Magnet

This is a material or substance that attracts other materials or substances.

Substances attracted by a magnet are called *magnetic materials*. E.g. iron, steel, cobalt and nickel

Material include;

These include magnetic and nonmagnetic materials

Ferro-magnetic materials

These are materials that are strongly attracted by a magnet. E.g. iron, cobalt and nickel.

Electromagnet material

This is a type of magnet whose magnetism is produced by the flow of electric current

However substances that are not attracted by a magnet are known as *non-magnetic materials* e.g. carbon, copper, brass, wax, glass, plastics, wood, sulphur etc

They are classified as *diamagnetic* **or** *paramagnetic materials*.

Dia-magnetic materials

Dia-magnetic materials are materials that are very very weakly attracted by a magnet.

Para-magnetic materials

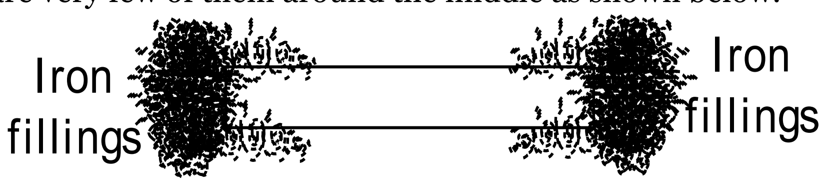
Paramagnetic materials are materials that are weakly attracted by a magnetic e.g. aluminium, brass, copper etc.

Properties of magnets

i) *Magnets attract only certain materials.*
ii) *Magnets have two poles called the North Pole and South Pole which come to rest in a north-south direction in a freely suspended magnet.*
iii) *Magnets have two ends called magnetic poles. The attractive force of a magnet is strongest at its ends i.e. its magnetic poles.* This can be shown by the experiment below.

Experiment to show that attractive force of a magnet is strongest at its ends.

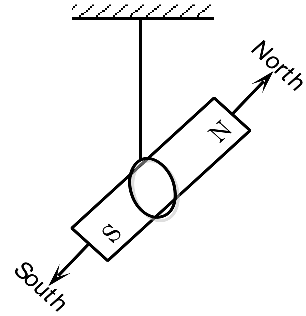
i) Dip a bar magnet in iron fillings and observe.
ii) When removed, it's observed that most of iron fillings cluster around the two ends while there are very few of them around the middle as shown below.



iii) This shows that the attractive force is strongest at the ends.

Experiment to show that a freely suspended magnet comes to rest in a north-south direction

- Suspend a bar magnet with a cotton thread from a wooden stand so that the magnet is free to rotate in a horizontal plane.
- Turn the magnet around and let it oscillate for a while. It comes to rest in a particular direction, which is approximately the north-south direction.
- Mark the pole, which points in the north, with letter N and the other pole, which points to the south with letter S.
- Twist the thread again and let the magnet go. After a while, it comes to rest in the same direction again. I.e. The pole of the magnet marked N always points to the north and the other pole marked S points to the south.



- The pole, which points to the north, is called the North seeking Pole or North Pole (N-pole). The other one is called the South seeking Pole or South Pole (S-pole).

Law of magnets

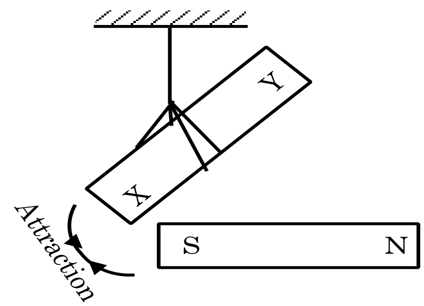
It starts that "like poles repel and unlike poles attract"**.**

Polarities of a magnet

Two methods are involved in testing for the polarity of a magnet

i) Using magnets of known polarity
ii) And suspension method.

An experiment to identify the pole of a magnetic material using a magnet of known poles



i) Suspend an iron bar and mark its ends X and Y.
ii) Bring the N-pole of magnet slowly towards the end X and after towards end Y. In each case note the observation.
iii) Repeat the above procedure using the S-pole of magnet.
iv) It's observed that both ends of the iron bar are attracted to both ends of the magnet. Repulsion never occurs.
v) Thus the iron bar is not magnetised.

This can be summarised in the table below

Pole of suspended magnet	**Pole of hand held magnet**	**Action observed**
S	N	Attraction
N	N	Repulsion
S	S	Repulsion
N	S	Attraction

Magnetization

Magnetisation is the process of making a magnet. These include,

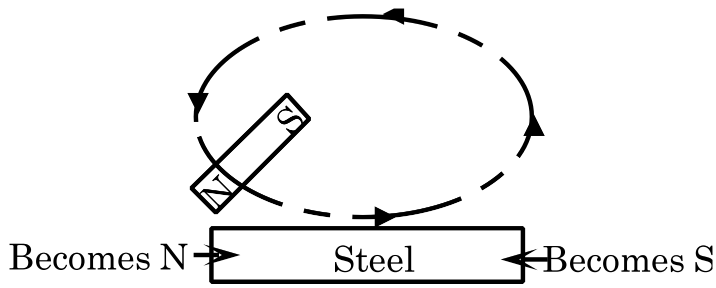
i) Stroking method
ii) Electrical method
iii) Induction method

1. Stroking method

In this method the metal bar is magnetized using a permanent magnet. The permanent magnet is passed several times over bar in the same direction.

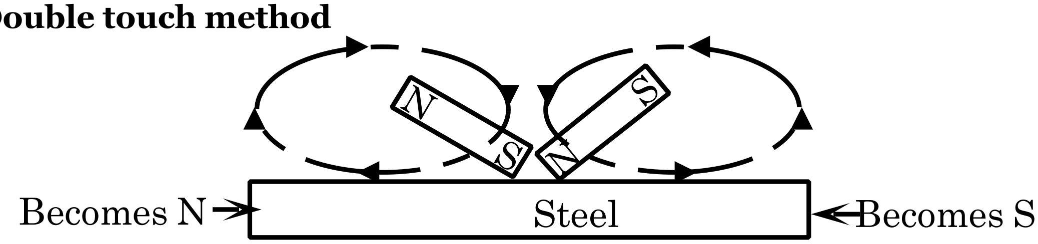
a) Single touch method

i) Place the metal bar on the bench.
ii) The N-pole of the permanent magnet is placed at one end and the bar is stroked until the other end is reached.
iii) The magnet is lifted at this end and the stroking is repeated for several times as shown below.



iv) The metal bar will be magnetized with poles shown above. The metal bar can attract other magnetic material i.e. it is magnetized.
NOTE: The pole created at the end of the stroke is opposite to the pole of the permanent magnetising magnet.

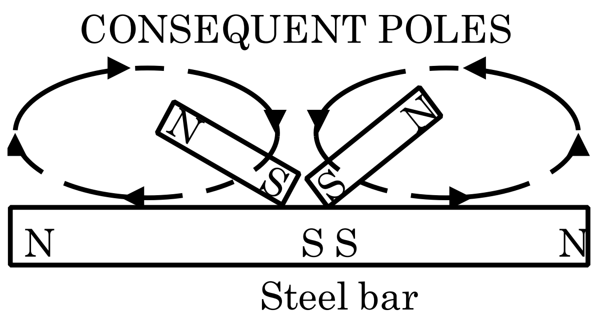
b) Double touch method



The material is stroked using two unlike poles of permanent magnets at the same time from the centre outwards for several times as shown above.
The pole made at the end of the bar where the stroking ends is opposite to that used for stroking.

Consequent poles

If a steel bar is magnetised by double touch method using two S poles we obtain a N pole at both ends of the bar and a double S pole in the centre. In this condition the bar is said to possess **consequent poles**.



