# KEY TERMS

**angular momentum** the product of the moment of inertia and angular velocity

**change in momentum** the difference between the final and initial values of momentum; the mass times the change in velocity

**elastic collision** collision in which objects separate after impact and kinetic energy is conserved

**impulse** average net external force multiplied by the time the force acts; equal to the change in momentum

**impulse–momentum theorem** the impulse, or change in momentum, is the product of the net external force and the time over which the force acts

**inelastic collision** collision in which objects stick together after impact and kinetic energy is not conserved

**isolated system** system in which the net external force is zero

**law of conservation of momentum** when the net external force is zero, the total momentum of the system is conserved or constant

**linear momentum** the product of a system's mass and velocity

**point masses** structureless particles that cannot rotate or spin

**recoil** backward movement of an object caused by the transfer of momentum from another object in a collision

# SECTION SUMMARY

## 8.1 Linear Momentum, Force, and Impulse

- Linear momentum, often referenced as *momentum* for short, is defined as the product of a system's mass multiplied by its velocity,
  $\mathbf{p} = m\mathbf{v}$.
- The SI unit for momentum is kg m/s.
- Newton's second law of motion in terms of momentum states that the net external force equals the change in momentum of a system divided by the time over which it changes, $\mathbf{F}_{\text{net}} = \frac{\Delta \mathbf{p}}{\Delta t}$.
- Impulse is the average net external force multiplied by the time this force acts, and impulse equals the change in momentum, $\Delta \mathbf{p} = \mathbf{F}_{\text{net}} \Delta t$.
- Forces are usually not constant over a period of time, so we use the average of the force over the time it acts.

## 8.2 Conservation of Momentum

- The law of conservation of momentum is written $\mathbf{p}_{\text{tot}}$ = constant or $\mathbf{p}_{\text{tot}} = \mathbf{p}'_{\text{tot}}$ (isolated system), where $\mathbf{p}_{\text{tot}}$ is the initial total momentum and $\mathbf{p}'_{\text{tot}}$ is the total momentum some time later.
- In an isolated system, the net external force is zero.
- Conservation of momentum applies only when the net external force is zero, within the defined system.

## 8.3 Elastic and Inelastic Collisions

- If objects separate after impact, the collision is elastic; If they stick together, the collision is inelastic.
- Kinetic energy is conserved in an elastic collision, but not in an inelastic collision.
- The approach to two-dimensional collisions is to choose a convenient coordinate system and break the motion into components along perpendicular axes. Choose a coordinate system with the $x$-axis parallel to the velocity of the incoming particle.
- Two-dimensional collisions of point masses, where mass 2 is initially at rest, conserve momentum along the initial direction of mass 1, or the $x$-axis, and along the direction perpendicular to the initial direction, or the $y$-axis.
- Point masses are structureless particles that cannot spin.

# KEY EQUATIONS

## 8.1 Linear Momentum, Force, and Impulse

| | |
|---|---|
| impulse | $\mathbf{F}_{\text{net}} \Delta t$ |
| impulse–momentum theorem | $\Delta \mathbf{p} = \mathbf{F}_{\text{net}} \Delta t$ |
| linear momentum | $\mathbf{p} = m\mathbf{v}$ |
| Newton's second law in terms of momentum | $\mathbf{F}_{\text{net}} = \frac{\Delta \mathbf{p}}{\Delta t}$ |

## 8.2 Conservation of Momentum

| | |
|---|---|
| law of conservation of momentum | $\mathbf{p}_{\text{tot}}$ = constant, or $\mathbf{p}_{\text{tot}} = \mathbf{p}'_{\text{tot}}$ |

| | |
|---|---|
| conservation of momentum for two objects | $\mathbf{p}_1 + \mathbf{p}_2 = \text{constant}$, or $\mathbf{p}_1 + \mathbf{p}_2 = \mathbf{p}'_1 + \mathbf{p}'_2$ |
| angular momentum | $\mathbf{L} = I\boldsymbol{\omega}$ |

## 8.3 Elastic and Inelastic Collisions

| | |
|---|---|
| conservation of momentum in an elastic collision | $m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = m_1\mathbf{v}'_1 + m_2\mathbf{v}'_2,$ |
| conservation of momentum in an inelastic collision | $m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = (m_1 + m_2)\mathbf{v}'$ |
| conservation of momentum along *x*-axis for 2D collisions | $m_1\mathbf{v}_1 = m_1\mathbf{v}'_1\cos\theta_1 + m_2\mathbf{v}'_2\cos\theta_2$ |
| conservation of momentum along *y*-axis for 2D collisions | $0 = m_1\mathbf{v}'_1\sin\theta_1 + m_2\mathbf{v}'_2\sin\theta_2$ |

