OCR A Physics A level

Topic 6.3: Electromagnetism

(Content in italics is not mentioned specifically in the course specification but is nevertheless topical, relevant and possibly examinable)

Definition of the Magnetic Field

A magnetic field is a region of space in which moving charged particles are subject to a magnetic force. Magnetic fields are also created by moving charges and it is the interaction of two magnetic fields that results in a magnetic force.

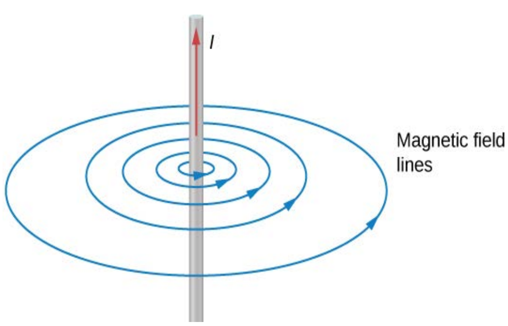
Magnetic Fields

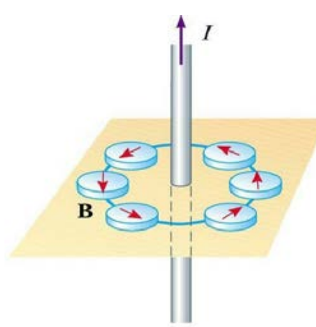
In a current carrying wire, the flowing electrons are the moving charges. They generate a circular magnetic field around the wire that can deflect a small magnet e.g. a compass needle. A simple way to demonstrate the magnetic field produced by a current carrying wire is to move a compass around the wire. If the current and the resulting magnetic field are large enough, the compass will be seen to point in the direction of the field.

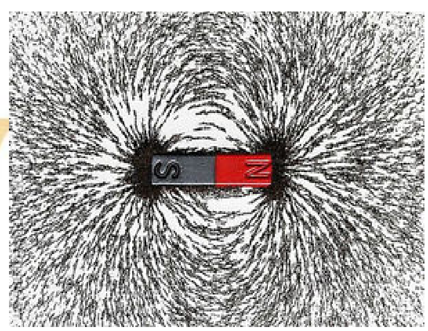
A permanent magnet is an object made from a magnetized material that creates its own persistent magnetic field. In such magnets (often in the shape of a bar or bar magnet), the electrons in the material move in an ordered way to produce an overall magnetic field around the material.

The magnetic field of bar magnets is often demonstrated using iron filings (iron cut into small pieces about the size of grains of sand). Iron, as a ferromagnetic material, has the property that in a magnetic field its atoms tend to align with the field such that its electrons move in an ordered way. This then creates an induced magnetic field in the iron so that the induced north pole points in the direction of the magnetic field at that point in space.

The magnetic field of the permanent magnet and the induced magnetic field in each iron filing interact causing the iron filings and the permanent magnet to be subject to a magnetic force. As the permanent magnet is much larger than the iron filings, it will not move however the iron filings shift their positions to line up with the field. This is similar to the concept of a test charge in determining an electric field (see Electric Fields 6.2). The pattern of iron filings clearly demonstrates the magnetic field around the permanent magnet.

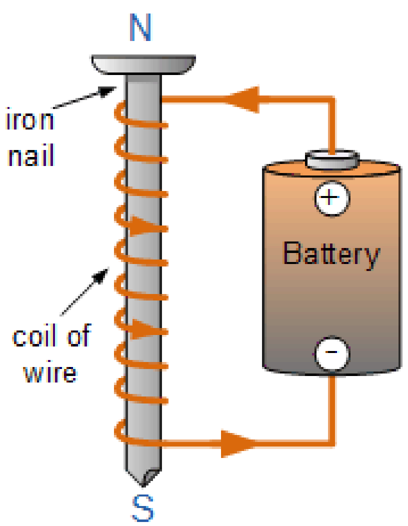


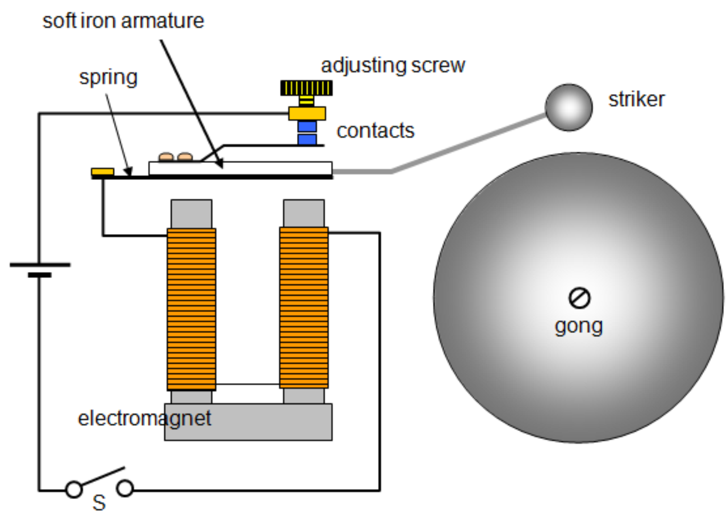




Electromagnets

*An **electromagnet** uses the field generated by a **current carrying wire** to create a large magnetic field that can be **magnified or reduced by raising or lowering the current**. Electromagnets, made from coils of wire (often called **solenoinds**), act as bar magnets when an electric current passes through them. Often, the coil is wrapped around a **soft core** such as mild steel, which causes an **induced field in the core** and **greatly enhances the magnetic field** produced by the coil. Additionally, a coil with **more turns** causes a **greater magnetic field**. Electromagnets are used in circuit breakers to disconnect a circuit and then reconnect it at a later time. This is utilised in an electric bell.*





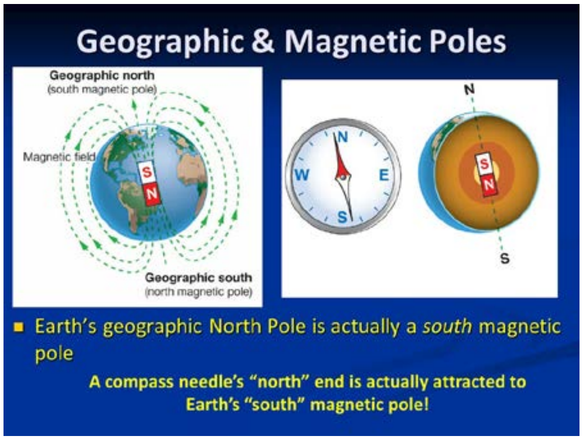
<u>Magnetically Hard and Soft Materials</u>

