# CAIE Physics A-level

## Topic 3: Dynamics

### Notes

# 3 - Dynamics

## 3.1 - Momentum and Newton's Laws of Motion
➔ **Newton's 1st law -** An object will remain at rest or travelling at a constant velocity, until it experiences a resultant force
➔ **Newton's 2nd law -** The acceleration of an object is proportional to the resultant force experienced by the object: $F = ma$ where **F** is the resultant force, **m** is the object's mass and **a** is its acceleration.
It is important to note that the **resultant force and acceleration are always in the same direction**.
➔ **Newton's 3rd law -** For each force experienced by an object, the object exerts an equal and opposite force.

The **mass** of an object is the property of a body and is a **measure of its resistance to acceleration**. The larger the mass of an object, the smaller the acceleration it experiences for a given resultant force experienced. This can be demonstrated by considering Newton's 2nd law: **F = ma**.
For example, object 1 has a mass of 1 kg and object 2 has a mass of 10 kg and they both experience a resultant force of 10 N.

$$a = \frac{F}{m}$$   Object 1: $\frac{10}{1} = 10$ ms⁻²

Object 2: $\frac{10}{10} = 1$ ms⁻²

As you can see, the object with the larger mass (object 2) will experience a smaller acceleration for a given resultant force of 10 N.

**Linear momentum** is the product of mass and velocity of an object.
$$Momentum = mass \times velocity$$

Newton's 2nd law states $F = ma$, therefore, $F = \frac{\Delta(mv)}{\Delta t}$ as $a = \frac{\Delta v}{\Delta t}$.
From this you can see that force is the **rate of change of momentum**.

The **weight** of an object is the **gravitational force experienced by it**, and varies depending on the strength of the gravitational field the object is in.
The weight of a body on Earth can be calculated by finding the **product of its mass and g** (the acceleration due to gravity).
$$Weight = mass \times g$$

## 3.2 - Non-Uniform Motion

A body falling in a uniform gravitational field will experience a constant weight as the strength of a uniform gravitational field is constant. Below is a description of the motion of an object, with an initial velocity of 0 ms⁻¹, in a uniform gravitational field:

1. The object experiences weight downwards and air resistance upwards. As the magnitude of weight is larger than air resistance, it will **accelerate** downwards as **there is a resultant force** (Newton's 2nd law).
2. As the object's velocity increases, the magnitude of air resistance increases, therefore the resultant force and acceleration downwards will decrease.
3. Air resistance will continue increasing up until the point where the magnitude of weight and air resistance is equal. As there is no resultant force, the object travels at a constant velocity, known as the **terminal velocity**.
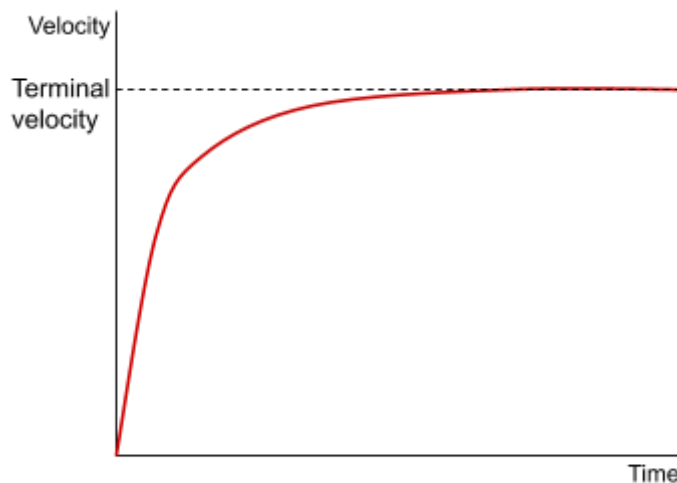


