10th Standard Science

Chapter 13 - Magnetic Effects of Electric Current

Introduction

A magnet is a material which can attract substances like iron, nickel, cobalt and steel.
A magnet has 2 poles – north and south.
When suspended freely the 2 poles seek the north and south pole of earth.
When broken into pieces each piece becomes a magnet.

Magnetic Field

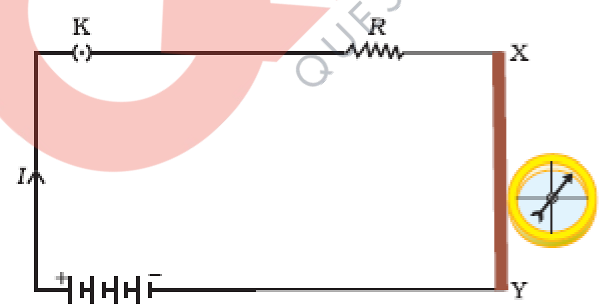
The region around a magnet where its influence is felt by any other magnetic element is known as a magnetic field.
Magnetic field can be measured in Tesla or Weber/m^2

Magnetic Field Lines

Magnetic field lines come out of the north pole of a magnet externally and get into the South Pole forming closed loops.
Magnetic field lines are closest at the poles, where the magnetic field strength is the maximum.
No two magnetic field lines intersect each other.
The direction of the magnetic field at a point is indicated by the tangent at that point.

Natural Magnet

Magnetite or Lodestone (Fe_3O_4), the black ore of iron is a naturally existing magnet.
Oersted's Experiment



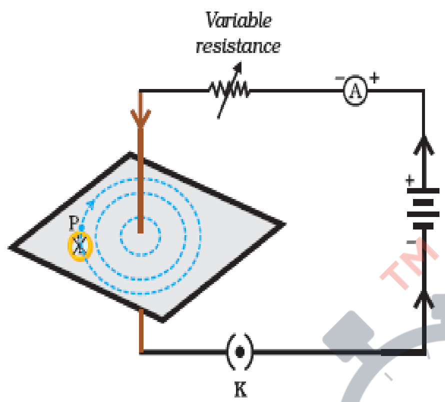
The needle is deflected which means that the electric current through the copper wire has produced a magnetic effect.
This means we can say that electricity and magnetism are linked to each other.

Magnet in a Magnetic Field

When a magnet is placed in a magnetic field it aligns itself along the field lines with the North Pole in the direction of the magnetic field.

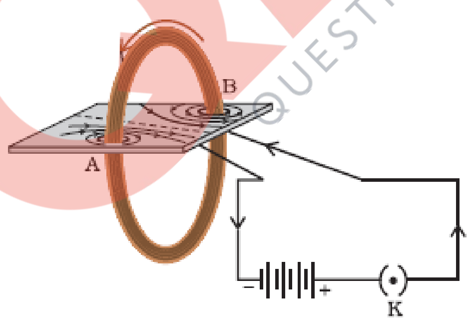
On the surface of earth a magnetic field exists due to the contents of the earth making it behave like a magnet. Because of this a magnetic needle is used to find the direction on the surface of the earth.

Magnetic Field around a Current Carrying Straight Conductor



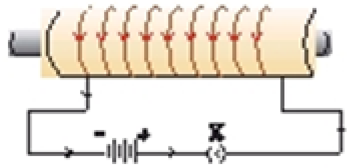
If the current in the copper wire is changed, the deflection in the needle also changes. In fact, if the current is increased, the deflection also increases.
It indicates that the magnitude of the magnetic field produced at a given point increases as the current through the wire increases.

Magnetic Field around a Current Carrying Circular Conductor

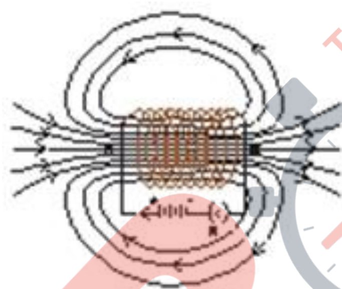


The magnetic field produced by a current-carrying wire at a given point depends directly on the current passing through it.
If there is a circular coil having n turns, the field produced is n times as large as that produced by a single turn.