*Magnetic materials can be split into magnetically **soft** materials like iron, which can be magnetized but **do not stay magnetized** away from the external field, and magnetically **hard** materials, which do. **Permanent magnets are made from hard magnetic materials** that are subjected to a strong magnetic field during manufacture to align their internal crystalline structure. To demagnetize a permanent magnet, a large magnetic field can be applied in the reverse direction to the field of the permanent magnet. Alternatively, the internal structure can be disrupted by **hitting the magnet** with a hammer or **heating the magnet** to a high temperature as these processes cause the atoms to vibrate and lose their order structure.*

<u>Magnetic Field of the Earth</u>

*The earth has an expansive magnetic field due to the movement of charged particles within its molten iron core. Like all bar magnets, it has a north and south pole however the **magnetic north is actually in the southern hemisphere** and vice versa. This is why when a compass is placed in the magnetic field of the earth it points approximately to the geographic north: it is aligning with the field so **points its north pole towards the magnetic south.***

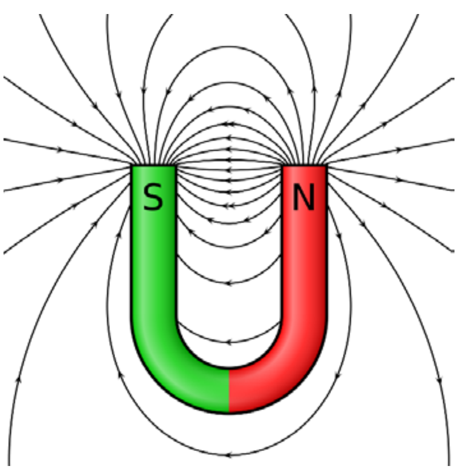
*The magnetic field of the earth is incredibly important as it protects us from the **solar wind** (high energy charged particles from the sun). The solar wind, as a stream of charged* *particles, has its own magnetic field and so the interaction between this field and the earth's magnetic field causes these harmful particles to be deflected and concentrated at the poles. This causes the aurora borealis and the aurora australis (the northern and southern lights).*

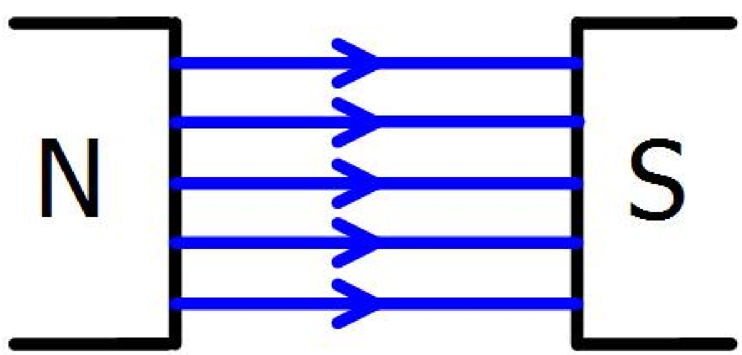


Magnetic Field Lines

Just like electric fields (see Electric Fields 6.2), magnetic fields can also be represented by field lines or lines of magnetic flux which point from the north pole to the south pole. The density of these lines of flux represents the strength of the magnetic field. In fact, the two terms magnetic flux density and magnetic field strength are interchangeable.

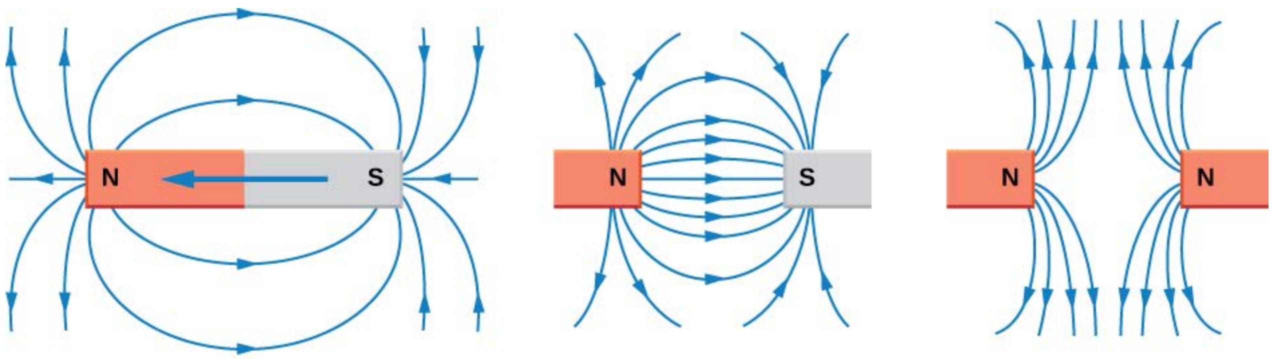
The concentrated field lines at the poles of a bar magnet represents where the field is strongest. Equally spaced, parallel field lines demonstrate a uniform magnetic field. A uniform magnetic field is very difficult to create though a good approximation is the field between the poles of a horseshoe magnet.





In nuclear fusion (see Nuclear and Particle Physics 6.4) a toroidal (doughnut-shaped) container (sometimes called a tokamak) is used to generate a near uniform circular *magnetic field so that high energy protons can be forced into close proximity and hopefully fused.*

As with electric fields (see Electric Fields 6.2), like poles repel and opposite poles attract. The magnetic field lines for several bar magnet geometries are seen below. Magnetic field lines that extend from north to south represent attraction and field lines that diverge represent repulsion.

