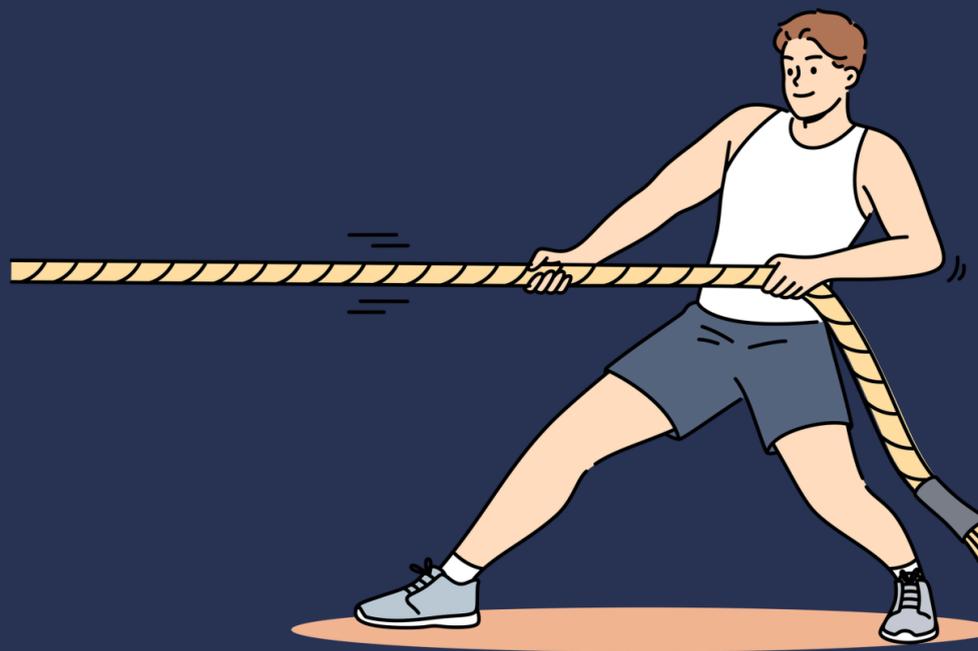


# GCSE PHYSICS

## FORCES



# CHECKLIST

4.5.1 Forces and Their Interactions				
Topic	Success Criteria	Progress		
Scalar and Vector Quantities	I can explain the difference between scalar and vector quantities.			
	I can describe how to represent a vector quantity.			
Contact and Non-Contact Forces	I can give a definition for the term 'force'.			
	I can describe the difference between a contact and a non-contact force.			
	I can give examples of contact forces.			
	I can give examples of non-contact forces.			
	I can state whether force is a scalar or vector quantity.			
	I can describe the interaction between pairs of objects which produce a force on each object.			
Gravity	I can describe what weight is.			
	I can describe what affects the force of gravity close to the Earth.			
	I can describe what affects the weight of an object.			
	I can recall and apply the correct equation to calculate the weight of an object.			
	I can rearrange the equation linking gravitational field strength, mass and weight to calculate gravitational field strength or mass.			
	I can describe where the weight of an object can be considered to act.			
	I can describe how the weight and mass of an object are related.			
	I can name the piece of equipment used to measure weight.			

# CHECKLIST

Topic	Success Criteria	Progress		
Resultant Forces	I can explain what is meant by a resultant force.			
	I can calculate the resultant of two forces that act in a straight line.			
	(HT only) I can describe examples of the forces acting on an isolated object or system.			
	(HT only) I can use free body diagrams to describe qualitatively examples where several forces lead to a resultant force on an object, including balanced forces when the resultant force is zero.			
	(HT only) I can describe the relationship between a single force and its two components when it is resolved.			
	(HT only) I can use vector diagrams to illustrate the resolution of a single force into two components, to include both magnitude and direction.			
	(HT only) I can use vector diagrams to illustrate equilibrium situations, to include both magnitude and direction.			
	(HT only) I can use vector diagrams to determine the resultant of two forces, to include both magnitude and direction.			

## 4.5.2 Work Done and Energy Transfer

Topic	Success Criteria	Progress		
Work Done and Energy Transfer	I can describe how force causes work to be done on an object.			
	I can recall and apply the correct equation to calculate the work done by a force on an object.			
	I can rearrange the equation linking distance, force and work done to calculate the force or the distance moved by an object along the line of action of a force.			
	I can convert between newton-metres and joules.			
	I can describe the energy transfer involved when work is done.			
	I can explain how work done against the frictional forces acting on an object affects the temperature of an object.			

# CHECKLIST

4.5.3 Forces and Elasticity			
Topic	Success Criteria	Progress	
Forces and Elasticity	I can give examples of the forces involved in stretching, bending, or compressing an object.		
	I can explain why, to change the shape of a stationary object, more than one force has to be applied.		
	I can describe the difference between elastic deformation and inelastic deformation caused by stretching forces.		
	I can describe the relationship between the extension of an elastic object and the force applied.		
	I can recall and apply the correct equation to calculate the force applied to a spring.		
	I can rearrange the equation linking extension, force and spring constant to calculate the spring constant or extension of an elastic object.		
	I can describe the relationship between the work done on a spring and the elastic potential energy stored, provided the spring is not inelastically deformed.		
	I can describe the difference between a linear and non-linear relationship between force and extension.		
	I can apply the correct equation from the physics equation sheet to calculate the work done in stretching (or compressing) a spring (up to the limit of proportionality).		
	I can calculate relevant values of stored energy and energy transfers.		
	I can interpret data from an investigation of the relationship between the extension of an elastic object and the force applied.		
	I can describe a method to investigate the relationship between force and extension for a spring (required practical activity 6).		

# CHECKLIST

4.5.4 Moments, Levers and Gears			
Topic	Success Criteria	Progress	
Moments, Levers and Gears	I can describe examples in which forces cause rotation.		
	I can explain what is meant by the moment of a force.		
	I can recall and apply the correct equation to calculate the moment of a force.		
	I can rearrange the equation linking force, distance and the moment of a force to calculate the size of a force or its distance from a pivot.		
	I can describe how the total clockwise movement about a pivot compares to the total anti-clockwise movement about that pivot if an object is balanced.		
	I can explain how levers and gears transmit the rotational effects of forces.		

Topic	Success Criteria	Progress	
Velocity	I can give a definition for velocity.		
	I can state whether velocity is a scalar or vector quantity.		
	(HT only) I can explain qualitatively, with examples, how speed and velocity are affected by motion in a circle.		
The Distance-Time Relationship	I can describe what a distance-time graph can be used to represent.		
	I can state what can be calculated from the gradient of a distance-time graph.		
	(HT only) I can describe how to use a distance-time graph to calculate the speed of an accelerating object at any particular time.		
	I can draw distance-time graphs from measurements.		
	I can interpret lines and slopes of distance-time graphs to translate the graphical information into numerical form.		
	I can determine speed from a distance-time graph.		

# CHECKLIST

4.5.5 Pressure and Pressure Differences in Fluids			
Topic	Success Criteria	Progress	
Pressure in a Fluid 1	I can name the states of matter that can be a fluid.		
	I can describe the direction of the force caused by the pressure in fluids.		
	I can recall and apply the correct equation to calculate the pressure at the surface of a fluid.		
	I can rearrange the equation linking area, force and pressure to calculate the force normal to a surface or the area of that surface.		
Pressure in a Fluid 2 (HT Only)	I can calculate the pressure due to a column of liquid by applying the correct equation from the physics equation sheet.		
	I can rearrange the equation linking density of the liquid, height of the column, gravitational field strength and pressure to calculate the height of the column, the density of the liquid or the gravitational field strength.		
	I can explain why, in a liquid, pressure at a point increases with the height of the column of liquid above that point.		
	I can explain why, in a liquid, pressure at a point increases with the density of the liquid.		
	I can calculate the differences in pressure at different depths in a liquid.		
	I can explain what causes upthrust on an object in a fluid.		
	I can describe the factors which influence floating and sinking.		
Atmospheric Pressure	I can state what the Earth's atmosphere is.		
	I can describe what happens to the atmosphere with increasing altitude.		
	I can describe a simple model of the Earth's atmosphere and of atmospheric pressure.		
	I can explain why atmospheric pressure varies with height above a surface.		

# CHECKLIST

4.5.6 Forces and Motion			
4.5.6.1 Describing Motion along a Line			
Topic	Success Criteria	Progress	
Distance and Displacement	I can give a definition for distance.		
	I can state whether distance is a scalar or vector quantity.		
	I can give a definition for displacement.		
	I can state whether displacement is a scalar or vector quantity.		
	I can express displacement in terms of both magnitude and direction.		
Speed	I can state whether speed is a scalar or vector quantity.		
	I can describe what happens to speed when people walk, run or travel in a car.		
	I can give some factors that affect the speed at which a person can walk, run or cycle.		
	I can recall the typical speed for a person walking.		
	I can recall the typical speed for a person running.		
	I can recall the typical speed for a person cycling.		
	I can recall the typical values of speed for different types of transportation systems.		
	I can give two examples of things other than objects that have varying speed.		
	I can give a typical value for the speed of sound in air.		
	I can make measurements of distance and time.		
	I can calculate the speed of an object from measurements of the distance and time.		
	I can recall and apply the correct equation to calculate the distance travelled by an object moving at a constant speed.		
	I can rearrange the equation linking distance travelled, speed and time to calculate the speed of an object or the time taken to travel a particular distance.		
I can calculate the average speed for an object with non-uniform motion.			

# CHECKLIST

Topic	Success Criteria	Progress		
Acceleration	I can recall and apply the correct equation to calculate the average acceleration of an object.			
	I can rearrange the equation linking acceleration, change in velocity and time taken to calculate the change in velocity or time taken for an accelerating object.			
	I can give the term used to describe an object that is slowing down.			
	I can estimate the magnitude of everyday accelerations.			
	I can describe how to use a distance-time graph to calculate acceleration.			
	(HT only) I can describe how to calculate the distance travelled by an object (or displacement of an object) from a velocity-time graph.			
	I can draw velocity-time graphs from measurements.			
	I can interpret lines and slopes of velocity-time graphs to determine acceleration.			
	(HT only) I can interpret closed areas in velocity-time graphs to determine distance travelled (or displacement).			
	I can apply the equation linking final velocity, initial velocity, acceleration and distance from the physics equation sheet.			
	I can rearrange the equation linking final velocity, initial velocity, acceleration and distance from the physics equation sheet.			
	I can state the approximate acceleration of an object falling freely under gravity near the Earth's surface.			
	I can interpret the changing motion of an object falling through a fluid in terms of the forces acting on it.			
	I can explain what is meant by terminal velocity.			
I can draw and interpret velocity-time graphs for objects that reach terminal velocity.				

# CHECKLIST

4.5.6.2 Forces, Accelerations and Newton's Laws of Motion				
Topic	Success Criteria	Progress		
Newton's First Law	I can state Newton's First Law.			
	I can describe the relationship between the resistive forces and the driving forces acting on an object when it is travelling at a steady speed.			
	I can apply Newton's First Law to explain the motion of objects moving with a uniform velocity.			
	I can apply Newton's First Law to explain the motion of objects where speed and/or direction changes.			
	(HT only) I can give the term used to describe the tendency of objects to continue in their state of rest or of uniform motion.			
Newton's Second Law	I can state Newton's Second Law.			
	I can recognise and use the symbol for proportionality.			
	I can recall and apply the correct equation to calculate the resultant force acting on an accelerating object.			
	I can rearrange the equation linking acceleration, mass and resultant force to calculate the acceleration or the mass of an object.			
	(HT only) I can explain what inertial mass is.			
	(HT only) I can define inertial mass as a ratio of other variables.			
	I can estimate the speed, accelerations and forces involved in large accelerations for everyday road transport.			
	I can recognise and use the symbol that indicates an approximate value.			
	I can describe a method to investigate the effect of varying the force on the acceleration of an object of constant mass (required practical activity 7).			
	I can describe a method to investigate the effect of varying the mass of an object on the acceleration produced by a constant force (required practical activity 7).			
Newton's Third Law	I can state Newton's Third Law.			
	I can apply Newton's Third Law to examples of equilibrium situations.			

# CHECKLIST

4.5.6.3 Forces and Braking				
Topic	Success Criteria	Progress		
Stopping Distance	I can describe the two distances that make up the stopping distance of a vehicle.			
	I can describe how the speed of the vehicle affects the stopping distance for a given braking force.			
	I can estimate how the distance for a vehicle to make an emergency stop varies over a range of speeds typical for that vehicle.			
	I can interpret graphs relating to stopping distance for a range of vehicles.			
Reaction Time	I can give the typical range of reaction times for a person.			
	I can name four factors that can affect a driver's reaction time.			
	I can explain methods to measure human reaction times and recall typical results.			
	I can interpret and evaluate measurements from simple methods to measure the different reaction times of students.			
	I can evaluate the effect of various factors on thinking distance based on given data.			
Factors Affecting Braking Distance 1	I can describe what affects the braking distance of a vehicle.			
	I can describe what is meant by poor road conditions.			
	I can describe what is meant by poor condition of a vehicle.			
	I can explain the factors which affect the distance required for road transport vehicles to come to rest in emergencies, and the implications for safety.			
	I can estimate how the distance required for road vehicles to stop in an emergency varies over a range of typical speeds.			
Factors Affecting Braking Distance 2	I can explain the energy transfers involved when a force is applied to the brakes of a vehicle.			
	I can explain how the speed of the vehicle will affect the braking force needed to stop a vehicle in a certain distance.			
	I can explain how the size of the braking force will affect the deceleration of a vehicle.			
	I can explain the dangers caused by large decelerations.			

# CHECKLIST

4.5.7 Momentum (HT Only)			
Topic	Success Criteria	Progress	
Momentum is a Property of Moving Objects	I can recall and apply the correct equation to calculate the momentum of a moving object.		
	I can rearrange the equation linking mass, momentum and velocity to calculate the mass or velocity of a moving object.		
Conservation of Momentum	I can describe what is meant by the conservation of momentum.		
	I can describe and explain examples of momentum in an event, such as a collision.		
	I can complete calculations involving an event, such as the collision of two objects.		
Changes in Momentum	I can explain what causes a change in momentum.		
	I can combine two equations to show that force is equal to the rate of change of momentum.		
	I can apply the equation linking force, change in momentum and time taken from the physics equation sheet.		
	I can rearrange the equation linking force, change in momentum and time taken from the physics equation sheet.		
	I can reference the concept of rate of change of momentum to explain safety features such as: <ul style="list-style-type: none"> <li>• air bags;</li> <li>• seat belts;</li> <li>• gymnasium crash mats;</li> <li>• cycle helmets;</li> <li>• cushioned surfaces for playgrounds.</li> </ul>		
	I can apply equations relating force, mass, velocity and acceleration to explain how the changes involved are interrelated.		

# SCALAR QUANTITIES

Scalars describe quantities where direction does not affect the outcome.

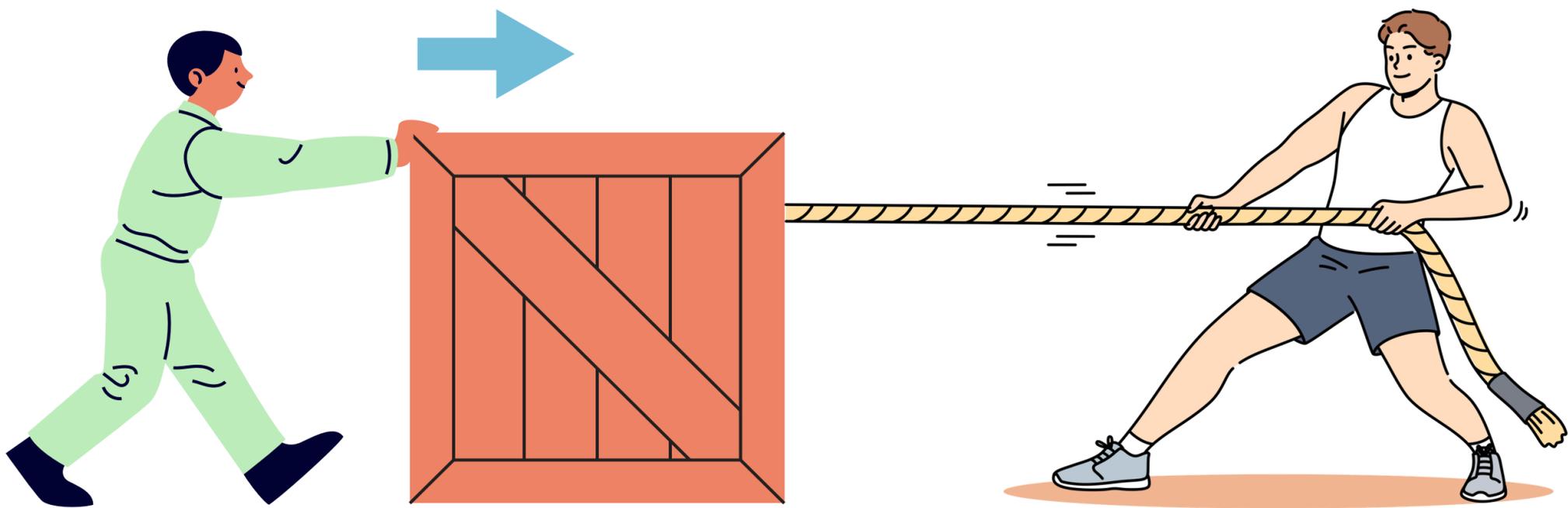
For example, if you say an object has a mass of 5 kg, it does not matter whether the object is moving north, south, or not moving at all – the mass stays the same. Scalars are simpler to work with mathematically because they are represented by a single number with units.

## Uses / Importance

- Used in calculations where direction is irrelevant
- Forms the foundation of basic physics calculations
- Easier to measure directly

## Examples

- Mass (kg) – amount of matter
- Distance (m) – total length travelled
- Speed (m/s) – how fast something moves
- Time (s) – duration
- Energy (J) – capacity to do work
- Temperature ( $^{\circ}\text{C}$  or K) – degree of hotness



# VECTOR QUANTITIES

Vectors do not just tell us how much, but also which way.  
Direction is crucial because it changes the physical effect.

## For example:

- A force of 10 N to the right is not the same as 10 N to the left.
- A velocity of 20 m/s north is different from 20 m/s south.

Because direction matters, vectors are often represented using arrows.

## Uses / Importance

- Essential for analysing motion
- Required for force diagrams
- Needed to calculate resultant forces

## Examples

- Displacement (m in a direction)
- Velocity (m/s in a direction)
- Force (N in a direction)
- Weight
- Acceleration



# REPRESENTING VECTORS

## When drawing vectors:

- A longer arrow means a larger magnitude
- The angle or orientation of the arrow shows direction

This method allows us to visually compare vectors.

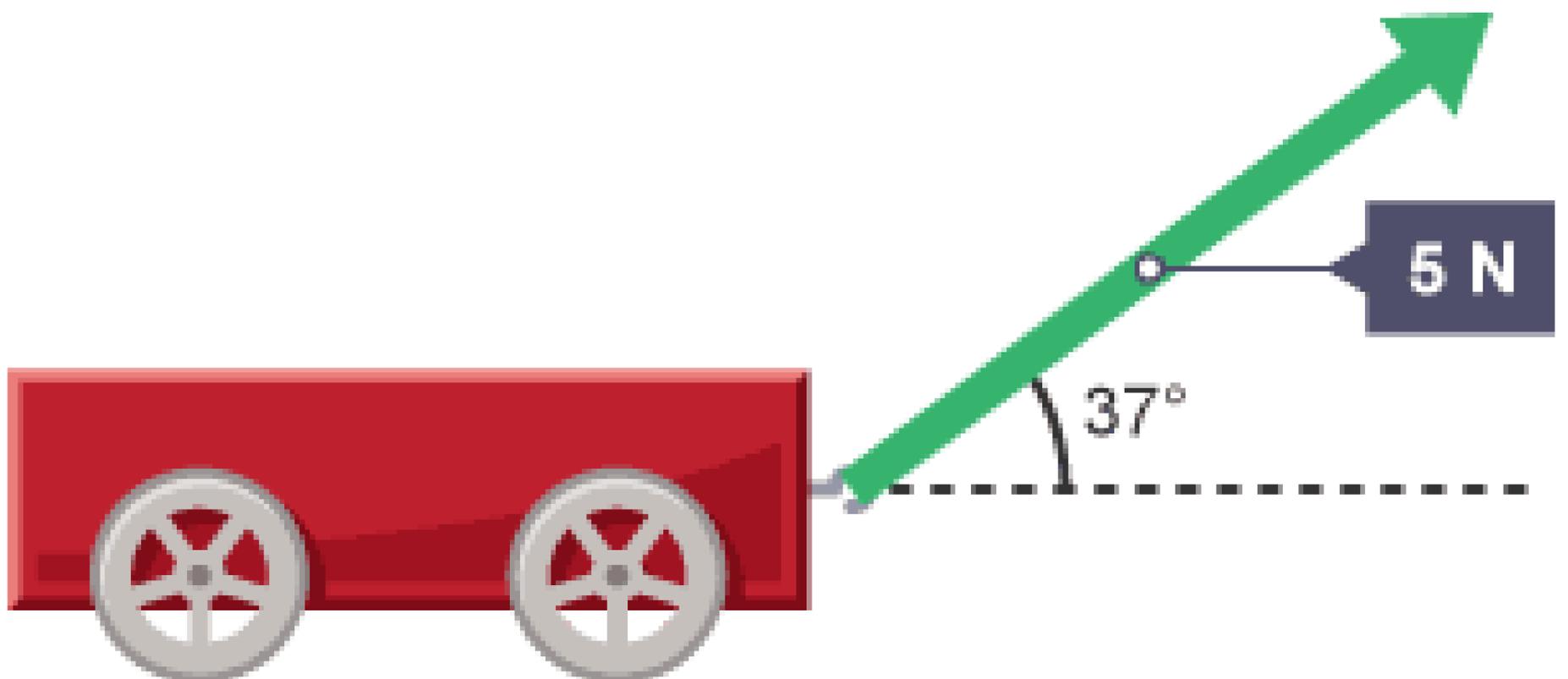
## Uses

- Drawing force diagrams
- Comparing velocities or forces
- Finding resultant forces graphically

## Example

If one tennis ball moves at 5 m/s and another at 10 m/s in the same direction:

- The 10 m/s arrow is drawn twice as long



# FORCES

Forces arise whenever objects interact.

They can act by:

- Touching (contact forces)
- Acting at a distance (non-contact forces)

## Effects of Forces

A force can:

- Change speed (speed up or slow down)
- Change direction
- Change shape

## Examples

- Engine thrust increases speed
- Gravity changes direction of a comet
- Compression squashes a spring



# CONTACT FORCES

Contact forces act only when two objects are physically touching.

## FRICTION

A force that opposes motion between two surfaces in contact.

Explanation:

Friction always acts in the opposite direction to motion or attempted motion.

