Chapter 9 – Momentum and its Conservation

301. I can identify momentum as the product of mass and velocity.

1. Momentum of an object is due to only the velocity of the object. T or F?

   False. It also includes mass.

2. A small person could possibly have more momentum than a large person. T or F?

   False. The smaller person could have more mass and/or more velocity that totals more momentum.

3. Linear momentum is the
   a. product of the mass and velocity of a moving object
   b. quantity of motion used with objects rotating about a fixed axis
   c. average force and the time interval over which it acts
   d. angular momentum and torque

   B

303. I can analyze the momentum of a system of objects in one dimension.

4. You are gliding on ice skates and you throw a heavy ball forward. Like we have been practicing this chapter, the system is:
   a) You
   b) The Ball
   c) You and the Ball

   C

5. A 65-kg teacher rides their 8-kg bike during a triathlon. The teacher maintains an average biking velocity of 8.33 m/s for 6.5 hours. Find the teacher’s momentum during the bike portion of the race.

   a. 475 kg•m/s
   b. 541 kg•m/s
   c. 608 kg•m/s
   d. 2,190 kg•m/s

   B

304. I can distinguish between elastic and inelastic collisions

6. What is the difference between an elastic collision and an inelastic collision? (Note: technically, we are talking about a completely inelastic collision. Up to now we’ve been calling it just an “inelastic collision”, which is not the proper name for it.)

   a) A completely inelastic collision is where the objects stick together; an elastic collision is where they bounce off without losing any kinetic energy
   b) Momentum is not conserved for completely inelastic collisions, but it is conserved for elastic
   c) Momentum is not conserved for either type of collision

   A
9.1. Calculate momentum of individual objects as well as of a system of objects.

7. The standard unit for momentum is the kg*m/sec. T or F?
   True.

8. Which has more momentum: a bullet (m=0.1 kg) travelling 1,000 m/s or a motorcycle (m=100 kg) travelling at 0.5 m/s?
   a) Bullet
   b) Motorcycle
   c) Equal momentum
   d) Can't tell from the information

   A. (100 kg m/s for bullet vs. 50 kg m/s for motorcycle)

9.2. Explain connection between Newton's 3rd law and conservation of momentum (perhaps making rigorous using impulse-momentum theorem).

9.3. Use conservation of momentum to solve various problems.

9. A young man is moving forward on roller-skates with a momentum of 600 kg-m/s when someone throws a cannonball from in front of him. He catches the cannonball, which initially had a momentum of -300 kg-m/s. What will happen? (Think about whether he has positive or negative momentum after the collision)
   a. He will be moving forward.
   b. He will stop.
   c. He will be moving backward.

   A. He will be moving slower, but he will still be moving forward with a momentum of 300 kg m/s.

"Cart Explosion"

10. Gaston and Belle are standing together on an ice rink (at rest). Gaston proposes to Belle, and she refuses. Suddenly, he pushes her away, and they both begin moving in opposite directions. Belle is gliding away with a velocity of +3 m/s (to the right). Gaston's mass is 140 kg and Belle's mass is 60 kg. What is Gaston's momentum after the explosion? (Hint: this problem is not extremely complicated)
   a) -60 kg-m/s
   b) -180 kg-m/s
   c) -520 kg-m/s

   B. Must be the equal and opposite Belle's. The total momentum must be zero.

Sticking "inelastic"

11. A child throws a 0.50 kg piece of putty with a velocity of 6 m/s at a stationary 1.5 kg toy truck. The putty sticks to the truck. What is the final velocity of the putty/truck combo?
   a) 6 m/s
   b) 12 m/s
   c) 3 m/s
   d) 1.5 m/s

