Momentum and Impulse

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Concept 1 Momentum and Impulse

- Define momentum.
- Define impulse.
- Given mass and velocity of an object, calculate momentum.
- Calculate the change in momentum of an object.
- State the relationship that exists between the change in momentum and impulse.
- Using the momentum-impulse theorem and given three of the four variables, calculate the fourth.

Rachel Flatt performs a layback spin at the 2011 Rostelecom Cup

When an ice skater spins, angular momentum must be conserved. When arms or feet are far away from the body, the spin rotates slower and when the arms and feet are brought in close to the body, the spin must rotate much faster.

Momentum and Impulse

Suppose you wish to change the motion of an object. If a bowling ball and a ping-pong ball are each moving with a velocity of 5 mph, you know that it will require more effort to stop the bowling ball than the ping pong ball because of the greater mass of the bowling ball. If you have two bowling balls, one moving at 5 mph and the other moving at 10 mph, you know it will take more effort to stop the ball with the greater speed. It is clear that both the mass and the velocity of a moving object contribute to what is necessary to change the motion of the moving object. The product of the mass and velocity of an object is called **momentum.** Momentum is a vector quantity that has the same direction as the velocity of the object. Momentum is often represented by the Greek letter rho, ρ.

$\rho = mv$

The momentum of a 0.500 kg ball moving with a velocity of 15.0 m/s will be

$$\rho = mv = (0.500 \text{ kg})(15.0 \text{ m/s}) = 7.50 \text{ kg} \cdot \text{m/s}$$

You should note that the units for momentum are kg·m/s.

According to Newton's first law, the velocity of an object cannot change unless a force is applied. If we wish to change the momentum of a body, we must apply a force and the longer the force is applied, the greater will be the change in momentum. The quantity of force multiplied by the time it is applied is called **impulse**. Impulse is a vector quantity that has the same direction as the force. The units for impulse are N·s but we know that Newtons are also kg·m/s^2 and so N·s = (kg·m/s^2)(s) = kg·m/s – the same as momentum. When an impulse is applied to an object, the momentum of the object changes. The change of momentum is equal to the impulse.

$Ft = \Delta mv$

Example Problem: Calculating Momentum

A 0.15 kg ball is moving with a velocity of 35 m/s. Find the momentum of the ball.

Solution: $\rho = mv = (0.15 \text{ kg})(35 \text{ m/s}) = 5.25 \text{ kg} \cdot \text{m/s}$

Example Problem: If a ball with mass 5.00 kg was to have a momentum of 5.25 kg · m/s, what velocity would it need?

Solution: $v = \frac{\rho}{m} = \frac{5.25 \, \mathbf{kg{\cdot}m/s}}{5.00 \, \mathbf{kg}} = 1.05 \, \mathbf{m/s}$

It should be clear from the equation relating impulse to change in momentum, $Ft = \Delta mv$, that any amount of force would (eventually) bring a moving object to rest. The point is that if the force is very small, it would need to be applied for a long time and a greater force could bring the moving object to rest in a shorter period of time. That small piece of information has a very large effect on how we do things.

If you jump off a porch and land on your feet with your knees locked in the straight position, your motion would be brought to rest in a very short period of time and thus the force would need to be very large – large enough, perhaps, to damage your joints or bones. If, on the other hand, when your feet first touched the ground, you allowed your knees to flex so that the period of time over which your body was brought to rest is increased, then the force on your body would be smaller and it would be less likely that you would damage your legs.

Suppose that when you hit the ground, your velocity was 7.0 m/s and that velocity was brought to rest in 0.05 seconds. If your mass is 100. kg, what force was required to bring you to rest?

$F = \frac{\Delta mv}{t} = \frac{(100. \text{ kg})(7.0 \text{ m/s})}{0.050 \text{ s}} = 14,000 \text{ N}$

Suppose that all the data above remains the same except that when you first touch the ground, you allow your knees to bend and so the stopping time is extended to 0.50 seconds. What force would be required to bring you to rest this time?

