AS Level Physics

Chapter 6 – Further Mechanics

6.1.1 Impulse

Notes

NEWTON'S THREE LAWS OF MOTION

Newton's 2nd Law of Motion

Newton's 2nd Law of motion states:

"The rate of change of momentum of an object is directly proportional to the applied resultant force and occurs in the direction of the resultant force"

- In other words, the resultant force is proportional to the change of momentum per second.
- At GCSE you learn that Newton's 2nd law is defined as $F = ma$ (force = mass x acceleration). At A-level we will look at how this equation is derived from Newton's 2nd law in its general form as stated above. But first you need to know what momentum is:

Momentum:

The momentum of an object is the product of its mass and velocity.

$$\boldsymbol{p} = \boldsymbol{m} \times \boldsymbol{v}$$

where:
p = Momentum measured in $kg\ ms^{-1}$.
m = mass measured in kg.
v = velocity measured in ms^{-1}.

Momentum is a vector and therefore has both magnitude and direction. This means momentum to the right can be considered positive and momentum to the left can be negative.

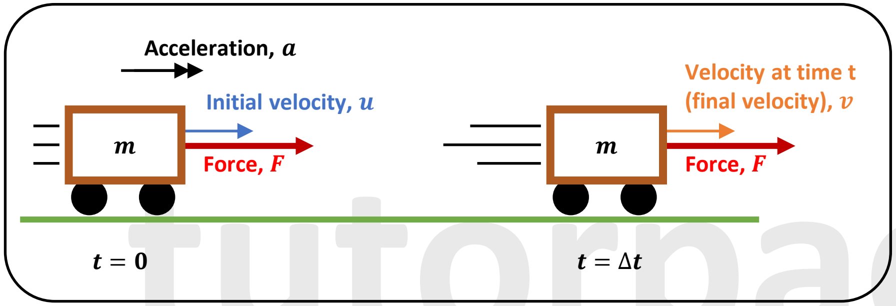
NEWTON'S THREE LAWS OF MOTION

Newton's 2nd Law of Motion

- Note, force acting on an object can cause a change in its momentum. A large force results in a greater rate at which the objects momentum changes.
- E.g. the harder you throw a ball, the greater is its rate of change of momentum and the more difficult it is to catch.

Newton's 2nd Law of Motion

- Now let's look at how $F = ma$ is derived from Newton's 2nd law.
- Consider an object of a constant **mass (m)** acted on by a **constant force, F**. This causes the object to move with a **constant acceleration (a)** causing the velocity to change from a **initial velocity (u),** at **time zero ($t = 0$),** to a **final velocity (v)** in a **time ($t = \Delta t$)** without a change of direction.



- The initial momentum of the object:

$$p_i = mu$$

- The final momentum of the object:

$$p_f = mv$$

- Therefore the momentum change:

$$\Delta p = final\ momentum - initial\ momentum$$

$$\Delta p = mv - mu$$

NEWTON'S THREE LAWS OF MOTION

Newton's 2nd Law of Motion

- According to Newton's 2nd law, the force is proportional to the rate of change of momentum, therefore:

$$F \propto \frac{change\ of\ momentum}{time\ taken} = \frac{\Delta p}{\Delta t}$$

$$F = \frac{mv - mu}{\Delta t}$$

$$F = \frac{m(v - u)}{\Delta t}$$

$$Therefore, F = ma$$

But we know that acceleration is:
$a = \frac{(v-u)}{\Delta t}$
And therefore we substitute a in the equation.

Where $a = \frac{(v-u)}{\Delta t}$ = the acceleration of the object.

