launch point with horizontal momentum. Where does the vertical momentum come from as the athlete vaults over the crossbar?

The vertical momentum comes from the impulsive force of Earth against the pole. Earth acquires an equal and opposite vertical momentum.

30. **Initial Momentum** During a soccer game, two players come from opposite directions and collide when trying to head the ball. They come to rest in midair and fall to the ground. Describe their initial momenta.

Because their final momenta are zero, their initial momenta were equal and opposite.

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

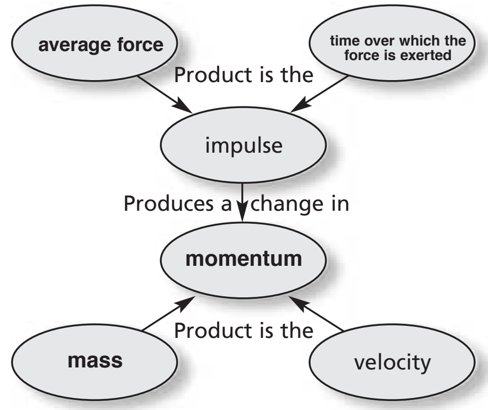
In the case of the skateboard, the ball, the skateboard, and you are an isolated system, and the momentum of the ball is shared. In the second case, unless Earth is included, there is an external force, so momentum is not conserved. If Earth's large mass is included in the system, the change in its velocity is negligible.

Chapter Assessment

Concept Mapping

page 250

32. Complete the following concept map using the following terms: *mass, momentum, average force, time over which the force is exerted.*



Mastering Concepts

page 250

33. Can a bullet have the same momentum as a truck? Explain. (9.1)

Yes, for a bullet to have the same momentum as a truck, it must have a higher velocity because the two masses are not the same.

$m_{bullet}v_{bullet} = m_{truck}v_{truck}$

34. A pitcher throws a curve ball to the catcher. Assume that the speed of the ball doesn't change in flight. (9.1)

a. Which player exerts the larger impulse on the ball?

The pitcher and the catcher exert the same amount of impulse on the ball, but the two impulses are in opposite directions.

b. Which player exerts the larger force on the ball?

The catcher exerts the larger force on the ball because the time interval over which the force is exerted is smaller.

35. 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? (9.1)

No net force on the system means no net impulse on the system and no net change in momentum. However, individual parts of the system may have a

74. Marble C, with mass 5.0 g, moves at a speed of 20.0 cm/s. It collides with a second marble, D, with mass 10.0 g, moving at 10.0 cm/s in the same direction. After the collision, marble C continues with a speed of 8.0 cm/s in the same direction.

a. Sketch the situation and identify the system. Identify the "before" and "after" situations and set up a coordinate system.

Before: $m_C = 5.0$ g

$m_D = 10.0$ g

$v_{Ci} = 20.0$ cm/s

$v_{Di} = 10.0$ cm/s

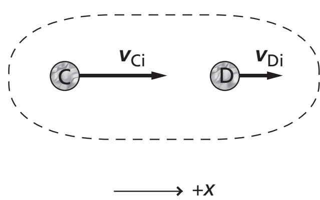
After: $m_C = 5.0$ g

$m_D = 10.0$ g

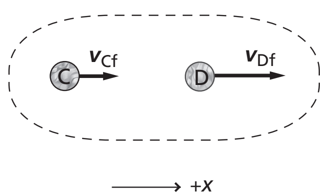
$v_{Cf} = 8.0$ cm/s

$v_{Df} = ?$

Before



After



b. Calculate the marbles' momenta before the collision.

$$m_C v_{Ci} = (5.0\times10^{-3}\text{ kg})(0.200\text{ m/s})$$
$$= 1.0\times10^{-3}\text{ kg·m/s}$$
$$m_D v_{Di} = (1.00\times10^{-2}\text{ kg})(0.100\text{ m/s})$$
$$= 1.0\times10^{-3}\text{ kg·m/s}$$

c. Calculate the momentum of marble C after the collision.

$$m_C v_{Cf} = (5.0\times10^{-3}\text{ kg})(0.080\text{ m/s})$$
$$= 4.0\times10^{-4}\text{ kg·m/s}$$

d. Calculate the momentum of marble D after the collision.