   D. Total momentum remains the same (3.0 kg m/s)
Bouncing "elastic"

12. A large (1.0kg) glider moving +3m/s slams into a small glider (0.25kg) going -4m/s in the opposite direction. The final velocity of the large glider is positive 1.5 m/s. What is the final velocity of the small glider?
   a) +2 m/s
   b) -2m/s
   c) 1.5 m/s
   d) 0.5 m/s
   e) 2.5 m/s

\[ \text{Initial momentum of large glider} = m_1 \cdot v_{1i} = 1 \cdot 3 = 3 \text{ kg\cdotm/s} \]
\[ \text{Initial momentum of small glider} = m_2 \cdot v_{2i} = 0.25 \cdot (-4) = -1 \text{ kg\cdotm/s} \]
\[ \text{Final momentum of large glider} = m_1 \cdot v_{1f} = 1 \cdot 1.5 = 1.5 \text{ kg\cdotm/s} \]
\[ \text{Final momentum of small glider} = m_2 \cdot v_{2f} = 0.25 \cdot v_{2f} \]
\[ \text{Conservation of momentum:} \]
\[ m_1 \cdot v_{1i} + m_2 \cdot v_{2i} = m_1 \cdot v_{1f} + m_2 \cdot v_{2f} \]
\[ 3 - 1 = 1.5 + 0.25 \cdot v_{2f} \]
\[ v_{2f} = \frac{1.5}{0.25} = 6 \text{ m/s} \]

9.4 Recognize conditions of validity for conservation of momentum (no external forces acting on the system)

13. The law of conservation of momentum states that a. momentum can be increased and decreased if it is not too great could be external forces
   b. the momentum of any closed system that doesn't lose or gain mass does not change closed + ISOLATED
   c. the momentum of any system does not change
   d. the momentum of any closed system with no net external force does not change

9.5 Calculate impulse

14. Before a collision, a 50.0-kg object is moving at +5.0 m/s. Find the impulse that acted on the object if, after the collision, it moves at +8.0 m/s.
   a. 4.5 kg\cdotm/s
   b. -4.5 kg\cdotm/s
   c. -1.5 \times 10^2 kg\cdotm/s
   d. 1.5 \times 10^2 kg\cdotm/s

\[ \text{Impulse} = \Delta p = m \cdot v_f - m \cdot v_i \]
\[ = (50 \text{ kg}) \cdot (8 \text{ m/s}) - (50 \text{ kg}) \cdot (5 \text{ m/s}) \]
\[ = 150 \text{ kg\cdotm/s} \]

15. The velocity of a 975-kg car is changed from 12.0 m/s to 27.0 m/s in 15.0 s by an external, constant force. What is the resulting change in momentum of the car?
   a. 1.46 \times 10^4 kg\cdotm/s
   b. 9.75 \times 10^2 kg\cdotm/s
   c. 2.19 \times 10^5 kg\cdotm/s
   d. 7.22 \times 10^4 kg\cdotm/s

\[ \Delta p = m \cdot \Delta v \]
\[ = (975 \text{ kg}) \cdot (27 \text{ m/s} - 12 \text{ m/s}) \]
\[ = 14,625 \text{ kg\cdotm/s} \]
16. Analyze the graph. Which quantity is equal to the impulse?

D. The area would equal \( F \times t \) which is the impulse.

9.6 Use impulse-momentum relation to solve problems

17. A constant force of 4.5 N acts on a 7.2-kg object for 10.0 s. What is the change in the object's velocity?

\[
\Delta v = \frac{F \times t}{m} = \frac{4.5 \, \text{N} \times 10.0 \, \text{s}}{7.2 \, \text{kg}} = 6.25 \, \text{m/s}
\]

A

18. The velocity of a 975-kg car is changed from 12.0 m/s to 27.0 m/s in 15.0 s by an external, constant force. What is the magnitude of the force?

\[
F = \frac{m \cdot \Delta v}{\Delta t} = \frac{975 \, \text{kg} \times 15.0 \, \text{s}}{27.0 \, \text{m/s} - 12.0 \, \text{m/s}} = 975 \, \text{N}
\]

A moving Semi-Truck slams into a compact car moving in the opposite direction.

19) The impulse on the compact car is the same as the impulse on the truck. True/False

True – Newton's 3rd law says forces are the same. Times must be the same, so same.
20) The force is the same magnitude on both 

   True – Newton’s 3rd law says forces are the same. Times must be the same, so same.

21) The change in speed is the same magnitude 

   False – The change in momentum is the same, but the change in speed would depend on the masses.

22) The change in momentum is the same magnitude 

   True – If it is a closed, isolated system, the changes in momentum would be the same.

23. A bicycle and a parked car have a head-on-collision. The force of impact is greater on the bicycle. T or F?

   False – Newton’s 3rd law says forces are the same. Times must be the same, so same.

