, defining the system and using a diagram.

18. You command *Spaceship Zero*, which is moving through interplanetary space at high speed. How could you slow your ship by applying the law of conservation of momentum?

19. Two trucks that appear to be identical collide on an icy road. One was originally at rest. The trucks stick together and move off at more than half the original speed of the moving truck. What can you conclude about the contents of the two trucks?

20. Explain, in terms of impulse and momentum, why it is advisable to place the butt of a rifle against your shoulder when first learning to shoot.

21. Two bullets of equal mass are shot at equal speeds at blocks of wood on a smooth ice rink. One bullet, which is made of rubber, bounces off the wood. The other bullet, made of aluminum, burrows into the wood. In which case does the wood move faster? Explain.

Problems

Section 9.1

22. Your brother's mass is 35.6 kg, and he has a 1.3-kg skateboard. What is the combined momentum of your brother and his skateboard if they are going 9.50 m/s?

23. A hockey player makes a slap shot, exerting a constant force of 30.0 N on the hockey puck for 0.16 s. What is the magnitude of the impulse given to the puck?

24. A hockey puck has a mass of 0.115 kg and is at rest. A hockey player makes a shot, exerting a constant force of 30.0 N on the puck for 0.16 s. With what speed does it head toward the goal?

25. Before a collision, a 25-kg object is moving at +12 m/s. Find the impulse that acted on the object if, after the collision, it moves at:
a. +8.0 m/s. **b.** −8.0 m/s.

26. A constant force of 6.00 N acts on a 3.00-kg object for 10.0 s. What are the changes in the object's momentum and velocity?

27. The velocity of a 625-kg auto is changed from 10.0 m/s to 44.0 m/s in 68.0 s by an external, constant force.
a. What is the resulting change in momentum of the car?
b. What is the magnitude of the force?

28. An 845-kg dragster accelerates from rest to 100 km/h in 0.90 seconds.
a. What is the change in momentum of the car?
b. What is the average force exerted on the car?
c. What exerts that force?

29. A 0.150-kg ball, moving in the positive direction at 12 m/s, is acted on by the impulse shown in the graph in **Figure 9–12.** What is the ball's speed at 4.0 s?

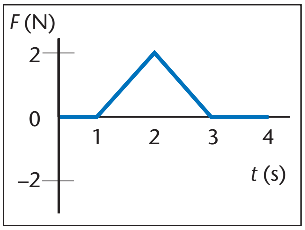


FIGURE 9–12

30. Small rockets are used to make tiny adjustments in the speed of satellites. One such rocket has a thrust of 35 N. If it is fired to change the velocity of a 72 000-kg spacecraft by 63 cm/s, how long should it be fired?

31. A car moving at 10 m/s crashes into a barrier and stops in 0.050 s. There is a 20-kg child in the car. Assume that the child's velocity is changed by the same amount as the car's in the same time period.
a. What is the impulse needed to stop the child?
b. What is the average force on the child?
c. What is the approximate mass of an object whose weight equals the force in part **b**?
d. Could you lift such a weight with your arm?
e. Why is it advisable to use a proper infant restraint rather than hold a child on your lap?

32. An animal-rescue plane flying due east at 36.0 m/s drops a bale of hay from an altitude of 60.0 m. If the bale of hay weighs 175 N, what is the momentum of the bale the moment before it strikes the ground? Give both magnitude and direction.

33. A 60.0-kg dancer leaps 0.32 m high.
a. With what momentum does the dancer reach the ground?
b. What impulse is needed to stop the dancer?
c. As the dancer lands, his knees bend, lengthening the stopping time to 0.050 s. Find the average force exerted on the dancer's body.
d. Compare the stopping force to the dancer's weight.

Section 9.2

34. A 95-kg fullback, running at 8.2 m/s, collides in midair with a 128-kg defensive tackle moving in the opposite direction. Both players end up with zero speed.
a. Identify "before" and "after" and make a diagram of the situations.
b. What was the fullback's momentum before the collision?
c. What was the change in the fullback's momentum?
d. What was the change in the tackle's momentum?
e. What was the tackle's original momentum?
f. How fast was the tackle moving originally?

35. Marble A, mass 5.0 g, moves at a speed of 20.0 cm/s. It collides with a second marble, B, mass 10.0 g, moving at 10.0 cm/s in the same direction. After the collision, marble A continues with a speed of 8.0 cm/s in the same direction.
a. Sketch the situation, identify the system, define "before" and "after," and assign a coordinate axis.
b. Calculate the marbles' momenta before the collision.
c. Calculate the momentum of marble A after the collision.
d. Calculate the momentum of marble B after the collision.
e. What is the speed of marble B after the collision?

36. A 2575-kg van runs into the back of a 825-kg compact car at rest. They move off together at 8.5 m/s. Assuming the friction with the road can be negligible, find the initial speed of the van.

37. A 0.115-kg hockey puck, moving at 35.0 m/s, strikes a 0.265-kg octopus thrown onto the ice by a hockey fan. The puck and octopus slide off together. Find their velocity.

38. A 50-kg woman, riding on a 10-kg cart, is moving east at 5.0 m/s. The woman jumps off the front of the cart and hits the ground at 7.0 m/s eastward, relative to the ground.
  a. Sketch the situation, identifying "before" and "after," and assigning a coordinate axis.
  b. Find the velocity of the cart after the woman jumps off.

39. Two students on roller skates stand face-to-face, then push each other away. One student has a mass of 90.0 kg; the other has a mass of 60.0 kg.
  a. Sketch the situation, identifying "before" and "after," and assigning a coordinate axis.
  b. Find the ratio of the students' velocities just after their hands lose contact.
  c. Which student has the greater speed?
  d. Which student pushed harder?