$F = \frac{\Delta mv}{t} = \frac{(100. \text{ kg})(7.0 \text{ m/s})}{0.50 \text{ s}} = 1400 \text{ N}$

With the longer period of time for the force to act, the necessary force is reduced to one-tenth of what was needed before.

Extending the period of time over which a force acts in order to lessen the force is a common practice in design. It is the reason for padded dashboards and air bags in automobiles as well as the reason for padded seats and padded shoes. This is also the reason that automobiles are now designed for the front end to crumple upon collision instead of remain stiff. This is the reason many barrels of water or sand are placed in front of abutments along the highway – in case an auto heads for the abutment, it will come to a stop more slowly by running through the barrels of water.

Example Problem: An 0.15 kg baseball is thrown horizontally at 40. m/s and after it is struck by a bat, it is traveling at -40. m/s.

(a) What impulse did the bat deliver to the ball?

(b) If the contact time of the bat and bat was 0.00080 seconds, what was the average force the bat exerted on the ball?

(c) Calculate the average acceleration of the ball during the time it was in contact with the bat.

Solution: We can calculate the change in momentum and give the answer as impulse because we know that the impulse is equal to the change in momentum.

(a)

$$\begin{aligned}\rho = m\Delta v &= (0.15 \text{ kg})(-40. \text{ m/s} - 40. \text{ m/s}) \\ &= (0.15 \text{ kg})(-80. \text{ m/s}) = -12 \text{ kg} \cdot \text{m/s}\end{aligned}$$

The minus sign indicates that the impulse was in the opposite direction of the original throw.

(b) $F = \frac{\Delta mv}{t} = \frac{-12 \text{ kg·m/s}}{0.00080 \text{ s}} = -15000 \text{ N}$

Again, the negative sign indicates the force was in the opposite direction of the original throw.

(c) $a = \frac{F}{m} = \frac{-15000 \text{ N}}{0.15 \text{ kg}} = -100,000 \text{ m/s}^2$

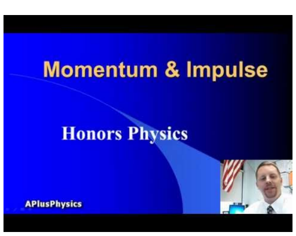
Summary

- The product of the mass and velocity of an object is called momentum, $\rho = mv$.
- Momentum is a vector quantity that has the same direction as the velocity of the object.
- The quantity of force multiplied by the time it is applied is called impulse.
- Impulse is a vector quantity that has the same direction as the force.
- Momentum and impulse have the same units, kg·m/s.
- The change of momentum of an object is equal to the impulse. $Ft = \Delta mv$

Practice

An Honors Physics lecture about momentum. Use this resource to answer the question that follows.

http://www.youtube.com/watch?v=XSR7khMBW64



MEDIA

Click image to the left for more content.

1. What are the names of the two trains whose momenta are compared in the video?

Review

1. A small car with a mass of 800. kg is moving with a velocity of 27.8 m/s.
   (a) What is the momentum of the car?
   (b) What velocity is needed for a 2400. kg car in order to have the same momentum?
2. A scooter has a mass of 250. kg. A constant force is exerted on it for 60.0 s. During the time the force is exerted, the scooter increases its speed from 6.00 m/s to 28.0 m/s.
   (a) What is the change in momentum?
   (b) What is the magnitude of the force exerted on the scooter?
3. The brakes on a 15,680 N car exert a stopping force of 640. N. The car's velocity changes from 20.0 m/s to 0 m/s.
   (a) What is the car's mass?
   (b) What was its initial momentum?
   (c) What was the change in momentum for the car?
   (d) How long does it take the braking force to bring the car to rest?

- **momentum:** A measure of the motion of a body equal to the product of its mass and velocity. Also called linear momentum**.**
- **impulse:** The product obtained by multiplying the average value of a force by the time during which it acts. The impulse equals the change in momentum produced by the force in this time interval.

References

1. User:deerstop/Wikimedia Commons. http://commons.wikimedia.org/wiki/File:Flatt-3.jpg. Public Domain