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

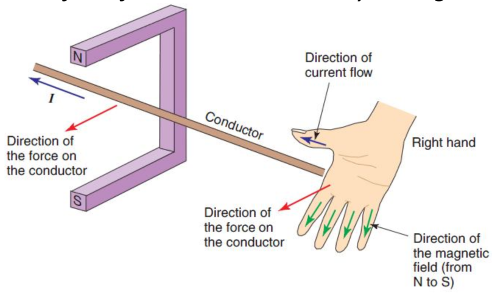
identify that the motor effect is due to the force acting on a current-carrying conductor in a magnetic field

If charged particles move in an external magnetic field it will experience a force. Similarly, if these charged particles are flowing through and confined within a conductor, then the conductor will also experience a force. The motor effect is the action of this force produced by a current carrying conductor in an external magnetic field.

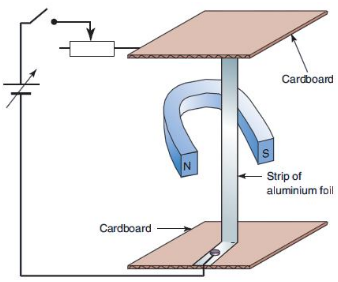
The motor effect is the basis for electrical motors and as electrical motors transform electrical potential energy into rotational kinetic energy through the force acting on the current carrying conductor.

The direction of the force is determined by the right hand palm rule.

As we can see, first we point our four fingers in the direction of the magnetic field. Then we point our thumb in the direction of the conventional current. Hence the direction of the force will be the direction our palm faces.



perform a first-hand investigation to demonstrate the motor effect



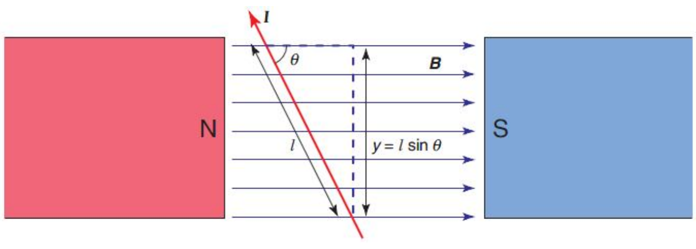
A strip of aluminium foil (1x30cm) was pinned between two pieces of cardboard, one piece resting on the bench top while the other was supported by clamp and retort stand. Connect to a DC power supply, wires, switch, a variable resistor and the strips as shown. Closing the switch will produce a current in a strip Position a horseshoe magnet such that the strip is between the poles. Now turn on the power pack and close the switch. Note the position of poles and the direction of current then record the movement of the foil strip. Now turn the magnet over such that the magnetic field is in the opposite direction. Also record the movement.

The strip will only experience a force when the switch was closed and current flowed. The direction of the force was in accordance with the right hand palm rule. When there was no magnet, there was no force. And if the magnet was there and the switch was open, no force was experienced.

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

The magnitude of the force on a current carrying conductor depends on the following factors:

- As the strength of the external magnetic field increases, so does the force, i.e. the force is proportional to the magnetic field strength (B).
- Similarly, the magnitude of the current (I) is also proportional to the force as an increase in current will increase the force. *Direction of current doesn't affect magnitude of the force*.
- The length of the conductor (ℓ)in the field is also proportional to the force, with the force increasing as the conductor's length increases.
- Finally, the force is at maximum when the conductor is perpendicular to direction of the magnetic field and minimum (i.e. zero) when parallel to the field. The component of the field perpendicular to the conductor is proportional to the magnitude of the force. So by letting θ be the angle between the field and the conductor, the force is the maximum value multiplied by sinθ.



These factors can be summed up by the formula:

$$F = BIl \sin \theta.$$

Direction of force can be found using right hand palm rule. On the left, force would be into the page.

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

$$F = BIl \sin\theta$$

When given diagrams, REMBMER the DIRECTION of force, as well as not to confuse the angle between conductor and field.
Sometimes, angle is given as a red herring when it is not really needed.

Find the force acting on a conductor of length 1 m carrying a current of 5A if:

1. The magnetic field strength is 2T and the conductor is perpendicular to the field
2. The magnetic field strength is 1T and the conductor is 30° with the field.
3. The magnetic field strength is 5T and the conductor is parallel to the field.

This problem can be solved by the equation F=Blℓsinθ, where I = 5A, and ℓ = 1m

1. B = 2T, θ=90°, F=?
   F = Blℓsinθ = 2 x 5 x 1 x sin(90°) = 2 x 5 x 1 x 1
   F = 10N
2. B=1T, θ=30°, F=?
   F = Blℓsinθ = 1 x 5 x 1 x sin(30°) = 1 x 5 x 1 x 0.5
   F = 2.5N
3. B=5T, θ=0°, F=?
   F = Blℓsinθ = 5 x 5 x 1 x sin(0°) = 5 x 5 x 1 x 0
   F = 0N

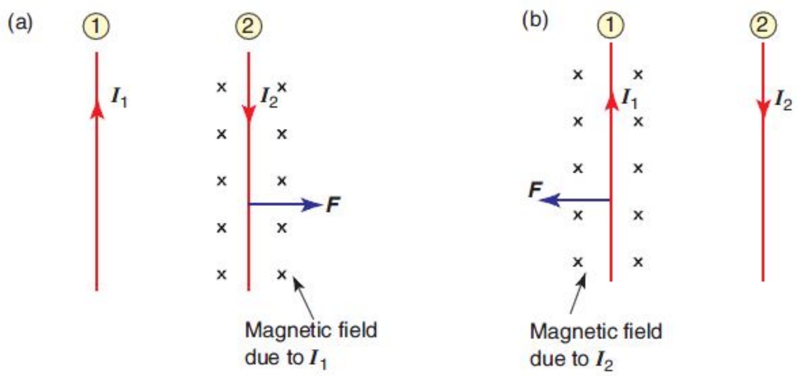
describe qualitatively and quantitatively the force between long parallel current-carrying conductors:

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

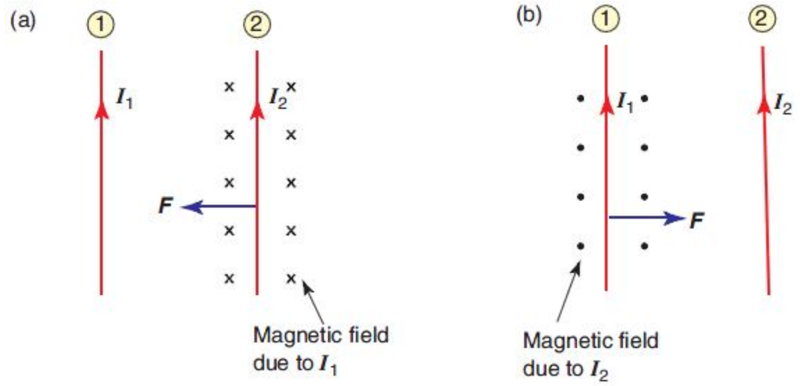
Qualitatively, an application of ampere's law yields a result which states that: Since two parallel wires each carrying a current will produce a magnetic field (Oersted), hence, the two parallel wires will exert a force on each other as each wire finds itself carrying a current in the magnetic field produced by the other wire.

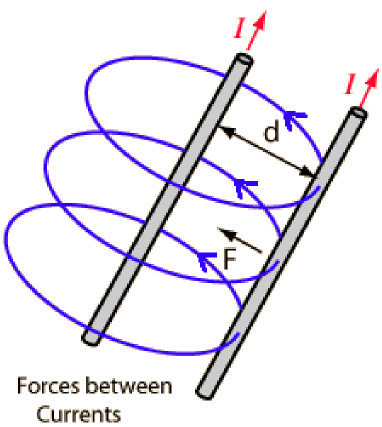
If two wires are carrying currents in opposite directions, then by using the right hand rule on both wires, we can determine the direction of the magnetic field. Hence, we can determine the force on the wires.

As below, in (a), I_1 produces a magnetic field into the page. And since we know the direction of I_2, by the right hand palm rule, we can determine the force acting on wire 2 is away from wire 1. Similarly for (b)



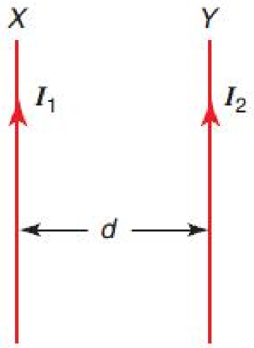
Now if the current is both travelling in the same direction, we see below, in (a), we determine the direction of the magnetic field produced by I_1. Then since we know the direction of I_2, by the right hand push rule, the force on line 2 is acting towards line 1 and similarly in (b). A 3d representation is shown on left.





This is identical to diagram (a) on the right.

Therefore, if two parallel conductors have current flowing through them in opposite directions, then the conductors repel each other. But if two parallel conductors have current flowing through them in the same direction, the conductors attract.



Now, quantitatively, this result is yielded by the formula

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

Where F is the force acting on one conductor, l is the length of the conductor, k being the constant 2.0 x 10^{-7} NA^{-2}, I_1 and I_2 are the current through the parallel conductors and d is the distance of separation between the two conductors.

Now for the derivation…

The magnetic field strength at distance, *d*, from a straight conductor length, *l*, is…

$$B = \frac{kI}{d}$$

Where k = 2.0 x 10^{-7} N A^{-2}

Now with this formula, we can apply it to the situation presented on the left: which depicts X and Y as conductors with currents I_1 and I_2 flowing through them, being separated by a distance d. Then the magnetic field strength due to the current through X (B_X, i.e. I_1) across conductor Y would be:

$$B_X = \frac{kI_1}{d}$$

And also, we know that the force experienced by conductor Y is also given by F = B$i\ell$sinθ

So it is:

$$F = I_2 l B_X$$

Hence, substituting B_x into the equation above, we get...

$$F = I_2 l\left(\frac{kI_1}{d}\right)$$

Rearranged to be the first equation given:

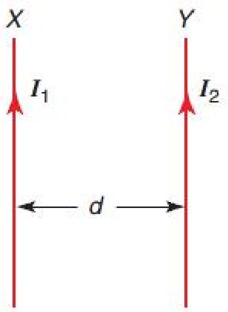
$$\frac{F}{l} = k\frac{I_1 I_2}{d}$$

solve problems using:

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

For example: What is the magnitude and direction of the force acting on a 10.0cm length of conductor X with current I_1 of 3.2A through X and I_2 of 1.2A through Y and the current is flowing in the same direction, while the distance of separation is 25cm?

These problems involve two parts, one to find the magnitude of the force, and the other to find the direction of the force using the right hand palm rule.



[Sol] Listing given data:

ℓ = 0.1m, I_1 = 3.2A, I_2 = 1.2A, d = 0.25m, k = 2.0x10^{-7} NA^{-2}, and since…

$$F = \frac{klI_1I_2}{d}$$

$$F = \frac{(2.0 \times 10^{-7})(0.1)(3.2 \times 1.2)}{0.25}$$

Therefore, F= 3.072 x 10^{-7} N

=3.1 x 10^{-7} N (2sf)

And this force on conductor X is to the right as two parallel conductors with the current flowing in the same direction attract each other.

OR alternatively, the magnetic field produced by I_2 is out of the page at X. Therefore, using the right hand push rule, we determine that the force on conductor X is to the right.

Remember to include direction of forces, calculating forces on common length not total length.

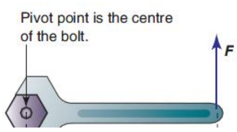
define torque as the turning moment of a force using:

$$\tau = Fd$$

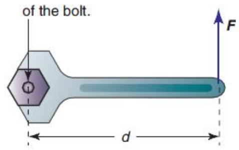
Torque is the tendency of an object being rotated around an axis, i.e. the turning effect of a force.

This depends on not just how much force is applied, but in what direction it is applied. Hence, to calculate torque, it is the product of the tangential component of the force and the distance the force is applied from the axis of rotation (pivot axis).

$$\tau = Fd.$$



A typical situation would be the spanner shown on the left tightening a bolt at the

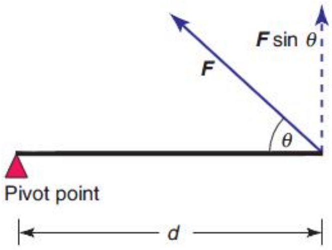


the force and the distance the force is applied from the axis of rotation (pivot axis).

$$\tau = Fd.$$

A typical situation would be the spanner shown on the left tightening a bolt at the centre which is the point of application, and the length of the handle would represent the distance.

We see that the unit for τ is Newton metres (Nm). But the above formula is only true for a force acing entirely perpendicular to the direction of the displacement vector from the turning point. Hence, to determine the tangential component of the force, we have to consider the diagram on the left.

