Chapter 2: Collisions

Practice, page 244

1. Let north be the positive direction.

$$m = 2.2\text{ kg}$$
$$\vec{v} = 2.50\text{ m/s}[\text{N}]$$
$$= +2.50\text{ m/s}$$
$$\vec{p} = ?$$

$$\vec{p} = m\vec{v}$$
$$= (2.2\text{ kg})(+2.50\text{ m/s})$$
$$= +5.5\text{ kg}\bullet\text{m/s}$$

The momentum of the skateboard is 5.5 kg•m/s [N].

2. Let east be the positive direction.

$$\vec{p} = 1.35\times10^{4}\text{ kg}\bullet\text{m/s}[\text{E}]$$
$$= +1.35\times10^{4}\text{ kg}\bullet\text{m/s}$$
$$m = 900\text{ kg}$$
$$\vec{v} = ?$$

$$\vec{p} = m\vec{v}$$
$$\vec{v} = \frac{\vec{p}}{m}$$
$$= \frac{+1.35\times10^{4}\text{ kg}\bullet\text{m/s}}{900\text{ kg}}$$
$$= +15.0\text{ m/s}$$

The car's velocity is 15.0 m/s [E].

3. Let west be the negative direction. Since solving for mass involves dividing two vectors, the vector notation is dropped.

$$p = 4.5\text{ kg}\bullet\text{m/s}[\text{W}]$$
$$= -4.5\text{ kg}\bullet\text{m/s}$$
$$v = 32.0\text{ m/s}[\text{W}]$$
$$= -32.0\text{ m/s}$$
$$m = ?$$

$$p = mv$$
$$m = \frac{p}{v}$$
$$= \frac{-4.5\text{ kg}\bullet\text{m/s}}{-32.0\text{ m/s}}$$
$$= 0.14\text{ kg}$$

The mass of the ball is 0.14 kg.

2.1 Questions, page 245

Knowledge

1. Another term for "quantity of motion" is *momentum*.

2. The two factors used to determine the momentum of an object are mass and velocity.

Applying Concepts

3. Let north be the positive direction.

$$m = 40.0 \text{ kg}$$
$$\vec{v} = 1.90 \text{ m/s}[\text{N}] = +1.90 \text{ m/s}$$
$$\vec{p} = ?$$

$$\vec{p} = m\vec{v} = (40.0 \text{ kg})(+1.90 \text{ m/s}) = +76.0 \text{ kg•m/s}$$

The momentum of the wagon is 76.0 kg•m/s[N].

4. Let east be the positive direction.

$$\vec{p} = 1.60 \text{ kg•m/s}[\text{E}] = +1.60 \text{ kg•m/s}$$
$$m = 0.170 \text{ kg}$$
$$\vec{v} = ?$$

$$\vec{p} = m\vec{v}$$
$$\vec{v} = \frac{\vec{p}}{m} = \frac{+1.60 \text{ kg•m/s}}{0.170 \text{ kg}} = +9.41 \text{ m/s}$$

The puck's velocity is 9.41 m/s[E].

5. Let north be the positive direction. Since solving for mass involves dividing two vectors, drop the vector notation.

$$p = 0.320 \text{ kg•m/s}[\text{N}] = +0.320 \text{ kg•m/s}$$
$$v = 2.0 \text{ m/s}[\text{N}] = +2.0 \text{ m/s}$$
$$m = ?$$

$$p = mv$$
$$m = \frac{p}{v} = \frac{+0.320 \text{ kg•m/s}}{+2.0 \text{ m/s}} = 0.16 \text{ kg}$$

The mass of the billiard ball is 0.16 kg.

6. Let south be considered the negative direction.

$$m = 40\ 000 \text{ kg}$$
$$\vec{v} = 80.0 \text{ km/h}[\text{S}] = -80 \frac{\cancel{\text{km}}}{\cancel{\text{h}}} \times \frac{1000 \text{ m}}{1 \cancel{\text{km}}} \times \frac{1 \cancel{\text{h}}}{3600 \text{ s}} = -22.\bar{2} \text{ m/s}$$
$$\vec{p} = ?$$

$$\vec{p} = m\vec{v} = (40\ 000 \text{ kg})(-22.\bar{2} \text{ m/s}) = -8.89 \times 10^5 \text{ kg•m/s}$$

The vehicle's momentum is 8.89×10^5 kg•m/s[S].

7. **a.** i. An object with a large mass and a small velocity will not displace the cup very much.
ii. An object with a large velocity and a small mass will not displace the cup very much.

b. i. The marbles at rest in the tube remain at rest unless acted upon.

ii. When the released marble collides with the target marbles, its "quantity of motion" is passed through the target marbles, causing one of them to be ejected.

c. Since one released marble will eject one marble and two released marbles will eject two marbles with the same speed, the momentum before the collision must equal the momentum after the collision.

8. The boulder will never catch the person if the momentum of the boulder and the momentum of the person remain the same because the boulder must have a smaller velocity since it has a greater mass.

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4. Let down be the negative direction.

a.
$$\vec{v}_i = 31.3\text{ m/s}[\text{down}] = -31.3\text{ m/s}$$
$$m = 4.00\text{ kg}$$
$$\vec{p}_i = ?$$

$$\vec{p}_i = m\vec{v}_i = (4.00\text{ kg})(-31.3\text{ m/s}) = -125.2\text{ kg•m/s} = -125\text{ kg•m/s}$$

The balloon's momentum just before hitting the ground is 125 kg•m/s [down].

b.
$$\vec{v}_f = 0 \leftarrow \vec{p}_f = 0$$
$$\vec{p}_i = 125.2\text{ kg•m/s}[\text{down}] = -125.2\text{ kg•m/s}$$
$$\Delta\vec{p} = ?$$

$$\Delta\vec{p} = \vec{p}_f - \vec{p}_i = -\vec{p}_i \leftarrow \vec{p}_f = 0$$
$$= -(-125.2\text{ kg•m/s}) = +125.2\text{ kg•m/s} = +125\text{ kg•m/s}$$

The change in momentum is 125 kg•m/s [up].

c.
$$\Delta t = 0.011\text{ s}$$
$$\Delta\vec{p} = 125.2\text{ kg•m/s}[\text{up}] = +125.2\text{ kg•m/s}$$
$$\vec{F} = ?$$

$$\vec{F} = \frac{\Delta\vec{p}}{\Delta t} = \frac{+125\text{ kg•m/s}}{0.011\text{ s}} = +1.1\times10^4\text{ N}$$

The force exerted on the balloon is 1.1×10^4 N [up].

5. Let the original (forward) direction of the car be the positive direction.

$$m = 2000\ \text{kg}$$
$$\vec{v}_i = 25\ \text{m/s}[\text{forward}] = +25\ \text{m/s}$$
$$\vec{v}_f = 0$$
$$\Delta t = 0.23\ \text{s}$$
$$\vec{F} = ?$$

$$\vec{F} = \frac{m(\vec{v}_f - \vec{v}_i)}{\Delta t}$$
$$= \frac{m(-\vec{v}_i)}{\Delta t} \quad \leftarrow \vec{v}_f = 0$$
$$= \frac{2000\ \text{kg}[-(+25\ \text{m/s})]}{0.23\ \text{s}}$$
$$= -2.2 \times 10^5\ \text{kg}\bullet\text{m/s}^2$$

The force exerted on the car is 2.2×10^5 N[backward].

6. Let the original (forward) direction of the ball be the positive direction.

$$m = 500\ \cancel{\text{g}} \times \frac{1\ \text{kg}}{1000\ \cancel{\text{g}}} = 0.500\ \text{kg}$$
$$\vec{v}_i = 5.00\ \text{m/s}[\text{forward}] = +5.00\ \text{m/s}$$
$$\vec{v}_f = 4.50\ \text{m/s}[\text{backward}] = -4.50\ \text{m/s}$$
$$\Delta t = 0.25\ \text{s}$$
$$\vec{F} = ?$$

$$\vec{F} = \frac{m(\vec{v}_f - \vec{v}_i)}{\Delta t}$$
$$= \frac{0.500\ \text{kg}[(-4.50\ \text{m/s}) - (+5.00\ \text{m/s})]}{0.25\ \text{s}}$$
$$= -19\ \text{kg}\bullet\text{m/s}^2$$

The force exerted on the ball is 19 N[backward].

