HSC Physics Notes - Motors and Generators

9.3 - 1. Motors use the effect of forces on current-carrying conductors in magnetic fields

1. discuss the effect on the magnitude of the force on a current-carrying conductor of variations in

- the strength of the magnetic field in which it is located

Force is proportional to the magnetic field strength (B). i.e. ↑**F** = ↑**B**

- the magnitude of the current in the conductor

The force is proportional to the current (**I**) in the conductor. i.e. ↑**F** = ↑**I**

- the length of the conductor in the external magnetic field

The force is proportional to the length (l) of the conductor. i.e. ↑**F** = ↑l

- the angle between the direction of the external magnetic field and the direction of the length of the conductor

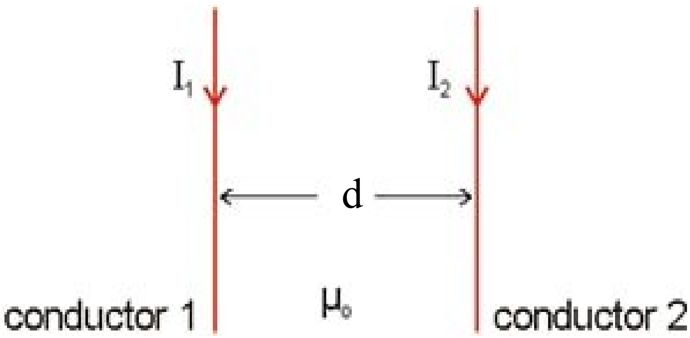
The force is at a **maximum** when conductor is at **right angles** to the field. The force is equal to **zero** when the conductor is **parallel** to the field. ↑**F** = ↑**Θ**.

$F = BIl\sin\Theta$ Can be used to determine force in a magnetic field

2. explain qualitatively and quantitatively the force between long parallel current-carrying conductors

Because we know that a wire carrying a current will produce a magnetic field, thus it will exert forces upon other fields or objects near or in the field. When two **long parallel** current-carrying conducting wires (known as a **solenoid**) are placed side by side with a finite distance between them, their magnetic fields will affect each other.

- If the **current** is flowing in the **same direction** in both conductors, the fields will **attract** (making a combined, larger field)
- If the **currents** of the conductors are flowing in **opposite directions**, the magnetic fields will **repel** from each other.



The **right-hand grip rule** can also be applied to determine the direction of flow of current and thus whether the two long parallel current-carrying conducting magnetic fields exert repelling or attracting fields with relation to each other.

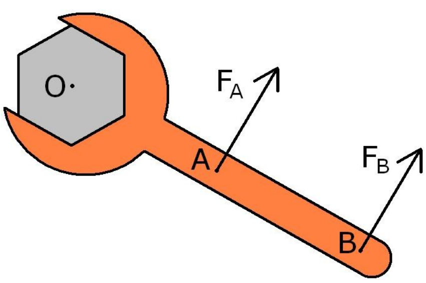
Determining the magnitude of force between two parallel current-carrying conducting wires is given by the following equation:

$$\frac{F}{l} = k\frac{I_1 I_2}{d}$$

where;
F = the force acting upon the length of a conductor *(N)*
l = length of chosen conductor *(m)*
k = constant (derived through careful analysis + testing) = **2.0 x 10^{-7} N A^{-2}**
I_1 and **I_2** = current of either conductor *(amps)*
d = distance between conductors *(m)*

3. define torque as the turning moment of a force using: $\tau = Fd$

Torque is the turning effect of an object when force is acting upon it. The torque of an object is greater when the distance of the force from the pivot point (where the torque occurs) is further away. Thus, as distance increasing, so does the torque of an object.



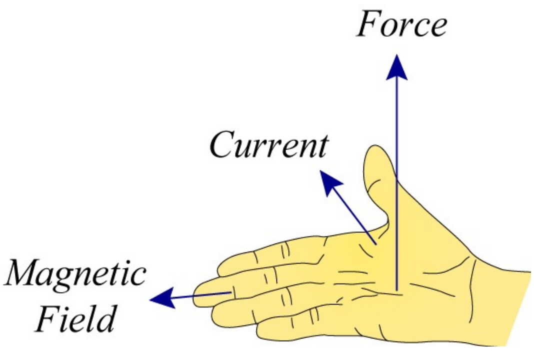
If the force applied is perpendicular to the line joining the point of application of the force and the pivot point, the following formula can be used:

$$\tau = Fd$$

where;
τ = Torque of an object *(Newton metre – Nm)*
F = Force *(N)*
d = Distance from the point of application to the pivot point *(m)*

4. identify that the motor effect is due to the force acting on a current-carrying conductor in a magnetic field

A current-carrying conductor produces a magnetic field. When the current-carrying conductor passes through an external magnetic field, the **magnetic field of the conductor interacts with the external magnetic field** and **the conductor experiences a force**. This effect was discovered in 1821 and is known as the **motor effect**.



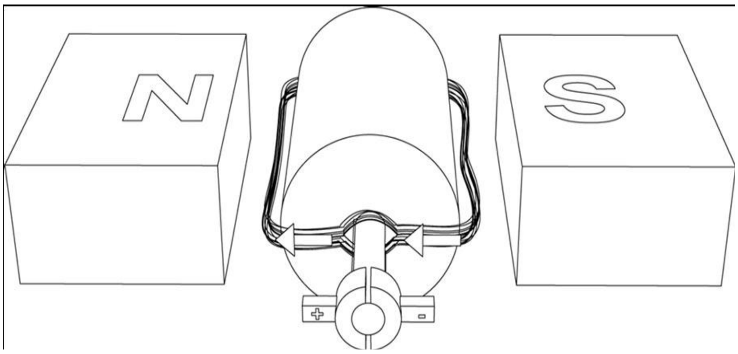
The direction of the force on the current-carrying conductor can be determined using the **right hand push rule** – remembering that magnetic field lines go from north to south.

5. describe the forces experienced by a current-carrying loop in a magnetic field and describe the net result of the forces

If a current-carrying wire (loop) is present in an external magnetic field, then the current-carrying conductor will experience forces exerted upon it. Applying the right hand push rule, one can determine the direction of force on the loop in the external magnetic field. The force acting on the sides of the coil that are perpendicular to the magnetic field can be calculated using:

$$F = nBIl\sin\Theta$$

where;
F = Force (*N*)
B = Magnetic field strength
I = Current (*A*)
l = length of current-carrying conductor (*m*)
n = number of loops in wire coil – armature



This extra force on each side of the conductor **increases the torque** of the armature (the rotational device which motors the motor). This **torque in turn rotates the coil** to a point where the current-carrying conductors are parallel with the magnets and the magnetic field – however **momentum pushes the armature further around** to the perpendicular position **where the split-ring commutator changes the direction of current** so the rotor can continue rotating in the same direction.

