CHAPTER 9

Momentum and Its Conservation

Practice Problems

9.1 Impulse and Momentum pages 229–235

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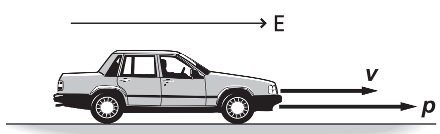
1. A compact car, with mass 725 kg, is moving at 115 km/h toward the east. Sketch the moving car.

a. Find the magnitude and direction of its momentum. Draw an arrow on your sketch showing the momentum.



$$p = mv$$
$$= (725\text{ kg})(115\text{ km/h})\left(\frac{1000\text{ m}}{1\text{ km}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right)$$
$$= 2.32\times10^4\text{ kg·m/s eastward}$$

b. A second car, with a mass of 2175 kg, has the same momentum. What is its velocity?

$$v = \frac{p}{m}$$
$$= \frac{(2.32\times10^4\text{ kg·m/s})\left(\frac{3600\text{ s}}{1\text{ h}}\right)\left(\frac{1\text{ km}}{1000\text{ m}}\right)}{2175\text{ kg}}$$
$$= 38.4\text{ km/h eastward}$$

2. The driver of the compact car in the previous problem 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 down.

$\Delta t = 2.0$ s

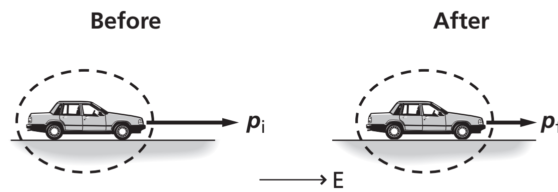
$F = -5.0\times10^3$ N

a. What is the change in momentum; that is, the magnitude and direction of the impulse, on the car?

$$\text{impulse} = F\Delta t$$
$$= (-5.0\times10^3\text{ N})(2.0\text{ s})$$
$$= -1.0\times10^4\text{ N·s}$$

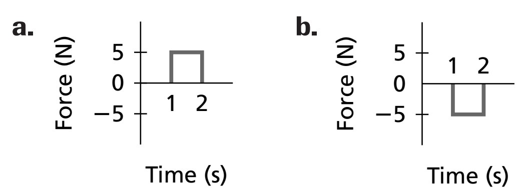
The impulse is directed westward and has a magnitude of 1.0×10^4 N·s.

b. Complete the "before" and "after" sketches, and determine the momentum and the velocity of the car now.



$$p_i = 2.32\times10^4\text{ kg·m/s eastward}$$
$$F\Delta t = \Delta p = p_f - p_i$$
$$p_f = F\Delta t + p_i$$
$$= -1.0\times10^4\text{ kg·m/s} + 2.32\times10^4\text{ kg·m/s}$$
$$= 1.3\times10^4\text{ kg·m/s eastward}$$
$$p_f = mv_f$$
$$v_f = \frac{p_f}{m} = \frac{1.3\times10^4\text{ kg·m/s}}{725\text{ kg}}$$
$$= 18\text{ m/s}$$
$$= 65\text{ km/h eastward}$$

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



■ **Figure 9-3**

a. $F\Delta t = p_f - p_i = mv_f - mv_i$

$$v_f = \frac{F\Delta t - mv_f}{m}$$

$$= \frac{(5.0\text{ N})(1.0\text{ s}) + (7.0\text{ kg})(2.0\text{ m/s})}{7.0\text{ kg}}$$

= 2.7 m/s in the same direction as the original velocity

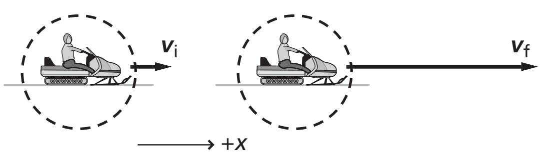
b. $$v_f = \frac{F\Delta t - mv_f}{m}$$

$$= \frac{(-5.0\text{ N})(1.0\text{ s}) + (7.0\text{ kg})(2.0\text{ m/s})}{7.0\text{ kg}}$$

= 1.3 m/s in the same direction as the original velocity

4. The driver accelerates a 240.0-kg snowmobile, which results in a force being exerted that speeds up the snowmobile 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.



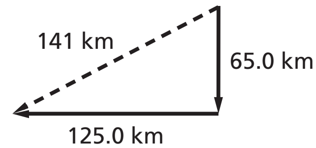
b. What is the snowmobile's change in momentum? What is the impulse on the snowmobile?

$$\Delta p = F\Delta t$$
$$= m(v_f - v_i)$$
$$= (240.0\text{ kg})(28.0\text{ m/s} - 6.00\text{ m/s})$$
$$= 5.28\times10^3\text{ kg·m/s}$$

c. What is the magnitude of the average force that is exerted on the snowmobile?

$$F = \frac{\Delta p}{\Delta t} = \frac{5.28\times10^3\text{ kg·m/s}}{60.0\text{ s}}$$
$$= 88.0\text{ N}$$

5. Suppose a 60.0-kg person was in the vehicle that hit the concrete wall in Example Problem 1. 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?

$$F\Delta t = \Delta p = p_f - p_i$$

$$F = \frac{p_f - p_i}{\Delta t}$$

$$F = \frac{p_f - mv_i}{\Delta t}$$

$$= \frac{(0.0\text{ kg·m/s}) - (60.0\text{ kg})(94\text{ km/h})}{0.20\text{ s}}\left(\frac{1000\text{ m}}{1\text{ km}}\right)\left(\frac{1\text{ h}}{3600\text{ s}}\right)$$

= 7.8×10^3 N opposite to the direction of motion

b. Some people think that they can stop their bodies from lurching forward in a vehicle that is suddenly braking by putting their hands on the dashboard. Find the mass of an object that has a weight equal to the force you just calculated. Could you lift such a mass? Are you strong enough to stop your body with your arms?

$$F_g = mg$$

$$m = \frac{F_g}{g} = \frac{7.8\times10^3\text{ N}}{9.80\text{ m/s}^2} = 8.0\times10^2\text{ kg}$$

Such a mass is too heavy to lift. You cannot safely stop yourself with your arms.

Section Review

9.1 Impulse and Momentum pages 229–235

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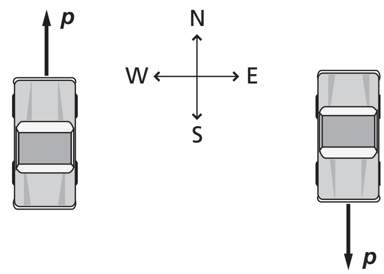
6. Momentum Is the momentum of a car traveling south different from that of the same car when it travels north at the same speed? Draw the momentum vectors to support your answer.

Yes, momentum is a vector quantity, and the momenta of the two cars are in opposite directions.



7. **Impulse and Momentum** When you jump from a height to the ground, 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.

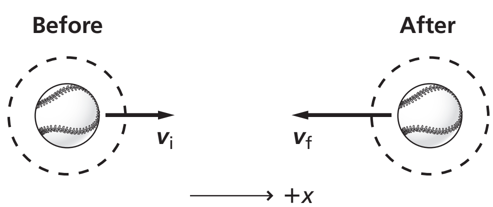
   You reduce the force by increasing the length of time it takes to stop the motion of your body.

8. **Momentum** Which has more momentum, a supertanker tied to a dock or a falling raindrop?

   The raindrop has more momentum, because a supertanker at rest has zero momentum.

9. **Impulse and Momentum** A 0.174-kg softball is pitched horizontally at 26.0 m/s. The ball moves in the opposite direction at 38.0 m/s after it is hit by the bat.

   a. Draw arrows showing the ball's momentum before and after the bat hits it.



   b. What is the change in momentum of the ball?

   $$\Delta p = m(v_f - v_i)$$
   $$= (0.174\text{ kg})(38.0\text{ m/s} - (-26.0\text{ m/s}))$$
   $$= 11.1\text{ kg·m/s}$$

   c. What is the impulse delivered by the bat?

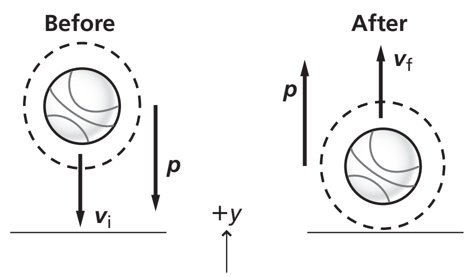
   $$F\Delta t = p_f - p_i$$
   $$= \Delta p$$
   $$= 11.1\text{ kg·m/s}$$
   $$= 11.1\text{ N·s}$$

   d. If the bat and softball are in contact for 0.80 ms, what is the average force that the bat exerts on the ball?

   $$F\Delta t = m(v_f - v_i)$$
   $$F = \frac{m(v_f - v_i)}{\Delta t}$$
   $$= \frac{(0.174\text{ kg})(38.0\text{ m/s} - (-26.0\text{ m/s}))}{(0.80\text{ ms})\left(\frac{1\text{ s}}{1000\text{ ms}}\right)}$$
   $$= 1.4\times10^4\text{ N}$$

10. **Momentum** The speed of a basketball as it is dribbled is the same when the ball is going toward the floor as it is when the ball rises from the floor. Is the basketball's change in momentum equal to zero when it hits the floor? If not, in which direction is the change in momentum? Draw the basketball's momentum vectors before and after it hits the floor.