- So from Newtons 2nd Law we have confirmed:

$$Resultant\ force\ (F_R) \propto rateof\ change\ of\ momentum\ (= ma)$$

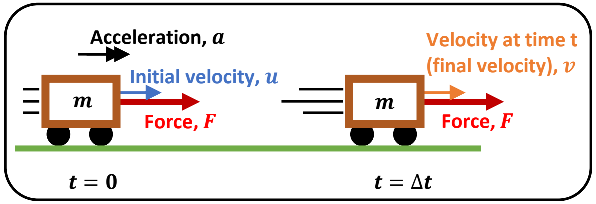
- This proportionality relationship can be written as below:

$$F_R = kma, \qquad where\ k = constant\ of\ proportionality$$

- Typically, k is made to equal 1 by defining the unit force (1 N) as the amount of force that gives an object, of mass 1kg, an acceleration of $1\ ms^{-2}$.
- Therefore, $k = 1$, gives us $F = ma$ following from Newton's 2nd law.
- Note: $F = ma$ is only valid so long as the mass of the object is constant.

IMPULSE = FΔt

An object with constant mass, m, acted upon by a constant force, F, which changes its velocity from initial velocity, u, to a final velocity, v, in time, t.



From Newton's 2nd law:

$$Resultant\ force = rate\ of\ change\ of\ momentum$$

$$F = \frac{mv - mu}{\Delta t}$$

Rearranging this equation gives:

$$F\Delta t = mv - mu$$

Therefore:

$$\boldsymbol{Impulse = F\Delta t = mv - mu}$$

Impulse $(Ns\ or\ kgms^{-1})$; F (N); Δt (s); m (kg); v, u (ms^{-1})

$$\boldsymbol{Impulse = Resultant\ Force \times time = momentum\ change}$$

Impulse $(Ns\ or\ kgms^{-1})$; Resultant Force (N); time (s); momentum change $(kgms^{-1})$

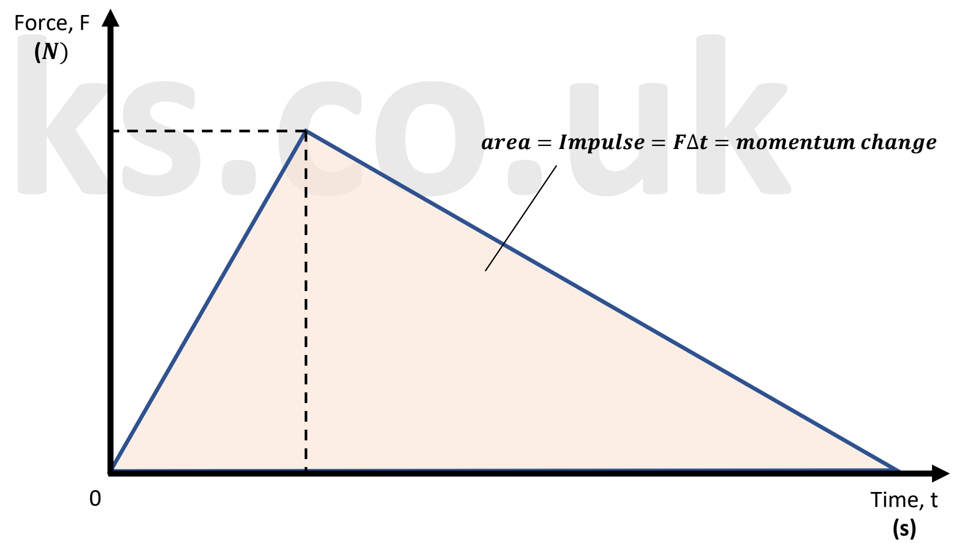
IMPULSE = FΔt

Force against time graph

Therefore an Impulse is the product of the magnitude of a force applied on an object and the time during which it is applied.

For example, when you kick a ball, an impulse is applied to the ball. You apply a force on the ball for a short period of time.

The area enclosed by a force against time graph represents the change of momentum and in turn impulse. This shows that the analysis for change in momentum is not only produced by a constant force but can also apply to a varying force.

