Physics- Paper 2-Revision notes-Trilogy

6.5 Forces

Engineers analyse forces when designing a great variety of machines and instruments, from road bridges and fairground rides to atomic force microscopes. Anything mechanical can be analysed in this way. Recent developments in artificial limbs use the analysis of forces to make movement possible.

6.5.1 Forces and their interactions

Scalar and vector quantities

Scalar quantities have magnitude only.
Vector quantities have magnitude and an associated direction.
A vector quantity may be represented by an arrow. The length of the arrow represents the magnitude, and the direction of the arrow the direction of the vector quantity.

Contact and non-contact forces

A force is a push or pull that acts on an object due to the interaction with another object. All forces between objects are either:

- contact forces – the objects are physically touching
- non-contact forces – the objects are physically separated.

Examples of contact forces include friction, air resistance, tension and normal contact force.
Examples of non-contact forces are gravitational force, electrostatic force and magnetic force.
Force is a vector quantity.

Gravity

Weight is the force acting on an object due to gravity. The force of gravity close to the Earth is due to the gravitational field around the Earth. The weight of an object depends on the gravitational field strength at the point where the object is.
The weight of an object can be calculated using the equation:

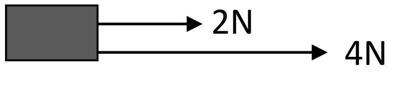
$$\text{Weight} = \text{mass} \times \text{gravitational field strength}$$
$$W = m\,g$$

- weight, W, in newtons, N
- mass, m, in kilograms, kg
- gravitational field strength, g, in newtons per kilogram, N/kg (In any calculation the value of the gravitational field strength (g) will be given. The gravitational field strength on Earth is taken as 10N/kg.)

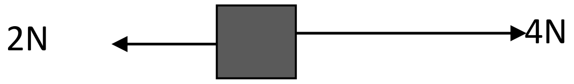
The weight of an object may be considered to act at a single point referred to as the object's 'centre of mass'.
The weight of an object and the mass of an object are directly proportional.
Weight is measured using a calibrated spring-balance (a newton meter).

Resultant forces

A number of forces acting on an object may be replaced by a single force that has the same effect as all the original forces acting together. This single force is called the resultant force.
A resultant force is the sum of forces acting on an object.



Resultant force = 2N + 4N = 6N to the right



Resultant force = 4N - 2N = 2N to the right

(HT only) A single force can be resolved into two components acting at right angles to each other. The two component forces together have the same effect as the single force.

(HT only) The vector diagrams can be used to illustrate resolution of forces, equilibrium situations and determine the resultant of two forces, to include both magnitude and direction (scale drawings only).

6.5.2 Work done and energy transfer

When a force causes an object to move through a distance work is done on the object. So a force does work on an object when the force causes a displacement of the object.
The work done by a force on an object can be calculated using the equation:

Work done = force × distance moved along the line of action of the force

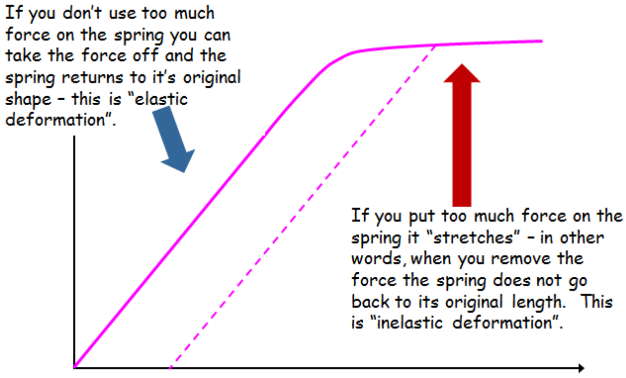
$$W = F\,s$$

- work done, W, in joules, J
- force, F, in newtons, N
- distance, s, in metres, m

One joule of work is done when a force of one newton causes a displacement of one metre.
1 joule = 1 newton-metre
Work done against the frictional forces acting on an object causes a rise in the temperature of the object.

6.5.3 Forces and elasticity

Forces are involved in stretching, bending or compressing an object



If you don't use too much force on the spring you can take the force off and the spring returns to it's original shape - this is "elastic deformation".

