Knowledge Organiser - Forces

Forces

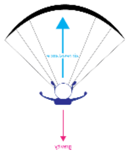
A **push** or **pull** applied by one object on another is a **force.**

Force is measure in **Newtons (N).**

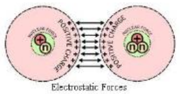
Forces between object can be either:

Contact:

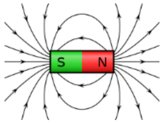
Non-contact:



Gravity



Electrostatic



Magnetic

Scalar quantities – has magnitude (size) only.
Example – speed, distance

Vector quantities – have magnitude and direction.
Example – velocity, displacement.
Displacement is measured in a straight line from start point to end point.
Velocity is speed ins a particular direction.

Speed

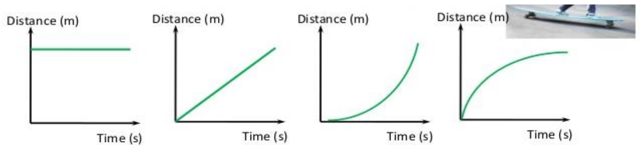
Speed tells us how fast an object is moving.

$$\text{Speed (v)} = \frac{\text{distance (d)}}{\text{Time (t)}}$$

To convert km/h into m/s multiply by 1000/3600
To convert m/s to km/h multiply by 3600/1000

Average speed is calculated as speed changes during a journey.

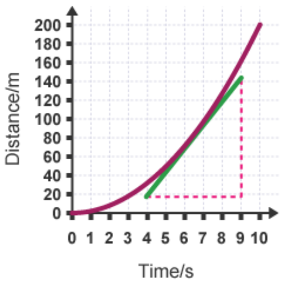
Distance – time graphs



A) Stationary object
B) Constant speed
C) Stationary to increasing speed
D) Increasing to stationary

The gradient of a distance-time graph is equal to the speed of an object.

HTIER – Tangents to distance-time graph



To find the speed at a particular point by drawing a **tangent** to the line and measuring the gradient of the tangent.

$$\text{Gradient} = \frac{(140 - 20)}{(9s - 4s)} = \frac{120m}{5s} = 24m/s$$

Acceleration

Acceleration happens when the velocity of an object increases.

Deceleration happens when the velocity of an object decreases – it has negative acceleration.

Remember – a faster increase in velocity is a greater the acceleration. A car which high acceleration reaches a high speed in a shorter time.

Calculating acceleration

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time taken}}$$

$$a\ (m/s^2) = \frac{\Delta v\ (m/s)}{t\ (s)}$$

Worked example:
A car accelerates from 10m/s to 60m/s in 12s.
Calculate the acceleration.

$$a\ (m/s^2) = \frac{\Delta v\ (m/s)}{t\ (s)}$$

$$a\ (m/s^2) = \frac{(60 - 10)}{12s}$$

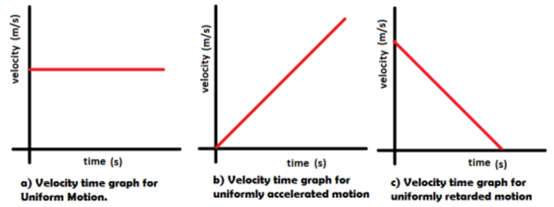
$$= 4.17\ m/s^2$$

HTier ONLY - Motion in a circle

To maintain constant speed, direction changes. This means the velocity changes as velocity is a vector. When the velocity changes it accelerates. There is a force acting at the centre of the circle in the same direction as acceleration causing the change in velocity to maintain the constant speed.

Velocity – time graphs

Velocity-time graphs show how the **velocity** of a **moving** object **changes** over **time**.