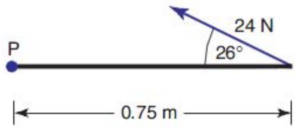


Given a pivot point, the turning effect of a force is only the component of the force perpendicular to the direction of the displacement vector from the pivot point. Therefore, it is F sinθ.

Thus, we can see that the above formula is only a special case of this condition where θ is 90°. But generally, the formula is:

$$\tau = Fd\,\sin\theta$$

Where θ is the angle between the direction of the force applied and the direction of the displacement vector from the pivot point to the point of application.



A simple problem would be: What would be the magnitude of the torque if the point of application is 0.75m away from the pivot point, and a force of 24N is applied at an angle of 26° to the lever?

[Sol] F = 24N, d = 0.75, θ = 26°

τ = Fdsinθ = 24x0.75xsin26° = 7.8906... Nm

Therefore, τ = 7.9 Nm (2sf)

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

As identified before, the motor effect is due to the force acting on a current-carrying conductor in a magnetic field. When a current carrying loop is placed in a magnetic field it will similarly experience a force. Firstly, this current carrying loop is placed on a rotational axis. The force experienced by the current carrying loop will be constant, but the torque changes.

The force is constant as the force is given by F = B*I*ℓ, with all three being constant. And by letting φ be the angle between the plane of the coil and the plane perpendicular to the direction of the magnetic field, we can apply the formula τ = Fdsinφ, but substituting F = B*I*ℓ, we get τ_1 = BIℓdsinφ on one side of the loop. Furthermore, since d is the distance from the pivot point to the point of application, this is half the width of the loop. Hence d = w/2. And if the angle between the plane of the coil and the plane of the magnetic field is θ, then φ = 90°-θ. Substituting these, τ = BIℓdsinφ becomes

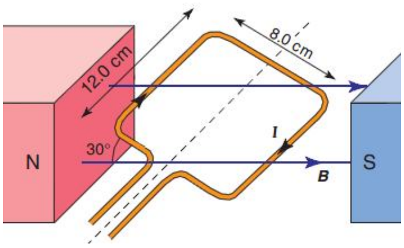
τ_1 = BIℓ (w/2) sin(90°-θ) = (BIAcosθ)/2

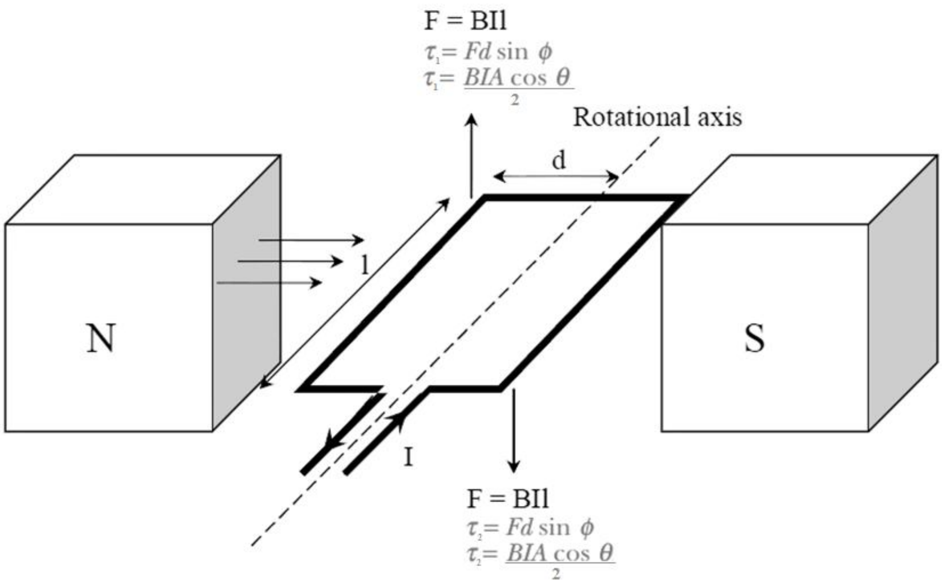
But since there is a turning force on both sides of the coil, see below, Hence,

$\tau = \tau_1 + \tau_2$

τ = (BIAcosθ)/2 + (BIAcosθ)/2

τ = BIAcosθ





A sample problem:

If a coil contains 30 loops and its plane is sitting at an angle of 60° to the direction of a magnetic field of 0.76T, the coil has the dimensions 12cmx8cm, and the current through the coil is 15mA, then determine the magnitude of torque.

[Sol] n=15, I=0.015A, ϑ= 60°, B=0.76T, A= 0.12x0.08=0.0096cm²

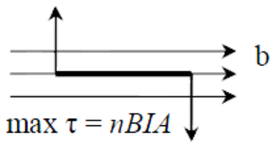
τ = nBIAcosϑ = 15x0.76x0.015x0.0096xcos60

τ = 8.208x10⁻⁴Nm

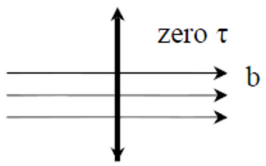
$\tau = nBIA\cos\vartheta$ =
15x0.76x0.015x0.0096xcos60
$\tau = 8.208\times10^{-4}$Nm
$\tau = 8.2\times10^{-4}$Nm (2sf)

$$F = BIl$$
$$\tau_2 = Fd\sin\phi$$
$$\tau_2 = \frac{BIA\cos\theta}{2}$$

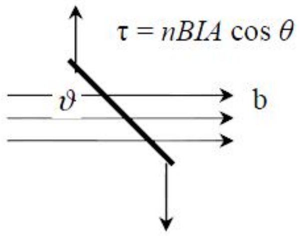
And if the coil has n loops of wire, the formula becomes τ = nBIAcosθ



Hence, we can see that when θ = 0º, i.e. the coil is lying parallel to the direction of the magnetic field, the torque is the greatest. Hence the coil will rotate.
From the diagram above, using the right hand palm rule, we can determine that there's a force acting 'up' on the left hand side of the coil, and there's a force acting down on the right hand side. This results in a clockwise rotation as simplified in the diagram on the left. A reversal of current will mean a force applied anticlockwise.



But when θ = 90º, we know that cosθ becomes zero. Hence the torque is zero when the coil is perpendicular to the direction of the magnetic field. This is regardless of the direction of the current flowing through the coil. <seen on left>



And finally, this can be generalised to any position, any number of coils and any current direction. If current direction is the same as the diagram above, then the coil will rotate in a clockwise direction when between the two previous situations.

To increase the speed (related to the torque) of the motor, you can:
Increase the force on each side of the coil, by increasing each variable (current, turns, magnetic field). Using a soft iron core as a part of the armature will concentrate the magnetic field. Increasing width of coil. Having curved pole faces for stator magnets, keeping torque largest for longest possible duration.

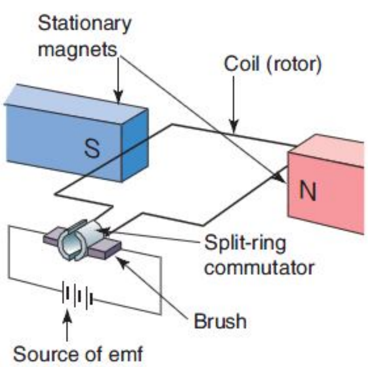
And continuing the sample problem from above, using the right hand palm rule, we can determine that the rotation is anticlockwise.

However, if a coil like this was placed in a motor, there would be a problem where the coil would simply rock back and forth if the current direction remains the same. So how is this overcome in an electric motor?

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

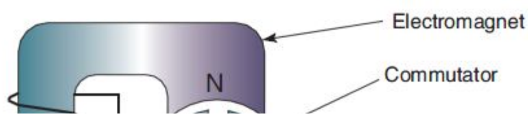
AND

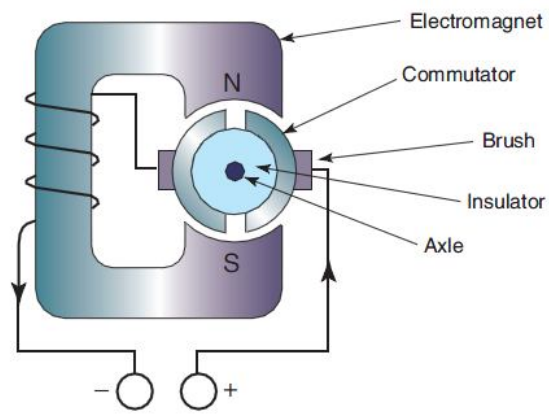
- identify that the required magnetic fields in DC motors can be produced either by current-carrying coils or permanent magnets



A simplified single-turn DC motor consists of several parts:

- A **source of emf** and an external circuit with resistors if necessary allow a current to flow in the internal circuit.
- A **split-ring commutator** can reverse the direction of the current flowing through the motor, as necessary. The split metal ring acts as the conducting metal pieces of the commutator. Each part is connected to either ends of the coil and also in contact with a carbon brush, connecting it to the conventional external circuit described above.
- The **coils** are wound around the **armature**, usually made of ferromagnetic materials. This is known together as the rotor as the armature and coil are free to rotate on an axle. The axle protrudes from the casing, enabling movements of the coil to do work. Current from the emf source flows through the coils. The number of turns of coils can be increased to increase torque.
- **Stationary magnets** provide an external magnetic field within which the armature coils rotate. These magnets are generally fixed to the casing as stators and in the form of a pair of permanent magnets (i.e. left), or a pair of electromagnets (with soft iron core and current carrying coils, below). The same electricity that runs through the armature coils can be used in the electromagnetic coils.



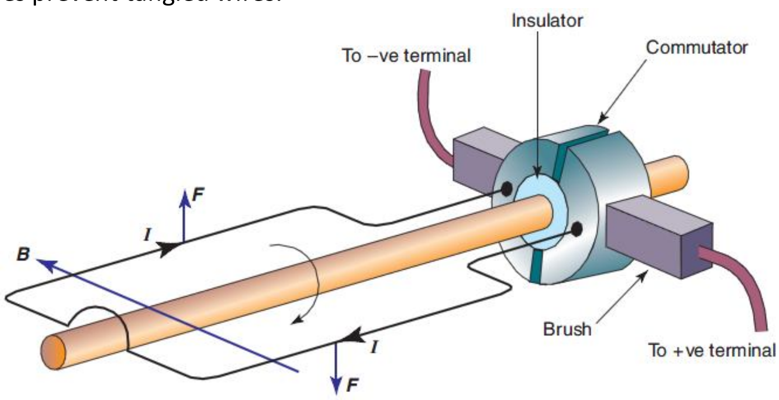


Current carrying armature coils experience a force in the external magnetic field, producing torque and hence rotational kinetic energy. The force on the sides of the coil is perpendicular to the magnetic field and calculated using $F = nBI\ell\sin\theta$ if the coil has *n* turns of wire, since these sides will experience a force *n* times greater.

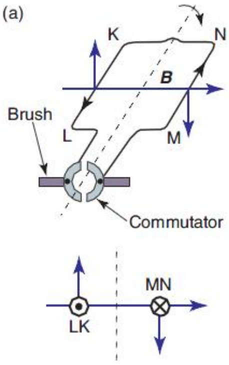
And hence we can also we can calculate the torque using $\tau = nBIA\cos\theta$.
But as previously mentioned, DC is only in one direction and the direction of the force on the rotor would be such that there is no net rotation, the coil potentially rocks back and forth.

But with the split-ring commutator, terminals to which each conducting surface of the split ring is in contact with changes, thus reversing the direction of the current every half a turn. It is set up such that the current direction changes whenever the torque falls to zero. This keeps the torque and hence rotation in one direction.

Graphite brushes are used as it conducts electricity while being a dry lubricant, also brushes prevent tangled wires.



(a)



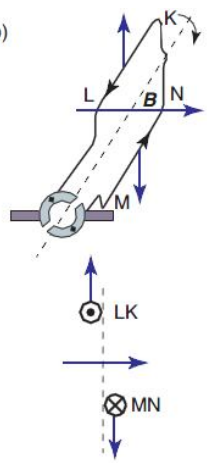
A simple DC motor can undergo rotation as commutator reverses the direction of the current.
We see first in (a) that when the plane of the coil is parallel to the direction of the magnetic field, hence the force will be perpendicular to the plane of the coil. The torque is at maximum. In this case, the direction of the current will result in a clockwise rotation of the coil. LK has a force upwards).

The torque will decrease in magnitude and approach zero as it becomes almost perpendicular to the direction of the magnetic field in (b). The momentum of the coil keeps it rotating even though the torque is very little.