**Example:**

- Walking without slipping
- Braking in cars
- Writing with a pen

## AIR RESISTANCE

Air resistance is friction with air particles that increases with speed because more air particles are hit per second

**That's why:**

- falling objects eventually reach terminal velocity
- parachutes work

## TENSION

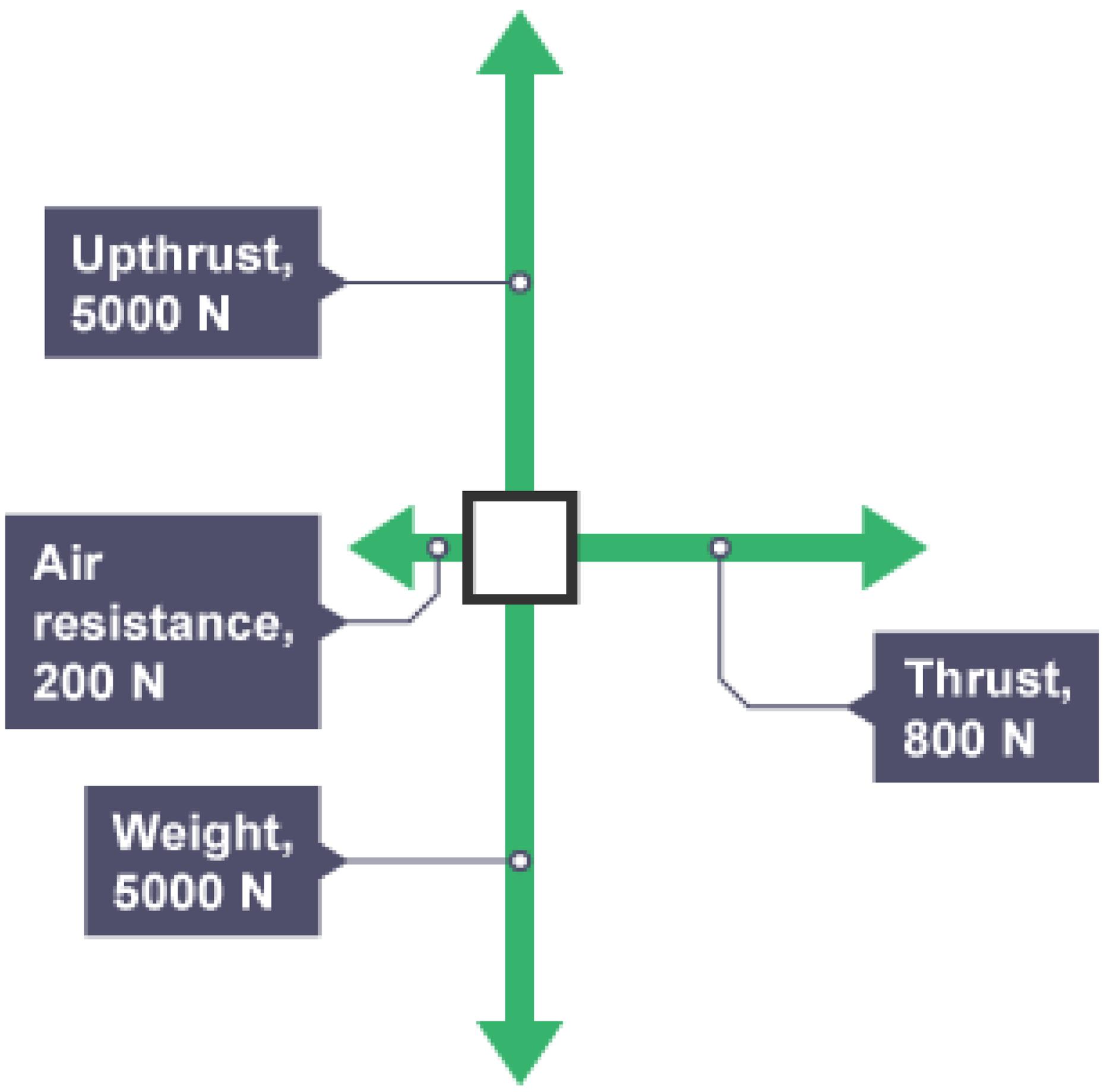
Tension exists inside the material.

Key ideas:

- Rope pulls on object
- Object pulls on rope
- Tension is the rope's response

This is why:

- tension always acts away from the object
- there is no tension if rope is slack



# NON CONTACT FORCE

A region where an object experiences a force without contact

## GRAVITATIONAL FORCE

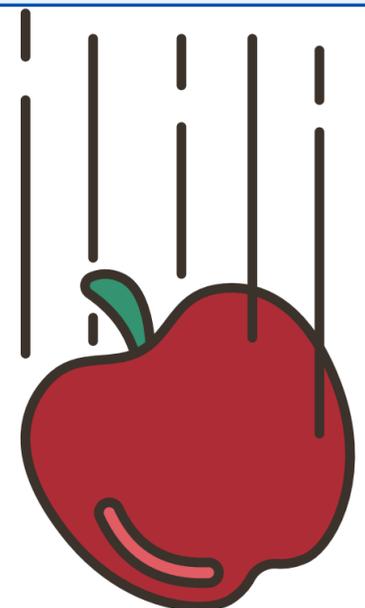
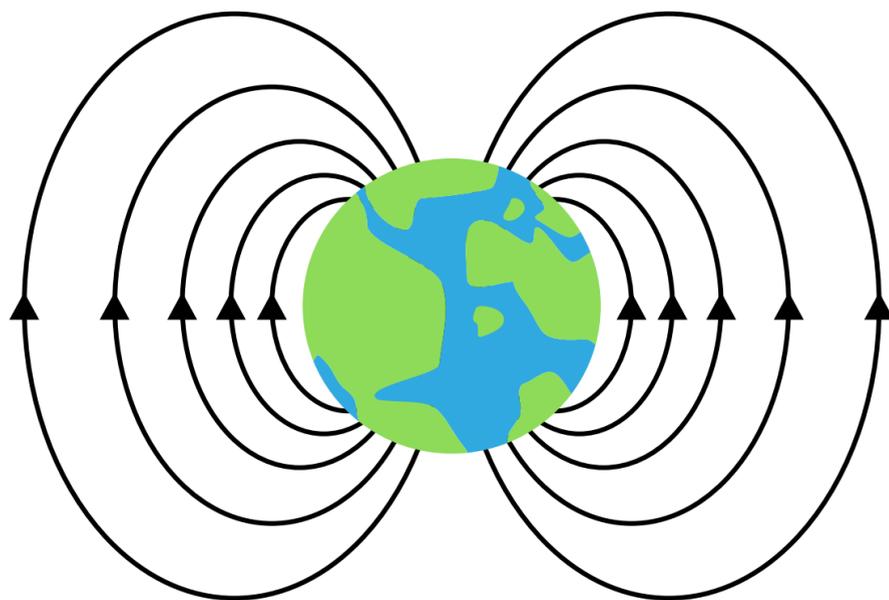
Every mass creates a gravitational field.

### Effects:

- stronger for larger masses
- weaker with distance

### This explains:

- falling objects
- planetary orbits
- weight differences on planets

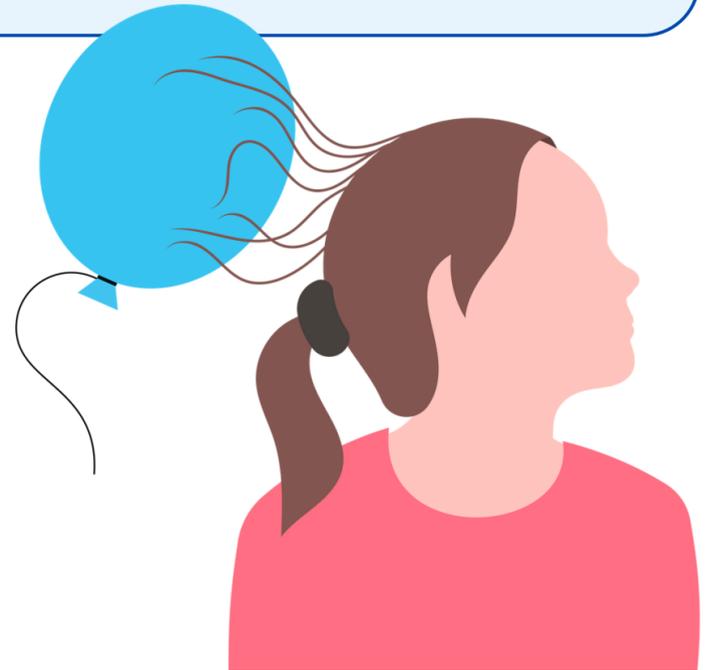


# ELECTROSTATIC FORCE

Force between charged objects; can be attractive or repulsive.

**Example:**

Proton and electron attraction.

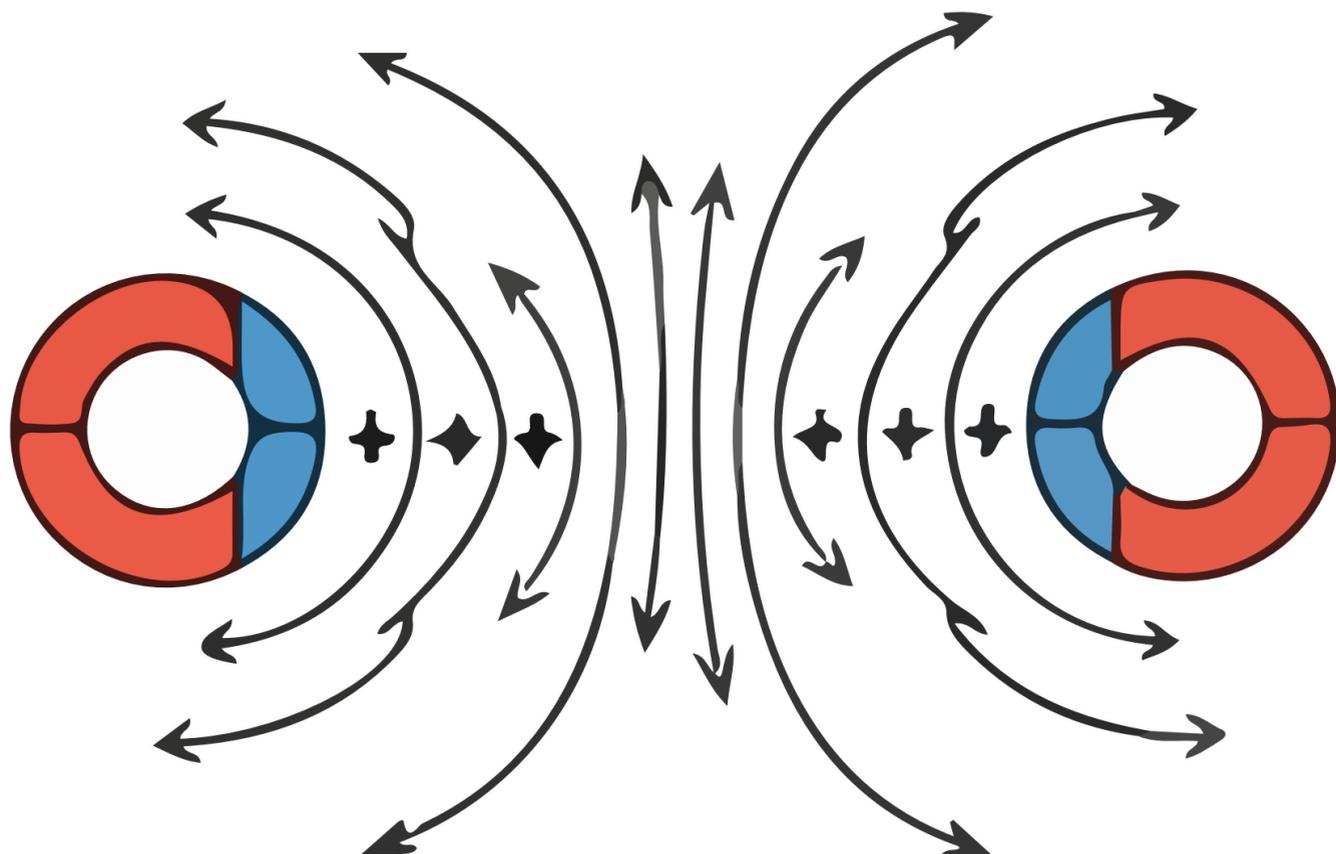


# MAGNETIC FORCE

Force between magnetic poles.

**Example:**

North and south poles attract.



# FORCES AS VECTORS

Forces are vector quantities because they have both magnitude and direction, and both affect how an object moves. The magnitude of a force tells us how strong it is and is measured in newtons (N), while the direction tells us where the force acts.

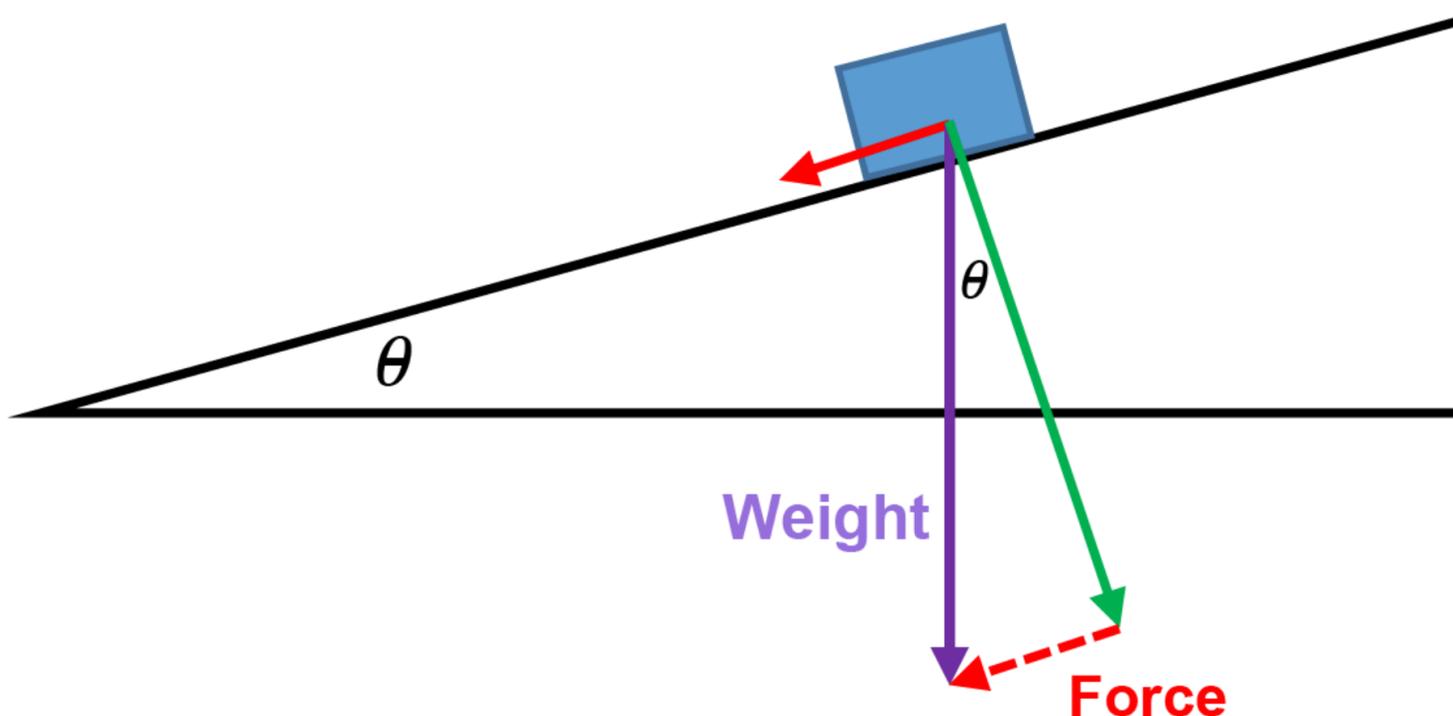
- Forces acting in the same direction add together
- Forces acting in opposite directions subtract

If the forces cancel out, the resultant force is 0 N and the forces are balanced. If they do not cancel, the forces are unbalanced, causing a change in motion.

## Forces are shown using arrows in diagrams:

- Arrow length represents magnitude
- Arrow direction represents force direction

Understanding forces as vectors is essential for calculating resultant forces and drawing free-body diagrams.

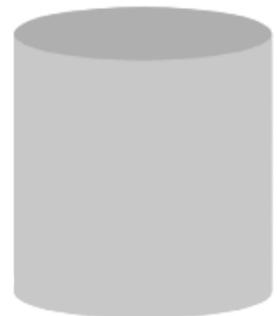


# DEFINING WEIGHT

Weight is the force due to gravity acting on an object's mass. It is a vector quantity because it has both magnitude and direction (towards the centre of the Earth).

Weight is measured in newtons (N) and changes depending on the strength of the gravitational field.

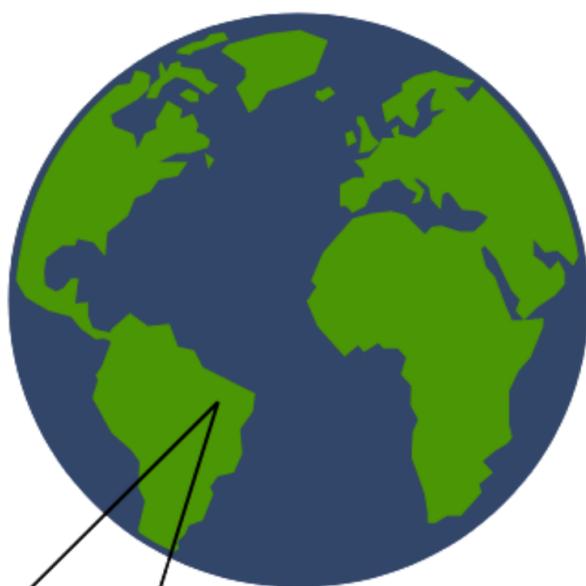
The weight of an object isn't the same on both earth and mars as the gravitational field strength is different.



Mass = 1 kg

On Earth

On Mars



Mass = 1 kg  
Gravity  $\cong 9.81 \text{ ms}^{-2}$   
Weight  $\cong 9.81 \text{ N}$



Mass = 1 kg  
Gravity  $\cong 3.72 \text{ ms}^{-2}$   
Weight  $\cong 3.72 \text{ N}$

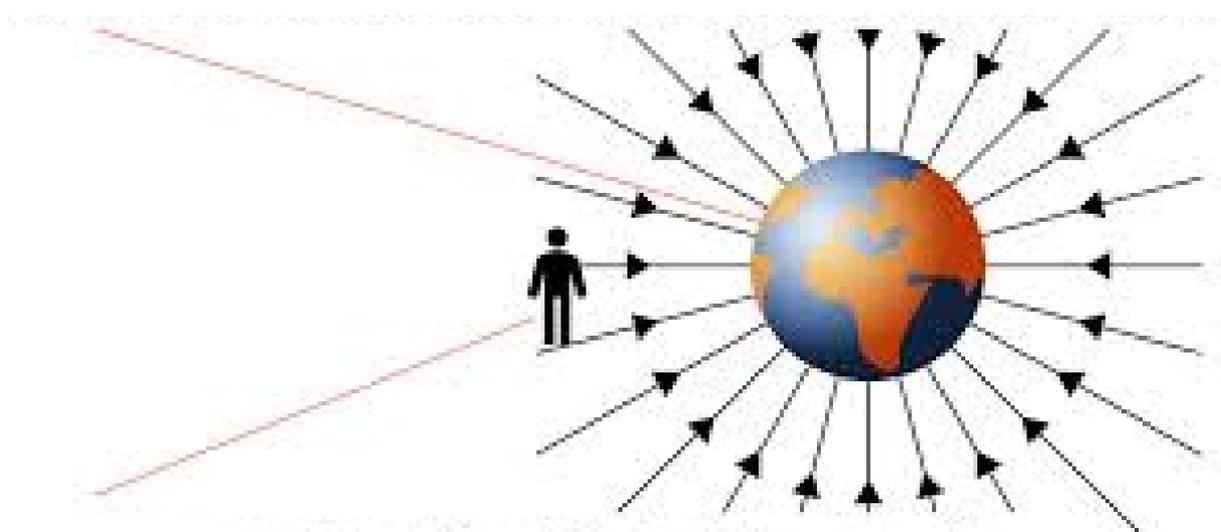
## DEFINING MASS

Mass is the amount of matter in an object and is measured in kilograms (kg). It is a scalar quantity and remains the same no matter where the object is in the universe. Mass is a measure of an object's inertia, meaning how difficult it is to change its motion.



## DEFINING GRAVITATIONAL FIELD STRENGTH

Gravitational field strength ( $g$ ) is the force per unit mass and is measured in  $\text{N/kg}$ . On Earth,  $g \approx 9.8 \text{ N/kg}$ , while on the Moon it is much smaller, which is why objects weigh less there but have the same mass.



The relationship between mass, weight, and gravity is:

## Weight and Mass

$$W = m \times g$$

Weight                      Mass                      Acceleration of gravity

## RESULTANT FORCES

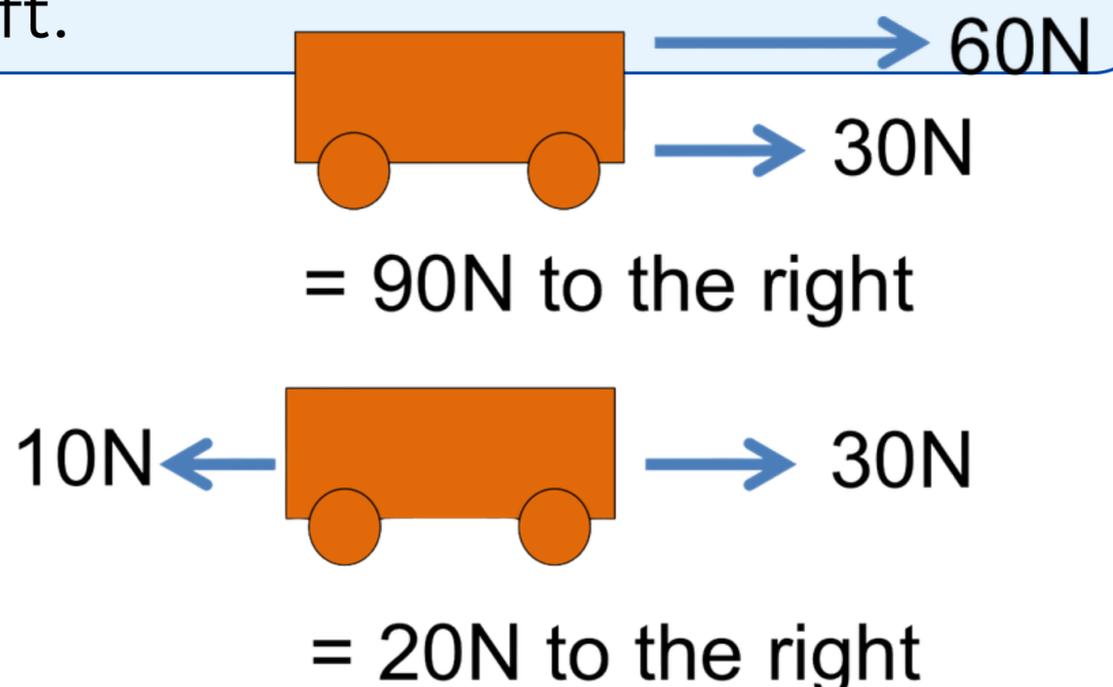
The resultant force is a single force that represents the combined effect of all the forces acting on an object. It determines how an object will move.

- Forces in the same direction are added together
- Forces in opposite directions are subtracted

If the resultant force is zero, the forces cancel each other out. If it is not zero, the object will experience a change in motion.

### Example:

If a force of 14 N acts to the left and 12 N acts to the right, the resultant force is 2 N to the left.



# FREE-BODY DIAGRAMS

A free-body diagram is a simplified diagram that shows all the forces acting on a single object. The object is usually represented as a dot or a simple shape, with forces drawn as arrows.