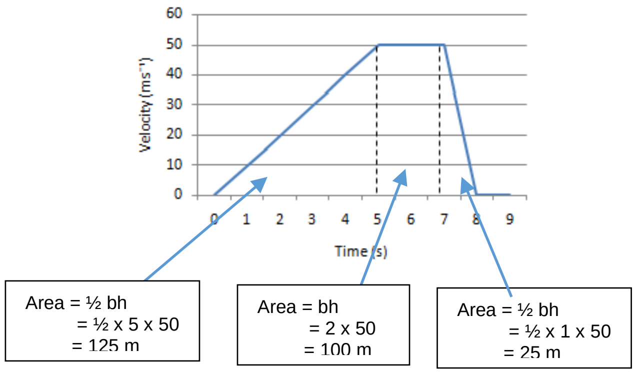
The sketch graph shows parts of the journey where velocity is positive or negative.

The **gradient** of a velocity-time graph shows how the velocity changes with time. A steep gradient shows the acceleration is large.

H Tier ONLY – Displacement

Displacement is equal to the area under a velocity-time graph. This is the distance the object travelled.

1. Divide the area under the graph into 3 simple shapes.



Total distance travelled = 125 + 100 + 25 = 250 m.

Calculating motion

Uniform motion is caused when acceleration is constant.

Calculating uniform motion uses the equation:

$$v^2 = u^2 + 2as$$

where
v = final velocity in m/s
a = acceleration in m/s^2
s = displacement in m
u = initial velocity in m/s

Worked example:
A car accelerates from 7.0 m/s at 3.5 m/s^2 for the next 11 m. What is the final velocity?

u = 7.0 m/s
a = 3.5 m/s^2
s = 11m

Substitute values into the equation:

$$v^2 = u^2 + 2as$$

$v^2 = 7^2 + (2 \times 3.5 \times 11)$
$= 49 + 77$
$= 126$

Therefore $v = \sqrt{126}$
= 11 m/s (to 2 sig figs)

Remember when an object is slowing down v will have a smaller value than u.

Rearranging gives:

$$a = \frac{(v^2 - u^2)}{2s}$$

Vertical motion

Remember:
Gravity of a falling object has an acceleration of approx. 9.8 m/s^2 (assuming no air resistance);
Deceleration if thrown up = - 9.8 m/s^2
Acceleration when falling = + 9.8 m/s^2

The equation can only be used when an object travels with constant uniform acceleration in a straight line.

Worked example:
A ball is thrown vertically upwards at 18 m/s. Calculate how high it goes assuming gravity = 9.8 m/s^2.

We take velocity as 0, as at the highest point the ball will be momentarily stationary.

u = 718 m/s
a = - 9.8 m/s^2
v = 0 m/s

$$v^2 = u^2 + 2as$$

$0 = (18)^2 + (2 \times -9.8 \times s)$
$0 = 324 - 19.6s$
$19.6s = 324$

$s = 324 / 19.6$
= 17 m (to 2 sig figs)

Weight and mass

Mass is the amount of substance present in an object. It is measure in **kilograms.** This does not change.

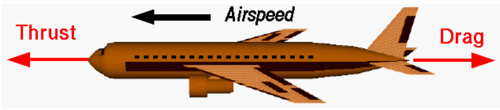
Weight is the force acting on the mass in a gravitational field. Weight can change according to the gravitational force. It is measured in **newtons.**

Weight = mass x gravitational field strength

Different planets and stars have differential gravitational field strengths therefore weight can change. Mass remains constant.

Forces and motion

Newton's first law



Objects have several forces acting on them. When a number of forces are replaced by a single force – with the same effect – this is called the **resultant force.**

When the forces are in balance, they cancel each other out and the resultant force is zero. The object behaves as if no forces are acting on it.

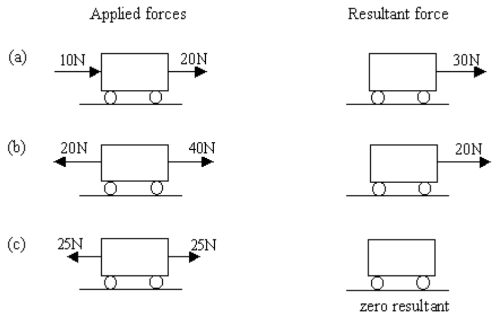
Newton's first law states if the resultant force is zero then it will:

- If stationary – remain stationary;
- If moving, remain at constant speed in a straight line.

e.g. a rock resting on the ground, walking at steady speed on a treadmill.