# CHAPTER REVIEW

## Concept Items

### 8.1 Linear Momentum, Force, and Impulse

1. What is impulse?
   a. Change in velocity
   b. Change in momentum
   c. Rate of change of velocity
   d. Rate of change of momentum

2. In which equation of Newton's second law is mass assumed to be constant?
   a. $\mathbf{F} = ma$
   b. $\mathbf{F} = \frac{\Delta\mathbf{p}}{\Delta t}$
   c. $\mathbf{F} = \Delta\mathbf{p}\Delta t$
   d. $\mathbf{F} = \frac{\Delta m}{\Delta a}$

3. What is the SI unit of momentum?
   a. N
   b. $\text{kg}\cdot\text{m}$
   c. $\text{kg}\cdot\text{m/s}$
   d. $\text{kg}\cdot\text{m/s}^2$

4. What is the equation for linear momentum?
   a. $\mathbf{p} = m\mathbf{v}$
   b. $\mathbf{p} = m/\mathbf{v}$
   c. $\mathbf{p} = \text{m}\mathbf{v}^2$
   d. $\mathbf{p} = \frac{1}{2}\text{m}\mathbf{v}^2$

### 8.2 Conservation of Momentum

5. What is angular momentum?
   a. The sum of moment of inertia and angular velocity
   b. The ratio of moment of inertia to angular velocity
   c. The product of moment of inertia and angular velocity
   d. Half the product of moment of inertia and square of angular velocity

6. What is an isolated system?
   a. A system in which the net internal force is zero
   b. A system in which the net external force is zero
   c. A system in which the net internal force is a nonzero constant
   d. A system in which the net external force is a nonzero constant

### 8.3 Elastic and Inelastic Collisions

7. In the equation $\mathbf{p}_1 + \mathbf{p}_2 = \mathbf{p}'_1 + \mathbf{p}'_2$ for the collision of two objects, what is the assumption made regarding the friction acting on the objects?
   a. Friction is zero.
   b. Friction is nearly zero.
   c. Friction acts constantly.
   d. Friction before and after the impact remains the same.

8. What is an inelastic collision?

a. when objects stick together after impact, and their internal energy is not conserved
b. when objects stick together after impact, and their internal energy is conserved
c. when objects stick together after impact, and always come to rest instantaneously after collision
d. when objects stick together after impact, and their internal energy increases

## Critical Thinking Items

### 8.1 Linear Momentum, Force, and Impulse

**9.** Consider two objects of the same mass. If a force of $100\ \text{N}$ acts on the first for a duration of $1\ \text{s}$ and on the other for a duration of $2\ \text{s}$, which of the following statements is true?
a. The first object will acquire more momentum.
b. The second object will acquire more momentum.
c. Both objects will acquire the same momentum.
d. Neither object will experience a change in momentum.

**10.** Cars these days have parts that can crumple or collapse in the event of an accident. How does this help protect the passengers?
a. It reduces injury to the passengers by increasing the time of impact.
b. It reduces injury to the passengers by decreasing the time of impact.
c. It reduces injury to the passengers by increasing the change in momentum.
d. It reduces injury to the passengers by decreasing the change in momentum.

**11.** How much force would be needed to cause a 17 kg · m/s change in the momentum of an object, if the force acted for 5 seconds?
a. 3.4 N
b. 12 N
c. 22 N
d. 85 N

### 8.2 Conservation of Momentum

**12.** A billiards ball rolling on the table has momentum $\mathbf{p}_1$. It hits another stationary ball, which then starts rolling. Considering friction to be negligible, what will happen to the momentum of the first ball?
a. It will decrease.
b. It will increase.
c. It will become zero.
d. It will remain the same.

**13.** A ball rolling on the floor with momentum $\mathbf{p}_1$ collides with a stationary ball and sets it in motion. The momentum of the first ball becomes $\mathbf{p'}_1$, and that of the second becomes $\mathbf{p'}_2$. Compare the magnitudes of $\mathbf{p}_1$ and $\mathbf{p'}_2$.
a. Momenta $\mathbf{p}_1$ and $\mathbf{p'}_2$ are the same in magnitude.
b. The sum of the magnitudes of $\mathbf{p}_1$ and $\mathbf{p'}_2$ is zero.
c. The magnitude of $\mathbf{p}_1$ is greater than that of $\mathbf{p'}_2$.
d. The magnitude of $\mathbf{p'}_2$ is greater than that of $\mathbf{p}_1$.