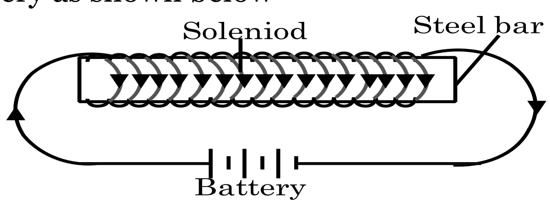
Therefore;
Consequent poles are similar poles at both ends of a magnet obtained when stroked using two similar poles in double touch method.

2. **Electrical method**

This is the best method of making magnets and only direct current is used.

Procedure

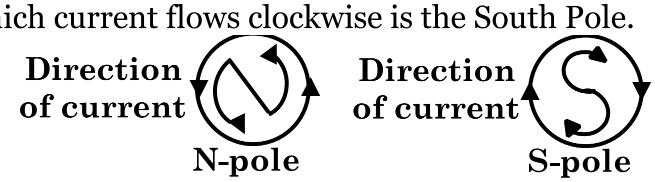
i) A metal bar is placed inside a long coil of a copper wire called a solenoid connected to a battery as shown below



ii) Current is switched on for a few minutes and then off.

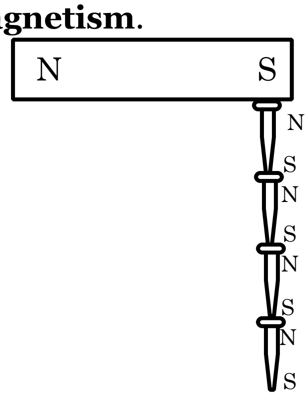
iii) The steel bar becomes magnetised.

- The end of the solenoid in which current flows anti-clockwise is the North Pole, while the end in which current flows clockwise is the South Pole.



3. **Magnetic induction**

When a magnetic material is placed in contact with a pole of permanent magnet for some time, magnetic properties are induced in it and the material acquires temporary magnetism called **induced magnetism**.



Note: The part of the magnetic material in contact with the pole of the magnet is induced with opposite pole.

Demagnetisation

This is the process of making a magnet lose its magnetic properties.
A magnet can be made to lose its magnetic properties by;

1. By heating it until its red hot and then cooling it when lying in the East-West direction.
2. By hammering it several times.
3. By using electrical method. This is the best method and is done by keeping the magnet in a solenoid in east-west direction and passing alternating current.
4. Dropping of the magnet several times while facing in the East- West direction.

Uses of a magnet(s)

1. Used in industries to lift heavy loads.
2. Used in electric motors and generators to rotate the wheels of a machine.
3. Used in bicycle dynamos to produce electricity.
4. They are used in telephone receivers and loud speakers**.**

Types of magnet.

Magnets are classified according to their ability to retain magnetic properties. These include,

1. **Hard magnetic materials**

These are Ferro-magnetic materials which are not easily magnetised but retain their magnetism for a long period. E.g. steel.

Uses of hard magnets include,

- Used in electricity meter.
- Used in radio loudspeaker.
- Used in telephone receiver etc.

2. **Soft magnetic materials**

These are Ferro-magnetic materials which are easily magnetised but loss their magnetism easily e.g. iron.

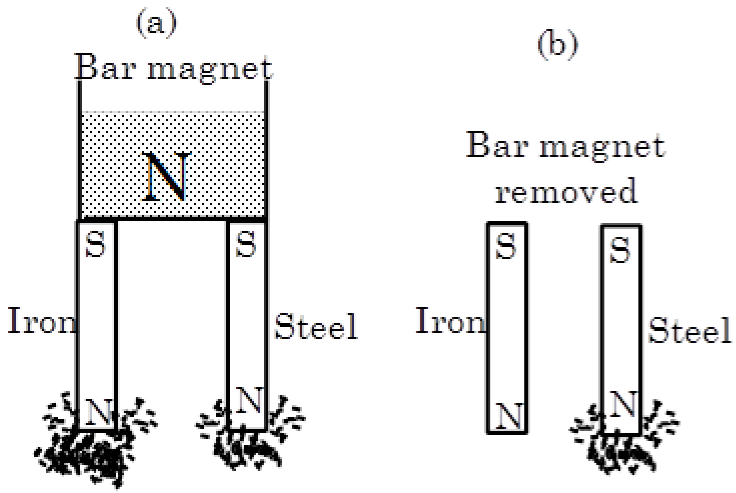
Soft magnetic materials are used in;

- Transformers
- Keepers
- Electric bells
- Relays
- Electromagnets
- Dynamos

Properties of steel and iron

Difference between steel and iron

This can be examined by the experiment below.

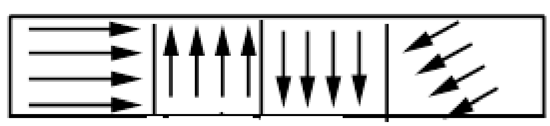


i) Un-magnetised strips of Iron and Steel are placed side by side in contact with the pole of a magnet.
ii) Both strips become magnetised by induction, and on dipping their free ends in iron fillings, it is observed that more iron fillings get attached on iron than steel. This means that induced magnetism is greater in Iron than Steel.
iii) When the permanent magnet was removed, steel remained with some iron filings while iron lost all. This means that Iron is easy to demagnetize and steel is not easy to demagnetise. Thus Steel is said to be magnetically hard while iron is magnetically soft.

Theory of magnetism (Domain theory)

The theory of magnetism states that "*all magnetic materials are made up of tinny magnets called diploes which are divided into regions called domains*".
When the substance is not Magnetised the dipoles face in different directions while when the substance is magnetised the dipoles faces in one direction as shown below.

a) magnetised material



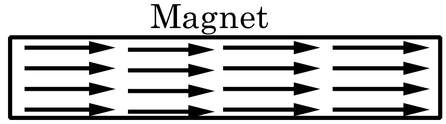
b) un magnetised materail

Magnetic saturation

When a magnetic material is magnetised, the dipoles position themselves parallel to one another. As the process continues a point is reached when all the dipoles face in one direction.
At this point the material said to be magnetically saturated.
magnetic saturation can there be defined as the process by which all the magnetic dipoles in each magnetic dipole align theme selves in the same direction.

Illustration

Magnet



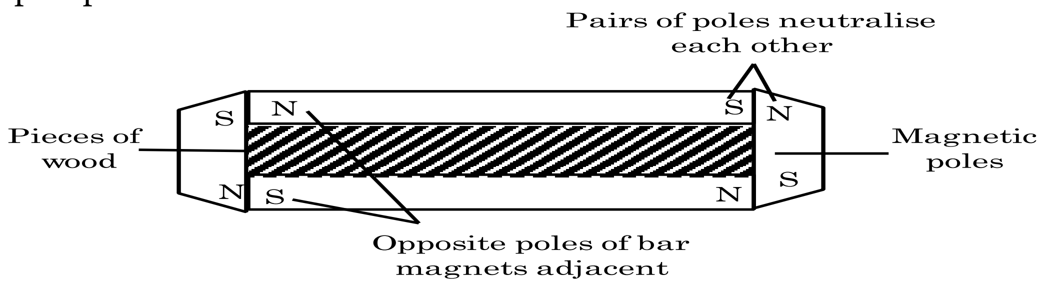
Dipoles made to face in the same direction

Storing (keeping) magnets

When a magnet is left alone, self-demagnetisation occurs caused by repulsion between the adjacent poles of the dipoles leading to a reverse in direction.

Soft iron keepers are used to avoid self-demagnetisation.

This is done by storing bar magnets in pairs with unlike poles opposite and pieces of soft iron keepers placed across the ends.



The keepers become strong induced magnets and their poles neutralized. Therefore the magnetic dipoles in the domains of both magnets and keepers form closed loops with no free poles.