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7. Let the original (forward) direction of the car be the positive direction. Since the force exerted by the pylon opposes the motion of the car, this force must act in the negative direction (backward).

a.

$$\Delta t = 0.012$$
$$\vec{F} = 18\ \text{N}[\text{backward}] = -18\ \text{N}$$
$$\Delta\vec{p} = ?$$

$$\Delta\vec{p} = \vec{F}\Delta t$$
$$= (-18\ \text{N})(0.012\ \text{s})$$
$$= -0.22\ \text{N}\bullet\text{s}$$
$$= -0.22\ \text{kg}\bullet\text{m/s}$$

The change in the momentum of the vehicle is 0.22 kg•m/s[backward].

b. $\Delta t = 0.012\ \text{s}$

$\vec{F} = 190\ \text{N}[\text{backward}]$
$= -190\ \text{N}$

$\Delta \vec{p} = ?$

$$\Delta \vec{p} = \vec{F}\Delta t$$
$$= (-190\ \text{N})(0.012\ \text{s})$$
$$= -2.3\ \text{N•s}$$
$$= -2.3\ \text{kg•m/s}$$

The change in the momentum of the vehicle is 2.3 kg•m/s [backward].

The wooden pylon provides more than ten times the change in momentum to the vehicle than the plastic pylon.

8. Let the direction of the applied force (forward) be positive.

a. $\vec{F} = 30\ \text{N}[\text{forward}]$
$= +30\ \text{N}$

$\Delta t = 4.0\ \text{s}$

$\Delta \vec{p} = ?$

$$\Delta \vec{p} = \vec{F}\Delta t$$
$$= (+30\ \text{N})(4.0\ \text{s})$$
$$= +1.2 \times 10^2\ \text{N•s}$$
$$= +1.2 \times 10^2\ \text{kg•m/s}$$

The change in the momentum of the wagon is 1.2×10^2 kg•m/s [forward].

b. $\vec{F} = 30\ \text{N}[\text{forward}]$
$= +30\ \text{N}$

$\Delta t = 8.0\ \text{s}$

$\Delta \vec{p} = ?$

$$\Delta \vec{p} = \vec{F}\Delta t$$
$$= (+30\ \text{N})(8.0\ \text{s})$$
$$= +2.4 \times 10^2\ \text{N•s}$$
$$= +2.4 \times 10^2\ \text{kg•m/s}$$

The change in the momentum of the wagon is 2.4×10^2 kg•m/s [forward].

The change in momentum is double when the force acts for twice the time interval.

2.2 Questions, page 251

Knowledge

1. $\vec{F} = m\vec{a}$**:** If an unbalanced force is applied to a mass, the mass will accelerate.

$\Delta\vec{p} = \vec{F}\Delta t$**:** If an unbalanced force is applied to a mass over a specified time, the mass will undergo a change in momentum.

2. **a.** If the amount of force acting on an object increases, the change in momentum increases.
b. If the time interval in which a force acting on an object increases, the change in momentum increases.

Applying Concepts

3. Let the original (forward) direction of the cart be positive. This means that the direction of the force to oppose this motion is in the negative direction.

$$\begin{aligned}\vec{F} &= 300 \text{ N}[\text{backward}] \\ &= -300 \text{ N} \\ \Delta t &= 4.0 \text{ s} \\ \Delta\vec{p} &= ?\end{aligned}$$

$$\begin{aligned}\Delta\vec{p} &= \vec{F}\Delta t \\ &= (-300 \text{ N})(4.0 \text{ s}) \\ &= -1.2\times10^3 \text{ N•s} \\ &= -1.2\times10^3 \text{ kg•m/s}\end{aligned}$$

The change in the momentum of the cart is 1.2×10^3 kg•m/s [backward].

4. Let the original (forward) direction of the wagon be positive. This means that the direction of the force to oppose this motion is in the negative direction.

$$\begin{aligned}\Delta\vec{p} &= 30.0 \text{ kg•m/s}[\text{backward}] \\ &= -30.0 \text{ kg•m/s} \\ \Delta t &= 4.5 \text{ s} \\ \vec{F} &= ?\end{aligned}$$

$$\begin{aligned}\vec{F} &= \frac{\Delta\vec{p}}{\Delta t} \\ &= \frac{-30.0 \text{ kg•m/s}}{4.5 \text{ s}} \\ &= -6.7 \text{ kg•m/s}^2 \\ &= -6.7 \text{ N}\end{aligned}$$

The required force is 6.7 N [backward].

5. Since solving for time involves dividing change in momentum by force, drop the vector notation.

$$\begin{aligned}F &= 65 \text{ N} \\ &= 65 \text{ kg•m/s}^2 \\ \Delta p &= 12 \text{ kg•m/s} \\ \Delta t &= ?\end{aligned}$$

$$\begin{aligned}F\Delta t &= \Delta p \\ \Delta t &= \frac{\Delta p}{F} \\ &= \frac{12 \text{ kg•m/s}}{65 \text{ kg•m/s}^2} \\ &= 0.18 \text{ s}\end{aligned}$$

The force acts on the ball for 0.18 s.

6. Let the direction of the force (forward) be the positive direction.

a.

$$\begin{aligned}\vec{F} &= 25 \text{ N}[\text{forward}] \\ &= +25 \text{ N} \\ \Delta t &= 3.0 \text{ s} \\ \vec{p}_{\text{i}} &= 0 \\ \vec{p}_{\text{f}} &= ?\end{aligned}$$

$$\begin{aligned}\Delta\vec{p} &= \vec{F}\Delta t \\ \vec{p}_{\text{f}} - \vec{p}_{\text{i}} &= \vec{F}\Delta t \\ \vec{p}_{\text{f}} &= \vec{F}\Delta t \quad \leftarrow \vec{p}_{\text{i}} = 0 \\ &= (+25 \text{ N})(3.0 \text{ s}) \\ &= +75 \text{ N•s} \\ &= +75 \text{ kg•m/s}\end{aligned}$$

The final momentum of the object is 75 kg•m/s [forward].

b. $\vec{p}_f = 75\ \text{kg•m/s}[\text{forward}]$
$= +75\ \text{kg•m/s}$
$m = 2.0\ \text{kg}$
$\vec{v}_f = ?$

$$\vec{p}_f = m\vec{v}_f$$
$$\vec{v}_f = \frac{\vec{p}_f}{m} = \frac{+75\ \text{kg•m/s}}{2.0\ \text{kg}} = +38\ \text{m/s}$$

The final velocity of the object is 38 m/s[forward].

7. Let the direction of the flying bird (forward) be the positive direction.

a. $m = 100\ \text{g} \times \frac{1\ \text{kg}}{1000\ \text{g}}$
$= 0.100\ \text{kg}$
$\vec{v}_i = 8.0\ \text{m/s}[\text{forward}]$
$= +8.0\ \text{m/s}$
$\vec{v}_f = 0$
$\Delta t = 0.013\ \text{s}$
$\vec{F} = ?$

$$\vec{F} = \frac{m(\vec{v}_f - \vec{v}_i)}{\Delta t}$$
$$\vec{F} = \frac{m(-\vec{v}_i)}{\Delta t} \leftarrow \vec{v}_f = 0$$
$$= \frac{0.100\ \text{kg}[-(+8.0\ \text{m/s})]}{0.013\ \text{s}} = -62\ \text{kg•m/s}^2 = -62\ \text{N}$$

The force required to stop the sparrow is 62 N[backward].

b. $m = 1.00\ \text{kg}$
$\vec{v}_i = 8.00\ \text{m/s}[\text{forward}]$
$= +8.0\ \text{m/s}$
$\vec{v}_f = 0$
$\Delta t = 0.050\ \text{s}$
$\vec{F} = ?$

$$\vec{F} = \frac{\Delta\vec{p}}{\Delta t}$$
$$\vec{F} = \frac{m\vec{v}_f - m\vec{v}_i}{\Delta t}$$
$$\vec{F} = \frac{-m\vec{v}_i}{\Delta t} \leftarrow \vec{v}_f = 0$$
$$= \frac{-(1.00\ \text{kg})(+8.00\ \text{m/s})}{0.050\ \text{s}} = -1.6\times10^2\ \text{kg•m/s}^2 = -1.6\times10^2\ \text{N}$$

The force required to stop the seagull is 1.6×10^2 N[backward].

