Ch- Magnetic Effects Of Electric Current

Magnet:

A substance which attracts small pieces of iron and points in N-S direction when suspended freely is known as a magnet.

Magnets are of two types : 1- Natural 2- Artificial or Man-made

Magnetic Field:

The space or region around a magnet within which magnetic force is exerted on other magnet is called the magnetic field of the magnet.

Magnetic Force:

The force with which a magnetic pole of a magnet attracts or repels another magnetic pole of another magnet is called magnetic force.

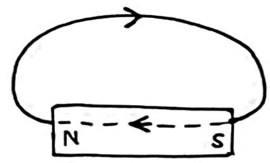
Magnetic Field Line:

The path along which unit north pole moves in a magnetic field is called magnetic field line.

Magnetic field lines are helpful to show the direction & strength of a magnetic field.

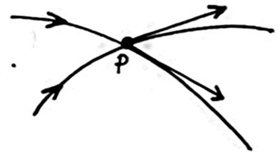
If magnetic field lines are very close to each other in a particular region, then the strength of the magnetic field in that region is very large. On the other hand, if the magnetic field lines are far from each other in a region, then the strength of magnetic field in that region is weak.

Properties of Magnetic Field lines:

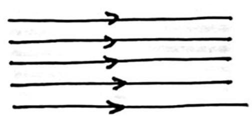


1. Magnetic field lines are closed continous curves.

2. The tangent at any point on the magnetic field lines gives the direction of the magnetic field at that point.

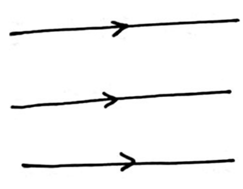


3. No two magnetic field lines can intersect each other.
4. Magnetic field lines are crowded in a region of strong magnetic field. On the other hand, magnetic field lines are far from each other in a region of weak magnetic field.



strong field

5. The direction of magnetic field lines is from N to south pole of a magnet.



Weak field.

Types of Magnetic Fields:

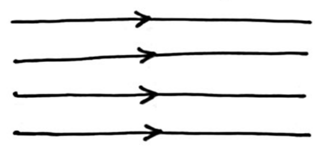
There are two types of magnetic fields:

1. Uniform magnetic field
2. Non-uniform magnetic field

Uniform Magnetic Field:

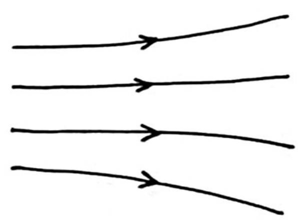
Magnetic field is said to be uniform if its magnitude is equal and direction is same at every point in the space.

Uniform magnetic field is represented by equi-distant parallel straight field lines.



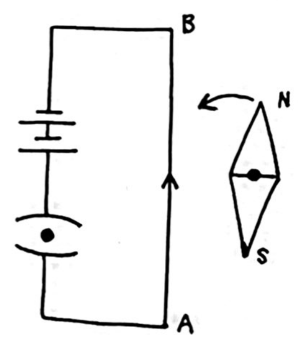
Non-Uniform Magnetic Field:

Magnetic field is said to be non-uniform magnetic field if its magnitude is not equal and direction is not same at every point in the space.



Oersted Experiment:

Henry Oersted performed an experiment to show that a magnetic field is set up around a current carrying conductor. An electric current was allowed to pass through a metallic conductor AB, placed parallel to the axis of a magnetic compass kept directly below the wire. The needle of the magnetic compass was found to deflect from its normal position when the current was switched on. When the current was switched off the needle was restored back to its normal position. This process was repeated. This led Oersted to conclude that current produces magnetic field around the conductor that caused deflection of the magnetic compass.



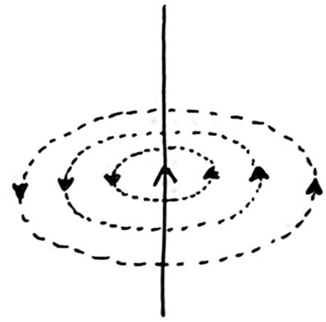
Ampere's Swimming Rule:

Consider a man swimming along the direction of the wire. If the electric current enters his feet and leaves his head, then the north pole of the needle of the magnetic compass will be deflected towards his left hand.

