IGCSE/GCE O-LEVEL

Electromagnetic Effect

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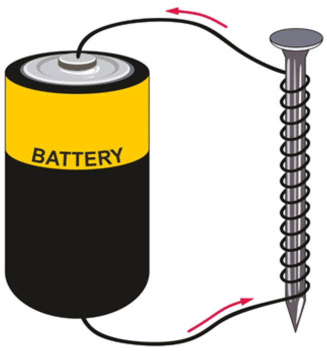
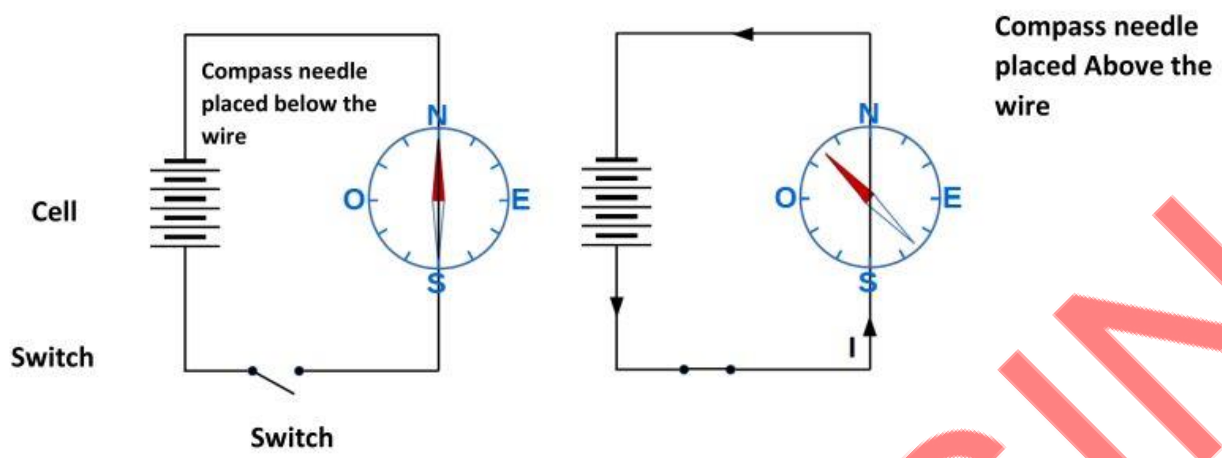
Electromagnetism

A process in which conductor becomes magnet when current passes through it is called electromagnetism.



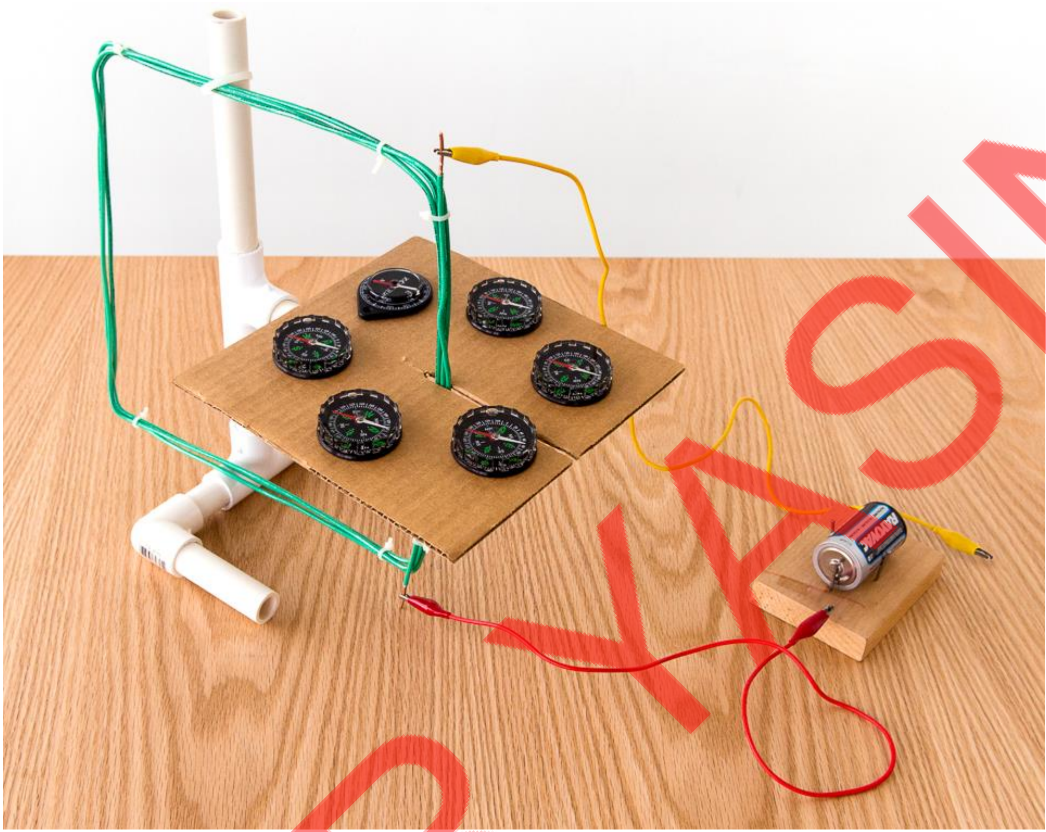
Electromagnet

Conductor which becomes magnet when current passes through it is called an electromagnet.

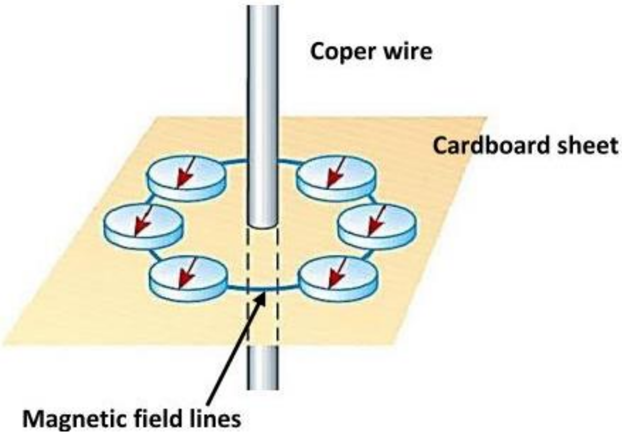


- Let say copper wire is connected to the cell through a switch.
- Initially switch is kept open.
- One of the compass needles placed above the wire and other compass needle is placed below the wire.
- Initially wire is placed in North – South direction.
- Since switch is open, no current will pass through the wire and both the compass needles will be pointed towards North showing that magnetic field is not produced by the wire.
- Now if we close the switch, current will pass through the copper wire and compass needle placed above the wire will be deflected in East direction whereas compass needle placed below the wire will be deflected in west direction showing that magnetic field is produced by the current – carrying copper wire.
- So this experiment shows that conductor produces magnetic field around it when current passes through it and it is demagnetized when current flowing through it is switched off.

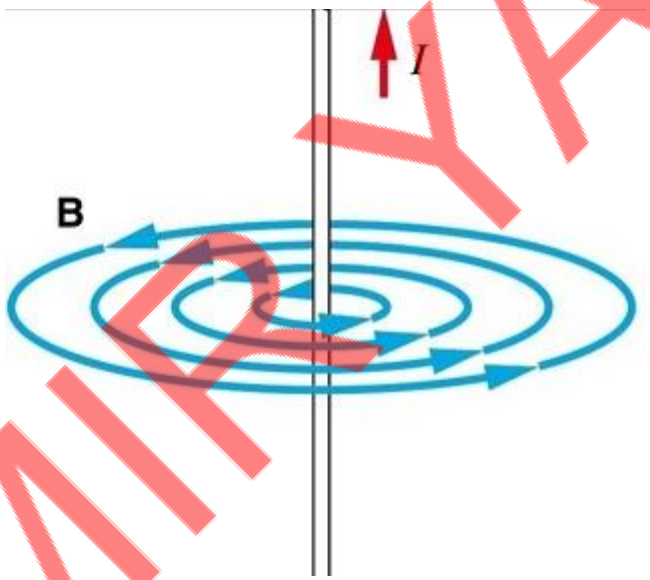
How to plot magnetic field lines around a straight current – carrying wire



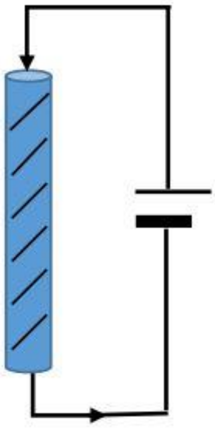
- Make a small hole at the center of rectangular shaped cardboard sheet.
- Pass long straight copper wire through the cardboard sheet such that it is the perpendicular to the cardboard sheet.
- Connect the wire with cell so that current pass through the wire.
- Place a compass needle on the cardboard sheet.
- On the cardboard sheet mark the positions of S and N ends of compass needle with pencil dots X and Y respectively.
- Move the needle so that S end of needle is now on point Y.
- Mark the new position of N end of compass needle with third dot Z.
- Repeat the steps and join all the dot t. Repeat the steps and join all the dots we will get a circle.



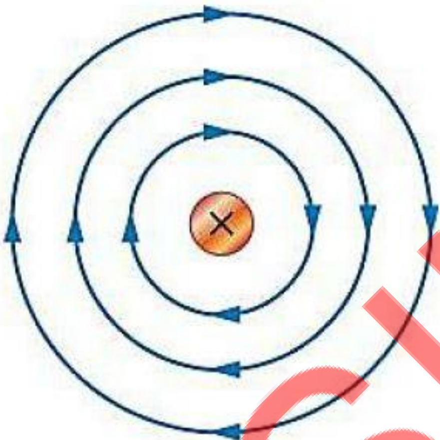
- This experiment shows that magnetic field lines produced by a single current carrying wire are inform of circle.
- Circles near the wire are close to each other representing strong magnetic field. Circles away from the wire are further apart from each other showing weak magnetic field.