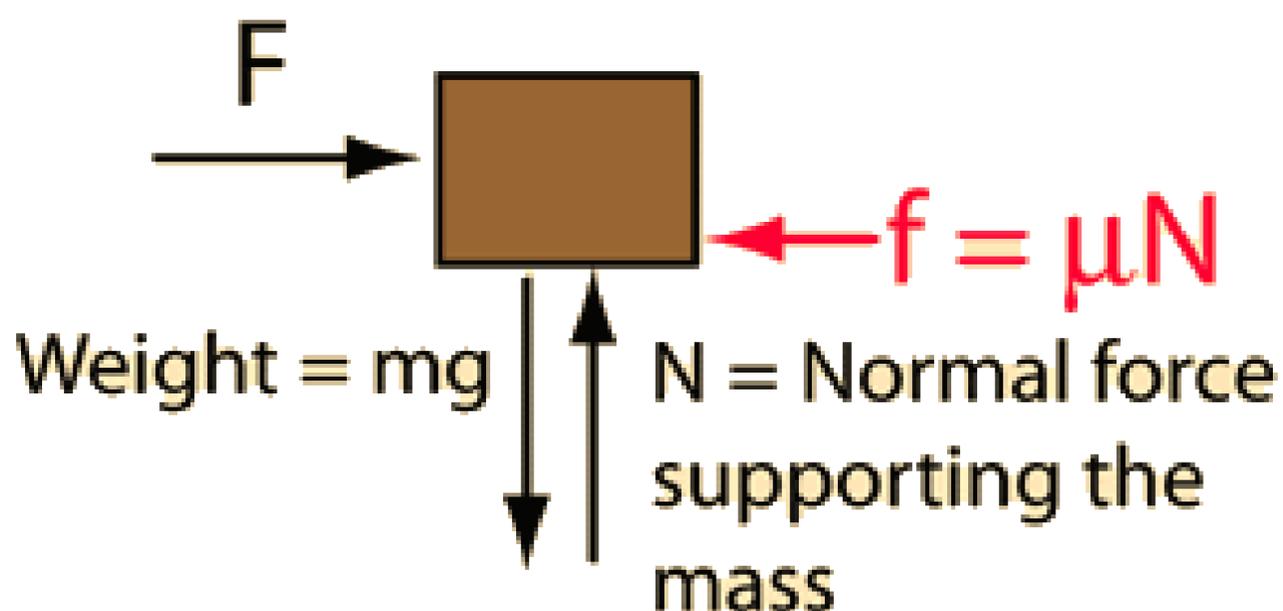
Rules for drawing free-body diagrams:

- Each force is drawn as an arrow starting on the object
- Arrow length represents the size of the force
- Arrow direction shows the direction of the force
- Each force is clearly labelled (e.g. weight, tension, friction)

**Free-body diagrams are used to:**

- Identify all the forces acting on an object
- Help calculate resultant forces
- Avoid missing or double-counting forces in exam questions

## Free Body Diagram

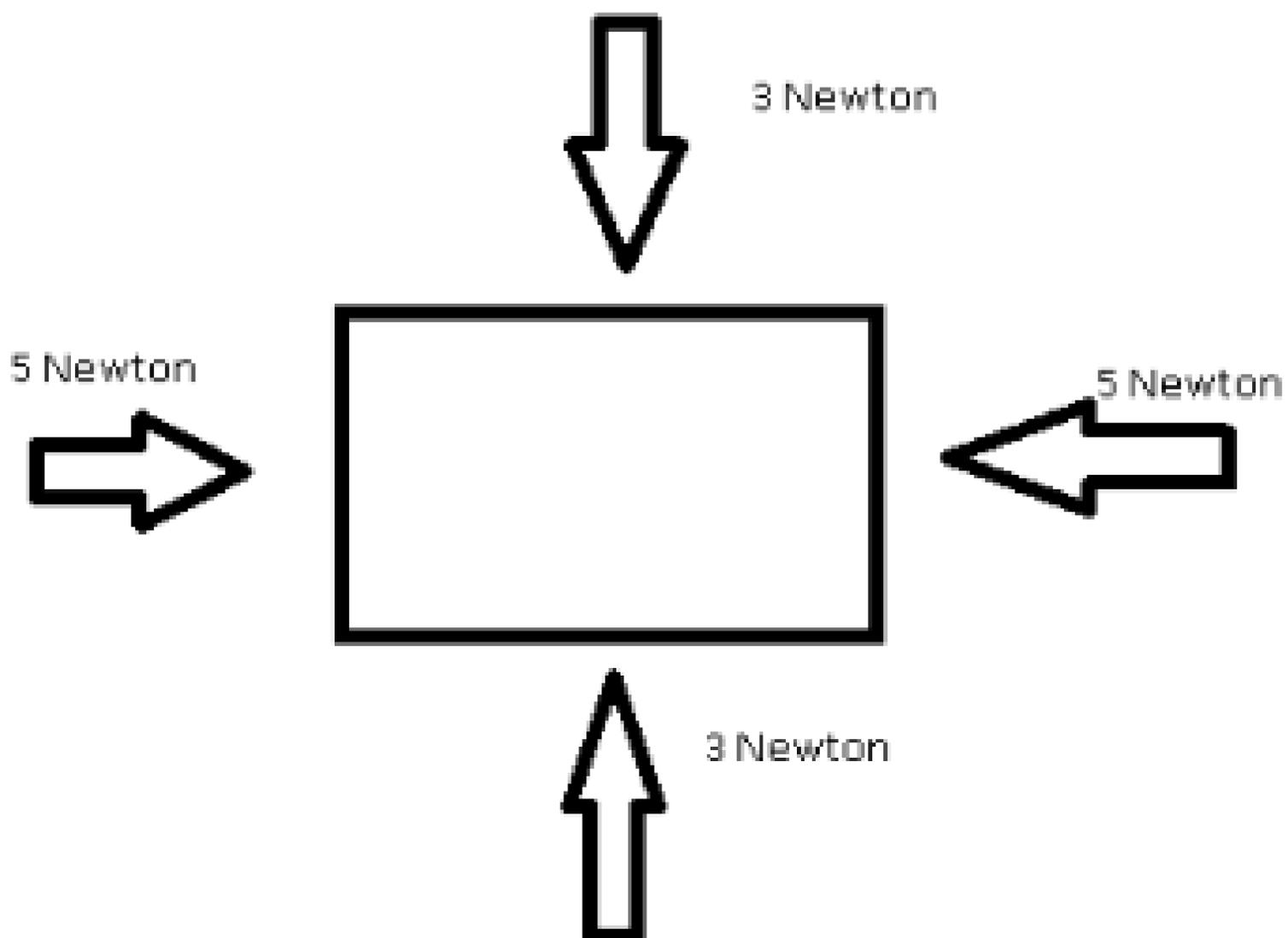


# BALANCED FORCES

Balanced forces occur when the resultant force on an object is 0 N. This means there is no change in motion. The object may be at rest or moving at a constant speed in a straight line.

## Example:

A book resting on a table has its weight balanced by the normal contact force from the table.



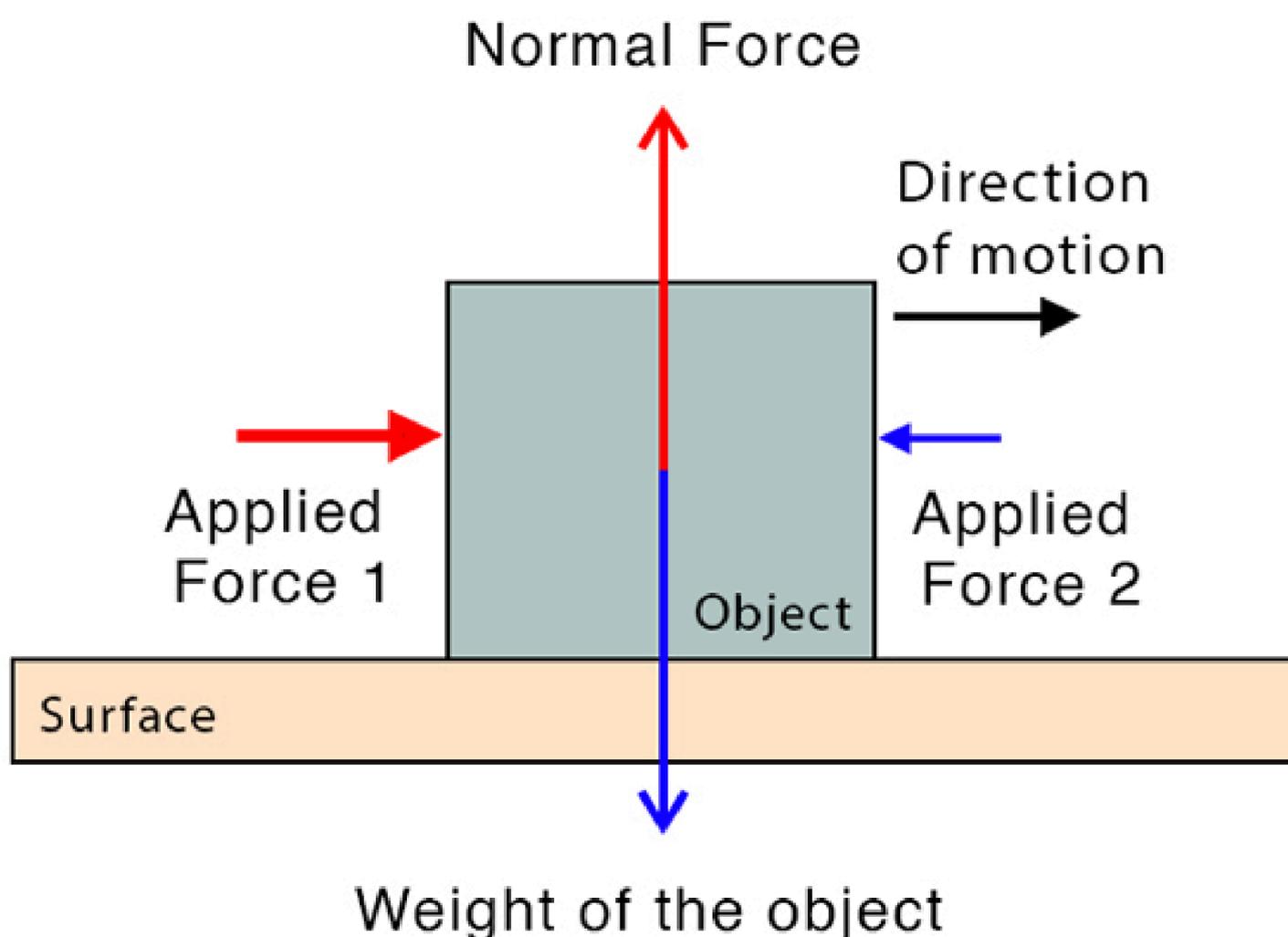
# UNBALANCED FORCES

Unbalanced forces occur when the resultant force is not zero. This causes the object to accelerate, slow down, or change direction.

## Example:

In a tug-of-war, if one side pulls harder than the other, the rope moves in the direction of the larger force.

## Unbalanced Force

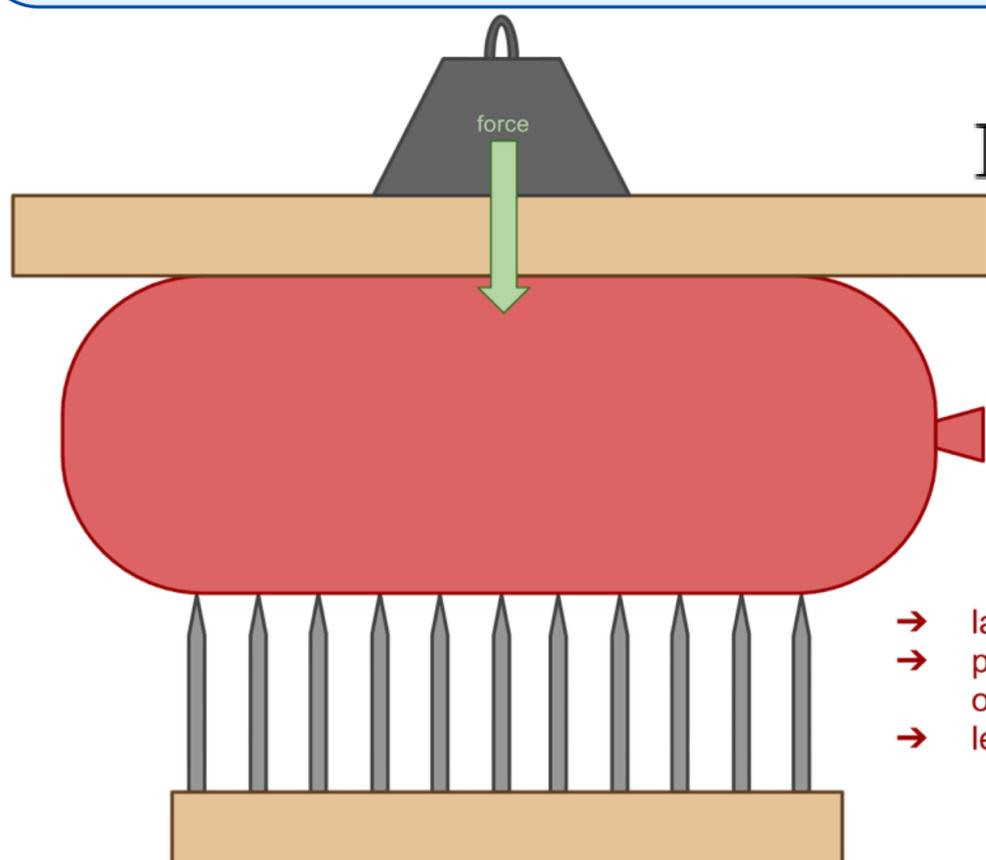


# PRESSURE

Pressure describes how concentrated a force is over an area. It is defined as the force per unit area, meaning the same force can have very different effects depending on how spread out it is.

This explains why sharp objects, like nails or drawing pins, easily penetrate surfaces. The force applied is concentrated over a very small area, producing a large pressure. In contrast, objects such as tractors have large tyres so that their weight is spread over a large area, reducing pressure and preventing them from sinking into soft ground.

- Small area → high pressure
- Large area → low pressure



$$\text{Pressure} = \frac{\text{Force}}{\text{Area}} \quad \text{or} \quad P = \frac{F}{A}$$

- larger surface area
- pressure spread out over many nails
- less pressure per nail



# PRESSURE IN A LIQUID (HIGHER TIER)

Pressure in a liquid depends on the depth and the density of the liquid. As depth increases, there is more liquid above a point, increasing the weight of liquid pressing down, which increases pressure. This is why pressure at the bottom of the ocean is much greater than at the surface.

A denser liquid exerts a greater pressure than a less dense liquid at the same depth because it has more mass per unit volume.

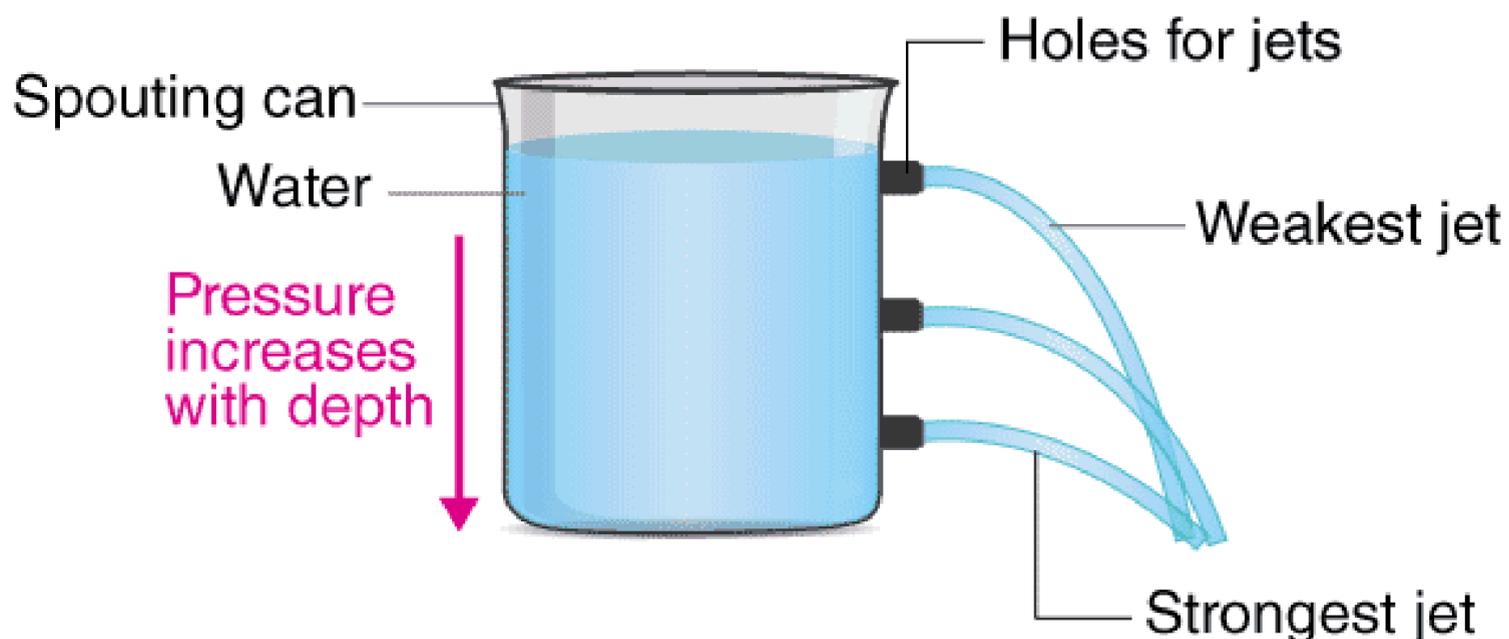
- Greater depth → higher pressure
- Greater density → higher pressure

the density  
of the liquid

the acceleration  
of gravity

$$P = \rho gh$$

the height of the liquid  
(or depth of the fluid)



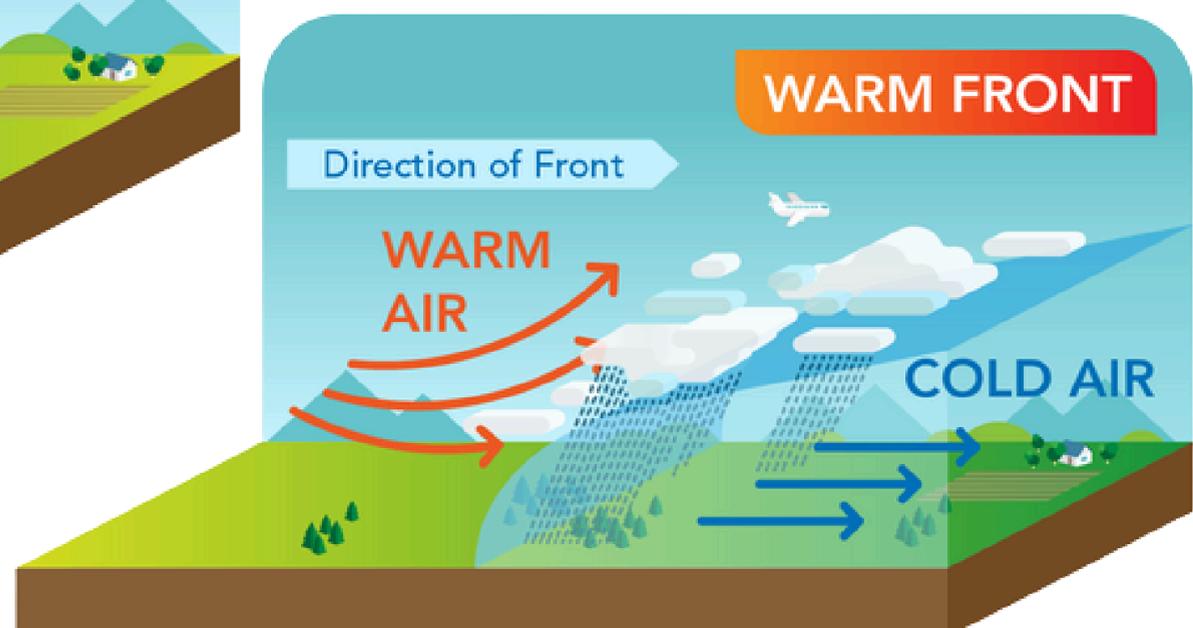
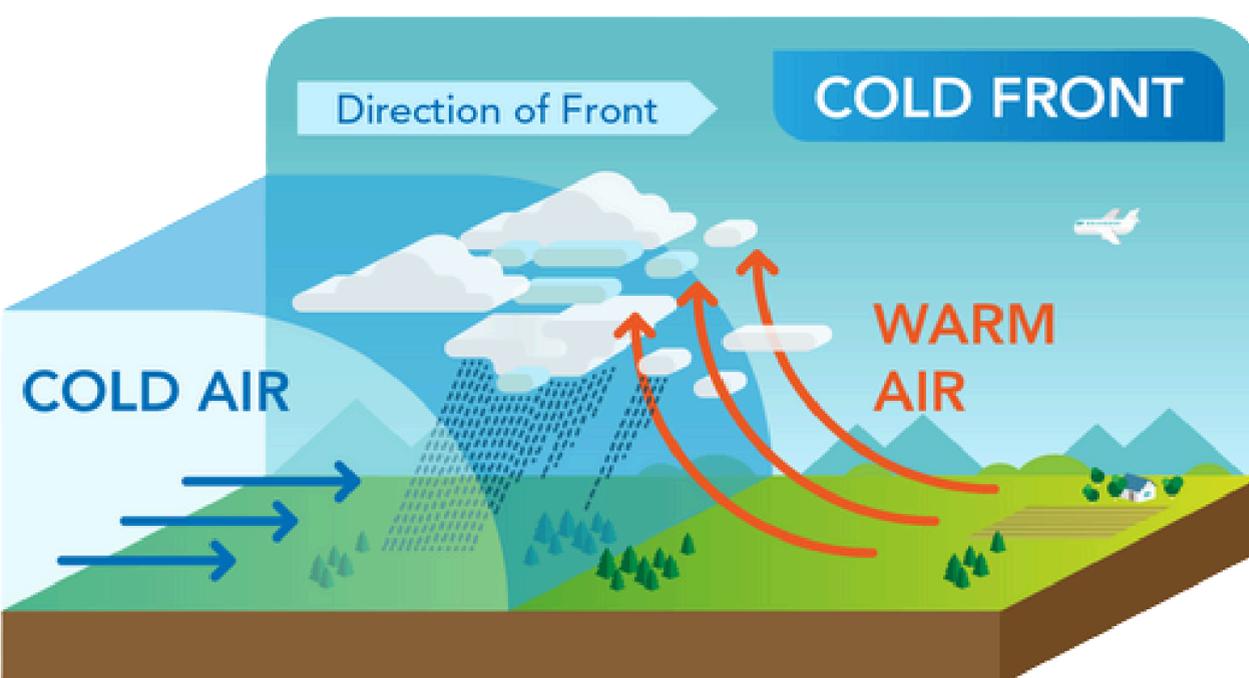
# ATMOSPHERIC PRESSURE

The Earth's atmosphere is a layer of air surrounding the planet. This air has weight, and because of this, it exerts a pressure known as atmospheric pressure. At sea level, atmospheric pressure is approximately 100 kPa.

Atmospheric pressure is caused by air molecules colliding with surfaces. The more air molecules above a surface, the greater the pressure. As altitude increases, the amount of air above decreases, so atmospheric pressure decreases with height.

- High altitude → less air above → lower pressure
- Low altitude → more air above → higher pressure

This is why atmospheric pressure is highest at sea level and lowest on mountains.