24. An automobile dashboard that is padded would lengthen the time of impact more than an unpadded dashboard in case of a collision. T or F?

   True – It would slow you down over a longer period of time.

25. When a stationary rocket fires its engine the rocket has the same amount of momentum as the exhaust of the rocket. T or F?

   True – It will move much slower, but it has the same momentum.

26. Two gliders having the same mass and speeds move toward each other on an air track and stick together. After the collision the velocity of the gliders is:
   a. twice the original velocity
   b. the same as the original velocity
   c. one half the original velocity
   d. zero
   e. not enough information to say

   D. Total momentum at the beginning is zero, therefore momentum at the end must be zero.

27. In order to catch a ball, a ball player moves their hand backward in the direction of the ball’s motion. Doing this reduces the force of impact on the player’s hand primarily because:
   a. the velocity of impact is reduced
   b. momentum of impact is reduced
   c. the time of impact is increased
   d. the time of impact is decreased

   C  \[ F \cdot \Delta t = \Delta p \]
28. A cannonball shot from a long-barrel cannon travels faster than one shot from a short barrel cannon because the cannonball receives a greater
   a. force
   b. impulse
   c. both a and b
   d. neither a or b

**B – longer time for the applied force**

9.9 I can explain what impulse is and its relationship with change in momentum

29. The product of the average force and the time interval over which it acts is the
   a. impulse
   b. velocity
   c. acceleration
   d. linear momentum

A. It also equals the change in momentum, but it is called impulse.

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**Linear Momentum**

3) A 0.32 kg ball is moving horizontally 30. m/s just before bouncing off a wall, thereafter moving 25. m/s in the opposite direction.
   (a) What is the magnitude of its change in momentum?

Answer: (a) 18. kg m/s  
Diff: 3

5) A ball, of mass 100. g, is dropped from a height of 12. m. Its momentum when it strikes the ground is

   A) 1.5 kg.m/s.  
   B) 4.8 kg.m/s.  
   C) 3.3 kg.m/s.  
   D) 2.4 kg.m/s.  
   E) 1.8 kg.m/s.

Answer: A  
Diff: 2

6) A bullet of mass 20. g, traveling at 350. m/s, strikes a steel plate at an angle of 30.° with the plane of the plate. It ricochets off at the same angle, at a speed of 320. m/s. What is the magnitude of the impulse that the wall gives to the bullet?

   A) 0.52 N.s  
   B) 4.3 N.s  
   C) 6.7 N.s  
   D) 0.30 N.s  
   E) 0.30 kN.s.

Answer: C (Remember the bullet changes direction.)  
Diff:2
An Olympic diver dives off the high-diving platform.

8) The magnitude of his momentum will be a maximum at which point (A, B, C, or D)?
   A) A  
   B) B  
   C) C  
   D) D

Answer: D  
Diff: 1

9) After leaving the platform, the diver's momentum will be least at which point?

   \[ \vec{p} = m \vec{v} = 0! \]

Answer: B  
Diff: 1

10) A handball of mass 0.10 kg, traveling horizontally at 25. m/s, strikes a wall and rebounds at 19. m/s. What is the change in the momentum of the ball?

   A) 0.60 kg m/s  
   B) 72 kg m/s  
   C) 1.2 kg m/s  
   D) 1.8 kg m/s  
   E) 5.4 kg m/s

Answer: A  
Diff: 2

11) The area under the curve on a F-t graph represents

   A) impulse  
   B) average mass.  
   C) momentum.  
   D) work.  
   E) power.

Answer: A  
Diff: 1
12) A 1200. kg ferryboat is moving south at 20. m/s. Its momentum is
   A) $1.7 \times 10^3$ kg m/s
   B) $2.4 \times 10^3$ kg m/s
   C) $1.2 \times 10^3$ kg m/s
   D) $24,000$ kg m/s
   E) $6.0 \times 10^2$ kg m/s

Answer: D
Diff: 2

Choose from the following list:
(a) pound
(b) slug-ft/s
(c) centimeter
(d) kg m/s
(e) newton

13) An SI unit of $\Delta p/\Delta t$ is which one of the choices above?

Answer: (e) Newton
Diff: 1

14) An SI unit of momentum is which one of the choices above?