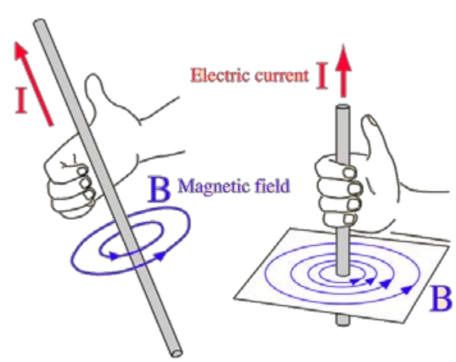


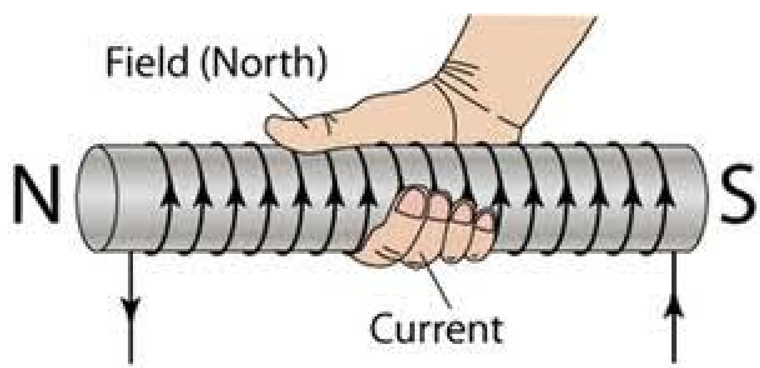
Magnetic field lines of a bar magnet

Magnetic field lines between unlike poles

Magnetic field lines between like poles

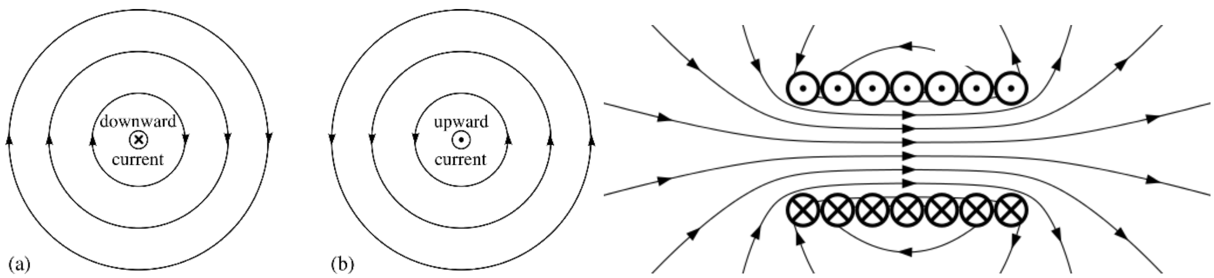
For a current carrying wire the field lines are concentric circles centred on the wire. Each circular line of flux has a much larger radius than the previous line so the magnetic flux density decreases dramatically at further distances away from the wire. The field curls around the wire either clockwise or anticlockwise depending on the direction of the current in the wire. This direction can be worked out using the right-hand grip rule. Point the thumb in the direction of the current and the direction in which your fingers wrap around is the direction of the magnetic field.





For a solenoid, the field patterns are similar to that of a bar magnet with a north and south pole. The right-hand grip rule applies here too. The fingers in this case show the direction of the current in the wires, clockwise or anticlockwise depending on which way the power supply is connected and which way the wires physically curl. The thumb then shows the direction of the field inside the solenoid and so points to the north pole.

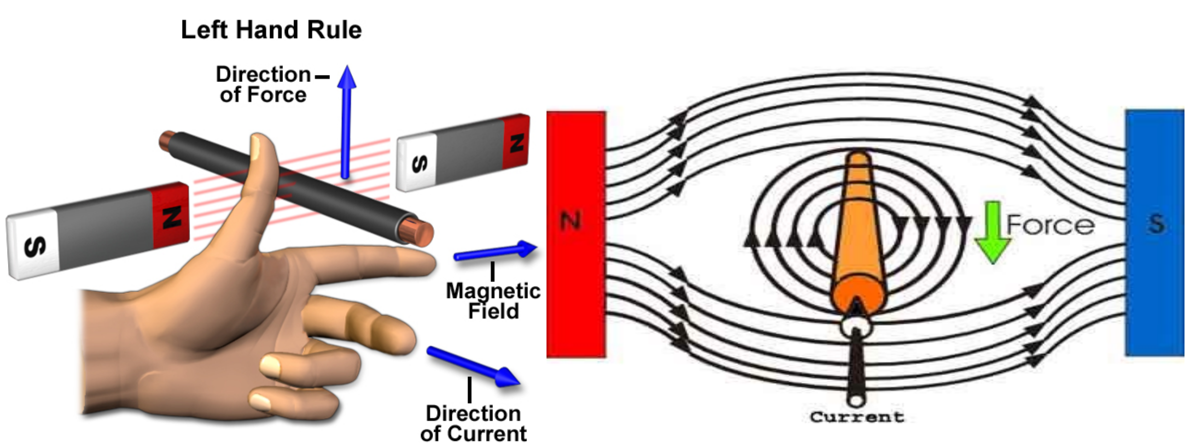
As the magnetic field around a wire acts in a plane perpendicular to the current, i.e. if the current points upwards in the z-direction the magnetic lines of flux lie in the x-y plane, diagrams in magnetism are inherently three-dimensional. Therefore, as drawing vector diagrams can be tough in 3D, there is a notation used to represent vectors pointing into or out of the page. A dot inside a circle represents a current or field line (or more generally a vector) coming out of the plane of the page and a cross inside a circle represents the current or field line pointing into the plane of the page. If you imagine the vector to be an arrow shot from a bow, when travelling towards you, i.e. out of the page, you would see the pointed end as a dot. When, shooting the bow, the advancing arrow appears to you as a cross, like the feathers or fletching on the back end of the arrow. The diagrams below show the currents in a wire and solenoid (dots and crosses) and the magnetic fields produced.



Fleming's Left-hand Rule

When a current carrying wire is placed into a magnetic field it experiences a force due to the interaction of its magnetic field and the external field. The direction of this force can be determined using Fleming's right-hand rule in which your first finger, second finger and thumb are all at right angles to each other, like the edges at the corner of a cube. The fingers then each represent a vector quantity as follows:

- The first finger (index finger) points in the direction of the magnetic field.
- The second finger (middle finger) points in the direction of the current (remember this is in the opposite direction to which electrons flow).
- The thumb is the direction of the force on the wire or the resultant motion of the wire in the absence of a resistive force.



Force on a Current Carrying Wire within a Magnetic Field

The force on a current carrying wire in a magnetic field is a result of the interaction between the magnetic field generated by the moving charges in the wire and the external field. This interaction is greatest when the current points in a direction is perpendicular to the magnetic field. Therefore, the size of the force depends upon the sine of the angle between the direction of the current and the magnetic field i.e. $\sin\theta$. Its magnitude relies on the size of the current, I, the length of the wire, L, the magnetic field strength or magnetic flux density, B. The magnetic flux density, B, is literally the amount of magnetic flux (proportional to the number of lines of magnetic flux) per unit area. Magnetic flux, ϕ is measured in units of Weber (Wb) and so the unit of magnetic flux density is Weber per square metre (Wbm^{-2}) otherwise known as the Tesla (T). Combining the proportionality above

$$F = BIL\sin\theta$$

1T is therefore the magnetic flux density required to generate a force of 1N on a wire carrying a current of 1A per metre perpendicular to the magnetic field.

Experimental Techniques to measure Magnetic Flux Density

The magnetic flux density can be determined using the above equation with the current at right angles ($\sin 90° = 1$) to the external magnetic field.

$$B = \frac{F}{IL}$$

To measure the magnetic flux density of a permanent magnet the above equation can be used. A horseshoe magnet is often used as it has a near uniform magnetic field in between the two poles and so the force generated will not vary quite so greatly with the position of the wire within the field.