Consequently the demagnetising effect disappears.

Magnetic field patterns

Magnetic field

Magnetic field is region (space) around a magnet where magnetic forces of attraction or repulsion are felt or experienced. It is represented by lines of force called magnetic field lines or magnetic flux.

A magnetic field line *is the path along which an isolated north pole is free to move.*

Magnetic field lines form a magnetic flux.

Magnetic flux is the number of magnetic field lines per unit area.

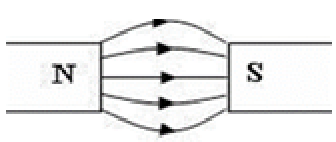
Magnetic field is strongest near the poles of the magnet and gets weaker further away.

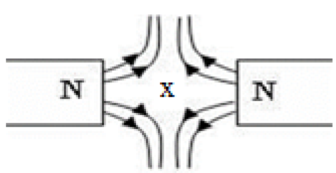
Drawing magnetic field patterns

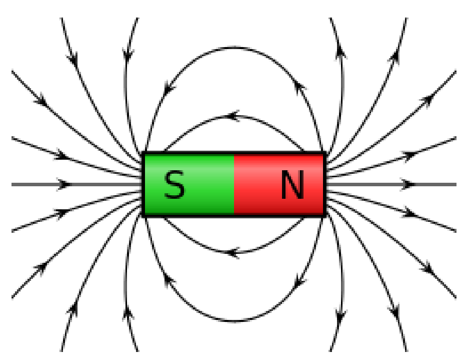
When drawing magnetic field lines, the following should be considered:

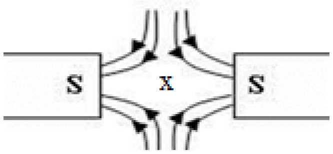
- Lines of force leave the N-pole and enter the S-pole.
- Arrows should be drawn to show the direction of the field lines.
- Lines of force should never cross each other.
- Magnetic field is strongest where the lines of force are close to each other.

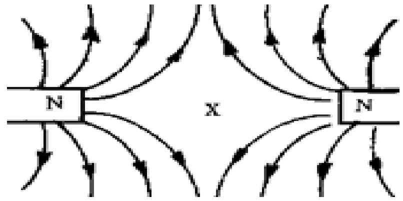
Examples

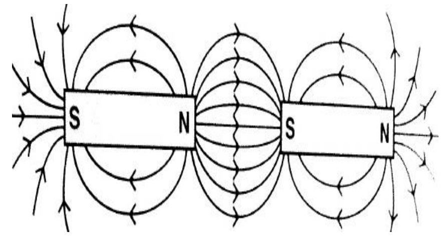








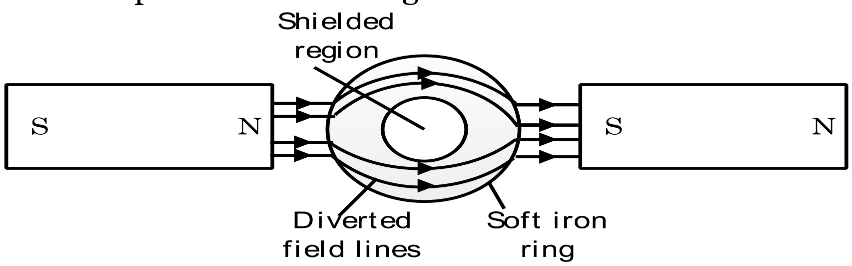




X is a neutral point and is defined as a point at which the resultant magnetic flux density is zero.

Magnetic shielding or screening

This is the creation of a magnetically neutral space or region in the neighbourhood of the magnetic field irrespective of the strength of the field.



Magnetic shielding can be used to protect (to shield) materials them from external magnetic field.eg

- In non-digital watches.
- In T.V tubes and cathode ray tubes.

Earth as a magnet

When a freely suspend a bar magnet is twisted, it comes to rest with the North-pole facing in the geographical north and South Pole in the geographical south. This makes us to think that there is pole in the geographical north trying to attract the North Pole of the bar magnet and likewise in the south.

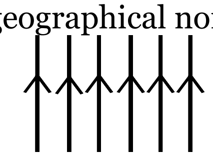
The earth’s magnetic field can be described by imagining that there is a giant bar magnet at the centre of the earth.

The imagined earth’s bar magnet behaves as if it’s inclined at an angle to its axis of rotation with its south pole in the geographical north and North Pole in the geographical south.

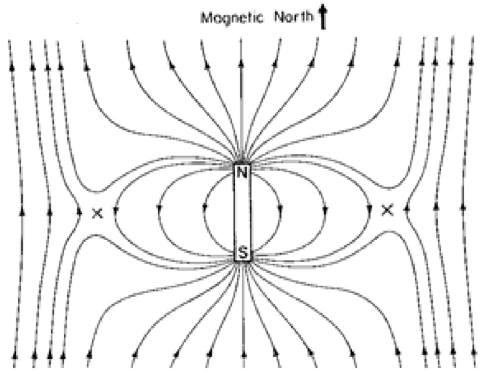
Therefore the south pole of the imagined earth’s bar magnet attracts the North Pole of the suspended magnet while North Pole attracts the south pole of the suspended magnet.

Earth’s magnetic field

The earth’s magnetic field lines are made up of parallel lines running from the geographical south (bottom) to the geographical north (top).



1. The combined effect due to the earth and a bar magnet with its north pole point North is shown below.

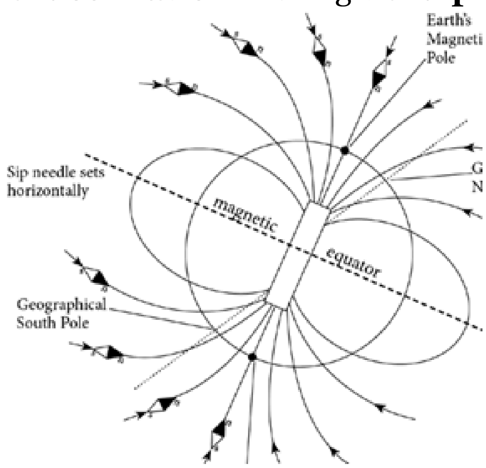


The point marked **x** is the neutral points because no lines of forces pass through this point. Thus the magnetic flux is zero.

The study of the earth's magnetic fields involves;

a) Two imaginary lines called **magnetic meridian** and **geographical meridian.**

b) Two angles called angle of **declination** and angle of **dip**.



Magnetic meridian

This is a vertical plane passing through an axis of rotation of a freely suspended magnet.

OR

Magnetic meridian at any place is the line joining the earth's magnetic poles.

Geographical meridian

This is a vertical plane passing through the axis of rotation of the earth. **OR**

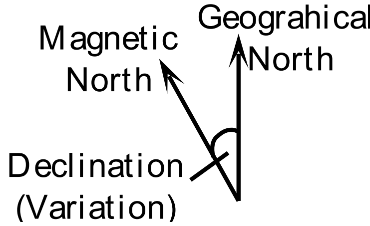
Geographical meridian at any place is the line joining the earth's geographical poles.

Angle of declination

Angle of declination is the angle between the magnetic and geographical meridians.

OR

This is the angle between magnetic north and true north.



Angle of dip / inclination

This is the angle between the horizontal surface of the earth and the direction of the magnetic field at a point.

Electromagnets

Definition

An electromagnet is a type of magnet whose magnetism is produced by the flow of electric current.

OR

Is a magnet formed when a magnetic material is placed in a solenoid carrying current

The magnetic field disappears when the current ceases.

Action

When current passes through a coil containing a soft magnetic material, a strong but temporary magnetism is induced on the soft magnetic material. The magnetism is lost when current is switched off and again produced when current is switched on.