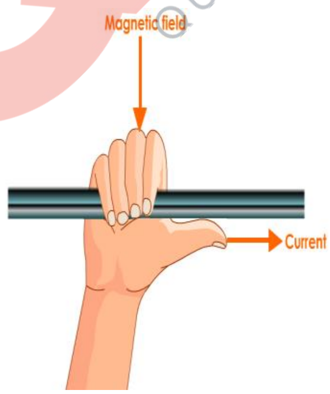
Magnetic Field Due To a Solenoid
A coil of many circular turns of insulated copper wire wrapped closely in the shape of a cylinder is called a solenoid.



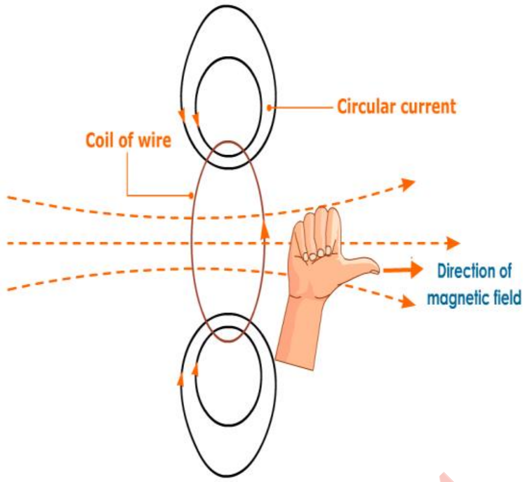
The magnetic field lines around a solenoid are as shown in the diagram below.
One end of the solenoid behaves as a magnetic north pole, while the other behaves as the South Pole.
The field lines inside the solenoid are in the form of parallel straight lines.
This indicates that the magnetic field is the same at all points inside the solenoid.
That is, the field is uniform inside the solenoid.



Rules for Determining Direction of Magnetic Field:
Right hand thumb rule for straight conductors
If a straight conductor is grasped in the palm of right hand with the thumb pointing along the direction of current flow, then the direction of the curled fingers point in the direction of the magnetic field.



Right hand thumb rule for circular conductors
If the direction of the circular current coincides with the direction of the curled fingers then the thumb points in the direction of the magnetic field.

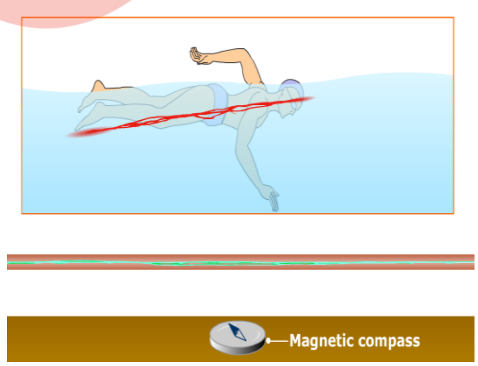


Maxwell's cork screw rule

If the direction of a linear motion of a cork screw represents the direction of the current through the conductor, then the direction of rotation of the cork screw gives the direction of the magnetic field.

Ampere's swimming rule

If a man swims along the wire carrying current such that his face is always towards the magnetic needle with current entering his feet and leaving his head, then the north pole of the magnetic needle is always deflected towards his left hand.



Magnetizing a Material:

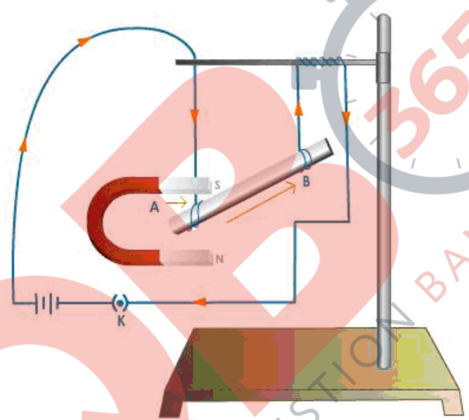
The process of converting a material into a magnet is called magnetizing.

Once magnetized the material is capable of exhibiting magnetic properties.

Permanent Magnets:
If the material which is magnetized does not lose its magnetic properties, it becomes a permanent magnet.
Steel exhibits this property.

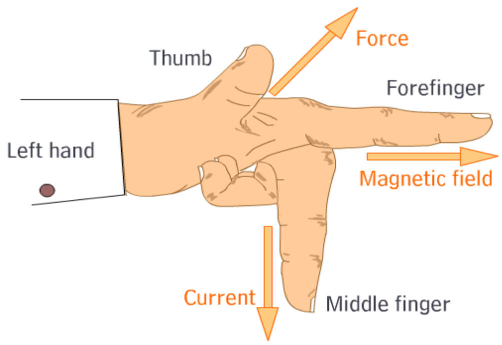
Electromagnets and Its Uses:
A strong magnetic field produced inside a solenoid can be
Used to magnetize a piece of magnetic material, like soft iron, when placed inside the coil.
The magnet so formed is called an electromagnet.
Electromagnets are used in electric bells, loudspeakers, telephone diaphragms and electric fan.
Giant electromagnets are also used in cranes to carry materials in bulk.