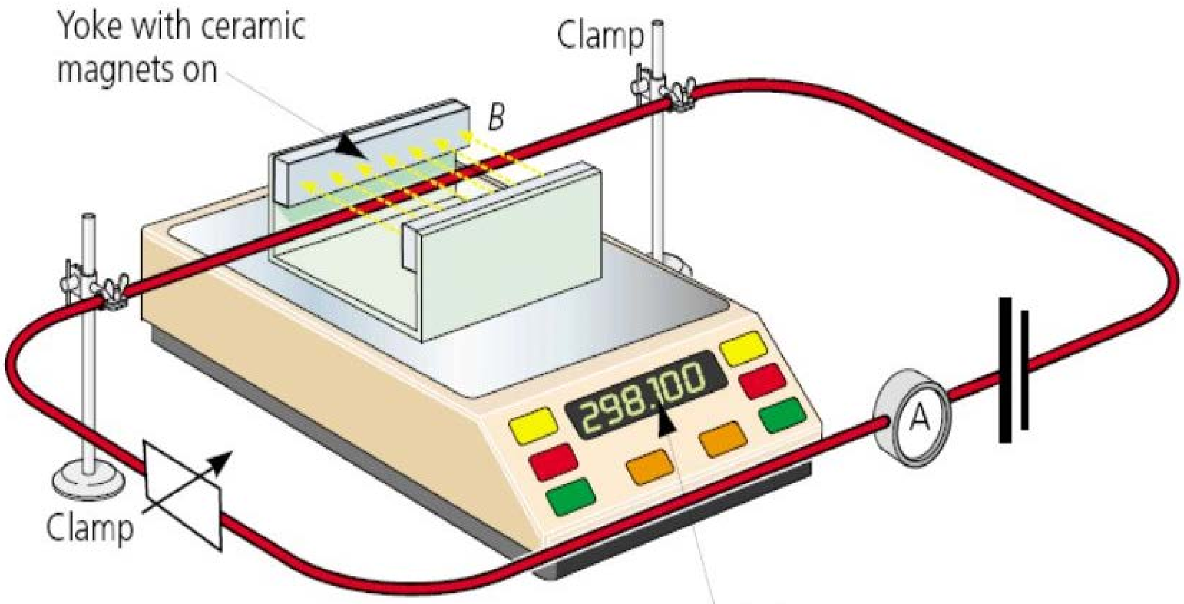
Firstly, place the horseshoe magnet on a set of digital balance scales and zero the scales. Then, connect a rigid piece of straight wire to a DC power supply, a variable resistor (rheostat) and an ammeter in series. Align the wire so that the force produced on the wire is upwards using Fleming's left-hand rule. This will ensure that the force on the magnet is downwards by Newton's third law of motion i.e. the force on the wire will produce a force equal in magnitude but opposite in direction of the magnet. Also, measure the length of the wire that is in the field using a ruler. The scales will then register the magnetic force as weight and give a value for the extra mass it assumes has been place on the scales. Record a series of values for the current and the mass registered by the scales. The current can be varied by altering the resistance of the circuit using the variable resistor. Finally plot a graph of the mass registered versus the current in the wire. By balancing the forces

$$mg = BIL$$

therefore the gradient of the $I - m$ graph will give

$$\frac{\Delta m}{\Delta I} = \frac{BL}{g}$$

As the constant g is known and L is measured, the magnetic flux density can be determined from the gradient.



Motion of a Charged Particle in a Uniform Magnetic Field

For charged particles (usually electrons) travelling within a wire at right angles to a uniform magnetic field it is possible to find the force acting upon each charge. Take the force on the wire carrying current as a whole, given by BIL. However, as

$$I = \frac{Q}{t}$$

from the definition of current and

$$v = \frac{L}{t}$$

as the mean speed of the charges is the distance travelled by the particles divided by the average time taken, by substituting these formulae into the force this gives

$$F = BQv$$

For negatively charged particles the velocity is in the opposite direction to the current and so the force will be negative. Although, as long as Fleming's left-hand rule is used correctly with the direction of the current being the opposite to the direction of the motion of negative particles and in the same direction as that of positive particles, this formula can be used to calculate the magnitude of the force and the sign can be ignored.

Derivation using the Mean Drift Velocity

To find the force on a single charge, one might use the formula for the ***mean drift velocity*** *of an electron in a wire*

$$I = -Anev$$

where the negative sign represents the current in the opposite direction to the velocity and where A *is the* ***cross-sectional area*** *of the wire,* n *is the* ***number density*** *of delocalized electrons or the number of delocalized electrons per unit volume i.e.* $n = \frac{N}{V}$ *and* e *is the elementary charge, the* ***charge on the electron*** *being* $-e$, *and* v *is the* ***mean drift velocity*** *of the charges i.e. the* ***average velocity*** *of the electrons in the direction of the current* ***neglecting their random delocalized motion****. This can be substituted into the equation for the force.*

$$F = -AnevBL$$

Using

$$v = \frac{L}{t}$$

then

$$F = -A\frac{N}{V}evBL$$

but as $\frac{A}{V}$ *represents the length of the wire and* $\frac{F}{N}$ *represents the force per electron or the force on a single charge*

$$F_e = -Bev$$

where F_e *is the force per electron or the force on a single electron.*

Motion of a Free Particle in a Magnetic Field

For a free particle in uniform magnetic field, the movement of the particle produces a **force perpendicular to its velocity**. This force produces an acceleration as $F = ma$ and changes the velocity of the particle as $a = \frac{\Delta v}{t}$. As the direction of the force is always perpendicular to the field this makes the particle follow a **curved trajectory** that **transcribes a circle**.

The ***speed of the particle is unchanged*** *as the work done on the particle is equal to the change in kinetic energy of the particle and no work is done.*

$$W = \Delta E_k$$

Work done is defined as the product of the force and the displacement in the direction of the force. As the ***force is centripetal*** *and the particle follows a circular path, that is to say the* *radius is constant, there is no displacement in the direction of the force and so there is no work done or change in kinetic energy.*

The force acts towards the centre of the circle and so the particle undergoes centripetal acceleration. Using the formula for centripetal acceleration where r is the radius of the circle and v is the speed of the particles

$$a = \frac{v^2}{r}$$

the force required to create this acceleration can be given by $F = ma$

$$F = \frac{mv^2}{r}$$

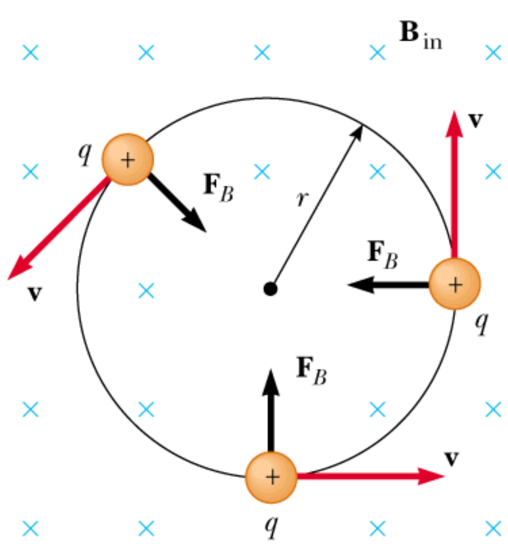
and as the force is due to the motion of a charge particle in a magnetic field we can state that