Magnetic Field Pattern for a Current Carrying Wire



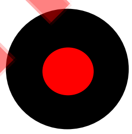
Front View

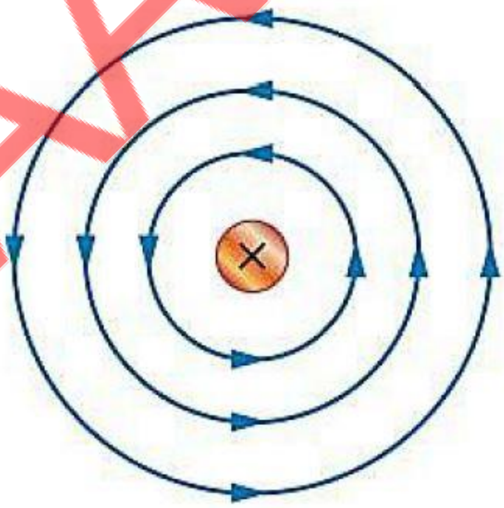


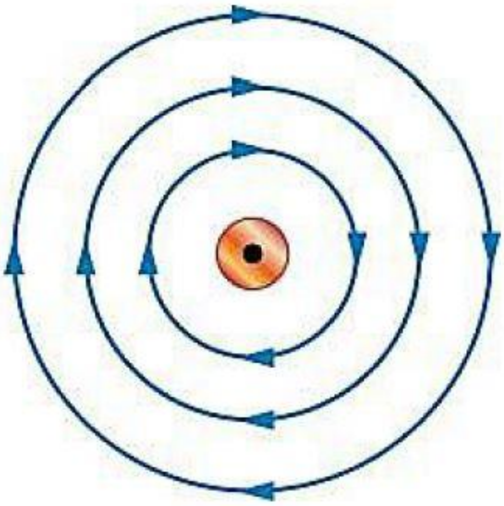
Top View

A copper wire (long and straight) is connected to the cell therefore current will pass through the wire and wire will produce magnetic field around it inform of circles.
Now if we take top view of the copper wire, it will appear as if current is flowing into the wire.
If current is flowing into the wire then it is represented by a cross.

Now if we reverse the direction of current passing through the copper wire then once again magnetic field will be produced by the wire.
Now if we take top view of copper wire then it will appear as if current is flowing out of the wire.
If current is flowing out of the wire then it is represented by a dot.





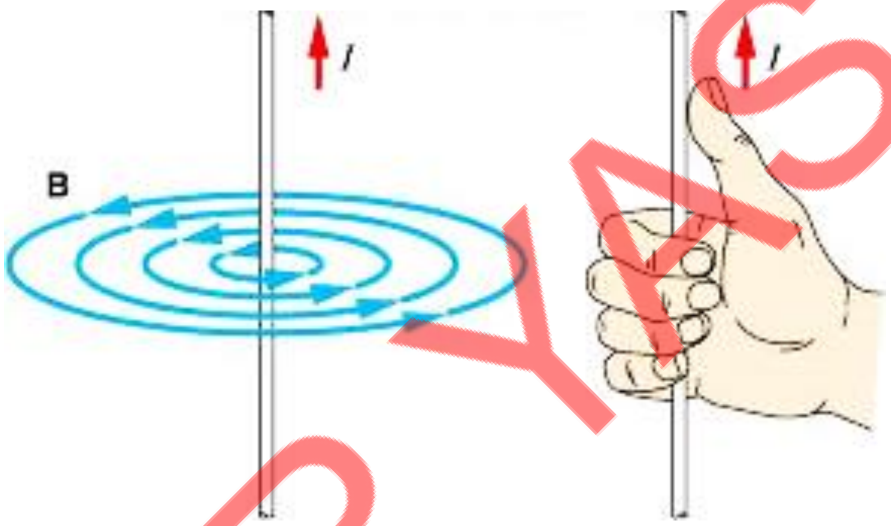


Direction of magnetic field around a current – carrying wire

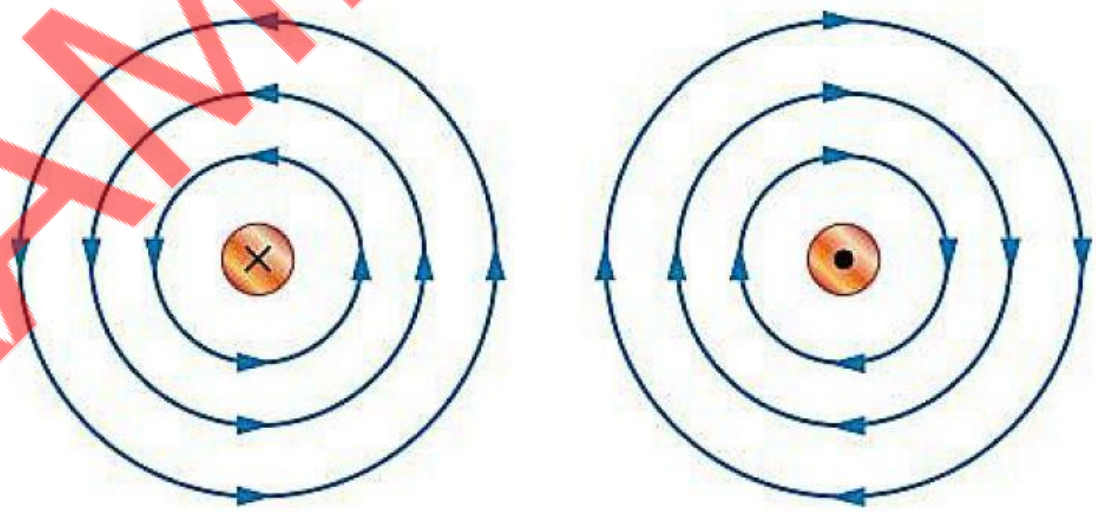
We can find direction of magnetic field around a current carrying wire using Right hand Grip rule.

Right Hand Grip Rule

- Grip the wire in right hand such that thumb represents the direction of flow of current. Now cruel the fingers around the wire.
- Curl fingers will represent the direction of magnetic field around the current carrying wire.



- So by using right hand grip rule we can see that if current is flowing into the wire then circles produced by the magnetic field are in clock-wise direction but if current is flowing out of wire then circles are in anti clock wise direction.



NOTE

Two factors affect the magnetic field around a current-carrying wire:-

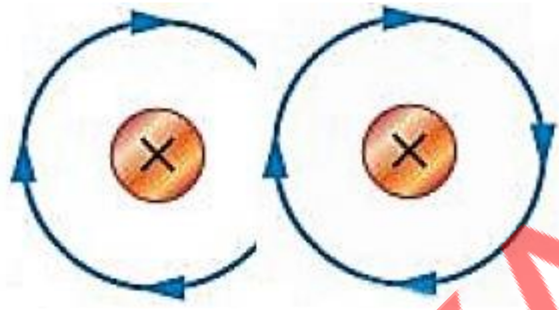
- Direction of Current
- Magnitude of current

If we reverse the direction of current then direction of magnetic field will also get reversed.

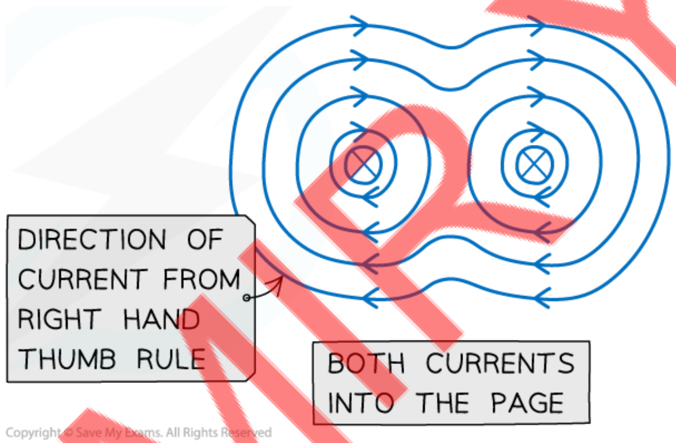
If we increase the current passing through the wire then number of circles around the wire will increase showing that strength of magnetic field is increase.

Magnetic field pattern for two current carrying wires placed near one another

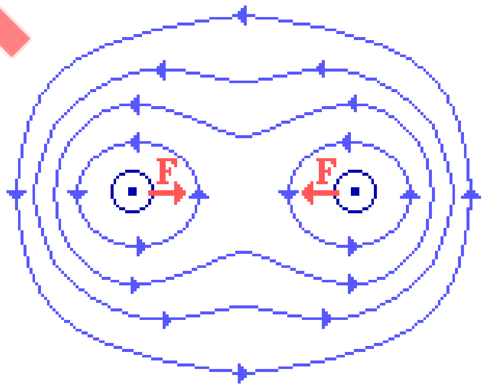
Let say that two current-carrying wires are placed near one another.
Current is flowing into both the wires therefore both the wires will produce magnetic field inform of clockwise circles.

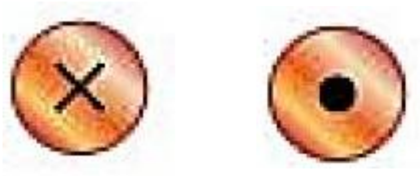


Now when both the magnetic fields will overleap then resultant magnetic field will be as follows

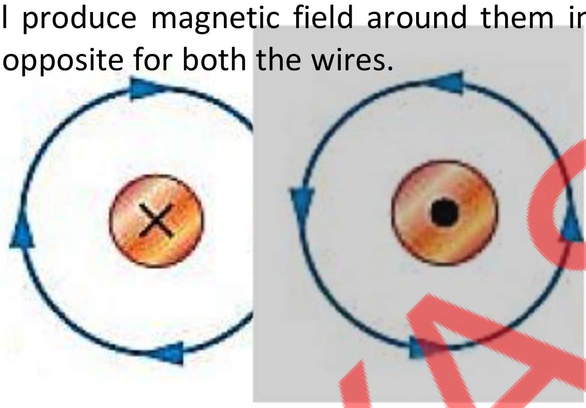


Now if we reverse direction of current through both the wires then pattern of resultant magnetic field will remain the same but direction of magnetic field will get reversed.