If you put too much force on the spring it "stretches" - in other words, when you remove the force the spring does not go back to its original length. This is "inelastic deformation".

To change the shape of an object (by stretching, bending or compressing), more than one force has to be applied – this is limited to stationary objects only.

If you don't use too much force on the spring you can take the force off and the spring returns to it's original shape – this is "elastic deformation". If you put too much force on the spring it "stretches" – in other words, when you remove the force the spring does not go back to its original length. This is "inelastic deformation

The extension of an elastic object, such as a spring, is directly proportional to the force applied, provided that the limit of proportionality is not exceeded.

Force = spring constant × extension

$$F = k\,e$$

- force, F, in newtons, N
- spring constant, k, in newtons per metre, N/m
- extension, e, in metres, m

.

This relationship also applies to the compression of an elastic object, where 'e' would be the compression of the object.
A force that stretches (or compresses) a spring does work and elastic potential energy is stored in the spring. Provided the spring is not in elastically deformed, the work done on the spring and the elastic potential energy stored are equal.

To calculate work done in stretching (or compressing) a spring (up to the limit of proportionality) using the equation:

Elastic potential energy = 0.5 × spring constant × extension ^{2}

$$E_e = \tfrac{1}{2}\,k\,e^2$$

6.5.4 Forces and motion

Describing motion along a line

Distance and displacement

Distance is how far an object moves. Distance does not involve direction. Distance is a scalar quantity.
Displacement includes both the distance an object moves, measured in a straight line from the start point to the finish point and the direction of that straight line. Displacement is a vector quantity.

Speed

Speed does not involve direction. Speed is a scalar quantity.
The speed of a moving object is rarely constant. When people walk, run or travel in a car their speed is constantly changing. The speed at which a person can walk, run or cycle depends on many factors including: age, terrain, fitness and distance travelled.

Typical values may be taken as:

- walking ~ 1.5 m/s
- running ~ 3 m/s
- cycling ~ 6 m/s

It is not only moving objects that have varying speed. The speed of sound and the speed of the wind also vary. A typical value for the speed of sound in air is 330 m/s.
For an object moving at constant speed the distance travelled in a specific time can be calculated using the equation:

Distance travelled = speed × time

$$s = v\,t$$

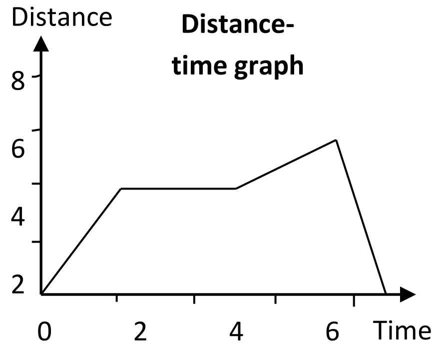
- distance, s, in metres, m
- speed, v, in metres per second, m/s
- time, t, in seconds, s

Velocity

The velocity of an object is its speed in a given direction. Velocity is a vector quantity.
(HT only) Motion in a circle involves constant speed but changing velocity.

The distance–time relationship

If an object moves along a straight line, the distance travelled can be represented by a distance–time graph.
The speed of an object can be calculated from the gradient of its distance–time graph. The gradient of a distance–time graph represents speed.
If there is a smooth slope on the graph then the object is moving at a constant speed. If there is a flat line then there is no movement. A steeper slope means a faster speed. If the slope is downwards the object is returning to the starting position.



(HT only) If an object is accelerating, its speed at any particular time can be determined by drawing a tangent and measuring the gradient of the distance–time graph at that time.

Acceleration

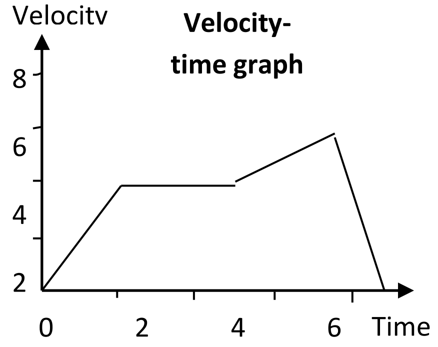
The average acceleration of an object can be calculated using the equation:

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

$$a = \Delta v/t$$

- acceleration, a, in metres per second squared, m/s2
- change in velocity, Δv, in metres per second, m/s
- time, t, in seconds, s

An object that slows down is decelerating.
The acceleration of an object can be calculated from the gradient of a velocity–time graph. If there is a smooth slope on your graph then the object is accelerating. If there is a flat line then the object is moving at a constant speed. A steeper slope means a larger acceleration. If there is a downwards slope then the object is decelerating.