N.B. Steel produces a weaker magnet than iron but keeps its magnetism much longer than iron. Hence iron is used for electromagnets to produce a stronger magnet than steel and to lose the magnetism quickly.

Factors that affect the strength of a magnet

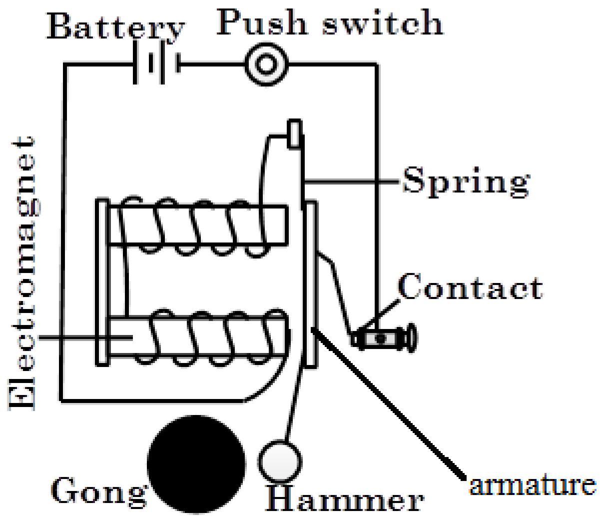
The strength of an electromagnet depends on;

1. Size (strength) of current in the coil.
2. Number of turns in the coil.
3. Shape of the material used. I.e. a horseshoe magnet is stronger than a bar magnet under the same conditions.
4. Nature of the material.

Uses of electro-magnets

i) Used in electric bells, electric motors, electric buzzers, telephone receivers, loudspeakers, microphones etc.
ii) Used by doctors to remove bits from eyes.
iii) Used in industries to lift heavy iron loads.

Electric bell



How it works.

i) When the switch is pressed, current flows across the contacts and around the coils attracting the armature to the electromagnet formed.
ii) The armature makes the hammer to hit the gong producing the sound and at the same time the contacts separate, stopping current flow; causing the electromagnet to lose its magnetism.
iii) The spring pulls back the armature, no sound is produced and hence completing the circuit again.
iv) The process is repeated and each time the circuit is completed and broken, the hammer strikes the gong and sound is heard. Hence the bell rings.

Energy changes in an electric bell

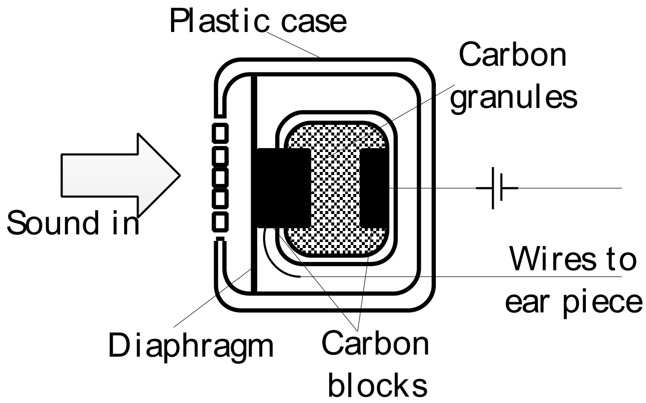
Chemical energy ⇨ Electrical ⇨ Magnetic ⇨ Kinetic ⇨ Sound energy.

Microphone

A microphone is a device which changes sound energy into electrical energy.
The electrical energy travels along the telephone cable and finally into sound.
A microphone uses a variable resistor whose resistance changes as sound waves hit it.

Structure

The variable resistor is made of two carbon blocks separated by carbon granules. One of the blocks is attached to a diaphragm. It controls the varying current sent to the earpiece.



How it works

i) When one speaks, sound forces the diaphragm to vibrate. The diaphragm moves the carbon block attached to it.
ii) As the carbon blocks are moved closer, the granules are compressed (squeezed).
iii) More granules are in contact with one another so that there are more paths for electricity to flow hence resistance to flow lowered.
iv) When the carbon granules are moved apart, the granules are loosened, so that there less paths for electricity hence resistance increased.
v) This resistance also varies in the same way with sound variations making the current to vary in the same way.

Electric currents in magnetic fields

We have already seen that electric currents cause magnetic fields around them. When a wire carries an electric current through another magnetic field, the two magnetic fields interact and the forces between the two magnetic fields can move wires and turn coils which carry the electric current flowing.

Origin of the force on a current carrying conductor placed in a magnetic field

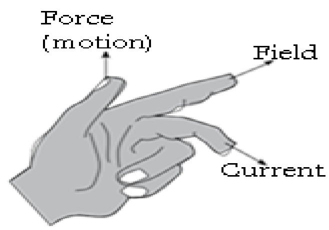
A magnetic field exists around a conductor carrying current. The magnetic field due to the current in the conductor interacts with the magnetic field due to the permanent magnet. This interaction results in a force being produced on the conductor.

Ways of increasing the force

i) Using a stronger magnet.
ii) Increasing the size of current.
iii) Increasing the length of the conductor in the magnetic field.
iv) Making the angle between the direction of the magnetic field and the conductor 90°.

Fleming's left hand rule

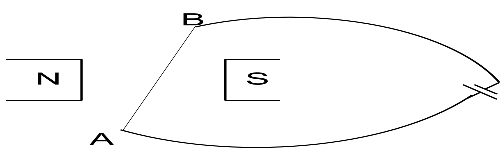
We can determine the direction of the force produced using Fleming's left hand rule.
It says; Hold the thumb, first finger and second finger of your left hand at right angles to each other as shown below.



- ✓ First finger points in direction of magnetic field of the permanent magnet (north to south).
- ✓ Second finger points in direction of current.
- ✓ Thumb points in direction of force.

Example

The diagram below shows a wire AB placed between the poles of a permanent magnet.



State what is observed when current flows in the wire using Fleming's left hand rule.

(i) In the direction AB.
The wire moves upwards

(ii) In the direction BA.
The wire moves downwards

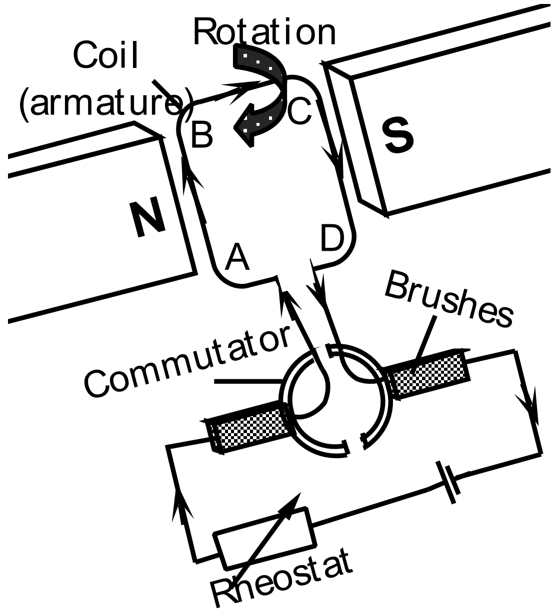
Applications of motor effect

- Simple d.c motor
- Moving coil loudspeaker.
- Moving coil galvanometer

A Simple D.C motor

This transfers electrical energy into mechanical energy.

STRUCTURE



It consists of a rectangular coil of wire placed between pieces of strong magnet, whose end connected is to the commutators. The coil is free to rotate in uniform field. The current is passed into and out of the coil through brushes

How it works

- When current is passed through the coil, equal opposite forces are exerted on the coil causing it to rotate in clockwise direction .i.e. side AB upwards and side CD downwards.
- When the coil reaches the vertical position, the brushes loose contact with the commutators hence the current is cutoff. The momentum of the coil however carries it beyond this vertical position.
- As the coil rotates, the commutators change brushes during the second vertical turn. The current in the coil is reversed.
- At this instant, the commutator is oriented so that it reverses the connections from the coil to the circuit, and the coil continues to rotate in the same direction.
- The motor will continue to rotate in the same direction until current is switch off.