    No, the change in momentum is upward. Before the ball hits the floor, its momentum vector is downward. After the ball hits the floor, its momentum vector is upward.



11. **Angular Momentum** An ice-skater spins with his arms outstretched. When he pulls his arms in and raises them above his head, he spins much faster than before. Did a torque act on the ice-skater? If not, how could his angular velocity have increased?

    No torque acted on him. By drawing his arms in and keeping them close to the axis of rotation, he decreased his moment of inertia. Because the angular momentum did not change, the skater's angular velocity increased.

12. Critical Thinking An archer shoots arrows at a target. Some of the arrows stick in the target, while others bounce off. Assuming that the masses of the arrows and the velocities of the arrows are the same, which arrows produce a bigger impulse on the target? *Hint: Draw a diagram to show the momentum of the arrows before and after hitting the target for the two instances.*

The ones that bounce off give more impulse because they end up with some momentum in the reverse direction, meaning they have a larger change in momentum.

Practice Problems

9.2 Conservation of Momentum pages 236–245

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

$p_i = p_f$

$mv_{Ai} + mv_{Bi} = 2mv_f$

$v_f = \frac{v_{Ai} + v_{Bi}}{2}$

$= \frac{2.2 \text{ m/s} + 0.0 \text{ m/s}}{2}$

$= 1.1$ **m/s**

14. 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?

$p_{Pi} + p_{Gi} = p_{Pf} + p_{Gf}$

$m_P v_{Pi} + m_G v_{Gi} = m_P v_{Pf} + m_G v_{Gf}$

Because $v_{Gi} = 0.0$ **kg·m/s,**

$m_P v_{Pi} = (m_P + m_G)v_f$

where $v_f = v_{Pf} = v_{Gf}$ **is the common final speed of the goalie and the puck.**

$v_f = \frac{m_P v_{Pi}}{(m_P + m_G)}$

$= \frac{(0.105 \text{ kg})(24 \text{ m/s})}{(0.105 \text{ kg} + 75 \text{ kg})} = 0.034$ **m/s**

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

$m_b v_{bi} + m_w v_{wi} = (m_b + m_w)v_f$

where v_f **is the common final speed of the bullet and piece of lumber.**

Because $v_{wi} = 0.0$ **m/s,**

$v_{bi} = \frac{(m_b + m_w)v_f}{m_b}$

$= \frac{(0.0350 \text{ kg} + 5.0 \text{ kg})(8.6 \text{ m/s})}{0.0350 \text{ kg}}$

$= 1.2\times10^3$ **m/s**

16. A 35.0-g bullet moving at 475 m/s strikes a 2.5-kg bag of flour that is on ice, at rest. The bullet passes through the bag, as shown in **Figure 9-7,** and exits it at 275 m/s. How fast is the bag moving when the bullet exits?

■ **Figure 9-7**

$m_B v_{Bi} + m_F v_{Fi} = m_B v_{Bf} + m_F v_{Ff}$

where $v_{Fi} = 0.0$ **m/s**

$v_{Ff} = \frac{(m_B v_{Bi} - m_B v_{Bf})}{m_F}$

$v_{Ff} = \frac{m_B(v_{Bi} - v_{Bf})}{m_F}$

$$= \frac{(0.0350\text{ kg})(475\text{ m/s} - 275\text{ m/s})}{2.5\text{ kg}}$$

$= 2.8$ **m/s**

17. The bullet in the previous problem strikes a 2.5-kg steel ball that is at rest. The bullet bounces backward after its collision at a speed of 5.0 m/s. How fast is the ball moving when the bullet bounces backward?

The system is the bullet and the ball.

$$m_{bullet}v_{bullet,\,i} + m_{ball}v_{ball,\,i} = m_{bullet}v_{bullet,\,f} + m_{ball}v_{ball,\,f}$$

$v_{ball,\,i} = 0.0$ **m/s and** $v_{bullet,\,f} = -5.0$ **m/s**

so $$v_{ball,\,f} = \frac{m_{bullet}(v_{bullet,\,i} - v_{bullet,\,f})}{m_{ball}} = \frac{(0.0350\text{ kg})(475\text{ m/s} - (-5.0\text{ m/s}))}{2.5\text{ kg}}$$

$= 6.7$ **m/s**

18. A 0.50-kg ball that is 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.

Say that the first ball (ball C) is initially moving in the positive (forward) direction.

$$m_C v_{Ci} + m_D v_{Di} = m_C v_{Cf} + m_D v_{Df}$$

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

$$= \frac{(0.50\text{ kg})(6.0\text{ m/s}) + (1.00\text{ kg})(-12.0\text{ m/s}) - (0.50\text{ kg})(-14\text{ m/s})}{1.00\text{ kg}}$$

$= -2.0$ **m/s, or 2.0 m/s in the opposite direction**

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19. A 4.00-kg model rocket is launched, expelling 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.*

$$p_{ri} + p_{fuel,\,i} = p_{rf} + p_{fuel,\,f}$$

where $p_{rf} + p_{fuel,\,f} = 0.0$ **kg·m/s**

If the initial mass of the rocket (including fuel) is $m_r = 4.00$ **kg, then the final mass of the rocket is**

$m_{rf} = 4.00\text{ kg} - 0.0500\text{ kg} = 3.95\text{ kg}$

$0.0\text{ kg·m/s} = m_{rf}v_{rf} + m_{fuel}v_{fuel,\,f}$

$$v_{rf} = \frac{-m_{fuel}v_{fuel,\,f}}{m_{rf}}$$

$$= \frac{-(0.0500\text{ kg})(-625\text{ m/s})}{3.95\text{ kg}}$$

$= 7.91$ **m/s**

20. A thread holds a 1.5-kg cart and a 4.5-kg cart together. 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?

Let the 1.5-kg cart be represented by "C" and the 4.5-kg cart be represented by "D".

$p_{Ci} + p_{Di} = p_{Cf} + p_{Df}$

where $p_{Ci} = p_{Di} = 0.0\ \text{kg·m/s}$

$m_D v_{Df} = -m_C v_{Cf}$

so $v_{Df} = \frac{-m_C v_{Cf}}{m_D}$

$= \frac{-(1.5\ \text{kg})(-27\ \text{cm/s})}{4.5\ \text{kg}}$

$= 9.0$ **cm/s to the right**

21. Carmen and Judi dock a canoe. 80.0-kg Carmen moves forward at 4.0 m/s as she leaves the canoe. At what speed and in what direction do the canoe and Judi move if their combined mass is 115 kg?

$p_{Ci} + p_{Ji} = p_{Cf} + p_{Jf}$

where $p_{Ci} = p_{Ji} = 0.0\ \text{kg·m/s}$

$m_C v_{Cf} = -m_J v_{Jf}$

so $v_{Jf} = \frac{-m_C v_{Cf}}{m_J}$

$= \frac{-(80.0\ \text{kg})(4.0\ \text{m/s})}{115\ \text{kg}}$

$= 2.8$ **m/s in the opposite direction**

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22. A 925-kg car moving north at 20.1 m/s collides with a 1865-kg car moving west at 13.4 m/s. The two cars are stuck together. In what direction and at what speed do they move after the collision?

Before:

$p_{i,\,y} = m_y v_{i,\,y}$

$= (925\ \text{kg})(20.1\ \text{m/s})$

$= 1.86\times10^4\ \text{kg·m/s}$

$p_{i,\,x} = m_x v_{i,\,x}$

$= (1865\ \text{kg})(-13.4\ \text{m/s})$

$= -2.50\times10^4\ \text{kg·m/s}$

$p_{f,\,y} = p_{i,\,y}$

$p_{f,\,x} = p_{i,\,x}$

$p_f = p_i$

$= \sqrt{(p_{f,\,x})^2 + (p_{f,\,y})^2}$

$$= \sqrt{(-2.50\times10^4\ \text{kg·m/s})^2 + (1.86\times10^4\ \text{kg·m/s})^2}$$

$$= 3.12\times10^4\ \text{kg·m/s}$$

$$v_f = \frac{p_f}{m_1 + m_2}$$

$$= \frac{3.12\times10^4\ \text{kg·m/s}}{(925\ \text{kg} + 1865\ \text{kg})} = 11.2\ \text{m/s}$$

$$\theta = \tan^{-1}\left(\frac{p_{f,\,y}}{p_{f,\,x}}\right)$$

$$= \tan^{-1}\left(\frac{1.86\times10^4\ \text{kg·m/s}}{-2.50\times10^4\ \text{kg·m/s}}\right)$$

$$= 36.6°\ \text{north of west}$$

23. A 1383-kg car moving south at 11.2 m/s is struck by a 1732-kg car moving east at 31.3 m/s. The cars are stuck together. How fast and in what direction do they move immediately after the collision?

