Momentum

An object which is heavy and travelling fast, has a large momentum - it would require a large 'impulse' to slow it down or stop it.

Momentum is thus linked to MASS and VELOCITY, and it has a direction too - it can be positive or negative.

The units is Ns (or kg m s^{-1}).

Momentum = mass x velocity

e.g. A ball of 300g is travelling at 2ms^{-1}
What is its momentum?

u

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v

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m

I

F

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t

Impulse

An impulse is something which **changes the momentum of a particle**.

For example:
- A bat hitting a ball
- Two balls colliding in snooker
- A jerk in a string pulled tight
- A car crashing into a lamp post
- Something speeding up or slowing down

Impulse-momentum principle

Impulse = change in momentum

So, Impulse is the change in momentum

$$I = m(v - u)$$

But it seems like it is also linked to **force** and **time**

$$F = ma \qquad a = \frac{v - u}{t}$$

$$I = m(v - u)$$

$$Ft = m(v - u)$$

e.g. A car of mass 600kg is travelling at $9ms^{-1}$ when a hazard ahead is spotted and the brakes applied, causing a force of 900N resisting its motion. Work out how long it takes for the car to come to rest.

e.g. A ball of mass 2kg is falling vertically under gravity when it hits the ground soil at a speed of $15ms^{-1}$. The ball sinks into the soil, being brought to a stop after 0.4s. Work out the resistive force of the soil on the ball.

$I = mv - mu$ **$I = Ft$** **...therefore $Ft = mv - mu$**

Impulse is a vector! Directions matter!

1. A stone of mass 3 kg is falling at a speed of 18 ms^{-1} when it hits the floor. If the stone is brought to rest by the impact, find the magnitude of the impulse exerted by the floor.

2. A bullet of mass 30 g is fired into a block of wood at a speed of 400 ms^{-1}. The bullet is brought to rest in 0.02 s. Find the average resistance exerted by the block of wood.

3. A truck of mass 1400 kg moving on a straight horizontal track at 2 ms^{-1} runs into fixed buffers and rebounds at 1 ms^{-1}. The average force exerted by the buffers on the truck is 3500 N. How long were the buffers in contact with the truck?

Calculated the impulse exerted on the object in the following cases:

1. A force of 30N is exerted on an object for 0.5s
2. A ball of mass 3kg was travelling at 10m/s is hit and slows to 6m/s without changing direction.
3. A ball of mass 3kg was travelling at 10m/s is hit so that it returns in the opposite direction at a speed of 6m/s
4. A rocket of mass 100kg travelling at 2000m/s hits the ground and stops.

Which of these show the greatest change in momentum?
Can you order them from greatest to least change in momentum?

A particle of mass 1kg travelling at $12ms^{-1}$ and then coming to rest

A particle of mass 1kg travelling at $17ms^{-1}$ and then slowing down to $6ms^{-1}$

A particle of mass 2kg travelling at $4ms^{-1}$ and then rebounding at $3ms^{-1}$

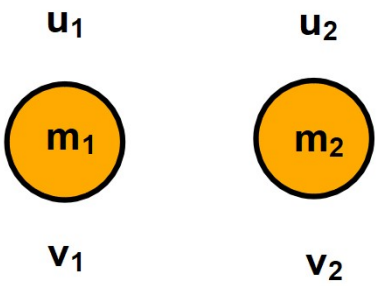
A particle of mass 1kg travelling at $11ms^{-1}$ and then rebounding at $2ms^{-1}$

Principle of Conservation of Momentum

When two bodies collide, each one exerts an equal and opposite force on the other. Which law of Newton's is this?

They are in contact for the same time, so they each exert an impulse on the other of equal magnitude **BUT OPPOSITE DIRECTIO**

The momentum before the collision = the momentum after the collision



These are vectors! You will have to take direction into account!