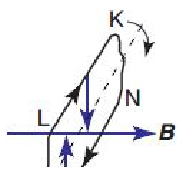
Just after this position [i.e. in (c)], the commutator changes the direction of the current and the force acting on both sides is reversed. I.e. side LK is now downwards and MN is now upwards. It is the momentum of the coil and the changing of direction of forces due to the change in current by the commutator which continues the coil's clockwise rotation as the torque increases to its maximum value in (d).

Then the cycle will repeat with torque approaching zero

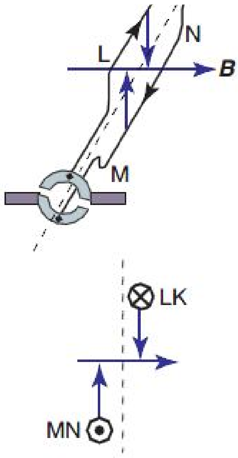
(b)



(c)

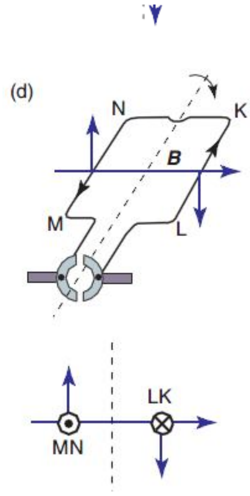


(d)



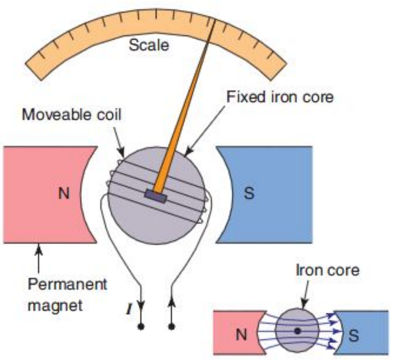
clockwise rotation as the torque increases to its maximum value in (d).

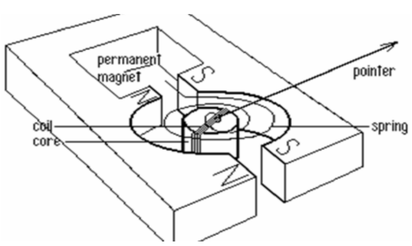
Then the cycle will repeat with torque approaching zero as the plane of the coil is almost perpendicular to the direction of the magnetic field. Momentum would keep the coil to rotate until just after it becomes perpendicular, the commutator changes the direction of the current. Momentum of the coil and the current direction change would again cause the coil to continue to rotate clockwise, etc.



Part	Description	Function
Stator - Pair of magnets	Pair of fixed magnets - either permanent or electromagnetic	Provides external magnetic field in which armature coils rotate
Rotor - Armature and coil	The rotor consists of many wires (coils) that are wound onto the frame (armature).	Creates rotational kinetic energy from torque. Increased no. of coils increases torque produced.
External circuit	Conventional DC circuit with emf source ending with graphite brushes in contact with conducting surface of commutator.	Provides emf which drives current through the armature coils.
Split ring commutator/Brushes	Split ring commutator provides conducting surfaces each in contact with graphite brushes connected to emf source Graphite bushes as it's a dry lubricant, reducing friction, high melting point (withstand high temp), and conducts electricity despite being non-metal, ensuring flow of electricity.	Rotation is in one direction, prevents tangled wires.

identify data sources, gather and process information to qualitatively describe the application of the motor effect in:
- the galvanometer
- the loudspeaker





Galvanometer

A galvanometer indicates the magnitude and direction of DC current passing through a particular point, using the motor effect to measure the magnitude. It is composed of a reading meter (scale), a needle with recoil spring to a wire wound into a coil around a soft iron core. The iron core and coil is suspended in an external magnetic field provided by a permanent magnet whose pole faces are curved around the coil. This ensures that the magnetic field is parallel to the plane of the coil and is relatively uniform within the coil's range of rotation. (*Also allowing the scale to be linear*)

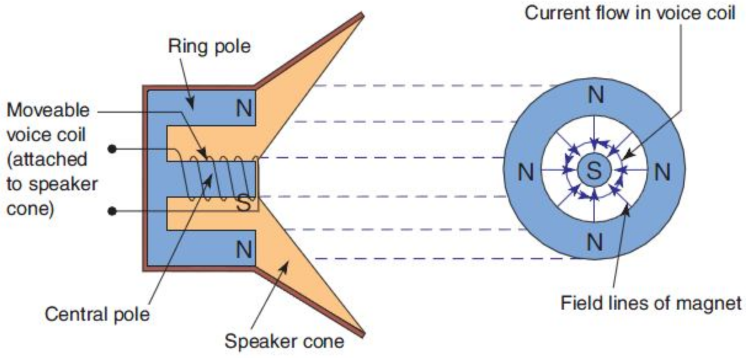
The coil consists of many loops of wire, and connected in series with the rest of the circuit. When current flows through the coil, the coil experiences a force due to the presence of the external magnetic field (motor effect). *The coil's iron core increases the force, allowing for more precise readings*. The force causes the needle to rotate until it is balanced by the counteracting force of the spring. Magnitude of the force, and hence degree of deflection depends on the amount of current through the coil.

The scale is previously calibrated to be accurate.

Loudspeaker

A loudspeaker is a sound producing device that converts electrical energy into sound energy. It consists of a circular magnet with north and south poles, within which is mounted a moveable coil. The coil is connected to an amplifier that produces an alternate current. When the current flows through the coil, it experiences a force as the coil is in an external magnetic field (motor effect). Thus the coils vibrate back and forth depending on the direction of the current.

But as the input current is an AC source, the coil which is attached to a paper cone vibrates sinusoidically, producing the longitudinal sound waves we hear. The higher the magnitude of the current, the more the coil moves, the greater the paper cone vibrates and the stronger the sound.



(a) Side view

(b) End view, showing that the field lines of the permanent magnet are always perpendicular to the current in the coil

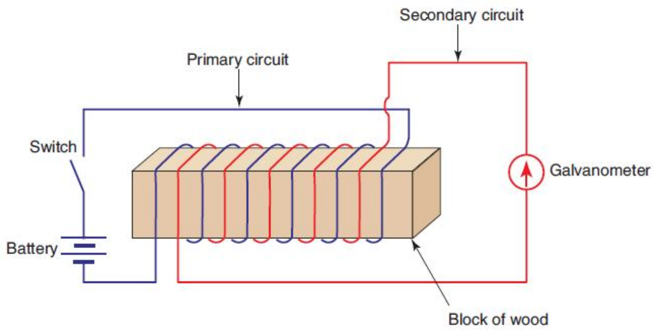
As on the left, a anticlockwise current flowing in the coil causes the coils to move out of the page.

2. The Relative Motion Between a Conductor and Magnetic Field is used to generate an electrical voltage.

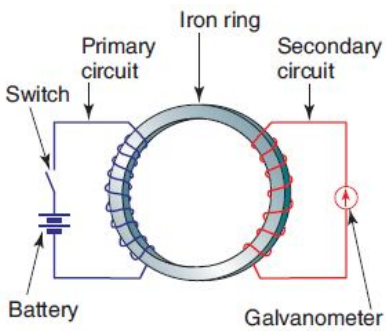
- outline Michael Faraday's discovery of the generation of an electric current by a moving magnet

Faraday was able to demonstrate the generation of an electrical current. This discovery of electromagnetic induction led to means of electricity generation today.

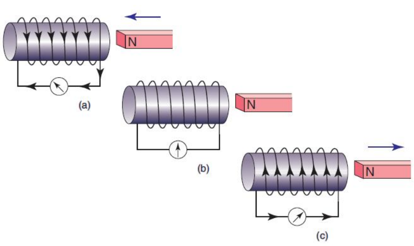
Initially, he wound 70m of copper wire around a piece of wood, and a second length wound between the gaps. The primary coil was connected in series to a battery and a switch, while the secondary circuit was connected to a galvanometer. When the switch was closed, a deflection was observed in the galvanometer, meaning a small current was detected in the secondary coil. When the switch was opened, a similar deflection in the opposite direction was detected. He emphasised that the current was temporary, only when there was a change in current through the primary circuit. There was no current when current was running, or when it was off.



The second experiment had the primary and secondary coils wound on either sides of a soft iron ring. Again the primary was connected to battery and switch and the secondary connected to a galvanometer. When the switch was closed, and current flowed through the primary coil, the galvanometer reacted rapidly, a greater deflection than if no iron core was present. Similarly, the needle soon came to rest and deflection was only registered when the current was turned on or off. He concluded that when the magnetic field of the primary coil was changing, a current is induced in the secondary coil.

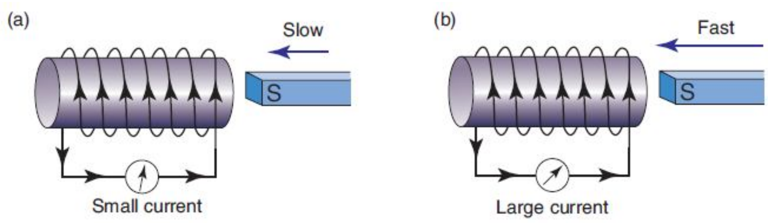


He was also able to demonstrate this by moving a magnet towards and then away from the end of a coil of wire. The coil forms a closed circuit with a galvanometer to detect any induced currents.



When the north of a magnet is brought near the end of the coil, the galvanometer needle initially registers a deflection, and then returns to the central position of the scale when the magnet is held without moving. But when the north of the magnet is brought away, the needle registers a deflection in the opposite direction. This indicates that an induced current exists when the magnet is moving. When a south pole of the magnet is used instead, the needle is deflected in exactly the opposite direction as it would when the north of the magnet is used.

Faraday also discovered that the speed at which a magnet is brought near or taken away affects the magnitude of the induced current. If the magnet moves quickly, the induced current has a greater magnitude, seen by a greater deflection of the galvanometer needle. Hence a moving magnet near a coil can generate an induced current.



Subsequently, Faraday attached two wires to a sliding contact touching a rotating copper disk located between poles of a horseshoe magnet. As the disk rotated, a current was induced producing a crude DC electric generator.

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

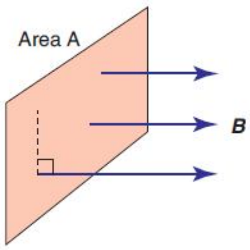
A electric current can be created either by moving the magnet towards or away from the end of a coil. Alternatively, the magnet can be held still and the end of the coil can be moved towards and away from the end of the magnet. The same effect is produced.

The magnet can be inserted into the end of the coil but it doesn't have to be, as long as it is moved towards or away from the end of the coil, the change in flux occurs in the coil and a current will be induced.

define magnetic field strength B as magnetic flux density

The strength of a magnetic field has so far been measured by a quantity known as a Tesla. This is also known as the magnetic flux density, i.e. the amount of magnetic flux passing through a unit area. A magnetic field can be represented by flux lines, where the closer they are, the greater the magnetic flux density. In the SI system, this is measured not only in Tesla, but also in Weber per square meter (Wb m^{-2}).

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



The closer the magnet is to the coil, the more flux threads the coil. An increase in strength of magnetic field changes the number of lines threading a coil.

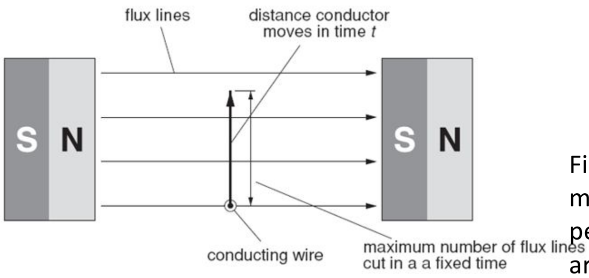
Consistent with a flow concept, of flux lines from the N pole spreading out and 'flowing' back to the S pole, the term magnetic flux is the name given to the amount of magnetic field passing through a given area, also denoted by Φ_B. This is measured in Weber (Wb) in the SI system. If perpendicular to a uniform magnetic field of strength B is an area, A, then the magnetic flux is the product of B and A. I.e.

$$\Phi_B = BA$$

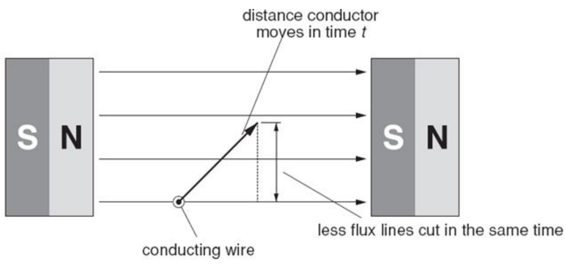
Sometimes, if the particular area is not perpendicular to the magnetic field, then the magnetic flux will be reduced. Hence the component of the magnetic flux density which is perpendicular to the area must be determined to find the magnetic flux through the given area. This is often denoted as:

$$\Phi_B = B_{\perp}A$$

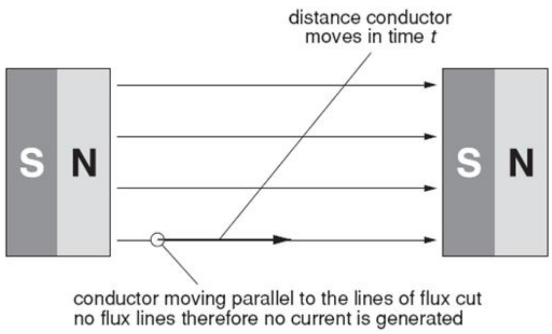
Where $B_{\perp}$ is the component of the magnetic flux density perpendicular to the area A. So $B_{\perp} = B \sin\theta$, where theta is the angle between the magnetic field and the surface area. Hence $\Phi_B = BA \sin\theta$



Firstly, the component of magnetic flux density is perpendicular to the surface area of the conductor.