Before:

$$p_{i,\,x} = p_{1,\,x} + p_{2,\,x}$$

$$= 0 + m_2v_{2i}$$

$$p_{i,\,y} = p_{1,\,y} + p_{2,\,y}$$

$$= m_1v_{1i} + 0$$

$$p_f = p_i$$

$$= \sqrt{{p_{1,\,x}}^2 + {p_{i,\,y}}^2}$$

$$= \sqrt{(m_2v_{2i})^2 + (m_1v_{1i})^2}$$

$$v_f = \frac{p_f}{m_1 + m_2}$$

$$= \frac{\sqrt{(m_2v_{2i})^2 + (m_1v_{1i})^2}}{m_1 + m_2}$$

$$= \frac{\sqrt{((1732\ \text{kg})(31.3\ \text{m/s}))^2 + ((1383\ \text{kg})(-11.2\ \text{m/s}))^2}}{1383\ \text{kg} + 1782\ \text{kg}}$$

$$= 18.1\ \text{m/s}$$

$$\theta = \tan^{-1}\left(\frac{p_{i,\,y}}{p_{i,\,x}}\right) = \tan^{-1}\left(\frac{m_1v_{1i}}{m_2v_{2i}}\right) = \tan^{-1}\left(\frac{(1383\ \text{kg})(-11.2\ \text{m/s})}{(1732\ \text{kg})(31.3\ \text{m/s})}\right) = 15.9°$$

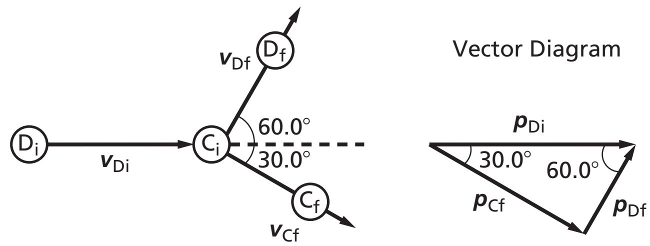
south of east

24. A stationary billiard ball, with a mass of 0.17 kg, is struck by an identical ball moving at 4.0 m/s. After the collision, the second ball moves 60.0° to the left of its original direction. The stationary ball moves 30.0° to the right of the moving ball's original direction. What is the velocity of each ball after the collision?

$$p_{Ci} + p_{Di} = p_{Cf} + p_{Df}$$

where $p_{Ci} = 0.0\ \text{kg·m/s}$

$$m_C = m_D = m = 0.17\ \text{kg}$$



The vector diagram provides final momentum equations for the ball that is initially stationary, C, and the ball that is initially moving, D.

$p_{Cf} = p_{Di} \sin 60.0°$

$p_{Df} = p_{Di} \cos 60.0°$

We can use the momentum equation for the stationary ball to find its final velocity.

$p_{Cf} = p_{Di} \sin 60.0°$

$mv_{Cf} = mv_{Di} \sin 60.0°$

$v_{Cf} = v_{Di} \sin 60.0°$

$= (4.0\ \text{m/s})(\sin 60.0°)$

$= 3.5$ **m/s, 30.0° to the right**

We can use the momentum equation for the moving ball to find its velocity.

$p_{Df} = p_{Di} \cos 60.0°$

$mv_{Df} = mv_{Di} \cos 60.0°$

$v_{Df} = v_{Di} \cos 60.0°$

$= (4.0\ \text{m/s})(\cos 60.0°)$

$= 2.0$ **m/s, 60.0° to the left**

25. A 1345-kg car moving east at 15.7 m/s is struck by a 1923-kg car moving north. They are stuck together and move with an initial velocity of 14.5 m/s at $\theta = 63.5°$. Was the north-moving car exceeding the 20.1 m/s speed limit?

Before:

$p_{i,x} = m_1 v_{1,i}$

$= (1345\ \text{kg})(15.7\ \text{m/s})$

$= 2.11\times10^4\ \text{kg·m/s}$

$p_f = p_i$

$= (m_1 + m_2)v_f$

$= (1345\ \text{kg} + 1923\ \text{kg})(14.5\ \text{m/s})$

$= 4.74\times10^4\ \text{kg·m/s}$

$p_{f,y} = p_f \sin \theta$

$= (4.74\times10^4\ \text{kg·m/s})(\sin 63.5°)$

$= 4.24\times10^4\ \text{kg·m/s}$

$p_{f,y} = p_{i,y} = m_2v_{2,i}$

$v_{2,i} = \frac{p_{f,y}}{m_2} = \frac{4.24\times10^4 \text{ kg·m/s}}{1923 \text{ kg}}$

$= 22.1 \text{ m/s}$

Yes, it was exceeding the speed limit.

Section Review

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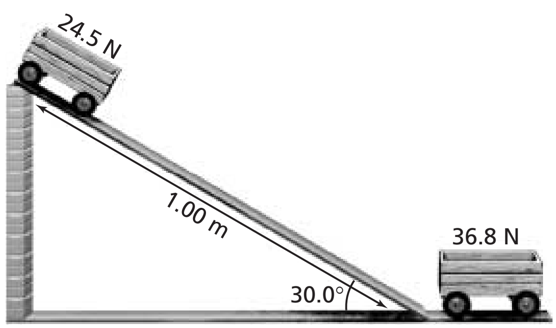
26. Angular Momentum The outer rim of a plastic disk is thick and heavy. Besides making it easier to catch, how does this affect the rotational properties of the plastic disk?

Most of the mass of the disk is located at the rim, thereby increasing its moment of inertia. Therefore, when the disk is spinning, its angular momentum is larger than it would be if more mass were near the center. With a larger angular momentum, the disk flies through the air with more stability.

27. Speed A cart, weighing 24.5 N, is released from rest on a 1.00-m ramp, inclined at an angle of 30.0° as shown in **Figure 9-14.** The cart rolls down the incline and strikes a second cart weighing 36.8 N.



■ **Figure 9-14**

a. Calculate the speed of the first cart at the bottom of the incline.

The force parallel to the surface of the ramp is

$F_{\parallel} = F_g \sin\theta$

where

$a = \frac{F_{\parallel}}{m}$ **and** $m = \frac{F_g}{g}$

so, $a = \frac{F_g \sin\theta}{F_g/g} = g\sin\theta$

The velocity and acceleration of the cart are related by the motion equation, $v^2 = v_i^2 + 2a(d - d_i)$ **with** $v_i = 0$ **and** $d_i = 0$**. Thus,**

$v^2 = 2ad$

$v = \sqrt{2ad}$

$= \sqrt{(2)(g\sin\theta)(d)}$

$= \sqrt{(2)(9.80 \text{ m/s}^2)(\sin 30.0°)(1.00 \text{ m})}$

$= 3.13 \text{ m/s}$

b. If the two carts stick together, with what initial speed will they move along?

$m_Cv_{Ci} = (m_C + m_C)v_f$

so, $v_f = \frac{m_Cv_{Ci}}{m_C + m_D}$

$= \frac{\left(\frac{F_C}{g}\right)v_{Ci}}{\frac{F_C}{g} + \frac{F_D}{g}}$

$= \frac{F_Cv_{Ci}}{F_C + F_D}$

$= \frac{(24.5 \text{ N})(3.13 \text{ m/s})}{24.5 \text{ N} + 36.8 \text{ N}}$

$= 1.25 \text{ m/s}$

28. Conservation of Momentum During a tennis serve, the racket of a tennis player continues forward after it hits the ball. Is momentum conserved in the collision? Explain, making sure that you define the system.

No, because the mass of the racket is much larger than that of the ball, only a small change in its velocity is required. In addition, it is being held by a massive, moving arm that is attached to a body in contact with Earth. Thus, the racket and ball do not comprise an isolated system.

29. Momentum 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?

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.

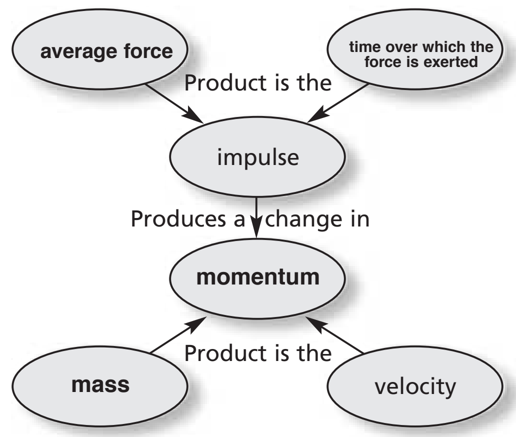
In the case of the skateboard, the ball, the skateboard, and you are an isolated system, and the momentum of the ball is shared. In the second case, unless Earth is included, there is an external force, so momentum is not conserved. If Earth's large mass is included in the system, the change in its velocity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

change in momentum as long as the net change in momentum is zero.