(HT only) The distance travelled by an object (or displacement of an object) can be calculated from the area under a velocity–time graph.
The following equation applies to uniform acceleration:

$$(\text{Final velocity})^2 - (\text{Initial velocity})^2 = 2 \times \text{acceleration} \times \text{distance}$$

$$v^2 - u^2 = 2\,a\,s$$

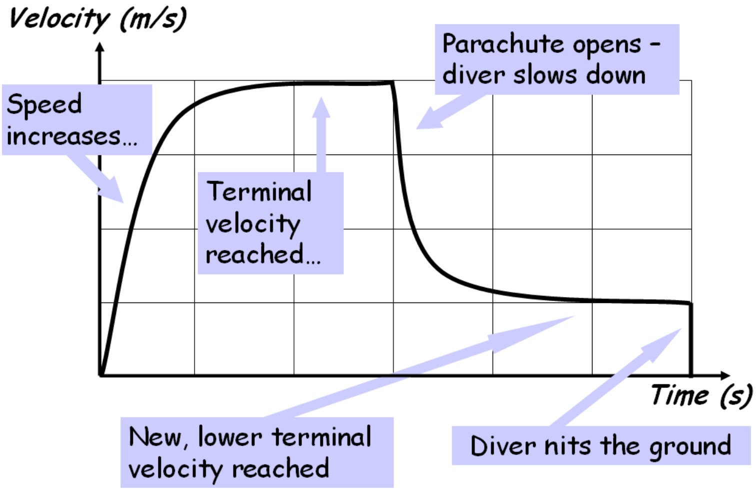
- final velocity, v, in metres per second, m/s
- initial velocity, u, in metres per second, m/s

- acceleration, a, in metres per second squared, m/s2
- distance, s, in metres, m

Near the Earth's surface any object falling freely under gravity has an acceleration of about 9.8 m/s^2.

Forces and terminal velocity

The faster an object moves through a fluid the greater the frictional force that acts on it.
An object falling through a fluid will initially accelerate due to the force of gravity. Eventually the resultant force will be zero and the object will move at its terminal velocity (steady speed).



The velocity–time graphs for objects can be used for objects that reach terminal velocity, including a consideration of the forces acting on the object.
An object falling through a fluid or gas will initially accelerate due to the force of gravity. Eventually the force of gravity will be balanced by the up thrust of the liquid/gas; this makes the resultant force zero and the object will move at its terminal velocity (steady speed).
The faster the object falls the greater the frictional force that acts.

Forces, accelerations and Newton's Laws of motion

Newton's First Law

Newton's First Law:
If the resultant force acting on an object is zero and:

- the object is stationary, the object remains stationary
- the object is moving, the object continues to move at the same speed and in the same direction. So the object continues to move at the same velocity.

So, when a vehicle travels at a steady speed the resistive forces balance the driving force.
So, the velocity (speed and/or direction) of an object will only change if a resultant force is acting on the object.
(HT only) The tendency of objects to continue in their state of rest or of uniform motion is called inertia

Newton's Second Law

Newton's Second Law:

The acceleration of an object is proportional ($\propto$) to the resultant force acting on the object, and inversely proportional to the mass of the object.
As an equation:

$$\text{Resultant force} = \text{mass} \times \text{acceleration}$$
$$F = m\,a$$

- force, F, in newtons, N
- mass, m, in kilograms, kg
- acceleration, a, in metres per second squared, m/s^2

(HT only) Students should be able to explain that:

- inertial mass is a measure of how difficult it is to change the velocity of an object
- inertial mass is defined as the ratio of force over acceleration

It is possible to estimate the speed, accelerations and forces involved in large accelerations for everyday road transport.

Newton's Third Law

Newton's Third Law:
Whenever two objects interact, the forces they exert on each other are equal and opposite.
Newton's Third Law can be applied to examples of equilibrium situations.

