CHAPTER 7 | IMPULSE AND MOMENTUM

CONCEPTUAL QUESTIONS

1. **REASONING AND SOLUTION**  The linear momentum $p$ of an object is the product of its mass and its velocity. Since the automobiles are identical, they have the same mass; however, although the automobiles have the same speed, they have different velocities. One automobile is traveling east, while the other one is traveling west. Therefore, the automobiles do not have the same momentum. Note that both momenta have the same magnitude, however, one car has a momentum that points east, while the other car has a momentum that points west.

2. **REASONING AND SOLUTION**  Since linear momentum is a vector quantity, the total linear momentum of any system is the resultant of the linear momenta of the constituents. The people who are standing around have zero momentum. Those who move randomly carry momentum randomly in all directions. Since there is such a large number of people, there is, on average, just as much linear momentum in any one direction as in any other. On average, the resultant of this random distribution is zero. Therefore, the approximate linear momentum of the Times Square system is zero.

3. **REASONING AND SOLUTION**
   
a. Yes. Momentum is a vector, and the two objects have the same momentum. This means that the direction of each object's momentum is the same. Momentum is mass times velocity, and the direction of the momentum is the same as the direction of the velocity. Thus, the velocity directions must be the same.

   b. No. Momentum is mass times velocity. The fact that the objects have the same momentum means that the product of the mass and the magnitude of the velocity is the same for each. Thus, the magnitude of the velocity of one object can be smaller, for example, as long as the mass of that object is proportionally greater to keep the product of mass and velocity unchanged.

4. **REASONING AND SOLUTION**
   
a. If a single object has kinetic energy, it must have a velocity; therefore, it must have linear momentum as well.

   b. In a system of two or more objects, the individual objects could have linear momenta that cancel each other. In this case, the linear momentum of the system would be zero. The kinetic
energies of the objects, however, are scalar quantities that are always positive; thus, the total kinetic energy of the system of objects would necessarily be nonzero. Therefore, it is possible for a system of two or more objects to have a total kinetic energy that is not zero but a total momentum that is zero.

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5. **REASONING AND SOLUTION**  
The impulse-momentum theorem, Equation 7.4, states that \( \vec{F} \Delta t = m \vec{v}_f - m \vec{v}_0 \).

a. If an airplane is flying horizontally with a constant momentum during a time \( \Delta t \), then from Equation 7.4, \( \vec{F} \Delta t = 0 \). There is no net impulse \( \vec{F} \Delta t \) on the plane during this time interval.

b. The fact that the net impulse on the plane is zero indicates that the impulses of the two horizontal forces must cancel each other. That is, the impulse of the thrust is equal in magnitude and opposite in direction to the impulse of the resistive force.

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6. **REASONING AND SOLUTION**  
The severity of the collision is determined by the amount of momentum transferred by the colliding object. If the child is moving twice as fast as the adult, and the mass of the child and the bicycle is one half that of the adult, the magnitude of the linear momenta (mass \( x \) speed) of the child and the adult are the same. Therefore, it does not matter whether one is struck by the fast-moving child or the slow-moving adult.

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7. **REASONING AND SOLUTION**  
An object slides along the surface of the earth and slows down because of kinetic friction.

a. If the object and the earth are considered to be part of the system, then the force of kinetic friction arises between components of the system. Therefore, the force of kinetic friction is an internal force, not an external force.

b. A force can only change the linear momentum of a system if the force is an external force. Since the force of friction is an internal force, it cannot change the total linear momentum of the two-body system. In fact, the total linear momentum of the two-body system remains the same. The linear momentum lost by the object is equal to the linear momentum gained by the earth.

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8. **REASONING AND SOLUTION**  
The impulse-momentum theorem, Equation 7.4, states that \( \vec{F} \Delta t = m \vec{v}_f - m \vec{v}_0 \). Assuming that the golf ball is at rest when it is struck with the club, \( \vec{F} \Delta t = m \vec{v}_f \).
During a good "follow-through" when driving a golf ball, the club is in contact with the ball for the longest possible time. From the impulse-momentum theorem, it is clear that when the contact time $\Delta t$ is a maximum, the final linear momentum $mv_f$ of the ball is a maximum. In other words, during a good "follow through" the maximum amount of momentum is transferred to the ball. Therefore, the ball will travel through a larger horizontal distance.

9. **REASONING AND SOLUTION**

a. Since the water leaves each nozzle with a speed that is greater than the speed inside the arm, the quantity $mv_f - mv_0$ is positive. From the impulse-momentum theorem, $\vec{F}\Delta t = mv_f - mv_0$, and we can deduce that there is a net positive or outward impulse. Therefore, a net outward force is exerted on the water.

b. From Newton's third law, the water must exert a net force that is equal in magnitude, but negative and directed toward the nozzle. The nozzle and the arm, in turn, move. Since each arm is free to rotate about the vertical axis, the arm will whirl.