Now, the component of magnetic flux density is at an angle to the surface area of the conductor. Hence the perpendicular component of magnetic flux density to the area A is less.



When the surface area is parallel to the magnetic field, there is no perpendicular component, no magnetic flux is generated as no flux lines are cut.

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

Electromagnetic induction is the creation of an emf in a conductor when it is in relative motion to a magnetic field, or in a changing magnetic field. Therefore, the effect is caused by change in the magnetic field strength (magnetic flux density - B).

Faraday knew that there must be a electromotive force (emf, E) for there to be a current flowing through the galvanometer in his experiment. Faraday noted that it was the change in the amount of magnetic flux threading the coil in the galvanometer circuit which produced the emf. More specifically, it was the rate at which the magnetic flux changes ($\Delta\Phi_B$) determines the magnitude of the generated emf. (i.e. the faster the relative movement, the greater the induced current).

This can be summed up with Faraday's Law of Induction:
The induced emf in a circuit is equal in magnitude to the rate at which the magnetic flux through the circuit is changing with time. Written in an equation as:

$$\varepsilon = -\frac{\Delta\Phi_B}{\Delta t}$$

Where $\Delta\Phi_B = \Phi_{Bfinal} - \Phi_{Binitial.}$ And the negative sign indicates that the the induced emf is in the opposite direction. (given by Lenz's law later).

Furthermore, if a coil has n turns of wire on it, a change in the magnetic flux threading the coil would induce an emf n times greater than that produced if the coil had only one turn of wire.

Hence, we see that:

$$\varepsilon = -\frac{n\Delta\Phi}{\Delta\tau}$$

Where E is the induced emf in V, n is the number of coils, $\Delta\Phi_B$ is the change in magnetic flux, Δt is the change in time.

To increase the electromotive force, we can increase the number of coils, decreasing the time, or increase the change in magnetic flux by increasing the area of the coil, or magnetic flux density (since Φ_B=AB).

plan, choose equipment or resources for, and perform a first-hand investigation to predict and verify the effect on a generated electric current when:
- the distance between the coil and magnet is varied
- the strength of the magnet is varied
- the relative motion between the coil and the magnet is varied

A coil of about 500 turns is used, and a current of about 510 micro amps can be induced when a magnet is pushed in or pulled out of the coil.

Size of induced current increases when:
- Using a strong magnet
- Faster relative motion between magnet and coil (greater change in flux) Note it doesn't matter whether the coil is being moved closer to the magnet or vice versa.
- Having more turns in the coil. (i.e. 750 turns)

The greatest induced current is when the magnet is pushed into the coil very fast. The greater the distance the coil is from the magnet, the less effect moving the magnet will have.

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

AND

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

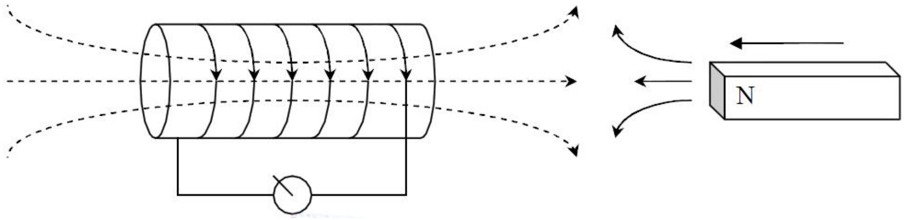
Lenz's law states that an induced emf always gives rise to a current that creates a magnetic field which opposes the original change in flux throughout the circuit.

This is in line with the law of conservation of energy because energy is neither created nor destroyed as some energy required to move a magnet towards or away from the coil is transformed into induced electrical energy in the coil.

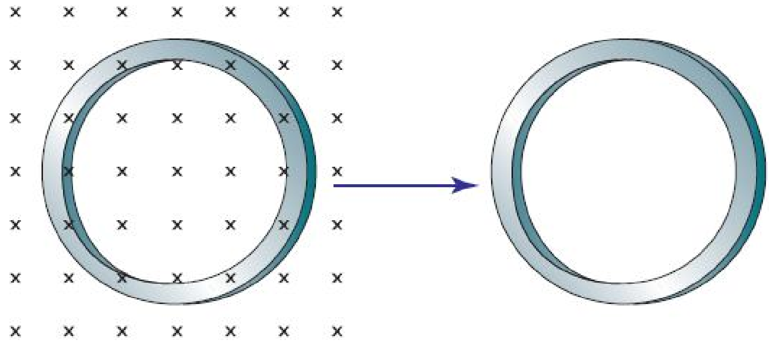
If the opposite of Lenz's law was true, then the changing flux in a coil would produce magnetic flux in the same direction as the original change of flux. The greater change in flux threading the coil in turn produces an even greater change in flux and the induced current would continue to increase in magnitude fed by its own changing flux. And creating energy without doing any work is impossible.

As seen in the below diagram, the induced magnetic field (dotted lines) oppose the change in flux caused by the moving magnet. Work is done in moving the magnet, and the kinetic energy of the magnet is transformed to the induced current flow (electrical energy).

Right hand coil rule can be applied to determine the direction of the induced current. Since the induced magnetic field has a north pole opposing the incoming north pole.



Another application of Lenz's law is when a metal ring moves out of a magnetic field, decreasing total field density. Induced current occurs so to retain the number of field lines passing through (right hand coil rule). Below, the induced current is clockwise when the ring is removed from the magnetic field.



Lenz's law explains the production of back emf in an electrical motor. Electric motors uses input voltage applied to the coils, causing them to rotate in an external magnetic field (motor effect). As the amount of magnetic flux threading the coil is constantly changing as the coil rotates, an emf is induced in the coils. By Lenz's law, this induced emf is in the opposite direction to the external supply emf. It is known as back emf, as it is in the opposite direction to supply emf.

The net voltage across the coil would equal the supply emf (or input voltage) minus the back emf. The magnitude of the back emf is proportional to the speed of armature rotation. Initially, back emf is zero, and current passing coil is maximum.

If there's no load on the motor to slow it down (and ignoring minimal friction effects), as the speed of coil rotation increases, back emf also increases until the back emf equals the external emf. At this point, there is no voltage over the coil, hence no net force acts on the coil, and so the armature rotates at a constant rate.

Upon the addition of a load, the coil rotates at a slower rate, less back emf is produced and net voltage across the coil is higher. And as the coil has a fixed resistance value, hence more current flows through the armature coil, resulting in increased torque to match the extra load.

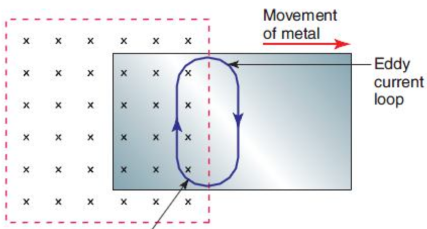
If motors are overloaded, it rotates too slowly, and does not produce sufficient back emf, current through armature coils is too high, causing the motor to burn out.

When motors switched on, they are usually protected from the initial high currents produced when the speed is still low and where there is little back emf. <see problem on left> A protective mechanism can be a series resistor which is turned off at high speeds.

I.e. A motor with an armature winding resistance of 10 Ohms is connected to a 240V supply. At normal load, back emf is equal to 232V. What is the current passing through the motor when it is operating initially, and then normally?

[Sol] Initially, V=240V, R = 10 Ohms
I = V/R = 240/10 = 24A
Normally, net emf = 240-232 = 8V
I = V/R = 8/10 = 0.8A

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



The eddy current loop can be explained in terms of the right-hand rule.

Eddy currents are closed loop currents which are induced in a conductor when it is in relative motion to a magnetic field. (i.e. the conductor is stationary in a changing magnetic field, or when it is moving through an external magnetic field.) Since eddy currents are closed loop currents, they form circular or whirling currents and produces its own magnetic field.

Being an application of Lenz's law the direction of the magnetic fields produced by Eddy currents oppose the changes of magnetic flux in the region of metallic objects (i.e. polarity of magnetic field set up by eddy currents oppose the relative motion of the object within the magnetic field which induced the eddy current).

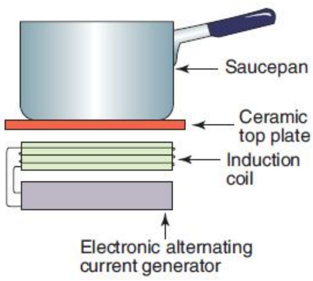
For instance, with the picture on the left, applying the right hand palm rule on the left edge of the magnetic field gives the direction of the eddy current (since direction of force is to the left, opposing the movement). Particles to the right of the magnetic field are not moving relative to the field, experiencing no force. The accumulated positive charge from the left is free to follow a downward path, through a region outside magnetic influence, completing the closed loop current.

The eddy current loop inside the magnetic field experiences a force whose direction can be determined by the right hand push rule. The direction of the force is opposite the direction of motion of the sheet, confirmed by Lenz's law.

Metal detectors in airports has an oscillator producing an alternating current in a coil inducing eddy currents in metallic objects. These eddy currents place a load on the coils reducing oscillator frequency, and when the frequency falls below a certain threshold value, it switches on the alarm circuit through the relay. (small loads won't reduce frequency below threshold value)

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

Eddy currents cause an increase in the temperature of the metals due to collisions between moving charges and the atoms of the metal, as well as agitation of atoms by a magnetic field changing direction at high frequency.



A gas stove is inefficient as it burns gas to produce heat, a large amount of heat is carried away to the environment. Cooktops with induction coils use AC current to set up rapidly changing magnetic fields. The field lines cut the metal of the saucepan, inducing eddy current in the saucepan. Since currents in the coils are very large, these eddy currents are very large, and as the metal pot isn't a perfect electrical conductor, it has resistance, <left> which causes the pot (and only the pot) to heat up. Heat energy is transferred from the pot to the food inside the pot by conduction.

Pots of ferromagnetic metals with significant resistance such as cast iron and some stainless steels works the best. It doesn't work with good conductors (i.e. Cu, Al) or non-conducting pots (i.e. glass).

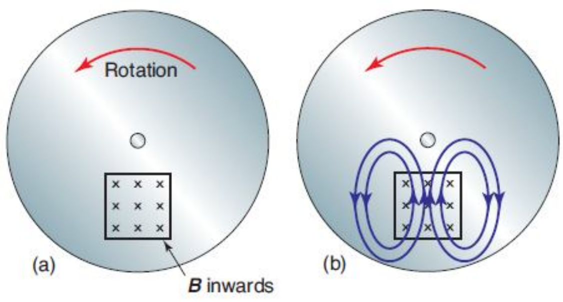
The cooking surface is not heated other than by heat lost from the pot. It is a good insulator (i.e. ceramic material) and ensures little heat is transferred from the pot to the surface (less wasted energy). Normally, the cooking surface is only marginally hot, decreasing chance of accidental burns, allowing direct contact with minimised harm. Also since no heat is lost to the air directly from the cooker, the kitchen is cooler. There is also no time-lag associated with conventional cooktops, hence there's more complete control over temperatures. Therefore, induction cookers are faster and twice as efficient than traditional heating element cookers.

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

Eddy currents can be used in smooth braking devices in trams and trains. An electromagnet is switched on so that an external magnetic field affects a part of the metal wheel. The wheel, (essentially a rotating flat conductor) is in relative motion to this magnetic field and experiences a change in flux as it cuts magnetic field lines. Hence eddy currents are generated in the disk. These eddy currents have their own magnetic field which oppose the original magnetic field (Lenz's law). This results in the motion of the wheel being opposed and it will slow down, hence slowing the vehicle.