Forces and braking

Stopping distance

The stopping distance of a vehicle is the sum of the distance the vehicle travels during the driver's reaction time (thinking distance) and the distance it travels under the braking force (braking distance). For a given braking force the greater the speed of the vehicle, the greater the stopping distance.

Reaction time

Reaction times vary from person to person. Typical values range from 0.2 s to 0.9 s.
A driver's reaction time can be affected by tiredness, drugs and alcohol. Distractions may also affect a driver's ability to react.

Factors affecting braking distance 1

The braking distance of a vehicle can be affected by adverse road and weather conditions and poor condition of the vehicle. Adverse road conditions include wet or icy conditions. Poor condition of the vehicle is limited to the vehicle's brakes or tyres.

Factors affecting braking distance 2

When a force is applied to the brakes of a vehicle, work done by the friction force between the brakes and the wheel reduces the kinetic energy of the vehicle and the temperature of the brakes increases.
The greater the speed of a vehicle the greater the braking force needed to stop the vehicle in a certain distance.
The greater the braking force the greater the deceleration of the vehicle. Large decelerations may lead to brakes overheating and/or loss of control.

6.5.5 Momentum (HT only)

Momentum is a property of moving objects

Momentum is defined by the equation:

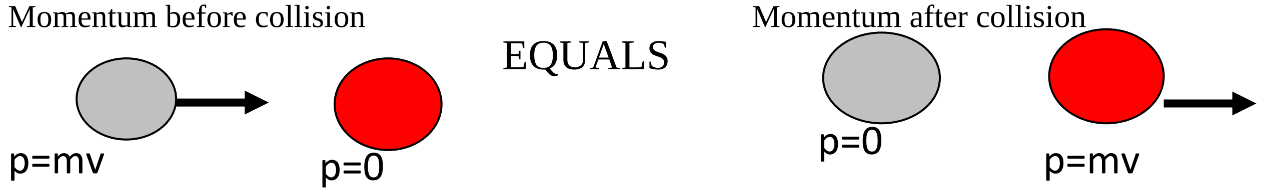
$$\text{Momentum} = \text{mass} \times \text{velocity}$$

$$p = m\,v$$

- momentum, p, in kilograms metre per second, kg m/s
- mass, m, in kilograms, kg
- velocity, v, in metres per second, m/s

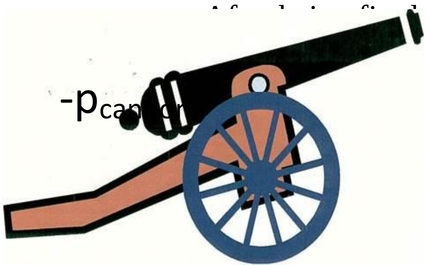
Conservation of momentum

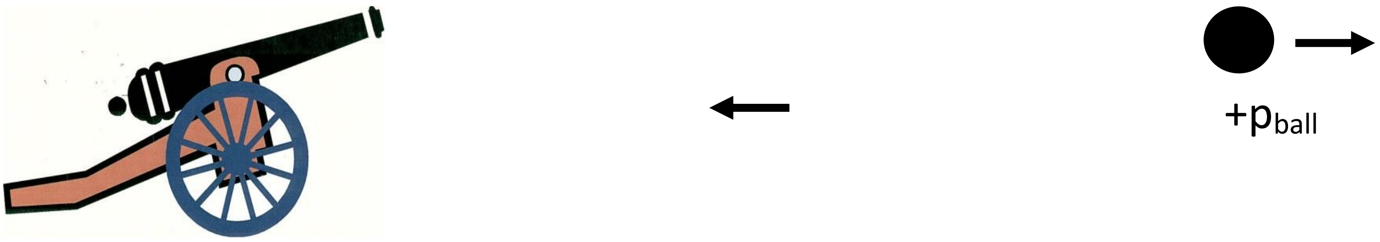
In a closed system, the total momentum before an event is equal to the total momentum after the event.
This is called conservation of momentum.
E.g. snooker balls



Another example is cannon before being fired and after being fired. Before the cannon is fired the momentum is zero, after it is fired the cannon ball moves forward and the cannon moves back. The momentum of the cannon ball is the same as the momentum of the cannon moving backwards.
In this sort of example we should choose one direction to be positive and the other direction to be negative.
The example below illustrates this point. The right is chosen as positive and the left is negative.