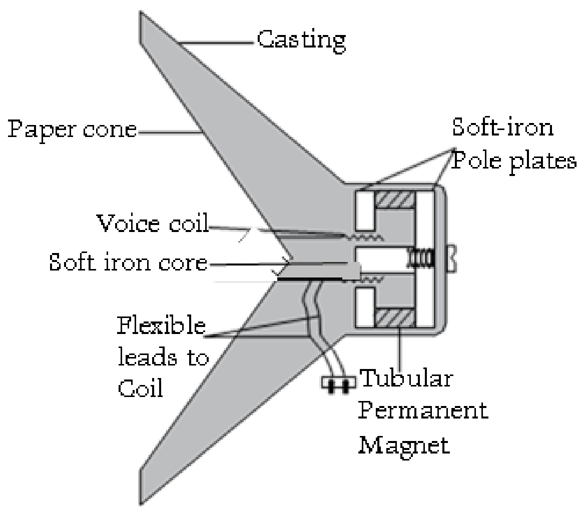
Note

The strength of a motor can be increased by:

i) Increasing the number of turns of the coil.
ii) Increasing the amount of current. This can be done by varying the rheostat.
iii) Increasing the strength of the magnet. This can be done by replacing the permanent magnet with electromagnet.
iv) Winding the coil on a soft iron armature.

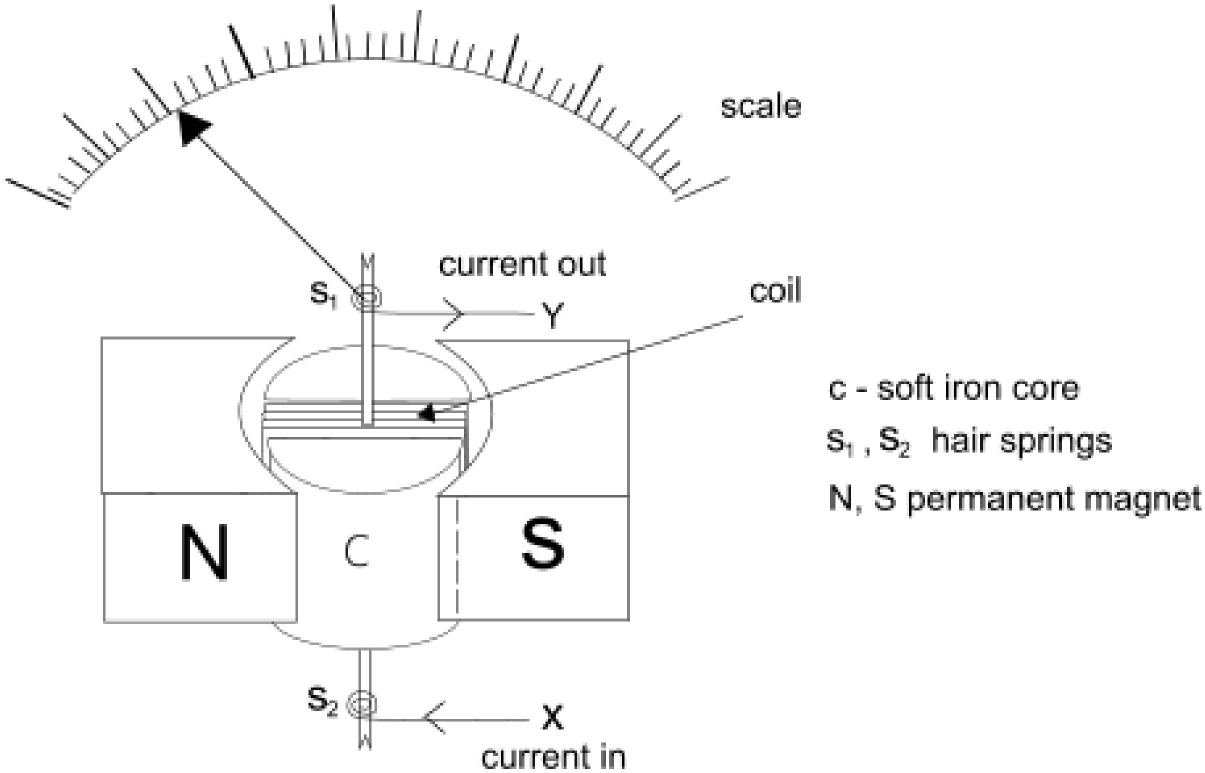
Energy (power) losses in an electric motor
The efficiency is reduced by the little energy lost in a motor in the following ways;
- ❖ Eddy currents (Induced currents)
- ❖ Magnetic reversals or hysteresis.
- ❖ Magnetic flux leakage.
- ❖ Back e.m.f in an electric motor.

Moving coil loud speaker
This is the most common type of speaker and uses a moving coil to cause the motion that reproduces sound waves in the air. It changes electrical energy into sound energy, which is sent into air.
The moving coil loudspeaker works on the principle of force exerted on a current carrying coil situated in a magnetic field.
Structure



How it works
- ❖ Varying current from the amplifier, flows through the terminal into the coil, which is in a magnetic field.
- ❖ A coil experiences a varying force, which causes it and the paper cone to vibrate. This sets the air in contact with it into vibration hence setting up a sound wave, which follows the same pattern as the original electrical signal. A vibrating cone produces sound.

Galvanometers, Ammeters and voltmeters
Moving coil galvanometer
This works on the same principle as the electric motor. It is used to detect the presence of small currents.
Structure



It consists of a coil of wire, which is pivoted so that it can rotate in a magnetic field.
At each end of the coil there is a coil spring through which the current to be measured enters and leaves. The coil is also connected to the pointer, which moves over the scale when it turns.

How it works

- When a current flows through a coil, there is a force on it, which makes it turn.
- The coil turns until the magnetic force on it is balanced by the force due to the tension in the coil springs.
- The position of the coil is then the measure of the current.
- A pointer is fixed on the coil so that the current can be read off form the scale.

Note

1. The scale of the moving coil is made uniform by fixing a cylinder of soft iron inside the coil. This has the effect of making the magnet field uniformly strong in the gap through which the coil rotates. Hence, force on the sides of the coil will be proportional to current.

2. The sensitivity of the galvanometer can be increased by;
   - Increasing the number of turns of coil.
   - Using a stronger magnet with a high magnetic flux.
   - Using a coil of larger area.
   - Using weak hair springs to give a small control couple.

Conversion of moving coil galvanometer into ammeter or a voltmeter

Ammeters and voltmeters are electric measuring instruments with scales, which have been graduated to read current in amperes and potential difference in volts respectively.

- The ammeter is always connected in series. The ammeter should therefore have low resistance compared with the rest of the circuit, so that it does not introduce unwanted resistance.
- The voltmeter is always connected in parallel. The voltmeter should therefore have high resistance compared with the rest of the circuit, so that it takes a comparatively negligible current, and can disturb the circuit as little as possible.

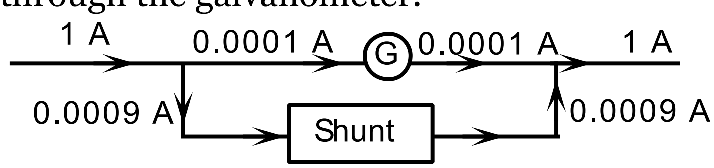
The conversion of a galvanometer into an ammeter or a voltmeter is carried out by connecting resistors of different values either in parallel or in series with the galvanometer. These resistors can be inside the instrument or outside.