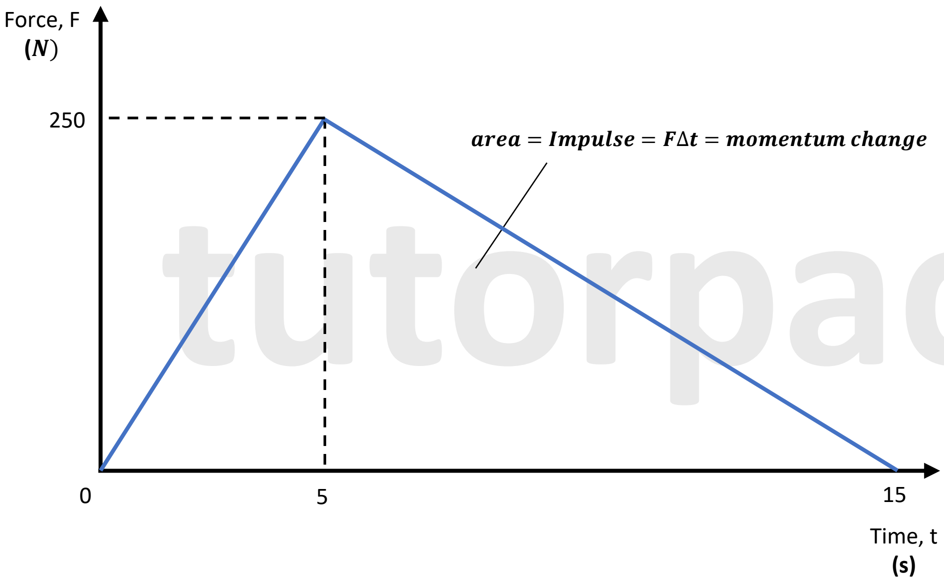


IMPULSE = FΔt

Worked Example 1:

A force acting on an object varies with time as demonstrated in the Force-time graph.

a) Calculate the impulse given to the object in a time of 15 seconds using the graph.



Solution:

$Impulse = change\ of\ momentum = Area\ enclosed\ by\ the\ F/t\ graph$

$$= \frac{1}{2} \times 15s \times 250N$$

$$= 1875\ Ns\ (or\ kgms^{-1})$$

IMPULSE = FΔt

Worked Example 2:

A force of 6 N acts for 12s on a 45kg object which is initially at rest.

Calculate:

a) The change of momentum of the object,

b) The velocity of the object at 12 s.

Solution:

a) Using: $\boldsymbol{Impulse = change\ of\ momentum = F\Delta t}$

Therefore:

$$change\ of\ momentum = F\Delta t = 6\ N \times 12\ s$$

$$\boldsymbol{Change\ of\ momentum = 72\ Ns}$$

b) Using: $\boldsymbol{change\ of\ momentum = F\Delta t = mv - mu}$

Initially the object is at rest therefore initial velocity, $u = 0ms^{-1}$

$$72\ Ns = (45\ kg)v - (45kg)(0ms^{-1})$$

$$v = \frac{72Ns}{45kg}$$

$$\boldsymbol{v = 1.6\ ms^{-1}}$$

IMPULSE = FΔt

Implications of impulse and change of momentum:

- Applying a large force for a short time or a small force for a long time gives us the impulse needed to accelerate an object at rest or decelerate a moving object and bring it to rest. This means:

A large duration in time (Δt) means a small force (F) exerted for a given change in momentum.

Remember:
$F = \frac{mv-mu}{\Delta t}$,
Therefore if you increase time you reduce the force.

- Crumple zones are used in front of cars to reduce the force exerted on the car and its passengers when involved in a crash. This is done by crumple zones collapsing slowly on impact and increasing the time taken for the car to come to a rest.

- In many sports where you hit a ball (i.e. football, tennis or baseball) players try to increase contact time between the foot, racquet or bat and the ball in order to maximise the balls speed.

- This maximises the impulse given to the ball, producing a greater change in momentum.

Remember:
$Impulse = F\Delta t = mv - mu$
Therefore if you increase contact time and speed the impulse also increases.

Please see '6.1.2 Impulse Worked Examples' pack for exam style questions.

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