Before being fired





6.6 Waves

Wave behaviour is common in both natural and man-made systems. Waves carry energy from one place to another and can also carry information. Designing comfortable and safe structures such as bridges, houses and music performance halls requires an understanding of mechanical waves. Modern technologies such as imaging and communication systems show how we can make the most of electromagnetic waves.

6.6.1 Waves in air, fluids and solids

Transverse and longitudinal waves

Waves may be either transverse or longitudinal. Transfer waves oscillate perpendicular to the direction of energy transfer of the waves. Ripples on the surface of water are transverse waves. So are all electromagnetic waves. Longitudinal waves oscillate parallel to the direction of energy transfer of the waves. Sounds waves in air are longitudinal waves.

Longitudinal waves show areas of compression and rarefaction.

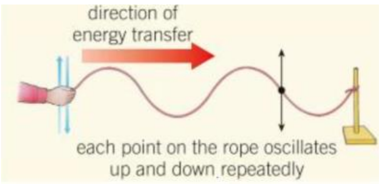


Figure 2 *Transverse waves*

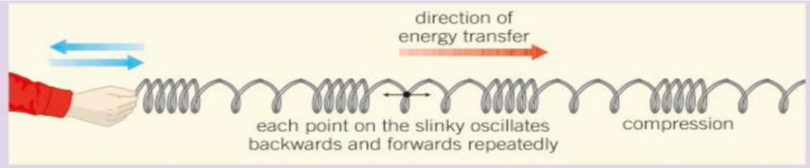
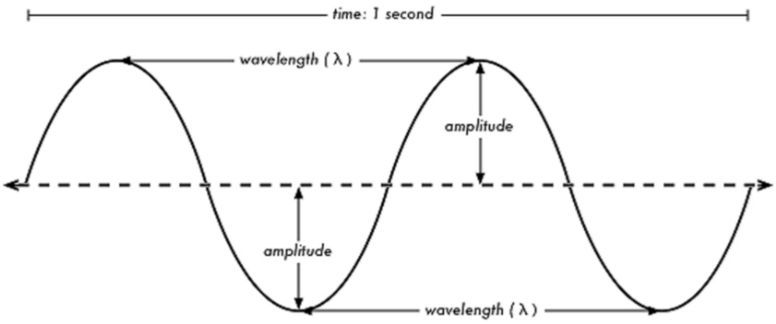


Figure 3 *Making longitudinal waves on a slinky*

For both ripples on a water surface and sound waves in air, it is the wave and not the water or air itself that travels.

Properties of waves

Wave motion can be described in terms of their amplitude, wavelength, frequency and period. The amplitude of a wave is the maximum displacement of a point on a wave away from its undisturbed position. The wavelength of a wave is the distance from a point on one wave to the equivalent point on the adjacent wave. The frequency of a wave is the number of waves passing a point each second.



Period = 1/ frequency

$$T = 1/f$$

- period, T, in seconds, s
- frequency, f, in hertz, Hz

The wave speed is the speed at which the energy is transferred (or the wave moves) through the medium. All waves obey the wave equation:

Wave speed = frequency × wavelength

$$v = f\lambda$$

- wave speed, v, in metres per second, m/s
- frequency, f, in hertz, Hz
- wavelength, λ, in metres, m

6.6.2 Electromagnetic waves

Types of electromagnetic waves

Electromagnetic waves are transverse waves that transfer energy from the source of the waves to an absorber.