# UPTHRUST

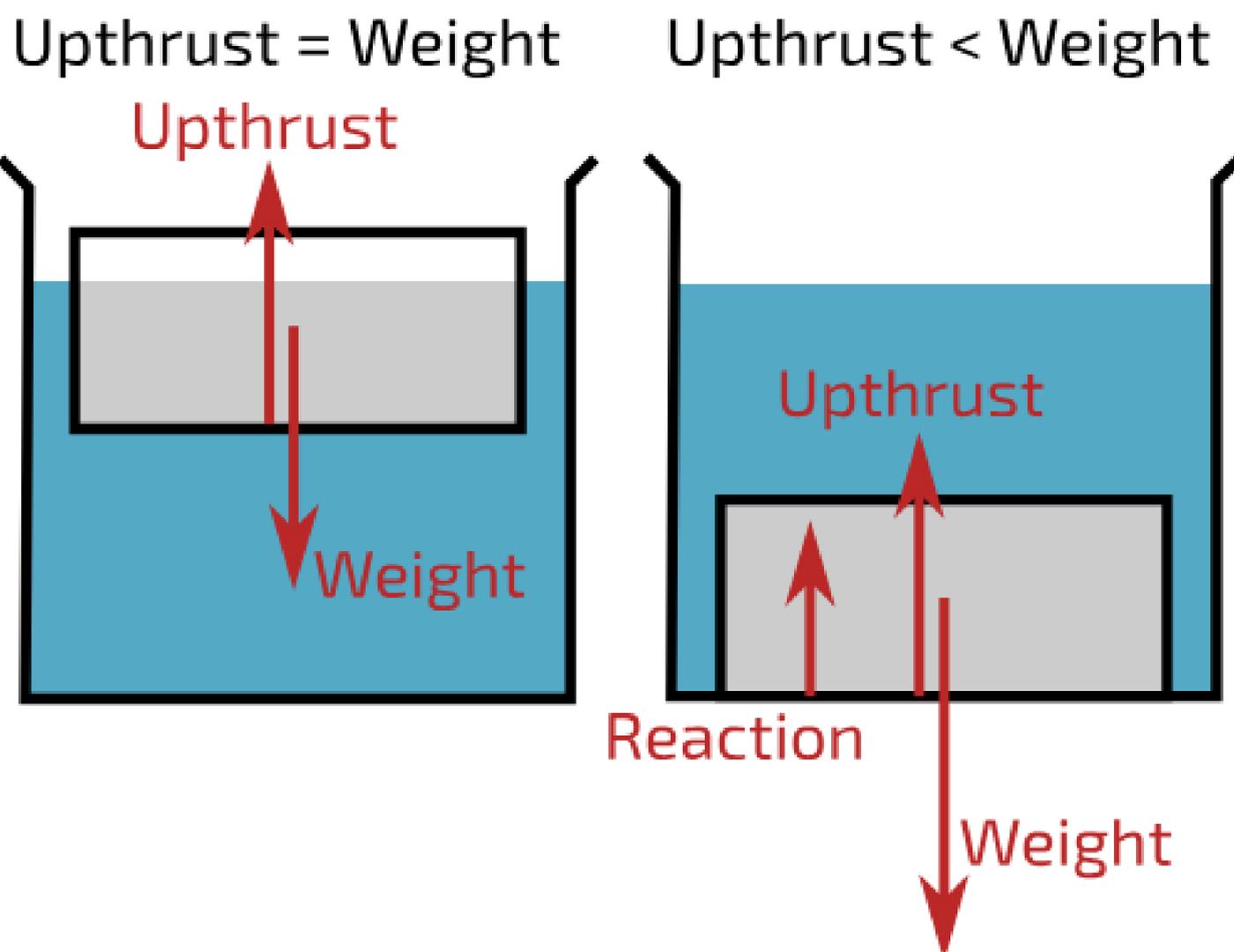
Upthrust is the upward force exerted by a fluid on an object that is partially or fully submerged. It acts in the opposite direction to the object's weight. Upthrust occurs because the pressure at the bottom of an object is greater than the pressure at the top, creating a resultant force upwards.

The size of the upthrust depends on:

- The density of the fluid
- The volume of fluid displaced (equal to the volume of the object submerged)

Denser fluids provide a greater upthrust, which is why objects float more easily in liquids like seawater compared to freshwater.

Upthrust is also the reason objects appear to weigh less in water.



# FLOATING & SINKING

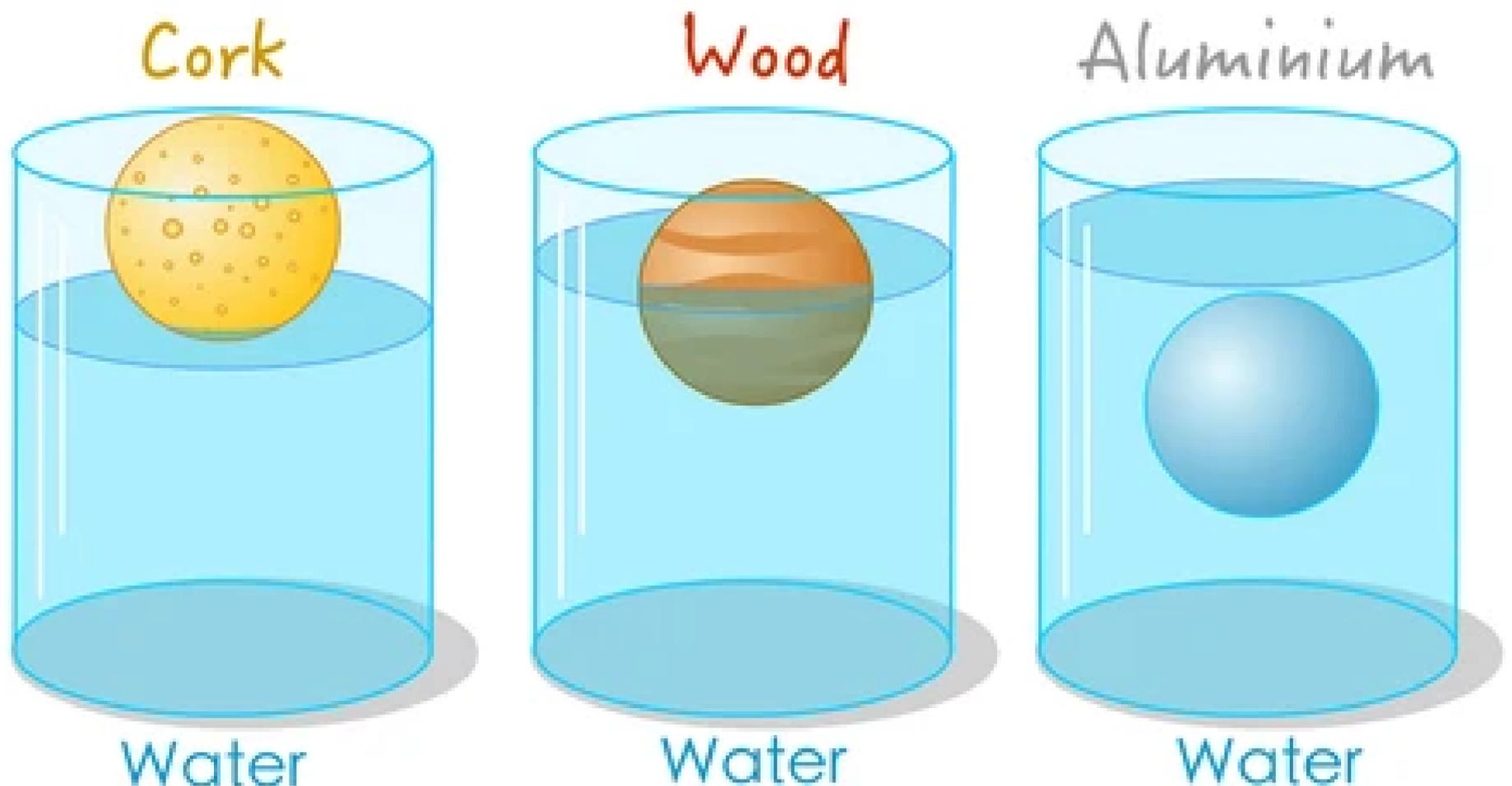
Whether an object floats or sinks depends on the balance between upthrust and weight, as well as the object's density.

- If upthrust  $\geq$  weight, the object floats
- If upthrust  $<$  weight, the object sinks

## Density is key:

- If the object's density is less than the fluid's density, it floats
- If the object's density is greater than the fluid's density, it sinks

An object denser than the fluid cannot displace enough fluid to produce an upthrust large enough to balance its weight.

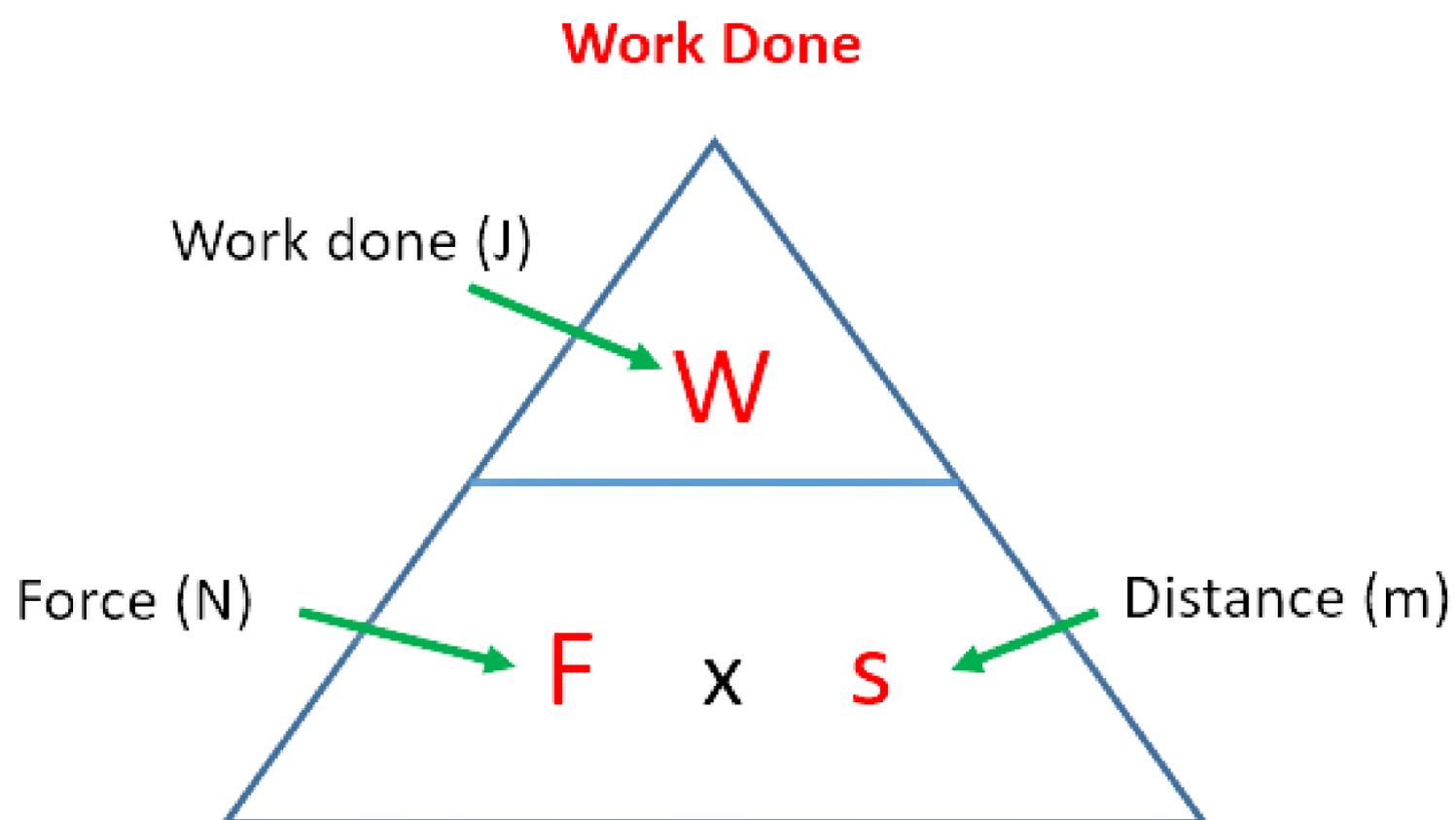


# WORK DONE

Work is done when a force causes an object to move through a distance in the direction of the force. In physics, simply applying a force is not enough, there must be movement. If a force is applied but the object does not move, no work is done

**For example,** pushing against a wall without moving it does no work, but lifting a ball upward does work because the force causes movement in the same direction as the force.

- Force + movement in same direction → work done
- Force with no movement → no work done



$$\text{Work done (J)} = \text{Force (N)} \times \text{Distance (m)}$$

The distance must be in the line of action of the force

# WORK DONE & ENERGY TRANSFER

Whenever work is done, energy is transferred. The amount of energy transferred is equal to the work done, and both are measured in joules.

- Energy transferred (J) = Work done (J)

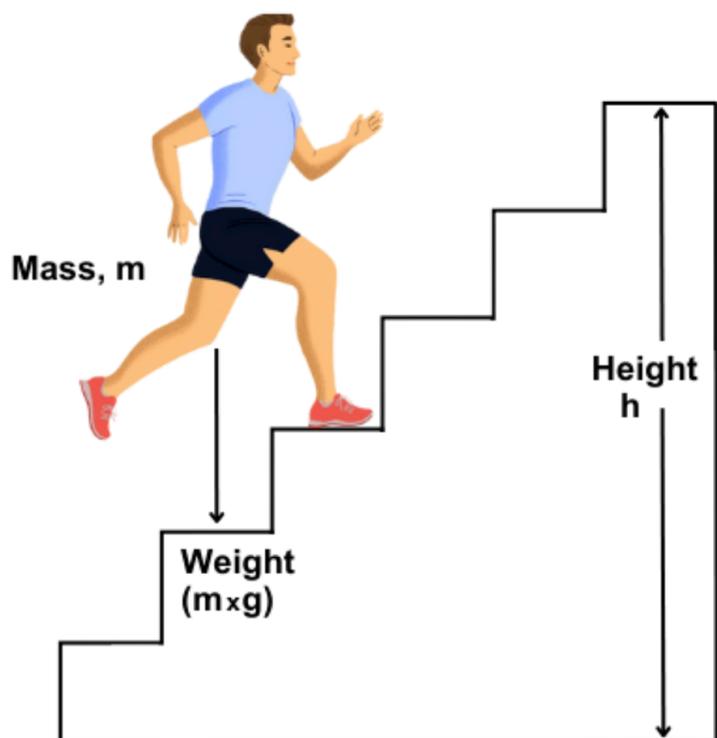


If a force acts in the direction of motion, energy is transferred to the object, usually to its kinetic energy store.

- If a force acts opposite to the direction of motion, energy is transferred away from the object, often to the thermal energy store of the object and its surroundings

## WORK DONE AGAINST GRAVITY

When an object is lifted vertically, work is done against its weight. This work transfers energy to the object's gravitational potential energy store.



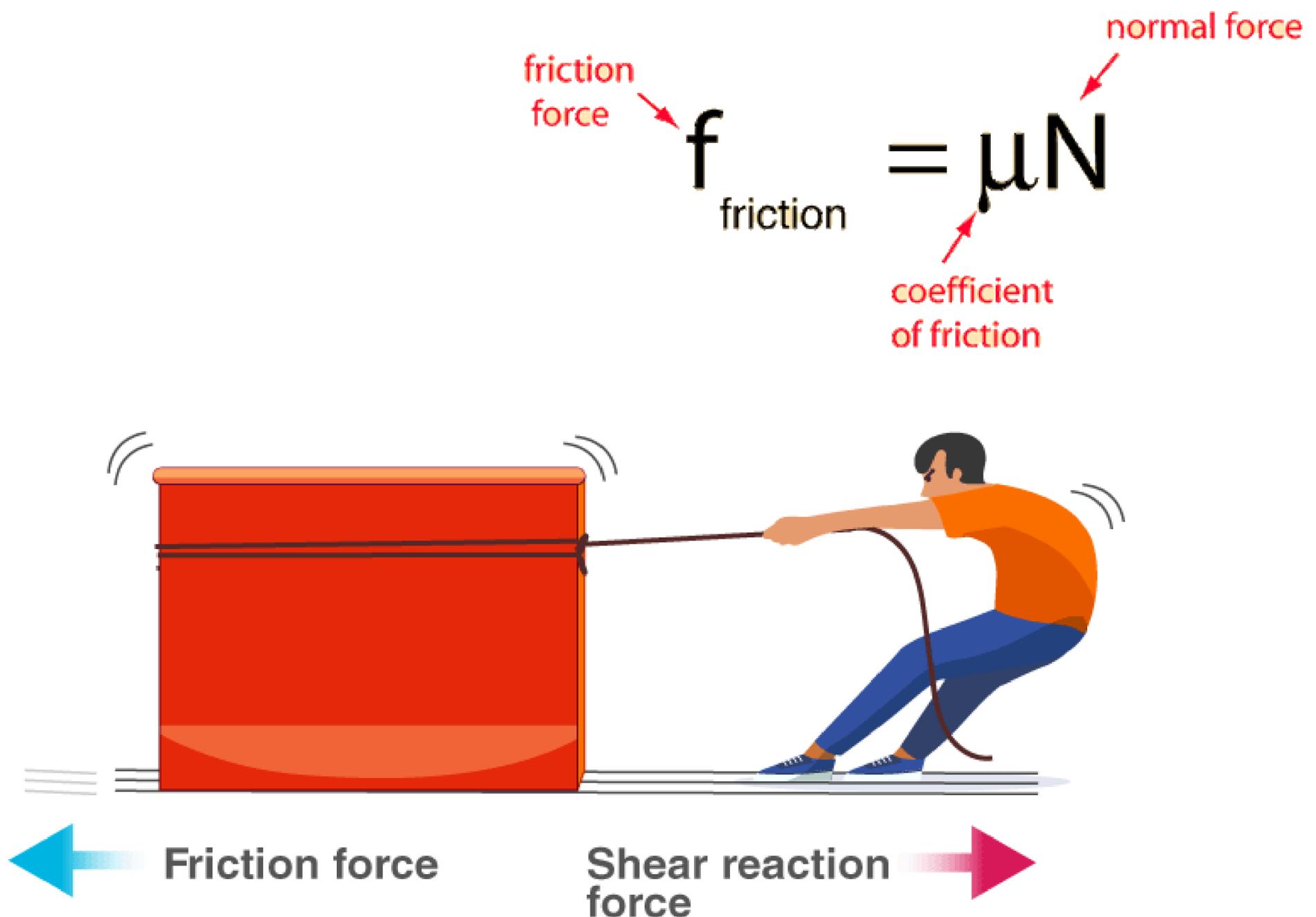
$$W_{grav} = F \cdot d = m \cdot g \cdot \Delta h$$

# WORK DONE & FRICTION

Friction is a force that acts opposite to motion. When an object moves while friction is present, work is done against friction. This work causes energy to be transferred by heating, increasing the temperature of the object and its surroundings.

Friction occurs because surfaces are not perfectly smooth. Small imperfections on the surfaces rub against each other, slowing the object down and converting kinetic energy into thermal energy.

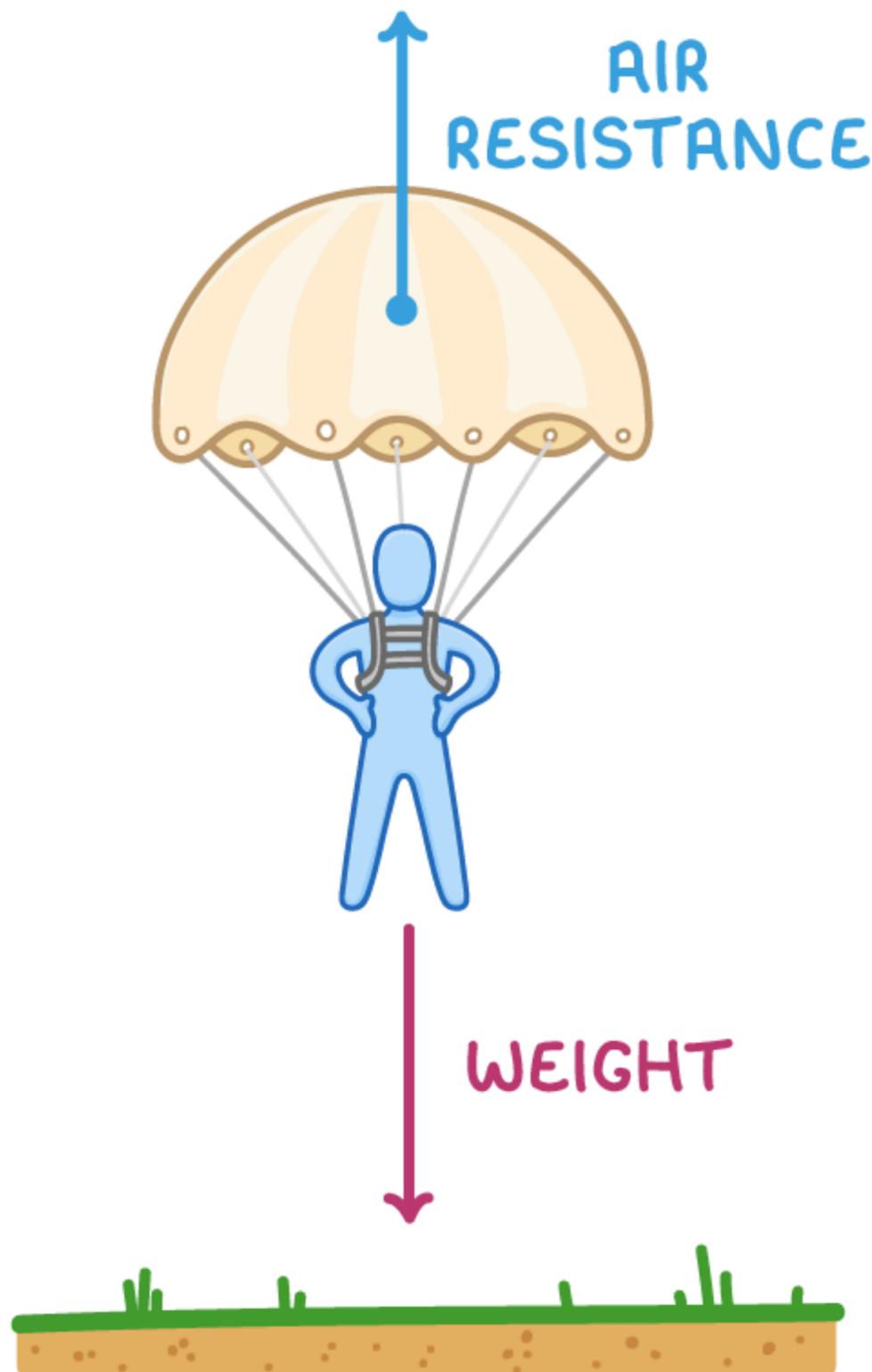
- Friction slows objects down
- Energy is transferred to the thermal store



# AIR RESISTANCE

Air resistance is a type of friction that acts on objects moving through air. Air particles collide with the object, opposing its motion. Work done against air resistance transfers energy to the thermal energy store of the object and the surrounding air.

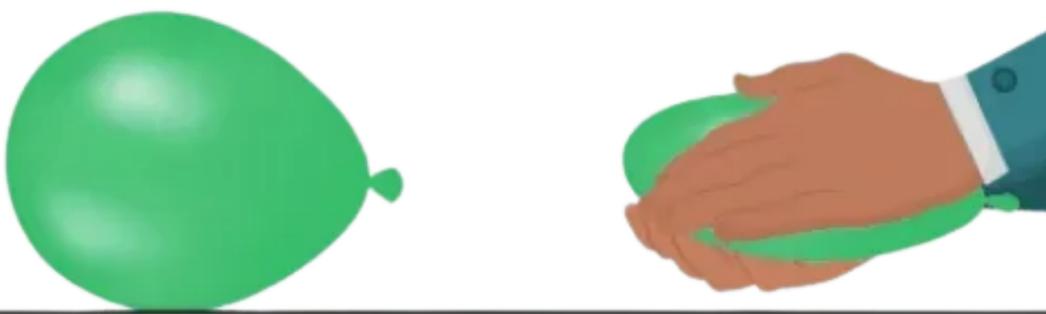
A clear example is a rocket's return module heating up as it travels through the atmosphere. The work done against air resistance causes a large transfer of energy by heating.