36. Why are cars made with bumpers that can be pushed in during a crash? (9.1)

Cars are made with bumpers that compress during a crash to increase the time of a collision, thereby reducing the force.

37. An ice-skater is doing a spin. (9.1)

a. How can the skater's angular momentum be changed?

by applying an external torque

b. How can the skater's angular velocity be changed without changing the angular momentum?

by changing the moment of inertia

38. What is meant by "an isolated system?" (9.2)

An isolated system has no external forces acting on it.

39. 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? (9.2)

Momentum is conserved. The change in momentum of gases in one direction must be balanced by an equal change in momentum of the spacecraft in the opposite direction.

40. A cue ball travels across a pool table and collides with the stationary eight ball. The two balls have equal masses. After the collision, the cue ball is at rest. What must be true regarding the speed of the eight ball? (9.2)

The eight ball must be moving with the same velocity that the cue ball had just before the collision.

41. Consider a ball falling toward Earth. (9.2)

a. Why is the momentum of the ball not conserved?

The momentum of a falling ball is not conserved because a net external force, gravity, is acting on it.

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

One such system in which total momentum is conserved includes the ball plus Earth.

42. A falling basketball hits the floor. Just before it hits, the momentum is in the downward direction, and after it hits the floor, the momentum is in the upward direction. (9.2)

a. Why isn't the momentum of the basketball conserved even though the bounce is a collision?

The floor is outside the system, so it exerts an external force, and therefore, an impulse on the ball.

b. In what system is the momentum conserved?

Momentum is conserved in the system of ball plus Earth.

43. 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. (9.2)

The external force of a car's brakes can bring the car to a stop by stopping the wheels and allowing the external frictional force of the road against the tires to stop the car. If there is no friction—for example, if the road is icy—then there is no external force and the car does not stop.

44. Children's playgrounds often have circular-motion rides. How could a child change the angular momentum of such a ride as it is turning? (9.2)

The child would have to exert a torque on it. He or she could stand next to it and exert a force tangential to the circle on the handles as they go past. He or she also could run at the ride and jump onboard.

Applying Concepts

pages 250–251

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

A force, *F*, exerted on an object over a time, Δt, causes the momentum of the object to change by the quantity $F\Delta t$.

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

Yes, if the smaller force acts for a long enough time, it can provide a larger impulse.

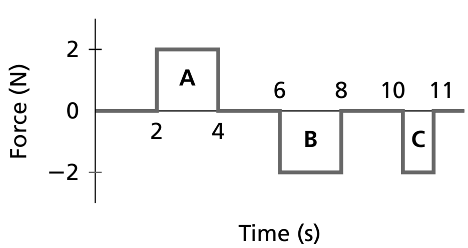
47. Foul Ball You are sitting at a baseball game when a foul ball comes in your direction. You prepare to catch it bare-handed. To catch it safely, should you move your hands toward the ball, hold them still, or move them in the same direction as the moving ball? Explain.

You should move your hands in the same direction the ball is traveling to increase the time of the collision, thereby reducing the force.

48. 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.

The bullet is in the rifle a longer time, so the momentum it gains is larger.

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

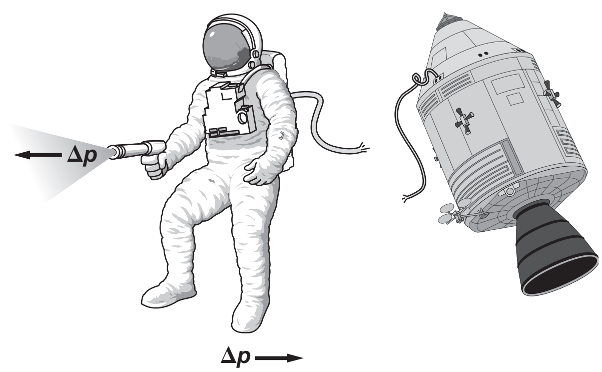


■ **Figure 9-15**

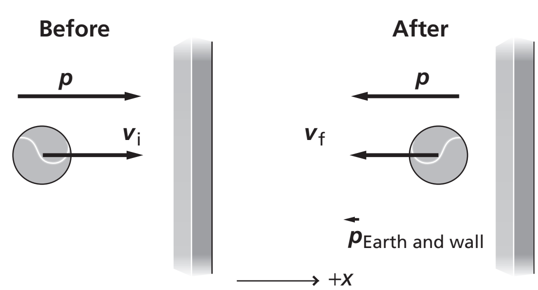
After time A, the object moves with a constant, positive velocity. After time B, the object is at rest. After time C, the object moves with a constant, negative velocity.

50. 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. Use the language of the impulse-momentum theorem and a diagram to explain why this method was effective.

When the gas pistol is fired in the opposite direction, it provides the impulse needed to move the astronaut toward the spaceship.



51. Tennis Ball As a tennis ball bounces off a wall, its momentum is reversed. Explain this action in terms of the law of conservation of momentum. Define the system and draw a diagram as a part of your explanation.



Consider the system to be the ball, the wall, and Earth. The wall and Earth gain some momentum in the collision.

52. Imagine that you command spaceship *Zeldon,* which is moving through interplanetary space at high speed. How could you slow your ship by applying the law of conservation of momentum?

By shooting mass in the form of exhaust gas, at high velocity in the same direction in which you are moving, its momentum would cause the ship's momentum to decrease.

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

If the two trucks had equal masses, they would have moved off at half the speed of the moving truck. Thus, the moving truck must have had a more massive load.

54. 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.

When held loosely, the recoil momentum of the rifle works against only the mass of the rifle, thereby producing a larger velocity and striking your shoulder. The recoil momentum must work against the mass of the rifle and you, resulting in a smaller velocity.

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

Momentum is conserved, so the momentum of the block and bullet after the collision equals the momentum of the bullet before the collision. The rubber bullet has a negative momentum after impact, with respect to the block, so the block's momentum must be greater in this case.

Mastering Problems

9.1 Impulse and Momentum

pages 251–252

Level 1

56. Golf Rocío strikes a 0.058-kg golf ball with a force of 272 N and gives it a velocity of 62.0 m/s. How long was Rocío's club in contact with the ball?

$$\Delta t = \frac{m\Delta v}{F} = \frac{(0.058\text{ kg})(62.0\text{ m/s})}{272\text{ N}}$$

$$= 0.013\text{ s}$$

57. A 0.145-kg baseball is pitched at 42 m/s. The batter hits it horizontally to the pitcher at 58 m/s.

a. Find the change in momentum of the ball.

Take the direction of the pitch to be positive.

$$\Delta p = mv_f - mv_i = m(v_f - v_i)$$

$$= (0.145\text{ kg})(-58\text{ m/s} - (+42\text{ m/s}))$$

$$= -14\text{ kg·m/s}$$

b. If the ball and bat are in contact for 4.6×10^{-4} s, what is the average force during contact?

$$F\Delta t = \Delta p$$

$$F = \frac{\Delta p}{\Delta t}$$

$$= \frac{m(v_f - v_i)}{\Delta t}$$

$$= \frac{(0.145\text{ kg})(-58\text{ m/s} - (+42\text{ m/s}))}{4.6\times10^{-4}\text{ s}}$$

$$= -3.2\times10^{4}\text{ N}$$

58. Bowling A force of 186 N acts on a 7.3-kg bowling ball for 0.40 s. What is the bowling ball's change in momentum? What is its change in velocity?

$$\Delta p = F\Delta t$$

$$= (186\text{ N})(0.40\text{ s})$$

$$= 74\text{ N·s}$$

$$= 74\text{ kg·m/s}$$

$$\Delta v = \frac{\Delta p}{m}$$

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

$$= \frac{(186\ \text{N})(0.40\ \text{s})}{7.3\ \text{kg}}$$

$$= 1.0\times10^1\ \text{m/s}$$

59. A 5500-kg freight truck accelerates from 4.2 m/s to 7.8 m/s in 15.0 s by the application of a constant force.

a. What change in momentum occurs?

$$\Delta p = m\Delta v = m(v_f - v_i)$$

$$= (5500\ \text{kg})(7.8\ \text{m/s} - 4.2\ \text{m/s})$$

$$= 2.0\times10^4\ \text{kg·m/s}$$

b. How large of a force is exerted?

$$F = \frac{\Delta p}{\Delta t}$$

$$= \frac{m(v_f - v_i)}{\Delta t}$$

$$= \frac{(5500\ \text{kg})(7.8\ \text{m/s} - 4.2\ \text{m/s})}{15.0\ \text{s}}$$

$$= 1.3\times10^3\ \text{N}$$

60. In a ballistics test at the police department, Officer Rios fires a 6.0-g bullet at 350 m/s into a container that stops it in 1.8 ms. What is the average force that stops the bullet?

$$F = \frac{\Delta p}{\Delta t}$$

$$= \frac{m(v_f - v_i)}{\Delta t}$$

$$= \frac{(0.0060\ \text{kg})(0.0\ \text{m/s} - 350\ \text{m/s})}{1.8\times10^{-3}\ \text{s}}$$

$$= -1.2\times10^3\ \text{N}$$

61. Volleyball A 0.24-kg volleyball approaches Tina with a velocity of 3.8 m/s. Tina bumps the ball, giving it a speed of 2.4 m/s but in the opposite direction. What average force did she apply if the interaction time between her hands and the ball was 0.025 s?