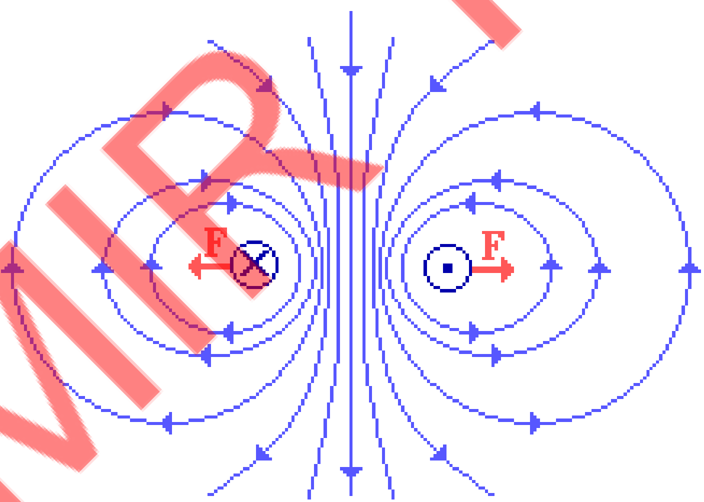




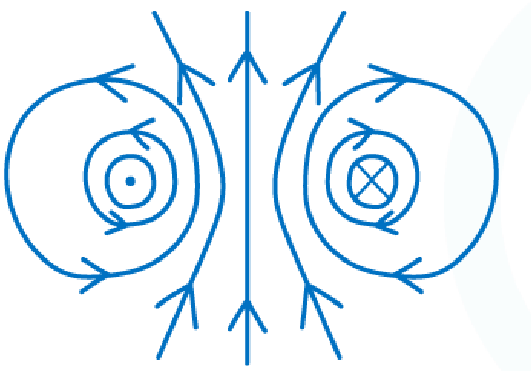
Now let's say two current-carrying wires are placed near one another in such a way that current is flowing in opposite direction through both the wires.
Once both the wires will produce magnetic field around them inform of circle but direction of circle will be opposite for both the wires.



Now when both the magnetic field will overlap then resultant magnetic field will be like that.

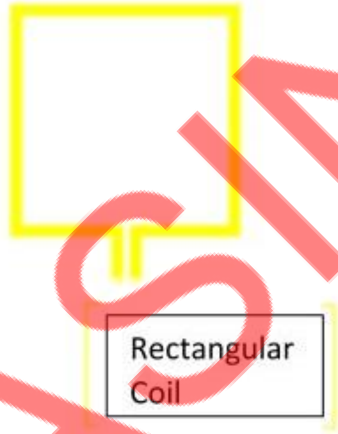


Now if we reverse direction of current through both the wires then pattern will remain same, direction of resultant magnetic field will get reversed.

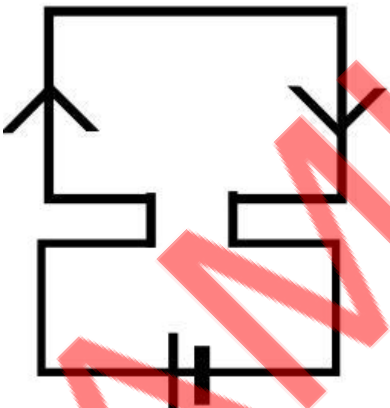


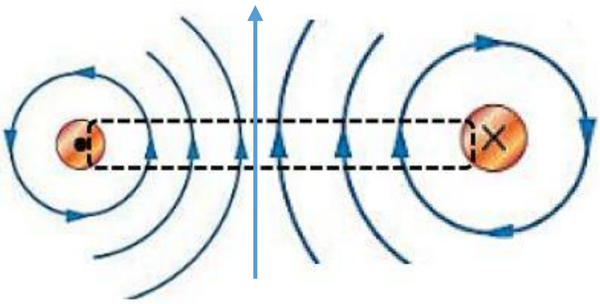
Coil

A single loop of a wire is called a coil.
Since loop can be circular or rectangular therefore coil can be circular or it can be rectangular



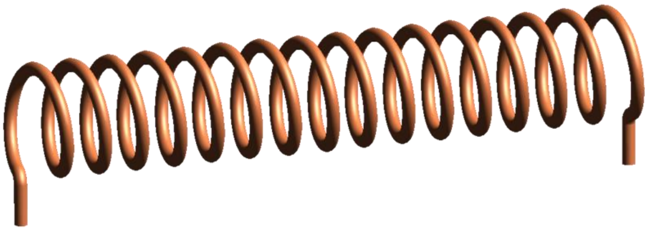
- Let say a rectangular coil is connected to a cell.
- Current will pass through the coil. Coil will become magnetic.
- Magnetic field will be produced by the coil.
- If we plot magnetic field pattern for the coil with respect to top view then magnetic field pattern for the coil will as follows.



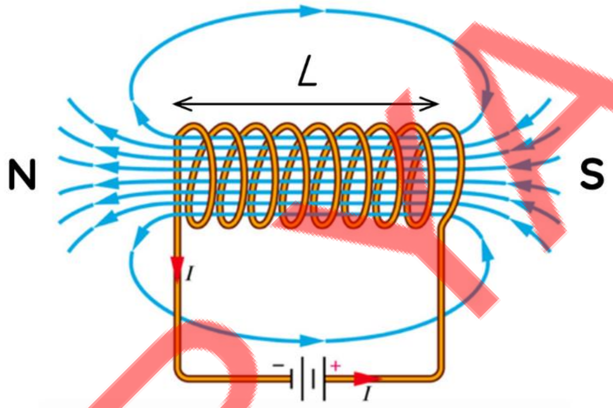


Solenoid

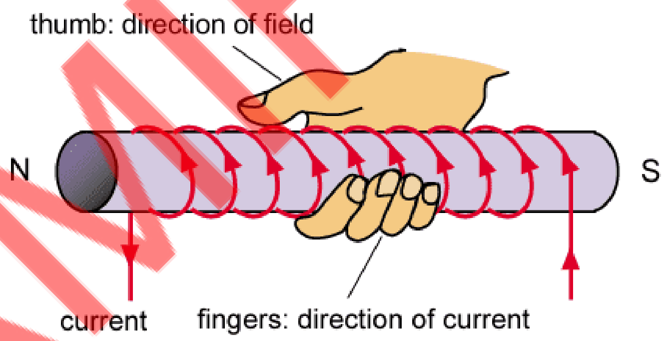
A piece of wire which has large number of loops in it is called a solenoid.
In other words we can say that solenoid consists of large no of coils.
Since coil can be circular or rectangular therefore solenoid can also be circular or rectangular



Since current is passing through the solenoid therefore it will produce magnetic field as follows.



We can find direction of magnetic field inside solenoid by using right hand grip rule.

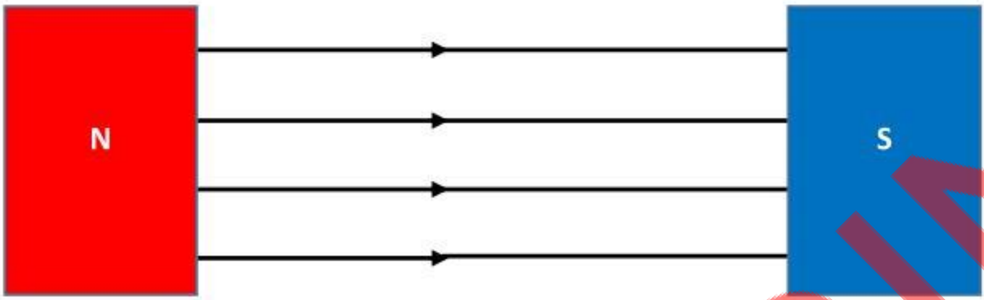


Curl the fingers of right hand in the direction of current passing through the solenoid. Thumb will point the direction of magnetic field inside the solenoid.

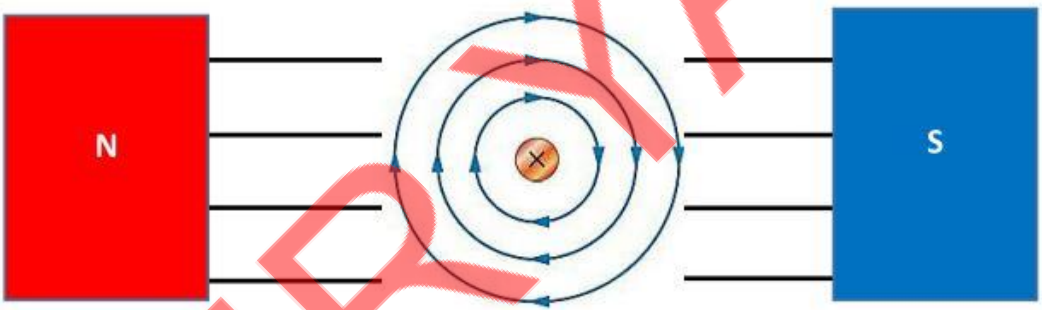
NOTE

1. If we place iron bar (iron-core) inside the solenoid then strength of magnetic field produced by the solenoid will increase because iron bar will also become magnet.
2. We can also increase the strength of magnetic field inside the solenoid by:-
   i. Increasing no of turns of solenoid.
   ii. Increasing the current passing through the solenoid.

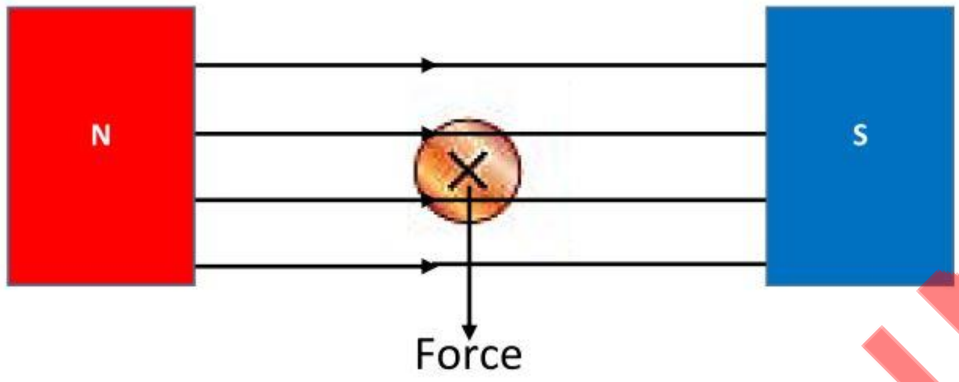
Force exerted by the magnetic field on a current-carrying conductor



- Let say these are North Pole and South Pole of permanent magnet.
- Magnetic field will be produced between the poles of the magnet.
- Magnetic field produced by the permanent magnet is inform field.
- Uniform magnetic field is a strong magnetic field and is represented by straight and parallel lines.