But since the strength of induced eddy currents is proportional to the speed of the vehicle, braking force reduces as the train slows, resulting in smooth braking.

This is also used in many free-fall amusement rides where smooth braking is important. Copper plates attached to the ride capsule passes between active electromagnets near the bottom.



3. Generators are used to provide large scale power production

- describe the main components of a generator

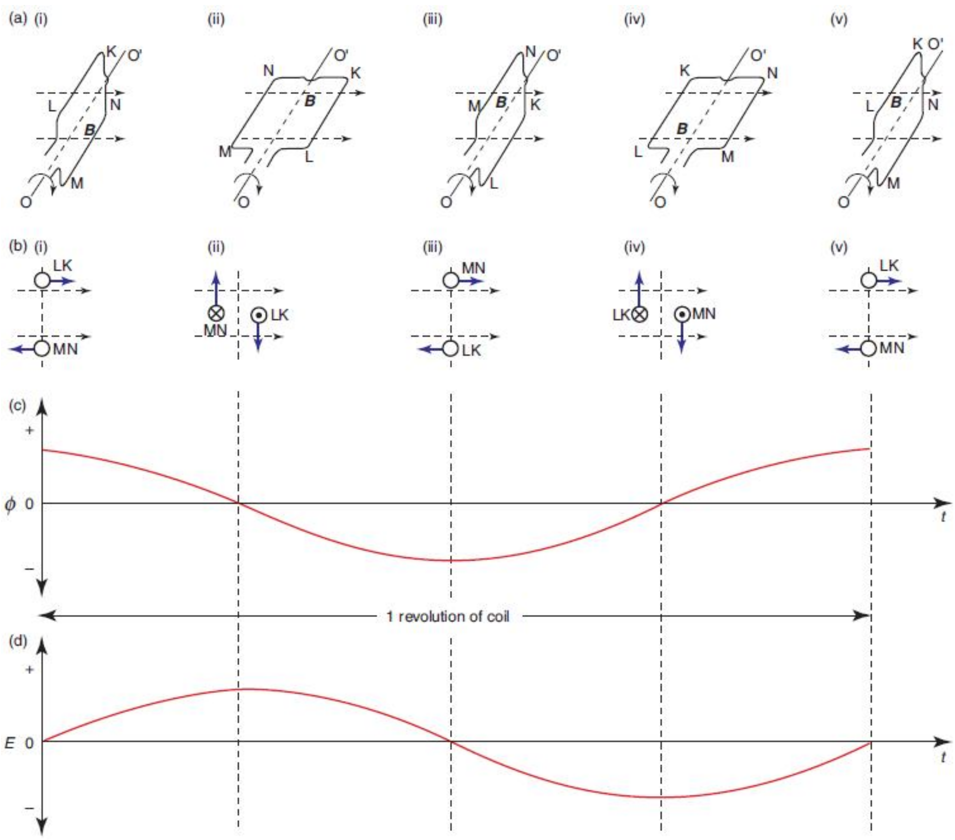
A generator is a device including all the elements necessary to transform mechanical kinetic energy into electrical energy according to Faraday's law.

Generators have a stator, which are the stationary functioning parts of a generator supplying the external magnetic field in which the coil rotates; consisting of either permanent magnets or electromagnets (coils of insulated wire wound around a soft iron core).

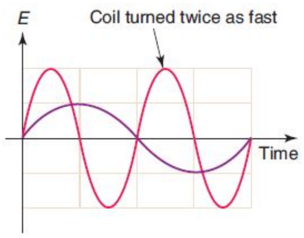
There is also the rotor which is the rotating part of the generator composed of several components. An armature which is a cylinder of laminated iron mounted on an axle is carried in bearings and rotates when torque is applied and on the armature is wound several coils of wires. This makes up the rotor.

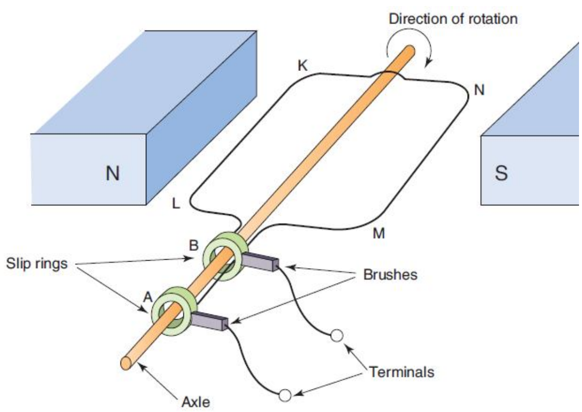
Graphite brushes maintain contact with the ends of coils via slip rings (AC) or commutators (DC generators) and conduct electricity from the coils to the external circuit via generator terminals.

Slip rings in AC generators allow current to pass from the coils to the brushes without tangling of wires. In DC generators, commutators are used, although they are also switching devices reversing the direction of the electric current every half cycle, maintaining the same current direction.

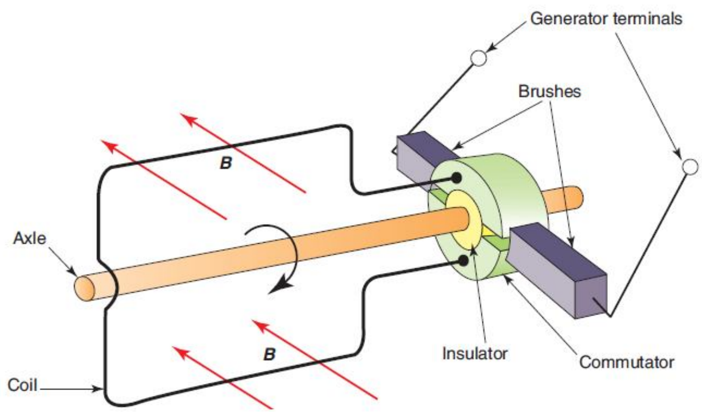


Sinusoidal waveform generated by an AC generator.





AC Generator



DC Generator (not sinusoidal - see comparison next page) compare the structure and function of a generator to an electric motor

Both a generator and an electric motor have a similar basic structure: a stator of permanent magnets or electromagnets can supply an external magnetic field while a rotor, a coil wound on a armature mounted on an axle, rotates in the external magnetic field. The coils are connected to an external circuit to the external circuit.

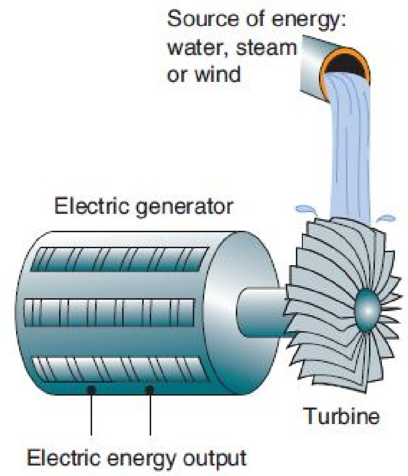
Emf is also generated in both devices (back emf for motors). And max torque, max emf in both devices are when the coil is parallel to the magnetic field, though for different reasons.

However, they vary in function i.e. generators transform electrical energy from kinetic energy while electric motors transform kinetic energy from electrical energy.

In a generator, kinetic energy acts on the coil, forcing it to rotate in a magnetic field at a constant rate. Since the flux threading the coil varies with time, it induces an emf according to Faraday's law. The emf through the coils is connected with generator terminals via slip rings (AC) or commutator (DC) to output electrical energy.

But in an DC electric motor, a source of emf (electrical energy) is provided, driving the current through the coil. It also has a commutator and the current through a conductor in an external magnetic field experiences a force (motor effect), and hence the coil rotates and does work on a load attached to the motor; i.e. converting electrical energy to mechanical kinetic energy. However, an AC induction motor works very differently as a changing magnetic field in the stator induces a current in the rotor.

In DC generators and motors the commutator also plays a different role. In a generator, it makes the direction of the current constant, but in a motor, it reverses the direction of the current which had constant direction.



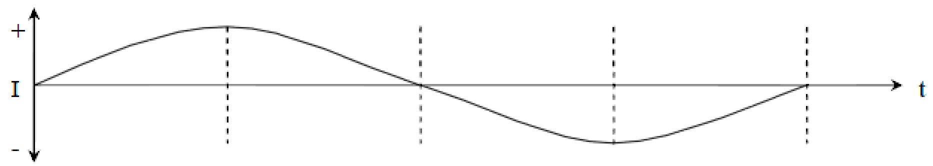
A generator turns a source of energy (i.e. kinetic) into electrical energy.

But the motor transforms electrical energy to kinetic energy to do work.

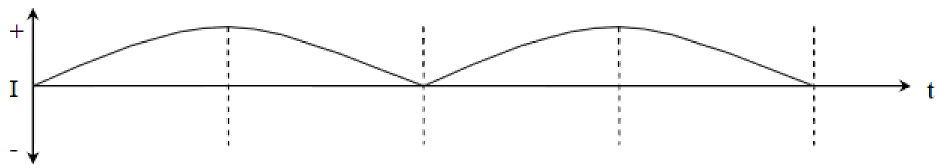
Although rotor and stator can be exchanged in some cases, most components remain fundamentally the same.

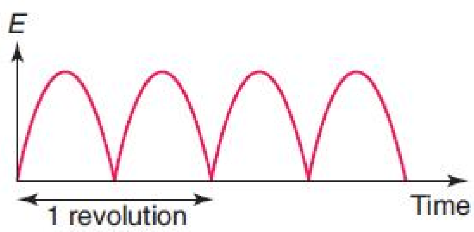
describe the differences between AC and DC generators

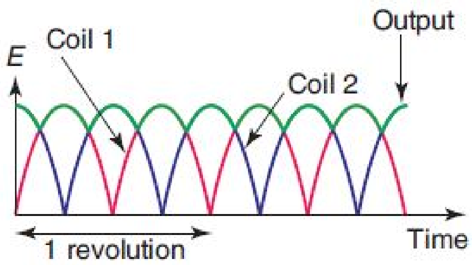
A generator produces an emf varying like a sine wave, hence periodically varying in direction. In AC generators, slip rings are used to connect the rotating coil to brushes and then to terminals. These slip rings in AC generators maintain the variations in current direction producing an alternating current.



However, in DC generators, a commutator is used instead of a slip ring. The commutator is composed of a split ring each of which connected to one end of the coil, and each in contact with a brush connected to a terminal. Acting as a switching device for reversing the direction of the electric current every half cycle, the commutator keeps the current a constant direction, i.e. producing a DC current.

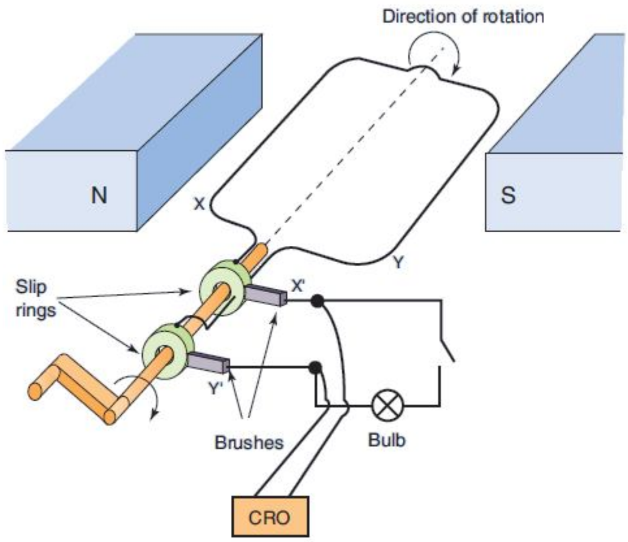






Comparing the output of a one coil and two coil DC generator, it can be seen that the 2 coil DC generator has a more steady DC.

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



Aim: To observe the output of an AC generator using a cathode ray oscilloscope and comparing differences in output resulting from different rotation speeds.

A hand operated AC generator is connected to a cathode ray oscilloscope (CRO). Turn the handle slowly, and note the pattern of the wave detected by the CRO. Now turn the handle fast and note the waveform pattern.

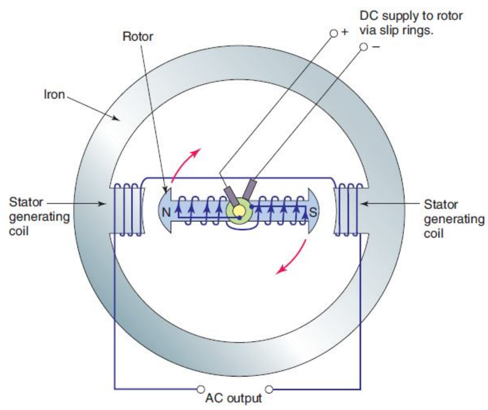
Alternatively, a light-bulb and switch can be connected to the AC generator. Close the switch, turn the handle slowly and observe the light bulb. Then turn the handle faster and comment on the intensity of light.