Answer: (d) kg m/s
Diff: 1

15) A 1.0 kg cheese-ball vertically falls and strikes the floor with a speed of 20. m/s, and it bounces straight up with a speed of 15. m/s. The magnitude of its change of momentum is 5.0 kg m/s.

Answer: FALSE (remember it changes direction. Momentum is a vector. The magnitude would be 175 kg m/s)
Diff: 2

**Impulse**

1) Daisy (50. kg mass) skates on ice at 4.0 m/s to greet her friend (70. kg mass), who is standing still, with open arms. As they collide, while holding each other, with what speed do they both move off together?

A) 2.5 m/s
B) 1.7 m/s
C) zero
D) 5.0 m/s

Answer: B
Diff: 2

2) Momentum of a system isn't always constant. What condition assures that momentum is conserved for a system?

Answer: Momentum is conserved for a "closed and isolated" system; i.e., if the net external force acting on the system is zero.
Diff: 1
3) A .050 kg beachball approaches at 6.0 m/s. A player hits it directly back with a speed 7.0 m/s.
(a) What was the momentum change (magnitude) of the ball?
(b) If the contact time was 0.040 s, what was the average force on the ball during contact?

Answer: (a) 6.5 kg m/s
(b) 93. Newtons
Diff: 3

5) Two cars suffer a head-on collision. What is conserved in the collision?
A) mechanical energy and momentum
B) kinetic energy
C) momentum
D) (neither energy nor momentum is conserved)

Answer: C
Diff: 1

6) An 80. kg man is skating Northward and happens to collide with a 20.0 kg boy who is ice skating toward the East. Immediately after the collision, the man and boy are seen to be moving together at 2.5 m/s in a direction 60 degrees North of East. How fast was the boy moving before the collision?

Answer: 6.3 m/s
Diff: 2

7) An empty coal-car (mass 20,000 kg) of a train coasts along at 10. m/s. An unfortunate 3000 kg elephant falls from a bridge and drops vertically into the car. Determine the speed of the car immediately after the elephant is added to its contents.

Answer: 8.7 m/s
Diff: 2

8) A 3.0 kg ball of putty moving at 1.0 m/s collides and sticks to a 2.0 kg ball initially at rest. The putty and ball then move with a momentum of
A) 1 kg m/s.
B) 2 kg m/s.
C) 4 kg m/s.
D) 3 kg m/s.
E) 0 kg m/s.

Answer: D
Diff: 2

9) Two cars collide head-on on a level friction-free road. The collision was completely inelastic and both cars quickly came to rest during the collision. What is true about the velocity of this system's center of mass?
A) It was always zero.
B) It was never zero.
C) It was not initially zero, but ended up zero.

Answer: A
Diff: 2
10) A Ping-Pong ball moving East at a speed of 4 m/s collides with a stationary bowling ball. The Ping-Pong ball bounces back to the West, and the bowling ball moves very slowly to the East. Which object experiences the greater magnitude impulse during the collision?

A) neither; both experienced the same magnitude impulse
B) it's impossible to tell since the velocities after the collision are unknown
C) the bowling ball
D) the Ping-Pong ball

Answer: A
Diff: 2

11) A car (mass = 1500 kg) and a small truck (mass = 2000 kg) collide at right angles at an icy intersection. The car was traveling East at 20 m/s and the truck was traveling North at 20 m/s when the collision took place.

![Diagram of car and truck collision]

What is the speed of the combined wreck, assuming a completely inelastic collision?

Answer: 14.3 m/s
Diff: 2

13) A 100 kg football linebacker moving at 2 m/s tackles head-on an 80 kg halfback running 3 m/s. Neglecting the effects due to digging in of cleats

A) this is a simple example of an elastic collision.
B) the linebacker will drive the halfback backward.
C) neither player will drive the other backward.
D) the halfback will drive the linebacker backward.

Answer: D
Diff: 2

14) Car A (mass = 1000 kg) moves to the right along a level, straight road at a speed of 6.0 m/s. It collides directly with car B (mass = 200 kg) in a completely inelastic collision. What is the momentum after the collision if car B was initially at rest?