SNOW Rule: If electric current flows from South to North direction in a wire kept Over a magnetic compass, then the north pole of the needle of the compass will be deflected towards West.

Magnetic Field due to current through a straight conductor:

When a straight conductor carries electric current, a magnetic field is set up around the conductor. This magnetic field causes the deflection in the needle of the magnetic compass.



The magnetic field is produced in the form of concentric circles around the conductor. The figure alongside shows the shape & direction of magnetic field lines around a straight conductor.

Factors affecting strength of magnetic field of a current carrying conductor:

1. The amount of current flowing through a conductor:
   The strength of magnetic field due to a current carrying conductor is directly proportional to the amount of current flowing through it.
   i.e. $B \propto I$

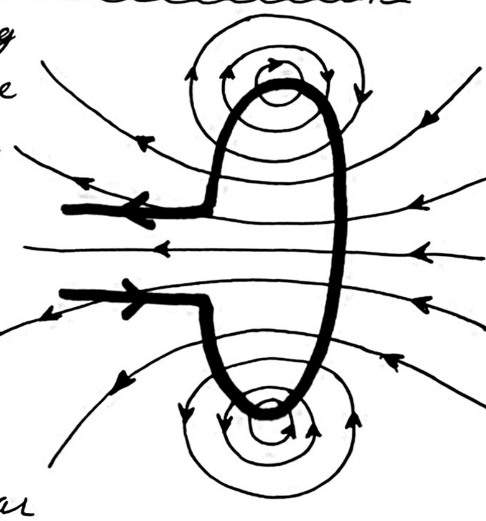
2. Distance from the conductor:
   The strength of the magnetic field due to a current carrying conductor is inversely proportional to the distance from the conductor.
   i.e. $B \propto \frac{1}{r}$

Right Hand Thumb Rule:

If a current carrying conductor is imagined to be held in the right hand such that the thumb points in the direction of the current, then the curled fingers of the hand indicate the direction of the magnetic field.

Magnetic Field due to a current through a circular wire or loop:

The magnetic field around a straight current carrying conductor or wire can be increased by bending the wire into a circular loop. A circular wire is made up of large no. of straight wires. Each small straight section of the current carrying wire contributes to the magnetic field lines & the direction of all these lines is in the same direction.



At the centre of the circular wire, the field lines become straight and perpendicular to the plane of the coil.

Factors affecting magnetic field due to a current carrying circular coil:

1. The amount of current flowing through the wire: The strength of magnetic field due to current carrying circular wire is directly proportional to the amount of current flowing through it.

   i.e $B \propto I$

2. The radius of the circular wire: The strength of the magnetic field at the centre of current carrying circular wire is inversely proportional to it radius.

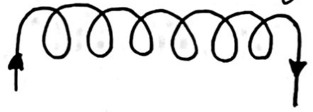
   i.e $B \propto \frac{1}{r}$

3. Number of turns of the circular wire: The strength of the magnetic field at the centre of the current carrying circular wire is directly proportional to the number of turns of the wire.

   i.e $B \propto n$

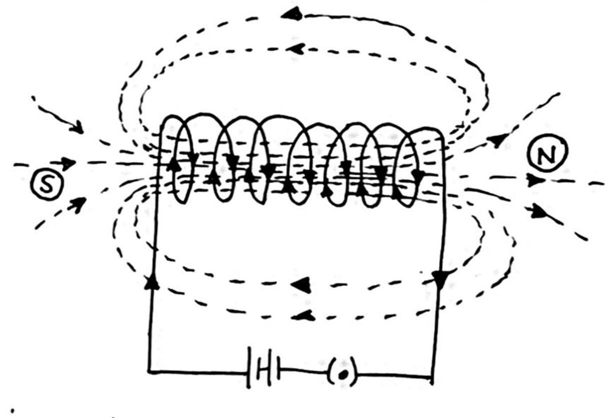
Magnetic Field due to current in a Solenoid:

A solenoid is a coil of many turns of an insulated copper wire closely wound in the shape of a tight spring.