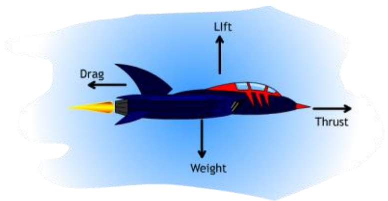
Resultant forces

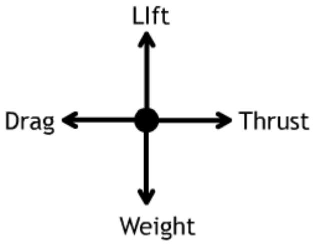
When several forces are acting on an object the combined effect can be calculated. The combined force is called **resultant force.**



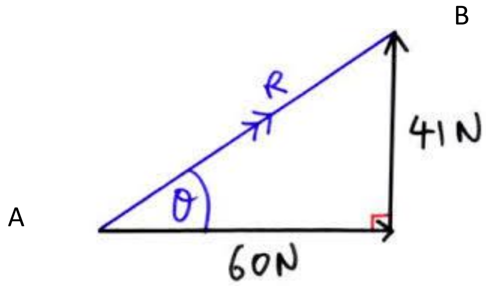
Free-body diagrams

Free-body diagrams show the **magnitude** and **direction** of the forces acting on an object. The force arrows always start from the centre of the point.





H Tier ONLY – Finding forces using vector diagrams

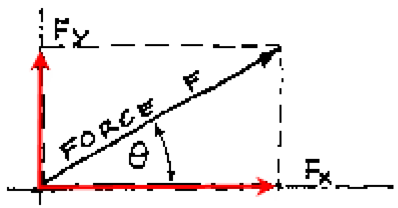


Using the magnitude and directions of the forces acting construct the diagram above. Use a scale appropriate to the magnitudes of the forces (e.g. 1cm = 10N)

The resultant force (R) is the imaginary line from A to B. The magnitude can be found by measuring the length of the line and applying the scaling.

The direction is found by measuring the angle θ.

Using a single force of known direction, it is possible to find the two forces which combined to produce the resultant force:



Draw a scale diagram of the force at the angle given to the horizontal. Draw a straight line down to the x-axis and measure the length of the line

Fx = horizontal component of the force.

Repeat for y-axis.

Fy = vertical component.

Forces and acceleration

Newton's second law

Force, mass and acceleration are linked by the equation:

$$F = ma$$

Where:
F = the resultant force in N
m = mass in kg
a = acceleration in m/s^2

Worked example:
A car has a mass of 1250 kg. What force is needed to give it an acceleration of 7 m/s^2.

F = ma
= 1250 x 7
= 8750 N

H Tier ONLY – Inertia

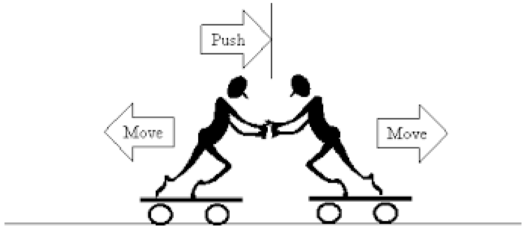
Massive objects are hard to start moving and to stop. The reluctance to start movement is called **inertia.**

Inertial mass is the measure of how difficult it is to change the velocity of an object. It is defined by the ratio equation of:

$$\text{Inertial mass} = \frac{\text{force}}{\text{acceleration}}$$

Newton's third law

Newton's third law states that whenever **two objects** interact the **forces,** they exert on each other are **equal** and **opposite**.



The forces in the pair:
- Are the same;
- Act in opposite directions;
- Act on different objects.