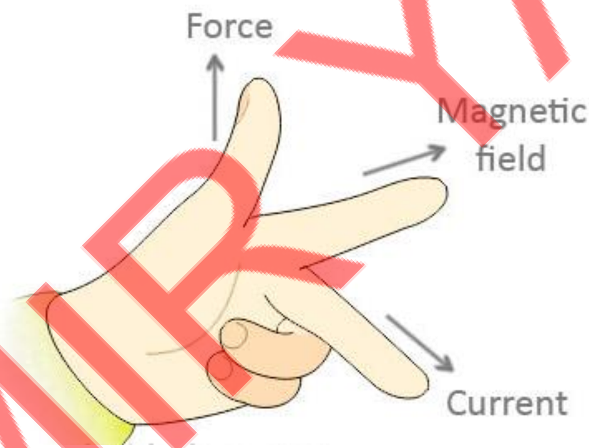


Let say a copper wire is placed perpendicularly inside the magnetic field.
If we pass current through the wire then a magnetic field will be produced by the wire as well.
Magnetic field produced by the wire is non-uniform magnetic field.
Non-uniform magnetic field is a weak field which is represented by circles.
Now since two magnetic fields are laying in the same region therefore both the magnetic field will overlap to produce resultant magnetic field.
The region above the wire will have stronger field whereas region below the wire will have weaker field.
Now when conductor is placed in magnetic field it moves from strong magnetic field to weak magnetic field.
Therefore copper wire will move downwards.
Therefore force is acting on the wire downwards.



So when a current-carrying conductor is placed in a uniform magnetic field then magnetic field exerts a force on the conductor.
Force exerted by the magnetic field is perpendicular to both direction of current and magnetic field produced by the permanent magnet.
We can reverse direction of force by either reversing direction of current passing through conductor or direction of magnetic field produced by the permanent magnet.

Fleming's Left Hand Rule



We can find (Label) direction of force exerted by the magnetic field on a current-carrying conductor by using Fleming's left hand rule.
First of all 1st finger, 2nd finger and thumb of left hand are placed perpendicularly with respect to each other.
First finger is pointed in the direction of magnetic field produced by the permanent magnet.
Second finger is pointed in the direction of current passing through the conductor
Thumb automatically represent the direction of force acting on the wire.

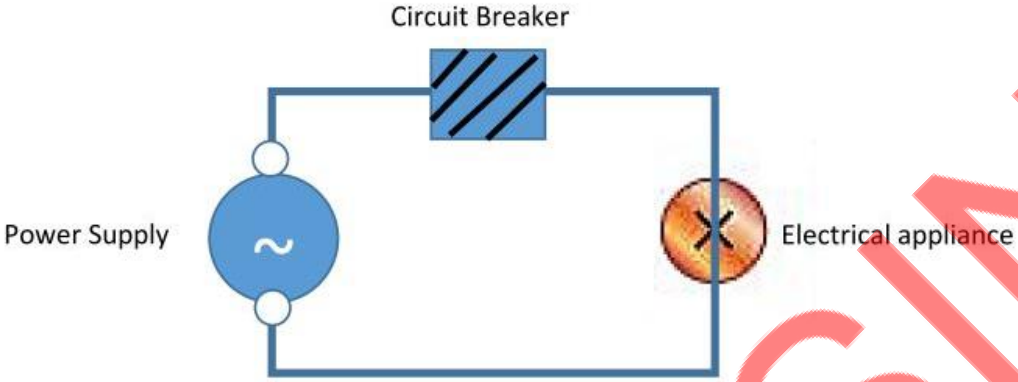
NOTE

Force exerted by the magnetic field on a current-carrying wire depends upon three things:-

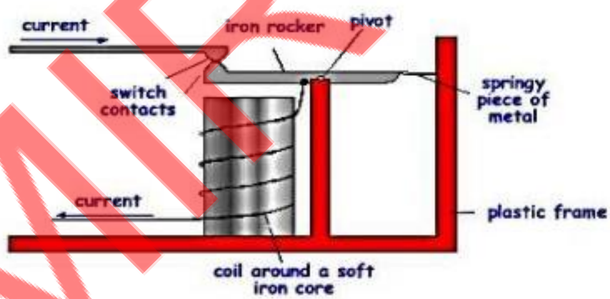
i) Length of wire lying inside the magnetic field.
ii) Current passing through the wire.
iii) Strength of magnetic field produced by the permanent magnet.

Uses of Magnetic and Electromagnets

1. Circuit Breaker



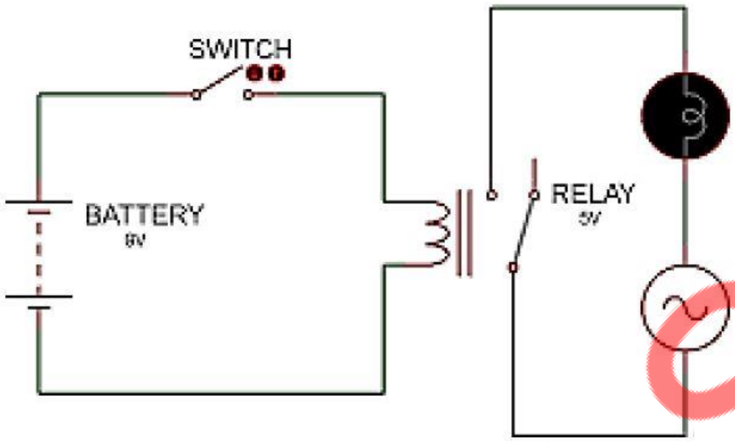
- When current above certain value passes through circuit breaker then it disconnects the flow of current passing through electric circuit and thus prevents electrical appliances from getting damaged.
- For example of current rating of circuit breaker is 5A then as long as 5A current will pass through the circuit breaker it will allow the current to pass through it and electrical device but if current exceeds 5A then circuit breaker will disconnect the flow of current through the electrical device.
- After removing the fault we can reset the circuit breaker and once again current will pass through the circuit breaker and electrical device.



- The current in the circuit flows through the switch and coil.
- When current is small, the electromagnet is not strong enough to pull the steel cylinder down.
- When current exceeds the certain value then coil pulls cylinder down and opens the switch so that current does not pass through the electric circuit.
- The trip is reset by passing down the lever arm through a switch to close the circuit once again.

2. Relay

It is operated on small current and automatically switches on / switches off another device which is being operated on large current.

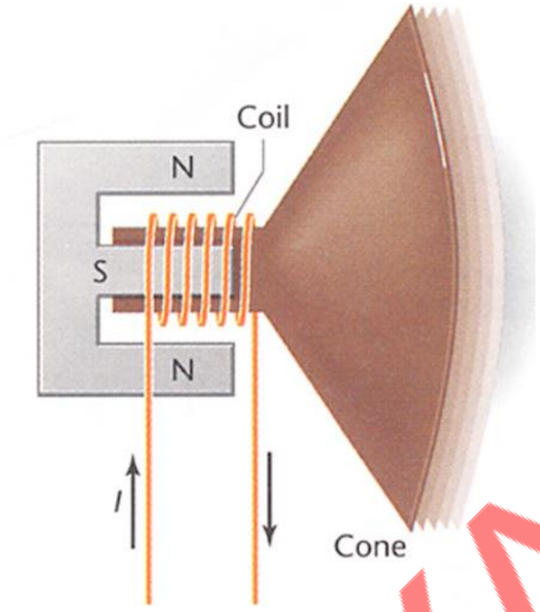


Circuit A Circuit B

- Relay is connected in circuit A having small current whereas Air Conditioner is connected in the circuit B which has large current in it.
- When switch of circuit A is closed then metal cylinder of relay becomes magnet which pull one end of the metal lever.
- The other end of lever closes the spring contacts of circuit B due to which current passes through A.C.
- Now if current passing through relay is switched off then once again gap will be produced between the springy contact of circuit B and A.C will automatically switched off.

3. Loud Speaker

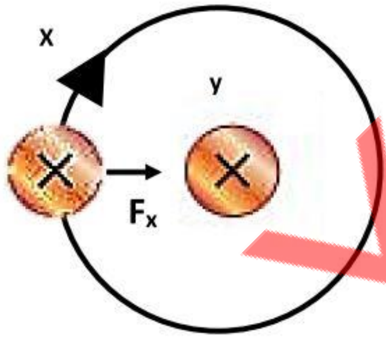
Loudspeaker converts electrical energy into sound energy.



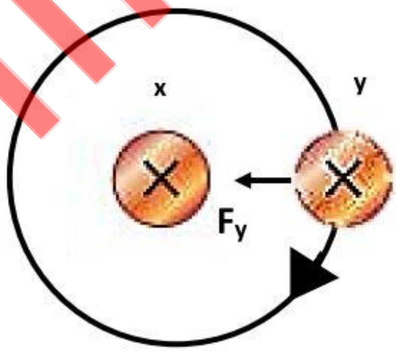
- When alternating current passes through the coil placed inside permanent magnet the coil continuously compressed and stretches due to force acting on it.
- The vibrating coil is then connected to stiff paper cone.
- When paper cone moves backward and forward in air then compression and rarefaction are produced in air and hence sound is produced.

Force between two parallel current –carrying conductors

- Let's say X and Y are two current carrying conductors (wires) which are paced near one another.
- Let's say current is flowing in the same direction through both the wires.
- Let's say current flowing into both the wires.
- Since current is flowing into both the wires therefore both the wires will produce magnetic field around them and both the wires will lie in each other's magnetic field.