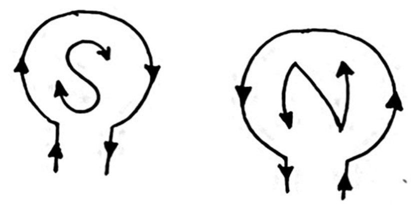
When an electric current flows through the solenoid, a magnetic field is set up which is similar to the magnetic field of a bar magnet.

One end of the solenoid acts as South pole and the other acts as North pole.



Clock Rule:

If the current flows in a clockwise direction when the coil is seen end-on, then that end of the solenoid acts as a South pole. On the other hand, if the current flows in anti-clockwise direction when the coil is seen end-on, then that end of the solenoid acts as a North pole.

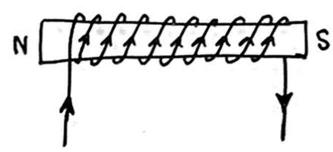


NOTE:

1. Magnetic field inside a long solenoid is uniform & strong
2. Magnetic field outside a long solenoid is non-uniform
3. Magnetic field inside a solenoid decreases as we move towards the ends.

Electromagnets:

When a soft iron bar is placed inside a solenoid carrying current, it becomes a magnet as long as current flows through the solenoid. Such a magnet is known as electromagnet.



Uses:

1. Used to lift heavy iron pieces
2. Used in devices like electric bell, horn, telephone, loudspeaker, microphone, radio, etc.

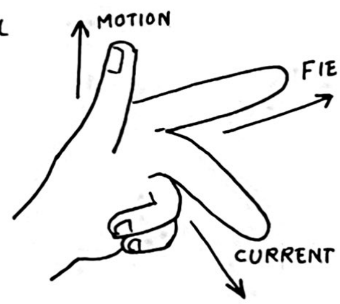
Force on a current carrying conductor placed in a magnetic field:

When a current carrying conductor is placed in a magnetic field, it experiences a force perpendicular to the direction of magnetic field. This force is called Lorentz force. Due to this force a current carrying conductor is displaced from its rest position.

The direction of this force can be found by Fleming's left hand Rule.

Fleming's Left Hand Rule:

Stretch the left hand such that the thumb, first finger and the central finger are mutually perpendicular to each other. If the first finger points in the direction of the magnetic field and the central finger points in the direction of current, then the thumb will point in the direction of motion of conductor.



Factors affecting Lorentz force:

1. Strength of magnetic field: The magnitude of force is directly proportional to the strength of magnetic field.

   i.e. $F \propto B$

2. Strength of current: The magnitude of force is directly proportional to the strength of electric current.

   i.e. $F \propto I$

3. Length of conductor: The magnitude of force is directly proportional to the length of the conductor.

   i.e. $F \propto l$

$\therefore \quad F \propto IBl$

or $\quad F = k\,BIl$

If $k = 1$, $\quad \boxed{F = BIl}$

Definition of magnetic field strength (B):

$$F = BIl$$

$$\therefore \quad B = \frac{F}{Il}$$

If $I = 1$ and $l = 1$, then $B = F$

Thus, Magnetic field strength (B) is defined as the force acting per unit current per unit length of a conductor placed perpendicular to the direction of the magnetic field.

S.I. Unit of Magnetic field strength: SI unit of magnetic field is tesla (T).

$$B = \frac{F}{I \times l}$$

$$\therefore \quad 1\,T = \frac{1\,N}{1\,A \times 1\,m} = 1\,N\,A^{-1}\,m^{-1}$$

Thus, magnetic field strength is said to be 1 tesla if 1 metre long conductor carrying current 1 ampere experiences 1 newton force, when placed perpendicular to the direction of the magnetic field.