H Tier ONLY - Momentum

Momentum is dependent upon the mass and velocity of an object.

Momentum = mass x velocity
p = m x v

p = momentum in kg m/s
m = mass in kg
v = velocity in m/s

Changes in momentum happening if an object stops suddenly. For example, if a car suddenly stops its momentum is **zero**. The larger the force applied the quicker its momentum becomes zero.

This is calculated combining formula already met:
F= ma and a = (v-u)/t

Since momentum = mv the equation becomes:

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

Worked example:
A car of mass 1500kg is moving at 14 m/s when it hits a wall. The force on the car is 5600N. Calculate the stopping time.

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

Ft = m (v-u)

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

$$t = \frac{1500 \times (14-0)}{5600} = \frac{21000}{5600}$$

t = 3.75 s

Crumple zones on cars are designed to increase the time it takes for a car to stop – the momentum does not change as quickly. This reduces the force on the car occupants.

H Tier ONLY – Conservation of momentum

This is used to calculate the velocities before and after a collision. The principle is that the total momentum before a collision is equal to the momentum after the collision (in a closed system).

The equation used is:

$$m_1u_1 + m_2u_2 = (m_1 + m_2)\,v$$

Keeping safe on the road

The time taken for the driver to stop a moving car when reacting to a stimulus is called **reaction time.**

Thinking distance – the distance travelled during the reaction.

Braking distance – the distance travelled before the car stops after the brake has been applied.

Stopping distance = thinking + braking distances

Factors affecting stopping distance are:

- Driver tiredness;
- Influence of drugs/alcohol;
- Distraction;
- Road conditions – ice/wet
- Car had bald tyres;
- Car has poor brakes;
- The car speed is great.

Rapid deceleration can cause:

- Heating damage caused by friction;
- Injury;
- Loss of control of the vehicle.

H Tier ONLY

A rapid change in momentum can cause injury to the passengers due to the high forces exerted. The seat belts and air bags are designed to bring passengers to rest over a longer period of time.

To estimate the forces needed to sop the vehicle you use the following equations together:

$v^2 = u^2 + 2as$

followed by

F = ma

Moments

A moment is a **turning effect**. The point the moment acts around is called the **pivot/fulcrum**. The size of the moment is dependent on:

- Size of the force;
- Perpendicular distance from the pivot to the line of action of the force.

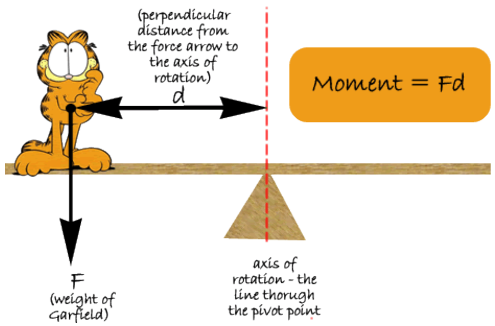
The equation used is:

moment = force x perpendicular distance

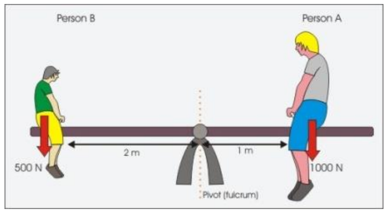
M = Fd

The unit of moment is **newton-metre (Nm).**

Moments are described as clockwise or anti-clockwise depending on their direction.

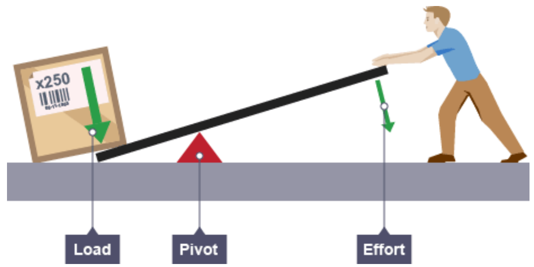


When a beam is balanced it is in equilibrium. The sum of the clockwise moments is equal to the sum of the anti-clockwise moments.