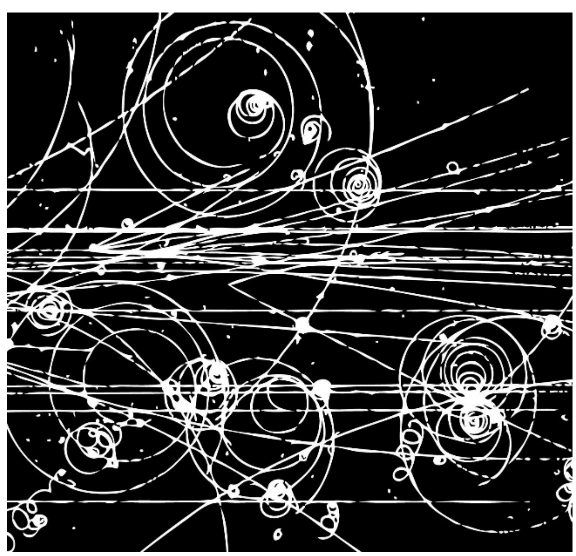
$$\frac{mv^2}{r} = BQv$$

The radius of the circle then depends on the speed of the particle, the mass of the particle, its charge and the magnetic field strength. This is given by

$$r = \frac{mv}{BQ} = \frac{p}{BQ}$$

where p is the momentum of the particle. Faster and more massive particles will have wider arcs, whereas particles in stronger magnetic fields or with larger charges will undergo motion in smaller circles.





This can be used to identify particles in collision (see Nuclear and Particle Physics 6.4). As particles with a particular momentum to charge ratio, $\frac{p}{Q}$, will undergo a spiralling motion with a specific radius, we can apply a known magnetic field and measure the radius of the trajectory to evaluate the momentum to charge ratio. A bubble chamber is an apparatus designed to make the tracks of ionizing particles visible as a row of bubbles in a liquid. In a particle collision, it is impossible to predict the products just as it is impossible to know which nuclei will decay next in a radioactive sample. If the products are placed in a bubble chamber the trajectories like those above can be measured and from the radii of the spirals and the known magnetic field strength applied to the bubble chamber the nature of the particles can be determined.

Velocity Selection

Velocity selectors use a combination of magnetic and electric fields to isolate particles with a specific velocity. This is possible due to the fact both the magnetic and electric forces are charge dependent. A uniform electric field is made to act in the opposite direction to the magnetic field by positioning two parallel plates with a voltage across them at right angles to a uniform magnetic field from a horseshoe magnet. The force due to the electric field, E_s, is given by (see Electric Fields 6.2)

$$F = E_s Q$$

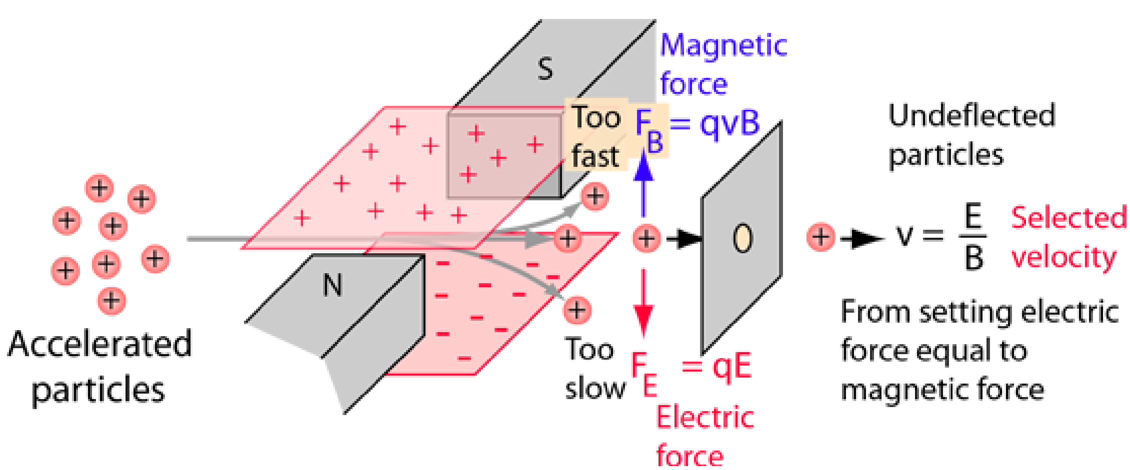
The force due to the magnetic field, B_s, is

$$F = B_s Q v$$

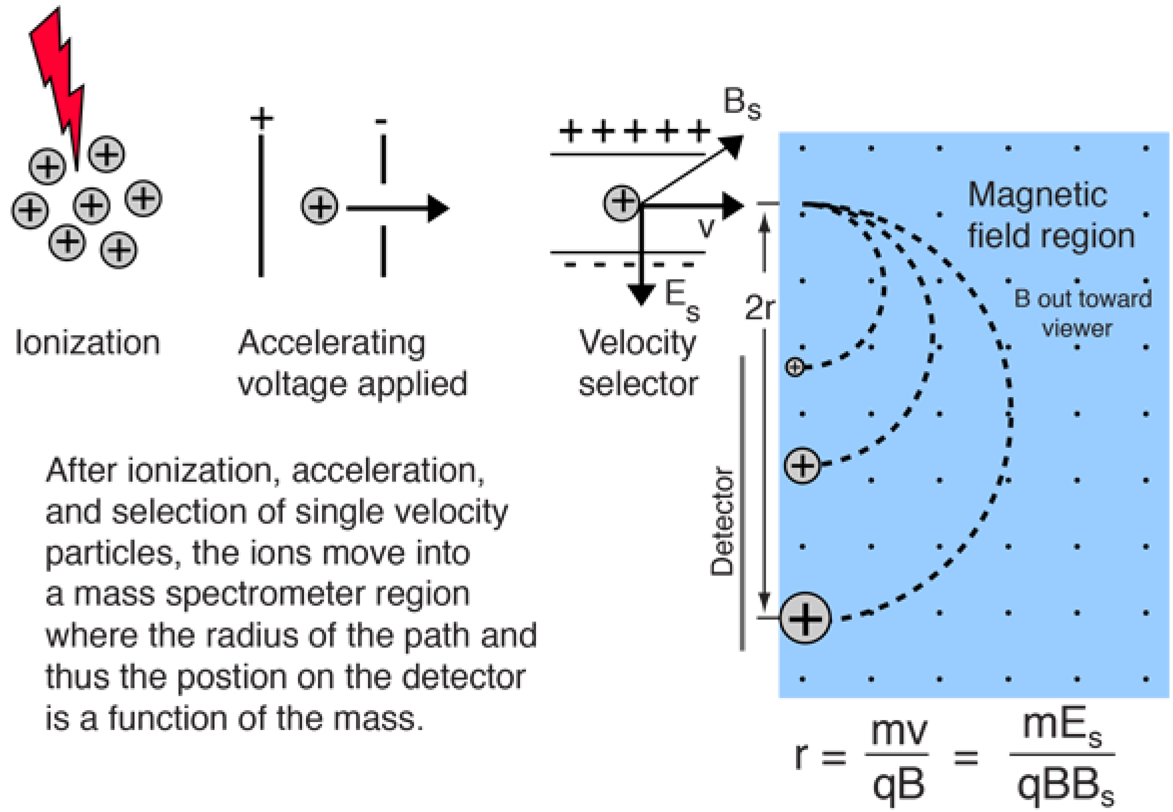
thus when the forces balance the velocity is given by

$$v = \frac{E_s}{B_s}$$

The particles travelling at this velocity will travel in a straight line. Particles travelling at any other velocity will curve and collide with the plates.



