Module 3 Section 5: Newton’s Laws of Motion and Momentum

Newton’s 1st Law

Newton’s 1st law of motion states that:

“The velocity of an object will not change unless a resultant force acts on it.”

Momentum

The **linear momentum** of an object depends on two things — its mass and velocity. The product of these two values is the momentum of the object.

$$p = m \times v$$

p = linear momentum in $kg\,ms^{-1}$

v = velocity in ms^{-1}

m = mass in kg

Newton’s 2nd law

Newton’s 2nd law of motion says that the rate of change of momentum of an object is equal to the net force which acts on the object.
This can be written as the equation:

$$F = \frac{\Delta p}{\Delta t}$$

F = net force (in N)

$\frac{\Delta p}{\Delta t}$ = rate of change of momentum (in $kg\,ms^{-1}$)

Try to remember:

- The net force is the vector sum of all the forces (page 79).
- The net force is always measured in newtons.
- The mass is always measured in kilograms.
- The change in momentum is always in the same direction as the net force and is measured in $kg\,ms^{-1}$.

Conservation of Momentum

The law of conservation of momentum states, **the vector sum of the momenta of bodies in a system stays constant even if forces act between the bodies, provided there is no external resultant force**. Which means the total momentum before an interaction must be equal to the total momentum after an interaction.

Consider this example:

Before colliding

The total momentum before is:

$p = mv$ = 2.0 × 8.0 + 1.5 × (-4.0)

= 10 kg m s^{-1}

Remember momentum is a vector quantity so the velocity of the green ball is -4.0 m s^{-1}

After colliding

The total momentum after must be 10 kg m s^{-1}.

10 = 2.0 × v + 1.5 × 2.0

Therefore, v = 3.5 m s^{-1}.

This is an example of an **inelastic collision** as the kinetic energy of before the collision is not equal to the kinetic energy after the collision, some **kinetic energy has been lost**.

In an **elastic collision** the kinetic energy before colliding is equal to the kinetic energy afterwards.

Newton’s 3rd Law

There are a few different ways of stating **Newton’s 3rd law**, but the clearest way is:

“If object A exerts a force on object B, then object B exerts an equal but opposite force on object A.”

You’ll also hear the law as “every action has an equal and opposite reaction”. But this can wrongly sound like the forces are both applied to the same object. (If that were the case, you’d get a resultant force of zero and nothing would ever move anywhere.)

The two forces actually represent the same interaction, just seen from two different perspectives:

Impulse

Newton’s Second Law can be rearranged to give:

$$F\Delta t = \Delta p$$

The **impulse** of a force is defined as the product of average force and time:

$$\text{impulse} = F\Delta t$$

So, the impulse on a body is equal to the change in momentum of that body.

$$F\Delta t = \Delta p$$

$F\Delta t$ = impulse in Ns

Δp = change in momentum in $kg\,ms^{-1}$

Elastic and Inelastic collisions

An **elastic collision** is one where momentum is conserved and **kinetic energy** is conserved — i.e. no energy is dissipated as heat, sound, etc. Kinetic energy is the energy that an object has due to its motion.

$$E_K = \frac{1}{2}mv^2$$

E_K = kinetic energy in J

v = velocity in ms^{-1}

m = mass in kg