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9. Let the direction of the force (forward) be the positive direction.

$\vec{F} = 400\ \text{N}[\text{forward}]$
$= +400\ \text{N}$
$\Delta t = 0.012\ \text{s}$
impulse = ?

$$\text{impulse} = \vec{F}\Delta t = (+400\ \text{N})(0.012\ \text{s}) = +4.8\ \text{N•s}$$

The impulse is 4.8 N•s[forward].

10. Let the direction of the force (forward) be the positive direction.

$\vec{F} = 2.2 \times 10^6 \text{ N}[\text{forward}]$
$= +2.2 \times 10^6 \text{ N}$
$\Delta t = 0.050 \text{ s}$
impulse = ?

$$\begin{aligned}\text{impulse} &= \vec{F}\Delta t \\ &= \left(+2.2 \times 10^6 \text{ N}\right)(0.050 \text{ s}) \\ &= +1.1 \times 10^5 \text{ N•s}\end{aligned}$$

The impulse provided by the barrier is 1.1×10^5 N•s[forward].

11. Let the original direction (forward) of the hockey puck be the positive direction.

$m = 0.17 \text{ kg}$
$\vec{v}_i = 28 \text{ m/s}[\text{forward}]$
$= +28 \text{ m/s}$
$\vec{v}_f = 0$
impulse = ?

$$\begin{aligned}\text{impulse} &= \vec{F}\Delta t \\ &= \Delta\vec{p} \\ &= \vec{p}_f - \vec{p}_i \\ &= m\vec{v}_f - m\vec{v}_i \\ &= -m\vec{v}_i \quad \leftarrow \vec{v}_f = 0 \\ &= -(0.17 \text{ kg})(+28 \text{ m/s}) \\ &= -4.8 \text{ kg•m/s} \\ &= -4.8 \text{ N•s}\end{aligned}$$

The impulse is 4.8 N•s[backward].

12. Let west be the positive direction.

$m = 4000 \text{ kg}$
$\vec{v}_i = 28 \text{ m/s}[\text{W}]$
$= +28 \text{ m/s}$
$\vec{v}_f = 0$
impulse = ?

$$\begin{aligned}\text{impulse} &= \vec{F}\Delta t \\ &\Delta\vec{p} \\ &= \vec{p}_f - \vec{p}_i \\ &= m\vec{v}_f - m\vec{v}_i \\ &= -m\vec{v}_i \quad \leftarrow \vec{v}_f = 0 \\ &= -(4000 \text{ kg})(+28 \text{ m/s}) \\ &= -1.1 \times 10^5 \text{ kg•m/s} \\ &= -1.1 \times 10^5 \text{ N•s}\end{aligned}$$

The impulse provided by the barrier is 1.1×10^5 N•s[E].

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13. Since the change in momentum is the same in both cases, as the time decreases, the force must increase. Stomping your feet on the cement floor decreases the time of the change in momentum; so, force must be increased. A greater force will remove the snow easier.

14. Since the change in momentum is the same in both cases, the force must increase as the time decreases. Hitting the ball with a hickory bat decreases the time of the change in momentum; so, the force must increase. A greater force will hit the ball farther.

2.3 Questions, page 256

Knowledge

1. Momentum is the "quantity of motion" and impulse is the "quantity required to change the quantity of motion." Impulse is the cause of a change in momentum.

2. Change in momentum is equal to the impulse.

3. $\text{impulse} = \vec{F}\Delta t$ and $\text{impulse} = \vec{p}_\text{f} - \vec{p}_\text{i}$

4. **Units for Impulse**

$$\begin{aligned} \text{N•s} &= \left(\text{kg•m/s}^2\right)\text{•s} \\ &= \text{kg•m/s} \end{aligned}$$

Units for Momentum

$$\text{kg•m/s}$$

Therefore, the units for impulse are equal to the units for momentum.

Applying Concepts

5. a. Let the original (forward) direction of the ball be positive. This means that the direction of the force provided by the cushion to oppose this motion is in the negative direction.

$$\begin{aligned} \vec{F} &= 1.5\ \text{N}[\text{backward}] \\ &= -1.5\ \text{N} \\ \Delta t &= 0.020\ \text{s} \\ \text{impulse} &= ? \end{aligned}$$

$$\begin{aligned} \text{impulse} &= \vec{F}\Delta t \\ &= (-1.5\ \text{N})(0.020\ \text{s}) \\ &= -3.0\times10^{-2}\ \text{N•s} \end{aligned}$$

The impulse is 3.0×10^{-2} N•s [backward].

b. Let the original (forward) direction of the ball of putty be the positive direction.

$$\begin{aligned} m &= 0.30\ \text{kg} \\ \vec{v}_\text{i} &= 2.1\ \text{m/s}[\text{forward}] \\ &= +2.1\ \text{m/s} \\ \vec{v}_\text{f} &= 0 \\ \text{impulse} &= ? \end{aligned}$$

$$\begin{aligned} \text{impulse} &= \vec{F}\Delta t \\ &= \vec{p}_\text{f} - \vec{p}_\text{i} \\ &= m\vec{v}_\text{f} - m\vec{v}_\text{i} \\ &= -m\vec{v}_\text{i} \quad \leftarrow \vec{v}_\text{f} = 0 \\ &= -(0.30\ \text{kg})(+2.1\ \text{m/s}) \\ &= -0.63\ \text{kg•m/s} \\ &= -0.63\ \text{N•s} \end{aligned}$$

The impulse is 0.63 N•s [backward].

6. Since $\Delta\vec{p} = \vec{F}\Delta t$, the change in momentum is the same as the impulse in both cases.

a. $\Delta\vec{p} = 3.0\times10^{-2}\ \text{kg•m/s}[\text{backward}]$

b. $\Delta\vec{p} = 0.63\ \text{kg•m/s}[\text{backward}]$

7. Let east be the positive direction.

a. $m = 0.43\ \text{kg}$

$\vec{v}_i = 14\ \text{m/s}[\text{E}]$
$= +14\ \text{m/s}$

$\vec{p}_i = ?$

$$\begin{aligned}\vec{p}_i &= m\vec{v}_i \\ &= (0.43\ \text{kg})(+14\ \text{m/s}) \\ &= +6.02\ \text{kg}\bullet\text{m/s} \\ &= +6.0\ \text{kg}\bullet\text{m/s}\end{aligned}$$

The initial momentum of the soccer ball is 6.0 kg•m/s [E].

b. $m = 0.43\ \text{kg}$

$\vec{v}_f = 12\ \text{m/s}[\text{W}]$
$= -12\ \text{m/s}$

$\vec{p}_f = ?$

$$\begin{aligned}\vec{p}_f &= m\vec{v}_f \\ &= (0.43\ \text{kg})(-12\ \text{m/s}) \\ &= -5.16\ \text{kg}\bullet\text{m/s} \\ &= -5.2\ \text{kg}\bullet\text{m/s}\end{aligned}$$

The final momentum of the soccer ball is 5.2 kg•m/s [W].

c. $\vec{p}_i = 6.02\ \text{kg}\bullet\text{m/s}[\text{E}]$
$= +6.02\ \text{kg}\bullet\text{m/s}$

$\vec{p}_f = 5.16\ \text{kg}\bullet\text{m/s}[\text{W}]$
$= -5.16\ \text{kg}\bullet\text{m/s}$

$\Delta\vec{p} = ?$

$$\begin{aligned}\Delta\vec{p} &= \vec{p}_f - \vec{p}_i \\ &= (-5.16\ \text{kg}\bullet\text{m/s}) - (6.02\ \text{kg}\bullet\text{m/s}) \\ &= -11.18\ \text{kg}\bullet\text{m/s} \\ &= -11.2\ \text{kg}\bullet\text{m/s}\end{aligned}$$

The change in momentum of the soccer ball is 11.2 kg•m/s [W].

d. $\Delta\vec{p} = 11.18\ \text{kg}\bullet\text{m/s}[\text{W}]$

impulse = ?

$$\begin{aligned}\text{impulse} &= \vec{F}\Delta t \\ &= \Delta\vec{p} \\ &= 11.18\ \text{kg}\bullet\text{m/s}[\text{W}] \\ &= 11.2\ \text{N}\bullet\text{s}[\text{W}]\end{aligned}$$

The impulse provided by the goal post is 11.2 N•s [W].