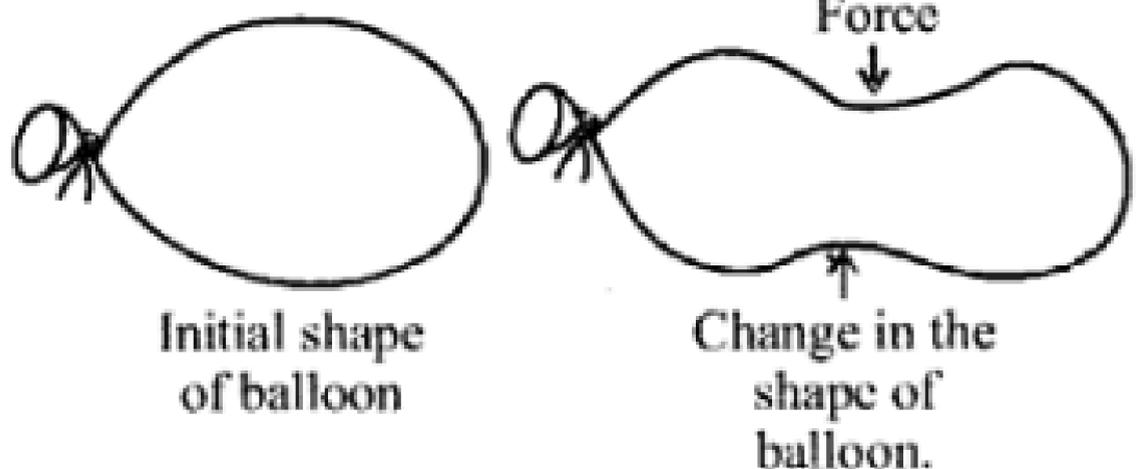
# FORCES & CHANGING SHAPE

A stationary object changes shape only when more than one force acts on it. These forces can cause the object to stretch, compress, or bend, depending on their directions and points of application. In many situations, more than one type of shape change can occur at the same time.

- **Stretching:** forces act in opposite directions away from the object
- **Compression:** forces act in opposite directions towards the object
- **Bending:** forces act at different points or at angles, distorting the object



Forces that changes shape

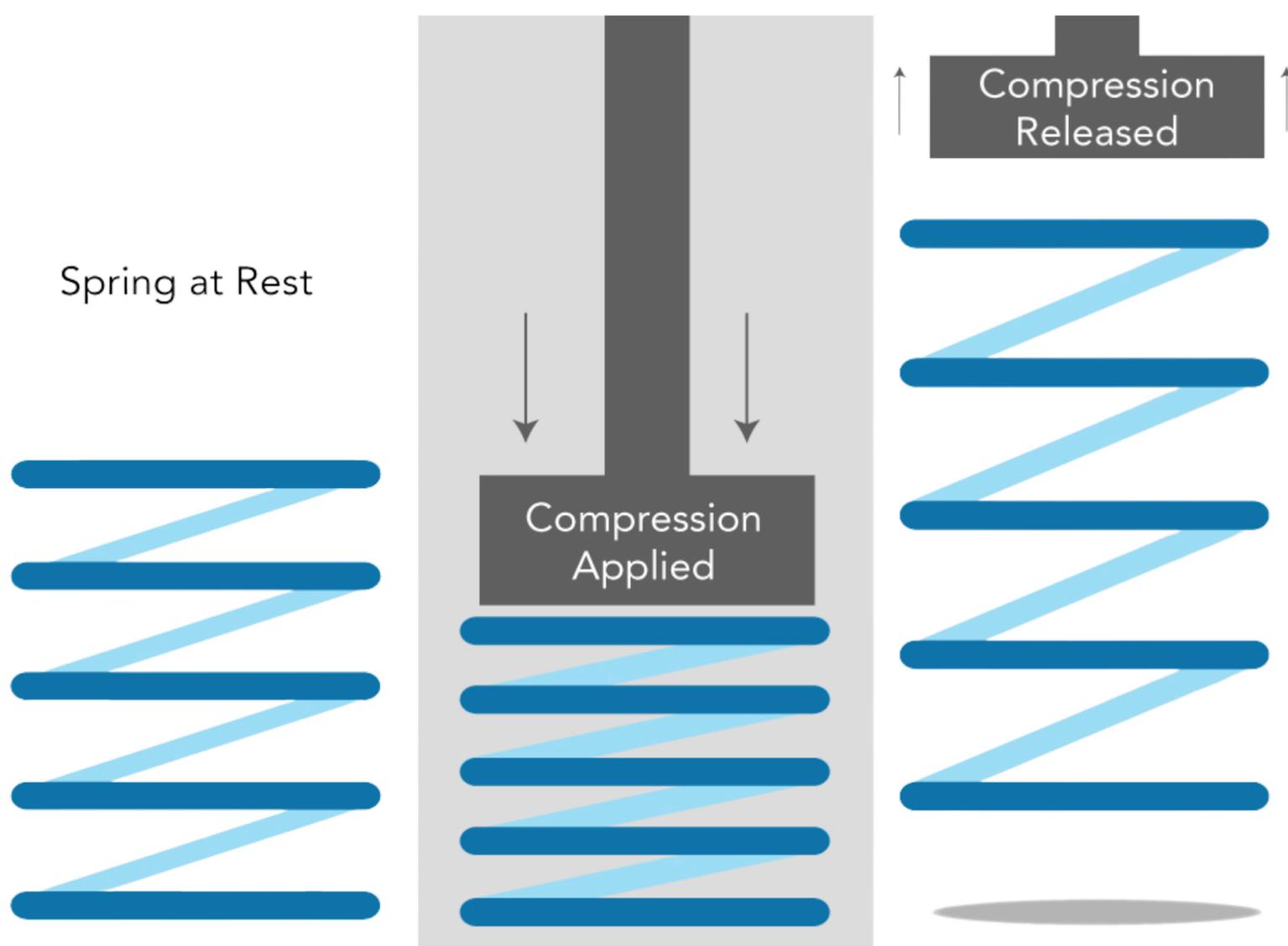


# COMPRESSION

Compression occurs when forces push towards each other, squashing an object. A common example is a spring placed on a flat surface with a mass on top. The weight of the mass pushes downward, while the surface exerts an upward reaction force.

These two forces act towards each other, causing the spring to compress.

- Requires two opposing forces
- Forces act towards each other
- Example: mass compressing a spring on a table





## STRETCHING

Stretching occurs when forces pull away from each other, extending an object. For example, a spring hanging vertically stretches when a mass is attached to its bottom. The weight of the mass pulls downward, while the tension in the spring pulls upward.

- Requires two opposing forces
- Forces act away from each other
- Example: mass hanging from a spring

## BENDING

Bending happens when forces act at different points on an object or act at angles to each other. A classic example is a diving board bending when a swimmer stands at one end. The swimmer's weight acts downward, while the support provides an upward reaction force at a different point.

- Forces act at different points
- Often involves a combination of compression and stretching
- **Example:** diving board, ruler bent by hands



# ELASTIC & INELASTIC DEFORMATION

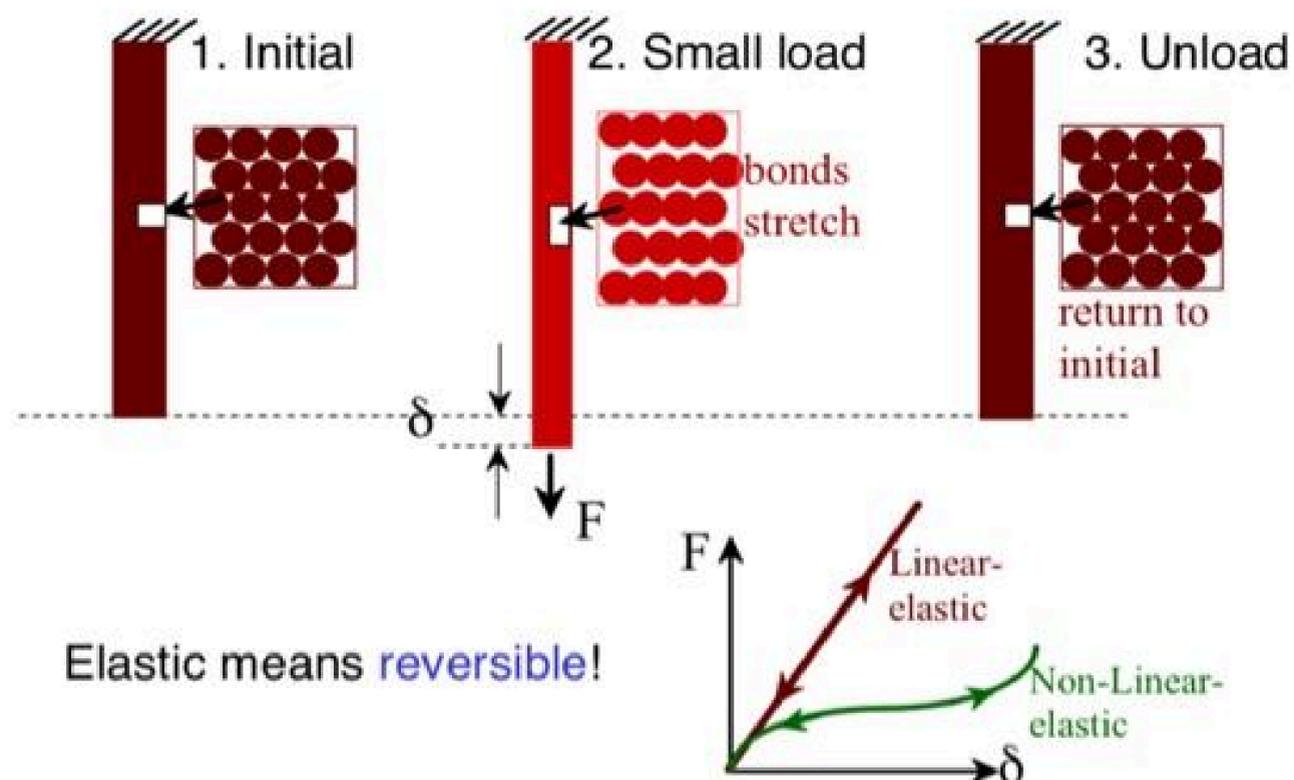
A deformation is a change in shape caused by forces. Deformations can be elastic or inelastic, depending on whether the object returns to its original shape when the force is removed.

## ELASTIC DEFORMATION

Elastic deformation occurs when an object returns to its original shape and length after the force is removed.

- Occurs in springs, rubber bands, fabrics
- Shape change is temporary

### ELASTIC DEFORMATION: ATOMISTIC VIEW



# IN-ELASTIC DEFORMATION

Inelastic deformation occurs when an object does not return fully to its original shape after the force is removed.

- Occurs in plastic, clay, glass
- Shape change is permanent



**CAR COLLISION**

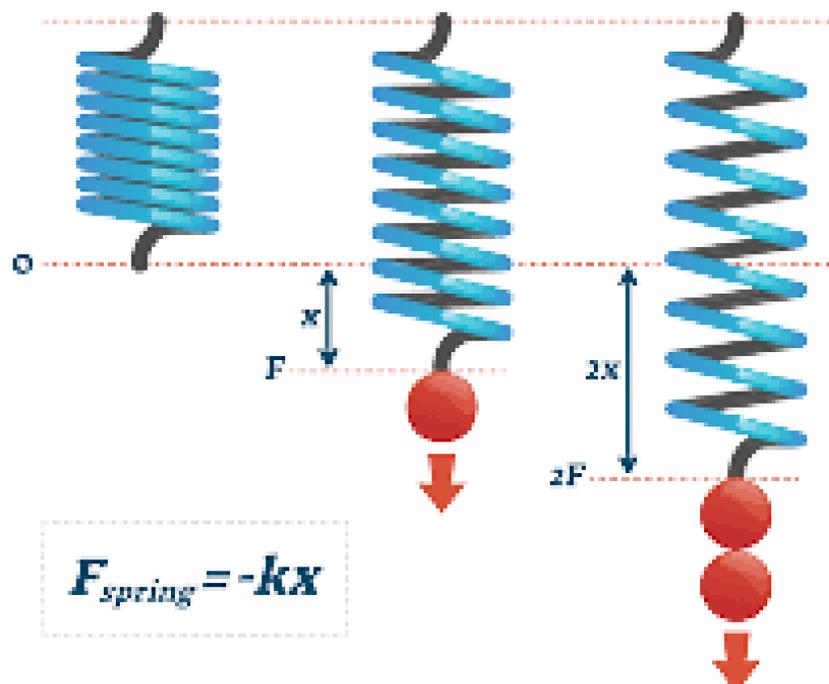


**CAN CRUSHING**

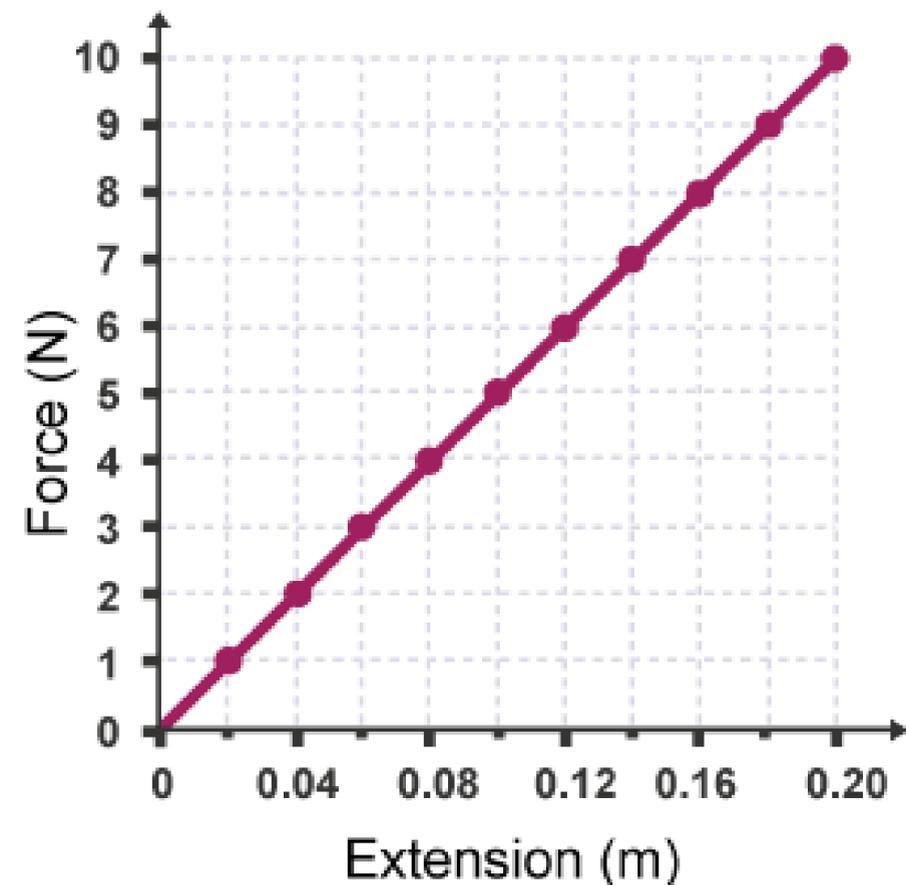
## HOOKE'S LAW

Hooke's Law describes the relationship between the force applied to an elastic object and the extension produced. It states that the extension of an elastic object is directly proportional to the force applied, up to the limit of proportionality.

- Doubling the force doubles the extension
- Valid only up to the limit of proportionality
- Beyond this limit, the object no longer obeys Hooke's Law



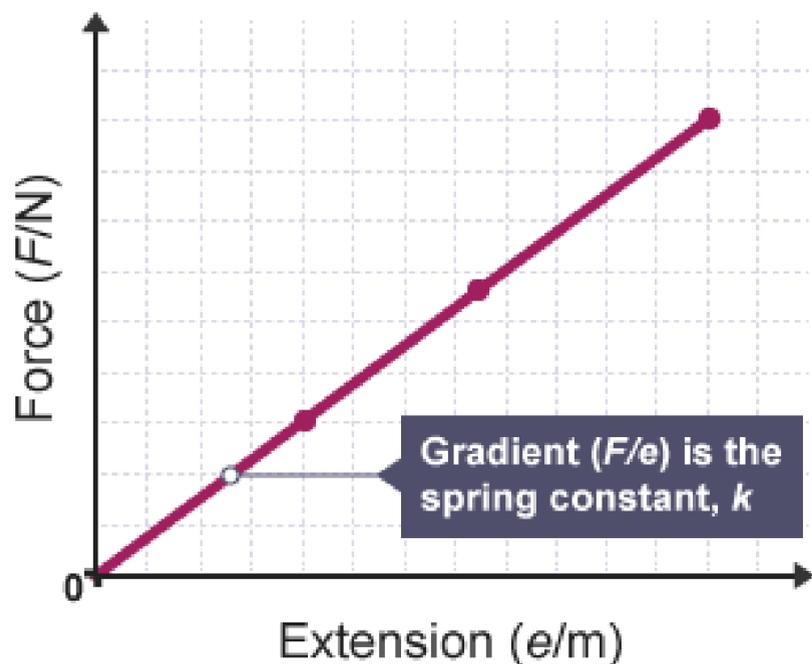
# FORCE-EXTENSION GRAPHS



**Force-extension** graphs show how extension changes as force increases.

- A straight line indicates the object obeys Hooke's Law
- A curve indicates non-linear behaviour (beyond limit of proportionality)

# SPRING CONSTANT FROM GRAPHS

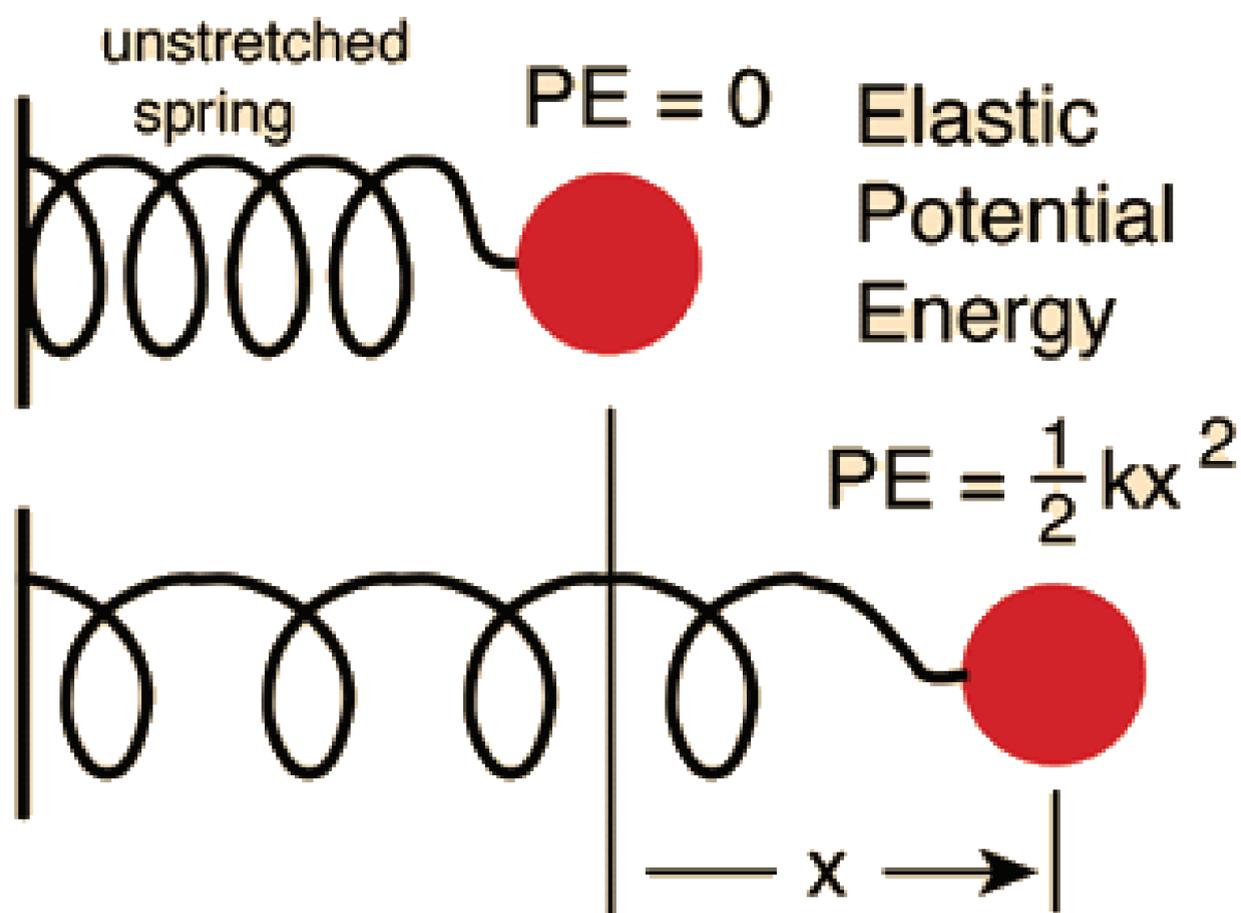


## Spring Constant from Graphs

- If force is on y-axis and extension on x-axis:
  - $k = \text{gradient}$
- If extension is on y-axis and force on x-axis:
  - $k = 1/\text{gradient}$
- Steep line  $\rightarrow$  stiffer spring (larger  $k$ )
- Shallow line  $\rightarrow$  less stiff spring (smaller  $k$ )

# FORCE-EXTENSION GRAPHS

When a spring is stretched or compressed, work is done, and energy is transferred to the spring's elastic potential energy store. As long as the spring has not exceeded its limit of proportionality, the work done equals the elastic potential energy stored.



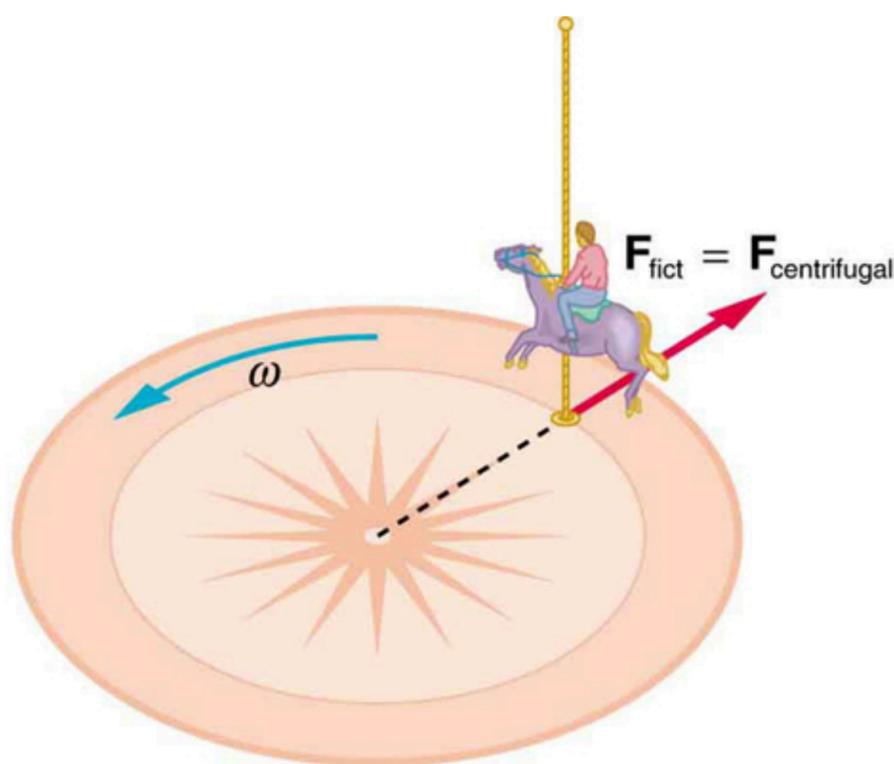
If the extension doubles, the energy stored increases by four times, because the extension is squared.