40. A 0.200-kg plastic ball moves with a velocity of 0.30 m/s. It collides with a second plastic ball of mass 0.100 kg, which is moving along the same line at a speed of 0.10 m/s. After the collision, both balls continue moving in the same, original direction, and the speed of the 0.100-kg ball is 0.26 m/s. What is the new velocity of the first ball?

41. A 92-kg fullback, running at 5.0 m/s, attempts to dive directly across the goal line for a touchdown. Just as he reaches the line, he is met head-on in midair by two 75-kg linebackers both moving in the direction opposite the fullback. One is moving at 2.0 m/s, the other at 4.0 m/s. They all become entangled as one mass.
  a. Sketch the situation, identifying "before" and "after."
  b. What is their velocity after the collision?
  c. Does the fullback score?

42. A 5.00-g bullet is fired with a velocity of 100.0 m/s toward a 10.00-kg stationary solid block resting on a frictionless surface.
  a. What is the change in momentum of the bullet if it is embedded in the block?
  b. What is the change in momentum of the bullet if it ricochets in the opposite direction with a speed of 99 m/s?
  c. In which case does the block end up with a greater speed?

43. The diagrams in **Figure 9–13** show a brick weighing 24.5 N being released from rest on a 1.00-m frictionless plane, inclined at an angle of 30.0°. The brick slides down the incline and strikes a second brick weighing 36.8 N.

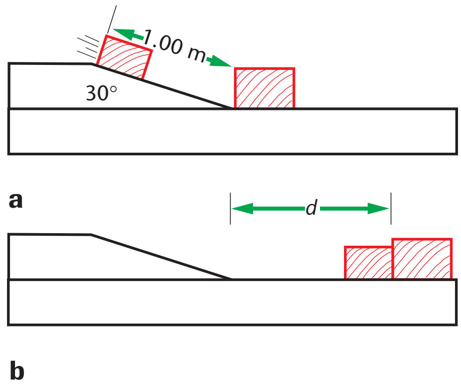


FIGURE 9-13

  a. Calculate the speed of the first brick at the bottom of the incline.
  b. If the two bricks stick together, with what initial speed will they move along?
  c. If the force of friction acting on the two bricks is 5.0 N, how much time will elapse before the bricks come to rest?
  d. How far will the two bricks slide before coming to rest?

44. Ball A, rolling west at 3.0 m/s, has a mass of 1.0 kg. Ball B has a mass of 2.0 kg and is stationary. After colliding with ball B, ball A moves south at 2.0 m/s.
  a. Sketch the system, showing the velocities and momenta before and after the collision.
  b. Calculate the momentum and velocity of ball B after the collision.

45. A space probe with a mass of 7.600×10^3 kg is traveling through space at 125 m/s. Mission control decides that a course correction of 30.0° is needed and instructs the probe to fire rockets perpendicular to its present direction of motion. If the gas expelled by the rockets has a speed of 3.200 km/s, what mass of gas should be released?

46. The diagram in **Figure 9–14,** which is drawn to scale, shows two balls during a collision. The balls enter from the left, collide, and then bounce away. The heavier ball at the bottom of the diagram has a mass of 0.600 kg, and the other has a mass of 0.400 kg. Using a vector diagram, determine whether momentum is conserved in this collision. What could explain any difference in the momentum of the system before and after the collision?

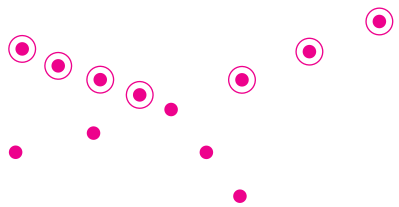


FIGURE 9-14

Extra Practice For more practice solving problems, go to Extra Practice Problems, Appendix B.

Critical Thinking Problems

47. A compact car, mass 875 kg, moving south at 15 m/s, is struck by a full-sized car, mass 1584 kg, moving east at 12 m/s. The two cars stick together, and momentum is conserved in the collision.
   a. Sketch the situation, assigning coordinate axes and identifying "before" and "after."
   b. Find the direction and speed of the wreck immediately after the collision, remembering that momentum is a vector quantity.
   c. The wreck skids along the ground and comes to a stop. The coefficient of kinetic friction while the wreck is skidding is 0.55. Assume that the acceleration is constant. How far does the wreck skid?

48. Your friend has been in a car accident and wants your help. She was driving her 1265-kg car north on Oak Street when she was hit by a 925-kg compact car going west on Maple Street. The cars stuck together and slid 23.1 m at 42° north of west. The speed limit on both streets is 50 mph (22 m/s). Your friend claims that she wasn't speeding, but that the other car was. Can you support her case in court? Assume that momentum was conserved during the collision and that acceleration was constant during the skid. The coefficient of kinetic friction between the tires and the pavement is 0.65.

Going Further

Team Project How can you survive a car crash? Work with a team to design a model for testing automobile safety devices. Your car can be a dynamics cart or other device with low-friction wheels. Make a seat out of wood that you securely mount on the car. Use clay to model a person. For a dashboard, use a piece of metal fastened to the front of the cart. Allow the car to roll down a ramp and collide with a block at the bottom of the ramp. Devise a testing procedure so that the car starts from the same distance up the ramp and comes to rest at the same place in every test. First, crash the car with no protection for the person. Examine the clay and describe the damage done. Then, design a padded dash by using a piece of rubber tubing. Use a piece of string or ribbon to make a lap and shoulder belt. Fasten the belt to the seat. Finally, model an air bag by placing a small, partially inflated balloon between the passenger and the dashboard. Summarize your experiments, including an explanation of the forces placed on the passenger in terms of the change in momentum, the impulse, the average force, and the time interval over which the impulse occurred.

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