Force on Current Carrying Conductor in a Magnetic Field



A current carrying conductor experiences a force when placed in a magnetic field.
The direction of force is reversed when the direction of current in the conductor is reversed.

Fleming's Left Hand Rule



According to Fleming's left hand rule, when the thumb, forefinger and middle finger of the left hand are held mutually perpendicular to each other, with the forefinger pointing in the direction of the magnetic field and the middle finger in the direction of the current, then, the thumb points in the direction of the force exerted on the conductor.

Electric Motor

An electric motor is a device which converts electrical energy into magnetic energy.

DC Motor

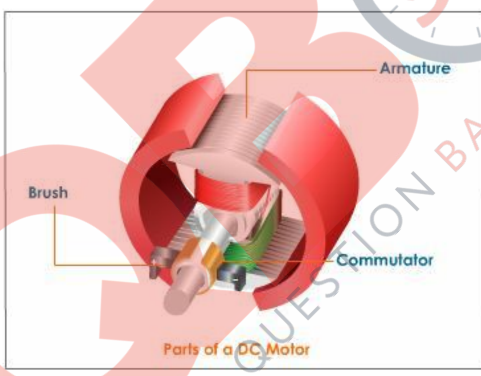
Principle

When a rectangular coil carrying current is placed in a magnetic field, a torque acts on the coil which rotates it continuously.

When the coil rotates, the shaft attached to it also rotates and thus it is able to do mechanical work.

Construction and Working

Parts of a DC Motor



Armature

A D.C. motor consists of a rectangular coil made of insulated copper wire wound on a soft iron core. This coil wound on the soft iron core forms the armature. The coil is mounted on an axle and is placed between the cylindrical concave poles of a magnet.

Commutator

A commutator is used to reverse the direction of flow of current. Commutator is a copper ring split into two parts C_1 and C_2. The split rings are insulated from each other and mounted on the axle of the motor. The two ends of the coil are soldered to these rings. They rotate along with the coil. Commutator rings are connected to a battery. The wires from the battery are not connected to the rings but to the brushes which are in contact with the rings.

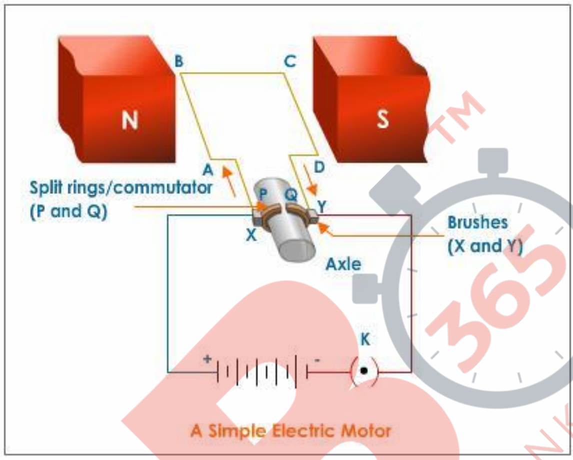
Brushes

Two small strips of carbon, known as brushes press slightly against the two split rings, and the split rings rotate between the brushes.

The carbon brushes are connected to a D.C. source.

Working of a DC Motor

When the coil is powered, a magnetic field is generated around the armature. The left side of the armature is pushed away from the left magnet and drawn towards the right, causing rotation.



When the coil turns through 90^0, the brushes lose contact with the commutator and the current stops flowing through the coil.

However the coil keeps turning because of its own momentum.

Now when the coil turns through 180^0, the sides get interchanged. As a result the commutator ring C_1 is now in contact with brush B_2 and commutator ring C_2 is in contact with brush B_1. Therefore, the current continues to flow in the same direction.

The efficiency of the DC Motor Increases by:

Increasing the number of turns in the coil.

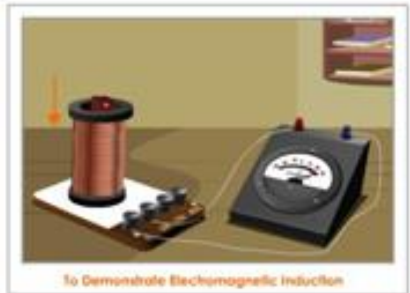
Increasing the strength of the current.