Here, the handle turns the coil within an external magnetic field. Since there are slip rings, this consequently produces an alternating current, clearly seen by the sinusoidal pattern observed on the CRO. The faster the handle is turned, the more flux threads the coil and more emf is generated. Therefore, the amplitude of the waveform on the CRO increases.

With the light bulb, the faster rotation and greater emf is seen with brighter light emitted, demonstrating variations in AC output at different rotation speeds.

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

DC brushes can be easily worn out, requiring high maintenance.



Rotor and stator can be exchanged in AC, with easier fixed connections and no slip rings or commutator required.

AC and DC generators differ in features, the most prominent being the use of slip rings in AC generators maintaining a current alternating in direction (alternating current - AC), while split ring commutators are used in DC generators to switch the direction every half cycle to keep the current in one direction (direct current - DC).

From maintenance point of view, since in AC generators, slip rings are continuous smooth surfaces which allow for graphite brushes to remain in constant contact. The smooth surface means that brushes in AC generators are advantageous as they do not wear as fast. In contrast, DC generators have split ring commutators and brushes under spring pressure are constantly striking the leading edge of successive ring segments. Hence, DC generators need to have their brushes constantly replaced.

Furthermore, pieces of metal from commutator segments can become lodged in gaps, causing a short and reduction in generator output whereas in AC generators slip rings are already continuous and this cannot happen. Hence, maintenance wise, AC generators require less maintenance and are more reliable than DC generators.

DC generators face a limitation where the output current must be induced in the rotor. Hence, the larger the current required, the larger and heavier the rotor coils, placing strains on bearings and support structures.

However, AC generators are advantageous as the roles of stator and rotor can be exchanged, with current induced in the stator windings while a rotor provides the external magnetic field through permanent magnets or in large applications, electromagnets (i.e. in power stations). Not only does this mean that drawing higher current from the stator in AC generators is also easier as it is a fixed connection, but stationary connection also means that there is no wear as slip rings aren't required

While in DC generators, drawing high currents through commutator-brush connections increase instances of electric arcs forming as brushes break contact with each split ring segment, reducing generator efficiency. Hence, AC generators are more advantageous for larger applications with higher current demands than DC generators.

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

The initial years of electrical distribution saw intense competition between DC and AC power. Edison General Electric promoted direct current (DC) which was the standard in those days. DC generators (aka dynamos) used a commutator to give a DC output. However, since DC can only be generated and distributed at the voltage used by consumers, Edison produced electricity at those voltages (110V) and this resulted in a large current through conductors (P=IV) which meant power losses over one mile was excessive and expensive.

Power loss is measured by I^2R, and since DC cannot be easily transformed, Edison's only alternative was to decrease the resistance to minimise power loss. Hence Edison relied on thick copper wiring with low resistance. Power supply for a large city using DC required proliferation of power stations and copper wiring. Furthermore, there were problems with commutators at high speeds in steam driven generators.

However, Westinghouse overcame the problems faced by Edison after purchasing patent rights for Tesla's AC generator and AC transmission system. Unlike DC, AC voltage could be stepped up and down easily using transformers. This means that although electricity is generated at relatively low voltages , the voltage during transmission can be stepped up, so that current through the conductor is lower (P=IV). Since power loss is I^2R, then power loss is significantly reduced by the square of the factor the current was lowered. At the consumer's side, the voltage is again stepped down for consumption. Hence Westinghouse's AC system allows for great distance transmission with smaller energy losses, meaning power stations can be fewer in number, can be built further from cities, with no need for heavy sophisticated copper wiring networks.

The competition was intense because DC worked well with the principal load of those days (light bulbs and motors) and many of Edison's inventions worked on DC only. Despite AC's advantages of long distance transmission, AC was initially unable to operate motors. Furthermore, Edison wrote books and ran campaigns promoting the dangers of AC, electrocuting animals, providing electric chairs for prisons, etc. But Tesla's induction motor popularised AC, and finally the competition to design a system to provide electricity to Buffalo from a Niagara Falls power plant 30km away saw Westinghouse win the contract with an AC system. This turning point later caused the proliferation of AC systems.

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

Today, power stations are situated far from cities where consumers are located. Increasing resistance of metallic transmission conductors over longer distances means heat is generated in transmission lines from resistive energy loss. If electricity is transmitted at a low voltage, the conductor will have a high current (P=IV). And since power loss is given by $P_{loss}=I^2R$, a high current means larger energy loss. Furthermore, the line experiences a voltage drop when carrying a large current (V=IR). This can greatly reduce the voltage available to consumers.

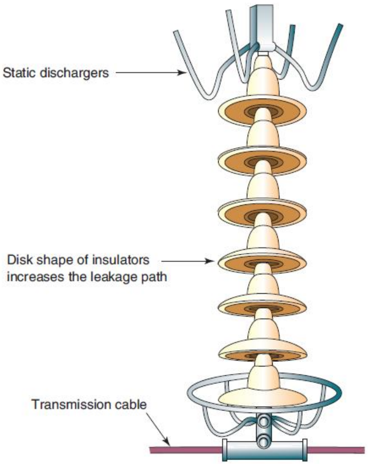
For instance, if a 10km transmission line has a resistance of 0.40Ω, and electricity with voltage 240V and power of 120kW is sent through this line from a power station to a town. Then we can determine: 1.The current through the line, and 2.Voltage drop across the transmission lines, 3. Voltage available in town, and 4. Power loss in transmission lines.
[Sol] 1. Using P=IV, with P=120000W, and V=240V, then I=P/V=120000/240=500A
2. Using V=IR, with I=500A, R=0.40Ω, V=500x0.40=200V, therefore, Voltage drop is 200V.
3. $V_{town}=V_{station}-V_{lines}$, therefore, V_{town}=240-200=40V, therefore, the town has 40V of voltage available.
4. $P_{loss}=I^2R$, therefore, $P_{loss}=(500)^2$x0.40=100000W

With long distances, resistance of the transmission line increases. As R=ρℓ/A
Where R is the resistance, ρ is the resistivity, ℓ is the length of the conductor, A is the area of the cross section.

As seen on left, resistance increases with distance, and from the above example, there is significant power loss occurring, and less voltage available to the town. However, since $P_{loss}=I^2R$, if the current is halved, power loss is reduced by a factor of four. I.e. power loss is reduced by the square of the factor the current is lessened. Therefore, using transformers to increase the voltage of AC, current decreases (inversely proportional, P=IV). Therefore, power losses through transmission lines can be minimised by the use of transformers to step up voltage and transmitting electricity at the highest practicable voltage reduces current and hence minimising power loss.

Also, careful choice of transmission line materials can also reduce power loss during transmission (as $P_{loss}=I^2R$). Hence transmission lines are typically made of copper or aluminium with low resistivity.

gather and analyse information to identify how transmission lines are:
- insulated from supporting structures
- protected from lightning strikes



Insulation

Transmission lines must be sufficiently insulated from its supporting structure to prevent sparks jumping from one to the other. In dry air, sparks can jump up to 33cm from a 330kV line, jumping larger distances with greater potential difference. Hence, in high voltage power lines, ceramic or rubber disk shaped insulators are strong and are non-conductors, hence having high insulating properties. The disk shape not only increases the distance across the surface that a current must pass over, but it also sheds water and prevents dust build-up, since either moisture or dust can make conductive paths across the insulator surface. These disks can form segments of a link when insulators can be joined together, further distancing the transmission cable from the structure. A longer pathway reduces the chance of sparks and higher voltages require greater distances of separation. Cores of non-conducting fibre-glass in these links ensures there's no continuity of conduction through the insulator.

Lightning strikes

Thunderclouds discharge lightning to the highest point on the Earth below, hence tall transmission towers are prone to lightning strikes. The metal tower acts as a conductor and is well earthed as it stands on metal with a large surface area buried beneath the ground. This allows charge from lightning strikes to easily dissipate and conveys it harmlessly to the ground. There are also overhead earth lines (or shield conductors) carrying no current and are not insulated from the tower structure. Since earth lines are positioned higher, they prevent lightning strikes to the lower transmission wires. When lightning strikes earth lines, the line neutralises charge build up as current is conveyed directly to the structure and then the ground. Towers are also widely spaced to ensure that if one tower is struck, surrounding towers suffer no damage.

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

A New York City blackout in 2003, exposing society's dependence on electricity.

AC generators has provided AC electricity for society, and the increased ability to use AC appliances (e.g. washing machines, dishwashers, etc.) has increased leisure times and improved living standards (e.g. fridge). However, more entertainment options (e.g. video games) has contributed to a more sedentary lifestyle also with loss of social contact. Automation of systems (e.g. banking, stock market) has been possible with computer systems dependent on AC electricity. Similarly dependent are health technologies improving living standards. Improved lighting also allows people to have more leisure time or work longer and street lighting increases security. However, reliance on electricity leaves society vulnerable to electrical failure.

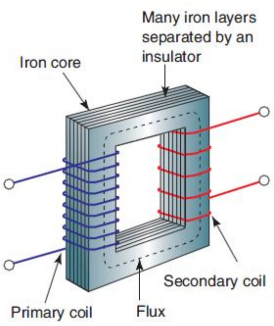
Environmentally, newer electricity dependent technologies have replaced older polluting technologies (e.g. light bulbs and electric heating in place of kerosene lamps and fireplaces). Electrified transport networks has also reduced pollution (i.e. from steam trains). However, AC generators usually produce electricity via environmentally damaging processes, e.g. burning coal releases CO_2 and nuclear waste contaminates the environment. And mining for these resources (e.g. coal, uranium) is environmentally damaging. Chance of nuclear meltdown is also potentially catastrophic. Hydroelectric dams redirect water and displace wildlife and towns. Visual pollution of power cables and clean AC generators (e.g. wind farms) is also a concern.

AC generators has yielded a plethora of devices and applications dependent on AC electricity which benefits society. However, society's dependence on electricity and exploitation of natural resources must be addressed to avoid problems with over-dependence and ecological sustainability.

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

David Lin
Mr Ogle

describe the purpose of transformers in electrical circuits



In electric circuits, a transformer is a device, composed of two insulated multi-turn coils wound onto a common core, that increase or decrease AC voltages. Hence an alternating current in the primary coil induces a varying magnetic flux in the transformer's core and hence a varying magnetic flux threads the secondary coil. This varying magnetic flux threading the secondary coil produces an AC current at the terminals of the secondary coil corresponding with the same frequency as the AC voltage supplied to the primary coil terminals.

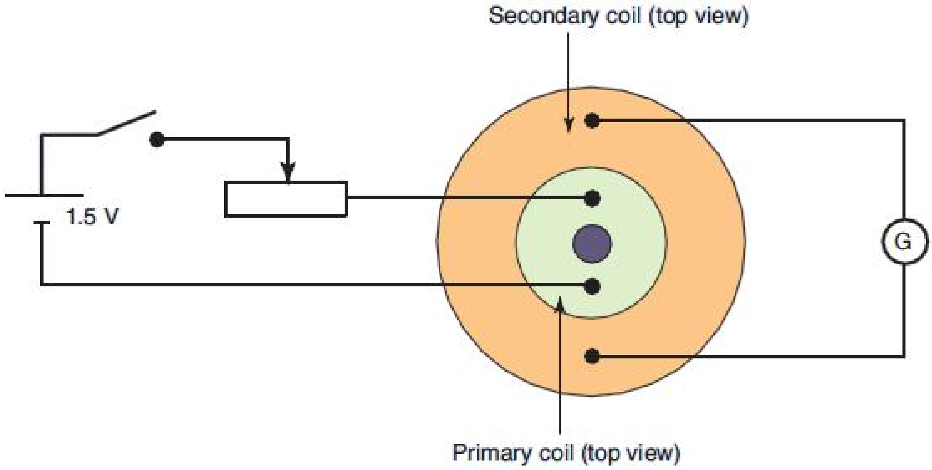
This allows devices which require voltages well below or above the supply voltage to be run. For instance, a 24V device (e.g. semi-conductor) or a 1500V device (e.g. CRT TV) to run on a 240V AC power supply.

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

Have two coils with different numbers of turns, one coil fitting inside the other. Now, connect the external source of DC current to the inner coil (primary), and a galvanometer to the external coil (secondary). Connect a switch and variable resistor in series in the primary coil. Set the variable resistor to its lowest setting.

Now, turn on the DC power supply and close the switch, observe the initial deflection on the galvanometer. Close the switch and change the value of variable resistor slowly and rapidly. Open the switch, and record results.