The net force is a continual rotation determined by the right hand push rule at a magnitude calculated by the above formula.

6. describe the main features of a DC electric motor and the role of each feature

The DC electric motor relies on the motor effect to create a continuous spinning motion in which a **current** must be continuously supplied into the motor to keep the magnetic fields interacting and the external field exerting forces on the current-carrying conductors. The main features are:

- **Armature** – the ferromagnetic cylinder which rotates on an axle to produce the rotational motion of the DC electric motor.
- **Coil** – is wrapped/coiled around the armature on opposite sides so that the current changes direction about the armature. It is responsible for giving the current a medium to flow.
- **Split-ring commutator** – is used so that the current is kept perpendicular to the magnetic field lines. The commutator's role is to change the direction of the current at the right point to ensure the armature continues rotation in the same direction.
- **Brushes** – are used to keep the current flowing into the commutator without sparking.
- **Magnets** – produce the external magnetic field which interacts with the field produced by the coiled wire about the armature.

7. identify that the required magnetic fields in DC motors can be produced either by current-carrying coils or permanent magnets

The **magnetic field** of a DC motor can be **provided either by permanent magnets or by electromagnets**. The **permanent magnets are fixed** to the body of the motor. **Electromagnets can be created using a soft iron shape that has coils of wire around it**. The current that flows through the armature coil can be used in the electromagnet coils.

1. solve problems using:

$$\frac{F}{l} = k\frac{I_1 I_2}{d}$$

Which simply involves practising questions where there are **two long parallel current-carrying conductors** to determine the force between them.

2. perform a first-hand investigation to demonstrate the motor effect

Wire + Electronic Balance:

The **current-conducting wire is placed on an electronic balance which passes between two oppositely 'polarised' magnets** i.e. one north and one south. When the wire is balanced on the electronic scales, it is zeroed. When the current is pushed through the current-carrying wire **the balance will record a positive or negative value depending on the direction of the current** – however, despite whether the reading displayed is negative or positive, the fact that there is **a change in magnitude shows the wire is experiencing a force exerted upon it**. This force is a result of the interaction of the external magnetic field between the two magnets and the produced field from the wire. **This shows the motor effect**.

3. solve problems and analyse information about the force on current-carrying conductors in magnetic fields using:

$$F = BIl\sin\Theta$$ A current-carrying conductor in a magnetic field creates a force.

where;
F = Force (*N*)
B = Strength of magnetic field (*T*)
I = Current (*A*)
l = length of current-carrying conductor (*m*)
θ = angle at which the conductor is at to the direction of the magnetic field

The direction of the current can be obtained using the right hand push rule.

4. solve problems and analyse information about simple motors using:

$$\tau = nBIA\cos(\theta)$$

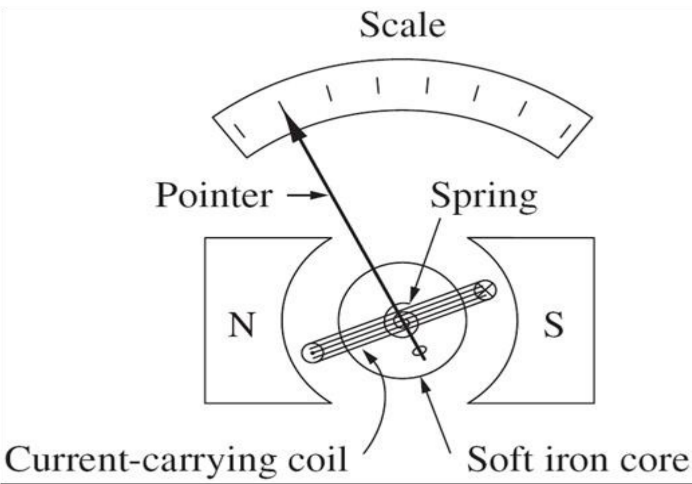
where;
τ = Torque (*Nm*)
n = number of coils
B = Strength of magnetic field (*T*)
I = Current (*A*)
θ = angle between magnetic field lines and plane of coil

5. identify data sources, gather and process information to qualitatively describe the application of the motor effect in:

– the galvanometer

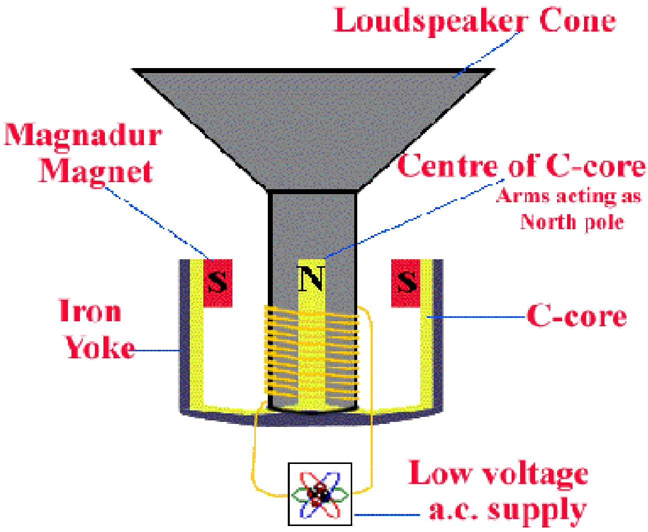
A galvanometer is used to measure the magnitude and direction of direct current (**DC**). It uses the motor effect to do this.

A coil consisting of **many loops is connected in series** and coiled around a soft iron core. When the current flows through the current-carrying wire, **the coil experiences a force due to the presence of an external magnetic field** – exemplifying the motor effect.



The **needle** attached to the core **is rotated until the magnetic force acting on the coil is equalled by a counter balancing, tensioned spring**. The **magnets are curved** around the coil, thus shaping the magnetic field surrounding into a radial shape so the **plane of the coil will always be parallel with the magnetic field**. This also results in constant torque as the coil/spring rotate therefore making the scale of the galvanometer linear so that the **force** α **current**.

- the loudspeaker



Loudspeakers are used to transform electrical energy (impulses) into sound energy. A loudspeaker consists of a **circular magnet that has one pole on the outside and the other on the inside**. The voice coil sits in between the poles (essentially wrapped around the centre core) which is connected to an amplifier which produces the amplified sound.