(a) Conversion of a galvanometer (milliammeter) into an ammeter.

Here the galvanometer (milliammeter) is modified to measure high current in amperes.

A low resistance called ***a shunt*** is connected in parallel with the galvanometer.

Most current to be measured takes the easy path through the shunt. The shunt allows most current flows through it and a very small proportion passes through the galvanometer. Thus the galvanometer is protected against excessive current and overheating. E.g. if a galvanometer is to read 1 A, a shunt must be chosen so that 0.999 A flows through the shunt and only 0.0001 A flows through the galvanometer.



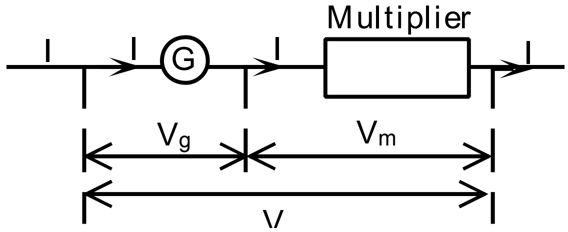
If the galvanometer is required to read a high current a lower resistance shunt must be used.

(b) Conversion of a galvanometer (milliammeter) into a voltmeter.

Here the galvanometer (milliammeter) is modified to measure high voltages in volts.

A high resistance called ***a multiplier*** is connected in series with the galvanometer.

Because of high resistance the intensity of the current through the galvanometer is reduced. Same current will be passed through both the instruments and resistor.



Example

A milliammeter of resistance 5ohms gives a full scale deflection for a current of 10 mA. How can it be adopted to read;

a. 1.0 A,
b. 10 V?

Solution

a) Current through G = 10 mA = 0.01 A

Current through the shunt will be = 1 - 0.01 = 0.99 A.

Since the shunt and G are in parallel, the p.d across them is the same

I.e. P.d across G = P.d across shunt

$0.01 \times 5 = 0.05$ V = P.d across shunt

Resistance of the shunt = $\frac{V}{I} = \frac{0.05}{0.99} = 0.0505\ \Omega$

$\therefore$ A shunt of resistance 0.0505 Ω should be connected in parallel with the milliammeter.

b) Total resistance, R = (X+5) Ω

From Ohms law, $R = \frac{V}{I} = \frac{10}{0.01} = 1000\ \Omega$

$\therefore X + 5 = 1000\ \Omega, \quad \Rightarrow X = 1000 - 5 = 995\ \Omega$

$\therefore$ A high resistance (multiplier) of 995 Ω should be connected in series with the milliammeter.

Electromagnetism

Definition

Electromagnetic Induction is the Induction of an electromotive force in a circuit by varying the magnetic flux linked with the circuit.

This means that current (or e.m.f) can be induced when:

1. The magnetic field around an electromagnet is increased and decreased.
2. Constantly moving a permanent magnet in and out of a coil of wire.
3. Constantly moving a conductor near a stationary permanent magnet.

The size of induced e.m.f or current can be increased by;

v) Increasing the speed of motion of the magnet or coil.
vi) Increasing the magnetic field strength by using a strong magnet.
vii) Increasing the number of turns on the coil.

Faraday's laws of electromagnetism

1. A changing magnetic flux in circuit induces an e.m.f in it.
2. The induced electromotive force in a circuit is directly proportional to the rate of change of the magnetic flux or field lines linking the circuit.

Lenz's law

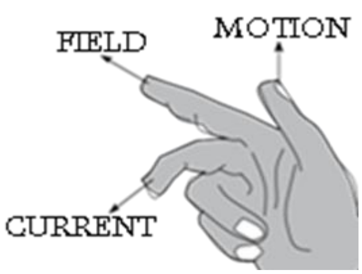
Faraday's laws refer to e.m.f only and not to current, because if there is no complete circuit, there is an induced e.m.f but no current.
Lenz studied the direction of the induced current in a complete circuit but following Faraday's law, hence Lenz's law.
Lenz's law states "***the direction of the induced current is always opposite to the changing causing it".***

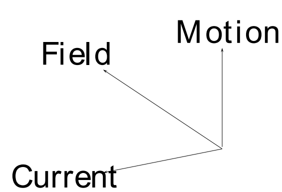
Fleming's right-hand rule (Dynamo rule)

This is a method used to predict the direction of induced current/e.m.f.

- ✓ Arrange the thumb, first finger and second finger of the right hand mutually at right angles.
- ✓ Point the first finger in the direction of the field.
- ✓ Point the thumb in the direction of the motion.
- ✓ Then, the second finger will point in the direction of the induced current.

In summary; thu**M**b- **M**otion**, f**irst **F**inger – **F**ield**,** se**C**ond finger – **C**urrent**.**





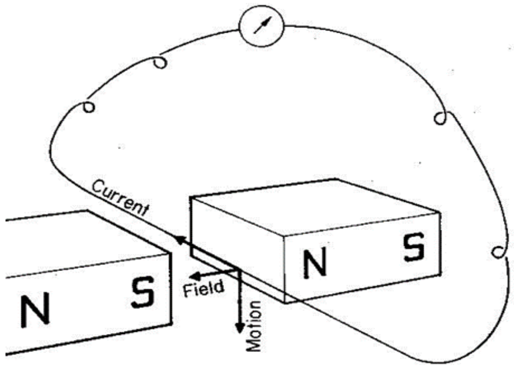
Remember:
(We use the **R**ight hand for **D**irection of **C**urrent produced **or RDC)**

Direction of induced current in a straight wire

A wire is placed between the poles of a permanent magnet and connected to a galvanometer. The wire is moved up and down at right angles to the magnetic flux.

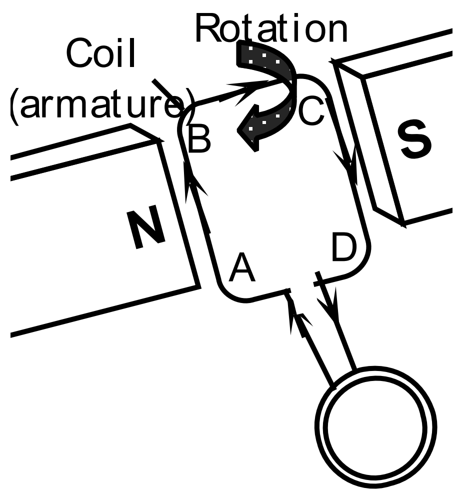
- It's observed that when the wire is moved down, the galvanometer deflects to the right meaning that induced current is following in clockwise direction.
- When the wire is moved up, the deflection is reversed indicating that the current is reversed. (Anticlockwise).

The above observation can be verified using Fleming's right hand rule as shown below



Induced current in a rotating coil

Consider a rectangular coil ABCD rotating in a clockwise direction in a uniform magnetic field.



As the side AB comes up through the field, the induced current is in part AB and part CD of the coil. The direction of the induced current in AB is from A to B while in part CD it is from C to D. (use Fleming's right-hand rule) A current will therefore flow in the rectangular coil.