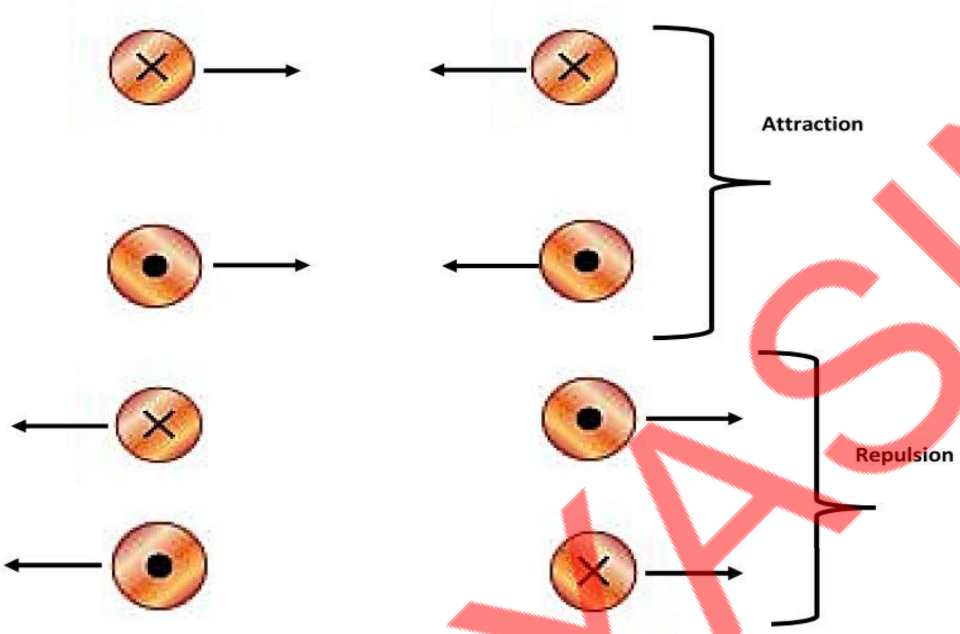


- For example wire X will lie inside the magnetic field produced by the wire Y.
- Since current is flowing into wire Y therefore it will produce magnetic field inform of clockwise circles.
- Now by considering directions of current and magnetic field passing through wire X and Fleming's left hand rule we can find direction of force on wire X.



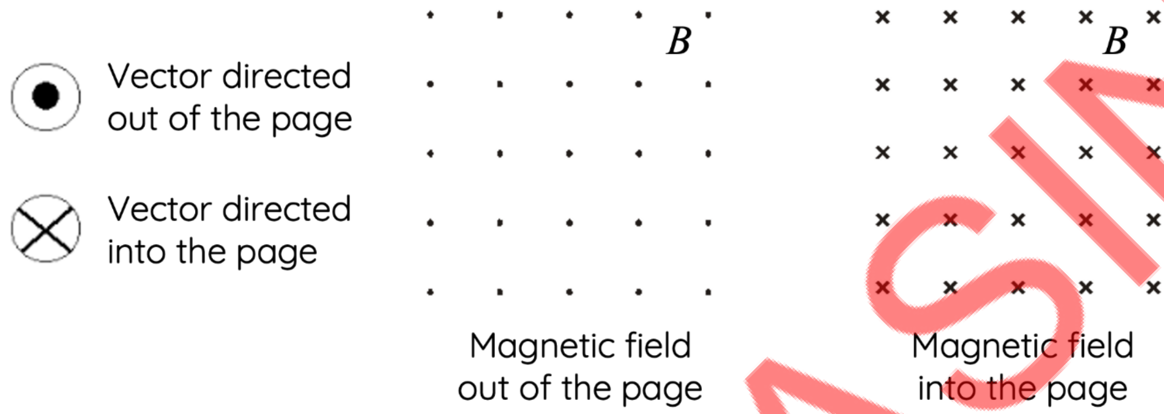
- Similarly wire Y will lie inside the magnetic field produced by wire X.
- Now once again by considering the directions of magnetic field and current passing through wire Y we can label force acting on wire Y using Fleming's left hand rule.
- It means "when two current-carrying conductors are placed near one another then they exert a force on each other".

- If current flowing through both the conductors is in the same direction then conductor exert attraction force on each other i.e conductor attract each other.
- If current flowing through conductor in opposite direction then conductor exert repulsive force on each other i.e. conductor repel each other.

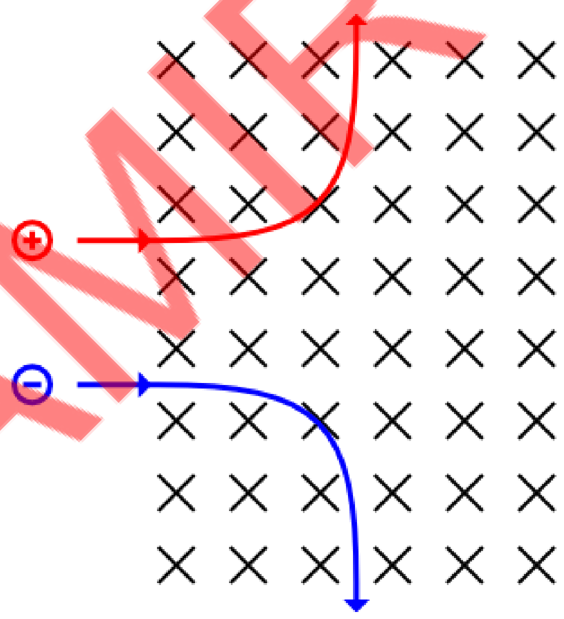


Force exerted by the magnetic field on a moving charge

With respect to top view, magnetic field can be shown using dots or it can be shown using crosses



- When charge passes through the magnetic field then magnetic field exerts a force on the charge.
- Force exerted by the magnetic field on the charge is not only perpendicular to the magnetic field but it is also perpendicular to motion of charge particle.
- We can reverse direction of force by either reversing direction of motion of charge or direction of magnetic field.



We can find direction of force by using Fleming's left hand rule.

Fleming's Left Hand Rule

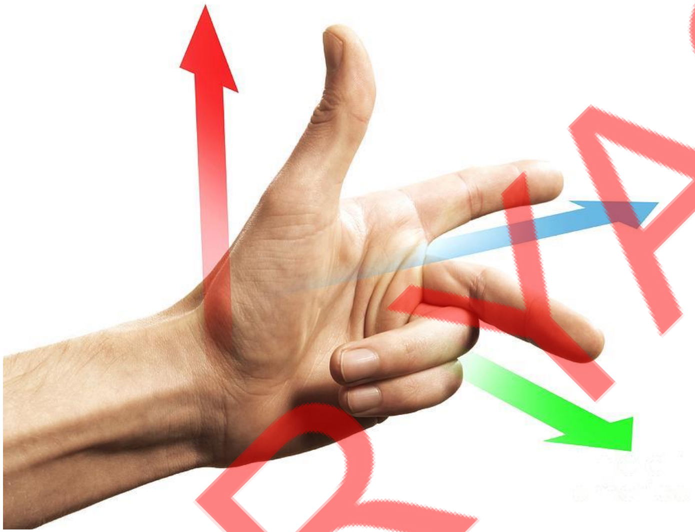
We can find (Label) direction of force exerted by the magnetic field on a charge by using Fleming's left hand rule.

First of all 1st finger, 2nd finger and thumb of left hand are placed perpendicularly with respect to each other.

First finger is pointed in the direction of magnetic field produced by the permanent magnet.

Second finger is pointed in the direction of motion of the charge.

Thumb automatically represent the direction of force acting on the charge.



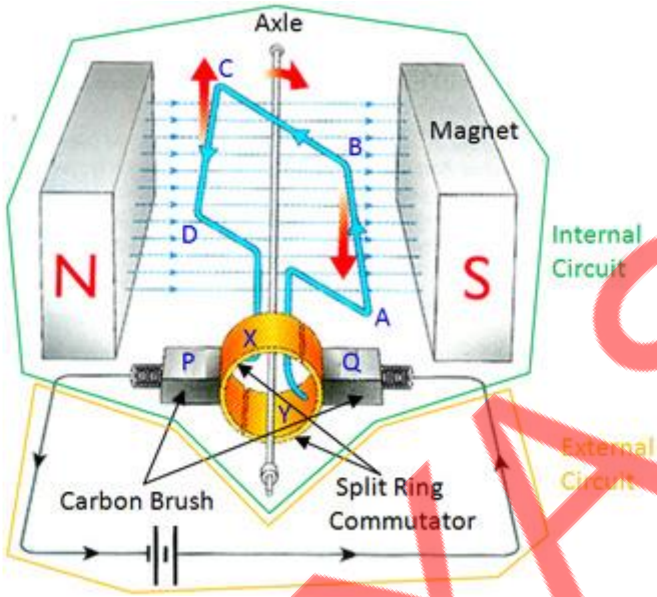
NOTE

1. When charge passes perpendicularly through the magnetic field then speed of charge particle remains constant
2. When charge particle enters perpendicular inside the magnetic field then it moves along the curved path inside the magnetic field and after coming out of magnetic field it once again moves along straight line.
3. Force exerted by the magnetic field on the moving depends upon the speed of charge particles and strength of magnetic field.
4. Magnetic field exerts force on moving charge only i.e it does not exert a force in stationary charge.
5. Magnetic field does not exert a force on charge moving in parallel direction to that of magnetic field.

Direct Current Motor

D.C Motor

A device which converts electrical energy into mechanical energy is called D.C motor. D.C motor works on the principle of turning effect of coil placed in magnetic field.



Parts

D.C motor consists of

- A rectangular coil ABCDA mounted on axle PQ. This rectangular coil rotate about axis PQ.
- A permanent magnet. The rectangular coil is placed between the poles of the permanent magnet.
- Split ring commutators (X & Y) are connected with ends of rectangular coil.
- The commutators rotate with the coil.
- Two carbon brushes (P & Q) which press lightly against the commutators.

Working

- When switch is closed, current passes through the coil.
- Force acts on section AB of the coil in downward direction and force acts on section CD of coil in upward direction.
- Due to these forces coil rotated in anticlockwise direction until it reaches to vertical direction.
- When the coil is in vertical position the current is cut off because the split ring commutator is not in contact with the carbon brushes.
- The momentum of coil carries it past the vertical position.
- When coil once again becomes horizontal then split ring X comes in contact with carbon brush Q and Y comes in contact with carbon brush P.
- Due to this direction of flow of current reversed for sides AB and CD.
- An upward force acts on side AB and downward force acts on side CD.
- Therefore coil continues to rotate in anticlockwise direction.

NOTE

1. In D.C motor the function of split ring commutator is to reverse the direction of flow of current in the coil every half the revolution.
This occurs when commutator changes contact from one brush to other this ensures that the coil will always turn in one direction.

2. The turning effect on a current carrying coil in D.C motor can be increased by:-

i) Increasing the no of turns of the coil.

ii) Increasing the current in the coil.