Increasing the area of cross-section of the coil.

Increasing the strength of the radial magnetic field.

Electromagnetic Induction

The phenomenon by which an emf or current is induced in a conductor due to a change in the magnetic field near the conductor is known as electromagnetic induction.



Michael Faraday the English scientist was the first person to prove that a magnet can create a current.

To test this he moved a magnet towards and away from the coil of wire connected to a galvanometer.

He observed that there was a deflection in the galvanometer indicating that a current is induced in it.

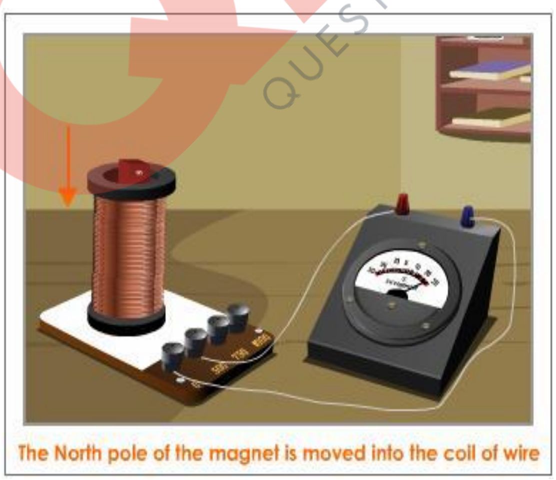
The current obtained due to the relative motion between the coil and the magnet is called induced current.

The phenomenon by which an emf or current is induced in a conductor due to change in the magnetic field near the conductor is known as electromagnetic induction.

Faraday arrived at a few conclusions by moving a bar magnet in and out of the coil of wire.

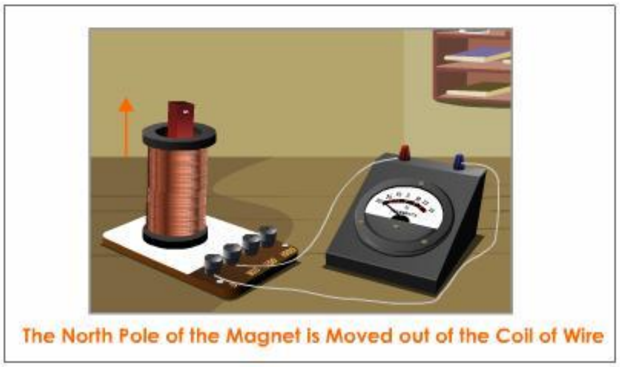
Some of the experiments performed by Faraday and his observations are tabulated here. Go through them.

Experiment



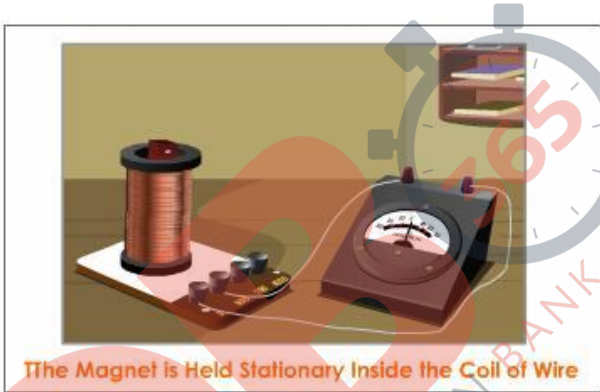
Observation

Deflection in the galvanometer indicates that the current is induced in the coil due to the relative motion between the magnet and the coil.



Observation

The deflection in the galvanometer is reversed when the same pole of the magnet is moved in the opposite direction.



Observation

The galvanometer pointer comes back to the zero position indicating that the deflection in the galvanometer lasts as long as there is relative motion between the magnet and the coil.

Observation

The deflection in the galvanometer is reversed when the opposite pole is moved in the same direction.

Observation

The deflection in the galvanometer changes with the change in number of turns of the coil - more the number of turns in the coil greater the deflection. The magnetic field goes around each loop of wire in the coil, so if we increase the number of coils the change in magnetic field is more.

The magnet is moved faster in and out of the coil. The deflection is more if the magnet is moved faster. That is, the rate at which the current is induced is more when the magnet is moved faster.