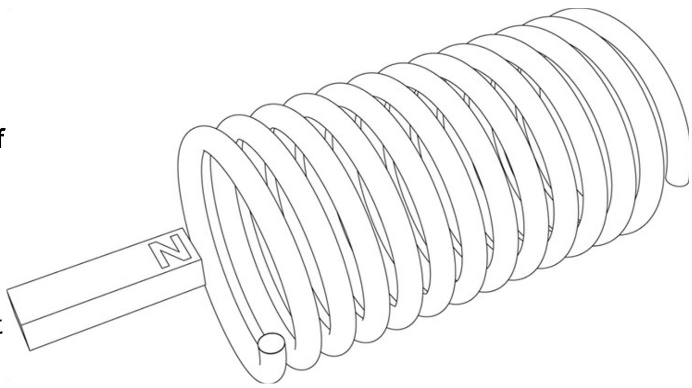
This voice coil is caused to vibrate or move in and out of the magnet due to the motor effect. The **force** acting upon the magnetic field produced from the coil **pushes the amplified waves out of the speaker cone** so that it can be heard.

The **field lines of the permanent magnets are always perpendicular to the current in the coil.**

2. The relative motion between a conductor and magnetic field is used to generate an electrical voltage

1. outline Michael Faraday's discovery of the generation of an electric current by a moving magnet

Michael Faraday discovered that **when moving a bar magnet** (or any type for that matter) **through a coil of wire that an electrical current was produced**. This is the opposite of the motor effect and is known as **induction**. Relative motion between a magnet and a coil induce a current, in which the s**trength of the current being induced can be changed by the relative speed of the magnet** through/around the coil of wire (faster magnet, larger current).



Faraday noticed that when putting the north end of a magnet into a coil, the current began to flow and direction could be determined. When pulling the magnet in the opposite direction, the direction of the current changed concurrently.

2. define magnetic field strength B as magnetic flux density

The **strength of a magnetic field, *B*, is also known as the magnetic flux density.** In the SI system, *B* is measured in Tesla (T) or Weber per square metre (Wb m^{-2}).
It is also important to note that the stronger a magnetic field is (stronger magnetic flux), the closer the field lines will be when drawing.

Magnetic flux is given the symbol: Φ_B

3. describe the concept of magnetic flux in terms of magnetic flux density and surface area

Magnetic flux is the name given to the amount of magnetic field passing through a given area. If the particular area, *A*, is perpendicular to a uniform magnetic field of strength *B* (as shown in figure 7.8 on the opposite page) then the magnetic flux Φ_B is the product of B and A. So to calculate magnetic flux, multiply the normal magnetic flux density component by the area through which the magnetic field lines are passing.

$$\Phi_B = B \perp A$$

4. describe generated potential difference as the rate of change of magnetic flux through a circuit

The generated potential difference (or voltage) is equal in magnitude to the rate at which the magnetic flux through the circuit is changing with time. The equation derived to calculate the total generated potential difference is as follows:

$$\varepsilon = -\frac{\Delta \Phi_B}{\Delta t}$$ The negative sign indicates the direction of the induced emf.

where;

ε = generated potential difference (*V*)

Φ_B = magnetic flux density (*T*)

t = time (*s*)

5. account for Lenz's Law in terms of conservation of energy and relate it to the production of back emf in motors

Lenz's Law states that an induced current is always in a direction such that its magnetic field opposes the changing field that created it.

Lenz's Law is a result of conservation of energy. We know that energy cannot be created or destroyed and as a result of this, **Lenz's law applies to the generation of back emf in motors** (and the motor effect). It applies as following:

If we have a current flowing through a wire in the presence magnetic field in a motor, then this will cause the coil to spin. However, this relative motion between the rotating current-carrying coil and the magnetic field will produce a current (as a result of the motor effect and induction). This current, in the same direction as the initial current, would grow infinitely larger and eventually overload the system; also producing energy from no work. This would break the law of conservation of energy. Thus, the current produced as a result of the rotating coil flows in the opposite direction, conserving the system's energy - this is known as back emf.

When the coil of a motor rotates, a back emf is induced in the coil due to its motion in the external magnetic field.

Therefore, Lenz identified this issue and devised his law (above).

6. explain that, in electric motors, back emf opposes the supply emf

Due to Lenz's law and the result of a back emf in a rotating coil within a motor, **there must be energy conserved throughout the system**. For this to occur, **the back emf that is induced must oppose or flow in the opposite direction of the supplied emf** that is being put into the system.

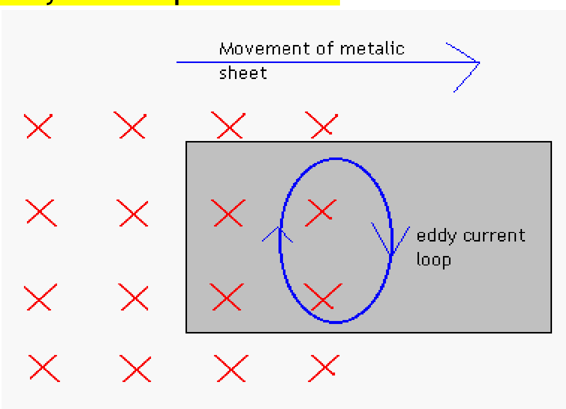
The smaller the back emf is, he greater the current flowing through the coil. When the motion of the coil is resisted, say by a load, then the coil will be spinning slower and so the back emf (which is induced due to the relative motion of a coil and a magnetic field) will be less.

Therefore the net voltage in a motor is the supply voltage minus the produced back emf.

Note: *Preliminary formulas may need to be used in questions, such as* $V = IR$

7. explain the production of eddy currents in terms of Lenz's Law

Eddy currents are **produced between the relative movement of a metal** (not necessarily magnetic) and a **magnetic field**. They are *small circular paths*. Due to resistance eddy currents **produce heat** and these currents **produce a magnetic field that, due to Lenz's law, opposes the original changing magnetic field.**

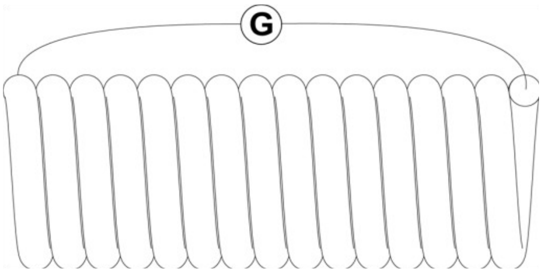


The *right hand push rule can be applied* to determine the direction of the force on the eddying current (which is meant to resemble the swirl of water after a boat takes off).

An eddy current can be produced or mimicked by dropping a small magnet down a metallic (preferably non-magnetic) tube. As the magnetic makes relative movement to the metal, swirling eddy currents will be produced vertically down the cylinder in big rings.

1. perform an investigation to model the generation of an electric current by moving a magnet in a coil or a coil near a magnet

A permanent magnet was moved from left to right through an insulated coil of wire to generate a current in the coil. The coil was attached to a multimeter on each end to measure the current flowing through.