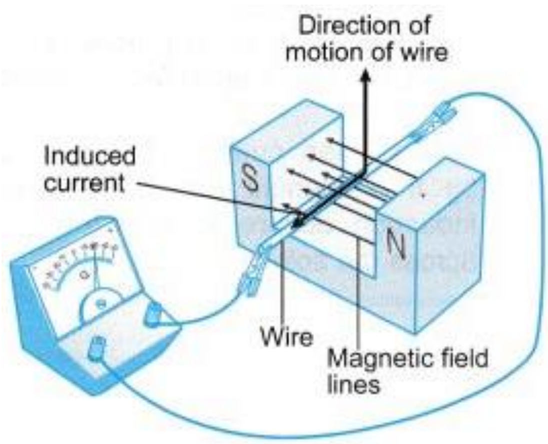
iii) Inserting soft iron core in the coil.

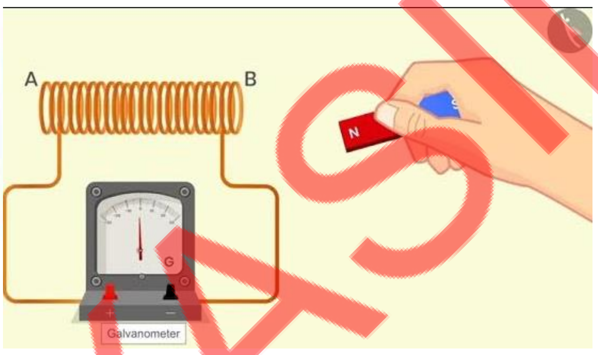
3. D.C motor is usually used in battery operated toys, DVD players and hard disk drives.

Electromagnetic Induction

A process in which EMF is produced by the conductor when magnetic field passing through it changes is called electromagnetic induction.

- E.M.F produced by the conductor is called induced EMF and current generated by the conductor is called induced current.



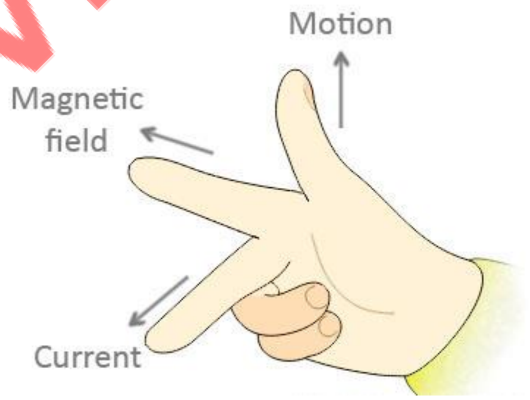


NOTE

1. As long as wire is moved in the magnetic field or bar magnet is moved near the coil, induced EMF is generated by the wire or solenoid but as soon as wire or bar magnetic stops, induced EMF becomes zero.
2. If we reverse the direction of motion of wire or direction of motion of bar magnet then direction of induced EMF will also gets reversed.

Fleming's Right Hand Rule

We can find direction of induced current in this case by using Fleming's Right Hand Rule.



- First of all place first finger, second finger and thumb of right hand perpendicularly with respect to each other.
- Point first finger in the direction of magnetic field produced by the permanent magnet. Point thumb in the direction of motion of wire.
- Second finger will automatically represent the direction of induced current.

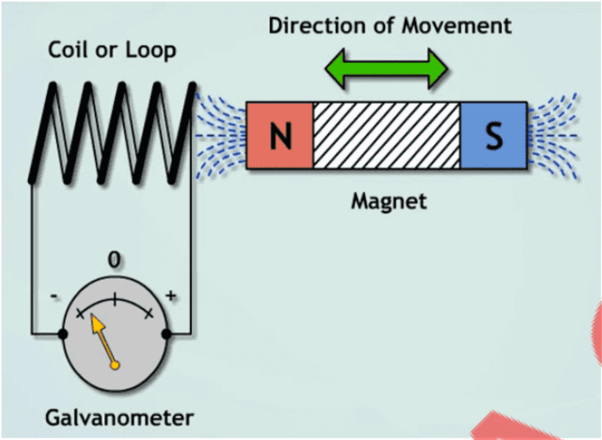
The direction of the induced current is from A to B.

NOTE

We can reverse direction of induced current by either reversing direction of magnetic field or direction motion of wire.

Faraday's Law of Electromagnetic Induction

When magnetic field passing through a conductor changes then conductor produces induced EMF such as that induced EMF is directly proportional to rate of change of magnetic field passing through the conductor.

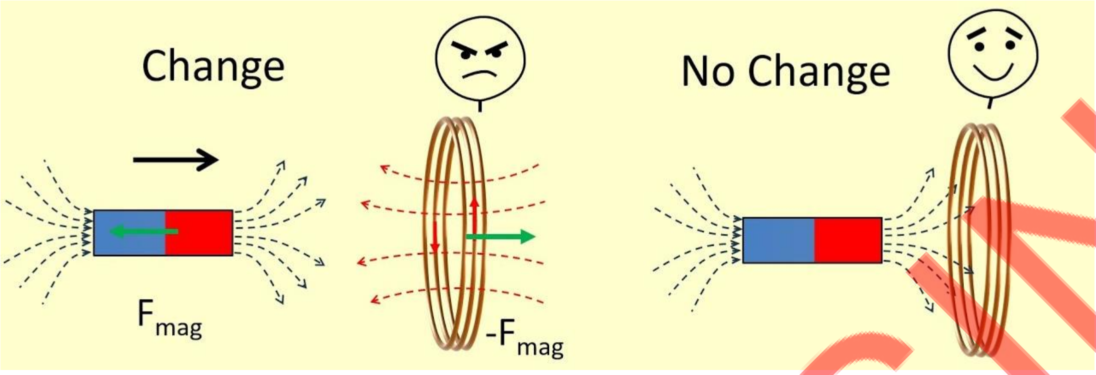


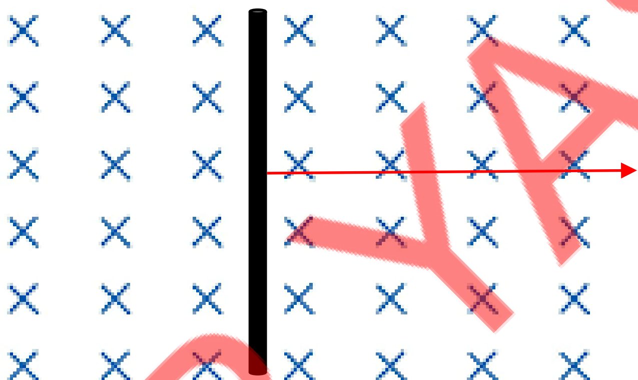
NOTE

1. Induced EMF is produced only when magnetic field passing through the conductor changes.
2. Magnetic field passing through the conductor can be changed in two ways.
   i) Either move conductor within stationary magnetic field.
   ii) or move magnetic field near stationary conductor.

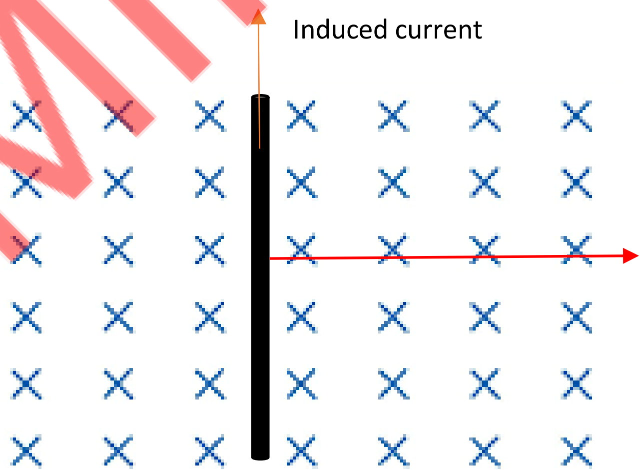
Lenz's Law

Direction of induced current is always such that it opposes its own cause.

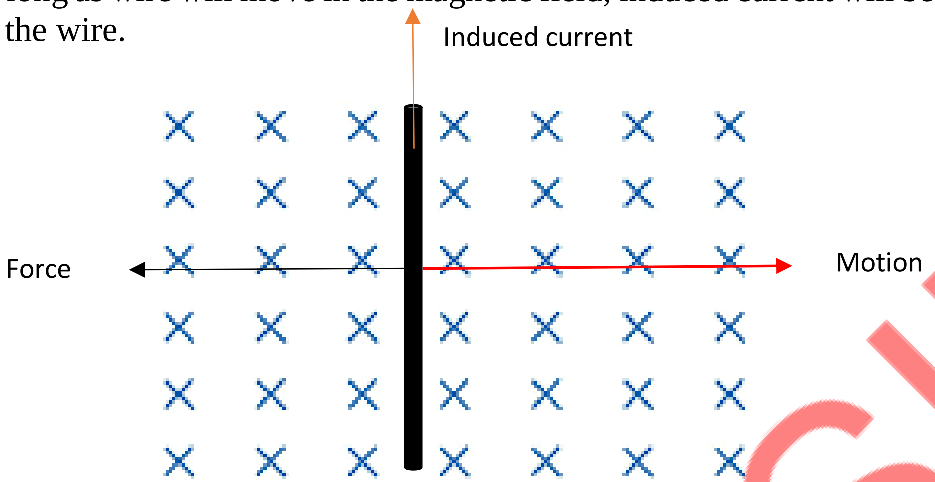




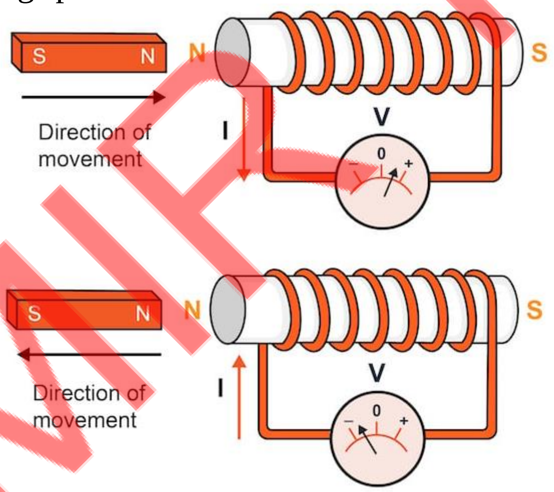
- Let's say straight wire is moved perpendicularly inside the magnetic field which is directed into the plane of paper in rightward direction.
- Induced current will be produced by the wire and cause of induced current in this situation is rightward motion of the wire.



- As long as wire will move in the magnetic field, induced current will be produced by the wire.