Mutual Induction

The phenomenon of production of induced emf in one coil due to change of current in a neighboring coil is called mutual induction. Let us perform an experiment to understand this.

Place two coils P and S close to each other as shown here.

Connect a battery and a key to the primary coil P and connect the secondary coil S to a sensitive galvanometer G.

Whenever the key is pressed or released the galvanometer shows a deflection.

Now observe the deflection of the galvanometer needle by pressing and releasing the key.

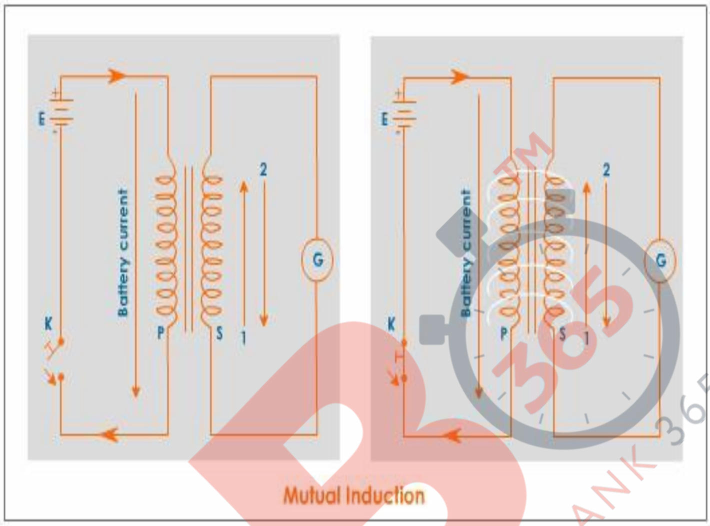
The needle deflects because the current flowing through the primary coil induces a current in the secondary coil.

How does Mutual Induction Occur?

When the key K is pressed, current starts flowing through the coil P and this increases the magnetic flux linked with P.

Since S is very close to P, the magnetic flux linked with S also increases. Thus induced emf, hence induced current is produced in S.

The direction of induced current in S is given by the arrow marked 1, in accordance with Lenz's law.

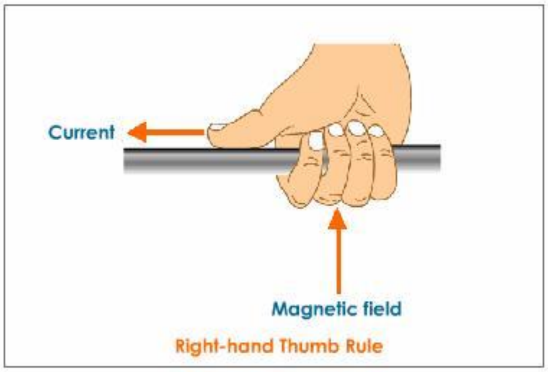


Similarly, when the key is released, magnetic flux associated with the coils decreases and this gives rise to induced current in the direction shown by the arrow marked 2.

That is mutual induction is the production of induced emf in the secondary coil during the time of make or break of current in the primary coil.

Rules for Determining the Direction of Induced Current

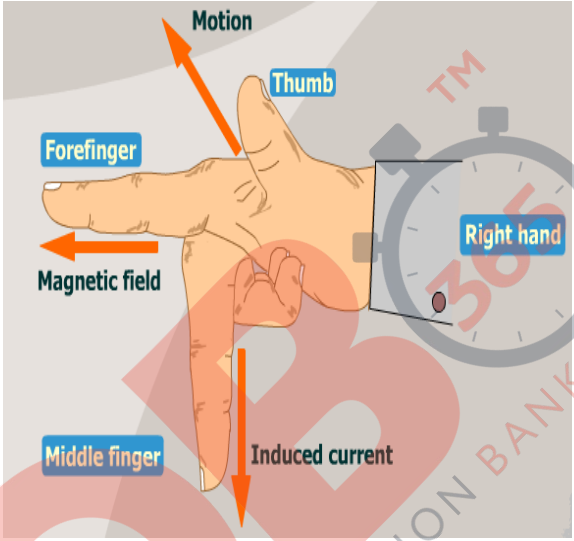
The direction of induced current can be determined by using Fleming's Right Hand Rule.