Force acting on a moving charge in a magnetic field:

We know, $F = BIl$

If Q charge flows in time t, then

$$I = \frac{Q}{t}$$

$$\therefore \quad F = \frac{BQl}{t}$$

or $$F = BQ\left(\frac{l}{t}\right)$$

$\frac{l}{t} = v$, velocity of charge

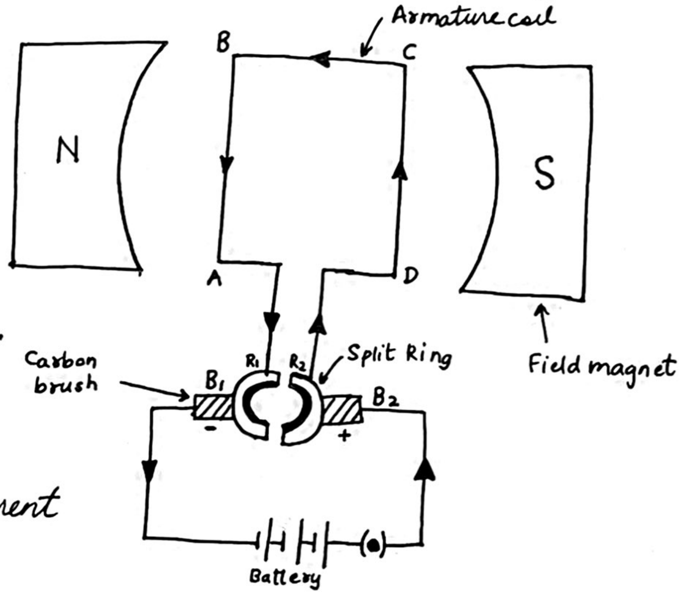
$$\therefore \quad \boxed{F = BQv}$$

Electric Motor: Electric motor is a device that converts electrical energy into mechanical energy.

Principle: Electric motor is based on the fact that a current carrying conductor placed perpendicular to the magnetic field experiences a force.

Construction:

1. Armature Coil: It consists of a single loop of an insulated copper wire in the form of a rectangle. Rectangle ABCD is an armature coil.
2. Strong field Magnet: Armature coil is placed between two pole pieces of a strong magnet. This magnet produces a strong magnetic field.



3. Split ring type Commutator: It consists of two halves (R_1 & R_2) of a metallic ring. The two ends of the armature coil are connected to these two halves of the ring. Commutator reverses the direction of current in the armature coil.
4. Brushes: Two carbon brushes B_1 & B_2 press against the commutator. These brushes act as the contacts between the commutator and the terminals of the battery.
5. Battery: A battery is connected across the carbon brushes. This battery supplies the current to the armature coil.

Working:

When current flows through the coil, arms AB & CD experience magnetic force. According to Fleming's left hand rule, arm AB of the coil, experiences a force in the downward direction. Similarly, arm CD of the coil experiences a force in the upward direction. Both these forces are equal but opposite in direction. These forces constitute a couple which rotates the coil in clockwise direction until the coil is in vertical position.

At this position, the contacts of the commutator & brushes break. So the supply of current to the coil is cut off. Hence, no force acts on the armature coil. But the coil does not come to rest. It goes on rotating due to inertia of motion of the coil until commutator again comes in contact with the brushes B_1 & B_2.

When the commutator comes in contact with brushes B_1 & B_2 after rotation, the direction of the current in arms AB & CD is reversed. The force acting on the arm AB is in the downward direction & the force acting on the arm CD is in the upward direction.

These two equal & opposite forces again constitute a couple. This couple rotates the coil again in the clockwise direction. Thus, the coil of d.c. motor continues to rotate in the same direction. Hence, electrical energy is converted into mechanical energy.

Uses of D.C. Motor:

1. It is used in electric cars, rolling mills, electric cranes & electric lifts.
2. It is used in drilling machines, electric fans, hair dryers, record players, tape recorders etc.
3. It is used in centrifugal machines likes mixers & blenders, refrigerators & washing machines.