We can see that there is only a current induced in the secondary coil if there is a changing magnetic flux threading the first coil. Otherwise, no current is induced.



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

The magnitude of secondary core voltage can be higher or lower than that in the primary coil and is dependent on the number of turns of wire on the primary coil, n_p, and secondary coil, n_s.

In an ideal transformer, the rate of change of flux *($\Delta\Phi/\Delta t$)* is the same through both coils. And using Faraday's law, voltage in the secondary coil (V_s) can be found by:

$$V_s = n_s \frac{\Delta\Phi}{\Delta t}$$

And similarly voltage through the primary coil (V_p) can be found by:

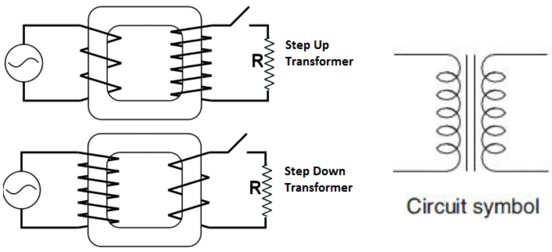
$$V_p = n_p \frac{\Delta\Phi}{\Delta t}$$

Equating these two equations produces the equation:

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

This equation illustrates that the ratio of the voltage through the primary coil and the secondary coil is equal to the ratio of the number of turns in the primary coil and secondary coil.

- compare step-up and step-down transformers



A step up transformer is such that the output voltage, V_s, is greater than the input voltage, V_p. I.e. the number of turns in the secondary coil, n_s, is greater than the number of turns in the primary coil, n_p.
Conversely, a step down transformer is such that the output voltage, V_s, is less than the input voltage, V_p. I.e. the number of turns in the secondary coil, n_s, is less than the number of turns in the primary coil, n_p.
A power station would use a step up transformer to increase the voltage and (reduce the current) for long distance transmission. While a substation would use a step down generator to reduce the voltage for consumer use.
Note: Diagram on left does not depict transformers in proper circuit diagram form.

- explain why voltage transformations are related to conservation of energy

When voltage is stepped up or down, there isn't a gain or loss of energy from nowhere. The transformer equation is consistent with the principle of conservation of energy because during transformation, the supply of energy (i.e. power) in the primary coil is greater or equal to the supply of energy in the secondary coils. So if 100J of energy is supplied per second to the primary coil, the maximum energy that can be obtained in the second coil is 100J per second.
If the transformation is indeed ideal and no power loss takes place, then:
Power of primary (P_p) = Power of secondary (P_s)

$$\therefore V_p I_p = V_s I_s$$

$$\therefore \frac{V_p}{V_s} = \frac{I_s}{I_p}$$

$$\therefore \frac{V_p}{V_s} = \frac{n_p}{n_s} = \frac{I_s}{I_p}$$

However, in reality, the amount of useable energy that can be obtained in the second coil is less than the energy in the primary coil due to energy dissipated (usually as thermal energy due to occurrences of eddy currents in the iron core). The implications of this is that if voltage is stepped up, then current must be reduced, and vice versa is also usually true. (since P=IV)

- solve problems and analyse information about transformers using: $\frac{V_p}{V_s} = \frac{n_p}{n_s}$

For example, in a device, the transformer reduces 240V AC to 12.0V AC. If the secondary coil has 30turns and the device draws 500mA, then find:

a. The number of turns in the primary coil
b. The current in the primary coil
c. The power output of the transformer.

[Sol] a. Finding n_p, V_p=240V, V_s=12V, n_s=30

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

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

Therefore, n_p = (30x240)/12.0 = 600
Hence the primary coil has 600 turns.
b. Finding I_p, I_s=0.5A, n_s=30, n_p=600

$$\frac{I_s}{I_p} = \frac{n_p}{n_s}$$

$$I_p = \frac{I_s}{n_p} n_s$$

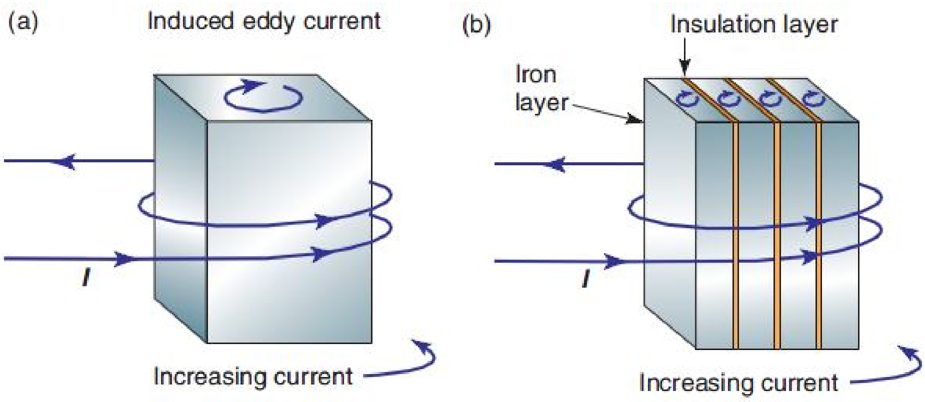
Therefore, I_p= (0.5x30)/600 = 0.025 A
c. Finding P_s, V_s=12.0V, I_s=0.5A
P_s= V_sxI_s = 12.0x0.5 = 6W

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

Eddy currents occur within a metal due to changing flux threading the metal. These induced current are circular in movement and at right angles to the direction of the changing flux.

In transformers, the iron core also experiences eddy currents, and unnecessary heat losses occur due to iron's high resistance to eddy currents. This heat represents a power loss to the circuit.

There are two solutions to this problem. One is by constructing a laminated iron core with many thin layers of iron pressed together separated by thin insulating layers. The insulating layers are perpendicular to the direction of the magnetic flux so the size of the eddy currents is greatly reduced to only one lamina rather than the whole core and hence heating effects are reduced.



Another approach is to make the core out of *ferrites* (complex oxides of iron and other metals). These materials transmit magnetic flux easily, but are poor conductors. Hence, eddy currents are also significantly reduced.

Overheating can not only damage transformers, but by heating up the coils, it increases their resistance, promoting further energy losses, decreasing transformer efficiency. To prevent this there are many ways to cool the transformer: i.e. increased ventilation, non conducting liquid medium such as oil and heat sink blades to increase surface area help increase heat dissipation to prevent transformer damage and lower efficiency.

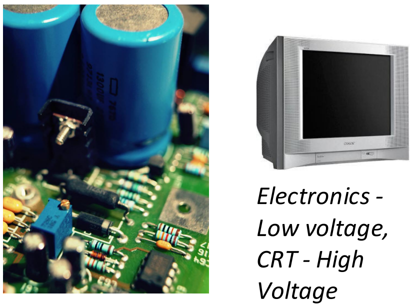
explain the role of transformers in electricity sub-stations

Over long distances, difficulties in power loss arise when transmitting electricity with low voltage. However, since power loss is measured by I^2R, step up transformers at the power station reduce the power loss by increasing the voltage (hence reducing the current, P=IV) during transmission.

Therefore, in the transmission lines, voltage can be as high as 330kV. But these voltages cannot be used by consumers as they are dangerous (sparks) and are much higher than the voltage used by consumer appliances.

The role of transformers in electricity sub-stations is to progressively step down the voltage as it approaches its point of use. Subsequent substations step down the voltage (from 330kV to 132kV, 66kV, etc) until city transformers (11kV) and finally local transformers (415/240V for industrial/consumer use). The output voltage at each stage of distribution is carefully chosen to balance transmission losses (i.e. current requirements) and energy demand over the distribution area.

discuss why some electrical appliances in the home that are connected to the mains domestic power supply use a transformer



Electronics - Low voltage, CRT - High Voltage

Electricity is supplied to households at 240V and many appliances are designed to run efficiently at this voltage (e.g. light bulbs, motors). These appliances have no need for a transformer and are connected directly to the mains domestic power supply. But devices designed to operate on lower voltages must contain a transformer built into the power supply unit to step down the voltage. For instance most electronics can only use low DC voltage and so they have a rectifier built into the transformer to convert AC to DC in addition to stepping down the voltage. Alternatively, some devices require high voltage AC, (i.e. CRT TVs require 25kV), and a step up transformer is required.

While other devices such as microwaves have components which run directly off the mains domestic power supply (turntable motor and microwave transducer), but other components run off low voltages (e.g. control and display panel units). Hence step down transformers are built-in for those low voltage components.

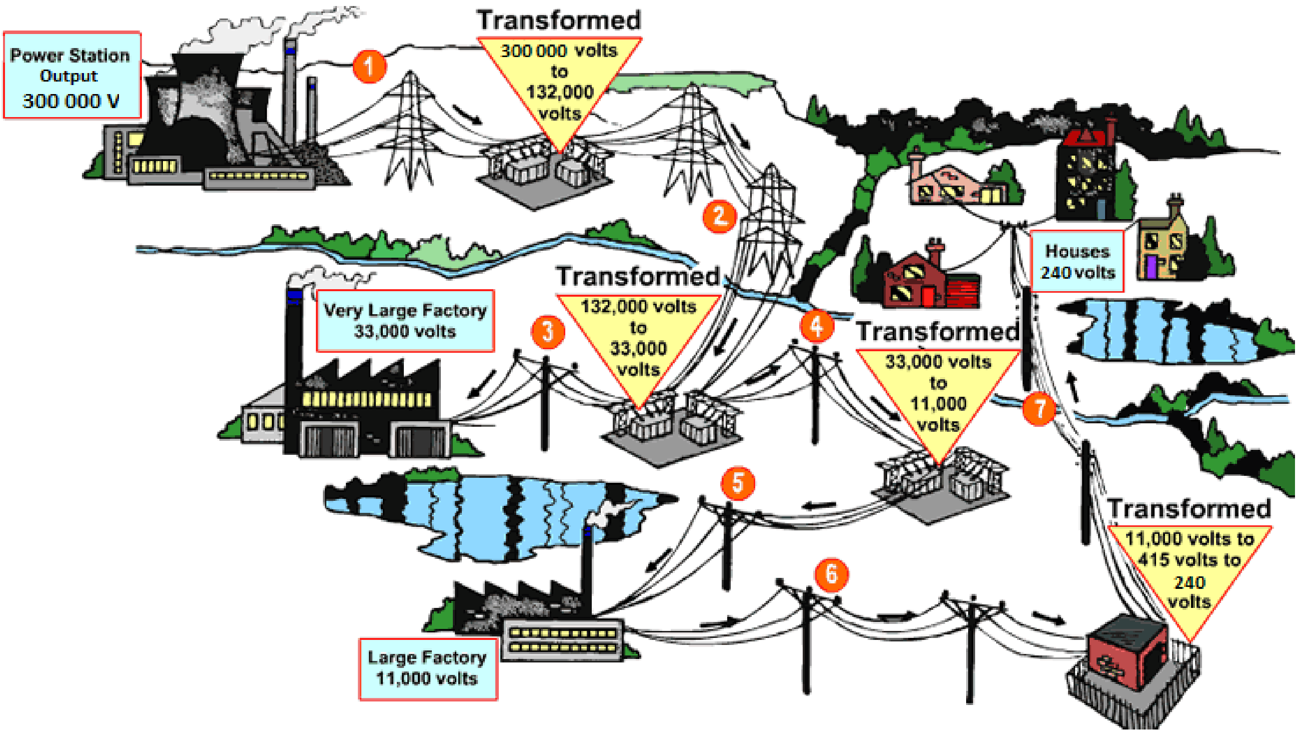
gather and analyse secondary information to discuss the need for transformers in the transfer of electrical energy from a power station to its point of use

Most devices in home and industry run at 240/415V respectively. Without transformers, electricity must be produced and transmitted at these low voltages (high currents). Hence, energy will be dissipated as heat energy due to high current ($P_{loss}=I^2R$), and power loss will be costly particularly over long distances. Hence, without transformers, this low voltage electricity can only be transmitted a few kilometres, and the number of power stations will multiply for a city with high electricity demands. Furthermore, if different voltages are needed, these must be produced at separate power stations and distributed via separate systems, further adding to the network of cables required.

Transformers used with AC electricity overcomes these issues. Firstly, it is more efficient to produce electricity at relatively high voltages (23kV) than at low voltages. Then the voltage of electricity produced by the power station can be stepped up prior to transmission. An even higher voltage (500 or 330kV) means a much lower current, and power loss is reduced by the square of the factor the current was reduced by (since $P_{loss}=I^2R$). This allows for long distance transmission with minimal energy loss.