Stretch the forefinger, the middle finger and the thumb of the right hand, such that they are mutually perpendicular to each other. If forefinger indicates the direction of the magnetic field, the

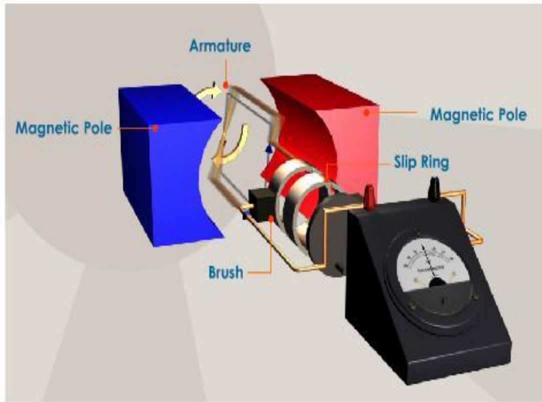
thumb indicates the direction of motion of the conductor, then, middle finger indicates the direction of induced current in the conductor.
The electric generator works on the above explained phenomenon.

Fleming's Right Hand Rule
Fleming's Right Hand Rule – Stretch the forefinger, the middle finger and the thumb of the right hand, such that they are mutually perpendicular to each other. If forefinger indicates the direction of the magnetic field, thumb indicates the direction of motion of the conductor, then the middle finger indicates the direction of induced current in the conductor.



Electric Generator (AC)
The electric generator converts mechanical energy into electrical energy.
The two types of generators are DC and AC generators:
DC Generators - A cycle dynamo and a car dynamo are examples of DC generators. They produce DC.
AC Generators - AC Generators or alternators are used in power stations and industries to produce AC.
AC Generator
Principle
When a straight conductor is moved rapidly in a magnetic field, then a current is induced in the conductor. It is based on the phenomenon of electromagnetic induction.

Construction
Main Parts of the AC Generator
An AC generator consists of a magnet with concave cylindrical poles, an armature, and a current collecting arrangement.
The current collecting arrangement consists of slip rings and brushes.



Parts of an AC Generator

Armature is a soft iron core on which a coil having a large number of turns of insulated copper wire is wound. Magnetic poles are concave and cylindrical. The concave poles produce a radial magnetic field.

The ends of the armature are connected to two slip rings. They rotate along with the coil. The slip rings are made of metal and are insulated from each other.

There are two brushes B_1 and B_2 made of carbon. One end of each brush is in contact with the rotating slip rings and the other end is connected to an external circuit. Here the brushes are connected to a galvanometer and brushes do not rotate with the coil.

The axle is rotated mechanically from outside by a diesel engine, flowing water, steam or high-speed wind.

Working

As the armature rotates about an axis perpendicular to the magnetic field, it keeps on changing its relative orientation with respect to the field.

Thus the flux keeps on changing continuously with time.

This change in magnetic flux induces an emf.

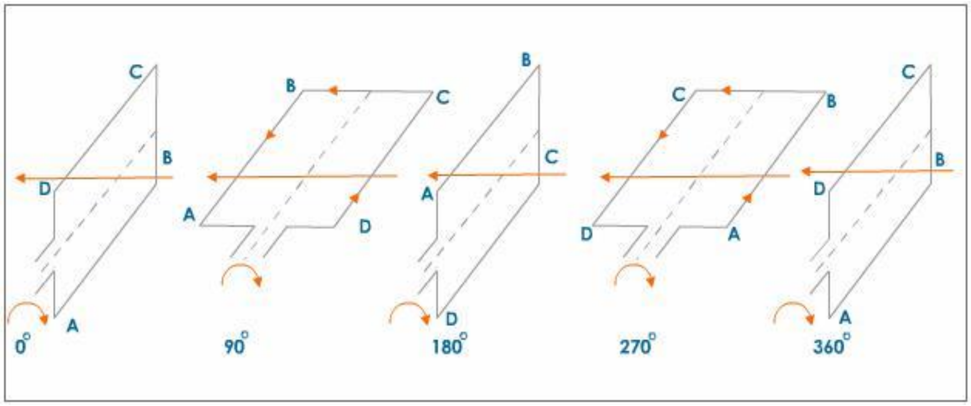
If the outer terminals of the armature are connected to an external circuit, an electric current flows through it.

The deflection of the galvanometer needle indicates that an emf is induced.

The direction of the induced emf is reversed after every half rotation of the coil.

Thus in one rotation of the coil, the current changes its direction twice.

