Impulse and collisions

Impulse as change of momentum, force-time graphs, conservation of momentum in one and two dimensions, and elastic and inelastic collisions.

Impulse

Newton's second law in terms of momentum $p = mv$ is

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

so $F\,\Delta t = \Delta p$. The product $F\,\Delta t$ is the **impulse** of the force, with units N s. It equals the **change in momentum**.

> **Impulse** $= F\,\Delta t = \Delta p = mv - mu$**. It is a vector: its direction is the direction of the force.**

Force-time graphs

When the force changes, the impulse is the **area under the force-time graph**. For a graph made of straight lines, use triangles and rectangles.

> TRY IT
>
> A force rises uniformly from 0 to 40 N in 0.10 s and then falls uniformly to 0 in a further 0.10 s. Find the impulse.

Area of the triangle $= \frac{1}{2} \times 0.20 \times 40 = 4.0$ N s.

> TRY IT
>
> The impulse acts on a ball of mass 0.50 kg initially at rest. Find its speed after the force.

$\Delta p = 4.0 = 0.50v$, so $v = 8.0$ m s^{-1}.

Reducing the force

For a given change of momentum, a longer contact time gives a smaller average force. This is why crumple zones, air bags and bending the knees on landing protect the body.

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NOTE

Always take the sign of the velocity into account. A ball hitting a wall at 10 m s^{-1} and rebounding at 8 m s^{-1} has a change of velocity of 18 m s^{-1}, not 2.

Conservation of momentum

In a collision with no external resultant force, the total momentum is the same before and after:

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

TRY IT

A 2.0 kg trolley moving at 3.0 m s^{-1} collides with a stationary 1.0 kg trolley and they stick together. Find their common speed.

$2.0 \times 3.0 = 3.0v$, so $v = 2.0$ m s^{-1}.

In two dimensions

Momentum is a vector, so it is conserved separately in two perpendicular directions. Resolve each velocity into components, apply conservation to each direction, then combine the components.

TRY IT

A 0.20 kg ball moving at 5.0 m s^{-1} hits a stationary ball of the same mass. After the collision the first moves at 3.0 m s^{-1} at 53° to its original direction. Find the speed and direction of the second ball.

Along the original direction: $0.20 \times 5.0 = 0.20 \times 3.0\cos 53° + 0.20v_x$, so $v_x = 5.0 - 1.8 = 3.2$ m s^{-1}.

Perpendicular: $0 = 0.20 \times 3.0 \sin 53° - 0.20v_y$, so $v_y = 2.4$ m s^{-1} (on the other side).

Speed $= \sqrt{3.2^2 + 2.4^2} = 4.0$ m s^{-1} at $\tan^{-1}\dfrac{2.4}{3.2} = 37°$ to the original direction. The two directions are at right angles, $53° + 37° = 90°$, which is what happens in an elastic collision of equal masses.

Elastic and inelastic collisions

- In an **elastic** collision the total **kinetic energy** is conserved. Objects bounce apart, and the relative speed of approach equals the relative speed of separation.
- In an **inelastic** collision some kinetic energy is transferred to thermal energy, sound or deformation. Momentum is **still** conserved.

To decide which, compare total kinetic energy before and after.

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TRY IT

In the sticking collision above, is kinetic energy conserved?

Before: $\frac{1}{2} \times 2.0 \times 3.0^2 = 9.0$ J. After: $\frac{1}{2} \times 3.0 \times 2.0^2 = 6.0$ J. Kinetic energy has been lost, so the collision is inelastic.

Momentum is conserved in every collision with no external force. Kinetic energy is conserved only in an elastic one.

Investigating collisions

In the laboratory, use light gates or video analysis to find the speeds of trolleys or spheres before and after impact. Compare the total momentum and total kinetic energy, and give the percentage change, to see how far momentum is conserved and how much energy is lost.

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