9 Force and Momentum

9.1 Momentum and Impulse

Force is needed to change the velocity of an object.

The **effect of a force** on an object depends on.

- The **mass** of the object.
- The amount of force.

Newton's laws of motion only apply where

- **Gravity is weak**, and
- The speed of objects is **much less than the speed of light**.

The **momentum** of an object is defined as its mass $\times$ velocity. $p = mv$

- The unit of momentum is kgms^{-1}.
- Momentum is a **vector quantity** with the same direction as the object's velocity.

Momentum and Newton's Laws of Motion

Newton's first law tells us that a force is needed to change the momentum of an object.

- If the momentum is constant, there is no resultant force acting on it.
- If a moving object with constant momentum **gains or loses mass**, its **velocity would change** to keep its momentum constant.
  - E.g. a cyclist speeding past a service point collects a water bottle and **gains mass** therefore **loses velocity**.

Newton's second law states the force is proportional to the **change in momentum per second**.

$$\begin{aligned} F \propto \frac{\text{change of momentum}}{\text{time taken}} &= \frac{mv - mu}{t} \\ &= \frac{m(v-u)}{t} \\ &= ma \end{aligned}$$

The change of momentum of an object can be written as $\Delta(mv)$.

$$F = \frac{m\Delta v}{\Delta t} \qquad \text{for constant } m$$
$$F = \frac{v\Delta m}{\Delta t} \qquad \text{for constant } v$$

The **impulse of a force** is defined as force × time for which the force acts.

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

The impulse of a force is equal to the **change of momentum** of the object.

The unit of momentum can be given in the **newton second** (Ns) or kgms^{-1}

Force-time Graphs

The area under the line of a force-time graph represents the change of momentum or the impulse of the force.

9.2 Impact Forces

The **average force of impact** is given by

$$\text{average force of impact } F = \frac{\text{change in momentum}}{\text{contact time}}$$

9.3 Conservation of Momentum

For the forces to be considered a **force pair**, they must be the same type. E.g. weight and normal reaction would not constitute a force pair.

- The Earth exerts a **force due to gravity** on an object, which exerts and equal and opposite force on the Earth.
- A jet engine exerts a **force on the hot gas** in the engine to expel the gas, which exerts an equal and opposite force on the engine.

If no external resultant force acts on the object, interactions between objects can **transfer momentum** between them, but the total momentum does not change.

The **principle of conservation of momentum** states that for a system of interacting objects, the total momentum remains constant, provided no external resultant force acts on the system.

1. Consider two objects collide with each other then separate.
2. They exert **equal and opposite forces** on each other when they are in contact.
3. So the change of momentum of one object is equal and opposite to the change of momentum of the other object.
4. So the total amount of momentum is unchanged.

$$\text{Impact force } F_I = \frac{m_A v_A - m_A u_A}{t}$$

And

$$\text{total final momentum} = \text{total initial momentum}$$

If colliding objects stick together as a result of the collision, they have the **same final velocity**, so

$$(m_A + m_B)V = m_A u_A + m_B u_B$$