**14.** Two cars are moving in the same direction. One car with momentum $\mathbf{p}_1$ collides with another, which has momentum $\mathbf{p}_2$. Their momenta become $\mathbf{p'}_1$ and $\mathbf{p'}_2$ respectively. Considering frictional losses, compare $(\mathbf{p'}_1 + \mathbf{p'}_2)$ with $(\mathbf{p}_1 + \mathbf{p}_2)$.
a. The value of $(\mathbf{p'}_1 + \mathbf{p'}_2)$ is zero.
b. The values of $(\mathbf{p}_1 + \mathbf{p}_2)$ and $(\mathbf{p'}_1 + \mathbf{p'}_2)$ are equal.
c. The value of $(\mathbf{p}_1 + \mathbf{p}_2)$ will be greater than $(\mathbf{p'}_1 + \mathbf{p'}_2)$.
d. The value of $(\mathbf{p'}_1 + \mathbf{p'}_2)$ will be greater than $(\mathbf{p}_1 + \mathbf{p}_2)$.

### 8.3 Elastic and Inelastic Collisions

**15.** Two people, who have the same mass, throw two different objects at the same velocity. If the first object is heavier than the second, compare the velocities gained by the two people as a result of recoil.
a. The first person will gain more velocity as a result of recoil.
b. The second person will gain more velocity as a result of recoil.
c. Both people will gain the same velocity as a result of recoil.
d. The velocity of both people will be zero as a result of recoil.

## Problems

### 8.1 Linear Momentum, Force, and Impulse

**16.** If a force of $50\ \text{N}$ is applied to an object for $0.2\ \text{s}$, and it changes its velocity by $10\ \text{m/s}$, what could be the mass of the object?
a. $1\ \text{kg}$
b. $2\ \text{kg}$
c. $5\ \text{kg}$
d. $250\ \text{kg}$

**17.** For how long should a force of 130 N be applied to an object of mass 50 kg to change its speed from 20 m/s to 60 m/s?
a. 0.031 s
b. 0.065 s
c. 15.4 s

d. 40 s

## 8.3 Elastic and Inelastic Collisions

**18.** If a man with mass 70 kg, standing still, throws an object with mass 5 kg at 50 m/s, what will be the recoil velocity of the man, assuming he is standing on a frictionless surface?

a. –3.6 m/s
b. 0 m/s
c. 3.6 m/s
d. 50.0 m/s

**19.** Find the recoil velocity of a $65 \text{ kg}$ ice hockey goalie who catches a $0.15 \text{ kg}$ hockey puck slapped at him at a velocity of $50 \text{ m/s}$. Assume that the goalie is at rest before catching the puck, and friction between the ice and the puck-goalie system is negligible.

a. $-0.12 \text{ m/s}$
b. $0 \text{ m/s}$
c. $0.12 \text{ m/s}$
d. $7.5 \text{ m/s}$

# Performance Task

## 8.3 Elastic and Inelastic Collisions

**20.** You will need the following:

- balls of different weights
- a ruler or wooden strip
- some books
- a paper cup

Make an inclined plane by resting one end of a ruler on a stack of books. Place a paper cup on the other end. Roll a ball from the top of the ruler so that it hits the paper cup. Measure the displacement of the paper cup due to the collision. Now use increasingly heavier balls for this activity and see how that affects the displacement of the cup. Plot a graph of mass vs. displacement. Now repeat the same activity, but this time, instead of using different balls, change the incline of the ruler by varying the height of the stack of books. This will give you different velocities of the ball. See how this affects the displacement of the paper cup.

# TEST PREP

# Multiple Choice

## 8.1 Linear Momentum, Force, and Impulse

**21.** What kind of quantity is momentum?

a. Scalar
b. Vector

**22.** When does the net force on an object increase?

a. When $\Delta \mathbf{p}$ decreases
b. When $\Delta t$ increases
c. When $\Delta t$ decreases

**23.** In the equation $\Delta \mathbf{p} = m(\mathbf{v}_f - \mathbf{v}_i)$, which quantity is considered to be constant?

a. Initial velocity
b. Final velocity
c. Mass
d. Momentum

**24.** For how long should a force of $50 \text{ N}$ be applied to change the momentum of an object by $12 \text{ kg} \cdot \text{m/s}$?