Electromagnetic Induction:

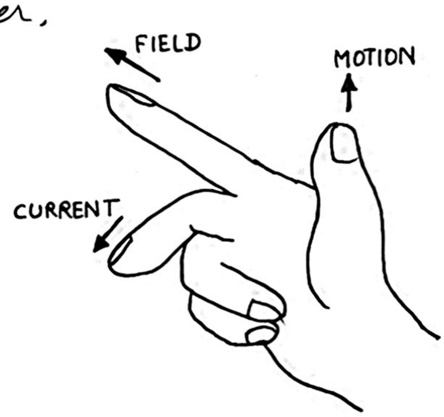
The phenomenon of producing induced current in a closed circuit or coil due to the change in magnetic field in the circuit or a closed coil is known as electromagnetic induction.

Factors on which induced current depends:

1. The no. of turns in the coil :- The magnitude of induced current is directly proportional to the no. of turns in the coil, i.e. larger the no. of turns in a coil greater is the current induced.
2. The strength of the magnet :- A strong magnet moved towards or away from the closed coil produces a large induced current i.e. the magnitude of induced current is directly proportional to the strength of the magnet.
3. The speed with which the magnet moves towards the coil:- If the magnet moves very quickly, then large induced current is produced in the closed coil.

Fleming's Right Hand Rule:

Stretch the right hand such that the first finger, the central finger & the thumb are mutually perpendicular to each other. If the first finger points in the direction of the magnetic field & the thumb points along the direction of motion of the conductor, then the direction of induced current is given by the direction of the central finger.



NOTE: Fleming's Right hand rule is also known as Dynamo Rule.

Types of Current: There are two types of current :-

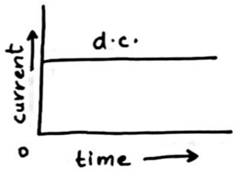
1. Direct current
2. Alternating current

Direct Current:

The electric current whose magnitude is either constant or variable but the direction of flow in a conductor remains the same is called direct current.

It is of two types:

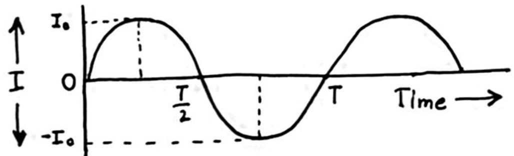
a. Constant d.c



b. Variable d.c.

Alternating Current:

An electric current whose magnitude changes with time and direction reverses periodically is called alternating current.



Advantages of A.C. over D.C.:

1. The cost of generation of a.c. is less than the cost of generation of d.c.
2. A.C. can be easily converted into d.c
3. A.C. can be controlled without much loss of electric power than d.c.
4. A.C. can be transmitted to distant places without much loss of electric power than d.c.

Disadvantages of A.C. over D.C.:

1. A.C. is more dangerous than d.c.
2. A.C. cannot be used in the process of electrolysis.

Electric Generator:

An electric device used to convert mechanical energy into electric energy is called an electric generator.

Principle: Electric generator works on the principle of electromagnetic induction. When the coil of electric generator rotates in a magnetic field, induced current flows in the circuit connected with the coil.

Types of electric generator:

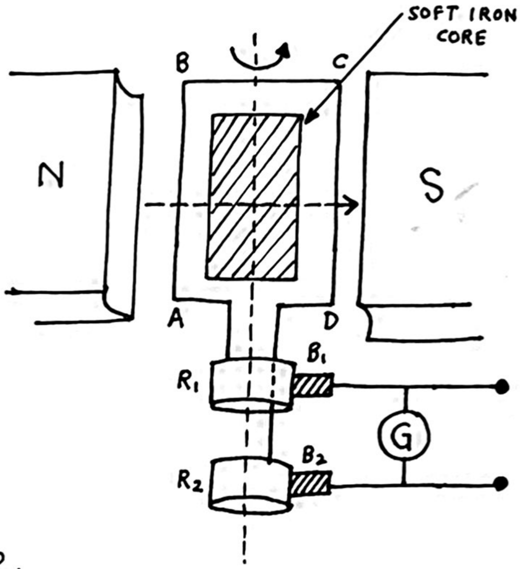
1. AC generator
2. DC generator

AC generator: AC generator converts mechanical energy into electrical energy in the form of alternating current or AC.