# FORCES & ROTATION

Forces do not only cause objects to speed up, slow down, change direction, or deform, they can also cause objects to rotate. Rotation happens when a force acts at a distance from a pivot, which is a fixed point about which an object turns. The rotation produced can be clockwise or anticlockwise.

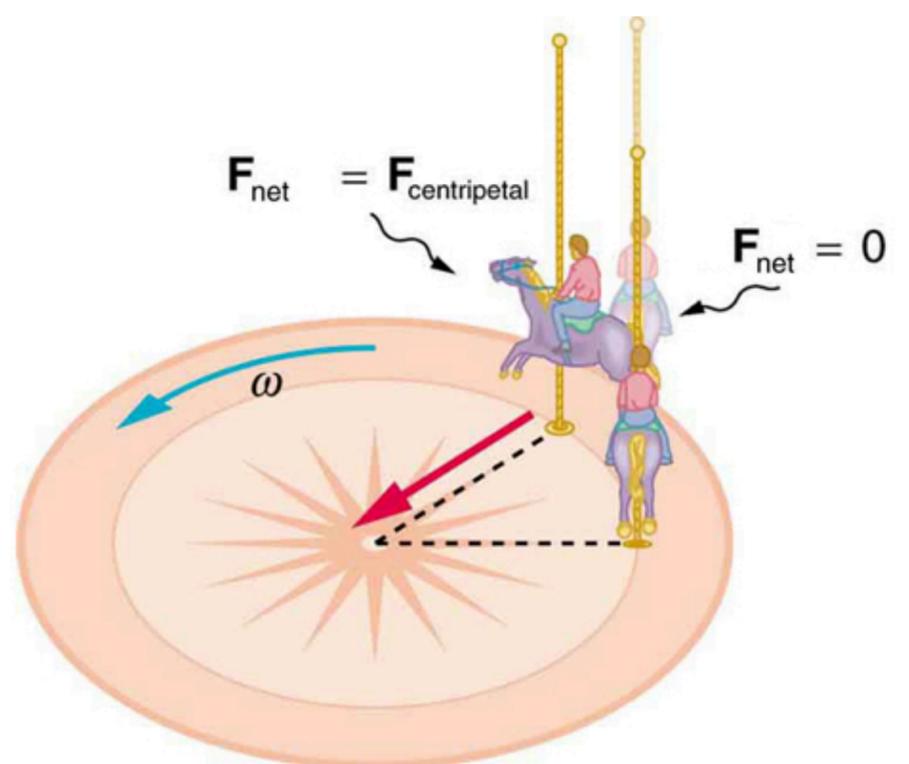
**Examples** of rotation caused by forces include a **child on a see-saw**, **turning a spanner**, or **opening and closing a door**.

Even when forces are balanced, rotation can still occur if the forces do not act through the same point.



Merry-go-round's rotating frame of reference

(a)

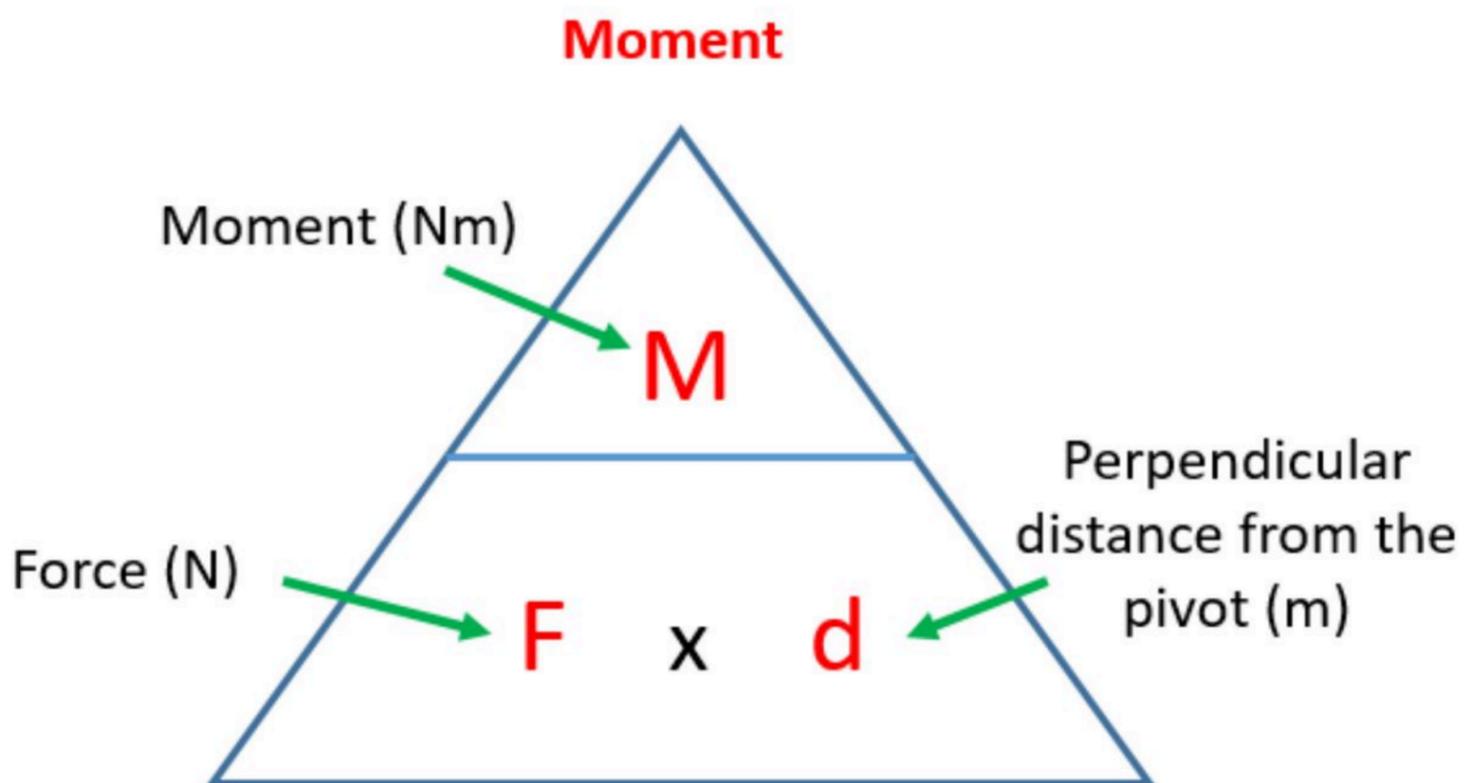


Inertial frame of reference

(b)

# MOMENT OF A FORCE

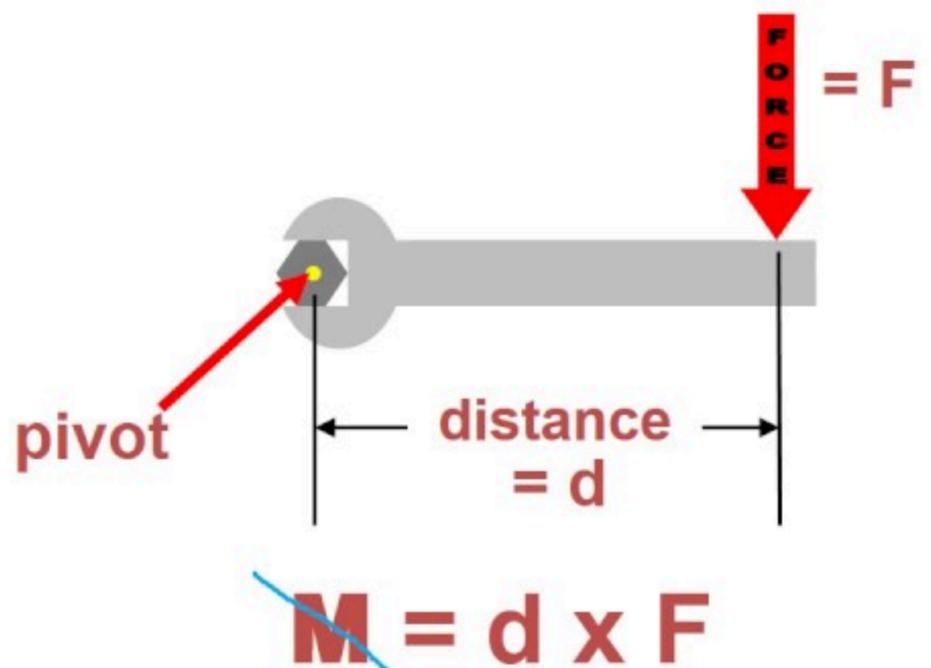
A moment is the turning effect of a force about a pivot. How strong the turning effect is depends on both the size of the force and how far it acts from the pivot.



$$\text{Moment (Nm)} = \text{Force (N)} \times \text{Distance (m)}$$

The distance must be perpendicular from the line of action of the force to the pivot.

The perpendicular distance is crucial. If the force acts closer to the pivot, the turning effect is smaller. This is why door handles are placed far from hinges, the larger distance creates a larger moment, making the door easier to open.



# PRINCIPLE OF MOMENTS

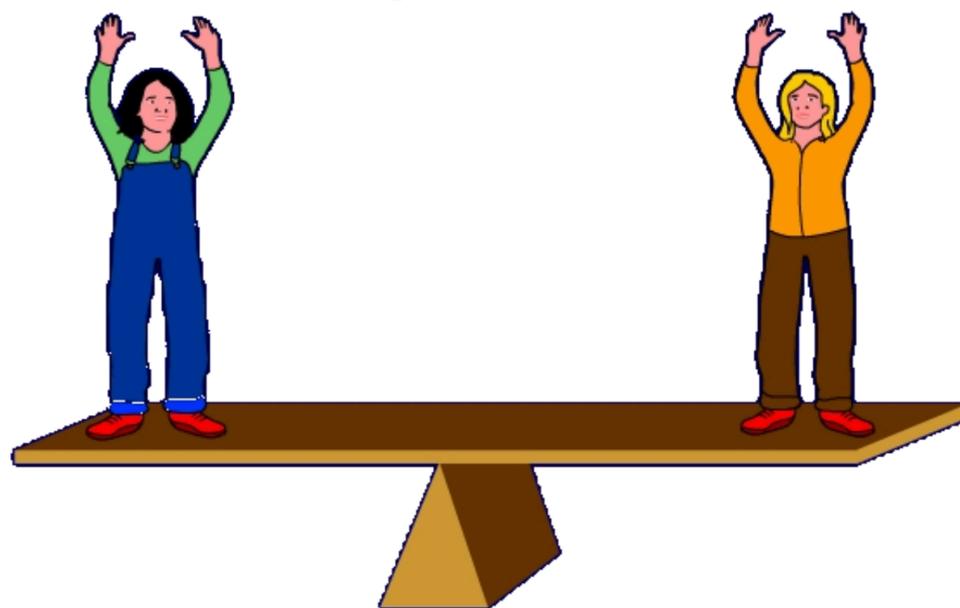
The principle of moments states that for an object to be balanced, the total clockwise moments about a pivot must equal the total anticlockwise moments.

**total clockwise moment = total anticlockwise moment**

Only forces acting perpendicular to the distance from the pivot produce a moment. On a horizontal beam, this means forces acting vertically up or down.

This principle is commonly used to solve problems involving see-saws, beams, and balancing objects

## Principle of moments



If the anticlockwise moment and clockwise moment are equal then the see-saw is balanced. This is known as the **principle of moments**.

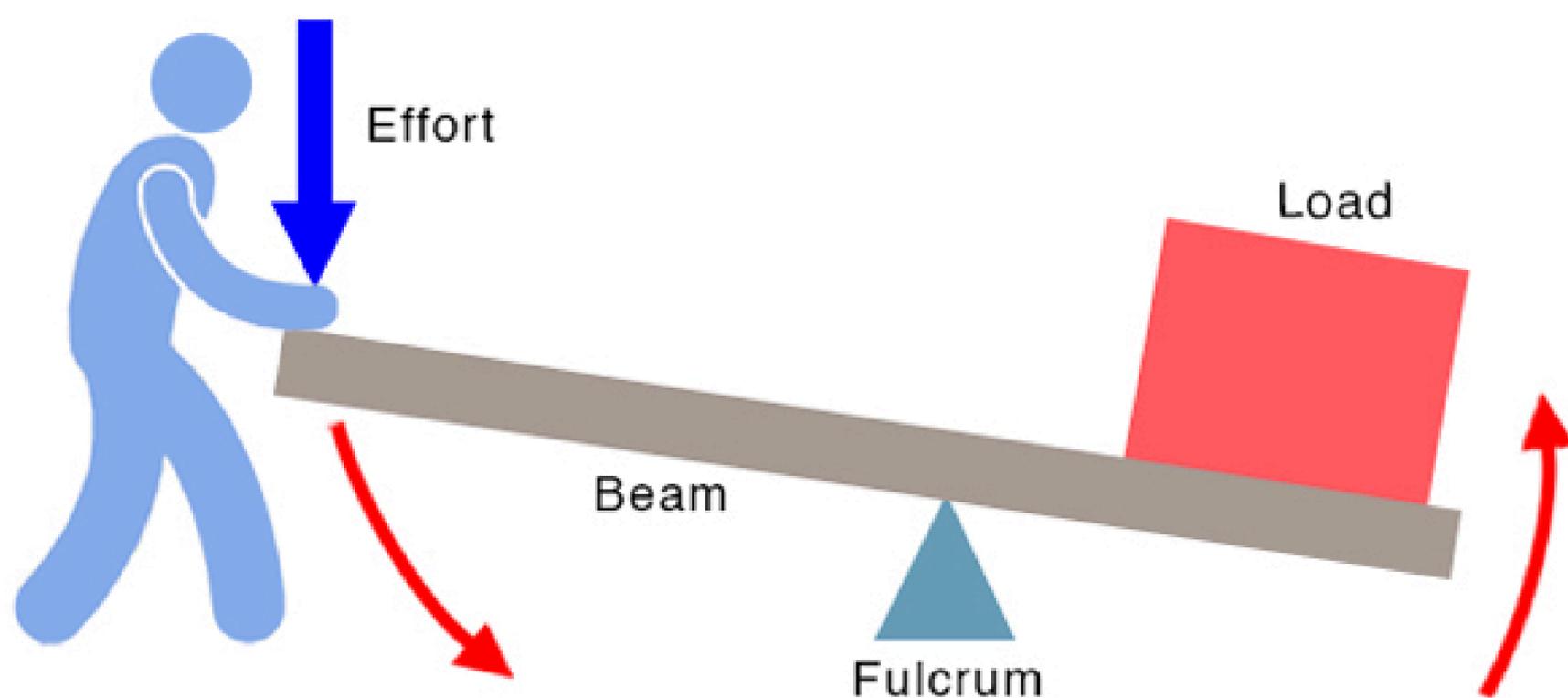
# LEVERS

A lever is a rigid object that rotates about a pivot and is used to increase the turning effect of a force. Levers make tasks easier by allowing a small force applied at a large distance from the pivot to produce a large force close to the pivot.

To make a lever more effective:

- Increase the size of the applied force
- Increase the distance of the force from the pivot

**Examples** of levers include bottle openers and crowbars. These tools act as force multipliers, making it easier to lift heavy objects or remove tightly sealed lids.



# GEARS

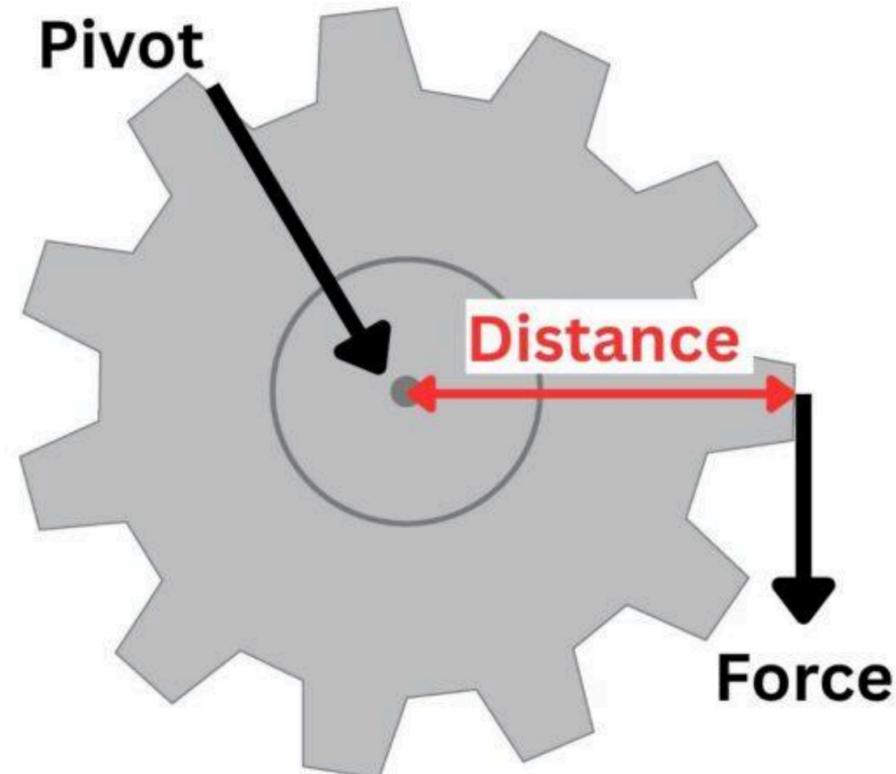
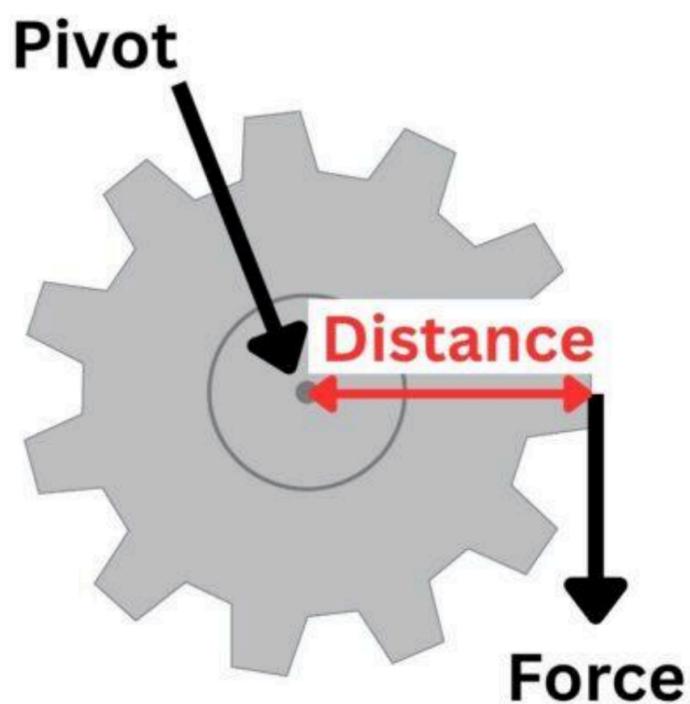
Gears work in a similar way to levers by using moments to transmit and amplify turning effects. They consist of toothed wheels that rotate around an axle, which acts as the pivot. When two gears mesh, turning one gear causes the other to turn.

## Key points about gears:

- Gears rotate in opposite directions
- The force between gears is the same, but the moment depends on gear size
- Larger gears have a larger moment because the force acts further from the axle

If a large gear is driven by a small gear, the large gear turns more slowly but with a greater turning effect (low gear).

If a small gear is driven by a large gear, the small gear turns faster but with a smaller turning effect (high gear).



# DISTANCE

Distance is a measure of how far an object travels, regardless of direction. It is a scalar quantity, meaning only magnitude matters. For example, if an athlete runs one full lap of a 300 m track, the distance travelled is 300 m.

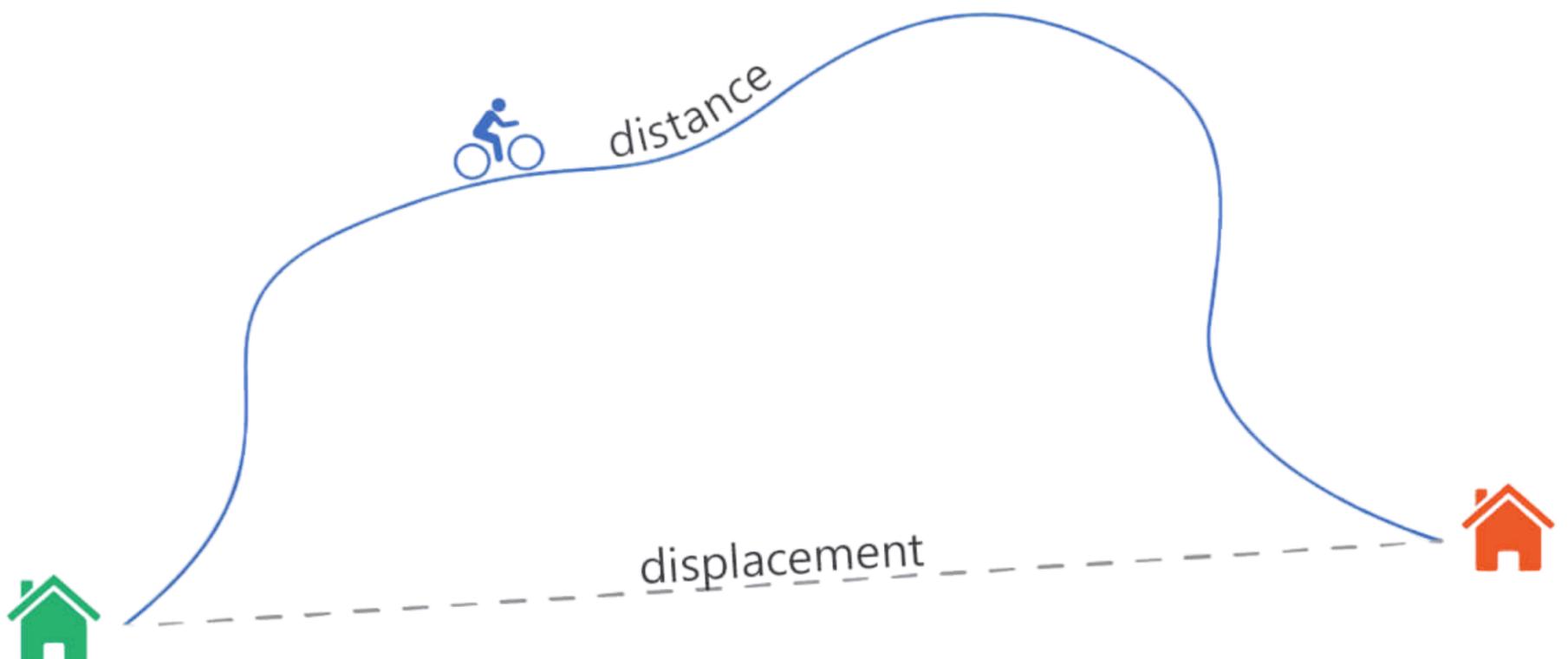
- Distance = total path length
- Scalar quantity
- Direction not important

# DISPLACEMENT

Displacement measures how far an object is from its starting position, including direction. It is a vector quantity. In the same race example, if the athlete ends 100 m to the right of the start point, their displacement is 100 m to the right, even though the distance travelled was 300 m.

- Displacement = straight-line change in position
- Vector quantity
- Includes direction

If an athlete completes a full lap and returns to the starting point, the displacement is zero, even though the distance is not.