As the magnet approached from the left, the **multimeter measured a small current which in turn produced a magnetic field which opposed the magnetic field produced by the permanent magnet** - making it harder to push through.

*When the bar was placed **in the middle**, the induced current travelled in the same direction* (toward to the magnet) as before but the **current was far stronger due to the larger magnetic flux in the centre.**

Upon removing the magnet out the right side of the magnet, **the current lowered again** to approximately the same amperes as before putting the magnet in. The current was still in the same direction. If I were to reverse the poles of the magnet (i.e. turn it around) then the induced current would travel in the opposite direction as before; **this is to ensure the magnetic field produced by the induced current opposes the permanent magnets field** - due to Len's Law.

Note: The right hand grip rule was applied to verify that the two magnetic fields opposed each other - however this could be physically felt by their repulsion.

2. plan, choose equipment or resources for, and perform a first-hand investigation to predict and verify the effect on a generated electric current when: **same experiment as above**

– the distance between the coil and magnet is varied

As the distance is increased the strength of the magnetic field decreases thus less current is induced. This was verified by numerous repeated tests at many lengths of 3cm further away each time. **D↑ = A↓**

– the strength of the magnet is varied

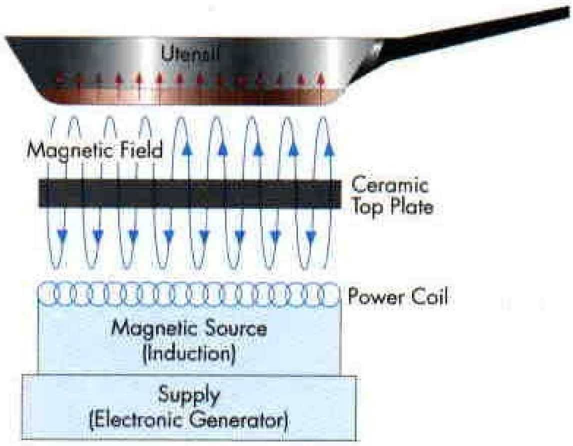
As the strength of the magnet increased, the induced current was greater (and thus the induced magnetic field was greater too). This was tested with varying strength in magnets so the flux was different for each test. **B↑ = A↑**

– the relative motion between the coil and the magnet is varied

The faster the relative movement between the coil and magnet, the greater the induced current.
V↑ = A↑

3. gather, analyse and present information to explain how induction is used in cooktops in electric ranges

Induction cooktops use the fact that **a conductor in the presence of a changing magnetic field will have induced eddy currents created which create a magnetic field to oppose the first magnetic field**.



Induction cooktops have **a coil beneath the surface which AC power is supplied to** (DC power would not work as the magnetic field is required to vary so a varying current is needed) which in turn **produces a varying magnetic field**. The changing magnetic field beneath the cooktop **induces eddy currents in the metallic pan** - and also **agitating the actual atoms** within the pan/pot. **Due to the resistance** (a property or an eddy current), **heat is given off into the metallic pan/pot** to cook the food.

The rapidly changing magnetic field(s) directly heat up the metallic object on top so no heat is lost, compared to the older gas or heated coil style of cooktops.

4. gather secondary information to identify how eddy currents have been utilised in electromagnetic braking

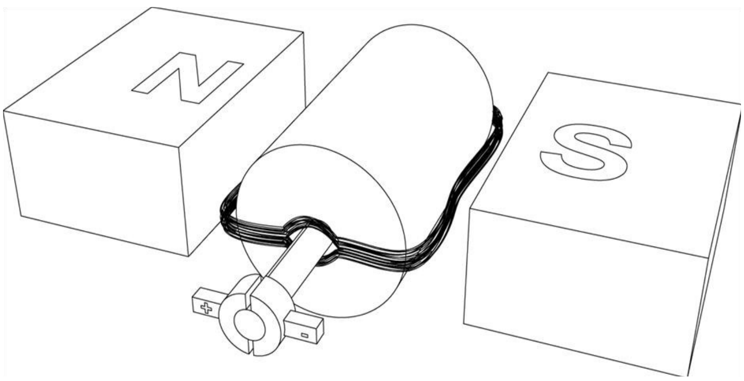
Electromagnetic braking systems utilise eddy currents to interact with electromagnets as to create a stopping force for moving vehicles.

The electromagnetic brakes consist of **electromagnets** positioned on either side of a **rotating disc**. The **electromagnets will be creating a magnetic field as a result of the current flowing through them**; and as a result of Len's Law, the spinning disc (non-magnetic) will interact with this magnetic field, **producing eddy currents**. These eddy currents produced as a result of the relative motion between the disc and electromagnetic fields **will produce their own magnetic field which opposes the electromagnetic field - which is the braking force**.

Electromagnets are chosen rather than permanent magnets, because the ***electromagnets can be switched off*** when not needing to brake (so there is no magnetic field while the disc spins). *The* ***strength*** *of the magnetic field from the electromagnets* ***can be increased*** by increasing the current in them, resulting in hard or soft braking.