DC Generator: DC generator converts mechanical energy into electrical energy in the form of direct current or dc.

AC Generator:

Construction — The main components of ac generator are:



1. Armature:- Armature coil ABCD consists of large no. of turns of insulated copper wire wound over soft iron core.
2. Strong Field Magnet :- A strong permanent magnet whose N & S poles are cylindrical in shape is a field magnet. The armature coil rotates between the pole pieces of the field magnet. The uniform magnetic field provided by the field magnet is perpendicular to the axis of rotation of the coil.
3. Slip Rings:- The two ends of the armature coil are connected to two brass slip rings R_1 & R_2. These rings rotate alongwith the armature coil.
4. Brushes:- Two carbon brushes B_1 & B_2 are pressed against the slip rings. The brushes are fixed while slip rings rotate alongwith the armature. These brushes are connected to the external circuit across which the output is obtained.

Working:- When the armature coil ABCD rotates in the magnetic field provided by the strong field magnet, it cuts the magnetic lines of force. Thus, the changing magnetic field produces induced current in the coil. The direction of the induced current in the coil is determined by the Fleming's Right hand rule.

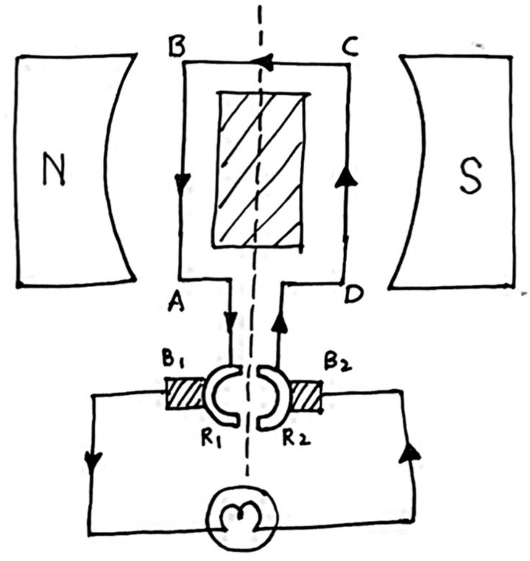
The current flows out through the brush B_1 in one direction in the first half of the revolution & through the brush B_2 in the next half revolution in the reverse direction. This process is repeated. Therefore, induced current produced is of alternating nature. Such a current is called alternating current.

DC Generator or Dynamo:

Construction:

1. Armature coil — It consists of a large number of turns of insulated copper wire wound on soft iron core in the form of a rectangle coil. Rectangle coil ABCD is the armature coil.

2. Strong Field Magnet – Armature coil is placed between two pole pieces N & S of a strong magnet. This magnet provides a strong magnetic field.



3. Split Ring type Commutator – It consists of two halves R_1 & R_2 of a metallic ring. The two ends of the armature coil are connected to these two halves of the ring.

4. Brushes – Two carbon brushes B_1 & B_2 press against the commutator.

5. Bulb – The output is shown by the glowing bulb connected across the carbon brushes.

Working:

When the coil of a d.c generator rotates in the magnetic field, induced potential difference is produced in the coil. This induced potential difference gives rise to flow of current through the bulb & hence the bulb glows.

In DC generator, the flow of current in the circuit is in the same direction as long as the coil rotates in the magnetic field. This is because one brush is always in contact with arm of the armature coil moving up and the other brush is in contact with the arm of the armature moving downward in the magnetic field.

Safety Fuse: An electric fuse is a safety device used to save the electrical appliances from burning when large current flows in the circuit. Electric fuse is a wire made of aluminium or tin-lead alloy. The melting point of the material of which the electric fuse wire is made should be low.

Earthing: The process of sharing of excess or leaked charge by the electrical appliance with the earth is called earthing. For earthing an appliance, the earth wire of the appliance is connected to the earth connection in socket.