Momentum and Impulse

Have you ever wondered how a karate expert can break a stack of cement bricks with the blow of a bare hand? Or why falling on a wooden floor hurts less than falling on a cement floor? Or why follow through is important in golf, baseball, and boxing? To understand these things, you need to recall the concept of inertia. Inertia was discussed in terms of objects at rest and objects in motion. In this lesson we are concerned only with the concept of inertia in motion – momentum.

Momentum

We know that it's harder to stop a large truck than a small car when both are moving at the same speed. We say that the truck has more momentum than the car. By **momentum**, we mean *inertia in motion*. More specifically, momentum is the product of an object's mass and its velocity.

$$\text{momentum} = \text{mass} \times \text{velocity}$$

or, in abbreviated form,

$$\text{momentum} = mv$$

Note: Momentum is measured in $\text{kg} \cdot \text{m/s}$.

We can see from this definition that a moving object can have a large momentum if it has a large mass, a large velocity, or both. For example, a fast moving car can have more momentum than a slow moving truck. And a truck at rest has no momentum at all.

Impulse Changes Momentum

If the momentum of an object changes, either the mass of the velocity or both change. If the mass remains unchanged, as is most often the case, then the velocity changes and acceleration occurs.

Q. What causes acceleration?

A. Force.

Two factors affect how much an object's momentum changes while under the influence of a force:

1. The magnitude of the force.
   - The greater the force acting on an object, the greater its change in momentum.

2. How long the force acts.
   - A force acting for a long time produces more change in momentum than does the same force acting for a short time.

The quantity *force x time interval* is called **impulse**. In shorthand notation

$$\text{impulse} = F\Delta t$$

Note: Impulse is measured in $N \cdot s$.

The greater the impulse exerted on something, the greater will be the change in its momentum. The exact relationship is

$$\text{impulse} = \text{change in momentum}$$

or

$$F\Delta t = \Delta(mv)$$

This relationship is used to analyze a variety of situations where the momentum changes. Consider the following examples.

Example 1 Increasing Momentum
Imagine you are firing a bow and arrow at a far-off target. When you draw the bow, will you pull the string back to your elbow, or all the way to your shoulder? Why?

In order to reach the target, the arrow must be going pretty fast as it leaves the bow. Since the arrow starts at rest, that means you have to change its momentum by quite a bit. To do this, you must increase (a) the amount of force the bow exerts on the arrow, (b) the length of time the bow exerts a force on the arrow, or (c) both. Pulling the string back as far as possible increases both the force and the time it is exerted, thus producing a large impulse. This large impulse in turn produces a large change in the momentum of the arrow.

Example 2 Decreasing Momentum
Why, when you catch a baseball, do you pull your hand backward?

By pulling your hand backward you extend the impact time between the ball and your hand. This time represents the time during which the momentum of the ball is brought to zero. A longer impact time decreases the resulting deceleration and reduces the force of the impact. For example, if the time of impact is extended 100 times, the force of impact is reduced 100 times.

Example 3 Decreasing Momentum
How does a karate expert break a brick?

When a karate expert strikes a brick, the momentum of her hand is decreased. In order to break the brick she must exert a very high impact force. This is accomplished by reducing the impact time to as short an interval as possible. When the momentum of her hand is being reduced by the brick, a shorter impact time increases the resulting deceleration and increases the force of the impact.

Note: The karate expert also allows her hand to bounce back from the brick, rather than pulling it back. Why? Because the impulse is significantly greater (up to twice as much) when an object bounces.

Motion Worksheet #9

1. Distinguish between mass and momentum. Which is inertia and which is inertia in motion?

2. Which has the greater mass, a heavy truck at rest or a rolling skateboard? Which has the greater momentum?

3. Distinguish between impact and impulse. Which designates a force and which is force multiplied by time?

4. When the force of impact on an object is extended in time, does the impulse increase or decrease?

5. Distinguish between impulse and momentum. Which is force x time and which is inertia in motion?

6. Does impulse equal momentum, or a change in momentum?

7. For a constant force, suppose the duration of impact on an object is doubled.
   a. How much is the impulse increased?
   b. How much is the resulting change in momentum increased?

8. In a car crash, why is it advantageous for an occupant to extend the time during which the collision takes place?

9. If the time of impact in a collision is extended by four times, how much does the force of impact change?

10. Why is it advantageous for a boxer to roll with a punch? Why should he avoid moving into an oncoming punch?

11. What is the momentum of an 8 kg bowling ball rolling at 2 m/s?

12. If the bowling ball in question 11 rolls into a pillow and stops in 0.5 s, calculate the average force exerted on the pillow.

13. What is the momentum of a 50 kg carton that slides at 4 m/s across an icy surface?

14. The carton in question 13 skids onto a rough surface and stops in 3 s. Calculate the force of friction it encounters.

15. What impulse occurs when an average force of 10 N is exerted on a cart for 2.5 s? What is the change in the cart's momentum?

16. When you ride a bicycle at full speed and the bike stops suddenly, why do you have to push hard on the handlebars to keep from flying forward?

17. In terms of impulse and momentum, why are air bags in automobiles a good idea?

18. Why is it difficult for a firefighter to hold a hose that ejects a large amount of water at high speed?

19. You can't throw a raw egg against a wall without breaking it, but you can throw it at the same speed into a sagging sheet without breaking it. Explain.

20. Suppose you roll a bowling ball into a pillow and the ball stops. Now suppose you roll it against a spring and it bounces back with an equal and opposite momentum. Which object exerts the greater impulse, the pillow or the spring?

Motion Worksheet #9 Key

1. Mass is inertia; momentum is inertia in motion.

2. The truck has the greater mass; the skateboard has the greater momentum.

3. Impact designates a force; impulse = force x time.

4. Increases.

5. Impulse = force x time; momentum is inertia in motion.

6. Change in momentum.

7. The impulse doubles; the change in momentum doubles.

8. Greater time means less force.

9. It is reduced to one fourth.

10. Greater time means less force; less time means greater force.

11. 16 $kg \cdot m/s$

12. 32 N

13. 200 $kg \cdot m/s$

14. 66.6 N

15. 25 $N \cdot s$; 25 $kg \cdot m/s$

16. So the reaction force of the handlebars on you will produce a backward-acting impulse to bring your momentum to zero.

17. Air bags increase your stopping time in a head-on collision. Greater time of impact means less impact force.

18. The hose tends to recoil from the ejected water.

19. The time it takes to stop is extended as the sheet sags. More time means less impact force, and an egg that is less likely to break.

20. The spring exerts a greater impulse because it produces a bigger change in the ball's momentum.