Impact and Momentum - definition and units

In this leaflet the concepts of Impulse and Momentum will be introduced.

Momentum

If the mass of an object is m and it has a velocity $\mathbf{v}$, then the momentum of the object is defined to be its mass multiplied by its velocity.

$$\boxed{\text{momentum} = m\mathbf{v}}$$

Momentum has both magnitude and direction and thus is a vector quantity. The units of momentum are kg m s^{-1} or newton seconds, N s.

This is often referred to as linear momentum in order to distinguish it from angular momentum.

Worked Example 1.

A cyclist and his bike have a combined mass of 100 kg and are travelling along a straight horizontal road at 9 m s^{-1}. A motorcyclist and her bike, which have a combined mass of 300 kg, travel in the opposite direction at 21 m s^{-1}. What is the momentum of the cyclist and what is the momentum of the motorcyclist?

Solution

If we define the direction of the cyclist as positive, then:

$$\begin{aligned} \text{momentum of cyclist} &= 100 \times 9 &&= 900 \text{ kg m s}^{-1} \\ \text{momentum of motorcyclist} &= 300 \times (-21) &&= -6300 \text{ kg m s}^{-1} \end{aligned}$$

Impulse

If a force $\mathbf{F}$ acts for a short time, t, on a body, the impulse of $\mathbf{F}$ on the body is the quantity $\mathbf{F}t$. It is a vector quantity and like momentum, has units kg m s^{-1} or N s.

$$\boxed{\text{impulse} = \mathbf{F}t}$$

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In general the impulse of **F** is given by $\int \mathbf{F}\,dt$. For motion in one dimension only, $\mathbf{F} = F\mathbf{i}$, $\mathbf{v} = v\mathbf{i}$ and if we integrate Newton's second law of motion, $\mathbf{F} = m\dfrac{d\mathbf{v}}{dt}$, with respect to time, we obtain:

$$\begin{aligned}\text{The impulse of } \mathbf{F} &= \int F\mathbf{i}\,dt \\ &= [m\mathbf{v}]_U^V = mV\mathbf{i} - mU\mathbf{i} = \text{Change in momentum}\end{aligned}$$

where the speed of the body changes from U to V under the action of **F**.

Often impulse is found indirectly by considering the change in momentum of a body, which is especially useful when the force and time are unknown, but both the momentum before and after can be found, as for example in a collision.

Worked Example 2.

A child kicks a stationary football, of mass 0.5 kg, which then moves with a velocity of 15 m s^{-1}. What impulse does the child impart on the football?

Solution

From the formulae given above:

$$\begin{aligned}\text{Impulse} &= \text{Change in momentum} \\ &= \text{final momentum} - \text{initial momentum} \\ &= 0.5 \times 15 - 0.5 \times 0 \\ &= 7.5 \text{ kg m s}^{-1} \text{ (2 s.f.)}\end{aligned}$$

It is interesting to note that this momentum could be produced in a number of ways, e.g. by a force of 10 N acting for a 0.75 seconds or by a force of 30 N acting for 0.25 seconds.

Exercises

1. A rhino, of mass 1800 kg, is running at 9 m s^{-1}. What is the rhino's momentum?

2. The momentum of a bullet, of mass 19 grams, is 8.55 kg m s^{-1}. What is the velocity of the bullet?

3. A badmington player hits a shuttlecock, that came over the net at 32 m s^{-1}, back in the same direction that it came from, with a velocity of 28 m s^{-1}. If the shuttlecock has a mass of 40 grams, what is the impulse that the player (through the racket) imparts on the shuttlecock?

4. A bus, of mass 4000 kg, reduces its speed from 25 m s^{-1} to 12 m s^{-1} in 8 seconds. What is the average braking force?

Answers (All 2 s.f.)

1. 16000 kg m s^{-1} 2. 450 m s^{-1} 3. 2.4 kg m s^{-1} 4. 6500 N.

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