3. Generators are used to provide large scale power production

1. describe the main components of a generator



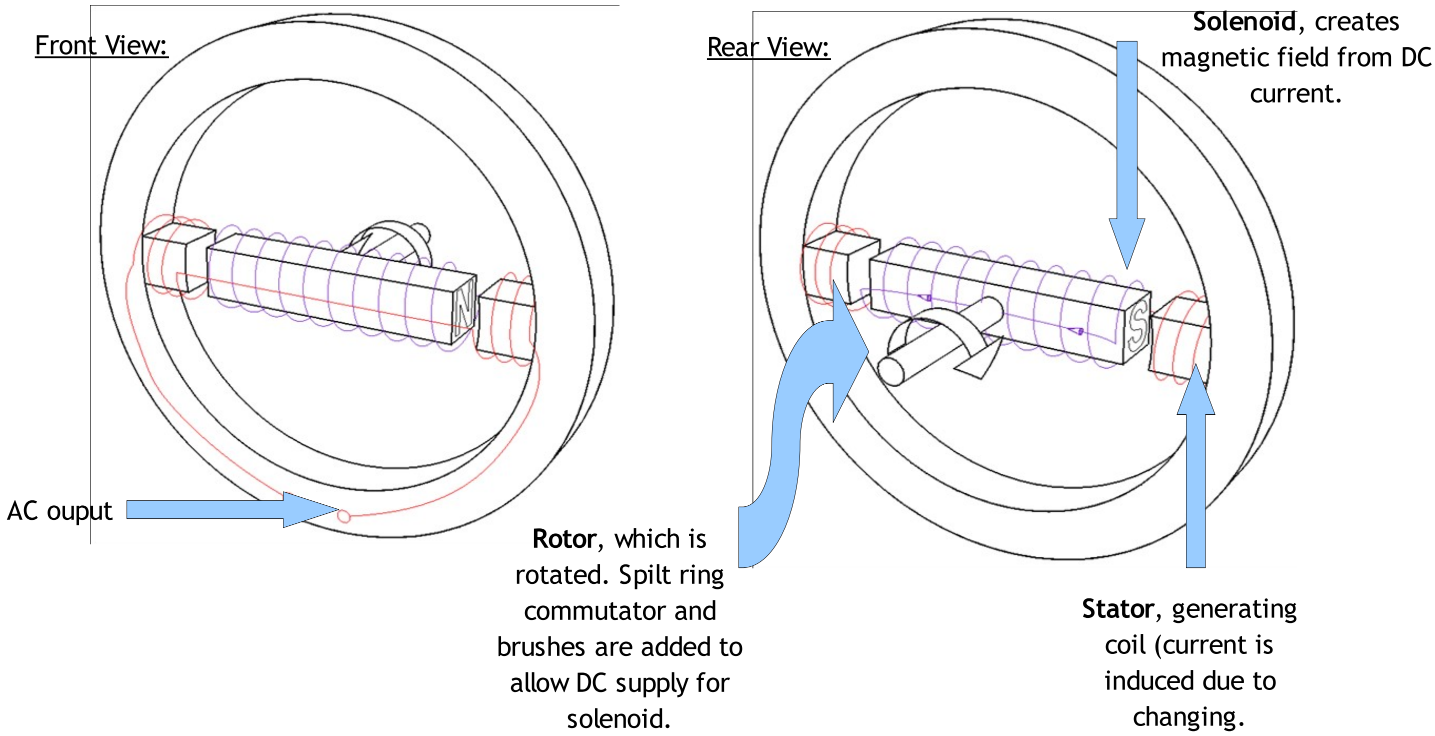
The DC generator functions exactly the same as a motor but simply in reverse. Instead of creating torque due to the current flowing through the motor; **in a generator a current is generated from the spinning of the central armature - the torque**.

The **stationary** parts of a generator are called the **stator**, while the **moving** parts are known as the **rotor**. You can determine the magnitude and direction of torque using:

$$\tau = nBIAcos(\theta)$$

2. compare the structure and function of a generator to an electric motor

Because the operation of a motor and generator are simply in reverse, then the generator and the motor can in fact be the device, however, **power station generators are different**. A power station generator **produces AC current**. It has the **magnetic field rotating inside a stationary coil**.



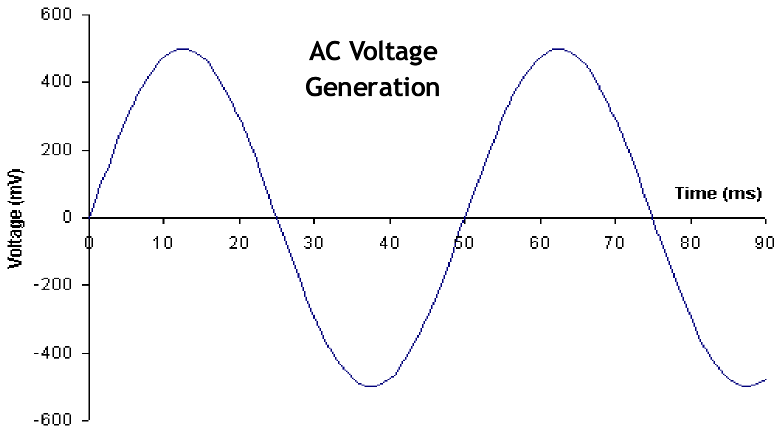
To determine the direction of the current in a generator, the right hand push rule can be modified. Where fingers are the direction of magnetic field, thumb is the direction of turning motion and palm is the direction of the current in the wire.

3. describe the differences between AC and DC generators

AC and DC generators operate in the same way, but generate different kinds of electricity. **Slip rings are used in the AC** generators, while a simple split-ring commutator is used in the DC generator. AC Generators are preferred because:

- Slip rings won't wear down or break as easily as split ring commutators
- **Mains power is AC**; therefore there is no need for a DC to AC converter when AC generators are in use

Both the AC and DC generators are used to **transform mechanical kinetic energy into electrical energy**. The energy output from either of these generators can be represented graphically:



The AC generator's voltage output represents a sine wave curve (right) while the DC generator will be the same, however, not produce negative values.

The AC generator alternates its current output in intervals, whereas the DC generator is a constant flow in the one direction.

4. discuss the energy losses that occur as energy is fed through transmission lines from the generator to the consumer

Power stations and **generators are most often located large distances away from the centre of busy cities** where most people reside. This long distance presents **problems in transferring electricity** to those in the large CBD areas which are so far away. We know (and see) that the large power cables overhead or beneath the ground in some cities are used to transport electricity to households are businesses; however, **the length and size of these wires resists the flow of electricity.**

The resistance of the wires used to transport electricity to the consumer is the most costly and inefficient part of the process. The resistance (R) of the metallic conducting wire is proportional to it's resistivity and length, also inversely proportional to it's area. Thus:

$$R = \frac{pl}{A}$$

where;
R = overall resistance of the wires
p = resistivity of the wires (depending on type of wire)
l = length (*m*)
A = area

Now, by the knowledge that $V = IR$ we can determine the power loss. $P = VI$, thus by multiplying both sides of the first formula by I, we determine that $P_{loss} = I^2 R$

- The **significant resistance** which the long metallic wires pose **can be minimised by forcing the electricity through at a higher voltage** (emf)
- The implementation of **transformers** across the country has enabled household and infrastructure powered by electricity to succeed because they **allow the transfer of electricity over long distances with minimal resistance.** Transformers and substations are used to **step-up and step-down** the AC electricity so that the resistance along the transfer is negated with a voltage boost.

5. assess the effects of the development of AC generators on society and the environment

Society:

- The production AC generators have allowed the **transfer of AC electricity to domestic homes which are used to power lights, cooking utensils, refrigerators** etc. Without AC electricity, modern man would not survive in terms of food gathering and cooking.
- Many businesses require electricity to power many machines to operate their company. Without the introduction of AC generators there could not have been simple electronics in homes.
- Has laid the foundations for **infrastructure to be built and continued** – technology now relies on

electricity which is provided through the transport of AC electricity

Environment:

- The **traditional AC generators** (which occupy most of Australia's current generators) **are powered by fossil fuels** in order to produce the torque on an armature. The burning of these fossil fuels contributes to **the greenhouse effect**, depleting the ozone layer. Thus the production of the AC generator has had a huge negative impact on the environment in this light.
- **AC generators also give means to alternate, sustainable**, green and renewable **forms of generation**. **Hydro-power** and **wind/turbine** powered AC generators are now populating numerous coastlines, replacing traditional fossil fuel AC generators.
  This in effect helps sustain the environment while providing essential AC electricity to people. (This in effect also produces jobs to build these renewable stations - society).