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

$$= \frac{(0.24\ \text{kg})(-2.4\ \text{m/s} - 3.8\ \text{m/s})}{0.025\ \text{s}}$$

$$= -6.0\times10^1\ \text{N}$$

62. Hockey 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?

$$F\Delta t = (30.0\ \text{N})(0.16\ \text{s})$$

$$= 4.8\ \text{N·s}$$

63. Skateboarding 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 moving at 9.50 m/s?

$$p = mv$$

$$= (m_{boy} + m_{board})v$$

$$= (35.6\ \text{kg} + 1.3\ \text{kg})(9.50\ \text{m/s})$$

$$= 3.5\times10^2\ \text{kg·m/s}$$

64. 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?

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

where $v_i = 0$

Thus $v_f = \frac{F\Delta t}{m}$

$$= \frac{(30.0\ \text{N})(0.16\ \text{s})}{0.115\ \text{kg}}$$

$$= 42\ \text{m/s}$$

65. Before a collision, a 25-kg object was moving at +12 m/s. Find the impulse that acted on the object if, after the collision, it moved at the following velocities.

a. +8.0 m/s

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

$$= (25\ \text{kg})(8.0\ \text{m/s} - 12\ \text{m/s})$$

$$= -1.0\times10^2\ \text{kg·m/s}$$

b. −8.0 m/s

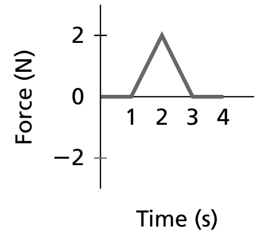
$$F\Delta t = m\Delta v = m(v_f - v_i)$$

$$= (25\ \text{kg})(-8.0\ \text{m/s} - 12\ \text{m/s})$$

$$= -5.0\times10^2\ \text{kg·m/s}$$

Level 2

66. 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 9-16.** What is the ball's speed at 4.0 s?



■ **Figure 9-16**

$F\Delta t = m\Delta v$

Area of graph $= m\Delta v$

$\frac{1}{2}(2.0\text{ N})(2.0\text{ s}) = m(v_f - v_i)$

$2.0\text{ N·s} = (0.150\text{ kg})(v_f - 12\text{ m/s})$

$v_f = \frac{2.0\text{ kg·m/s}}{0.150\text{ kg}} + 12\text{ m/s}$

$= 25\text{ m/s}$

67. **Baseball** A 0.145-kg baseball is moving at 35 m/s when it is caught by a player.

a. Find the change in momentum of the ball.

$\Delta p = m(v_f - v_i)$

$= (0.145\text{ kg})(0.0\text{ m/s} - 35\text{ m/s})$

$= -5.1\text{ kg·m/s}$

b. If the ball is caught with the mitt held in a stationary position so that the ball stops in 0.050 s, what is the average force exerted on the ball?

$\Delta p = F_{average}\Delta t$

so, $F_{average} = \frac{\Delta p}{\Delta t} = \frac{m(v_f - v_i)}{\Delta t}$

$= \frac{(0.145\text{ kg})(0.0\text{ m/s} - 35\text{ m/s})}{0.500\text{ s}}$

$= -1.0\times10^2\text{ N}$

c. If, instead, the mitt is moving backward so that the ball takes 0.500 s to stop, what is the average force exerted by the mitt on the ball?

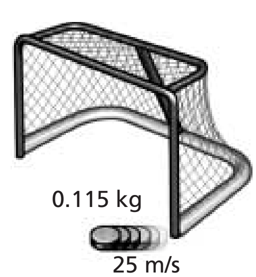
$\Delta p = F_{average}\Delta t$

so, $F_{average} = \frac{\Delta p}{\Delta t} = \frac{m(v_f - v_i)}{\Delta t}$

$= \frac{(0.145\text{ kg})(0.0\text{ m/s} - 35\text{ m/s})}{0.500\text{ s}}$

$= -1.0\times10^1\text{ N}$

68. **Hockey** A hockey puck has a mass of 0.115 kg and strikes the pole of the net at 37 m/s. It bounces off in the opposite direction at 25 m/s, as shown in **Figure 9-17.**



■ **Figure 9-17**

a. What is the impulse on the puck?

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

$= (0.115\text{ kg})(-25\text{ m/s} - 37\text{ m/s})$

$= -7.1\text{ kg·m/s}$

b. If the collision takes 5.0×10^{-4} s, what is the average force on the puck?

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

$$F = \frac{m(v_f - v_i)}{\Delta t}$$

$$= \frac{(0.115\text{ kg})(-25\text{ m/s} - 37\text{ m/s})}{5.0\times10^{-4}\text{ s}}$$

$$= -1.4\times10^{4}\text{ N}$$

69. A nitrogen molecule with a mass of 4.7×10^{-26} kg, moving at 550 m/s, strikes the wall of a container and bounces back at the same speed.

a. What is the impulse the molecule delivers to the wall?

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

$$= (4.7\times10^{-26}\text{ kg})(-550\text{ m/s} - 550\text{ m/s})$$

$$= -5.2\times10^{-23}\text{ kg·m/s}$$

The impulse the wall delivers to the molecule is -5.2×10^{-23} kg·m/s. The impulse the molecule delivers to the wall is $+5.2\times10^{-23}$ kg·m/s.

b. If there are 1.5×10^{23} collisions each second, what is the average force on the wall?

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

$$F = \frac{m(v_f - v_i)}{\Delta t}$$

For all the collisions, the force is

$$F_{total} = (1.5\times10^{23})\frac{m(v_f - v_i)}{\Delta t}$$

$$= (1.5\times10^{23})\frac{(4.7\times10^{-26}\text{ kg})(-550\text{ m/s} - 550\text{ m/s})}{1.0\text{ s}}$$

$$= 7.8\text{ N}$$

Level 3

70. **Rockets** Small rockets are used to make tiny adjustments in the speeds 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?

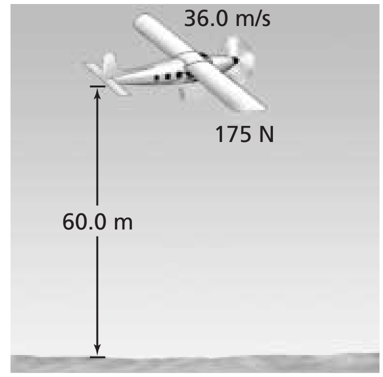
$$F\Delta t = m\Delta v$$

$$\text{so, } \Delta t = \frac{m\Delta t}{F}$$

$$= \frac{(72{,}000\text{ kg})(0.63\text{ m/s})}{35\text{ N}}$$

$$= 1.3\times10^{3}\text{ s, or 22 min}$$

71. An animal rescue plane flying due east at 36.0 m/s drops a bale of hay from an altitude of 60.0 m, as shown in **Figure 9-18.** 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.



■ **Figure 9-18**

First use projectile motion to find the velocity of the bale.

$p = mv$

To find v, consider the horizontal and vertical components.

$v_x = 36.0 \text{ m/s}$

$v_y^2 = v_{iy}^2 + 2dg = 2dg$

Thus,

$v = \sqrt{v_x^2 + v_y^2} = \sqrt{v_x^2 + 2dg}$

The momentum, then, is

$$p = \frac{F_g v}{g} = \frac{F_g \sqrt{v_x^2 + 2dg}}{g}$$

$$= \frac{(175 \text{ N})\sqrt{(36.0 \text{ m/s})^2 + (2)(60.0 \text{ m})(9.80 \text{ m/s}^2)}}{9.80 \text{ m/s}^2}$$

$$= 888 \text{ kg·m/s}$$

The angle from the horizontal is

$$\tan\theta = \frac{v_y}{v_x}$$

$$= \frac{\sqrt{2dg}}{v_x}$$

$$= \frac{\sqrt{(2)(60.0 \text{ m})(9.80 \text{ m/s}^2)}}{36.0 \text{ m/s}}$$

$$= 43.6°$$

72. Accident A car moving at 10.0 m/s crashes into a barrier and stops in 0.050 s. There is a 20.0-kg child in the car. Assume that the child's velocity is changed by the same amount as that of the car, and in the same time period.

a. What is the impulse needed to stop the child?

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

$$= (20.0 \text{ kg})(0.0 \text{ m/s} - 10.0 \text{ m/s})$$

$$= -2.00\times10^2 \text{ kg·m/s}$$

b. What is the average force on the child?