**Air resistance** will affect both the vertical and horizontal components of a projectile's motion as shown in the diagram below:
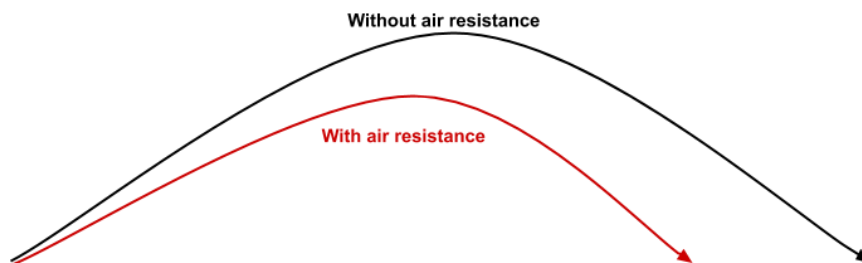


As you can see, with air resistance the maximum height is reached earlier, and the vertical and horizontal distance travelled decreases.

## 3.3 - Linear Momentum and its Conservation

The **principle of conservation of momentum** states that **momentum is always conserved** in any interaction where **no external forces act**.

This means the momentum before an event (e.g a collision) is equal to the momentum after. This fact is used to find the velocity of objects after collisions, for example:
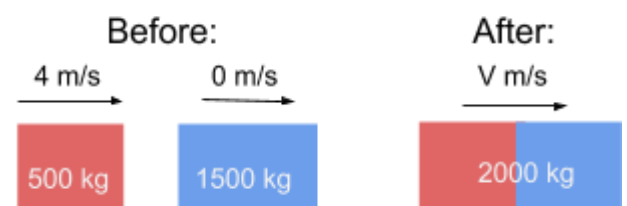
A car with a mass of 500 kg, and a velocity of 4 m/s, collides with a stationary truck with a mass of 1500 kg. The two vehicles join together and move on with a velocity V. Find the value of V.



First find the momentum before the collision.

Total momentum before = $(500 \times 4) + (1500 \times 0)$    = 2000 kgms$^{-1}$

**Total momentum before = Total momentum after**

Therefore, $2000 = 2000 \times V$        $V =$ **1 ms⁻¹**

There are two types of collision:
- **Elastic** - where **both** momentum and kinetic energy are conserved
- **Inelastic** - where **only** momentum is conserved, while some of the kinetic energy is converted into other forms (e.g heat, sound, gravitational potential) and may be larger or smaller after a collision

For a **perfectly elastic collision** the relative speed of approach before the collision **is equal** to the relative speed of separation after the collision.

For example, consider 2 steel balls of equal mass, one is at rest and the other is travelling at a velocity of v. The moving ball collides with the ball which is at rest, and transfers all its momentum and kinetic energy to it. This means that the ball which was at rest will now move away from the other steel ball (which came to rest after the collision), at a velocity equal to the relative speed of approach.
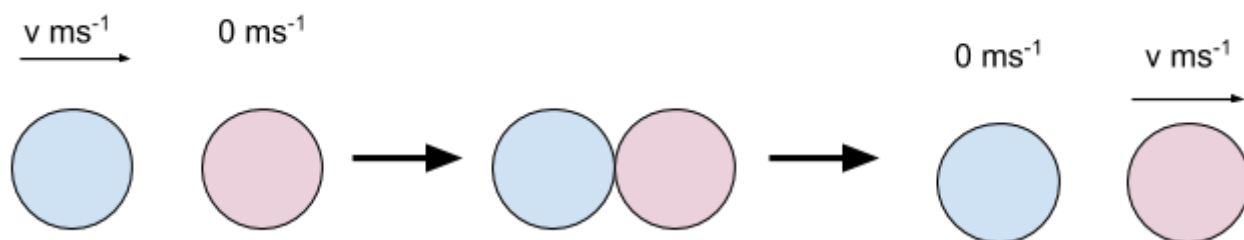
Most collisions are **inelastic**, meaning their kinetic energy is not conserved. For example, in a collision between two vehicles, kinetic energy is converted into elastic potential energy and thermal energy, through the deformation of crumple zones, and also sound energy.