1. plan, choose equipment or resources for, and perform a first-hand investigation to demonstrate the production of an alternating current

The set up of an AC generator was required to demonstrate the production of an alternating current. This was done in the same way a DC generator is created, however, with the use of slip rings rather than the split-ring commutator.

Equipment required: **refer to orange dot points 1.6 and 3.3** in which the rotor of the generator was rotated continually had a high torque through 360° in which the direction of current would change every full rotation.

The alternating current was measured using a multimeter and then continued on through a series to test if the current was in fact 'real' and was strong enough to power a resistor (a globe).

2. gather secondary information to discuss advantages/disadvantages of AC and DC generators and relate these to their use

	Advantages	Disadvantages
AC	• **Voltage can be stepped up or down** so that the voltage can be transported long distances using transformers • **Slip Rings are used** for ease and do not break easily • Can be **transferred at extremely high voltages** so that energy is not lost	• **Back emf opposes the supplied emf**. This is a problem because it reduces the overall transported energy • **Emits electromagnetic radiation** (EMR) so wire shielding is required for safety • **Frequency** must be monitored at **50Hz** • The electrons in AC electricity tend to travel toward the edge of conductor making it less efficient: **skin effect**
DC	• **No shielding from EMR** is required • The **magnetic field is stable** (using permanent magnets) so there is **no back emf** • Many appliances use DC power	• **Cannot be transformed** by stepping up or down due to the direction of current • **Split-ring commutator** is needed which often **breaks** and can spark resulting in danger and damage

3. analyse secondary information on the competition between Westinghouse and Edison to supply electricity to cities

Edison ► DC electricity

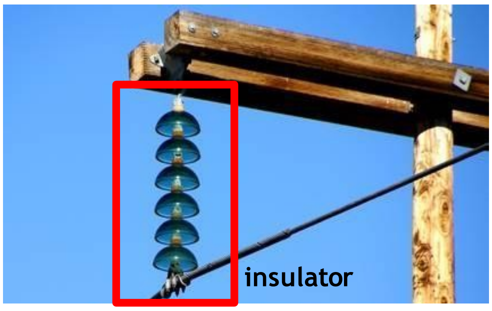
- Generated his own direct current in **generators known as *dynamos*** using split-ring commutators, however these proved ineffective and rather **dangerous in steam powered stations.**
- Killed a number of animals in the name of science and testing to show how AC electricity was far more dangerous than DC - however, we know all electricity is dangerous.
- Saw threat to his DC power when Westinghouse bought the patents to Tesla's work and designs in AC power and so **published a large article in defence of his own DC power with warnings and threats about deaths to those from AC power.** (DC power is in fact more dangerous).

Westinghouse ► AC electricity

- **Bought** the patents and works of **Tesla** for $1,000,000.
- The invention of the **electric chair** (and what type of electricity to use)
- The **Niagara Falls Power Plant** project was established to give the winner money if they could utilise the power of the falls in a generator. Westinghouse's AC design won this competition.
- The **Electric Chair War.**
- **AC was deemed to be more efficient because it could be stepped down** using transformers – from 300kV down to 240V mains power.

4. gather and analyse information to identify how transmission lines are:

– insulated from supporting structures



Transmission lines have the **possibility to spark** in dry and humid air. In dry air, a wire will spark 1cm for every 10kV and so most high voltage wires are approximately 330kV, therefore sparking 33cm (and even more in humid conditions). **To prevent these sparks from reaching other cables and the structures which support the cables, insulators are used to separate them.**

These insulators are often numerous discs (which increase the leakage distance) in a straight line, **ceramic** make because of its great insulating nature, and extend about 10-100cm in length to prevent the wires from interacting with the structure.

– protected from lightning strikes

When lightning strikes from the bottom of the storm cloud, it will do so at the highest point on the earth which can often be the towers carrying high voltage power lines. These power lines are fitted with one ***earth cable*** **which carries no current.**

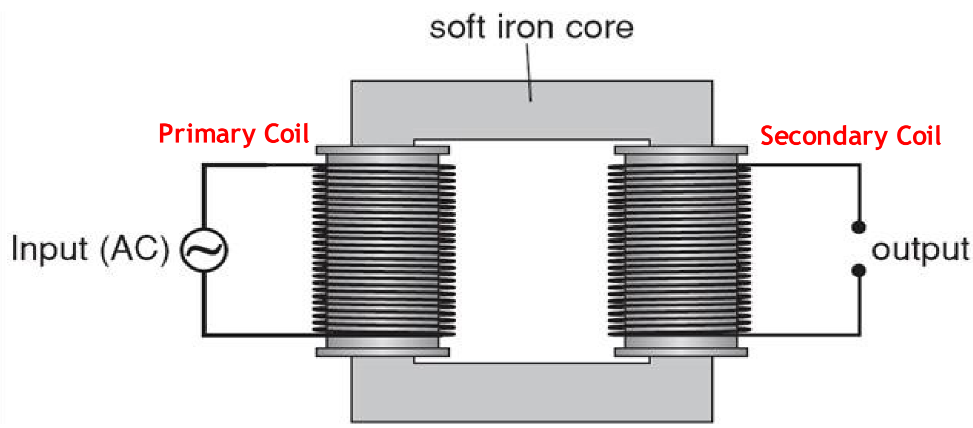
The continuous earth line can be used to carry a current in times when other lines fail, however **the earth line can be used to carry extremely high voltage lightning strikes into the Earth.**

4. Transformers allow generated voltage to be increased or decreased before it is used

1. describe the purpose of transformers in electrical circuits

Transformers are used in electrical domestic circuits and appliances **to change the voltage in appliances so that they can function** or perform their task. Voltage and current are directly related (***V* = *IR***) so that when voltage is increased, current must decrease. However, power ($P = I^2R$) stays the same.

2. compare step-up and step-down transformers



AC current is required for a transformer to operate because it requires an alternating magnetic field. Step-up transformers increase the voltage of the system, and Step-down transformers will decrease the emf. Transformers operate on the fact that alternating magnetic fields produce a changing current.

Transformers which step down will have the primary coil at a higher voltage than the second, and to do this (since they are proportionally related by ***V = IR***) then **the second coil will have a lower voltage**, however higher current. Step-up transformers have the power coming into the first coil at a high current, and is then lowered to increase the voltage (emf).