8. **a.** Since the change in momentum for the person is the same in both cases, with or without the air bag, as time increases, the force must decrease. The air bag increases the time to change the momentum of the person, so the force on the person must be less.

b. Since the change in momentum for the person is the same in both cases, with or without the foam in the helmet, as time increases, the force must decrease. The foam increases the time to change the momentum of the person, so the force on the person must be less.

9. As the boxer being punched "gives" with the punch, he is increasing the time that the momentum changes; so, the force that the boxer feels is less.

10. Let the original (forward) direction of the ball be the positive direction.

a. $m = 0.20\ \text{kg}$

$\vec{v}_i = 2.5\ \text{m/s}[\text{forward}]$
$= +2.5\ \text{m/s}$

$\vec{v}_f = 2.0\ \text{m/s}[\text{backward}]$
$= -2.0\ \text{m/s}$

impulse = ?

$$\begin{aligned}\text{impulse} &= \vec{F}\Delta t\\ &= \vec{p}_f - \vec{p}_i\\ &= m\vec{v}_f - m\vec{v}_i\\ &= (0.20\ \text{kg})(-2.0\ \text{m/s}) - (0.20\ \text{kg})(2.5\ \text{m/s})\\ &= -0.90\ \text{kg•m/s}\\ &= -0.90\ \text{N•s}\end{aligned}$$

The wall provided an impulse of 0.90 N•s [backward].

b. $m = 0.20\ \text{kg}$

$\vec{v}_i = 2.5\ \text{m/s}[\text{forward}]$
$= +2.5\ \text{m/s}$

$\vec{v}_f = 0$

impulse = ?

$$\begin{aligned}\text{impulse} &= \vec{F}\Delta t\\ &= \vec{p}_f - \vec{p}_i\\ &= m\vec{v}_f - m\vec{v}_i\\ &= -m\vec{v}_i \quad \leftarrow \vec{v}_f = 0\\ &= -(0.20\ \text{kg})(+2.5\ \text{m/s})\\ &= -0.50\ \text{kg•m/s}\\ &= -0.50\ \text{kg•m/s}\end{aligned}$$

The wall provided an impulse of 0.50 N•s [backward].

The wall provided the greater impulse on the rubber ball.

11. Let the original (forward) direction of the ball be the positive direction.

Rubber Ball

$\text{impulse} = 0.90\ \text{N•s}[\text{backward}]$
$= -0.90\ \text{N•s}$

$\Delta t = 0.012\ \text{s}$

$\vec{F} = ?$

$$\begin{aligned}\text{impulse} &= \vec{F}\Delta t\\ \vec{F} &= \frac{\text{impulse}}{\Delta t}\\ &= \frac{-0.90\ \text{N•s}}{0.012\ \text{s}}\\ &= -75\ \text{N}\\ &= 75\ \text{N}[\text{backward}]\end{aligned}$$

Putty Ball

$\text{impulse} = 0.50\ \text{N•s}[\text{backward}]$
$= -0.50\ \text{N•s}$

$\Delta t = 0.012\ \text{s}$

$\vec{F} = ?$

$$\begin{aligned}\text{impulse} &= \vec{F}\Delta t\\ \vec{F} &= \frac{\text{impulse}}{\Delta t}\\ &= \frac{-0.50\ \text{N•s}}{0.012\ \text{s}}\\ &= -42\ \text{N}\\ &= 42\ \text{N}[\text{backward}]\end{aligned}$$

The force exerted by the wall was greater with the rubber ball.

12. Shock-absorbing bumpers, crumple zones, padded dashboards, collapsible steering columns, seat belts, and air bags all increase the time that the change in momentum is occurring, so the force is less.

Practice, page 257

15.

Safety Technology	Class of Collision
shock-absorbing bumpers	primary
crumple zones (in the frame)	primary
padded dashboard, steering wheel, etc.	secondary
seat belts	secondary, tertiary
air bags	secondary, tertiary

Practice, page 259

16. **a.** **action force:** force of the air bag on the occupant
reaction force: force of the occupant on the air bag

b. **action force:** force of the bumper on the concrete barrier
reaction force: force of the concrete barrier on the bumper

c. **action force:** force of the swimmer on the water
reaction force: force of the water on the swimmer

d. **action force:** force of the hiker on the ground
reaction force: force of the ground on the hiker

e. **action force:** force of the car tire on the ground
reaction force: force of the ground on the car tire

2.4 Questions, pages 262 and 263

Knowledge

1. The three classes of collisions are

- primary collision, which involves a vehicle and another obstacle
- secondary collision, which involves the occupant of the vehicle colliding with the interior of the vehicle
- tertiary collision, which involves the internal organs of the occupant colliding within the occupant's body

Secondary and tertiary collisions cause injuries to the occupants of a vehicle.

2. The force of object 1 on object 2 is equal to the force of object 2 on object 1, but these forces act in opposite directions.

$$\vec{F}_{1\text{ on }2} = -\vec{F}_{2\text{ on }1}$$

Applying Concepts

3. For all interactions between two objects, only force, time, impulse, and change in momentum must always be equal for both objects. The forces must be the same as stated in Newton's third law of motion. The time must be the same because the forces can only act when the vehicles are touching, thus making the time interval equal. Impulse must be the same because it depends on the force and the time interval. The change in momentum will be the same because it is equal to the impulse.

4. **a.** Both vehicles will experience the same force.

b. Both vehicles will experience the same impulse.

c. Both vehicles will experience the same change in momentum.

d. The car will experience the larger acceleration.

e. The car will experience the greater change in velocity.

f. All other things being equal, the vehicle that experiences the least change in its velocity would be the safer vehicle. So, the best vehicle to be in would be the large truck.

5. **a.** $\vec{F}_1 = +20\text{ N}$ and $\vec{F}_2 = -20\text{ N}$

b. **Astronaut 1**

$\vec{F}_1 = +20\text{ N}$

$m_1 = 100\text{ kg}$

$\vec{a} = ?$

$$\vec{F} = m\vec{a}$$
$$\vec{a} = \frac{\vec{F}}{m} = \frac{+20\text{ N}}{100\text{ kg}} = +0.20\text{ m/s}^2$$

Astronaut 2

$\vec{F}_2 = -20\text{ N}$

$m_2 = 80\text{ kg}$

$\vec{a} = ?$

$$\vec{F} = m\vec{a}$$
$$\vec{a} = \frac{\vec{F}}{m} = \frac{-20\text{ N}}{80\text{ kg}} = -0.25\text{ m/s}^2$$

c. **Astronaut 1**

$\vec{a} = +0.20\text{ m/s}^2$

$\Delta t = 0.20\text{ s}$

$\vec{v}_i = 0$

$\vec{v}_f = ?$

$$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$
$$\vec{a} = \frac{\vec{v}_f}{\Delta t} \quad \leftarrow \vec{v}_i = 0$$
$$\vec{v}_f = \vec{a}\Delta t = (+0.20\text{ m/s}^2)(0.20) = +0.040\text{ m/s}$$