a. $0.24 \text{ s}$
b. $4.15 \text{ s}$
c. $62 \text{ s}$
d. $600 \text{ s}$

## 8.2 Conservation of Momentum

**25.** In the equation $\mathbf{L} = I\boldsymbol{\omega}$, what is $I$?

a. Linear momentum
b. Angular momentum
c. Torque
d. Moment of inertia

**26.** Give an example of an isolated system.

a. A cyclist moving along a rough road
b. A figure skater gliding in a straight line on an ice rink
c. A baseball player hitting a home run
d. A man drawing water from a well

## 8.3 Elastic and Inelastic Collisions

**27.** In which type of collision is kinetic energy conserved?

a. Elastic
b. Inelastic

**28.** In physics, what are structureless particles that cannot rotate or spin called?

a. Elastic particles
b. Point masses
c. Rigid masses

**29.** Two objects having equal masses and velocities collide with each other and come to a rest. What type of a collision is this and why?

a. Elastic collision, because internal kinetic energy is conserved

b. Inelastic collision, because internal kinetic energy is not conserved
c. Elastic collision, because internal kinetic energy is not conserved
d. Inelastic collision, because internal kinetic energy is conserved

**30.** Two objects having equal masses and velocities collide with each other and come to a rest. Is momentum conserved in this case?
a. Yes
b. No

## Short Answer

### 8.1 Linear Momentum, Force, and Impulse

**31.** If an object's velocity is constant, what is its momentum proportional to?
a. Its shape
b. Its mass
c. Its length
d. Its breadth

**32.** If both mass and velocity of an object are constant, what can you tell about its impulse?
a. Its impulse would be constant.
b. Its impulse would be zero.
c. Its impulse would be increasing.
d. Its impulse would be decreasing.

**33.** When the momentum of an object increases with respect to time, what is true of the net force acting on it?
a. It is zero, because the net force is equal to the rate of change of the momentum.
b. It is zero, because the net force is equal to the product of the momentum and the time interval.
c. It is nonzero, because the net force is equal to the rate of change of the momentum.
d. It is nonzero, because the net force is equal to the product of the momentum and the time interval.

**34.** How can you express impulse in terms of mass and velocity when neither of those are constant?
a. $\Delta\mathbf{p} = \Delta(m\mathbf{v})$
b. $\frac{\Delta\mathbf{p}}{\Delta t} = \frac{\Delta(m\mathbf{v})}{\Delta t}$
c. $\Delta\mathbf{p} = \Delta(\frac{m}{\mathbf{v}})$
d. $\frac{\Delta\mathbf{p}}{\Delta t} = \frac{1}{\Delta t}\cdot\Delta(m\mathbf{v})$

**35.** How can you express impulse in terms of mass and initial and final velocities?
a. $\Delta\mathbf{p} = m(\mathbf{v}_\mathrm{f} - \mathbf{v}_\mathrm{i})$
b. $\frac{\Delta\mathbf{p}}{\Delta t} = \frac{m(\mathbf{v}_\mathrm{f} - \mathbf{v}_\mathrm{i})}{\Delta t}$
c. $\Delta\mathbf{p} = \frac{(\mathbf{v}_\mathrm{f} - \mathbf{v}_\mathrm{i})}{m}$
d. $\frac{\Delta\mathbf{p}}{\Delta t} = \frac{1}{m}\frac{(\mathbf{v}_\mathrm{f} - \mathbf{v}_\mathrm{i})}{\Delta t}$

**36.** Why do we use average force while solving momentum problems? How is net force related to the momentum of the object?
a. Forces are usually constant over a period of time, and net force acting on the object is equal to the rate of change of the momentum.
b. Forces are usually not constant over a period of time, and net force acting on the object is equal to the product of the momentum and the time interval.
c. Forces are usually constant over a period of time, and net force acting on the object is equal to the product of the momentum and the time interval.
d. Forces are usually not constant over a period of time, and net force acting on the object is equal to the rate of change of the momentum.

### 8.2 Conservation of Momentum

**37.** Under what condition(s) is the angular momentum of a system conserved?
a. When net torque is zero
b. When net torque is not zero
c. When moment of inertia is constant
d. When both moment of inertia and angular momentum are constant

**38.** If the moment of inertia of an isolated system increases, what happens to its angular velocity?
a. It increases.
b. It decreases.
c. It stays constant.
d. It becomes zero.