3. identify the relationship between the ratio of the number of turns in the primary and secondary coils and the ratio of primary to secondary voltage

$$\frac{V_p}{V_s} = \frac{n_p}{n_s}$$

If n_s is greater than n_p, the output voltage, V_s, will be greater than the input voltage, V_p. Such a transformer is known as a step-up transformer. If n_s is less than n_p, the output voltage, V_s, will be less than the input voltage, V_p. Such a transformer is known as a step-down transformer.

The number of turns in the coil are also important. If there are **more turns on the primary coil**, but less on the secondary, **then the transformer will be a step-down transformer** as it increases current and decreases voltage.

Note: because the voltage enters the **primary coil**, this is the **input voltage**. The voltage exists the *secondary coil* and is therefore the *output voltage*. In an ideal situation where the input and output voltages are equal, therefore the input and output currents of both must equal.

4. explain why voltage transformations are related to conservation of energy
Transformers are related to the conservation of energy because they '**transform' energy from one state to another**. *The Law of Conservation of Energy states that no energy can be created nor destroyed - there must be a trade-off or transforming of energy.*

The **power which is injected into the primary coil can not exceed the power which is ejaculated from the secondary coil**. This is related by the property: ***P = IV***. The voltage and current can be, however, altered and this is what function transformers and transformations of energy within them act on.

One would notice that not all the magnetic flux of the system is transferred to the secondary coil due to the production of eddy currents and production of heat as a result, which is then given off as thermal energy.

5. explain the role of transformers in electricity sub-stations
Transformers must be used to allow electricity to be efficiently transferred to consumers in a fast, economic manner. We know that voltage in transmission lines will decrease based on the area, length and resistivity of the wire so it is sent at extremely high voltages to reduce this loss.

- However, the **voltages are so high that they cannot possibly be sent to domestic homes for appliance or lighting operation** - this would cause fires and short fuses. To decrease the power and voltage of the electricity sent to homes, **transformers are used to step-down the voltage**.
- Substations are positioned across each state so that there are regular intervals that the voltage can be stepped up (for long distances as a result of loss) or stepped down to be transferred into homes.

6. discuss why some electrical appliances in the home that are connected to the mains domestic power supply use a transformer
The **mains power in a home is a stable 240V** alternating current which is **far than sufficient to power numerous household** appliances at once. Most electrical appliances do not need to utilise the full 240V of power however, most only needing 12-24V, for this to occur a **transformer needs to be used to step down the voltage of from the mains box - otherwise the appliance would short out with too high** (maximum) current flowing through the electrical circuit.

However, **some extremely large appliances which drain large levels of power** such as large TVs and other high demand appliances require **more than 240V**. For this reason, **such appliances contain a transformer to step up the voltage**, however, lowing the current in the circuit. If these appliances were not able to get the required voltage above 240V, they simply wouldn't have the power to turn on or function.

7. discuss the impact of the development of transformers on society

- Transformers have **allowed different voltage appliances to exist** and operate perfectly in homes at lower voltages. Transformers have allowed 240V mains power to be lowered (or increased) and thus allowing toasters to operate, computers etc.
- The introduction of transformers have made **homes safer when utilising electricity at lower voltages**.
- The invention and implementation of transformers have resulted in the **need for only one type of electricity (AC)** and same mains voltage to homes.
- Transformers with the ability to step-up voltage allow electricity to be **transported long distances** as they can be stepped up into high kV (this is needed since electricity loses voltage across transmission lines).
- As a direct result of transformers possessing the ability to transfer electricity at higher voltages, and therefore **minimising energy loss, consumers can save on money** and costs compared if the electricity were transported at lower voltages.

1. perform an investigation to model the structure of a transformer to demonstrate how secondary voltage is produced

A secondary voltage is induced in transformers due to Lenz's Law. When a current flows through the first (primary) coil, a magnetic field will be produced which covers the secondary coil entirely. Accordingly, with Lenz's Law, this secondary coil will also produce a current through it's coils.

The voltage/current can be altered by changing the ratio of coils on each of the coils. Refer to model.

Through experimentation, I found that the ratio of coils from primary to secondary coil was directly proportional to the ratio of voltage on each coil. I noticed, however, that this proportional correlation was affected because of the transfer of energy in the vibration of the transformer and also in the release of heat (minimised through the insulation of coil and lamination to prevent high eddy currents).

2. solve problems and analyse information about transformers using:

$$\frac{V_p}{V_s} = \frac{n_p}{n_s}$$

This formula demonstrates the direct proportion between the voltage in the solenoid to the respective number of coils on that conductor. This formula can be further extended to:

$$\frac{V_p}{V_s} = \frac{n_p}{n_s} = \frac{I_S}{I_P}$$

3. gather, analyse and use available evidence to discuss how difficulties of heating caused by eddy currents in transformers may be overcome

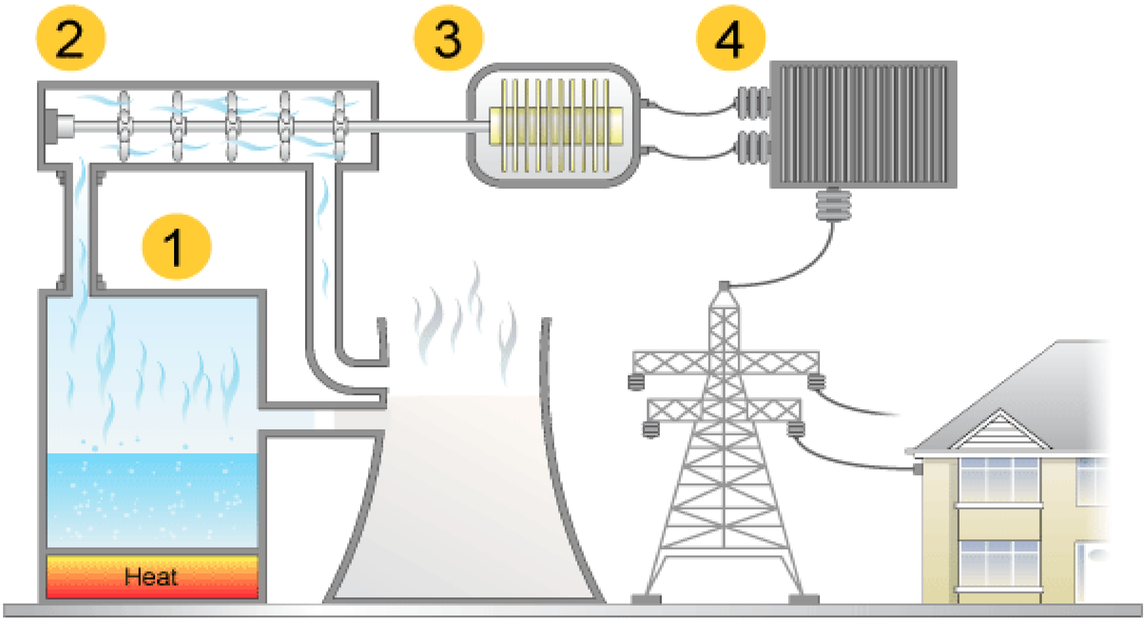
Due to the high current that is input into the primary coil, a large and strong magnetic field is created which envelops the secondary solenoid. The interaction between the magnetic field and the metallic structure and ferrous, soft-iron core causes large eddy currents to develop – and as a result, heat is produced and amplified in the same way that induction cooktops work. The heat is minimised in the following ways:

