



Unit 2: Work and Momentum

Lesson 2.4: Momentum, Impulse and conservation of momentum

Part 1: Momentum and Impulse (5.1)

As we learnt from ch1 to ch4, velocity, acceleration, or force are all quantities for describing the motion for a single object, but how about two objects, or how about when two or more objects **collide** to each other, what kind of impact acts on them?

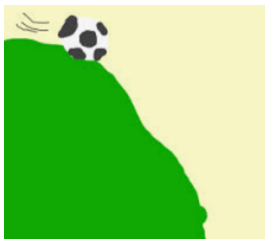
Good impact: in sports, hit a ball with a bat, or a puck propelled by a slap shot.

Bad impact: car accident, or airplane hit by bird...

Hence, we need a new quantity called **momentum** to quantitatively measure the impact of collision.

Linear Momentum: A quantity that describes the motion of an object travelling in a straight line as the product of its mass and velocity.

Formula: $\vec{p} = m\vec{v}$. Hence, the linear momentum is directly proportional to the object's velocity, so the momentum vector is along the same direction as the velocity.



Football



Big stone



Asteroid



Meteor

Example 1: Calculate the momentum and kinetic energy of a 5.0 kg groundhog travelling with a velocity of 1.0 m/s [NE].



Now, let's recap Newton's first law. Newton's first law of motion states that the velocity of an object stays unless acted on by an external force. So, in the absence of an external force, an object with constant mass must also have unchanged linear momentum.

If a net force is applied to the object, its velocity will change, and therefore, its linear momentum will also change.

$$\therefore \vec{F} = m\vec{a} = m \frac{\vec{v}_f - \vec{v}_i}{\Delta t} \quad \therefore \vec{F}\Delta t = m(\vec{v}_f - \vec{v}_i) = m\vec{v}_f - m\vec{v}_i = \vec{p}_f - \vec{p}_i = \Delta\vec{p} \quad \text{Formula: } \vec{F}\Delta t = \Delta\vec{p}$$

Hence, **Impulse** is the product of force and time that acts on an object to produce a change in momentum.

Real life situation:

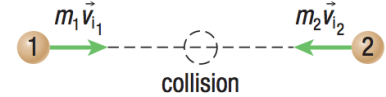
Egg drop challenge! Basically, the challenge is to create a container that will protect an egg from cracking or breaking from a high fall. Could you use what we've just learnt to explain what is the fundamental principle by designing a good egg protector?

Example 2: A 0.160 kg puck is travelling at 5.0 m/s [N]. A slapshot produces a collision that lasts for 0.0020 s and gives the puck a velocity of 40.0 m/s [S]. Calculate the impulse imparted by the hockey stick and determine the average force applied by the stick to the puck.



Part 2: Conservation of momentum in one dimension (5.2)

Law of Conservation of Momentum: When two objects collide in an **isolated** system, the collision does not change the total momentum of the two object. Whatever momentum is lost by one object in the collision is gained by the other. The total momentum of the system is conserved.



$$\text{Formula: } m_1 \vec{v}_{i1} + m_2 \vec{v}_{i2} = m_1 \vec{v}_{f1} + m_2 \vec{v}_{f2}$$

i.e., $\vec{p}_{i1} + \vec{p}_{i2} = \vec{p}_{f1} + \vec{p}_{f2}$, the total momentum of the objects before a collision is equal to the total momentum of the objects after the collision.

You can see the real life application of conservation of momentum everywhere, such as:

- bouncing off of cue ball when hit another billiard ball in a billiards game or,
- football player who catches a pass where two objects come together in a collision, or
- when an object or a collection of objects breaks apart in an explosion (i.e., Rocket propulsion; Fireworks; a squid gains momentum/velocity by ejecting water that possesses its own momentum, etc...).



Example 3: Collision analysis

A hockey player of mass 97 kg skating with a velocity of 9.2 m/s [S] collides head-on with a defence player of mass 105 kg travelling with a velocity of 6.5 m/s [N]. an instant after impact, the two skate together in the same direction. Calculate the final velocity of the two hockey players.