Conservation of Momentum in One Dimension

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Printed: December 14, 2013

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CONCEPT 1 Conservation of Momentum in One Dimension

- State the law of conservation of momentum.
- Use the conservation of momentum to solve one-dimensional collision problems.

If momentum is conserved, how is it possible for this whale to jump up out of the water?

Below the water level, there is a very large mass of water that is moving downward to balance the mass of the whale moving upward. The water that moves downward was pushed downward by the whale's tail.

Conservation of Momentum in One Dimension

When impulse and momentum were introduced, we used an example of a batted ball to discuss the impulse and momentum change that occurred with the ball. At the time, we did not consider what had happened to the bat. According to Newton's third law, however, when the bat exerted a force on the ball, the ball also exerted an equal and opposite force on the bat. Since the time of the collision between bat and ball is the same for the bat and for the ball, then we have equal forces (in opposite directions) exerted for equal times on the ball AND the bat. That means that the impulse exerted on the bat is equal and opposite (-Ft) to the impulse on the ball (Ft) and that also means that there was a change in momentum of the bat $[-\Delta(mv)_{\text{BAT}}]$ that was equal and opposite to the change in momentum of the ball $[\Delta(mv)_{\text{BALL}}]$.

The change in momentum of the ball is quite obvious because it changes direction and flies off at greater speed while the change in momentum of the bat is not obvious at all. The bat is more massive than the ball and if the bat is held firmly, the arms and shoulders of the batter become part of the bat in terms of mass and velocity and with greater mass, the change in velocity is much smaller.

If we define a system to contain two ice skaters and then have one of the ice skaters exert a force on the other skater, the force is called an internal force because both the object exerting the force and the object receiving the force are inside the system. In such a closed system, momentum is always conserved. If we defined a system to contain one

ice skater and the other ice skater was outside the system, then when one skater pushed the other, the force would be an external force because the receiver of the force is outside the system . . . the system is NOT closed. Momentum is not guaranteed to be conserved unless the system is closed.

In a closed system, momentum is always conserved. If we consider two billiard balls colliding on a billiard table and ignore friction, we are dealing with a closed system. The momentum of ball *A* before the collision plus the momentum of ball *B* before collision will equal the momentum of ball *A* after collision plus the momentum of ball *B* after collision.

Example Problem: Ball *A* has a mass of 2.0 kg and is moving due west with a velocity of 2.0 m/s while ball *B* has a mass of 4.0 kg and is moving west with a velocity of 1.0 m/s. Ball *A* overtakes ball *B* and collides with it from behind. After the collision, ball *A* is moving westward with a velocity of 1.0 m/s. What is the velocity of ball *B* after the collision?

Solution: Because of the law of **conservation of momentum**, we know that

$$\rho_{A\text{before}} + \rho_{B\text{before}} = \rho_{A\text{after}} + \rho_{B\text{after}}$$

.

$m_A v_A + m_B v_B = m_A v'_A + m_B v'_B$

$(2.0\text{ kg})(2.0\text{ m/s}) + (4.0\text{ kg})(1.0\text{ m/s}) = (2.0\text{ kg})(1.0\text{ m/s}) + (4.0\text{ kg})({v_B}'\text{ m/s})$

$4.0\text{ kg}\cdot\text{m/s} + 4.0\text{ kg}\cdot\text{m/s} = 2.0\text{ kg}\cdot\text{m/s} + 4{v_B}'\text{ kg}\cdot\text{m/s}$

$4{v_B}' = 8.0 - 2.0 = 6.0$

${v_B}' = 1.5\text{ m/s}$

After the collision, ball *B* is moving westward at 1.5 m/s.

Example Problem: A railroad car whose mass is 30,000. kg is traveling with a velocity of 2.2 m/s due east and collides with a second railroad car whose mass is also 30,000. kg and is at rest. If the two cars stick together after the collision, what is the velocity of the two cars?

Solution: $m_A v_A + m_B v_B = m_A v'_A + m_B v'_B$

$(30{,}000.\text{ kg})(2.2\text{ m/s}) + (30{,}000.\text{ kg})(0\text{ m/s}) = (60{,}000.\text{ kg})(v'\text{ m/s})$

$66000 + 0 = 60000v'$

$v' = \frac{66000}{60000} = 1.1\text{ m/s}$

After the collision, the two cars move off together toward the east with a velocity of 1.1 m/s.

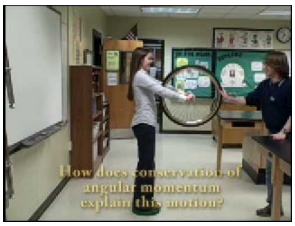
Summary

- In terms of conservation of momentum, both the object exerting the force and the object receiving the force must be inside the system in order for the system to be called "closed."
- In a closed system, momentum is always conserved.

Practice

The following video shows physics students experiencing the conservation of angular momentum. Use this resource to answer the question that follows.

http://www.youtube.com/watch?v=UZlW1a63KZs



MEDIA

Click image to the left for more content.

1. What is the relationship between the direction the girl is spinning and the direction the wheel is spinning? You may need to look back at the video again.

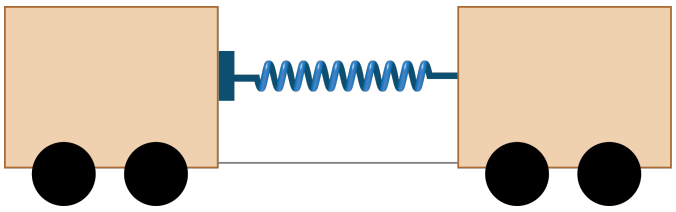
Review

1. A 0.111 kg hockey puck moving at 55 m/s is caught by a 80. kg goalie at rest. With what speed does the goalie slide on the (frictionless) ice?

2. A 0.050 kg bullet strikes a 5.0 kg stationary wooden block and embeds itself in the block. The block and the bullet fly off together at 9.0 m/s. What was the original velocity of the bullet?

3. A 0.50 kg ball traveling at 6.0 m/s due east collides head on with a 1.00 kg ball traveling in the opposite direction at -12.0 m/s. After the collision, the 0.50 kg ball moves away at -14 m/s. Find the velocity of the second ball after the collision.

4. Two carts are stationary with a compressed spring between them and held together by a thread. When the thread is cut, the two carts move apart. After the spring is released, one cart $m = 3.00$ kg has a velocity of 0.82 m/s east. What is the magnitude of the velocity of the second cart $(m = 1.70$ kg$)$after the spring is released?



5. Compared to falling on a tile floor, a glass may not break if it falls onto a carpeted floor. This is because

a. less impulse in stopping.
b. longer time to stop.
c. both of these
d. neither of these.

6. A butterfly is hit by a garbage truck on the highway. The force of the impact is greater on the

a. garbage truck.
b. butterfly.
c. it is the same for both.

7. A rifle recoils from firing a bullet. The speed of the rifle's recoil is small compared to the speed of the bullet because

a. the force on the rifle is small.
b. the rifle has a great deal more mass than the bullet.
c. the momentum of the rifle is unchanged.

d. the impulse on the rifle is less than the impulse on the bullet.
e. none of these.

- **Law of Conservation of Momentum:** The total linear momentum of an isolated system remains constant regardless of changes within the system.

References

1. Courtesy of NOAA. http://commons.wikimedia.org/wiki/File:Humpback_whale_noaa.jpg. Public Domain
2. CK-12 Foundation - Samantha Bacic. . CC-BY-NC-SA 3.0