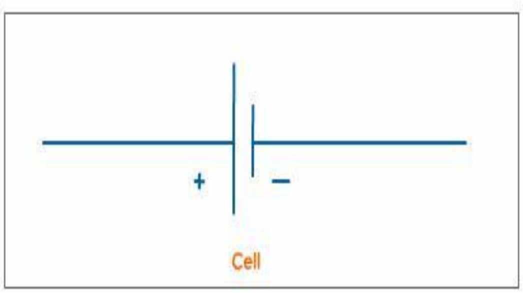
To understand how the direction of current changes go through the diagram given below:



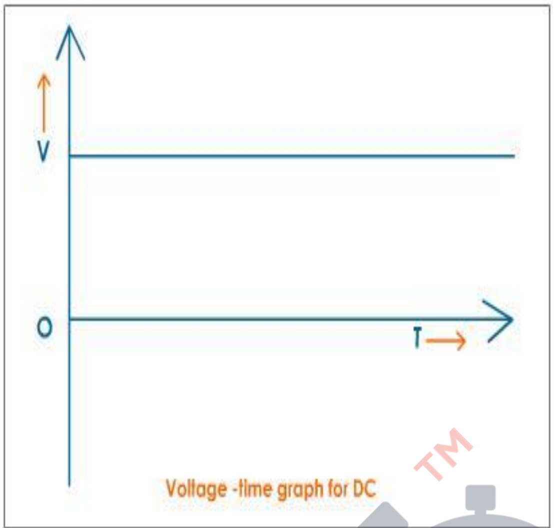
Such a current which changes its direction after equal intervals of time is called alternating current (AC).
To get a direct current (DC) generator a split-ring type commutator must be used. In this arrangement, one brush is at all times in contact with the arm moving up in the field while the other is in contact with the arm moving down. Thus a unidirectional current is produced in such a generator.
The AC current produced in India has a frequency of 50 hertz (Hz). The coil is rotated at the rate of 50 revolutions in 1 second. So in 50 revolutions the current changes its direction 100 times in one second.

DC Generator
The output produced here is unidirectional.
The slip rings are replaced with split rings to achieve this.
To get a direct current (DC) generator a split-ring type commutator must be used. In this arrangement, one brush is at all times in contact with the arm moving up in the field while the other is in contact with the arm moving down. Thus a unidirectional current is produced in such a generator.

Direct Current
When the current flows in the same direction it is called 'direct current' or DC
The current derived from a cell or battery is unidirectional. So it is a DC source.
It is represented in an electrical circuit as:

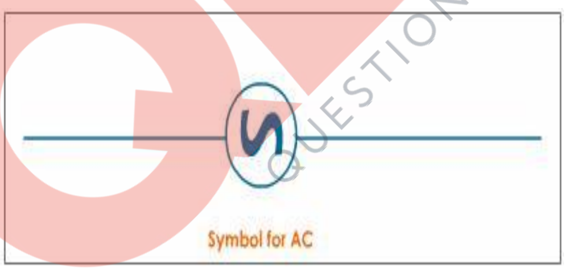


The voltage V/s time graph for a DC source is represented as follows:

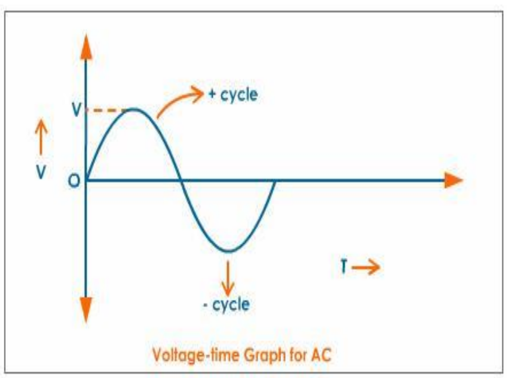


The +ve and -ve terminals are fixed.

Alternating Current:
The current changes its direction after equal intervals of time,
It is called alternating current.
Most of the power stations generate AC current.
It is represented in an electrical circuit as:



The voltage V/s time graph for an AC source is represented as follows:



It has no fixed terminals as the current changes its direction after every half cycle.

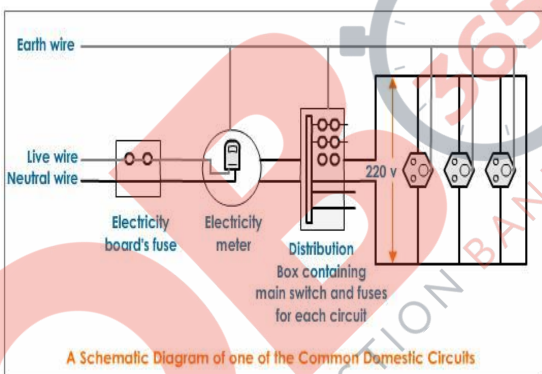
Domestic Electric Circuits:

Electric power is usually generated at places which are far away from the places where it is consumed. At the generating station, the electric power is generated at 11,000 volts. This voltage alternates at a frequency of 50 Hz.