Astronaut 2

$\vec{a} = -0.25\text{ m/s}^2$

$\Delta t = 0.20\text{ s}$

$\vec{v}_i = 0$

$\vec{v}_f = ?$

$$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$
$$\vec{a} = \frac{\vec{v}_f}{\Delta t} \quad \leftarrow \vec{v}_i = 0$$
$$\vec{v}_f = \vec{a}\Delta t = (-0.25\text{ m/s}^2)(0.20\text{ s}) = -0.050\text{ m/s}$$

d. **Astronaut 1**

$m_1 = 100\text{ kg}$

$\vec{v}_f = +0.040\text{ m/s}$

$\vec{p}_f = ?$

$$\vec{p}_f = m\vec{v}_f = (100\text{ kg})(+0.040\text{ m/s}) = +4.0\text{ kg•m/s}$$

Astronaut 2

$m_2 = 80\text{ kg}$

$\vec{v}_f = -0.050\text{ m/s}$

$\vec{p}_f = ?$

$$\vec{p}_f = m\vec{v}_f = (80\text{ kg})(-0.050\text{ m/s}) = -4.0\text{ kg•m/s}$$

e. **Astronaut 1**

$\vec{F}_1 = +20\text{ N}$

$\Delta t = 0.20\text{ s}$

impulse = ?

$$\begin{aligned}\text{impulse} &= \vec{F}\Delta t\\ &= (+20\text{ N})(0.20\text{ s})\\ &= +4.0\text{ N•s}\end{aligned}$$

Astronaut 2

$\vec{F}_2 = -20\text{ N}$

$\Delta t = 0.20\text{ s}$

impulse = ?

$$\begin{aligned}\text{impulse} &= \vec{F}\Delta t\\ &= (-20\text{ N})(0.20\text{ s})\\ &= -4.0\text{ N•s}\end{aligned}$$

6. According to Newton's third law, if you throw something in the direction opposite to that of the space capsule, the reaction force should move you in an opposite direction to that of your throw, which is toward the space capsule.

Practice, page 270

17. Let east be the positive direction.

a. $m_1 = 0.010\text{ kg}$ $\quad m_2 = 0.015\text{ kg}$

$\vec{v}_1 = 0.90\text{ m/s[E]} = +0.90\text{ m/s}$

$\vec{v}'_1 = 0.30\text{ m/s[W]} = -0.30\text{ m/s}$

$\vec{v}_2 = 0$ $\quad \vec{v}'_2 = ?$

$$\begin{aligned}\sum\vec{p}_{\text{before}} &= \sum\vec{p}_{\text{after}}\\ \vec{p}_1 + \vec{p}_2 &= \vec{p}'_1 + \vec{p}'_2\\ m_1\vec{v}_1 + m_2\vec{v}_2 &= m_1\vec{v}'_1 + m_2\vec{v}'_2\\ m_1\vec{v}_1 &= m_1\vec{v}'_1 + m_2\vec{v}'_2 \quad \leftarrow \vec{v}_2 = 0\\ (0.010\text{ kg})(+0.90\text{ m/s}) &= (0.010\text{ kg})(-0.30\text{ m/s}) + (0.015\text{ kg})\vec{v}'_2\\ 0.0090\text{ kg•m/s} &= -0.0030\text{ kg•m/s} + (0.015\text{ kg})\vec{v}'_2\\ 0.0120\text{ kg•m/s} &= (0.015\text{ kg})\vec{v}'_2\\ (0.015\text{ kg})\vec{v}'_2 &= 0.0120\text{ kg•m/s}\\ \vec{v}'_2 &= \frac{0.0120\text{ kg•m/s}}{0.015\text{ kg}}\\ &= +0.80\text{ m/s}\end{aligned}$$

The second marble has a velocity of 0.80 m/s[E].

b. **Before Collision**

$$\begin{aligned}\vec{p}_1 &= m_1\vec{v}_1\\ &= (0.010\text{ kg})(+0.90\text{ m/s})\\ &= +0.0090\text{ kg•m/s}\end{aligned}$$

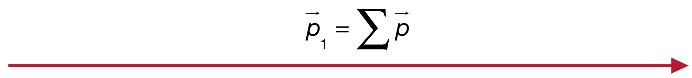
After Collision

$$\begin{aligned}\vec{p}'_1 &= m_1\vec{v}'_1\\ &= (0.010\text{ kg})(-0.30\text{ m/s})\\ &= -0.0030\text{ kg•m/s}\end{aligned}$$

$$\begin{aligned}\vec{p}'_2 &= m_2\vec{v}'_2\\ &= (0.015\text{ kg})(+0.80\text{ m/s})\\ &= +0.012\text{ kg•m/s}\end{aligned}$$

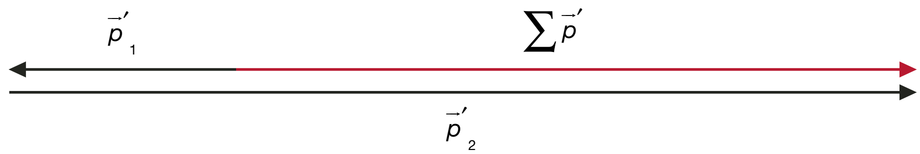
c. scale: 1 cm = 0.001 kg•m/s

Before Collision



The sum of the momentum before the collision is +0.0090 kg•m/s.

After Collision



The sum of the momentum after the collision is +0.0090 kg•m/s.

18. Let north be the positive direction.

$m_1 = 0.010\text{ kg}$ $\qquad \vec{v}_1 = 0.90\text{ m/s}[\text{N}]$ $\qquad \vec{v}_2 = 0$

$m_2 = 0.015\text{ kg}$ $\qquad \phantom{\vec{v}_1} = +0.90\text{ m/s}$ $\qquad \vec{v}\,'_{1\text{ and }2} = ?$

$$\begin{aligned}
\sum \vec{p}_{\text{before}} &= \sum \vec{p}_{\text{after}} \\
\vec{p}_1 + \vec{p}_2 &= \vec{p}\,'_{1\text{ and }2} \\
m_1\vec{v}_1 + m_2\vec{v}_2 &= (m_1 + m_2)\vec{v}\,'_{1\text{ and }2} \\
m_1\vec{v}_1 &= (m_1 + m_2)\vec{v}\,'_{1\text{ and }2} \quad \leftarrow \vec{v}_2 = 0 \\
(0.010\text{ kg})(+0.90\text{ m/s}) &= (0.010\text{ kg} + 0.015\text{ kg})\vec{v}\,'_{1\text{ and }2} \\
+0.0090\text{ kg•m/s} &= (0.025\text{ kg})\vec{v}\,'_{1\text{ and }2} \\
(0.025\text{ kg})\vec{v}\,'_{1\text{ and }2} &= +0.0090\text{ kg•m/s} \\
\vec{v}\,'_{1\text{ and }2} &= \frac{+0.0090\text{ kg•m/s}}{0.025\text{ kg}} \\
&= +0.36\text{ m/s}
\end{aligned}$$

The combined velocity of the marble and the putty ball after the collision is 0.36 m/s [N].

19. Let north be the positive direction.

$m_{1 \text{ and } 2} = 0.0100 \text{ kg}$ $m_1 = 0.0090 \text{ kg}$ $\vec{v}_{1 \text{ and } 2} = 0$ $\vec{v}'_1 = 4.0 \text{ m/s}[\text{N}] = +4.0 \text{ m/s}$ $m_2 = 0.0010 \text{ kg}$ $\vec{v}'_2 = ?$

$$\sum \vec{p}_{\text{before}} = \sum \vec{p}_{\text{after}}$$
$$\vec{p}_1 = \vec{p}'_1 + \vec{p}'_2$$
$$m_{1 \text{ and } 2}\vec{v}_{1 \text{ and } 2} = m_1\vec{v}'_1 + m_2\vec{v}'_2$$
$$(0.0100 \text{ kg})(0) = (0.0090 \text{ kg})(+4.0 \text{ m/s}) + (0.0010 \text{ kg})\vec{v}'_2$$
$$0 = 0.036 \text{ kg}\bullet\text{m/s} + (0.0010 \text{ kg})\vec{v}'_2$$
$$-0.036 \text{ kg}\bullet\text{m/s} = (0.0010 \text{ kg})\vec{v}'_2$$
$$(0.0010 \text{ kg})\vec{v}'_2 = -0.036 \text{ kg}\bullet\text{m/s}$$
$$\vec{v}'_2 = \frac{-0.036 \text{ kg}\bullet\text{m/s}}{0.0010 \text{ kg}}$$
$$= -36 \text{ m/s}$$

The 0.0010-kg piece of balloon has a velocity of 36 m/s [S].