10. **REASONING AND SOLUTION** To throw the villain forward, Superman must exert a force on him. For a system comprised of Superman and the villain, this force is an internal force. Internal forces cannot change the total linear momentum of the two-person system. Therefore, when Superman throws the villain forward, the villain gains forward momentum, and Superman must gain an equal amount of momentum in the backward direction. Therefore, Superman could not remain stationary after throwing the villain forward.

11. **REASONING AND SOLUTION** Since the satellite explodes in outer space far from any other body, it may be considered to be an isolated system. The forces of the explosion are forces that are internal to the system. Therefore, after the explosion, the total linear momentum of all the pieces must be equal to the linear momentum of the satellite before it exploded.

12. **REASONING AND SOLUTION** Let the system be defined by the jetliner (and all the other passengers, luggage, etc.) and the walking passenger. When the passenger walks toward the front of the plane, the linear momentum of this passenger increases. Any forces exerted by this passenger on the jetliner are internal forces and cannot change the total momentum of the system. Therefore, from momentum conservation, the forward momentum of the jetliner will decrease by the same amount as the momentum gained by the passenger. This amount is small compared to the forward momentum of the jetliner and goes unnoticed.
13. **REASONING AND SOLUTION**
   a. No. The person overhead jumps straight down and, therefore, applies only a vertical force to the boat. Since friction and air resistance are negligible, no horizontal force is applied to the boat. According to the impulse-momentum theorem, this means that the horizontal momentum of the boat cannot change.

   b. The speed of the boat decreases. Momentum is mass times velocity. The only way for the horizontal momentum of the boat to remain unchanged when the mass increases due to the presence of the jumper is for the magnitude of the boat’s velocity (that is, the speed) to decrease.

14. **REASONING AND SOLUTION**  Let the system be comprised of the asteroid, the catapult and the supply of stones. When the catapult is used to "throw" chunks of stones into space, the force exerted by the catapult is an internal force; therefore, the total momentum of the system must remain the same. When rocks are thrown in one direction, they carry linear momentum in that direction. From the conservation of momentum, the asteroid must carry an equal amount of momentum in the opposite direction. It will, therefore, move in that direction. Such a device could be used as a propulsion system to move the asteroid closer to earth.

15. **REASONING AND SOLUTION**  For a system comprised of the three balls, there is no net external force. The forces that occur when the three balls collide are internal forces. Therefore, the total linear momentum of the system is conserved. Note, however, that the momentum of each ball is not conserved. The momentum of any given ball will change as it interacts with the other balls; the momentum of each ball will change in such a way as to conserve the momentum of the system. It is the momentum of the system of balls, not the momentum of an individual ball, that is conserved.

16. **REASONING AND SOLUTION**  An elastic collision is one in which the total kinetic energy of the system after the collision is equal to the total kinetic energy before the collision. The kinetic energy of the individual objects in the system will, in general, change during a collision. They will change so that the total kinetic energy of the system remains the same before and after the collision. Even in an elastic collision, however, the kinetic energy of each object is not necessarily the same before and after the collision.

17. **REASONING AND SOLUTION**  Example 7 concerns the elastic collision between two balls: one initially moving (ball 1), and one initially at rest (ball 2). The results of that example show that the final speeds of the balls are given by
\[ v_{f1} = \frac{m_1 - m_2}{m_1 + m_2} v_{01} \]  
(7.8a)

and

\[ v_{f2} = \frac{2m_1}{m_1 + m_2} v_{01} \]  
(7.8b)

If the two objects have equal mass, \( m_1 = m_2 \), and Equation 7.8a indicates that \( v_{f1} = 0 \), and Equation 7.8b indicates that \( v_{f2} = v_{01} \). In other words, the first object is stopped completely and the second object takes off with the velocity the first object originally had.

18. **REASONING AND SOLUTION**  
Many objects have a point, a line, or a plane of symmetry. If the mass of the system is uniformly distributed, the center of mass of such an object lies at that point, on that line, or in that plane. The point of symmetry of a doughnut is at the geometric center of the hole. Thus, the center of mass of a doughnut is at the center of the hole.

19. **REASONING AND SOLUTION**  
Since more of the mass of the bat is located near the heavier end of the bat, the center of mass of the bat will be located nearer the heavier end.

20. **REASONING AND SOLUTION**  
A sunbather is lying on a floating, stationary raft. She then gets up and walks to one end of the raft. The sunbather and the raft are considered as an isolated system.

   a. As the sunbather walks to one end of the raft, she exerts a force on the raft; however, the force is internal to the isolated system. Since there are no external forces acting on the system, the linear momentum of the system cannot change. Since the linear momentum of the system is initially zero, it must remain zero. Therefore, the velocity of the center of mass of the system must be zero.

   b. The sunbather has linear momentum as she walks to one end of the raft. Since the linear momentum of the isolated system must remain zero, the raft must acquire a linear momentum that is equal in magnitude and opposite in direction to that of the sunbather. From the definition of linear momentum, \( \mathbf{p} = m\mathbf{v} \), we know that the direction of the linear momentum of an object is the same as the direction of the velocity of the object. Thus, the raft acquires a velocity that is opposite to the direction of motion of the sunbather.