Applications of induction

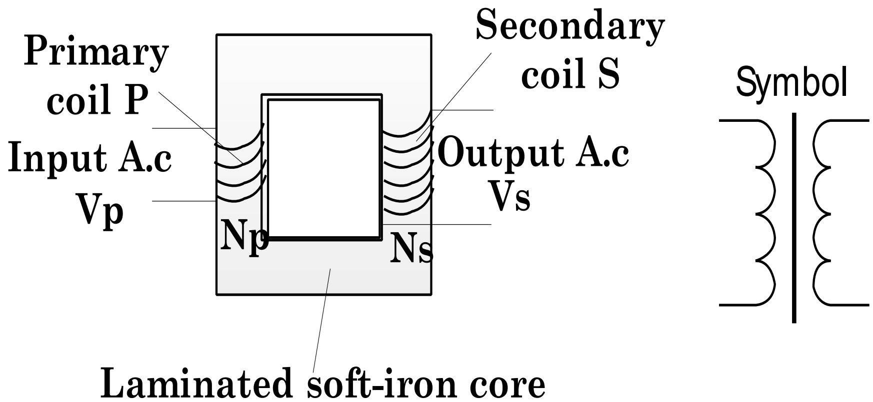
Transformer

A transformer is a device used for stepping up or down an alternating voltage.

The ease with which a transformer changes an alternating voltage has made it possible for the present day use of A.C. power for our homes and industry.

It transfers electrical energy from one circuit (primary) to another (secondary) by electromagnetic induction between two coils.
Thus, a transformer is used only with alternating voltage, if it is used with D.c it burns out.

Structure of a transformer



A simple type of transformer as shown above consists of:
(i) A primary coil P, to which the alternating voltage Vp to be changed is connected;
(ii) A secondary coil S from which the changed voltage Vs is obtained;
(iii) Soft-iron core made of laminations (thin insulated soft iron-sheets, round which the two insulated coils P and S are wound).

How a transformer works

An alternating current is changing all the time.
When an a.c. flows in the primary coil, it produces a continuous flux change in the primary coil and hence in the secondary coil.
The changing flux in the primary coil induces alternating e.m.f. at the secondary terminals. This is the principle of the transformer.

Turns ratio

An a.c. flowing through the primary coil at one voltage causes an a.c. to flow in the secondary coil at a higher or lower voltage.
The size of a.c. in the secondary coil depends on the number of turns on both coils. This is called **"turns ratio".**

$$\text{Turns ratio} = \frac{\text{Secondary turns}}{\text{Primary turns}} = \frac{N_S}{N_P}$$

This also equals the ratio by which the transformer changes the voltage of a.c.

$$\text{Thus;} \quad \frac{\text{Secondary turns}}{\text{Primary turns}} = \frac{V_S}{V_P} = \frac{N_S}{N_P} \text{ OR}$$

$$\frac{\text{p.d across primary}}{\text{e.m.f of secondary}} = \frac{\text{number of turns in primary}}{\text{number of turns in secondary}}$$

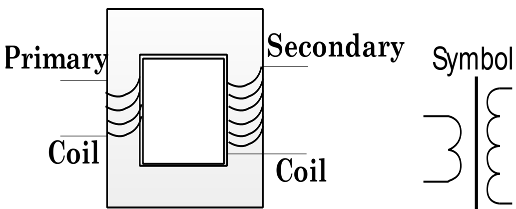
$$\frac{V_P}{V_S} = \frac{N_P}{N_S}$$

Types of transformers
Step-up transformer
If the number of turns on the secondary coil is greater than those on the primary, then, the *turns ratio* >1 i.e. $V_s > V_p$

The transformer changes voltage to a higher value and is called a **'step- up'** transformer.

Definition

A step-up transformer has more turns in the secondary coil than in the primary and increases an a.c voltage.

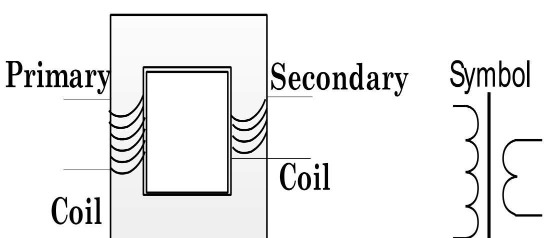


Step-up transformer

Step-down transformers
If the turns ratio <1 i.e. the primary coil has more turns than those on secondary, the transformer changes the voltage to a lower value and a **'step-down'** transformer.

Definition

A step-down transformer has few turns in the secondary than in the primary and it decreases a.c.



Step-down transformer

Power transfer in a transformer
The law of conservation of energy implies that Transformers cannot create energy therefore; power in the primary (input) equals the power in the secondary (output). i.e.

$$\text{Power input at primary} = \text{Power output at secondary}$$
$$I_P V_P = I_S V_S$$

Efficiency in a transformer

$$\text{Efficiency} = \frac{\text{Power output}}{\text{Power input}} \times 100\ \%$$

$$\text{Efficiency} = \frac{I_S V_S}{I_P V_P} \times 100\ \%$$

No machine is perfect so energy is always lost, therefore efficiency cannot be 100 %.

Energy (power) losses in a transformer

The efficiency is reduced by the little energy lost in a transformer in the following ways;

- Eddy currents (Induced currents)
- Heating effect of the coils (windings)
- Magnetic reversals or hysteresis.
- Magnetic flux leakage

Ways of reducing energy losses in a transformer

- Low- resistance thick copper coils so that internal energy losses in the windings (coils) are small.
- Laminated core to reduce eddy currents losses.
- Core made of soft magnetic material to reduce the energy required to bring about magnetic reversals.
- Efficient core design to ensure that all the primary flux is linked with the secondary.

Uses of transformers

- Step-down transformers are used where a large current is required e.g. for electric furnaces, welding etc.
- Step-up transformers are used where high output voltage but small current is required e.g. in transmission lines for distribution of electric energy, TV sets, X-ray tubes etc.

Discussion questions

1. (a) Describe with the aid of a diagram the operation of a transformer.

(b) A 240 V step-down mains transformer is designed to light ten 12 V, 20 W ray box lamps and draws a current of 1 A in the primary coil. Calculate the :
   (i) Power supplied to the primary coil
   (ii) Power delivered in the secondary coil
   (iii) Efficiency of the transformer.

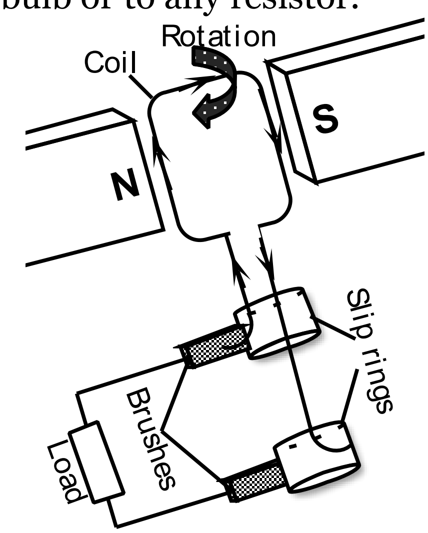
2. A transformer connected to 240 V a.c. mains is used to light a 12 V 36 W lamp.
   (a) What current does the lamp need to light correctly?
   (b) If the efficiency of the transformer is 75 %, what current is taken from the mains?
   (c) Calculate the magnitude of the series resistor that would be necessary if the lamp were connected directly to the mains.
3. A transmission line between a power station and a factory has resistance of $0.05\,\Omega$ in each of the two wires. If 100 A is delivered at 100 V,
   (a) What useful power is delivered into the load?
   (b) How much power is wasted during transmission?
   (c) What total power must be supplied by the generator?

1. A simple Alternating current (A.C) generator (Dynamo)

A simple alternating generator is used to produce current continuously by moving the coil very rapidly in a magnetic field.