Practice, page 271

20. **a.** This is a hit-and-stick collision.

b. Let east be the positive direction. Also, let the car be object 1 and the truck object 2.

$m_1 = 1500 \text{ kg}$ $\vec{v}'_{1 \text{ and } 2} = 1.0 \text{ m/s}[\text{E}] = +1.0 \text{ m/s}$ $\vec{v}_2 = 0$

$m_2 = 15\ 000 \text{ kg}$ $\vec{v}_1 = ?$

$$\sum \vec{p}_{\text{before}} = \sum \vec{p}_{\text{after}}$$
$$\vec{p}_1 + \vec{p}_2 = \vec{p}'_{1 \text{ and } 2}$$
$$m_1\vec{v}_1 + m_2\vec{v}_2 = (m_1 + m_2)\vec{v}'_{1 \text{ and } 2}$$
$$m_1\vec{v}_1 = (m_1 + m_2)\vec{v}'_{1 \text{ and } 2} \quad \leftarrow \vec{v}_2 = 0$$
$$(1500 \text{ kg})\vec{v}_1 = (1500 \text{ kg} + 15\ 000 \text{ kg})(+1.0 \text{ m/s})$$
$$(1500 \text{ kg})\vec{v}_1 = +16\ 500 \text{ kg}\bullet\text{m/s}$$
$$\vec{v}_1 = \frac{16\ 500 \text{ kg}\bullet\text{m/s}}{1500 \text{ kg}}$$
$$= +11 \text{ m/s}$$

The car's velocity before the collision was 11 m/s [E].

c. $$\vec{v}_1 = +11\frac{\text{m}}{\text{s}} \times \frac{1\ \text{km}}{1000\ \text{m}} \times \frac{3600\ \text{s}}{1\ \text{h}}$$
$$= +40\ \text{km/h}$$

The car's velocity was 40 km/h [E].

d. Yes, the car was exceeding the posted speed limit of 25 km/h.

2.5 Questions, page 271

Knowledge

1. A one-dimensional collision is a collision that occurs along a straight line.

2. The three types of collisions are hit and stick, hit and rebound, and explosion.

3. The sum of all the momentums before an interaction are equal to the sum of all the momentums immediately after the interaction.

$$\sum \vec{p}_{\text{before}} = \sum \vec{p}_{\text{after}}$$

Applying Concepts

4. Let east be the positive direction.

$m_1 = 3500$ kg $\vec{v}_1 = 20.0$ m/s [E] $= +20.0$ m/s $m_2 = 2000$ kg $\vec{v}_2 = 0$ $\vec{v}'_2 = 14.0$ m/s [E] $= +14.0$ m/s $\vec{v}'_1 = ?$

$$\sum \vec{p}_{\text{before}} = \sum \vec{p}_{\text{after}}$$
$$\vec{p}_1 + \vec{p}_2 = \vec{p}'_1 + \vec{p}'_2$$
$$m_1\vec{v}_1 + m_2\vec{v}_2 = m_1\vec{v}'_1 + m_2\vec{v}'_2$$
$$m_1\vec{v}_1 = m_1\vec{v}'_1 + m_2\vec{v}'_2 \quad \leftarrow \vec{v}_2 = 0$$
$$(3500\ \text{kg})(+20.0\ \text{m/s}) = (3500\ \text{kg})\vec{v}'_1 + (2000\ \text{kg})(+14.0\ \text{m/s})$$
$$+70\ 000\ \text{kg•m/s} = (3500\ \text{kg})\vec{v}'_1 + (+28\ 000\ \text{kg•m/s})$$
$$(3500\ \text{kg})\vec{v}'_1 = (+70\ 000\ \text{kg•m/s}) - (+28\ 000\ \text{kg•m/s})$$
$$\vec{v}'_1 = \frac{(+70\ 000\ \text{kg•m/s}) - (+28\ 000\ \text{kg•m/s})}{3500\ \text{kg}}$$
$$= +12.0\ \text{m/s}$$

The final velocity of the truck is 12.0 m/s [E].

5. Let east be the positive direction.

$m_1 = 3500 \text{ kg}$ $\quad \vec{v}_1 = 20.0 \text{ m/s}[\text{E}] = +20.0 \text{ m/s}$ $\quad m_2 = 2000 \text{ kg}$ $\quad \vec{v}_2 = 0$ $\quad \vec{v}'_{1 \text{ and } 2} = ?$

$$\sum \vec{p}_{\text{before}} = \sum \vec{p}_{\text{after}}$$
$$\vec{p}_1 + \vec{p}_2 = \vec{p}'_1 + \vec{p}'_2$$
$$m_1\vec{v}_1 + m_2\vec{v}_2 = (m_1 + m_2)\vec{v}'_{1 \text{ and } 2}$$
$$m_1\vec{v}_1 = (m_1 + m_2)\vec{v}'_{1 \text{ and } 2} \quad \leftarrow \vec{v}_2 = 0$$
$$(3500 \text{ kg})(+20.0 \text{ m/s}) = (3500 \text{ kg} + 2000 \text{ kg})\vec{v}'_{1 \text{ and } 2}$$
$$+70\ 000 \text{ kg•m/s} = (5500 \text{ kg})\vec{v}'_{1 \text{ and } 2}$$
$$(5500 \text{ kg})\vec{v}'_{1 \text{ and } 2} = +70\ 000 \text{ kg•m/s}$$
$$\vec{v}'_{1 \text{ and } 2} = \frac{+70\ 000 \text{ kg•m/s}}{5500 \text{ kg}}$$
$$= +12.7 \text{ m/s}$$

The velocity of the two vehicles after the collision is 12.7 m/s [E].

6. Let east be the positive direction. Also, since all of the velocities are in kilometres per hour and the final answer is to be in kilometres per hour, there is no need to convert the velocities into metres per second.

$m_1 = 2500 \text{ kg}$ $\quad \vec{v}_1 = 80.0 \text{ km/h}[\text{E}] = +80.0 \text{ km/h}$ $\quad m_2 = 1500 \text{ kg}$ $\quad \vec{v}_2 = 0$ $\quad \vec{v}'_2 = 60.0 \text{ km/h}[\text{E}] = +60.0 \text{ km/h}$ $\quad \vec{v}'_1 = ?$

$$\sum \vec{p}_{\text{before}} = \sum \vec{p}_{\text{after}}$$
$$\vec{p}_1 + \vec{p}_2 = \vec{p}'_1 + \vec{p}'_2$$
$$m_1\vec{v}_1 + m_2\vec{v}_2 = m_1\vec{v}'_1 + m_2\vec{v}'_2$$
$$m_1\vec{v}_1 = m_1\vec{v}'_1 + m_2\vec{v}'_2 \quad \leftarrow \vec{v}_2 = 0$$
$$(2500 \text{ kg})(+80.0 \text{ km/h}) = (2500 \text{ kg})\vec{v}'_1 + (1500 \text{ kg})(+60.0 \text{ km/h})$$
$$+2.00 \times 10^5 \text{ kg•km/h} = (2500 \text{ kg})\vec{v}'_1 + (+9.00 \times 10^4 \text{ kg•km/h})$$
$$(2500 \text{ kg})\vec{v}'_1 = (+2.00 \times 10^5 \text{ kg•km/h}) - (+9.00 \times 10^4 \text{ kg•km/h})$$
$$\vec{v}'_1 = \frac{(+2.00 \times 10^5 \text{ kg•km/h}) - (+9.00 \times 10^4 \text{ kg•km/h})}{2500 \text{ kg}}$$
$$= +44.0 \text{ km/h}$$

The final velocity of the van is 44.0 km/h [E].