A) 2.0 kkg m/s to the right
B) 6.0 kkg m/s to the right
C) 8.0 kkg m/s to the left
D) 10. kkg m/s to the right
E) zero

Answer: B
Diff: 2
15) Car A (mass = 1000 kg) moves to the right along a level, straight road at a speed of 6.0 m/s. It collides directly with car B (mass = 200 kg) in a completely inelastic collision. What is the speed of the car immediately after the collision?

A) 4.0 m/s  
B) 6.0 m/s  
C) zero  
D) 5.0 m/s  
E) 3.0 m/s

Answer: D  
Diff: 2

17) When a cannon fires a cannonball, the cannon will recoil backward because the
A) momentum of the cannon is greater than the energy of the cannonball.  
B) momentum of the cannonball and cannon is conserved.  
C) momentum of the cannon is conserved.  
D) energy of the cannonball and cannon is conserved.  
E) energy of the cannon is greater than the energy of the cannonball.

Answer: B  
Diff: 2

18) A mine railroad car, of mass 200 kg, rolls with negligible friction on a horizontal track with a speed of 10.0 m/s. A 70 kg stunt man drops straight down a distance of 4.0 m, and lands in the car. How fast will the car be moving after this happens?

Answer: 7.41 m/s  
Diff 2

The Conservation of Linear Momentum

2) Jennifer hits a stationary 200. gram ball and it leaves the racket at 40.0 m/s. If time lapse photography shows that the ball was in contact with the racket for 40.0 ms:

(a) What average force was exerted on the racket?
(b) What is the ratio of this force to the weight of the ball?

Answer: (a) 0.20 kN  
(b) 1.0 x 10^2  
Diff: 2

3) Suppose a bug splatters upon your windshield as you drive down the road. Which sustains the greater change of momentum?

A) insufficient information  
B) the bug  
C) both the same  
D) the car

Answer: C  
Diff: 2
4) An 80. gram bullet is fired horizontally into a 1.50 kg block resting on a very slippery tabletop. Before imbedding in the block, the bullet was moving at 210. m/s.
   (a) what is the speed of the block immediately after the collision?

   Answer: (a) 10.6 m/s

5) Automobile air bags reduce what during a collision?
   A) speed of the automobile
   B) the forces exerted upon the passenger
   C) the kinetic energy transferred to the passenger
   D) the impulse exerted upon the passenger

   Answer: B

6) A 0.17 kg baseball is thrown with a speed of 38. m/s and it is hit straight back to the pitcher with a speed of 62. m/s. What is the magnitude of the IMPULSE exerted upon the ball by the bat?

   Answer: 17. N.s

7) Two equal mass balls (one blue and the other gold) are dropped from the same height, and rebound off the floor. The blue ball rebounds to a higher position. Which ball is subjected to the greater magnitude impulse during its collision with the floor?
   A) the gold ball
   B) Both balls were subjected to the same magnitude impulse.
   C) It's impossible to tell since the time intervals and forces are unknown.
   D) the blue ball

   Answer: D

8) A small car meshes with a large truck in a head-on collision. Which of the following statements concerning the magnitude of the average collision force is correct?
   A) It is impossible to tell since the masses and velocities are not given.
   B) The small car experiences the greater average force.
   C) The small car and the truck experience the same average force.
   D) The truck experiences the greater average force.

   Answer: C

12) An arrow of mass 20. g is shot horizontally into a bale of hay, striking the hay with a constant velocity of 60. m/s. It penetrates a depth of 20. cm before stopping. What is the average stopping force acting on the arrow?

   Answer: 180. N

   Diff: 2
14) A machine gun, of mass 35. kg, fires 50. gram bullets, with a muzzle velocity of 750. m/s, at the rate of 300. rounds per minute. What is the average force exerted on the machine gun mount?

Answer: 188. N
Diff: 2

15) A 2000. kg car, traveling to the right at 30. m/s, collides with a brick wall and comes to rest in 0.20 s. The average force the car exerts on the wall is

A) 60. MN.
B) 0.30 MN.
C) 0.60 MN.
D) 12. MN.
E) 30. MN.

Answer: B
Diff: 2

17) Some automobiles have air bags installed on their dashboards as a safety measure. The impact of a collision causes the bag to inflate, and it then cushions a passenger's head when he is thrown forward in the car. Suppose that such a bag could lengthen the collision time between one's head and the dashboard by a factor of 10. What effect would this have on the force exerted on the head?