$$p_{Ci} + p_{Di} = p_{Cf} + p_{Df}$$
$$p_{Df} = p_{Ci} + p_{Di} - p_{Cf}$$
$$= 1.00\times10^{-3}\text{ kg·m/s} + 1.00\times10^{-3}\text{ kg·m/s} - 4.0\times10^{-4}\text{ kg·m/s}$$
$$= 1.6\times10^{-3}\text{ kg·m/s}$$

e. What is the speed of marble D after the collision?

$$p_{Df} = m_D v_{Df}$$
$$\text{so, } v_{Df} = \frac{p_{Df}}{m_D}$$
$$= \frac{1.6\times10^{-3}\text{ kg·m/s}}{1.00\times10^{-2}\text{ kg}}$$
$$= 1.6\times10^{-1}\text{ m/s} = 0.16\text{ m/s}$$
$$= 16\text{ cm/s}$$

75. Two lab carts are pushed together with a spring mechanism compressed between them. Upon release, the 5.0-kg cart repels one way with a velocity of 0.12 m/s, while the 2.0-kg cart goes in the opposite direction. What is the velocity of the 2.0-kg cart?

$$m_1 v_i = -m_2 v_f$$
$$v_f = \frac{m_1 v_i}{-m_2}$$
$$= \frac{(5.0\text{ kg})(0.12\text{ m/s})}{-(2.0\text{ kg})}$$
$$= -0.30\text{ m/s}$$

76. A 50.0-g projectile is launched with a horizontal velocity of 647 m/s from a 4.65-kg launcher moving in the same direction at 2.00 m/s. What is the launcher's velocity after the launch?

$$p_{Ci} + p_{Di} = p_{Cf} + p_{Df}$$
$$m_C v_{Ci} + m_D v_{Di} = m_C v_{Cf} + m_D v_{Df}$$
$$\text{so, } v_{Df} = \frac{m_C v_{Ci} + m_D v_{Di} - m_C v_{Cf}}{m_D}$$

Assuming that the projectile, C, is launched in the direction of the launcher, D, motion,

$$= \frac{(0.200\ \text{kg})(0.30\ \text{m/s}) + (0.100\ \text{kg})(0.10\ \text{m/s}) - (0.100\ \text{kg})(0.26\ \text{m/s})}{0.200\ \text{kg}}$$

= 0.22 m/s in the original direction

Mixed Review

pages 253–254

Level 1

83. 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?

The change in momentum is

$$\Delta p = F\Delta t$$
$$= (6.00\ \text{N})(10.0\ \text{s})$$
$$= 60.0\ \text{N·s} = 60.0\ \text{kg·m/s}$$

The change in velocity is found from the impulse.

$$F\Delta t = m\Delta v$$
$$\Delta v = \frac{F\Delta t}{m}$$
$$= \frac{(6.00\ \text{N})(10.0\ \text{s})}{3.00\ \text{kg}}$$
$$= 20.0\ \text{m/s}$$

84. The velocity of a 625-kg car 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?

$$\Delta p = m\Delta v = m(v_f - v_i)$$
$$= (625\ \text{kg})(44.0\ \text{m/s} - 10.0\ \text{m/s})$$
$$= 2.12\times10^4\ \text{kg·m/s}$$

b. What is the magnitude of the force?

$$F\Delta t = m\Delta v$$
$$\text{so, F} = \frac{m\Delta v}{\Delta t}$$
$$= \frac{m(v_f - v_i)}{\Delta t}$$
$$= \frac{(625\ \text{kg})(44.0\ \text{m/s} - 10.0\ \text{m/s})}{68.0\ \text{s}}$$
$$= 313\ \text{N}$$

85. Dragster An 845-kg dragster accelerates on a race track from rest to 100.0 km/h in 0.90 s.

a. What is the change in momentum of the dragster?

$$\Delta p = m(v_f - v_i)$$
$$= (845\ \text{kg})(100.0\ \text{km/h} - 0.0\ \text{km/h})\left(\frac{1000\ \text{m}}{1\ \text{km}}\right)\left(\frac{1\ \text{h}}{3600\ \text{s}}\right)$$
$$= 2.35\times10^4\ \text{kg·m/s}$$

and his momentum is

$p = mv = m\sqrt{2dg}$

$= (60.0\ \text{kg})\sqrt{(2)(0.32\ \text{m})(9.80\ \text{m/s}^2)}$

$= 1.5\times10^2\ \text{kg·m/s down}$

b. What impulse is needed to stop the dancer?

$F\Delta t = m\Delta v = m(v_f - v_i)$

To stop the dancer, $v_f = 0$**. Thus,**

$F\Delta t = -mv_f = -p = -1.5\times10^2\ \text{kg·m/s up}$

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.