Example 1

A **particle** P of mass 2kg is moving with **speed** $3ms^{-1}$ on a **smooth** horizontal **plane**. Particle Q of mass 3kg is at **rest** on the plane.
Particle P collides with particle Q and after the collision Q moves off with speed $7/3\ ms^{-1}$. Find:
a) the speed and **direction** of motion of P after the collision
b) the **magnitude** of the impulse received by P in the collision

Example 2

Two particles A and B of masses 2kg and 4kg **respectively** are moving towards each other in opposite directions along the same straight line on a smooth horizontal surface.
The particles collide.
Before the collision the speeds of A and B are $3ms^{-1}$ and $2ms^{-1}$ respectively.
After the collision the direction of motion of A is **reversed** and its speed is $2ms^{-1}$.
Find:
a) the speed and direction of B after the collision
b) the magnitude of the impulse given by A to B in the collision

Example 3

Two particles P and Q, of masses 8kg and 2kg respectively, are connected by a **light inextensible** string.
The particles are at rest on a smooth horizontal plane with the string **slack**.
Particle P is **projected** directly away from Q with speed $4ms^{-1}$.
a) Find the **common speed** of the particles after the string goes **taut**.
b) Find the magnitude of the impulse transmitted through the string when it goes taut.

Example 4

Two particles A and B of masses 2kg and 4kg respectively are moving towards each other in opposite directions along the same straight line on a smooth horizontal surface.
The particles collide. Before the collision the speeds of A and B are $3ms^{-1}$ and $2ms^{-1}$ respectively.
Given that the magnitude of the impulse due to the collision is 7Ns, find:
a) the **velocity** of A after the collision
b) the **velocity** of B after the collision

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Example 5

Unknown values:

Two particles, A and B, of masses m and 4m respectively, are moving in the same direction with speeds of 5u and u respectively, so that A is catching up with B. After they collide, the speed of B is 2u.
Find the velocity of A after the collision.
Find the magnitude of the impulse that A exerts on B.

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Coalescing particles

A particle P of mass 150 g is at rest on a smooth horizontal plane. A second particle Q of mass 100 g is projected along the plane with speed u m s^{-1} and collides directly with P. On impact the particles join together and move on with speed 4 m s^{-1}. Find the value of u.

An explosive charge of mass 150 g is designed to split into two parts, one with mass 100 g and the other with mass 50 g. When the charge is moving at 4 m s^{-1} it splits and the larger part continues to move in the same direction whilst the smaller part moves in the opposite direction. Given that the speed of the larger part is twice the speed of the smaller part, find the speeds of the two parts.

Momentum as a Vector (Year 2 content)

Mass and time are scalar quantities.
Momentum, Force, Velocity and Impulse are all vector quantities.

For one dimensional questions all direction is simply + or -.
For two dimensional questions, all the equations from this chapter can be used with vectors.
You can work separately with **i**, **j** (and **k**) components.

A particle of mass 0.2kg is moving with velocity (10**i** – 5**j**) ms^{-1} when it receives an impulse (3**i** – 2**j**)Ns. Find the new velocity of the particle.

$$\boldsymbol{I} = m(\boldsymbol{v} - \boldsymbol{u})$$

$$m_1\boldsymbol{u_1} + m_2\boldsymbol{u_2} = m_1\boldsymbol{v_1} + m_2\boldsymbol{v_2}$$

To find the **magnitude** of a vector (e.g. Impulse Momentum) use Pythagoras
To find the **direction** of a vector use trigonometry

Tip: Remember if the question asks for speed, this is the magnitude of velocity, if it asks for distance this is the magnitude of displacement.

An ice hockey puck of mass 0.17 kg receives an impulse **Q** Ns . Immediately before the impulse the velocity of the puck is (10**i** + 5**j**) ms^{-1} and immediately afterwards its velocity is (15**i** – 7**j**) ms^{-1}. Find the magnitude of **Q** and the angle between **Q** and **i**.

A particle of mass 0.15kg is moving with velocity $(20\mathbf{i} - 10\mathbf{j})\ ms^{-1}$ when it collides with a particle of mass 0.25kg moving with velocity $(16\mathbf{i} - 8\mathbf{j})\ ms^{-1}$. The two particles coalesce and form one particle of mass 0.4kg. Find the velocity of the combined particle.

Your Turn

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A tennis ball of mass 0.1 kg is hit by a racquet. Immediately before being hit, the ball has velocity $30\mathbf{i}$ m s^{-1}. The racquet exerts an impulse of $(-2\mathbf{i} - 4\mathbf{j})$ N s on the ball. By modelling the ball as a particle, find the velocity of the ball immediately after being hit.

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