A) The force would be reduced by a factor of about 3.
B) The force would be reduced by a factor of about 1000.
C) The force would be reduced by a factor of about 10.
D) The force would not be reduced, but the energy transferred to the head would be, thereby minimizing the damage done.
E) The force would be reduced by a factor of about 100.

Answer: C
Diff: 2

From the graph, determine the change in momentum after 10 seconds of a 100. kg object.

10 seconds

A) -100. kg m/s
B) -25. kg m/s
C) 75. kg m/s
D) -75. kg m/s
E) 25. kg m/s

Answer: D
Diff: 2
21) A 2.0 kg softball is pitched to you at 20 m/s. You hit the ball back along the same path, and at the same speed. If the bat was in contact with the ball for 0.10 s, the average force the bat exerted was

A) 0.40 kN
B) 40. N.
C) zero
D) 0.80 kN.
E) 0.85 kN.

Answer: D
Diff: 2

**Elastic and Inelastic Collisions**

3) In space, a 4.0 kg metal ball moving 30 m/s has a head-on collision with a stationary similar second ball. After the elastic collision, what are the velocities of the balls?

Answer: They exchange velocities: the first becomes zero, and the second acquires 30 m/s in the direction the first was moving.
Diff 2

6) A 2200 kg auto moving at 12.0 m/s runs into a 3800 kg truck which is moving in the same direction at 5.00 m/s. The collision is perfectly inelastic.

(a) What is the speed of the auto immediately after the collision?

Answer: (a) 7.57 m/s
Diff3

7) A car hits another and the two bumpers lock together during the collision. Is this an elastic or inelastic collision?

A) elastic
B) inelastic
C) insufficient information (it could be either)

Answer: B
Diff: 1

8) In an inelastic collision, the final total momentum is

A) more than the initial momentum.
B) less than the initial momentum.
C) the same as the initial momentum.
D) insufficient information to answer

Answer: C
Diff 1

14) Momentum is conserved during a completely inelastic collision.

Answer: TRUE
Diff 2
15) In a game of pool, the white cue ball hits the #5 ball and stops, while the #5 ball moves away with the same velocity as the cue ball had originally. The type of collision is
A) elastic.
B) elastic or inelastic, depending on the mass of the balls.
C) completely inelastic.
D) inelastic.

Answer: A
Diff: 2

Jet Propulsion and Rockets

1) Why does ion propulsion, which expels material much faster than ordinary chemical rockets, hold such promise for future space travel?

Answer: Much less fuel is needed since the same impulse can be delivered to the rocket by less mass expelled at greater speed.
Diff: 3

2) In space there is nothing for the rocket to "push against" so how does it accelerate?

Answer: In terms of forces, the rocket pushes the exhaust gases back and they in turn (action-reaction) push the rocket forward. In terms of momentum, in order to conserve momentum since the exhaust gases acquire negative momentum (moving backwards) the rocket acquires positive momentum (increasing velocity forward).
Diff: 3

3) Astronaut Jennifer's lifeline to her spaceship comes loose and she finds herself stranded, "floating" 100.m from the mothership. She throws her 2.00 kg wrench at 20.0 m/s in a direction away from the ship. If she and her spacesuit have a combined mass of 200. kg how long does it take her to coast back to her spaceship?

A) 1000. s
B) 750. s
C) 250. s
D) 2.50 minutes
E) 500. s

Answer: E
Diff: 2
16) A 60. kg person walks along a 100. kg log at the rate of 0.8 m/s (with respect to the log). With what speed does the log move, with respect to the shore?

Answer: 0.3 m/s
Diff: 2

9) A toy rocket, of mass 60 g, achieves a velocity of 80 m/s after 3.0 s when fired straight up. What average thrust force does the rocket engine exert?

A) 3.4 N
B) 1.2 N
C) 2.2 N
D) 3.3 N
E) 1.6 N

Answer: C
Diff: 2

1) A 60. gram toy rocket achieves a speed of 80. m/s after 3.0 s, when fired straight up. What is the average total force on the rocket during the 3 s?

A) 3.4 N
B) 1.6 N
C) 2.2 N
D) 3.2 N
E) 1.2 N

Answer: B
Diff: 2