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

$$\text{so, } F = \frac{m(v_f - v_i)}{\Delta t}$$

$$= \frac{(20.0 \text{ kg})(0.0 \text{ m/s} - 10.0 \text{ m/s})}{0.050 \text{ s}}$$

$$= -4.0\times10^3 \text{ N}$$

c. What is the approximate mass of an object whose weight equals the force in part **b**?

$$F_g = mg$$

$$\text{so, } m = \frac{F_g}{g} = \frac{4.0\times10^3\ \text{N}}{9.80\ \text{m/s}^2}$$

$$= 4.1\times10^2\ \text{kg}$$

d. Could you lift such a weight with your arm?

No.

e. Why is it advisable to use a proper restraining seat rather than hold a child on your lap?

You would not be able to protect a child on your lap in the event of a collision.

9.2 Conservation of Momentum

pages 252–253

Level 1

73. Football 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 the "before" and "after" situations and draw a diagram of both.

Before: $m_{FB} = 95$ kg

$v_{FB} = 8.2$ m/s

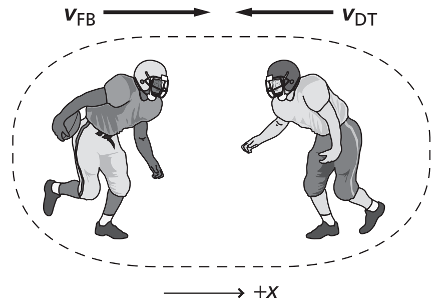
$m_{DT} = 128$ kg

$v_{DT} = ?$

After: $m = 223$ kg

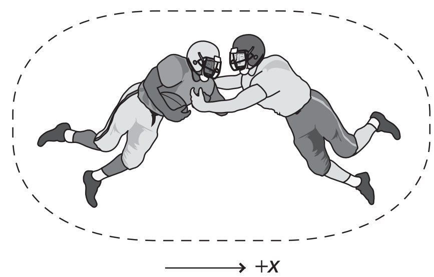
$v_f = 0$ m/s

Before



After

$v_{FB} = v_{DT} = 0$



b. What was the fullback's momentum before the collision?

$$p_{FB} = m_{FB}v_{FB} = (95\ \text{kg})(8.2\ \text{m/s})$$

$$= 7.8\times10^2\ \text{kg·m/s}$$

c. What was the change in the fullback's momentum?

$$\Delta p_{FB} = p_f - p_{FB}$$

$$= 0 - p_{FB} = -7.8\times10^2\ \text{kg·m/s}$$

d. What was the change in the defensive tackle's momentum?

$+7.8\times10^2$ **kg·m/s**

e. What was the defensive tackle's original momentum?

-7.8×10^2 **kg·m/s**

f. How fast was the defensive tackle moving originally?

$$m_{DT}v_{DT} = -7.8\times10^2\ \text{kg·m/s}$$

$$\text{so, } v_{DT} = \frac{-7.8\times10^2\ \text{kg·m/s}}{128\ \text{kg}}$$

$$= -6.1\ \text{m/s}$$

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

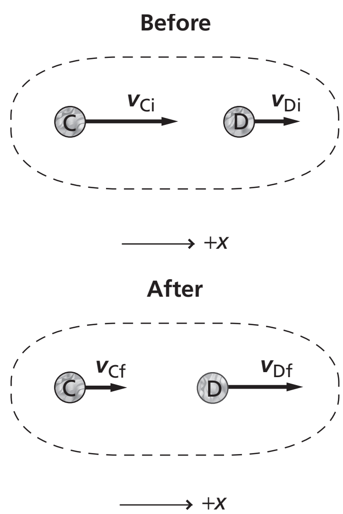
$v_{Di} = 10.0$ cm/s

After: $m_C = 5.0$ g

$m_D = 10.0$ g

$v_{Cf} = 8.0$ cm/s

$v_{Df} = ?$



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?

$p_{Df} = m_D v_{Df}$

so, $v_{Df} = \dfrac{p_{Df}}{m_D}$

$= \dfrac{1.6\times10^{-3}\text{ kg·m/s}}{1.00\times10^{-2}\text{ kg}}$

$= 1.6\times10^{-1}\text{ m/s} = 0.16\text{ m/s}$

$= 16\text{ cm/s}$

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?

$m_1 v_i = -m_2 v_f$

$v_f = \dfrac{m_1 v_i}{-m_2}$

$= \dfrac{(5.0\text{ kg})(0.12\text{ m/s})}{-(2.0\text{ kg})}$

$= -0.30\text{ m/s}$

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?

$p_{Ci} + p_{Di} = p_{Cf} + p_{Df}$

$m_C v_{Ci} + m_D v_{Di} = m_C v_{Cf} + m_D v_{Df}$

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

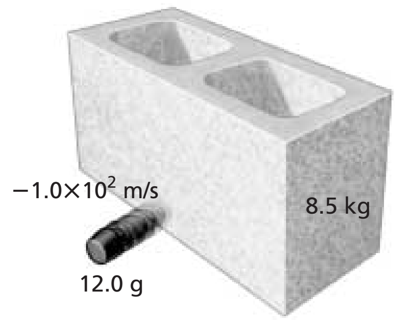
Assuming that the projectile, C, is launched in the direction of the launcher, D, motion,

$$v_{Df} = \frac{(0.0500\text{ kg})(2.00\text{ m/s}) + (4.65\text{ kg})(2.00\text{ m/s}) - (0.0500\text{ kg})(647\text{ m/s})}{4.65\text{ kg}}$$

$= -4.94$ **m/s, or 4.94 m/s backwards**

Level 2

77. A 12.0-g rubber bullet travels at a velocity of 150 m/s, hits a stationary 8.5-kg concrete block resting on a frictionless surface, and ricochets in the opposite direction with a velocity of -1.0×10^2 m/s, as shown in **Figure 9-19.** How fast will the concrete block be moving?



■ **Figure 9-19**

$$m_C v_{Ci} + m_D v_{Di} = m_C v_{Cf} + m_D v_{Df}$$

$$v_{Df} = \frac{m_C v_{Ci} + m_D v_{Di} - m_C v_{Cf}}{m_D}$$

since the block is initially at rest, this becomes

$$v_{Df} = \frac{m_C(v_{Ci} - v_{Cf})}{m_D}$$

$$= \frac{(0.0120\text{ kg})(150\text{ m/s} - (-1.0\times10^2\text{ m/s}))}{8.5\text{ kg}}$$

$= 0.35$ **m/s**

78. Skateboarding Kofi, with mass 42.00 kg, is riding a skateboard with a mass of 2.00 kg and traveling at 1.20 m/s. Kofi jumps off and the skateboard stops dead in its tracks. In what direction and with what velocity did he jump?

$$(m_L v_{Li} + m_s v_{si})v_i = m_L v_{Lf} + m_s v_{sf}$$

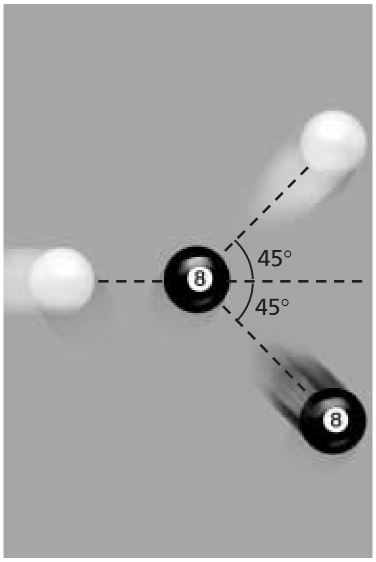
where $v_{sf} = 0$ **and** $v_{Li} = v_{si} = v_i$

Thus $v_{Lf} = \dfrac{(m_L + m_s)v_i}{m_L}$

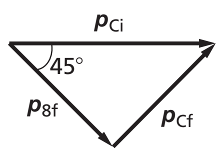
$$= \frac{(42.00\text{ kg} + 2.00\text{ kg})(1.20\text{ m/s})}{42.00\text{ kg}}$$

$= 1.26$ **m/s in the same direction as she was riding**

79. Billiards A cue ball, with mass 0.16 kg, rolling at 4.0 m/s, hits a stationary eight ball of similar mass. If the cue ball travels 45° above its original path and the eight ball travels 45° below the horizontal, as shown in **Figure 9-20,** what is the velocity of each ball after the collision?



■ **Figure 9-20**



We can get momentum equations from the vector diagram.

$p_{Cf} = p_{Ci} \sin 45°$

$m_C v_{Cf} = m_C v_{Ci} \sin 45°$

$v_{Cf} = v_{Ci} \sin 45°$

$= (4.0\ m/s)(\sin 45°)$

$= 2.8\ m/s$

For the eight ball,

$p_{8f} = p_{ci} \cos 45°$

$m_8 v_{8f} = m_C v_{Ci}(\cos 45°)$

where $m_8 = m_C$**. Thus,**

$v_{8f} = v_{Ci} \cos 45°$

$= (4.0\ m/s)(\cos 45°)$

$= 2.8\ m/s$

80. A 2575-kg van runs into the back of an 825-kg compact car at rest. They move off together at 8.5 m/s. Assuming that the friction with the road is negligible, calculate the initial speed of the van.

