

Newton's laws of motion

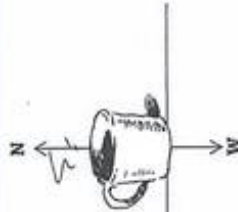
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Newton's first law

1

Newton's first law of motion:

An object will either stay at rest or move with constant velocity unless acted upon by an external net force.



If a coffee mug is sitting at rest on the table, Newton's first law tells us that the forces acting on the mug must be balanced ($N = W$).

On the other hand, if we know that the forces acting on the mug are balanced, and there is no net force, then Newton's first law tells us that the mug is either at rest or moving with constant velocity.

Exam Tip!
You will be expected to identify that if an object is at rest or moving with constant velocity, then the forces on that object are balanced – there is no resultant force.

What does Newton's first law tell us?

- A net force is needed to change an object's speed or direction (acceleration).
- An object at rest or travelling with constant velocity has no net force acting on it.

Newton's second law

2

Newton's second law of motion:

The net force acting on an object is directly proportional to its rate of change of momentum, and is in the same direction.

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

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

We can define the constant of proportionality k as 1 by defining the unit of force:

1 N = the force needed to accelerate 1 kg mass at a rate of 1 m s^{-2}

then,

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

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



If we know that the car is accelerating towards the right, then we know that there must be a resultant force acting on the car directed towards the right and, therefore, $F_{\text{eng}} > F_{\text{fric}} + F_{\text{air}}$.

On the other hand, if we know that the engine force F_{eng} is greater than $F_{\text{fric}} + F_{\text{air}}$, then we know that there is a resultant force towards the right and the car must, therefore, be accelerating to the right.

The special case: constant mass

If we take the case where mass m is constant, then the equation detailing Newton's second law can be written in an alternative form. Say a constant force F is acting on mass m that has initial velocity u . Then, after time t of the force being applied, it reaches its final velocity v , and we can say

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

$$F = \frac{m \Delta v}{\Delta t}$$

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

$$F = ma$$

Momentum

Momentum:

Momentum is a vector quantity and has the units kg m s^{-1} .

Conservation of momentum:

For a closed system, the total momentum in a given direction is conserved as long as no external force acts on the system.

Momentum equation:

$$p = mv$$

Exam Tip!

You will be expected to apply the principle of conservation of momentum to collision problems: The total linear momentum before the collision is equal to the total linear momentum after the collision.

Related equations

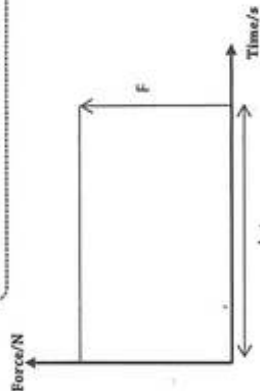
$$F = \text{rate of change of momentum}$$

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

$$\text{Impulse} = \text{change in momentum}$$

$$\text{Impulse} = \Delta(mv)$$

$$\text{Impulse} = \Delta(mv) = F \Delta t$$



Area under $F-t$ graph = $F \times \Delta t$
Area under $F-t$ graph = Impulse

Note: Cars travelling at greater speeds will require greater deceleration to stop and, therefore, use more fuel.

The force of impact during a car collision will also be greater if the car is travelling at a high speed.

Elastic collision: a collision where the kinetic energy is conserved during the collision

Inelastic collision: a collision where the kinetic energy is not conserved during the collision

Crumple zones

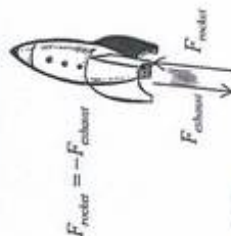
Vehicles are designed to have sections of their body that are intentionally meant to crumple in an accident. This extends the time and distance over which the car comes to a halt, decreasing acceleration and so changing the force acting on drivers and passengers. Air bags work in a similar way.

Newton's third law

In other words, forces come in pairs:

- If you push a door with a force of 10 N, the door will push back on your hand with 10 N, in the opposite direction.

- The weight of your person is exerting a force on the floor in the downwards direction, and the floor is exerting an equal force back on the soles of your feet in the upwards direction (this is what stops you falling through the earth).



Newton's third law is used in the explanation of how a rocket launches. The rocket's engine exerts a force on the exhaust gases and the gases exert an equal and opposite force on the rocket's engine, propelling the rocket upwards.

3

Newton's third law of motion:

If object A exerts a force on object B, then B will exert an equal but opposite force on object A.