	Magnetism	
6th term - 3	Unit - 1	Magnetism
9 th Std	Unit - 5	Magnetism and Electromagnetism
12th Physics vol - 1	Unit - 3	Magnetism And Magnetic Effects Of Electric Current
	Unit - 4	Magnetism & Magnetic Alternating Current
	Electricity	
6th term - 2	Unit - 2	Electricity
7th term - 2	Unit - 2	Electricity
8th term - 2	Unit - 2	Electricity
9 th Std	Unit - 4	Electric charge and Electric current
10th Std	Unit - 4	Electricity
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Magnetism

6^{th} term III
Unit - 1
Magnetism

Magnet of different shapes

After learning the method of changing the piece of iron into magnet (magnetization) we have been making and using several kinds of magnets. Such man-made magnets are called artificial magnets.

Bar-magnet, Horseshoe magnet, Ring magnet and Needle magnet are generally used artificial magnets.

Magnetic and Non Magnetic Materials

Substances which are attracted by magnet are called magnetic substances. Iron, cobalt, nickel are magnetic substances. Substances which are not attracted by magnet are called non-magnetic substances. Paper, plastic are called nonmagnetic substances.

Magnetic Poles

Place some iron filings on a paper. Place a bar magnet horizontally in the filings and turn it over a few times. Now lift the magnet. What do you see? Which part of the magnet has more iron filings sticking to it?

The parts of the magnet those attract the largest amount of iron filings are called as its poles. The attractive force of the magnet is very large near the two ends. These two ends are called its poles.

If you have a horseshoe magnet, or any other type of magnet at home, find the position of its poles by this experiment.

In experiments with magnets you will need to use iron filings again and again. You can do this by placing a magnet in a pile of sand and turning it around in the sand. The small pieces of iron present in the sand will stick to the magnet. If you cannot find sand you can look for iron pieces in clayey soil as well.

If you don't have iron filings, you can collect small pieces of iron and they will serve the purpose as well.

Finding directions with a magnet

Tie a piece of thread to the centre of a bar magnet and suspend it. Note, in which direction the magnet stops. Draw a line on a sheet of cardboard or the table along the direction in which the bar magnet stops (i.e) a line parallel to the bar magnet). Turn the magnet gently and let it come to stop again. Repeat it three or four times.

This is roughly the north-south direction. The end of the magnet that points to the north is called the North Pole. The end that points to the south is called the South Pole.

A freely suspended magnet always comes to rest in north-south direction.

The directive property of magnets has been used for centuries to find directions. Around 800 years ago, the Chinese discovered that a suspended lode stone stops in the north-south direction. Chinese used these lode stones to find directions.

The navigators of that country used to keep a piece of lode stone suspended in their boats and during a storm or mist, they used the lode stone to locate directions.

Magnetic compass

A compass is an instrument which is used to find directions. It is mostly used in ships and airplanes. As a rule, mountaineers also carry a compass with them so that they do not lose their way in unknown places.

The compass has a magnetic needle that can rotate easily. The marked end of the needle is the North Pole of the magnet.

Properties of Magnets
Attraction or Repulsion

Take two similar magnets, place them in four different ways. Unlike poles (S-N, N-S) attract each other. Like Poles (N-N, S-S) repel each other.

Do magnets lose their properties? When?

Magnets lose their properties if they are heated or dropped from a height or hit with a hammer.

Magnets lose their properties when they are placed near Cellphone, Computer, DVDs. These objects will also get affected by magnetic field.

Storage of Magnets

Improper storage can also cause magnets to lose their properties. To keep them safe, bar magnets should be kept in pairs with their unlike poles on the same side. They must be separated by a piece of wood and two pieces of soft iron should be placed across their ends.

For a horse-shoe magnet a single piece of soft iron can be used as a magnetic keeper across the poles.

Usage of Magnets

We use various equipment with magnets in day to day life.

.

Science Today – Bullet Trains

We know that like poles of the magnet repel each other. By using repulsion we can levitate a magnetic object.

Electromagnetic train is called as suspension train and also called as flying train. It does not require diesel or petrol. This technology uses the property of magnetic attraction and repulsion to run these super fast electromagnetic trains.

How does the electromagnetic train work?