Velocity selection is used in mass spectrometry which is a method of determining the molecular formula of an unknown substance. Firstly, molecules of the substance are broken down into their constituent atoms which are then ionized and accelerated through a large potential difference. These particles are next run through a velocity selector so that a small proportion of the ions emerge with equal velocities. Finally, they are directed into a uniform magnetic field which deflects these particles in a radial arc based on their mass to charge ratio. The size of the deflection can be recorded and the relative abundance of each element within the molecule is then recorded.



<u>Magnetic Flux Linkage</u>

Recall that the magnetic flux density, B, is the magnetic flux per unit area. Therefore, for a uniform magnetic field, the magnetic flux, ϕ, through an area, A, is defined as the product of the magnetic flux density and the area perpendicular to the lines of flux.

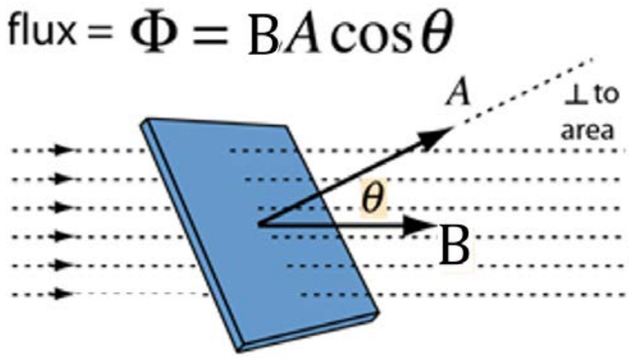
$$\phi = BA\cos\theta$$

where θ is the angle between the area and the magnetic flux lines.

For a solenoid, the magnetic flux is measured through the centre of the coil so that the area, A, is the cross-sectional area of the coil. The magnetic flux linkage is a measure of the flux in the whole solenoid and so is the sum of the magnetic flux through each turn of the coil that is to say the product of the magnetic flux and the number of turns in the coil.

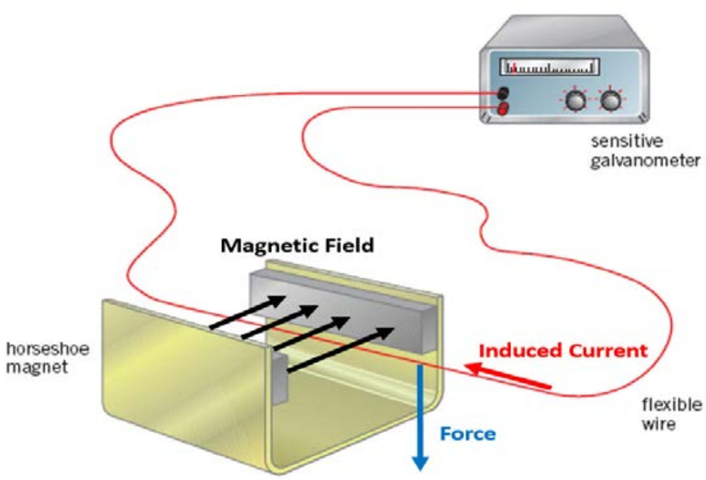
$$N\phi = BAN\cos\theta$$

The magnetic flux linkage is also measured in Weber (Wb) as the number of turns is a dimensionless quantity.



Electromagnetic Induction

Electromagnetic induction is when a current is induced due to a change in the magnetic flux linkage. The current is generally induced in a wire by either moving the wire through a non-uniform magnetic field or varying the magnetic field strength in time. Consider a wire without any current flowing through it moving at right angles to a magnetic field. The delocalised electrons within the metal are moving in the presence of a magnetic field therefore they are subject to a magnetic force. The nuclei within the metal will also be subject to a force. However as the nuclei have fixed positions, there is no resulting motion or induced current. From the diagram below, and by using Fleming's left-hand rule (remember the electrons are negative so the current is in the opposite direction to the movement of electrons), we can determine the direction of the force and resultant motion of the electrons. As the electrons move downwards, the induced conventional current produced is towards the left. When the direction of motion is reversed, the induced current is in the opposite direction. Moving the wire back and forth with an oscillating motion will cause an alternating current to be generated in the wire.



Faraday's law of electromagnetic induction states that the induced e.m.f. is proportional to the rate of change of magnetic flux linkage

$$\varepsilon \propto \frac{\Delta(N\phi)}{\Delta t}$$

where ε is the induced e.m.f.

Lenz's law states that the induced e.m.f. is generated in a direction that so it opposes the change that produced it. Therefore, if the wire is pushed downwards into the magnetic field as above, the current in the wire will be in the direction that produces a force to oppose its motion into the electric field i.e. it will produce a current left which via Fleming's left-hand rule will cause the wire to be forced upwards.

These laws can be combined to form

$$\varepsilon = -\frac{\Delta(N\phi)}{\Delta t}$$

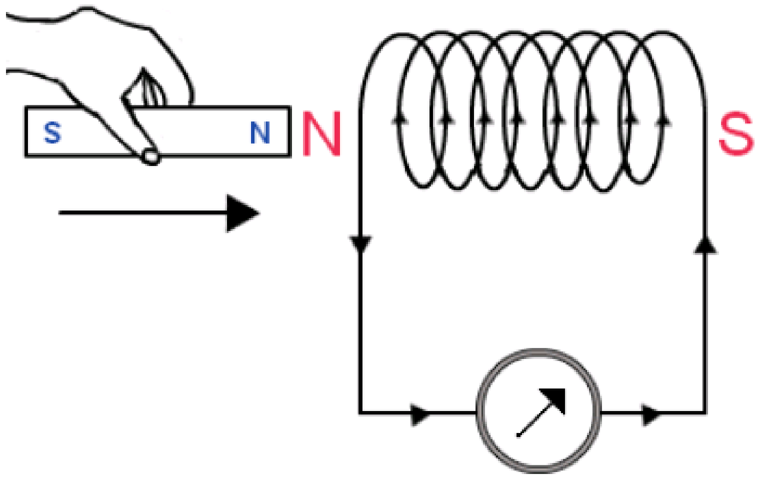
where the minus sign here is a statement of Lenz's law.