$p_{Ci} + p_{Di} = p_{Cf} + p_{Df}$

$m_C v_{Ci} = (m_C + m_D)v_f$

so, $v_{Ci} = \frac{m_C + m_D}{m_C}$

$v_f = \frac{(2575\ kg + 825\ kg)(8.5\ m/s)}{2575\ kg}$

$= 11\ m/s$

Level 3

81. In-line Skating Diego and Keshia are on in-line skates and stand face-to-face, then push each other away with their hands. Diego has a mass of 90.0 kg and Keshia has a mass of 60.0 kg.

a. Sketch the event, identifying the "before" and "after" situations, and set up a coordinate axis.

Before: $m_K = 60.0\ kg$

$m_D = 90.0\ kg$

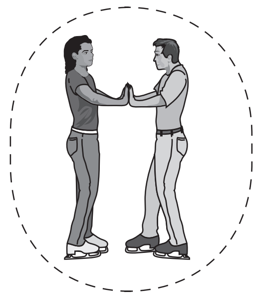
$v_i = 0.0\ m/s$

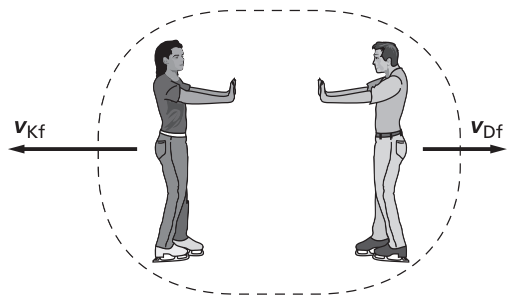
After: $m_K = 60.0\ kg$

$m_D = 90.0\ kg$

$v_{Kf} = ?$

$v_{Df} = ?$





b. Find the ratio of the skaters' velocities just after their hands lose contact.

$p_{Ki} + p_{Di} = 0.0 \text{ kg·m/s} = p_{Kf} + p_{Df}$

so, $m_K v_{Kf} + m_D v_{Df} = 0.0 \text{ kg·m/s}$

and $m_K v_{Kf} = -m_D v_{Df}$

Thus, the ratios of the velocities are

$$\frac{v_{Kf}}{v_{Df}} = -\left(\frac{m_D}{m_K}\right) = -\left(\frac{90.0 \text{ kg}}{60.0 \text{ kg}}\right) = -1.50$$

The negative sign shows that the velocities are in opposite directions.

c. Which skater has the greater speed?

Keshia, who has the smaller mass, has the greater speed.

d. Which skater pushed harder?

The forces were equal and opposite.

82. 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. The speed of the 0.100-kg ball is 0.26 m/s. What is the new velocity of the 0.200-kg ball?

$m_C v_{Ci} + m_D v_{Di} = m_C v_{Cf} + m_D v_{Df}$

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

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

= 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?

$$\Delta p = m(v_f - v_i)$$

$$= (845\ \text{kg})(100.0\ \text{km/h} - 0.0\ \text{km/h})\left(\frac{1000\ \text{m}}{1\ \text{km}}\right)\left(\frac{1\ \text{h}}{3600\ \text{s}}\right)$$

$$= 2.35\times10^4\ \text{kg·m/s}$$

b. What is the average force exerted on the dragster?

$$F = \frac{m(v_f - v_i)}{\Delta t}$$

$$= \frac{(845 \text{ kg})(100.0 \text{ km/h} - 0.0 \text{ km/h})}{0.90 \text{ s}}\left(\frac{1000 \text{ m}}{1 \text{ km}}\right)\left(\frac{1 \text{ h}}{3600 \text{ s}}\right)$$

$$= 2.6\times10^4 \text{ N}$$

c. What exerts that force?

The force is exerted by the track through friction.

Level 2

86. Ice Hockey A 0.115-kg hockey puck, moving at 35.0 m/s, strikes a 0.365-kg jacket that is thrown onto the ice by a fan of a certain hockey team. The puck and jacket slide off together. Find their velocity.

$$m_P v_{Pi} = (m_P + m_J)v_f$$

$$v_f = \frac{m_P m_{Pi}}{m_P + m_J}$$

$$= \frac{(0.115 \text{ kg})(35.0 \text{ m/s})}{(0.115 \text{ kg} + 0.365 \text{ kg})}$$

$$= 8.39 \text{ m/s}$$

87. A 50.0-kg woman, riding on a 10.0-kg cart, is moving east at 5.0 m/s. The woman jumps off the front of the cart and lands on the ground at 7.0 m/s eastward, relative to the ground.

a. Sketch the “before” and “after” situations and assign a coordinate axis to them.

Before: $m_w = 50.0$ kg

$m_c = 10.0$ kg

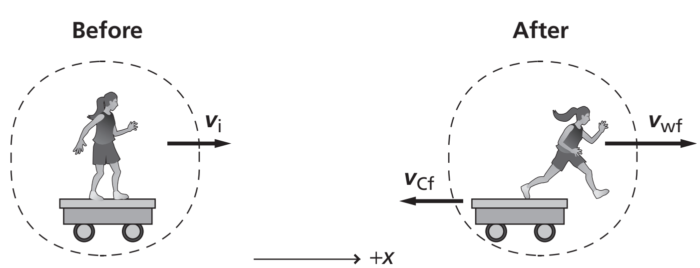
$v_i = 5.0$ m/s

After: $m_w = 50.0$ kg

$m_c = 10.0$ kg

$v_{wf} = 7.0$ m/s

$v_{cf} = ?$



b. Find the cart's velocity after the woman jumps off.

$$(m_w + m_c)v_i = m_w v_{wf} + m_c v_{cf}$$

$$\text{so, } v_{cf} = \frac{(m_w + m_c)v_i - m_w v_{wf}}{m_c}$$

$$= \frac{(50.0\text{ kg} + 10.0\text{ kg})(5.0\text{ m/s}) - (50.0\text{ kg})(7.0\text{ m/s})}{10.0\text{ kg}}$$

$$= -5.0\text{ m/s, or 5.0 m/s west}$$

88. Gymnastics Figure 9-21 shows a gymnast performing a routine. First, she does giant swings on the high bar, holding her body straight and pivoting around her hands. Then, she lets go of the high bar and grabs her knees with her hands in the tuck position. Finally, she straightens up and lands on her feet.

a. In the second and final parts of the gymnast's routine, around what axis does she spin?

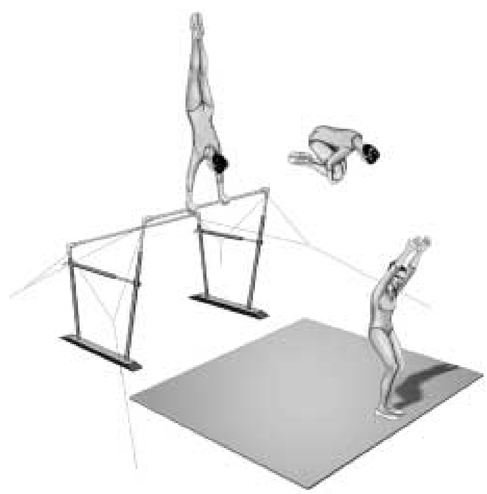
She spins around the center of mass of her body, first in the tuck position and then also as she straightens out.

b. Rank in order, from greatest to least, her moments of inertia for the three positions.

giant swing (greatest), straight, tuck (least)

c. Rank in order, from greatest to least, her angular velocities in the three positions.

tuck (greatest), straight, giant swing (least)



■ **Figure 9-21**

Level 3

89. A 60.0-kg male dancer leaps 0.32 m high.

a. With what momentum does he reach the ground?

$$v = v_0^2 + 2dg$$

Thus, the velocity of the dancer is

$$v = \sqrt{2dg}$$

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

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

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

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: $m_A = 92$ kg

$m_B = 75$ kg

$m_C = 75$ kg

$v_{Ai} = 5.0$ m/s

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

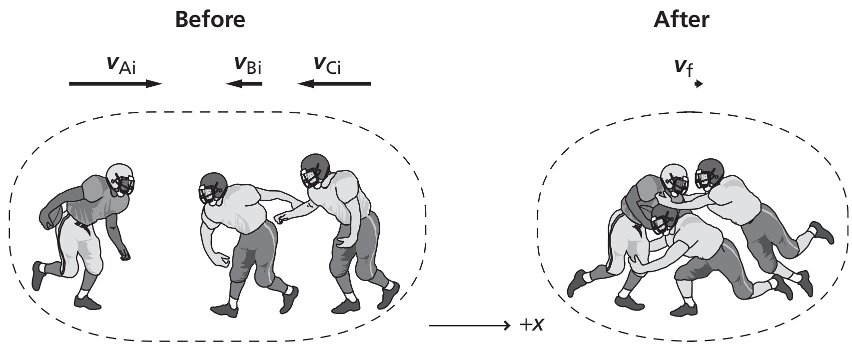
$v_{Ci} = -4.0$ m/s

After: $m_A = 92$ kg

$m_B = 75$ kg

$m_C = 75$ kg

$v_f = ?$



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

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

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

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

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

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

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

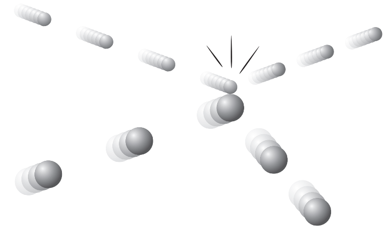
c. Does the fullback score a touchdown?