Structure

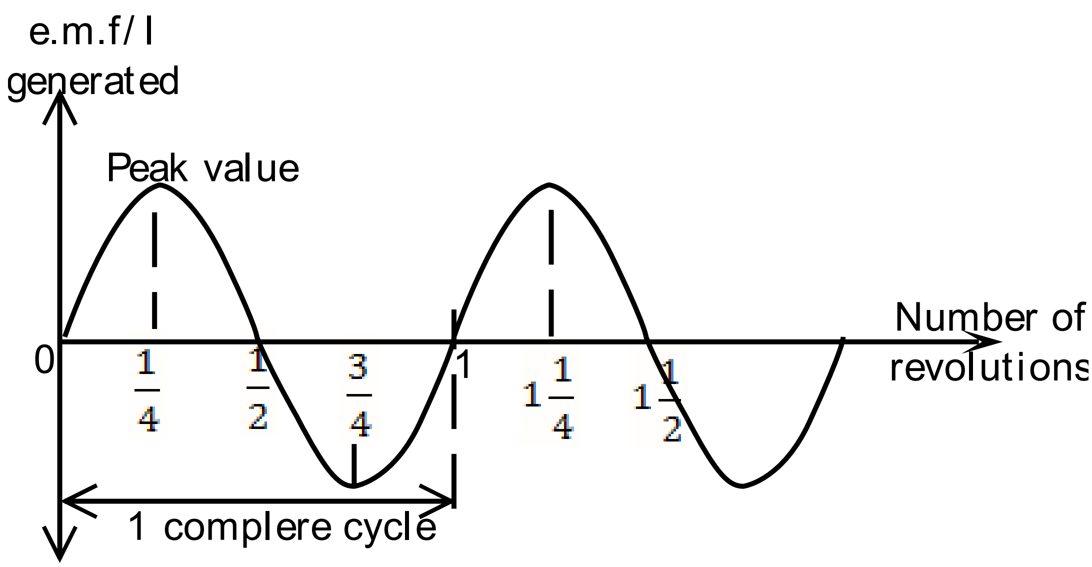
A simple A.C. generator consists of a permanent magnet NS, a rectangular coil of wire rotating about an axis perpendicular to a magnetic field, on a shaft. The coil is connected to two slip rings, also connected to two brushes, which are always in sliding contact with the rings. The brushes give connection to the *outer circuit* such as to a bulb or to any resistor.



How it works

- When the coil is rotating, it cuts across the magnetic field lines and a current is induced in it. The induced current is carried away by the brushes to the load (output).
- When the coil is in vertical position, it is moving parallel to the flux and therefore not cutting the lines. In this position, the current induced in the coil is zero.
- During the first quarter of rotation, the induced current also increases from zero to a maximum (peak) value when the coil is horizontal (parallel to the magnetic field lines).
- During the second quarter of rotation, the induced current decreases to zero again when the coil is vertical again, completing the first half of the rotation.
- During the second half of the rotation, the induced current follows in the same pattern but in a reversed direction, since the direction of motion of the sides of the coil across the magnetic field has also reversed. This completes the cycle.
- The process is repeated providing a continuous supply of changing direction current to the load. This is called alternating current.

The graph below shows the variation of current/e.m.f with position of the coil



It varies from zero (when the coil is in a vertical position and not cutting the magnetic flux) to a maximum (when the coil is in horizontal position and cutting the magnetic flux at the maximum rate) then reverses and varies in the same pattern.

Note:

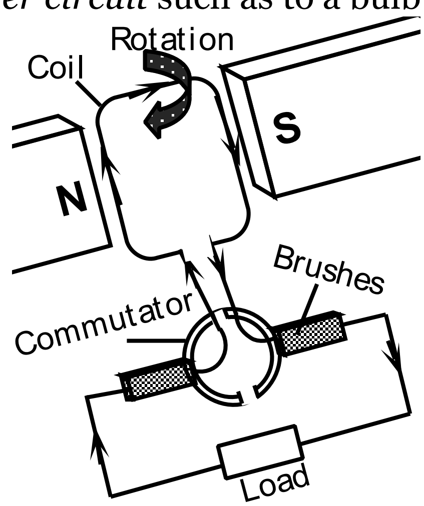
1. This type of current, which constantly changes direction is called alternating current (a.c.). Its maximum current is called the peak value. A rotation of 360° completes a full cycle.
2. If the load is a bulb for example, bulb continuously lights up, then goes off and then lights up again. This happens so long as the speed of rotation of the coil is low.
3. But if the speed of rotation is high, the bulb continues to light irrespective of the position of the coil. However, the brightness of the bulb increases and then decreases. This is because the current increases from zero to a maximum in one direction and does the same in the opposite direction.
4. The maximum output current may be increased by:
   - Rotating the coil faster.
   - Increasing the number of turns of the coil.
   - Increasing the cross-section area of the coil.
   - Using a stronger magnet.
   - Winding the coil on a soft iron core.

2. A simple direct current (D.C) generator (Dynamo)

A simple direct current generator is used to produce current continuously in the rotating coil and in the same direction in the outer circuit i.e. to generate a direct current (D.C.).

Structure

A simple D.C. generator consists of a permanent magnet, a rectangular coil of wire rotating about an axis perpendicular to a magnetic field, on ashaft. The coil is connected to a single insulated split ring (commutator) also connected to brushes, which are always in sliding contact with the rings. The brushes give connection to the *outer circuit* such as to a bulb or to any resistor.

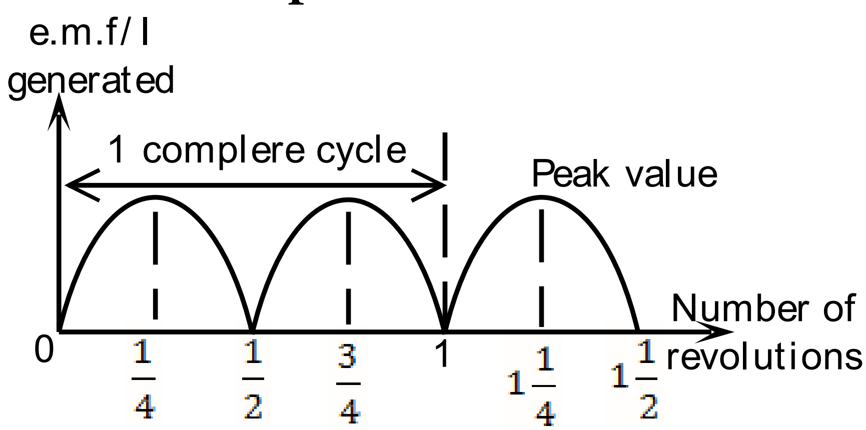


The commutator rotates with the coil on a common axis in such a way that it presses lightly against the fixed brushes. The two halves of the commutator change the brushes exactly at half-turn.

How it works

- When the coil is rotating, it cuts across the magnetic field lines and a current is induced in it. The induced current is carried away by the commutator to the load (output) and is maximum (peak value) when the coil is horizontal.
- During the first half turn, the coil is in a vertical position, the commutators are not touching the brushes, and there is no connection and current decreases to zero.
- During the second half-turn, sides of the coil exchange positions, commutators have also changed brushes. The current in the coil is reversed.
- At this instant, the commutator is oriented so that it reverses the connections from the coil to the circuit, making the current to the outer circuit to flow through the load in the same direction.
- Thus, the current does not change direction in the outer circuit and it is a **direct current (D.C.).**

The graph below shows the variation of current/e.m.f with position of the coil



It varies from zero (when the coil is in a vertical position and not cutting the magnetic flux) to a maximum when the coil is in horizontal position and cutting the magnetic flux at the maximum rate.

Note:

1. This type of current does not change direction, and is called direct current (D.c).
2. If the load is a bulb for example, the bulb continues to light irrespective of the position of the coil. However, the brightness of the bulb increases and then decreases. This is because the current increases from zero to a maximum in one direction.
3. The maximum output current may be increased by:
   - Rotating the coil faster.
   - Increasing the number of turns of the coil.
   - Increasing the cross-section area of the coil.
   - Using a stronger magnet.
   - Winding the coil on a soft iron core.