**39.** If both the moment of inertia and the angular velocity of a system increase, what must be true of the force acting on the system?
a. Force is zero.
b. Force is not zero.
c. Force is constant.
d. Force is decreasing.

### 8.3 Elastic and Inelastic Collisions

**40.** Two objects collide with each other and come to a rest. How can you use the equation of conservation of momentum to describe this situation?
a. $m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = 0$
b. $m_1\mathbf{v}_1 - m_2\mathbf{v}_2 = 0$
c. $m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = m_1\mathbf{v}_1'$
d. $m_1\mathbf{v}_1 + m_2\mathbf{v}_2 = m_1\mathbf{v}_2$

**41.** What is the difference between momentum and impulse?
   a. Momentum is the sum of mass and velocity. Impulse is the change in momentum.
   b. Momentum is the sum of mass and velocity. Impulse is the rate of change in momentum.
   c. Momentum is the product of mass and velocity. Impulse is the change in momentum.
   d. Momentum is the product of mass and velocity. Impulse is the rate of change in momentum.

**42.** What is the equation for conservation of momentum along the *x*-axis for 2D collisions in terms of mass and velocity, where one of the particles is initially at rest?
   a. $m_1\mathbf{v}_1 = m_1\mathbf{v}_1'\cos\theta_1$
   b. $m_1\mathbf{v}_1 = m_1\mathbf{v}_1'\cos\theta_1 + m_2\mathbf{v}_2'\cos\theta_2$
   c. $m_1\mathbf{v}_1 = m_1\mathbf{v}_1'\cos\theta_1 - m_2\mathbf{v}_2'\cos\theta_2$
   d. $m_1\mathbf{v}_1 = m_1\mathbf{v}_1'\sin\theta_1 + m_2\mathbf{v}_2'\sin\theta_2$

**43.** What is the equation for conservation of momentum along the *y*-axis for 2D collisions in terms of mass and velocity, where one of the particles is initially at rest?
   a. $0 = m_1\mathbf{v}_1'\sin\theta_1$
   b. $0 = m_1\mathbf{v}_1'\sin\theta_1 + m_2\mathbf{v}_2'\sin\theta_2$
   c. $0 = m_1\mathbf{v}_1'\sin\theta_1 - m_2\mathbf{v}_2'\sin\theta_2$
   d. $0 = m_1\mathbf{v}_1'\cos\theta_1 + m_2\mathbf{v}_2'\cos\theta_2$

## Extended Response

### 8.1 Linear Momentum, Force, and Impulse

**44.** Can a lighter object have more momentum than a heavier one? How?
   a. No, because momentum is independent of the velocity of the object.
   b. No, because momentum is independent of the mass of the object.
   c. Yes, if the lighter object's velocity is considerably high.
   d. Yes, if the lighter object's velocity is considerably low.

**45.** Why does it hurt less when you fall on a softer surface?
   a. The softer surface increases the duration of the impact, thereby reducing the effect of the force.
   b. The softer surface decreases the duration of the impact, thereby reducing the effect of the force.
   c. The softer surface increases the duration of the impact, thereby increasing the effect of the force.
   d. The softer surface decreases the duration of the impact, thereby increasing the effect of the force.

**46.** Can we use the equation $\mathrm{F}_{\mathrm{net}} = \frac{\Delta p}{\Delta t}$ when the mass is constant?
   a. No, because the given equation is applicable for the variable mass only.
   b. No, because the given equation is not applicable for the constant mass.
   c. Yes, and the resultant equation is $F = m\mathbf{v}$
   d. Yes, and the resultant equation is $F = ma$

### 8.2 Conservation of Momentum

**47.** Why does a figure skater spin faster if he pulls his arms and legs in?
   a. Due to an increase in moment of inertia
   b. Due to an increase in angular momentum
   c. Due to conservation of linear momentum
   d. Due to conservation of angular momentum

### 8.3 Elastic and Inelastic Collisions

**48.** A driver sees another car approaching him from behind. He fears it is going to collide with his car. Should he speed up or slow down in order to reduce damage?
   a. He should speed up.
   b. He should slow down.
   c. He should speed up and then slow down just before the collision.
   d. He should slow down and then speed up just before the collision.

**49.** What approach would you use to solve problems involving 2D collisions?
   a. Break the momenta into components and then choose a coordinate system.
   b. Choose a coordinate system and then break the momenta into components.
   c. Find the total momenta in the x and y directions, and then equate them to solve for the unknown.
   d. Find the sum of the momenta in the x and y directions, and then equate it to zero to solve for the unknown.