Unit 4 Parent Guide: Momentum, Impulse, Collisions

Momentum is the product of mass and velocity. We use the letter *p* to represent momentum:

$$p = mv$$

Momentum is a vector quantity. The direction of momentum is the same as the direction of velocity.

Part I: Momentum in an open system

Momentum can be changed by the application of external force. In an open system, momentum can change because of the interaction of external force on objects within the system. When a net force acts on an object, the object's momentum changes. The quantity of change in momentum is equivalent to the product of the net force and the time the force is applied. When an external force is applied, it must be applied for an interval of time. The product of force and time is called *impulse* and is defined in the following equation:

$$J = F\Delta t$$

Where J is impulse, F is force, and Δt is the time interval that the force is applied. Impulse is a useful quantity because it connects Newton's 2^{nd} Law with momentum.

Impulse-momentum theorem: The amount of impulse exerted on a system is equivalent to the change in momentum of the system.

When a golf club strikes a golf ball, the club exerts a large force on the ball for a brief time and the momentum of the ball increases. This change in momentum is equal to the impulse exerted on the ball. The ball receives a very large force for a very short time. Like many sports, golfers often need to make a ball move as fast as possible. In order for this to happen they should maximize the force by swinging hard, and maximize the time of impact by following through the swing.

The momentum-impulse theorem is also important in impacts that bring motion to a stop. In automobile collisions, the velocity of the car and occupants are stopped in a very short time. So for the purpose of safety, the auto industry has developed ways to increase the time required to stop. Seatbelts, padded dashboards, and crumple zones are built into cars to increase the stopping time and therefore decrease the force required to stop the occupants.

Part II: Momentum in a closed system

Momentum is conserved in a closed system. This is known as the Law of Conservation of Momentum. In the absence of any external force, the momentum of a system remains constant. This is useful because we can make predictions about the motion of a system of objects even when the parts of the system move independently of one another.

One application of conservation of momentum is to analyze collisions. In a collision, only the two colliding objects are in the system, and those two objects exert forces on one another to change the individual momenta but keep the total momentum the same. In the absence of any external forces, the total system momentum before the collision is the same after. The total system momentum is the vector sum of the momenta of the individual objects. Mathematically, this could be expressed as:

$$p_{1i} + p_{2i} = p_{1f} + p_{2f}$$

It is important to remember that momentum is a vector quantity. That means that the direction of positive and negative must be designated, as in previous units. Also a revisit of third law force pairs should be included here because a collision is essentially two interacting objects exerting equal and opposite forces on each other.

Elastic collisions: In an elastic collision, not only is momentum conserved, but kinetic energy is also conserved. A requirement for an elastic collision is that the colliding objects must not be attached after the collision. A good approximation of an elastic collision is between billiard balls.

Inelastic collisions: In an inelastic collision, momentum is conserved, but kinetic energy is transformed into some other form by work or heat. An inelastic collision is recognized by the deformation of the colliding objects and that they stick together after the collision. If two colliding objects stick together, then they will have the same velocity after the collision.

Recoil: The opposite of a collision is called an explosion. In an explosion, the system is composed of objects that initially are connected together, then separate by pushing one another apart. Even if both objects are initially at rest, with zero momentum, the total momentum is conserved.

Consider a bullet fired from a gun. Before the trigger is pulled, both the bullet and gun are at rest so the system momentum is zero. If momentum is conserved, then the system momentum will still be zero after the gun is fired. The sum of the two momenta must equal zero. The only way that is possible is if the gun's momentum is equal to the bullet's momentum, but in the opposite direction. So the vector sum of the two momenta is zero.