- *Lamination:* By **lamination the iron core** of the transformer, we insulate the transformer and will not conduct very much heat so that more energy can be transferred to the secondary coil. By using **insulating** lamination techniques, we can **optimise the efficiency** of the transformer by preventing large eddy currents from forming and instead, much smaller heat producing eddy currents are formed, reducing the amount of energy lost in the form of heat.

- *Ferrites:* May be used **instead of an iron core**. Ferrites are an **impure mixture of iron ores** and other substances which are **bad conductors of heat** and electricity. By **minimising the amount of metallic core**, we optimise the efficiency of the transformer as there is less area for eddy currents to form.

- *Coolant:* Obviously **does not minimise the amount of eddy currents produced** and therefore does not increase the efficiency of the system. Coolants are used to prevent transformers from overheating when eddy currents cannot be reduced by aforementioned techniques.

4. gather and analyse secondary information to discuss the need for transformers in the transfer of electrical energy from a power station to its point of use



i) **AC electricity is generated in power stations**, most commonly by the **combustion of fossil fuels** in order to rotate a turbine which powers a generator to create electricity.

ii) Electricity is stored until it reaches sufficient power and is **stepped up using a transformer to voltages approximately 330kV** across high power transmission lines as an AC power source.

iii) Power does not need to be stepped up and down along the way to it's domestic or industrial use because of the **efficiency to transport AC electricity over long distances**.

iv) A **transformer**, located in the most suitable (and close) vicinity which is **steps down the electricity to approximately 11000V which is then split and distributed to a small 'power box'** which contains a step down transformer.

v) The voltage is then **stepped down to 240V mains power** using the step-down transformer located near or at the house.

5. Motors are used in industries and the home usually to convert electrical energy into more useful forms of energy

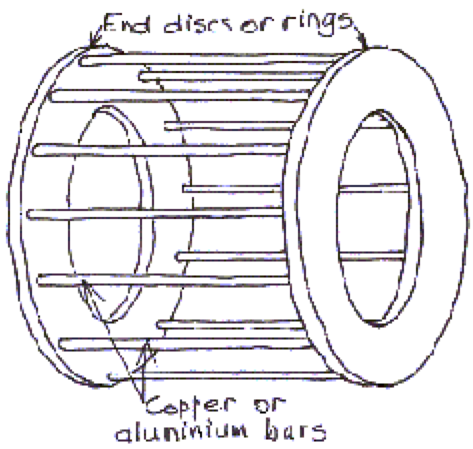
1. describe the main features of an AC electric motor
There are two types of AC electric motors:

AC Synchronous Motor:

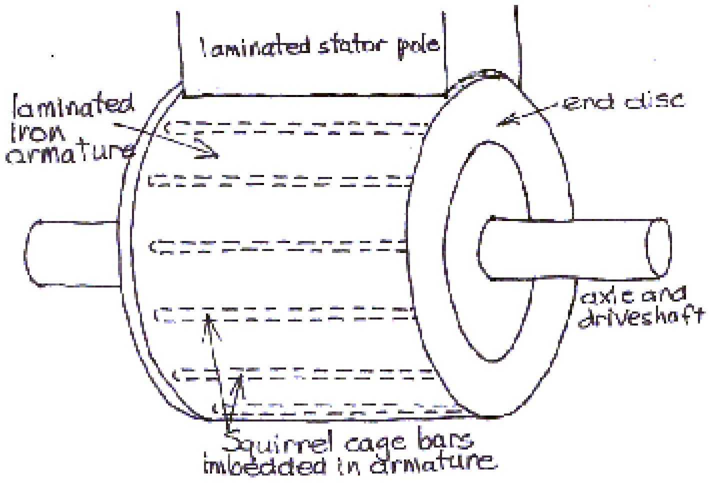
- **Cylindrical rotor** and same stator parts as DC motor
- **Slip rings**
- **Electromagnets** to provide a rapidly changing magnetic field that induce the alternating current

AC Induction Motor:

- **Squirrel Cage**: in which **long bars of copper** are attached on rings at either end that allow a current to pass from one end to the other
- Operates using **AC powered electromagnets** which create a rotating and changing magnetic field in the stator which is outside the rotor. The paired **magnets change polarity with the AC phase**, resulting in a torque.
- The changing **magnetic field will induce a current** in the long bars **that will also produce a magnetic field to oppose** the one that created it. This opposition because of the induced current creates the force, **torque**, which spins the rotor



"Squirrel cage" rotor



Induction motor rotor

1. perform an investigation to demonstrate the principle of an AC induction motor

A **sheet of aluminium foil** was placed **on top of a pool of water**. This allows the aluminium foil to move and spin. When a magnet above the foil is spun the aluminium sheet also spins. This is ***due to Lenz's Law, where the aluminium foil will induce eddy currents to create its own magnetic field which opposes the original changing magnetic field***. The interaction of these two magnetic fields causes the **aluminium foil to spin**.

2. gather, process and analyse information to identify some of the energy transfers and transformations involving the conversion of electrical energy into more useful forms in the home and industry

Since energy cannot cannot be destroyed or created, it is therefore only ever converted from one type to the next and utilised in the house and industry for many pracitcal applications. Using electrical energy, the household *television* is a prime example of the conversion of electrical energy into light energy (the picture we see), sound energy (the music and sound we hear); and the same can be applied to hair dryers which convert electrical energy to kinetic energy to rotate a motor which converts this kinetic energy into heat energy through heat plates.

kinetic energy or **heat energy** or **sound energy** or **gravitational potential energy** or **chemical energy**

The industry is also able to access this fundamental property of the conversion of energy from one state to the next. In industry, lifts (elevators) and escalators use the conversion of electrical energy to create both a kinetic energy to move people from one place to another but in the same process then gain and convert into a gravitational potential energy by going up and down. Car batteries are an example of the conversion of electrical energy into chemical energy for storage when they are recharged.