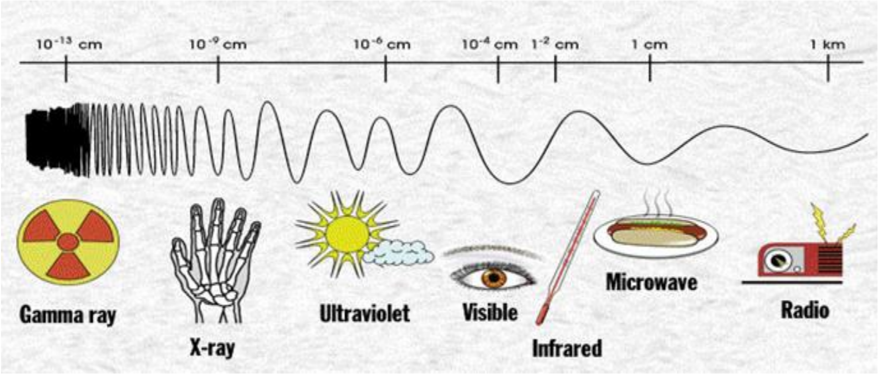
Electromagnetic waves form a continuous spectrum and all types of electromagnetic wave travel at the same velocity through a vacuum (space) or air.
The waves that form the electromagnetic spectrum are grouped in terms of their wavelength and their frequency. Going from long to short wavelength (or from low to high frequency) the groups are:
radio, microwave, infrared, visible light (red to violet), ultraviolet, X-rays and gamma rays.

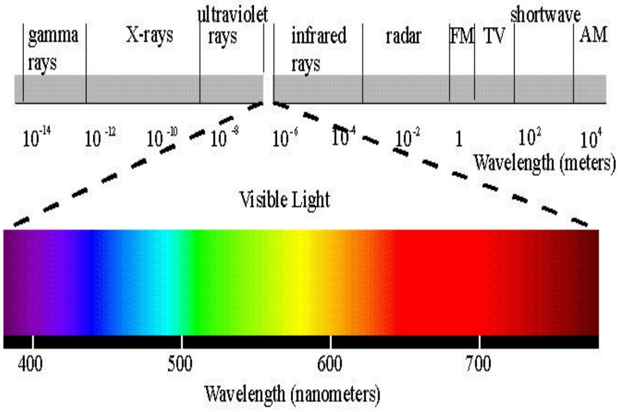
Long wavelength ⟶ Short wavelength

Radio waves	Microwaves	Infrared	Visible light	Ultraviolet	X-rays	Gamma rays

Low frequency ⟶ High frequency

Our eyes only detect visible light and so detect a limited range of electromagnetic waves.





Properties of electromagnetic waves 1

(HT only) Different substances may absorb, transmit, refract or reflect electromagnetic waves in ways that vary with wavelength.
(HT only) Some effects, for example refraction, are due to the difference in velocity of the waves in different substances.

Properties of electromagnetic waves 2

(HT only) Radio waves can be produced by oscillations in electrical circuits.
(HT only) When radio waves are absorbed they may create an alternating current with the same frequency as the radio wave itself, so radio waves can themselves induce oscillations in an electrical circuit.
Changes in atoms and the nuclei of atoms can result in electromagnetic waves being generated or absorbed over a wide frequency range. Gamma rays originate from changes in the nucleus of an atom.
Ultraviolet waves, X-rays and gamma rays can have hazardous effects on human body tissue. The effects depend on the type of radiation and the size of the dose. Radiation dose (in sieverts) is a measure of the risk of harm resulting from an exposure of the body to the radiation.

1000 millisieverts (mSv) = 1 sievert (Sv)

Ultraviolet waves can cause skin to age prematurely and increase the risk of skin cancer. X-rays and gamma rays are ionising radiation that can cause the mutation of genes and cancer.

Uses and applications of electromagnetic waves

Electromagnetic waves have many practical applications. For example:

- radio waves – television and radio
- microwaves – satellite communications, cooking food
- infrared – electrical heaters, cooking food, infrared cameras
- visible light – fibre optic communications
- ultraviolet – energy efficient lamps, sun tanning
- X-rays and gamma rays – medical imaging and treatments.

(HT only) Students should be able to give brief explanations why each type of electromagnetic wave is suitable for the practical application.

6.7 Magnetism and electromagnetism

Electromagnetic effects are used in a wide variety of devices. Engineers make use of the fact that a magnet moving in a coil can produce electric current and also that when current flows around a magnet it can produce movement. It means that systems that involve control or communications can take full advantage of this.