- As long as induced current will remain present in the wire, magnetic field will exert a force on the wire which will oppose the cause of induced current i.e rightward motion of the wire.
- So from this example we can see that induced current opposed its own cause which is the statement of Lenz's Law.
- Now we can find direction of induced current for a solenoid by using Lenz's Law and right hand grip rule.



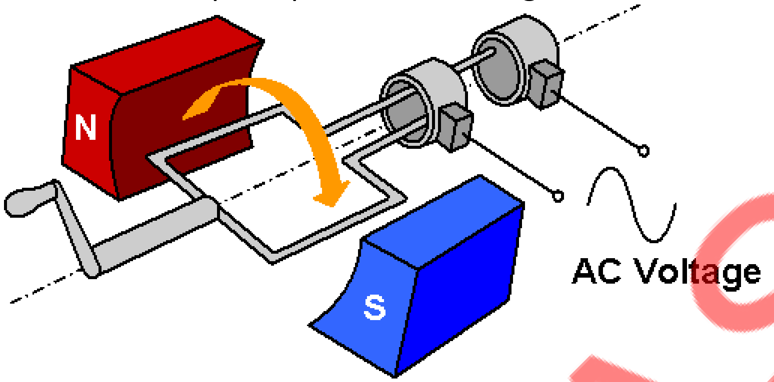
- If we move the bar magnet towards the coil then magnetic field passing through the coil will change and solenoid will produce induced current.
- Since induced current opposes its own cause therefore in this situation leftward motion of magnet will be opposed by induced current.
- For this North Pole will appear on the right side and South Pole will be induced on the left side of the solenoid.
- Now point the thumb of right hand towards the North Pole of solenoid and coil the fingers.
- Curl fingers will represent the direction of induced current passing through the solenoid.

Alternating Current Generator

A.C Generator

A device which converts mechanical energy into electrical energy is called A.C Generator.

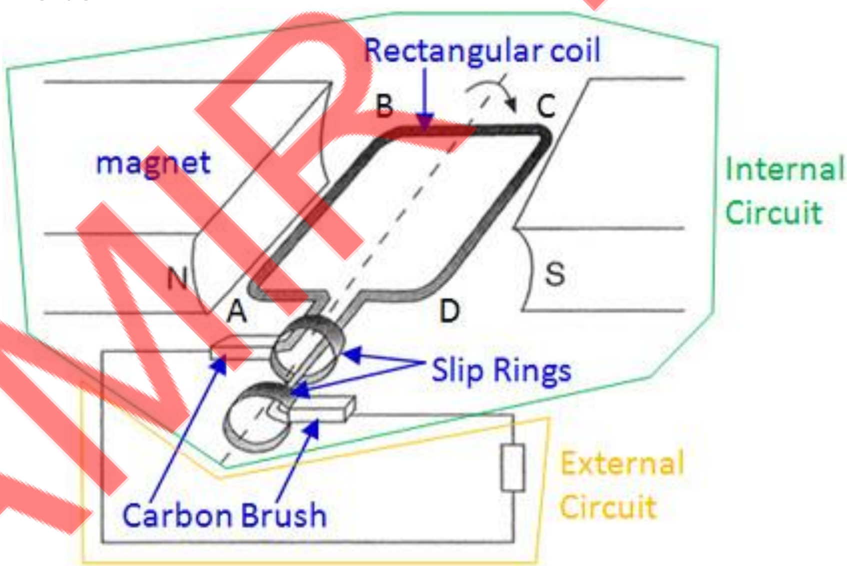
A.C Generator works on the principle of electromagnetic induction.



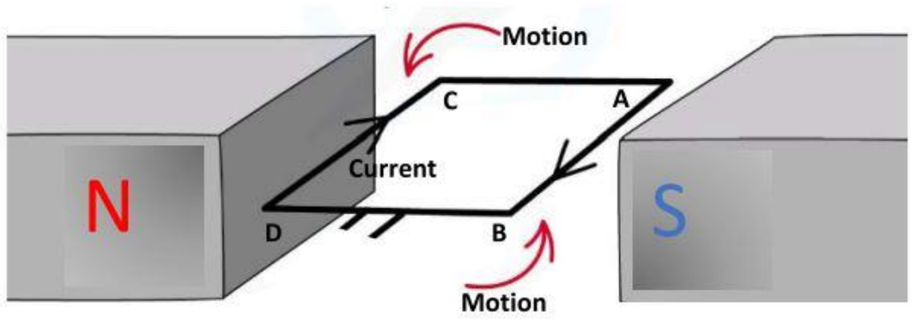
Parts

A.C Generator consists of

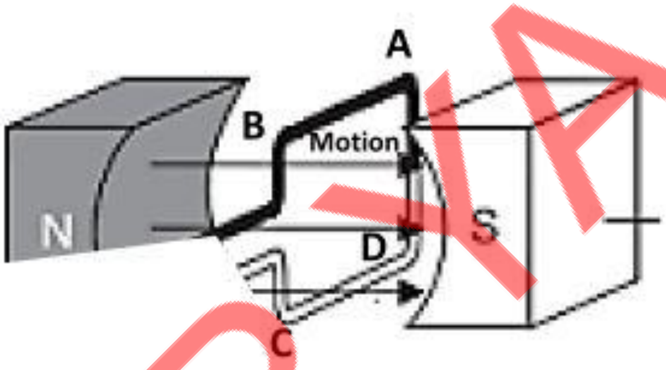
- A rectangular coil
- A magnet
- Slip rings
- Two carbon brush



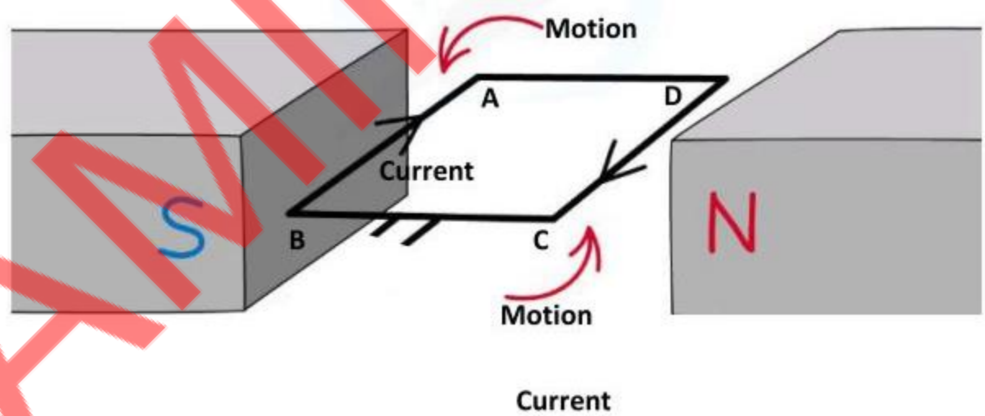
- Rectangular coil ABCD is connected to an axle and placed inside the poles of a permanent magnet.
- One end of coil is connected to slip ring which is pressed against carbon brush A and other end of the coil is connected to other slip ring which is pressed against carbon brush B.



- If we rotate the coil in anticlockwise direction then side AB of coil will move upwards and side CD of Coil will move downwards.
- Current will flow in opposite direction through both sides or current will flow in clockwise direction through the coil.



- After quarter rotation of coil sides AB and CD will move parallel to direction of magnetic field therefore no current will be produced by the coil.



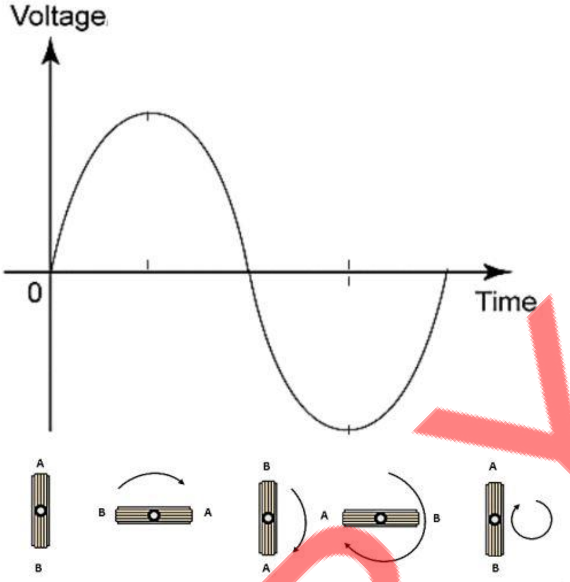
- After half rotation of coil side AB will now move downwards and side CD will move upwards and current will flow in anticlockwise direction with respect to side AB of coil.
- Once again after three quarter rotation of coil, both sides will move in parallel direction with respect to direction of magnetic field.
- No current will be produced by the coil. After one complete rotation of coil, coil will once again will be horizontal and current will be produced by the coil in clockwise direction with respect of side AB of coil.

Factors

Magnitude of current produced by the coil can be increased by:-

- using a coil with more turns
- winding the coil on iron frame
- using stronger magnet
- rotating coil at higher speed

Voltage-time graph for A.C Generator



- Initially when coil is perpendicular with respect to direction of magnet field then no current flows through the coil.
- After ¼ rotation of coil, coil is parallel with respect to magnetic field, rate of change of magnetic is maximum therefore max current is produced by the coil.
- After ½ rotation of coil, once again coil is perpendicular to magnetic field, no current is produced by the coil.
- After ¾ rotation of coil, once again coil is horizontal with respect to the magnetic field, maximum current is produced by the coil but in opposite direction.
- After one complete rotation once again coil is perpendicular and hence no current is produced by the coil.

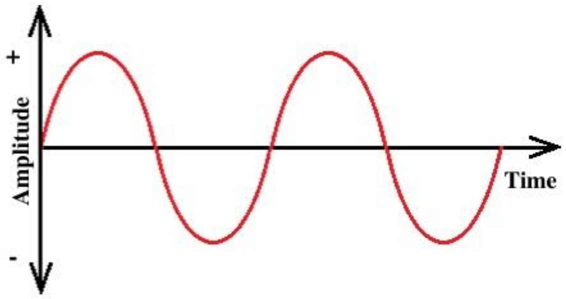
NOTE

Since direction of flow of current reverses after every half rotation of coil therefore A.C is produced by the coil.