7. Let right be the positive direction. Also, since every mass is given in grams, there is no need to convert them into kilograms.

$m_{1\text{ and }2} = 20.0\text{ g}$ $\quad \vec{v}_{1\text{ and }2} = 0$ $\quad m_1 = 12.0\text{ g}$ $\quad \vec{v}'_1 = 3.00\text{ m/s[left]} = -3.00\text{ m/s}$ $\quad m_2 = 8.0\text{ g}$ $\quad \vec{v}'_2 = ?$

$$\begin{aligned}
\sum \vec{p}_{\text{before}} &= \sum \vec{p}_{\text{after}} \\
\vec{p}_{1\text{ and }2} &= \vec{p}'_1 + \vec{p}'_2 \\
m_{1\text{ and }2}\vec{v}_{1\text{ and }2} &= m_1\vec{v}'_1 + m_2\vec{v}'_2 \\
(20.0\text{ g})(0) &= (12.0\text{ g})(-3.00\text{ m/s}) + (8.0\text{ g})\vec{v}'_2 \\
0 &= -36.0\text{ g}\bullet\text{m/s} + (8.0\text{ g})\vec{v}'_2 \\
+36.0\text{ g}\bullet\text{m/s} &= (8.0\text{ g})\vec{v}'_2 \\
(8.0\text{ g})\vec{v}'_2 &= +36.0\text{ g}\bullet\text{m/s} \\
\vec{v}'_2 &= \frac{+36.0\text{ g}\bullet\text{m/s}}{8.0\text{ g}} \\
&= +4.5\text{ m/s}
\end{aligned}$$

The velocity of the 8.0-g piece is 4.5 m/s[E].

8. Let east be the positive direction.

$m_1 = 75.0\text{ kg}$ $\quad \vec{v}_1 = 1.50\text{ m/s[E]} = +1.50\text{ m/s}$ $\quad \vec{v}_2 = 0$ $\quad \vec{v}'_{1\text{ and }2} = 0.80\text{ m/s[E]} = +0.80\text{ m/s}$ $\quad m_2 = ?$

$$\begin{aligned}
\sum \vec{p}_{\text{before}} &= \sum \vec{p}_{\text{after}} \\
\vec{p}_1 + \vec{p}_2 &= \vec{p}'_1 + \vec{p}'_2 \\
m_1\vec{v}_1 + m_2\vec{v}_2 &= (m_1 + m_2)\vec{v}'_{1\text{ and }2} \\
m_1\vec{v}_1 &= (m_1 + m_2)\vec{v}'_{1\text{ and }2} \quad \leftarrow \vec{v}_2 = 0 \\
(75.0\text{ kg})(+1.50\text{ m/s}) &= (75.0\text{ kg} + m_2)(+0.80\text{ m/s}) \\
+112.5\text{ kg}\bullet\text{m/s} &= (+60\text{ kg}\bullet\text{m/s}) + m_2(+0.80\text{ m/s}) \\
m_2(+0.80\text{ m/s}) &= (+112.5\text{ kg}\bullet\text{m/s}) - (+60\text{ kg}\bullet\text{m/s}) \\
m_2 &= \frac{(+112.5\text{ kg}\bullet\text{m/s}) - (+60\text{ kg}\bullet\text{m/s})}{+0.80\text{ m/s}} \\
&= 66\text{ kg}
\end{aligned}$$

The other player is 66 kg.

Practice, page 273

21. The egg shell corresponds to the skull, and the yolk corresponds to the brain.

22. A bicycle helmet is primarily designed to protect the rider from a frontal collision with a rigid barrier. A bicycle helmet cannot impair the rider's vision or hearing. In these ways, the egg helmet is similar to a bike helmet. However, a bicycle helmet is designed to withstand only one significant impact. As soon as a bicycle helmet withstands one severe impact, it should be discarded.

Practice, page 277

23. **a.** $m = 0.092 \text{ kg}$

$h = 0.65 \text{ m}$

$g = 9.81 \text{ m/s}^2$

$E_{\text{p(grav)}} = ?$

$$\begin{aligned} E_{\text{p(grav)}} &= mgh \\ &= (0.092 \text{ kg})(9.81 \text{ m/s}^2)(0.65 \text{ m}) \\ &= 0.586\,638 \text{ J} \\ &= 0.59 \text{ J} \end{aligned}$$

The gravitational potential energy is 0.59 J.

b. $E_{\text{p(top)}} = 0.586\,638 \text{ J}$

$E_{\text{k(bottom)}} = ?$

By the law of conservation of energy:

$$\begin{aligned} E_{\text{k(bottom)}} &= E_{\text{p(top)}} \\ &= 0.586\,638 \text{ J} \\ &= 0.59 \text{ J} \end{aligned}$$

The kinetic energy is 0.59 J. During the collision, this energy is used to do work by changing the shape of the helmet and possibly the egg.

c. $E_{\text{k}} = 0.586\,638 \text{ J}$

$m = 0.092 \text{ kg}$

$v = ?$

$$\begin{aligned} E_{\text{k}} &= \frac{1}{2}mv^2 \\ v &= \sqrt{\frac{2E_k}{m}} \\ &= \sqrt{\frac{2(0.586\,638 \text{ J})}{0.092 \text{ kg}}} \\ &= \sqrt{12.83 \text{ m}^2/\text{s}^2} \\ &= 3.571\,134\,274 \text{ m/s} \\ &= 3.6 \text{ m/s} \end{aligned}$$

The speed just before impact is 3.6 m/s.

d. Let the direction of the bag and its contents (forward) prior to impact be considered the positive direction.

$m = 0.092 \text{ kg}$

$\vec{v} = 3.571\,134\,274 \text{ m/s[forward]}$

$\quad = +3.571\,134\,274 \text{ m/s}$

$\vec{p} = ?$

$$\begin{aligned} \vec{p} &= m\vec{v} \\ &= (0.092 \text{ kg})(+3.571\,134\,274 \text{ m/s}) \\ &= +0.328\,544\,353\,2 \text{ kg•m/s} \\ &= +0.33 \text{ kg•m/s} \end{aligned}$$

The momentum is 0.33 kg•m/s [forward].

e. $\vec{p}_f = 0 \leftarrow \vec{v}_f = 0$

$\vec{p}_i = +0.328\ 544\ 353\ 2\ \text{kg•m/s}$

$\Delta\vec{p} = ?$

$$\begin{aligned}\Delta\vec{p} &= \vec{p}_f - \vec{p}_i \\ &= -\vec{p}_i \\ &= -(+0.328\ 544\ 353\ 2\ \text{kg•m/s}) \\ &= -0.33\ \text{kg•m/s}\end{aligned}$$

The change in momentum is 0.33 kg•m/s [backward].

f. $\Delta\vec{p} = -0.328\ 544\ 353\ 2\ \text{kg•m/s}$

impulse = ?

$$\begin{aligned}\text{impulse} &= \vec{F}\Delta t \\ &= \Delta\vec{p} \\ &= -0.328\ 544\ 353\ 2\ \text{kg•m/s} \\ &= -0.33\ \text{kg•m/s}\end{aligned}$$

The impulse required to stop the bag and its contents is 0.33 kg•m/s [backward].

g. $\Delta\vec{p} = -0.328\ 544\ 353\ 2\ \text{kg•m/s}$

$\Delta t = 0.040\ \text{s}$

$\vec{F} = ?$

$$\begin{aligned}\vec{F}\Delta t &= \Delta\vec{p} \\ \vec{F} &= \frac{\Delta\vec{p}}{\Delta t} \\ &= \frac{-0.328\ 544\ 353\ 2\ \text{kg•m/s}}{(0.040\ \text{s})} \\ &= -8.2\ \text{N}\end{aligned}$$

The force acting on the bag during the collision is 8.2 N [backward].

h. $\vec{v}_i = +3.571\ 134\ 274\ \text{m/s}$

$\vec{v}_f = 0$

$\Delta t = 0.040\ \text{s}$

$\vec{a} = ?$

$$\begin{aligned}\vec{a} &= \frac{\vec{v}_f - \vec{v}_i}{\Delta t} \\ &= \frac{-\vec{v}_i}{\Delta t} \leftarrow \vec{v}_f = 0 \\ &= \frac{-(+3.571\ 134\ 274\ \text{m/s})}{(0.040\ \text{s})} \\ &= -89.278\ 356\ 84\ \text{m/s}^2 \\ &= -89\ \text{m/s}^2\end{aligned}$$

The acceleration is 89 m/s^2 [backward].

i. $m = 0.092\ \text{kg}$

$\vec{a} = -89.278\ 356\ 84\ \text{m/s}^2$

$\vec{F}_{net} = ?$

$$\begin{aligned}\vec{F}_{net} &= m\vec{a} \\ &= (0.092\ \text{kg})(-89.278\ 356\ 84\ \text{m/s}^2) \\ &= -8.2\ \text{N}\end{aligned}$$

The force acting on the bag during the collision is 8.2 N [backward].