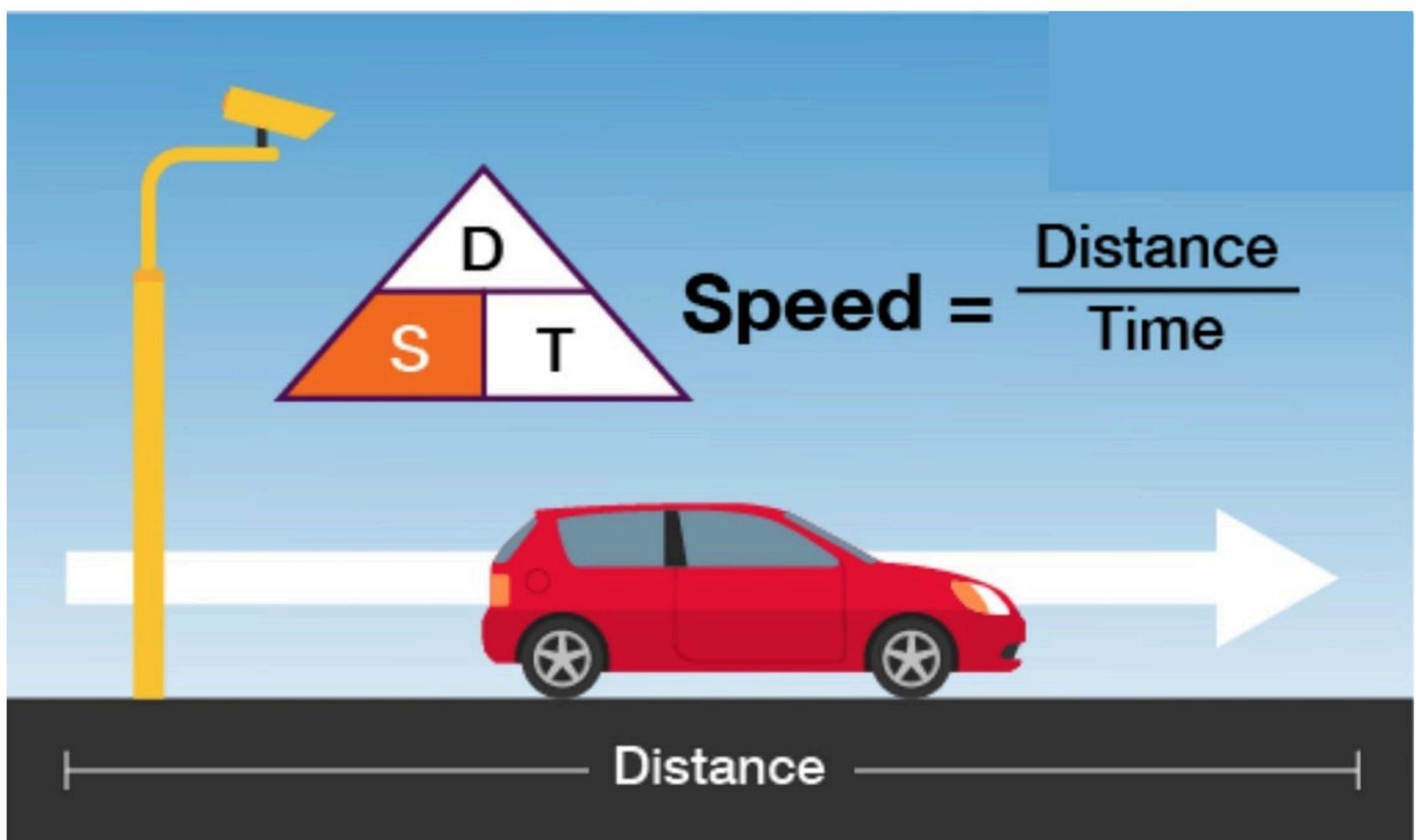
# SPEED

Speed describes how much distance an object travels per second. It is a scalar quantity because it has magnitude only.

$$\text{Average Speed} = \frac{\text{Total Distance Covered}}{\text{Total Time Taken}}$$

- Distance measured in metres (m)
- Time measured in seconds (s)
- Speed measured in metres per second (m/s)

Average speed does not show variations during the journey – the object may move faster or slower at different moments.



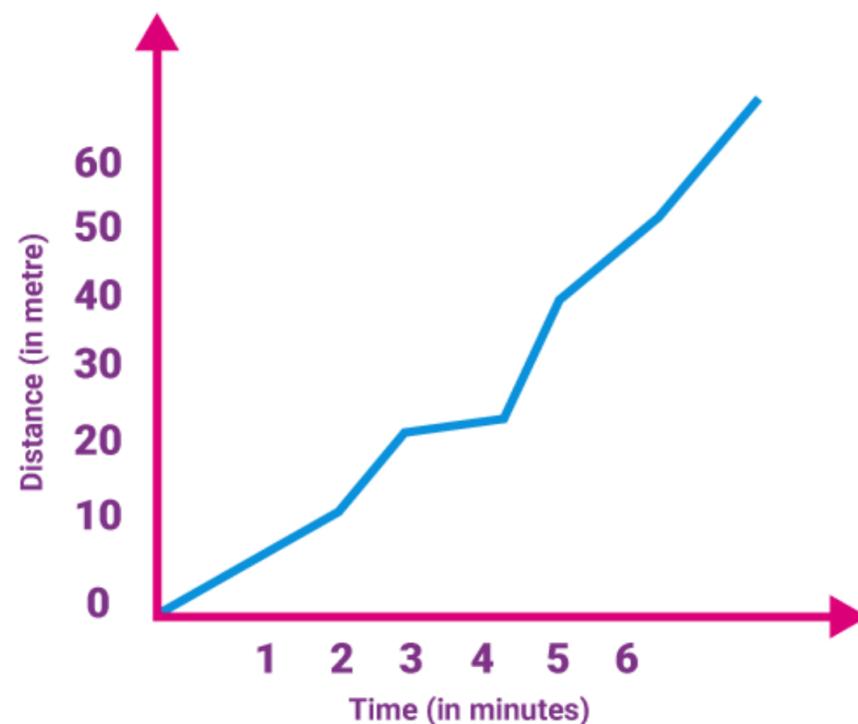
# NON-UNIFORM MOTION

In real life, objects rarely move at a constant speed. Non-uniform motion describes motion that is changing, either in speed, direction, or both.

## Examples include:

- Cars speeding up and slowing down
- People changing walking pace
- Race cars slowing for corners and speeding on straights

Non-uniform motion simply means motion is not constant.

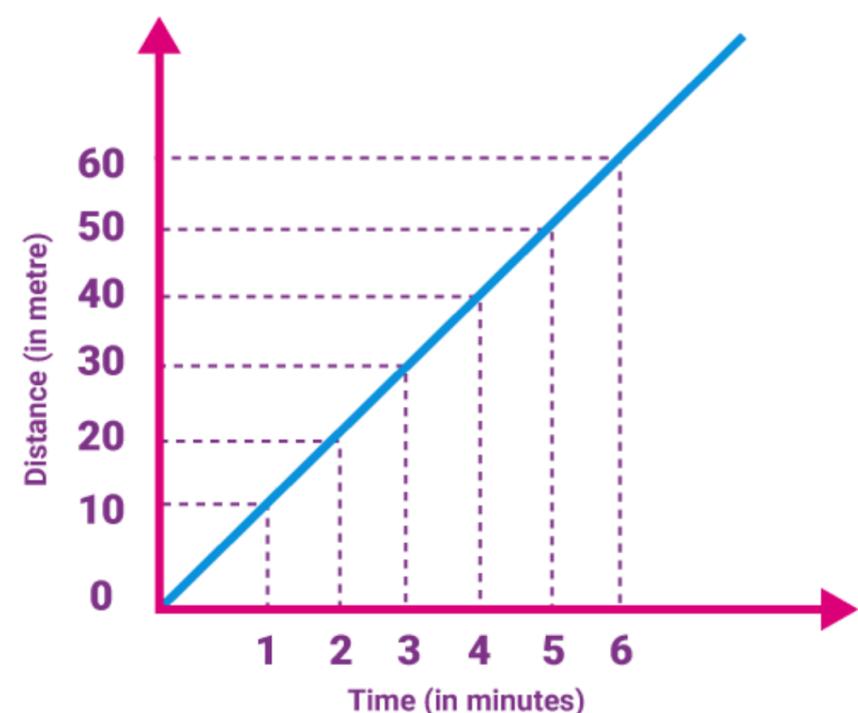


# UNIFORM MOTION

Uniform motion is defined as the movement of an object along a straight line at a constant speed, covering equal distances in equal intervals of time. It is characterized by zero acceleration and a constant velocity.

## Examples of Uniform Motion

- Car with Cruise Control: A car traveling on a straight, flat road at a constant speed of 50 km/h.

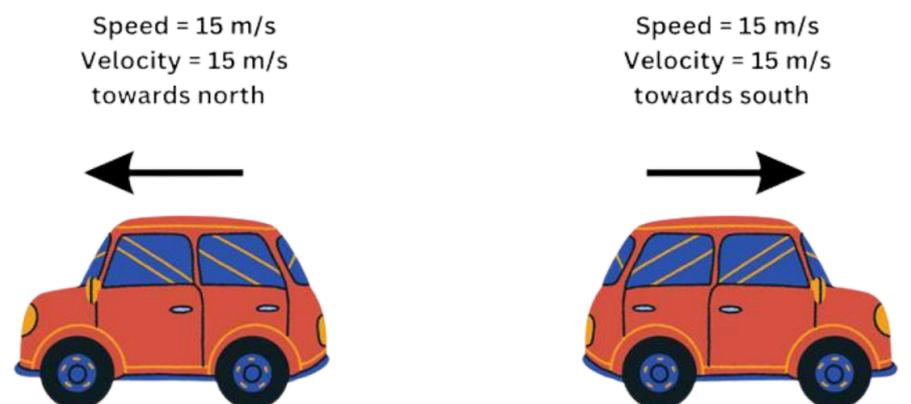


# VELOCITY

Velocity is similar to speed but includes direction, making it a vector quantity.

- Speed: scalar (e.g. 20 m/s)
- Velocity: vector (e.g. 20 m/s east)

Objects can have the same speed but different velocities if they move in different directions.

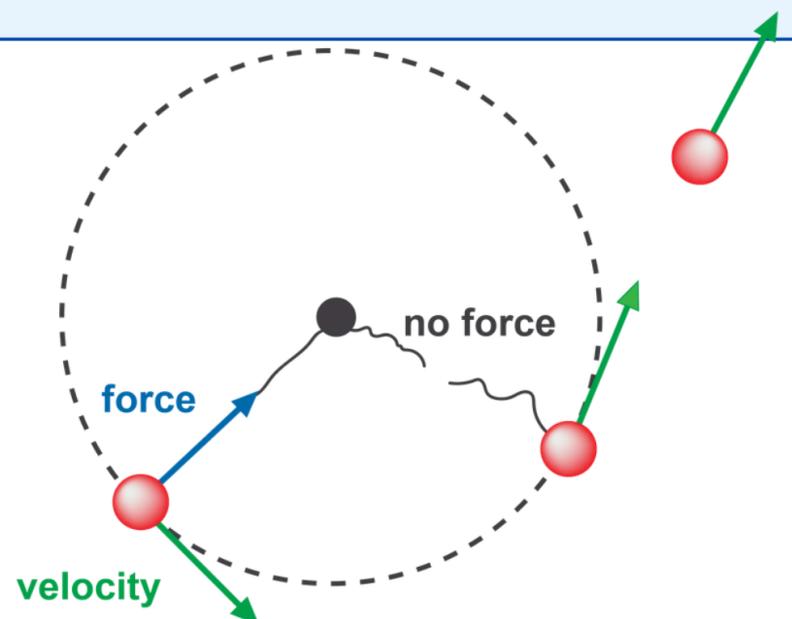


# CIRCULAR MOTION

In circular motion, an object may move at constant speed, but its velocity is always changing because the direction continuously changes.

- Speed constant
- Direction changing
- Velocity changing

This is why objects in circular motion are always accelerating, even if their speed does not change.



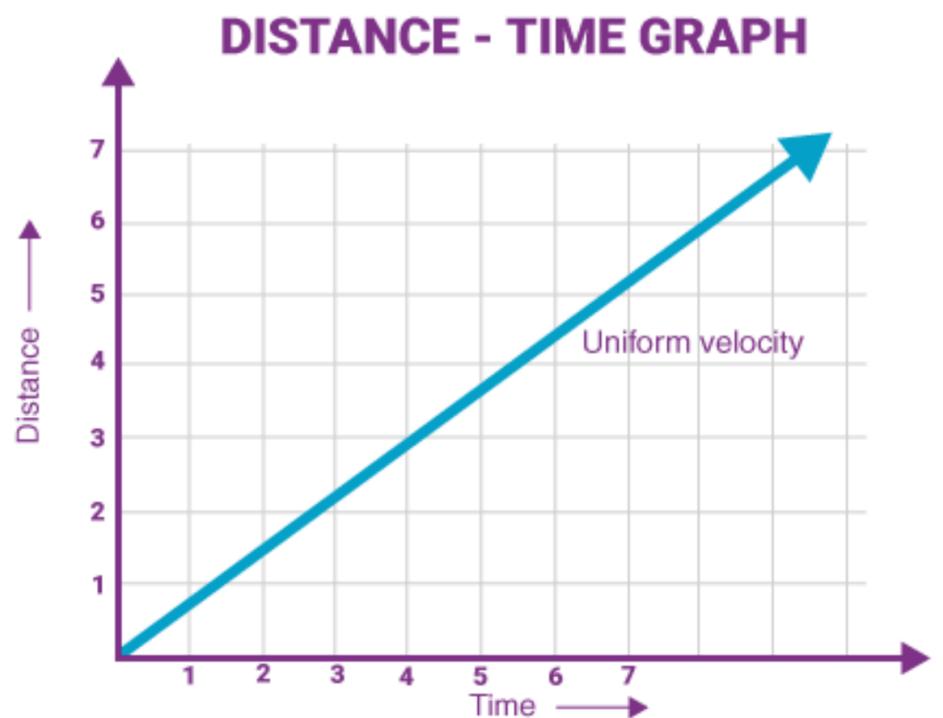
# DISTANCE-TIME GRAPHS

A distance-time graph shows how distance changes with time.

- Straight line → constant speed
- Steep slope → high speed
- Shallow slope → low speed
- Horizontal line → stationary

Gradient of a Distance-Time Graph

$$\text{Gradient} = \frac{\text{Change in Distance}}{\text{Change in Time}}$$

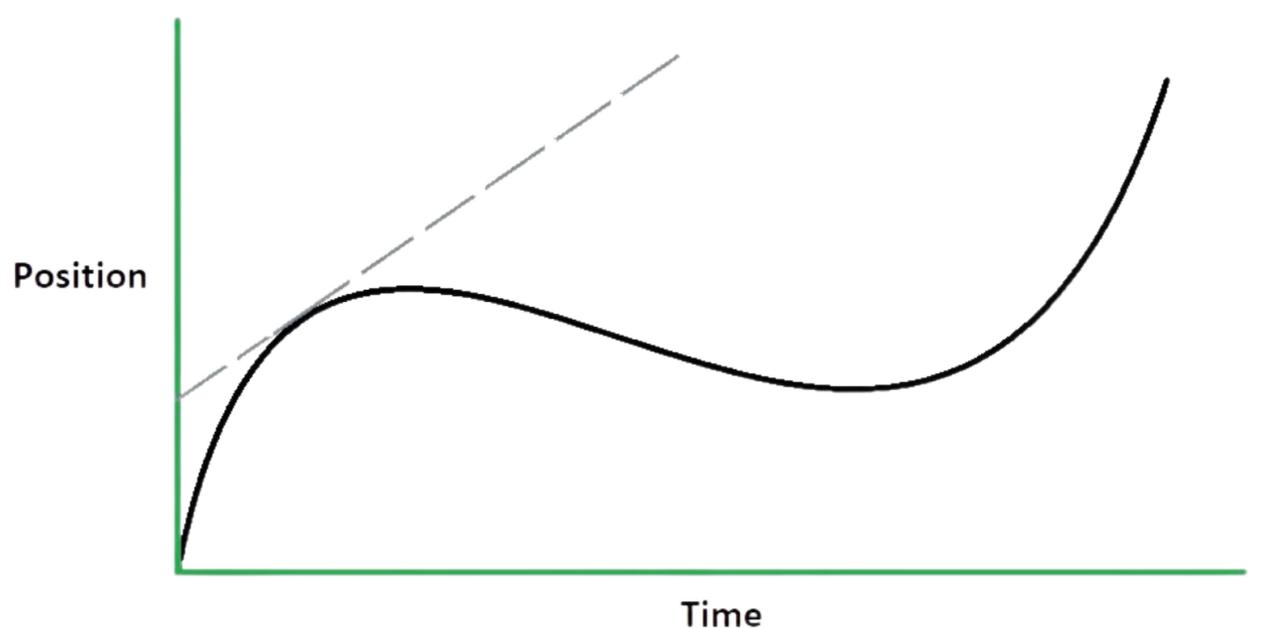


# INSTANTANEOUS SPEED

When speed is changing, the distance-time graph is curved. The instantaneous speed at a specific time is found by:

- Drawing a tangent to the curve
- Calculating the gradient of the tangent

The gradient at that point gives the speed at that exact moment.



# ACCELERATION

Acceleration is the rate of change of velocity. It describes how much velocity changes every second.

$$a = \frac{\Delta v}{\Delta t}$$

## Where:

- $a$  = acceleration ( $\text{m/s}^2$ )
- $\Delta v = v - u$
- $t$  = time (s)
- Speeding up  $\rightarrow$  positive acceleration
- Slowing down  $\rightarrow$  negative acceleration (deceleration)

# VELOCITY-TIME GRAPHS

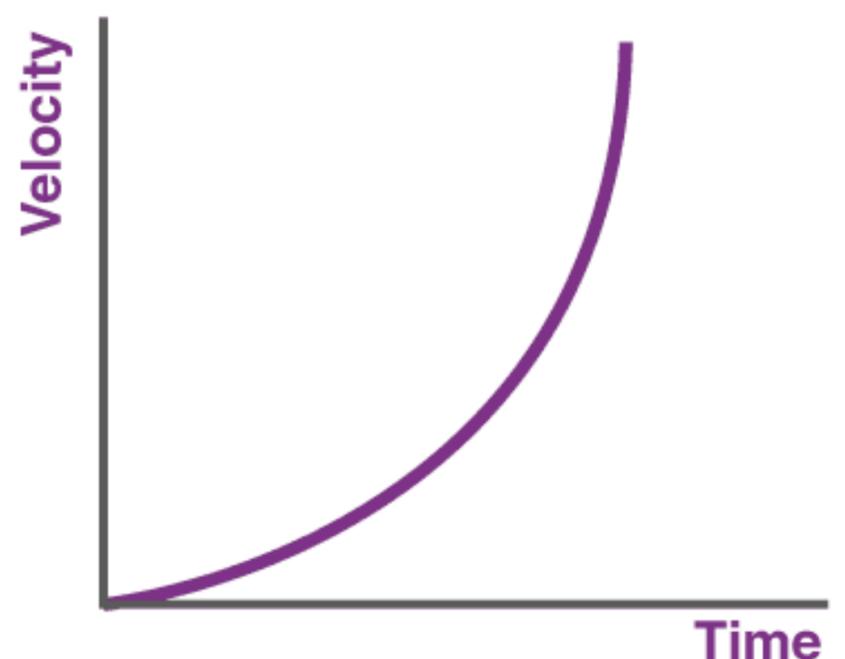
A velocity-time graph shows how velocity changes over time.

- Gradient = acceleration
- Steep slope  $\rightarrow$  large acceleration
- Flat line  $\rightarrow$  constant velocity (zero acceleration)

## Area Under Velocity-Time Graph

The area under the graph represents distance travelled.

- Rectangle  $\rightarrow$  constant velocity
- Triangle  $\rightarrow$  accelerating/decelerating motion
- Curve  $\rightarrow$  estimate by counting squares



# UNIFORM ACCELERATION EQUATION

For constant acceleration when time is not known:

## Used to calculate:

- final speed
- initial speed
- acceleration
- distance travelled

$$V^2 - U^2 = 2 a s$$

# FREEFALL & TERMINAL VELOCITY

In the absence of air resistance, all objects fall with the same acceleration which is  $g = 9.8 \text{ m/s}^2$

## During freefall:

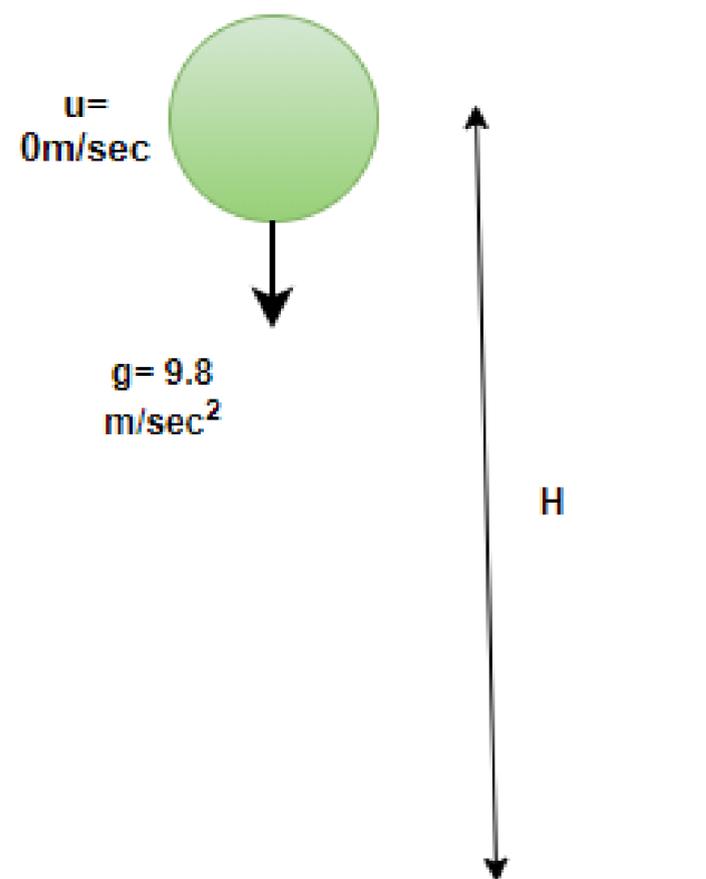
- Weight acts downward
- Air resistance acts upward

## As speed increases:

- Air resistance increases
- Resultant force decreases

## When air resistance equals weight:

- Resultant force = 0
- Acceleration = 0
- Object falls at terminal velocity



# STOPPING DISTANCE

The stopping distance of a vehicle is the total distance travelled from the moment a driver notices a hazard to the moment the vehicle comes to rest. It is made up of two separate parts: the distance travelled while the driver is reacting, and the distance travelled while the brakes are slowing the car down.

**Stopping distance = Thinking distance + Braking distance**

- Measured in metres (m)
- Increases as speed increases

## THINKING DISTANCE

Thinking distance is the distance travelled during the driver's reaction time, before the brakes are applied. During this time, the car continues to move at a constant speed because no braking force is acting yet.