The power is transmitted over long distances at high voltage to minimize the loss of energy in the transmission.

Domestic Wiring:

The electric power line enters our house through three wires- namely the live wire, the neutral wire and the earth wire. To avoid confusion we follow a colour code for insulating these wires. The red wire is the live wire, and the black wire is neutral. The earth wire is given green plastic insulation. The live wire has a high potential of 220 volts whereas the neutral wire has zero potential. Thus the potential difference between the live wire and the neutral wire is 220-0 = 220 volts.



The earth wire is much thicker in size and is made of copper. One end of it is connected to a copper plate buried deep under the earth. The earth connection is made to the electric meter and then to the main switch.

In our homes, we receive supply of electric power through a main supply (mains), either supported through overhead electric poles or by underground cables.

The live wire and neutral wire, coming from the electric pole, enter a box fitted just outside our house which has a main fuse F_1. The fuse is connected in series with the live wire. This is done so because it is only the live wire which has a high potential of 220 volts unlike the neutral wire which carries zero potential. The fuse F_1 has a high rating of about 50 amperes. Thus it prevents any damage such as fire to the entire electrical wiring entering the house due to short-circuit or overloading.

The two wires then enter the electricity meter which records the electrical power consumed by us in kilowatt-hour (kWh). This meter is installed by the electric supply Department of our city.

These two wires coming out of the meter are then connected to a main switch which is placed in a distribution box. Another fuse F_2 is placed in series with the live wire in this box for the sake of consumer safety.

There are two separate circuits in a house namely lighting circuit and power circuit. The lighting circuit with a 5 A fuse is used for running electric bulbs, fan, radio, TV, tube lights etc. and the power circuit with a 15 A fuse is used for running electric heater, electric iron, geyser, refrigerator etc as it draws more current.

The distribution circuits are always connected in parallel combination. In a parallel circuit even if there is a fault or short-circuiting in any one line, the corresponding fuse blows off leaving the other circuits and appliances intact and prevents damage to the entire house.

In case short-circuit occurs in the power circuit, then the power-fuse will blow off but our lights will continue to burn as the lighting circuit remains unaffected.

A constant voltage of the main line is available for all other electrical appliances.

Along with the two wires, a third wire called the earth wire also enters our house as shown in the fig. The earth connection is first made to the electric meter and then to the main switch. This wire then goes into the rooms along with the live and neutral wires.

Electric Fuse:

Electric fuse is a device which is used to limit the current in an electric circuit. The fuse safeguards the circuit and the electrical appliances from being damaged.

The fuse wire is generally an alloy of lead and tin. It has a low melting point and breaks the circuit if the current exceeds a safe value. The thickness and length of the fuse wire depends on the maximum current allowed through the circuit.

It is connected in series in the beginning of the electric circuits.

When the circuit current exceeds a specified value due to voltage fluctuations or short-circuiting, the fuse wire gets heated and melts. Thus it breaks the connection as shown in the figure and no current flows. This prevents damage to the appliance.

Causes of Damage to Electric Circuits:

Overloading

If too many electrical appliances of high power rating (like electric iron, water heater etc) are switched on at the same time, they draw an extremely large current from the circuit. This condition is called overloading and it can cause overheating of the wiring and lead to a fire. It can also happen due to an accidental hike in the supply voltage.

Short-circuiting

In an electric circuit a short - circuit occurs whenever the live wire and the neutral wire come in direct contact. The wires touch may each other due to faulty connection or sometimes due to the wearing off the insulation. This condition leads to overheating of the wires and causes a fire.

Earthing of Electrical Appliances:

To avoid the risk of electric shocks, the metal of an electrical appliance is 'earthed'.

Earthed means to connect the metal case of the appliance to the earth (at zero potential) by means of a metal wire (copper) called the earth wire. One end of the earth wire is buried deep in the earth; the other end of the wire is connected to the three pin socket.

When the electrical appliance is switched on, the metal casing of the appliance will remain at zero potential as it is in contact with the earth wire in the three pin socket. It thus prevents us from an electric shock even if we touch it accidentally.