6.7.1 Permanent and induced magnetism, magnetic forces and fields

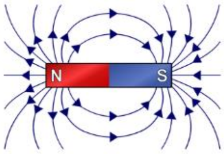
Poles of a magnet

The poles of a magnet are the places where the magnetic forces are strongest. When two magnets are brought close together they exert a force on each other. Two like poles repel each other. Two unlike poles attract each other. Attraction and repulsion between two magnetic poles are examples of non-contact force.

A permanent magnet produces its own magnetic field. An induced magnet is a material that becomes a magnet when it is placed in a magnetic field. Induced magnetism always causes a force of attraction. When removed from the magnetic field an induced magnet loses most/all of its magnetism quickly.

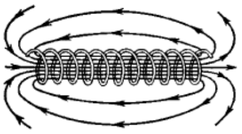
Magnetic fields

The region around a magnet where a force acts on another magnet or on a magnetic material (iron, steel, cobalt and nickel) is called the magnetic field. The force between a magnet and a magnetic material is always one of attraction. The strength of the magnetic field depends on the distance from the magnet. The field is strongest at the poles of the magnet.



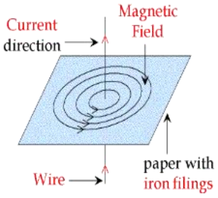
The direction of the magnetic field at any point is given by the direction of the force that would act on another north pole placed at that point. The direction of a magnetic field line is from the north (seeking) pole of a magnet to the south (seeking) pole of the magnet.

A magnetic compass contains a small bar magnet. The Earth has a magnetic field. The compass needle points in the direction of the Earth's magnetic field.



6.7.2 The motor effect

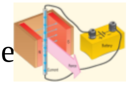
Electromagnetism



When a current flows through a conducting wire a magnetic field is produced around the wire. The strength of the magnetic field depends on the current through the wire and the distance from the wire. Shaping a wire to form a solenoid increases the strength of the magnetic field created by a current through the wire. The magnetic field inside a solenoid is strong and uniform. The magnetic field around a solenoid has a similar shape to that of a bar magnet. Adding an iron core increases the strength of the magnetic field of a solenoid. An electromagnet is a solenoid with an iron core.

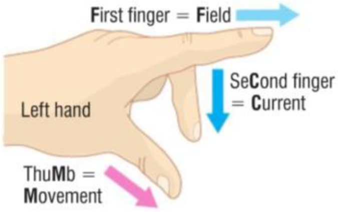
Fleming's left-hand rule (HT only)

When a conductor carrying a current is placed in a magnetic field the magnet producing the field and the conductor exert a force on each other. This is called the motor effect. Fleming's left-hand rule represents the relative orientation of the force, the current in the conductor and the magnetic field.



If the wire carrying the current is parallel to the magnetic field then it will not experience a force. The force a maximum when the wire is at 90^0 to the magnetic field.

The direction of the force can be determined by using your left hand (Fleming's left hand rule).



Index finger = magnetic field

Second finger = current

Thumb = direction of force

The size of the force can be increased by:

- increasing the strength of the magnetic field
- increasing the size of the current

The direction of the force is reversed if either the direction of the current or the direction of the magnetic field is reversed.

For a conductor at right angles to a magnetic field and carrying a current:

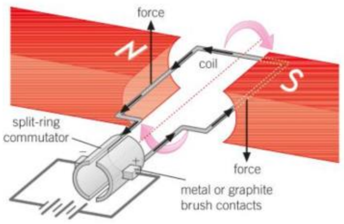
Force = magnetic flux density × current × length

$$F = B I l$$

- force, F, in newtons, N
- magnetic flux density, B, in tesla, T
- current, I, in amperes, A (amp is acceptable for ampere)
- length, l, in metres, m

Electric motors (HT only)

A coil of wire carrying a current in a magnetic field tends to rotate. This is the basis of an electric motor. The motor effect is used in several devices such as electric drills, hair dryers, loudspeaker etc. The speed of the motor is increased by increasing the size of the current. The direction of the motor can be reversed by reversing the direction of the current.



When a current passes through the coil, the coil spins because

- a force acts on each side of the coil due to motor effect
- The force on one side of the coil is in opposite direction to the force on the other side.

A DC (direct current) motor has a split ring commutator. This allows the current in the coil of wire to change every half turn. This ensures the force is in the same direction and, as a result, the coil gets spun in the same direction each time.