Thinking distance depends mainly on:

- The speed of the car
- The driver's reaction time

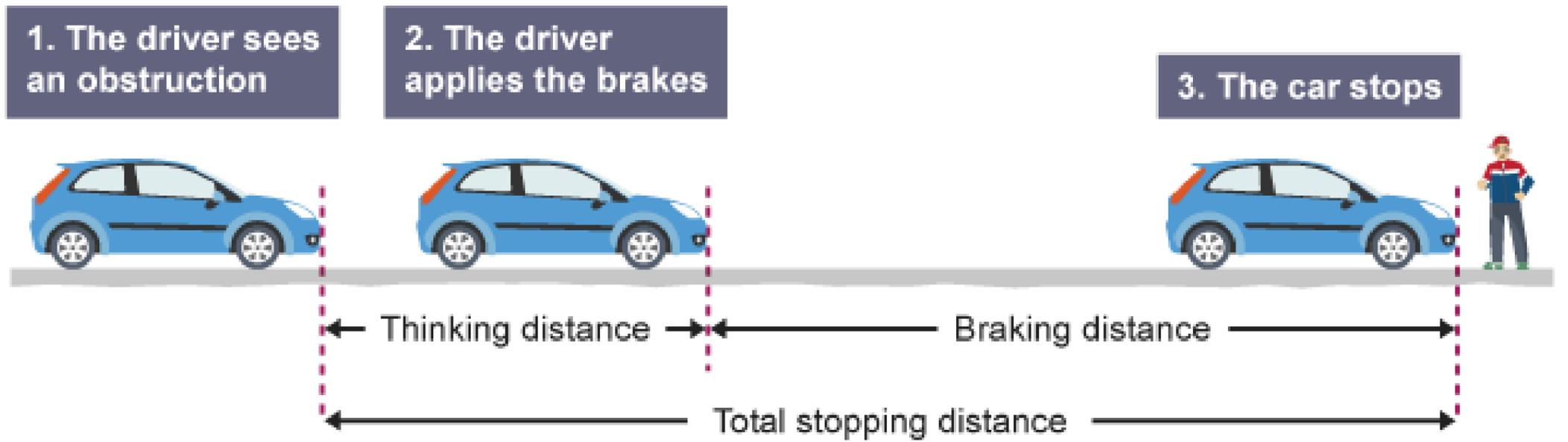
**Thinking distance = speed × reaction time**

## BRAKING DISTANCE

Braking distance is the distance travelled after the brakes are applied, while the car is slowing down. During this time, the car decelerates due to a braking force caused by friction in the braking system.

The main factor affecting braking distance is:

- Speed of the vehicle
- Poor road conditions (wet or icy roads)
- Poor vehicle condition (worn tyres, faulty brakes)
- Large vehicle mass (heavier vehicles take longer to stop)



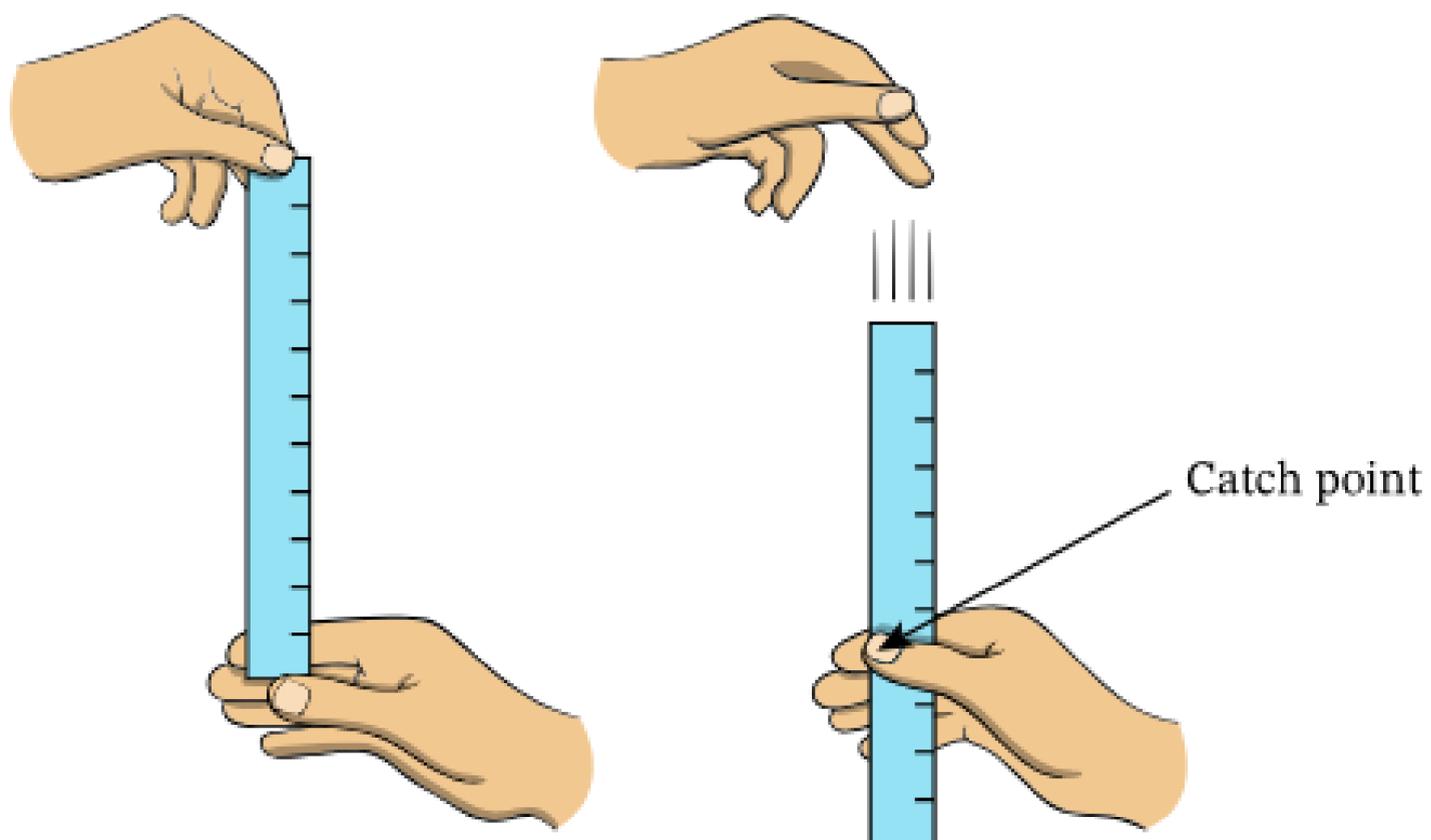
## REACTION TIME

Reaction time is the time between seeing a hazard and starting to react (e.g. pressing the brake pedal). For an alert person, reaction time is typically between 0.2 s and 0.9 s.

Reaction time can be measured using the ruler drop test, where:

- A ruler is dropped unexpectedly
- The distance it falls before being caught is measured
- A larger distance means a longer reaction time

Reaction time is important because even a small delay can significantly increase stopping distance at high speeds.



# ESTIMATING BRAKING FORCE (HIGHER TIER)

The work done by the brakes is equal to the loss in kinetic energy:

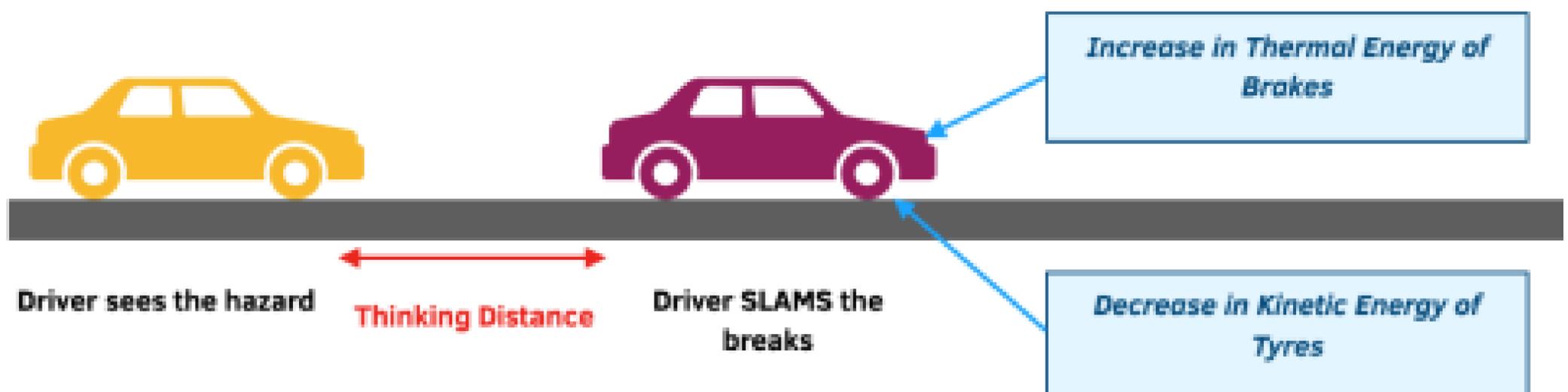
$$\text{Braking force} \times \text{braking distance} = \frac{1}{2}mv^2$$

This equation shows that:

- Braking distance is proportional to speed<sup>2</sup>
- Doubling speed makes braking distance four times larger

Large braking forces cause large decelerations, which can:

- Overheat brakes
- Reduce braking effectiveness
- Increase stopping distance further



# MOMENTUM

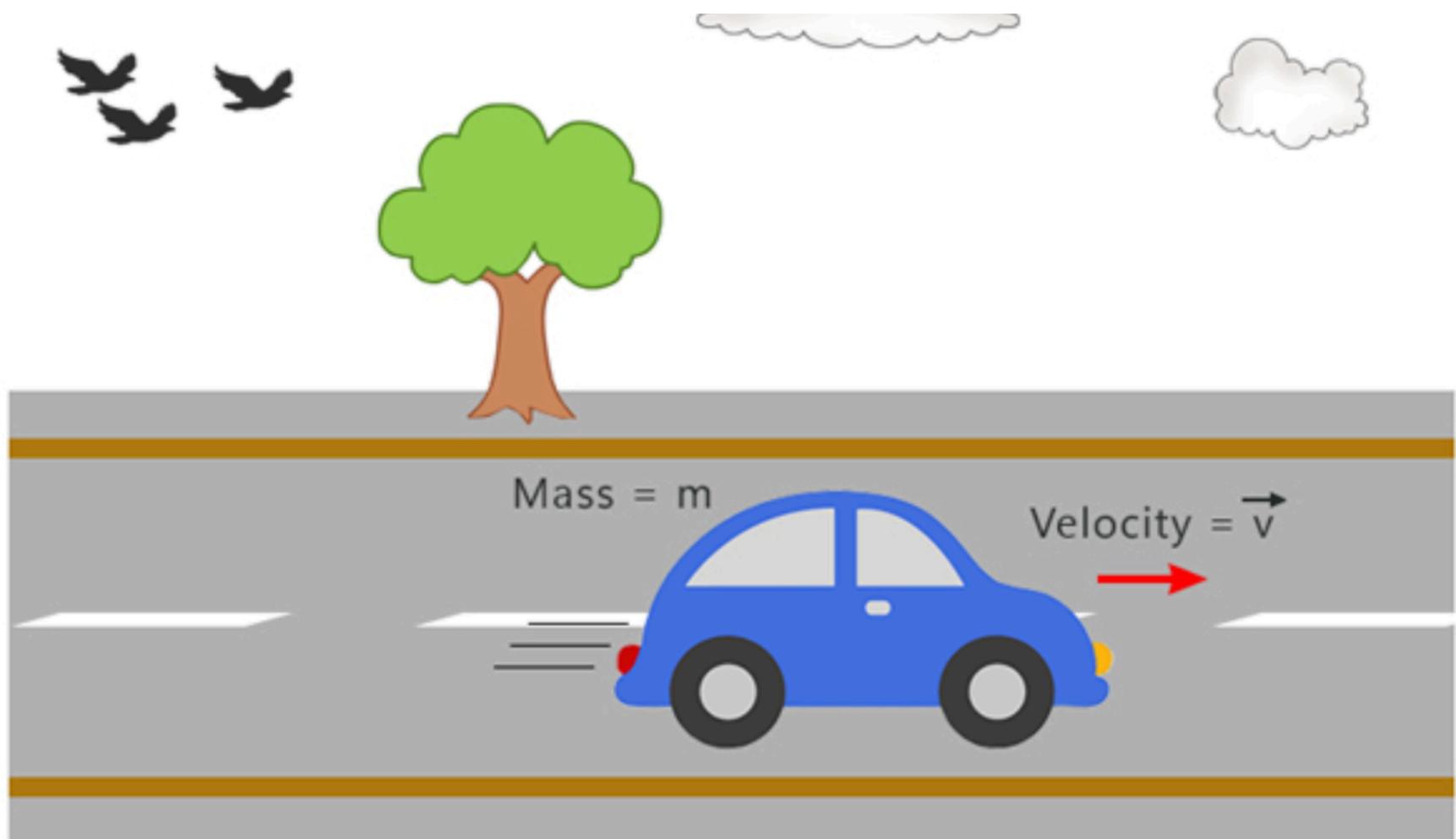
Momentum is a measure of how difficult it is to stop a moving object. An object has momentum only when it is moving. The greater the mass or the greater the velocity of an object, the greater its momentum.

$$p = m \times v$$

- $p$  = momentum (kg m/s)
- $m$  = mass (kg)
- $v$  = velocity (m/s)

If an object is at rest ( $v=0$ ), its momentum is zero.

Momentum depends on direction because velocity is a vector, so momentum is also a vector quantity. This means momentum can be positive or negative depending on the chosen direction.



## CHANGING MOMENTUM

The momentum of an object changes if:

- The object speeds up or slows down
- The object changes direction
- The object's mass changes

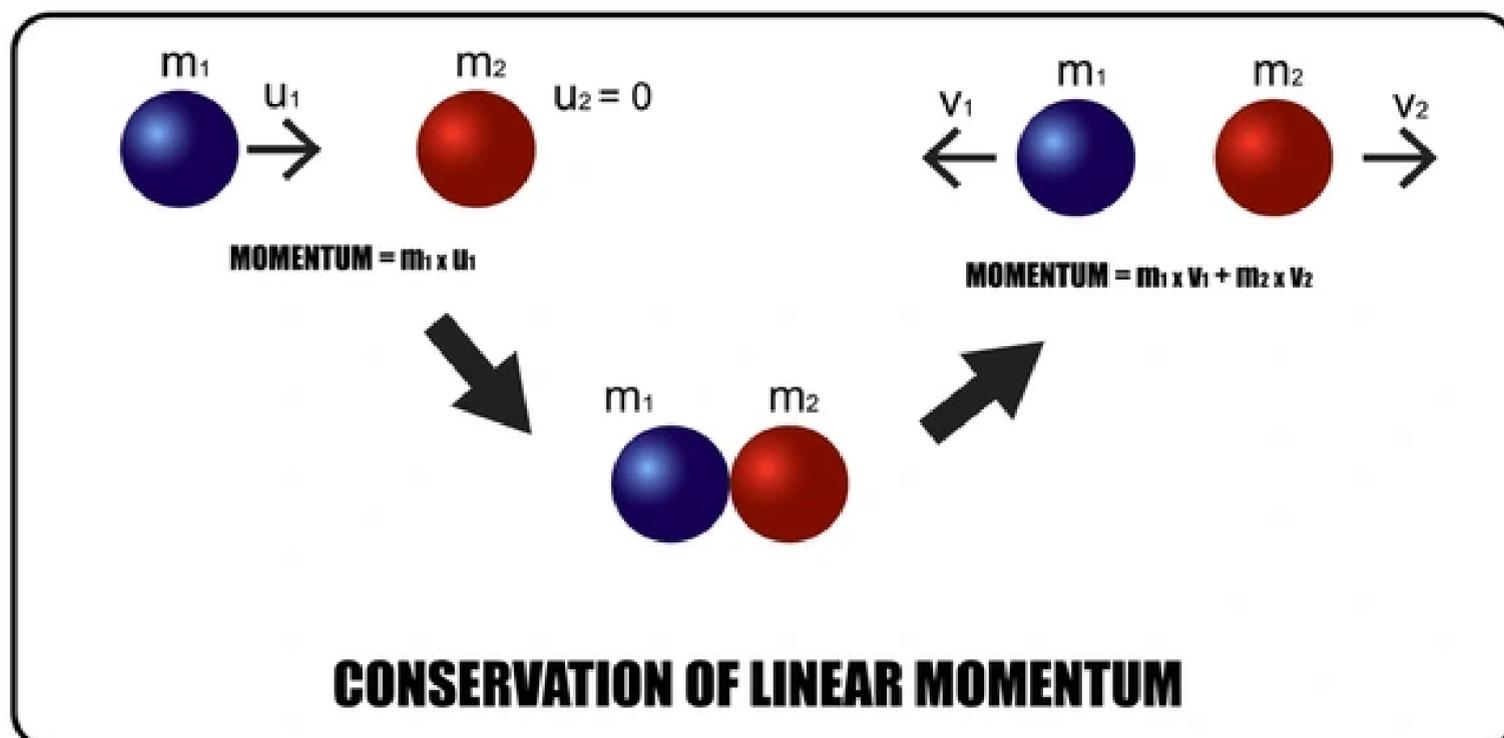
Objects with large momentum are harder to stop or change direction because a large change in momentum is required.

## CONSERVATION OF MOMENTUM

- The principle of conservation of momentum states that in a closed system, the total momentum before an event is equal to the total momentum after the event.

**Total momentum before = Total momentum after**

- A closed system means:
- No external forces act on the system (e.g. friction is negligible)
- Because momentum is a vector:
- Objects moving in opposite directions can cancel each other's momentum
- A system can have a total momentum of zero
- Momentum is always conserved during collisions and explosions.



# COLLISIONS

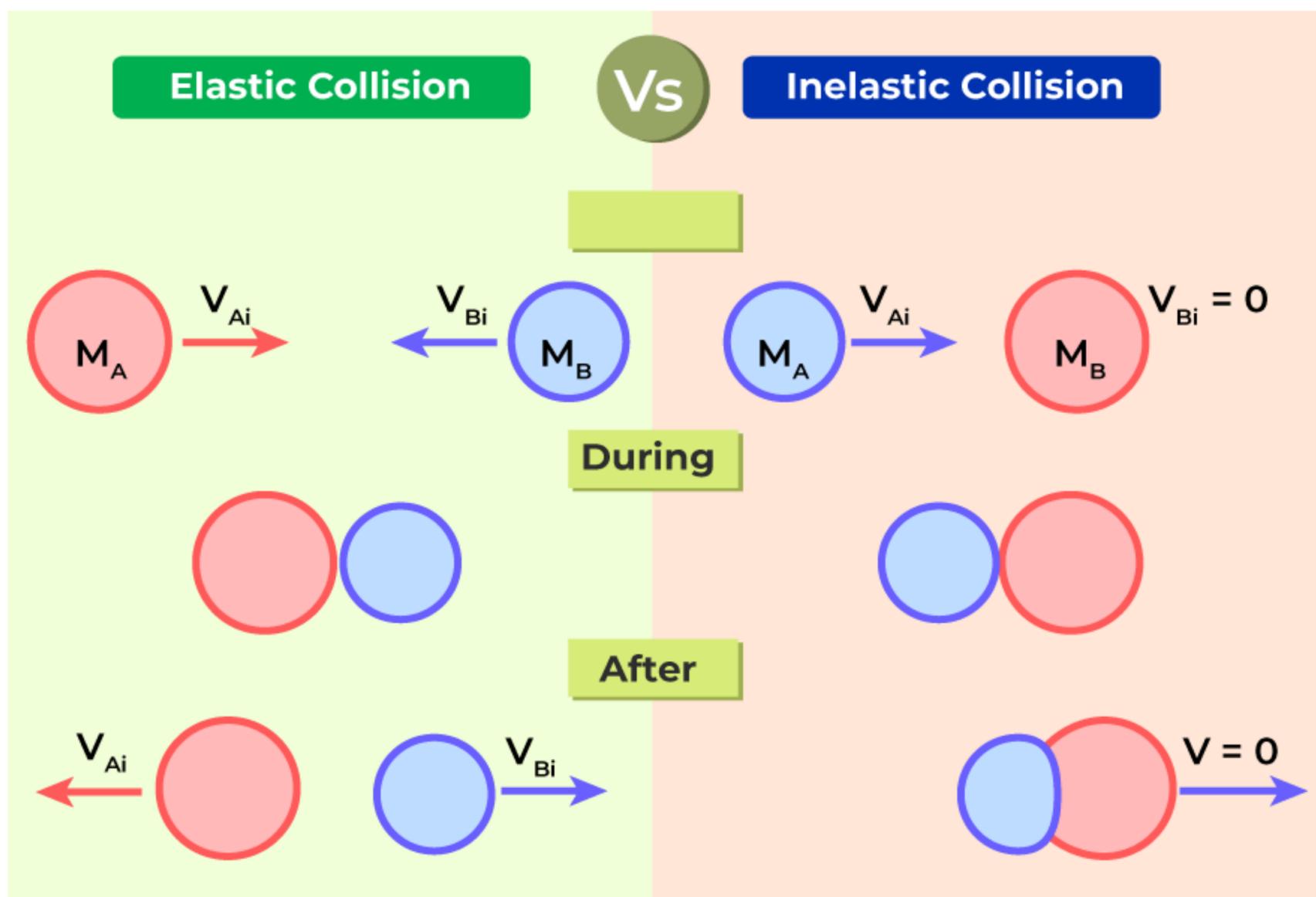
A collision is an event where objects interact and exchange momentum. There are two main types of collisions:

## Elastic Collisions

- Objects bounce apart after collision
- Objects move in different directions
- Momentum is conserved
- Kinetic energy is conserved (ideal case)

## Inelastic Collisions

- Objects stick together after collision
- Objects move in the same direction
- Momentum is conserved
- Kinetic energy is not conserved (some is transferred to heat, sound, or deformation)



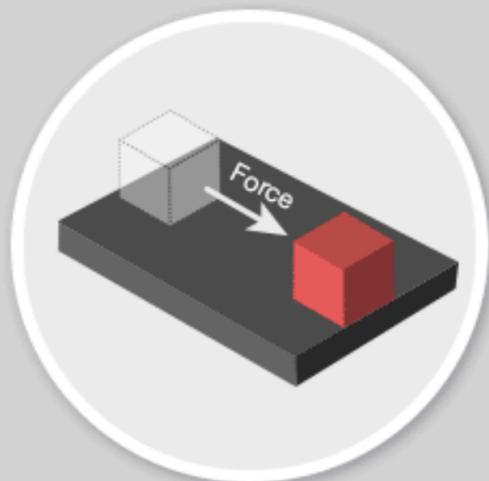
# FORCE AND MOMENTUM

When a force acts on an object, it causes a change in momentum. The force applied depends on how quickly the momentum changes.

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

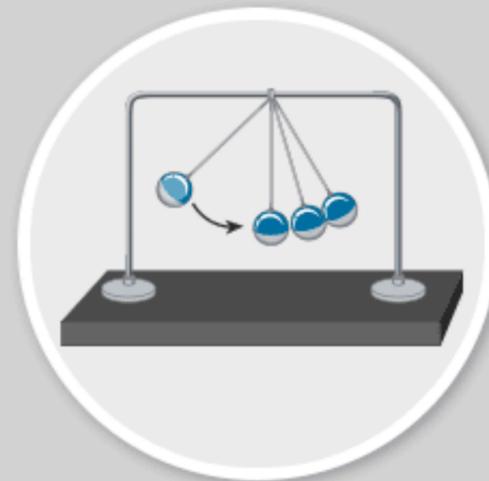
This equation shows that force is the rate of change of momentum.

- Same change in momentum over shorter time → larger force
- Same change in momentum over longer time → smaller force



## FORCE

Force is any interaction that, when unopposed, will change the motion of an object. A force can cause an object with mass to change its velocity, to accelerate.



## MOMENTUM

Momentum is the product of the mass and velocity of an object. It is a vector quantity, possessing a magnitude and a direction in three-dimensional space.

# VEHICLE SAFETY FEATURE

## Seat Belts

- Prevent passengers from being thrown forward
- Stretch slightly to increase stopping time
- Reduce force on passengers.

## Airbags

- Act as a soft cushion
- Increase time over which momentum changes
- Reduce injury to head and chest

## Crumple Zones

- Designed to deform during a collision
- Increase the time taken for the vehicle to stop
- Reduce force on passengers

Vehicles may appear heavily damaged after collisions because energy is absorbed by crumple zones to protect passengers