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.

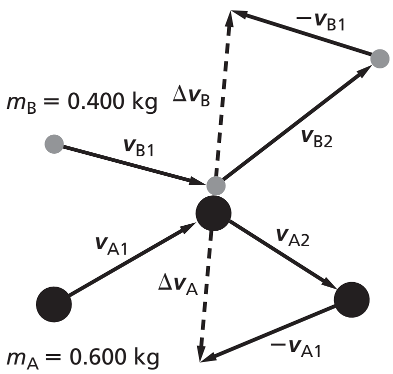
The student and the stool would spin slowly in the direction opposite to that of the wheel. Without friction there are no external torques. Thus, the angular momentum of the system is not changed. The angular momentum of the student and stool must be equal and opposite to the angular momentum of the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



Writing in Physics

page 254

93. How can highway barriers be designed to be more effective in saving people's lives? Research this issue and describe how impulse and change in momentum can be used to analyze barrier designs.

The change in a car's momentum does not depend on how it is brought to a stop. Thus, the impulse also does not change. To reduce the force, the time over which a car is stopped must be increased. Using barriers that can extend the time it takes to stop a car will reduce the force. Flexible, plastic containers filled with sand often are used.

94. While air bags save many lives, they also have caused injuries and even death. Research the arguments and responses of automobile makers to this statement. Determine whether the problems involve impulse and momentum or other issues.

There are two ways an air bag reduces injury. First, an air bag extends the time over which the impulse acts, thereby reducing the force. Second, an air bag spreads the force over a larger area, thereby reducing the pressure. Thus, the injuries due to forces from small objects are reduced. The dangers of air bags mostly center on the fact that air bags must be inflated very rapidly. The surface of an air bag can approach the passenger at speeds of up to 322 km/h (200 mph). Injuries can occur when the moving bag collides with the person. Systems are being developed that will adjust the rate at which gases fill the air bags to match the size of the person.

Cumulative Review

page 254

95. A 0.72-kg ball is swung vertically from a 0.60-m string in uniform circular motion at a speed of 3.3 m/s. What is the tension in the cord at the top of the ball's motion? (Chapter 6)

The tension is the gravitational force minus the centripetal force.

$$F_T = F_g - F_c$$
$$= mg - \frac{mv^2}{r} = m\left(g - \frac{v^2}{r}\right)$$
$$= (0.72\text{ kg})\left((9.80\text{ m/s}^2) - \frac{(3.3\text{ m/s})^2}{0.60\text{ m}}\right)$$
$$= -6.0\text{ N}$$

96. You wish to launch a satellite that will remain above the same spot on Earth's surface. This means the satellite must have a period of exactly one day. Calculate the radius of the circular orbit this satellite must have. *Hint: The Moon also circles Earth and both the Moon and the satellite will obey Kepler's third law. The Moon is 3.9×10⁸ m from Earth and its period is 27.33 days.* (Chapter 7)

$$\left(\frac{T_s}{T_m}\right)^2 = \left(\frac{r_s}{r_m}\right)^3$$
$$\text{so } r_s = \left(\left(\frac{T_s}{T_m}\right)^2 r_m{}^3\right)^{\frac{1}{3}}$$
$$= \left(\left(\frac{1.000\text{ day}}{27.33\text{ days}}\right)^2 (3.9\times10^8\text{ m})^3\right)^{\frac{1}{3}}$$
$$= 4.3\times10^7\text{ m}$$

97. A rope is wrapped around a drum that is 0.600 m in diameter. A machine pulls with a constant 40.0 N force for a total of 2.00 s. In that time, 5.00 m of rope is unwound. Find α, ω at 2.00 s, and I. (Chapter 8)

The angular acceleration is the ratio of the linear acceleration of the drum's edge and drum's radius.

$\alpha = \frac{a}{r}$

The linear acceleration is found from the equation of motion.

$x = \frac{1}{2}at^2$

$a = \frac{2x}{t^2}$

Thus, the angular acceleration is

$$\alpha = \frac{a}{r} = \frac{2x}{rt^2}$$

$$= \frac{(2)(5.00\text{ m})}{\left(\frac{0.600\text{ m}}{2}\right)(2.00\text{ s})^2}$$

$$= 8.33\text{ rad/s}^2$$

At the end of 2.00 s, the angular velocity is

$$\omega = \alpha t$$

$$= \frac{2xt}{rt^2}$$

$$= \frac{2x}{rt}$$

$$= \frac{(2)(5.00\text{ m})}{\left(\frac{0.600\text{ m}}{2}\right)(2.00\text{ s})}$$

$$= 16.7\text{ rad/s}$$

The moment of inertia is

$$I = \frac{\tau}{\alpha}$$

$$= \frac{Fr\sin\theta}{\left(\frac{2x}{rt^2}\right)} = \frac{Fr^2t^2\sin\theta}{2x}$$

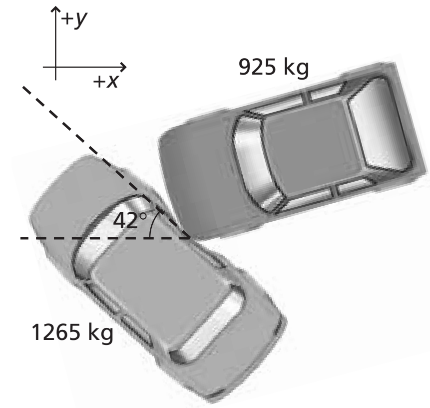
$$= \frac{(40.0\text{ N})\left(\frac{0.600\text{ m}}{2}\right)^2(2.00\text{ s})^2(\sin 90.0°)}{(2)(5.00\text{ m})}$$

$$= 1.44\text{ kg·m}^2$$

Challenge Problem

page 244

Your friend 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 22 m/s (50 mph). 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.



1. Your friend claims that she wasn't speeding, but that the driver of other car was. How fast was your friend driving before the crash?

The vector diagram provides a momentum equation for the friend's car.

$$p_{Ci} = p_f \sin 42°$$

The friend's initial velocity, then, is

$$v_{Ci} = \frac{p_{Ci}}{m_C} = \frac{(m_C + m_D)v_f \sin 42°}{m_C}$$

We can find v_f first by finding the acceleration and time of the skid. The acceleration is

$$a = \frac{F}{m} = \frac{\mu F_g}{m} = \frac{\mu(m_C + m_D)g}{m_C + m_D} = \mu g$$

The time can be derived from the distance equation.

$$d = \frac{1}{2}at^2$$

$$t = \sqrt{\frac{2d}{a}} = \sqrt{\frac{2d}{\mu g}}$$

The final velocity, then, is

$$v_f = at = \mu g\sqrt{\frac{2d}{\mu g}} = \sqrt{2d\mu g}$$

Using this, we now can find the friend's initial velocity.

$$v_{Ci} = \frac{(m_C + m_D)v_f \sin 42°}{m_C}$$

$$= \frac{(m_C + m_D)\sqrt{2d\mu g}\sin 42°}{m_C}$$

$$= \frac{(1265\text{ kg} + 925\text{ kg})\left(\sqrt{(2)(23.1\text{ m})(0.65)(9.80\text{ m/s}^2)}\right)(\sin 42°)}{1265\text{ kg}}$$

$$= 2.0\times10^1\text{ m/s}$$

2. How fast was the other car moving before the crash? Can you support your friend's case in court?

From the vector diagram, the momentum equation for the other car is

$$p_{Di} = p_f \cos 42°$$
$$= (m_C + m_D)v_f \cos 42°$$
$$= (m_C + m_D)\sqrt{2d\mu g}\,(\cos 42°)$$

The other car's initial velocity, then, is,

$$v_{Di} = \frac{p_{Di}}{m_D}$$
$$= \frac{(m_C + m_D)\sqrt{2d\mu g}\,(\sin 42°)}{m_D}$$
$$= \frac{(1265\text{ kg} + 925\text{ kg})\left(\sqrt{(2)(23.1\text{ m})(0.65)(9.80\text{ m/s}^2)}\right)(\cos 42°)}{925\text{ kg}}$$
$$= 3.0\times10^{1}\text{ m/s}$$

The friend was not exceeding the 22 m/s speed limit. The other car was exceeding the speed limit.