24. a. $m = 0.088\ \text{kg}$

$h = 1.00\ \text{m}$

$g = 9.81\ \text{m/s}^2$

$E_{p(grav)} = ?$

$$\begin{aligned}E_{p(grav)} &= mgh \\ &= (0.088\ \text{kg})(9.81\ \text{m/s}^2)(1.00\ \text{m}) \\ &= 0.863\ 28\ \text{J} \\ &= 0.86\ \text{J}\end{aligned}$$

The gravitational potential energy is 0.86 J.

b. $E_{p(top)} = 0.863\ 28\ \text{J}$

$E_{k(bottom)} = ?$

$$\begin{aligned} E_{k(bottom)} &= E_{p(top)} \\ &= 0.863\ 28\ \text{J} \\ &= 0.86\ \text{J} \end{aligned}$$

The kinetic energy is 0.86 J.

c. $E_k = 0.863\ 28\ \text{J}$

$m = 0.088\ \text{kg}$

$v = ?$

$$\begin{aligned} E_k &= \frac{1}{2}mv^2 \\ v &= \sqrt{\frac{2E_k}{m}} \\ &= \sqrt{\frac{2(0.863\ 28\ \text{J})}{(0.088\ \text{kg})}} \\ &= 4.429\ 446\ 918\ \text{m/s} \\ &= 4.4\ \text{m/s} \end{aligned}$$

The speed before impact is 4.4 m/s.

d. Let the direction of the bag and its contents (forward) prior to impact be considered the positive direction.

$m = 0.088\ \text{kg}$

$\vec{v} = 4.429\ 446\ 918\ \text{m/s}[\text{forward}]$
$= +4.429\ 446\ 918\ \text{m/s}$

$\vec{p} = ?$

$$\begin{aligned} \vec{p} &= m\vec{v} \\ &= (0.088\ \text{kg})(+4.429\ 446\ 918\ \text{m/s}) \\ &= +0.389\ 791\ 328\ 8\ \text{kg•m/s} \\ &= +0.39\ \text{kg•m/s} \end{aligned}$$

The momentum is 0.39 kg•m/s [forward].

e. $\vec{p}_f = 0$ ← $\vec{v}_f = 0$

$\vec{p}_i = +0.389\ 791\ 328\ 8\ \text{kg•m/s}$

$\Delta\vec{p} = ?$

$$\begin{aligned} \Delta\vec{p} &= \vec{p}_f - \vec{p}_i \\ &= -\vec{p}_i \\ &= -(0.389\ 791\ 328\ 8\ \text{kg•m/s}) \\ &= -0.39\ \text{kg•m/s} \end{aligned}$$

The change in momentum is 0.39 kg•m/s [backward].

f. $\Delta\vec{p} = -0.389\ 791\ 328\ 8\ \text{kg•m/s}$

impulse = ?

$$\begin{aligned} \text{impulse} &= \vec{F}\Delta t \\ &= \Delta\vec{p} \\ &= -0.389\ 791\ 328\ 8\ \text{kg•m/s} \\ &= -0.39\ \text{kg•m/s} \end{aligned}$$

The impulse required to stop the bag is 0.39 kg•m/s [backward].

g. $\Delta\vec{p} = -0.389\ 791\ 328\ 8\ \text{kg•m/s}$

$\Delta t = 0.040\ \text{s}$

$\vec{F} = ?$

$$\begin{aligned} \vec{F}\Delta t &= \Delta\vec{p} \\ \vec{F} &= \frac{\Delta\vec{p}}{\Delta t} \\ &= \frac{-0.389\ 791\ 328\ 8\ \text{kg•m/s}}{0.040\ \text{s}} \\ &= -9.7\ \text{N} \end{aligned}$$

The force that acted on the bag is 9.7 N [backward].

h. $\vec{v}_f = 0$

$\vec{v}_i = +4.429\ 446\ 918$ m/s

$\Delta t = 0.040$ s

$\vec{a} = ?$

$$\begin{aligned}\vec{a} &= \frac{\vec{v}_f - \vec{v}_i}{\Delta t} \\ &= \frac{-\vec{v}_i}{\Delta t} \quad \leftarrow \vec{v}_f = 0 \\ &= \frac{-(4.429\ 446\ 918\ \text{m/s})}{(0.040\ \text{s})} \\ &= -110.736\ 173\ \text{m/s}^2 \\ &= -1.1 \times 10^2\ \text{m/s}^2\end{aligned}$$

The acceration is 1.1×10^2 m/s^2 [backward].

i. $m = 0.088$ kg

$\vec{a} = -110.736\ 173$ m/s^2

$\vec{F}_{net} = ?$

$$\begin{aligned}\vec{F}_{net} &= m\vec{a} \\ &= (0.088\ \text{kg})(-110.736\ 173\ \text{m/s}^2) \\ &= -9.7\ \text{N}\end{aligned}$$

The force that acted on the bag is 9.7 N [backward].

2.6 Questions, page 281

Knowledge

1. **a.** Work is the transfer of energy from one object to another when a force is applied over a distance.
   b. Kinetic energy is energy due to the motion of an object.
   c. Gravitational potential energy is energy due to the position of an object above Earth's surface.

Applying Concepts

2. $F = 9.0 \times 10^6$ N

$d = 0.080$ m

$W = ?$

$$\begin{aligned}W &= Fd \\ &= (9.0 \times 10^6\ \text{N})(0.080\ \text{m}) \\ &= 7.2 \times 10^5\ \text{J}\end{aligned}$$

The work done on the car bumper is 7.2×10^5 J.

3. $m = 3000$ kg

$v = 22$ m/s

$E_k = ?$

$$\begin{aligned}E_k &= \frac{1}{2}mv^2 \\ &= \frac{1}{2}(3000\ \text{kg})(22\ \text{m/s})^2 \\ &= 7.3 \times 10^5\ \text{J}\end{aligned}$$

The kinetic energy of the truck is 7.3×10^5 J.

4. $m = 2500$ kg

$h = 1.80$ m

$g = 9.81$ m/s^2

$E_{p(grav)} = ?$

$$\begin{aligned}E_{p(grav)} &= mgh \\ &= (2500\ \text{kg})(9.81\ \text{m/s}^2)(1.80\ \text{m}) \\ &= 4.41 \times 10^4\ \text{J}\end{aligned}$$

The gravitational potential energy is 4.41×10^4 J.

5. $\Delta E = W$

$= 40.0\ \text{J}$

The object will gain 40.0 J of gravitational potential energy.

6. A bicycle helmet works by increasing the time interval for the impulse that will cause you to stop should your head strike another object in a collision. It is always preferable to have the impulse that stops you in a collision be delivered by a smaller force acting over a longer time interval.

The part of the helmet responsible for increasing the time interval is the compressible foam liner. The extra time taken to compress this liner in a collision correspondingly decreases the force exerted on your head in the collision.

A helmet also has a hard plastic outer shell that acts to spread the impact of the force over a larger surface area. At the point of impact on the helmet, the shell starts to bend and compress the foam underneath a large section. This has the effect of reducing the severity of the impact at the point of first contact.