But since electricity is consumed at low voltages, step down transformers are located at substations which progressively decrease the voltage: i.e. regional - 110kV, city - 33 or 11kV, until local pole mounted transformers step the voltage down to 240/415V at its point of use in households and industry.

This progressive stepping down process is carefully chosen at each stage of distribution to balance transmission losses (i.e. current requirements) and the energy demand over the distribution area.



- discuss the impact of the development of transformers on society

High Voltage AC can be stepped up by transformers for long distance transmission in high voltage transmission lines even across rural communities.

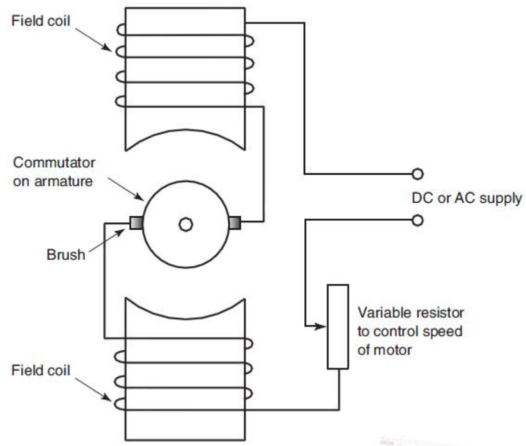
Transformers has allowed efficient long distance transmission of electrical energy by stepping up voltage (reducing current) to minimise power loss ($P_{loss}=I^2R$). Hence national power grids have been set up in almost every country, providing a convenient and flexible form of energy. Its increased accessibility means that remote communities can access grid-supplied electricity, and local transformers can step down the high voltage for consumer use. This raises living standards in these remote communities, with appliances such as fridges for food preservation, lighting for night security and air conditioning. Rural industries can also grow, and increase the scale of operations due to labour saving machinery dependent on electricity.

Furthermore, efficient long distance transmission of electricity has enabled power plants to be located remotely, closer to resources used in the production process (i.e. coal mines). Pollution from power generation is now away from residential areas. Furthermore, there is a decentralisation of industries since they no longer need to be clustered around the power station. Development of industrial areas away from residential zones further removes pollution from homes, but has increased travelling distances to workplaces.

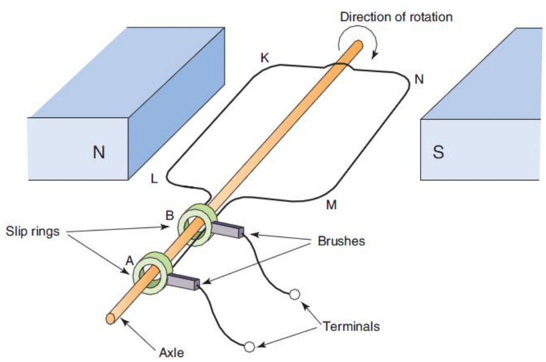
David Lin
Mr Ogle

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

- describe the main features of an AC electric motor



Universal Motor



Simple AC Motor, with terminals supplying an external source of emf.

Universal Motor

In an universal motor, single phase AC (as well as DC) can operate the motor. It's construction is similar to a DC motor with the external magnetic field provided by stators, namely electromagnets connected in series with the armature coils through brushes. The interaction between the current in the armature coils and the external magnetic field produces torque, rotating the rotor. Although current alternates once every half cycle (i.e. 100 times a second with 50Hz AC), the universal motor will continue to rotate in one direction as the magnetic field flux of the electromagnets are also changing direction 100 times a second. Hence the effects of changing AC current **and commutator cancels out?**

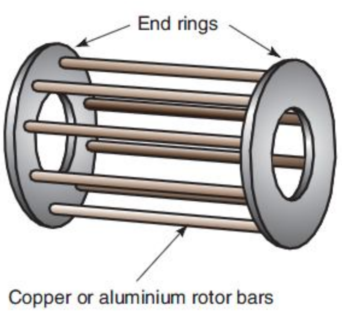
A variable resistor can be linked in series to the circuit controlling the speed of the universal motor by varying the current through the armature and field coils of electromagnets.

Simple AC Motor (synchronous motor)

Like DC motor, except slip rings are used in place of commutators. Stators (permanent or electromagnets powered by DC) provide an external magnetic field. Since the AC current reverses every half cycle, the motion must be synchronised so that the motor rotates at the same frequency as the supply frequency. A brief DC current may be needed to start the motor.

Single Phase AC Induction Motor

Used in most appliances, single phase AC motors have a single electromagnet fed by AC. The rotor consists of metal bars joined at ends which are perpendicular to the magnetic flux. The alternating magnetic field induces a current in the rotor bars and by Lenz's law, this current produces a magnetic field opposing the change in the electromagnet. Initially no torque is produced in the starting position so rotation of the rotor requires a manual push or a starting circuit. The direction of this start determines rotational direction as once the current induced is out of phase with the supply current, the magnetic field will exert a force on the rotor and cause it to rotate.

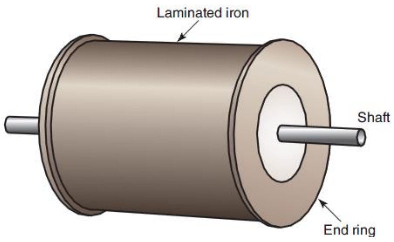


Above-Squirrel Cage Rotor
Below- with laminated iron

3 Phase AC Induction Motor

A three phase AC motor consists of a stator which consists of three pairs of coils with iron cores. Coils are paired on opposite sides of the stator, being linked electronically. Each of the three pairs of field coils is connected to a different phase of electricity supply and this produces a varying magnetic field inside the stator whose polarity rotates at the same frequency and direction as the mains supply (i.e. 50Hz, *the magnetic field rotating at the same rate the electromagnet in the power station generator is rotating with each pair of coils in the generator corresponding to a pair of coils in the stator of the motor.*)

The rotor consists of bars (aluminium or copper) attached to two rings resembling a squirrel-cage. The end rings allow a current flowing from one side of the bar to the other. This is encased in a laminated iron armature which intensifies the magnetic field threading the rotor cage conductors while lamination decreases heat energy dissipation due to eddy currents.



The armature is not connected to any external circuits, but is mounted on a shaft passing out the end of the motor while bearings reduce rotor friction and allow the armature to rotate freely in the external magnetic field. Hence, the induction motor has not commutators or brushes.

As the varying magnetic field threading the bar cage conductors rotates in the cylindrical space, the movement of the magnetic field is the same as the bars moving through a stationary magnetic field in the opposite direction. This induces a current in the bars, which by Lenz's law, opposes the change, and so the induced current in the conductor experiences a force within the external magnetic field in the same direction as the movement of the magnetic field. Hence, the interaction results in a torque being exerted on the rotor in the direction of the rotating stator field.

By determining the direction of the induced current produced by the changing magnetic flux threading the bar cage through the right hand push rule, we can determine the direction of the force on the conductor due to the current in the external magnetic field using the right hand push rule.

If the bars of the squirrel case rotates at the same speed as the magnetic field, no relative motion means there's no induced current, and hence no torque. The rotor is always rotating slower than the magnetic field of the stator as there is a retarding force, and the difference in rotational speed is the slip speed. (noticeable when there's a load to slow it down, increasing retarding forces, i.e. power drills

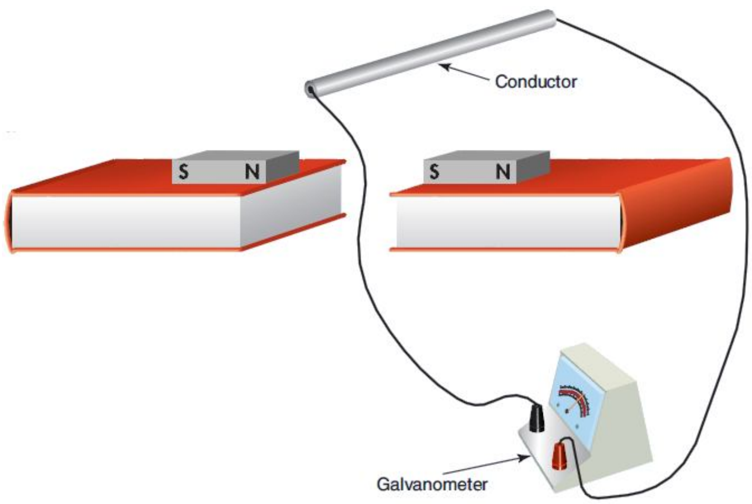
- perform an investigation to demonstrate the principle of an AC induction motor

Set up firstly by placing two bar magnets with a north and a south facing each other, elevated above the table (with books) having a gap in the middle, this will create an external magnetic field for the conductor to move through. Now, a copper or aluminium rod can be used, with ends attached by connecting wires to a galvanometer.

As conductor moves downwards through the magnetic field slowly or quickly between the poles of the magnet. Record the direction and note that the deflection of the needle is larger when the conductor is moved through the field faster, due to a greater change in flux. This can similarly be done for the conductor moving up through the magnetic field, noting that the current direction is the other way.

Placing the conductor at an angle to the magnetic field will reduce the current as only the perpendicular component of the magnetic field to the conductor will induce a current. Finally increasing the distance of separation between the magnetic poles will reduce the current, as magnetic field is weaker.

Now, placing the conductor stationary and moving the poles relative to the conductor will have a similar effect.



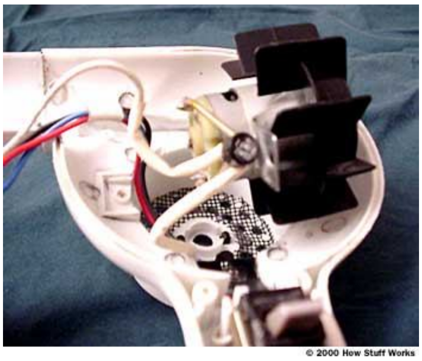
- gather, process and analyse information to identify some of the energy transfers and transformations involving the conversion of electrical energy into more useful forms in the home and industry

It is important to note that energy transfer is when the same form of energy moves from one object or location to another. I.e. heat energy dissipated by convection.
And energy transformation is when energy is changed from one form to another. For instance as an object falls, gravitational potential energy transforms to kinetic energy.

The Principle of Conservation of Energy states that energy cannot be created or destroyed but can be transformed from one form to another. Many energy transformations are not useful, but appliances usually utilise transformations of electrical energy into useful forms of energy related to its functions.

In the Home

For instance, a hair dryer has an electric motor. While some electrical energy is transformed into heat energy within the motor via eddy currents, electrical energy is <u>usefully transformed</u> into rotational kinetic energy, rotating the fan attached to the shaft of the motor. This rotational kinetic energy is also transformed into sound and heat energy, but most importantly as kinetic energy of air particles. Heating elements in the circuit transform electrical energy into heat energy and light energy, while heat energy is <u>usefully transferred</u> to air particles by conduction and convection.



Hair Dryer Motor, note fan attached to rotor

A power drill has a motor which transforms electrical energy into some heat energy (via eddy currents), sound energy and most importantly mechanical (or rotational kinetic energy). Hence the drill bit at the end of the motor shaft rotates. When drilling into wood, the mechanical (rotational kinetic) energy is transformed into heat energy (due to friction), sound energy and of course kinetic energy of the wood as it is displaced. Useful transformation being electrical energy to mechanical (rotational kinetic) energy, while useful transfer is kinetic energy of drill bit into kinetic energy of wood. [Same principle works with food blenders]

In kettles, heating element transforms electrical energy into light energy but more usefully into heat energy due to high resistance of heating element wiring. Then by direct conduction and convection, the heat energy is usefully transferred to water particles in the kettle.


High Resistance Heating Element in Kettle

Electrical energy is transformed into chemical potential energy when batteries are recharged. During discharge, chemical potential energy is usefully transformed to electrical energy.

In industry

A centrifugal water pump has a motor, transforming electrical energy into sound energy, heat energy (via eddy currents) and most usefully into mechanical (rotational kinetic) energy. This causes the rotor, an impellor with blades, to rotate within its cylindrical pump housing. As water enters at the centre (impellor eye), the blades do work on the water and push it in a outward circular path, usefully transferring rotational kinetic energy to the water. As it gains rotational kinetic energy, the water moves faster and faster until it exits outer edge of the pump housing where it slows down. Here, the rotational kinetic energy is usefully transformed into water potential energy according to Bernoulli's principle, and the higher water pressure causes flow of water to occur.

Questions

Sunday, 3 January 2010
8:25 PM

Lenz's law, is the direction opposite for emf, induced current, and/or magnetic field? (can we say that, by Lenz's law, back emf is in the opposite direction to external emf?)
Do you induce emf? Induced current? And eddy currents?
Polarity of magnetic fields or direction of magnetic fields

Is the axle a part of the rotor?