Centre of mass is when the weight of an object is considered to be acting at a single point. An object becomes unstable when the vertical line through its centre of mass falls outside its base. This point acts like a pivot and causes a turning effect.

A **lever** uses the moment of a force.



The effort force pushing down produces a clockwise moment about the pivot. This is greater than the anti-clockwise moment caused by the load at the other end. The load is lifted. The lift is small due to the load being bigger than the effort force.

Levers allow the movement of a large force using a smaller force. The energy transferred to the load is the increase in the gravitational potential energy:

E_p = m g h
= weight of load x vertical height increase.

The work done by the effort force is:

W = Fd
= effort force x distance moved along the line of action

The distance moved by the effort force must be greater than the distance moved by the load force, the effort force is smaller than the load force according to conservation of energy principles.

Gears are used to transmit the rotational effect of a force from one part of a machine to another. A small gear will transfer energy quickly but with a smaller force.

Linked gears are in contact. The direction of the rotation can be changed. Smaller gears rotate faster than larger ones. Larger gears rotate slowly but with more force.

Pressure in a fluid

A fluid can either be a liquid or a gas. The pressure in a fluid causes a force normal to (at right angles to) any surface. The pressure in a fluid acts in all directions.

Pressure is worked out using the force being applies over an area.

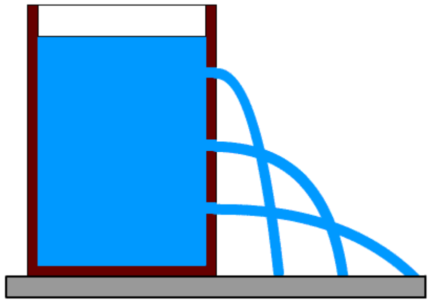
pressure, $p = \frac{\text{force normal to a surface}}{\text{area of that surface}}$

$p = \frac{F}{A}$

Pressure is measured in **pascals (Pa)** when a force is in N and the area in m^2.

$1 \text{ Pa} = 1 \text{ N/m}^2$

H Tier ONLY – Pressure at different depths in a liquid



The deeper in water you go, the pressure increases. This is caused by the greater weight of water above.

Pressure at certain depths in a liquid depends on the height of the liquid above the base (h), the density of the liquid (p) and the gravitational field strength (g):

$p = h\ p\ g$

H Tier ONLY – Floating and sinking

When an object floats it experiences a greater pressure on its base, compared to the top surface. This creates a resultant force upwards called **upthrust**.

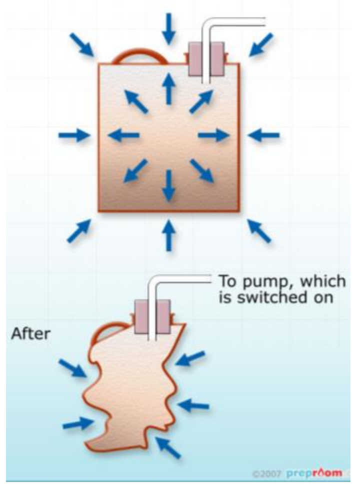
The density of the object placed n water determines whether it floats or sinks.

If the object sinks – its density is greater than the water and its weight is greater than the upthrust.

If the object float – its density is equal to the water and its weight is equal to the upthrust.

Atmospheric pressure

Air exerts a pressure.



When air particles are removed from a can there is a difference between the pressure inside compared to outside. The outside particles exert a greater pressure and the force causes the can to collapse.

Atmospheric pressure is caused by the amount of air above it. The higher up a mountain the lower the atmospheric pressure.

Forces and energy in springs

Forces can stretch and squash a spring. **Elastic deformation** occurs when the spring returns back to its original length when the force is remove. **Inelastic deformation** occurs when the spring is permanently altered.

There is a **linear relationship** between the amount of force applied and the stretch of the spring. The force is **directly proportional** to the extension. Beyond the limit of proportionality the relationship becomes non-linear.