OCR A Physics A-level

Topic 3.5: Newton's laws of motion and momentum

Notes

Newton's laws of motion

Newton's three laws

Newton's three laws are **universal** laws, which can be used to model the motion of objects.

Newton's first law: An object will **remain at rest** or continue to travel with **constant velocity** unless acted upon by a **resultant force**.

Newton's third law: When two objects interact, they exert **equal and opposite forces** on each other. These forces are always of the **same type**, and have the **same magnitude** but they act on **different objects**, and in **opposite directions**.

An example of this would be the gravitational attraction of the Earth to a person standing on it, which is equal and opposite to the gravitational attraction of the person to the Earth.

All forces obey this law, and can all be explained in terms of the **four fundamental forces**. These are the gravitational, electromagnetic, strong nuclear, and weak nuclear forces.

Newton's second law: The net force acting on an object is directly proportional to the **rate of change of momentum**, and is acting in the **same direction**. In SI units, the constant *k* of proportionality is taken as equal to 1.

$$F \propto \frac{\Delta p}{\Delta t} \rightarrow F = k\frac{\Delta p}{\Delta t} \rightarrow F = \frac{\Delta p}{\Delta t}$$

Linear momentum

The linear momentum, *p*, of an object is defined as the product of the object's mass, *m*, and its velocity *v*: $p = mv$. The SI unit for momentum is kgms^{-1}. It is a **vector quantity**, so we must consider both direction and magnitude. In one dimension, positive and negative signs are used to denote the directions.

F = *ma*

F = *ma* is a special case of Newton's second law, and is true where the **mass** of the object **remains constant** during the motion of the object. It can be derived from Newton's second law:

$$F = \frac{\Delta p}{\Delta t} = \frac{mv - mu}{t} = m\left(\frac{v-u}{t}\right) = ma$$

Impulse of a force

The forces acting on a body may vary over time, so we can use impulse to analyse this motion. It is a **measure of change in momentum**, so we can use Newton's second law to derive it. The impulse of a force is defined as the product of the force and the time for which it acts.

$$impulse = \Delta p = F\Delta t = m(v-u)$$

Consequently, the **area under a force-time graph** is the equal to the impulse over that time duration, and is also equal to the change in momentum.

Collisions

Conservation of momentum

When two or more objects collide, there is a transfer of both **momentum and kinetic energy**. Providing there are **no external forces** acting in the system, the total momentum is **conserved**. This means that the total initial momentum will be equal to the total final momentum. The principle of conservation of momentum states that *for a system of interacting objects, the total momentum in a specified direction remains constant, as long as no external forces act on the system.*

In a **perfectly elastic** collision, the total **kinetic energy** of the system will also **remain constant**. However, in an **inelastic** collision, some of the **kinetic energy will be lost** to other forms, such as heat and sound energy. The total energy and the momentum are conserved for both collision types.

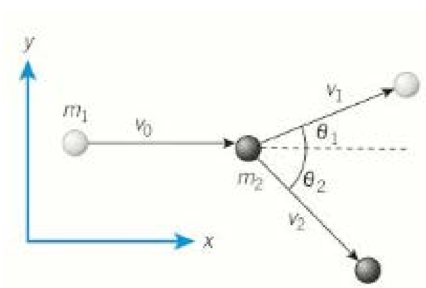
Collisions and interaction of bodies

For a one dimensional collision, the amount of momentum in a direction is always conserved. We ca use the principle of conservation of momentum to formulate:

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

For this formula to work, one direction of movement must be considered as negative, with negative symbols used in the formula for objects traveling in this direction.

In two dimensions, the conservation of momentum still applies, however we must consider **both** the x and the y directions **separately**.



***x* direction:** total initial momentum = total final momentum

$$m_1 v_0 = m_1 v_1 \cos\theta_1 + m_2 v_2 \cos\theta_2$$

***y* direction:** total initial momentum = total final momentum

$$0 = m_1 v_1 \sin\theta_1 + m_2 v_2 \sin\theta_2$$