Lenz's law can be thought of as a direct consequence of the conservation of energy. If a wire can be moved into the magnetic field of the horseshoe magnet and generate an e.m.f. then an electrical energy has been produced within the wire but where has this energy come from? Energy cannot be created, it must result from some form of work done on the wire. This is where Lenz's law comes into play.

The current induced in the wire causes a magnetic force which opposes the direction of motion. If the wire is being pushed downwards against the magnetic force then there is work done on the wire. This work can be seen as the product of the force and the displacement of the wire in the direction of the force. Interestingly, once the wire is in the magnetic field and stops moving the induced current falls to zero. This is clearly seen as a result of Faraday's law as there is no change in the magnetic flux linkage if the wire is stationary.

However, if the wire is then pulled out of the field a current is generated in the opposite direction. This in turn causes a force that resists the motion of the wire out of the field. The magnet attempts to pull the wire back into the field and once again work is done to transfer electrical energy into the wire.

If a bar magnet is pushed into a solenoid, the current in the solenoid will be produced in a direction so as to produce a magnetic field that opposes and so cancels out the magnetic field of the bar magnet. Lenz's law can be used here in conjunction with the right-hand grip rule to determine the direction of the current within the solenoid. For example, if a bar magnet with its north pole facing right is forced into a solenoid the Lenz's law can be used to show that the end of the solenoid closest to the approaching north pole becomes the north of the solenoid. Then, the right-hand grip rule can be used to discover the direction of the current i.e. anticlockwise from the perspective of the approaching bar magnet.



Experimental Techniques for investigating Magnetic Flux

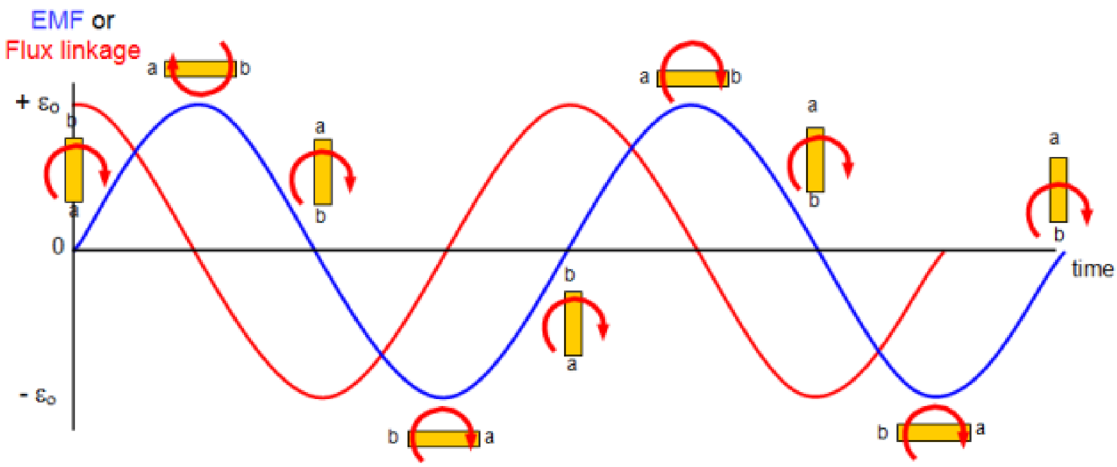
A search coil is a flat coil of insulated wire connected to a galvanometer (a sensitive ammeter). It is used to determine the strength of a magnetic field from the current induced in the coil when it is withdrawn. The coil is placed in a known magnetic field and quickly withdrawn to a region of space with a negligible magnetic field. This is done to calibrate the search coil as the induced current is directly proportional to the rate of change of flux linkage.

Assuming the coil is removed rapidly, the maximum current measured by the galvanometer is proportional to the magnetic field strength. As this is known in the calibration field, the constant of proportionality can be estimated. This process is then repeated in the magnetic field to be measured and the magnetic field strength can then be calculated. By measuring the area and counting the number of turns in the search coil, the magnetic flux can then be evaluated from the magnetic flux density.

A.C. Generators

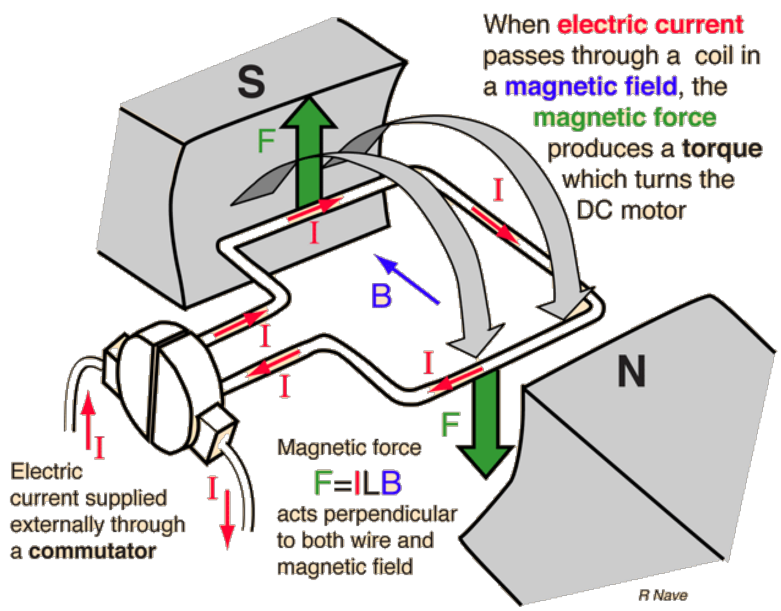
A generator converts kinetic energy into electrical energy which can then be used to power electrical appliances. One of the simplest designs utilises a coil of wire placed in a constant uniform magnetic field. The coil is then rotated and so the area perpendicular to the magnetic field is constantly changing as the sine of the angle between the field and the plane of the coil. This changing magnetic flux linkage causes an alternating current to be induced in the wire.

The graph below demonstrates how the magnetic flux linkage and induced e.m.f. vary in time as the coil is rotated at a constant angular velocity. The gradient of the graph of magnetic flux linkage is the change in flux linkage divided by the change in is time so this represents the negative of e.m.f. Here, you can see that at maximum flux linkage, the rate of change of flux linkage is zero and so the induced e.m.f. is also zero. However, at zero flux linkage the gradient is at a maximum and so the induced e.m.f. is at a maximum.