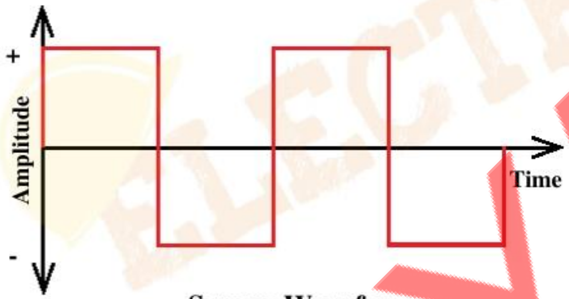
Current in which direction of flow of current reverses after every half cycle is called alternating current.

Alternating Current (A.C)

Current in which direction of flow reverses after every half cycle is called alternating current.



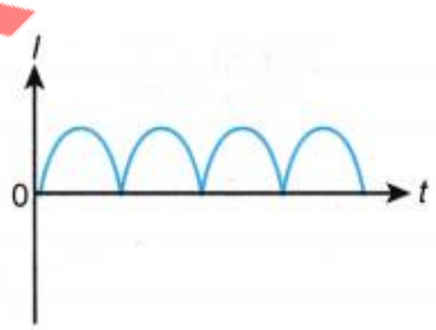
Sinusoidal Waveform



Square Waveform

Direct Current (D.C)

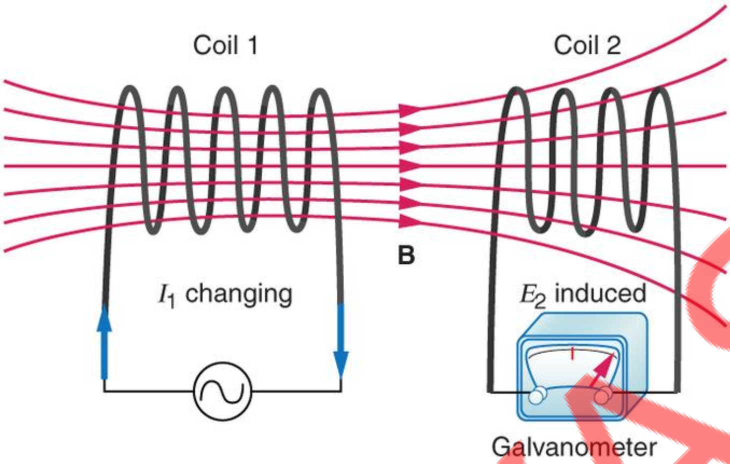
Current in which direction of flow remains uncharged is called direct current.



Mutual Induction

A process in which changing magnetic field of one coil produces induced EMF in a nearby coil is called mutual induction.

- Coil producing changing magnetic field is called primary coil.
- Coil producing induced EMF is called secondary coil.



Transformer

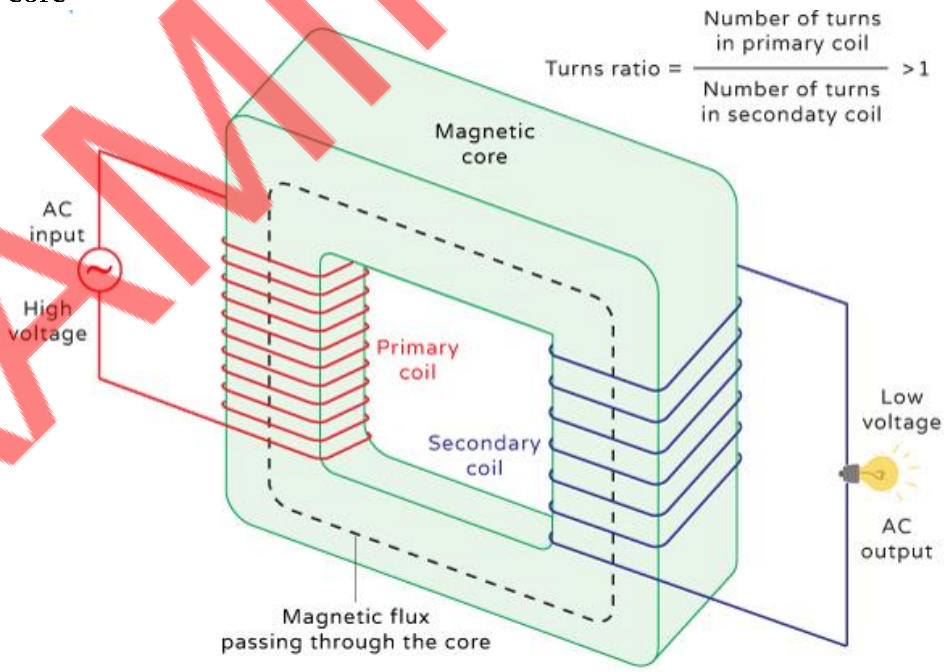
A device which is used increase or decrease the magnitude of voltage is called transformer.

- Transformer works on the principle of mutual induction.

Parts

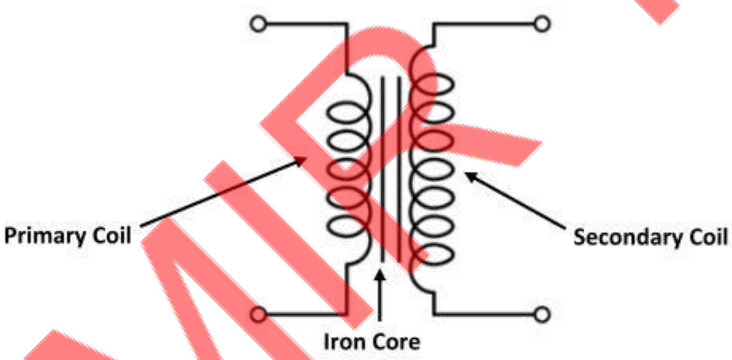
Transformer consists of:

- Primary coil
- Secondary coil
- Iron core



- Iron core consists of number of rectangular iron sheet and insulating material such as glass, plastic or rubber is placed between consecutive iron sheets.
- Primary coil is wound on one side of iron core.
- Primary coil is connected with source of alternating current.
- Primary coil is used to produce changing magnetic field.
- Secondary coil is wound on the opposite side of iron core. Secondary coil is connected with a resistor.
- Secondary coil is used to produce induced EMF/induced current.
- Iron core is used to transfer changing magnetic field produced by primary coil to secondary coil.
- Since both primary and secondary coils are not directly connected to each other therefore electrical energy is transferred from primary to secondary coil through changing magnetic field and changing magnetic field is transferred by iron core from primary to secondary coil.
- If we do not use iron core then there will be magnetic field loss i.e all the magnetic field lines produced by the primary coil will not reach to secondary coil and hence all the electrical energy of primary coil will not reach to secondary coil and hence there will be electrical energy loss.
- So iron core is used to minimum electrical energy loss in the transformer.

Symbol



The above diagram represents the symbol of transformer.
In transformer number of turns of primary and secondary coil are kept different due to which output voltage is either less than or greater than input voltage.

	Primary Coil	Secondary Coil
Number of turns	N_P	N_S
Voltage	V_P	V_S
Current	I_P	I_S

Then

$$\frac{Vs}{Vp} = \frac{Ns}{Np}$$

Let say power loss within transformer is negligible then

$$P_{in} = P_{out}$$

$$V_P I_P = V_S I_S$$

$$\frac{Vs}{Vp} = \frac{Ip}{Is}$$

Similarly

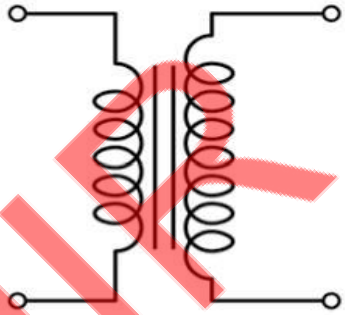
$$\frac{Ns}{Np} = \frac{Ip}{Is}$$

Types of Transformer

Step-Up Transformer

A transformer in which number of turns of secondary coil is greater than that of primary coil and is used to increase the magnitude of voltage is called step up transformer.

In step up transformer output voltage is greater than input voltage but output current is less than that of input current.



$$Ns > Np$$

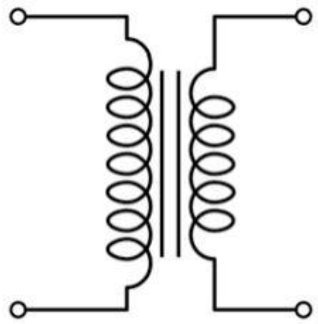
$$Vs > Vp$$

$$Is < Ip$$

Step-down Transformer

A transformer in which number of turns of secondary coil is less than that of primary secondary coil and is used to decrease the magnitude of voltage is called step down transformer.

In step down transformer output voltage is less than that input voltage but output current is greater than input current.



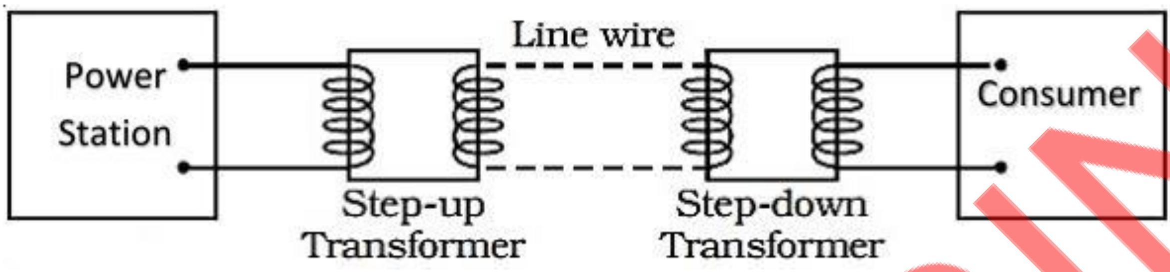
$$Ns < Np$$

$$Vs < Vp$$

$$Is > Ip$$

Transmission of Electricity

Electricity is produced in power station which is very far away from the consumer. Electricity is transferred from power station to consumer through overhead cables.



- When current passes through overhead cables then it losses energy / power due to the resistance offered by the cable.
- Now power lost by the current in the cable can be found by expression.

$$P = I^2R$$

- From above expression we can see that power lost depends upon resistance of cables and current passing through the cable.
- Now resistance of cable is decreased by making them as thick as possible and using a material of low resistivity.
- Current is decreased by using step-up transformer when current decreases than voltage increases.
- So we pass high voltage current through overhead cables using step up transformer.
- Before transferring the electricity to the consumer, it is passed through step down transformer.
- Step down transformer decreased the magnitude of voltage on which electrical devices are operated.