$F\Delta t = m\Delta v = m\sqrt{2dg}$

so, $F = \dfrac{m\sqrt{2dg}}{\Delta t}$

$= \dfrac{(60.0\ \text{kg})\sqrt{(2)(0.32\ \text{m})(9.80\ \text{m/s}^2)}}{0.050\ \text{s}}$

$= 3.0\times10^3\ \text{N}$

d. Compare the stopping force with his weight.

$F_g = mg = (60.0\ \text{kg})(9.80\ \text{m/s}^2) = 5.98\times10^2\ \text{N}$

The force is about five times the weight.

Thinking Critically

page 254

90. Apply Concepts 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 and the other at 4.0 m/s. They all become entangled as one mass.

a. Sketch the event, identifying the "before" and "after" situations.

Before: $m_A = 92\ \text{kg}$

$m_B = 75\ \text{kg}$

$m_C = 75\ \text{kg}$

$v_{Ai} = 5.0\ \text{m/s}$

$v_{Bi} = -2.0\ \text{m/s}$

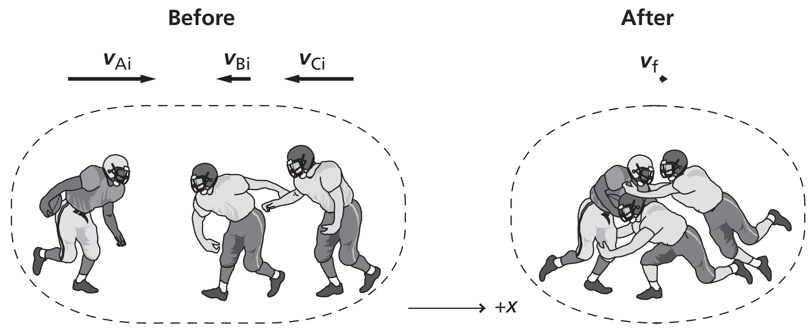
$v_{Ci} = -4.0\ \text{m/s}$

After: $m_A = 92\ \text{kg}$

$m_B = 75\ \text{kg}$

$m_C = 75\ \text{kg}$

$v_f = ?$



b. What is the velocity of the football players after the collision?

$$p_{Ai} + p_{Bi} + p_{Ci} = p_{Af} + p_{Bf} + p_{Cf}$$

$$m_A v_{Ai} + m_B v_{Bi} + m_C v_{Ci} = m_A v_{Af} + m_B v_{Bf} + m_C v_{Cf}$$

$$= (m_A + m_B + m_C)v_f$$

$$v_f = \frac{m_A v_{Ai} + m_B v_{Bi} + m_{Ci} v_{Ci}}{m_A + m_B + m_C}$$

$$= \frac{(92\ \text{kg})(5.0\ \text{m/s}) + (75\ \text{kg})(-2.0\ \text{m/s}) + (75\ \text{kg})(-4.0\ \text{m/s})}{92\ \text{kg} + 75\ \text{kg} + 75\ \text{kg}}$$

$$= \mathbf{0.041\ m/s}$$

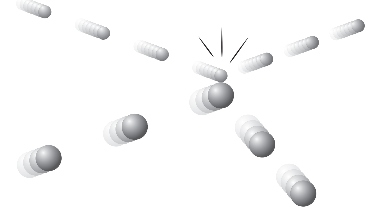
c. Does the fullback score a touchdown?

Yes. The velocity is positive, so the football crosses the goal line for a touchdown.

91. Analyze and Conclude A student, holding a bicycle wheel with its axis vertical, sits on a stool that can rotate without friction. She uses her hand to get the wheel spinning. Would you expect the student and stool to turn? If so, in which direction? Explain.

The student and the stool would spin slowly in the direction opposite to that of the wheel. Without friction there are no external torques. Thus, the angular momentum of the system is not changed. The angular momentum of the student and stool must be equal and opposite to the angular momentum of the spinning wheel.

92. Analyze and Conclude Two balls during a collision are shown in **Figure 9-22,** which is drawn to scale. 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. Explain any difference in the momentum of the system before and after the collision.



■ **Figure 9-22**

Dotted lines show that the changes of momentum for each ball are equal and opposite: $\Delta(m_A v_A) = \Delta(m_B v_B)$. Because the masses have a 3:2 ratio, a 2:3 ratio of velocity changes will compensate.