Electric Motors

The opposite of a generator is an electric motor. If a current is passed through the coil in the uniform field a force is produced on the coil. The direction of this force depends on the exact direction of the current in that part of the coil as determined by Fleming's left-hand rule. The forces on opposite sides of the coil are in opposite directions. As the net force on the coil is zero, these forces generate a pure turning effect on the coil known as the torque of a couple. If a DC current is supplied a split ring commutator is used to reverse the direction of the current once the coil has rotated through 180 degrees. This maintains a constant turning effect on the coil. However, if an AC source is used, then provided the coil is rotated at the frequency of the AC signal a commutator is only needed to prevent the wires attached to the ring from becoming tangled.



Transformers

Step-up and step-down transformers raise or lower the voltage of alternating current sources respectively by utilising electromagnetic induction. A simplified model of the transformer has an iron core with a primary input coil and a secondary output coil. The core is in the shape of thick ring so that both coils are around the same core though on the opposite sides. The alternating current in the primary coil then induces a varying magnetic flux in the iron core. This change in magnetic flux in turn induces a current in the secondary coil in agreement with Faraday's law. The iron core is used to ensure that the majority of the electrical energy is transferred between the primary and secondary coils. The primary coil has N_p turns and an e.m.f. of V_p which induces a changing magnetic flux

$$-\frac{V_p \Delta t}{N_s} = \Delta\phi$$

The changing magnetic flux induces an e.m.f., V_s, in the secondary coil which has N_s turns

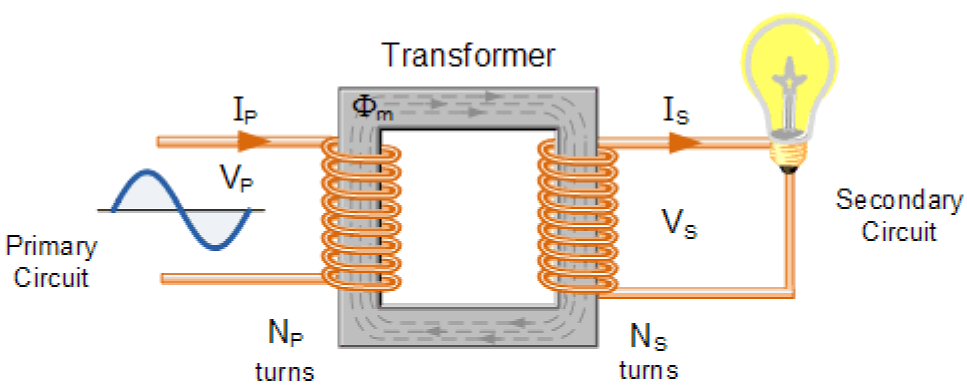
$$V_s = -\frac{N_s \Delta\phi}{\Delta t}$$

Therefore, substituting in the change in magnetic flux from the first equation into the expression of Faraday's law in the second equation, a relationship between the number of turns in each coil and the e.m.f.s in the primary and secondary coils can be derived.

$$\frac{N_s}{N_p} = \frac{V_s}{V_p}$$

From this ratio, it is clear that when $N_s > N_p$, i.e. there are more turns in the secondary coil, the transformer is step-up as $V_s > V_p$. Whereas when $N_s < N_p$, i.e. there are fewer turns in the secondary coil, $V_s < V_p$ so the transformer is step-down.

If the transformer were 100% efficient then the input power would be equal to the output power that is to say $I_p V_p = I_s V_s$ where I_p and I_s are the currents in the primary and secondary coils respectively. This is never the case as the changing magnetic field in the iron core causes the iron atoms to constantly align with the field and so energy is lost as magnetic heating.



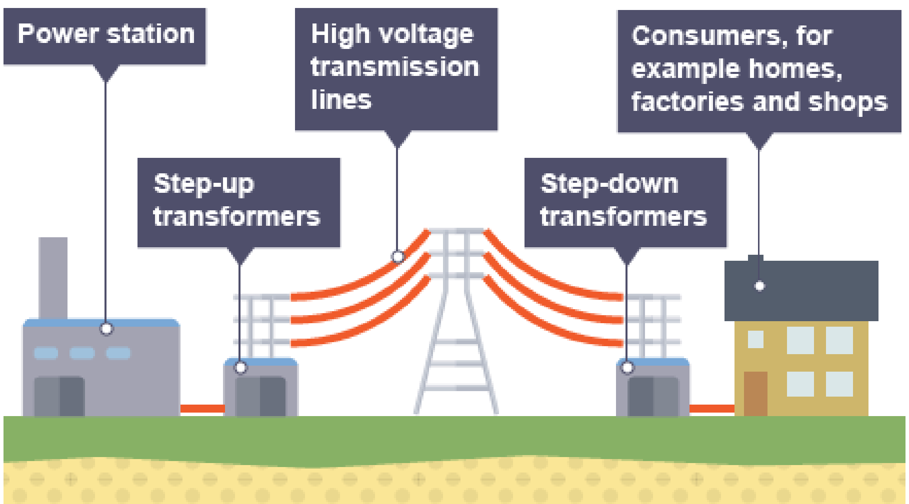
Applications of Transformers

Step-up transformers are used to reduce power losses in the transmission of electrical energy across the national grid. Although, the resistance per unit length of transmission lines is low (due to the wire being made of a low resistivity metal and having a large cross-sectional area) as the distances between power stations and consumers can be very large the resistances is often high. Therefore, to reduce power loss the current in the wires is reduced and the voltage increased in a step-up transformer at the power station and prior to transmission long distance. This reduces the power loss due to the equation

$$P_{loss} = I^2 R$$

where R is the resistance of the transmission lines and I is the current flowing through it.

Step-down transformers are then used to decrease the voltage from the transmission cables so that it is safer to distribute to consumers in homes and factories.



Transformers are also an integral part of many electrical devices in our homes. One example is a mobile phone charger. A mobile phones require a lower voltage than the 230V mains supply as some of the components may be sensitive to high voltages and technical faults may to occur with higher voltages. A step-down transformer is thus used in the charger to lower the voltage supplied to the phone.

Experimental Techniques for Investigating Transformers

The turn ratio equation above can be investigated by varying the number of turns in the primary and secondary coils and measuring the voltages across the input and output using a voltmeter but preferably an oscilloscope which can more effectively measure the changing voltage.

The efficiency of a transformer can be investigated by also measuring the current in each coil with an ammeter and a variable resistor (rheostat). The variable resistor is used to vary the current at a constant voltage. The efficiency, η, can be estimated by calculating the ratio of output power to input power that is to say

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% = \frac{I_p V_p}{I_s V_s} \times 100\%$$

Transformers can be made more efficient by:

- *Using **lower resistance wires** in the coils and so **reducing power loss to resistive heating**.*
- *Employing **laminated iron** in the core, where layers of iron are separated by a magnetic insulator. This channels magnetic flux more efficiently by **reducing eddy currents** in the core which cause **power loss to magnetic heating**.*
- ***Soft iron cores** are easier to magnetize and demagnetize therefore they are more susceptible to the changing magnetic fields and **improve the overall efficiency**.*