Electromagnets are used in Electromagnetic train. Electromagnets are magnetised only when current flows through them. When the direction of current is changed the poles of the electromagnets are also changed. Like poles of the magnets which are attached at the bottom of the train and rail track repel each other. So, the train is lifted from the track up to a height of 10 cm.

We Know that we can move any magnetic object with the force of attraction or repulsion properties of magnets. This train also moves with the help of the magnets attached on the sides of track and the magnets fitted at the bottom sideway of the train. By controlling the current we can control the magnets and movement of the train.

As there are no moving parts, there is no friction. So, the train can easily attain a speed of 300 km per hour. These trains are capable of running up to 600 km/ hour. They do not make any noise. They require less energy and they are eco-friendly.

Even though, many countries have taken effort to use these trains, such trains are used for public transport only in China, Japan and South Korea. In India the possibilities of introducing these trains are under consideration.

UNIT-5 - Magnetism and Electromagnetism

Magnetic field (B)

From the above activity we notice that magnets have an invisible field all around them which attracts magnetic materials.

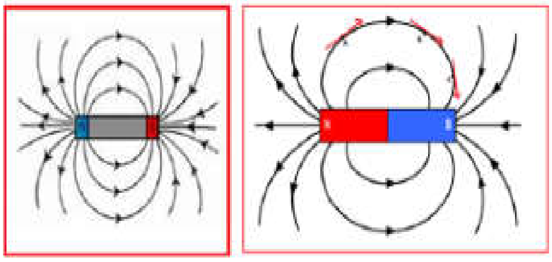
In this space we can feel the force of attraction or repulsion due to the magnet. Thus, magnetic field is the region around the magnet where its magnetic influence can be felt. It is denoted by B and its unit is Tesla.

The direction of the magnetic field around a magnet can be found by placing a small compass in the magnetic field

Magnetic field can penetrate through all kinds of materials, not just air. The Earth produces its own magnetic field, which shields the earth's ozone layer from the solar wind and it is important for navigation also.

Magnetic Field Lines

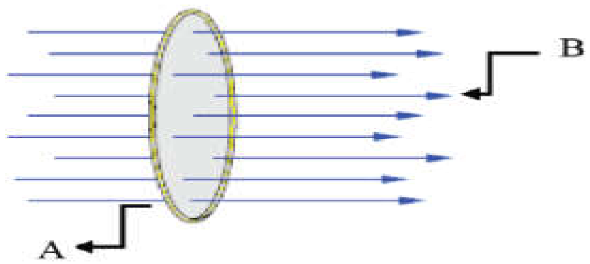
A magnetic field line is defined as a curve drawn in the magnetic field in such a way that the tangent to the curve at any point gives the direction of the magnetic field. They start at north pole and ends at south pole. The arrow mark indicates the direction of magnetic field at points A, B and C. Note carefully that the magnetic field at a point is tangential to the magnetic field lines.



Magnetic field lines

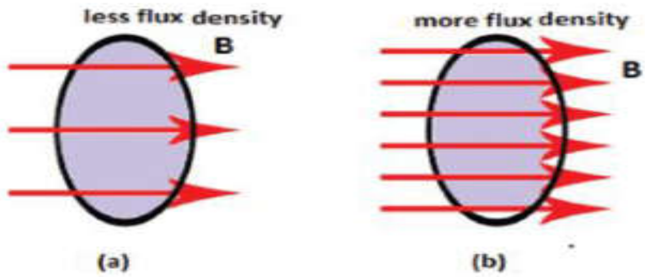
Magnetic flux

Magnetic flux is the number of magnetic field lines passing through a given area. It is denoted by ϕ and its unit is weber (Wb).



Magnetic flux

The number of magnetic field lines crossing unit area kept normal to the direction of field lines is called magnetic flux density.



Magnetic flux density

Some sea turtles (loggerhead sea turtle) return to their birth beach many decades after they were born, to nest and lay eggs. In a research, it is suggested that the turtles can perceive variations in magnetic parameters of Earth such as magnetic field intensity and remember them. This memory is what helps them in returning to their homeland.

Properties of magnetic lines of force

- Magnetic lines of force are closed, continuous curves, extending through the body of the magnet.
- Magnetic lines of force start from the North Pole and end at the South Pole.
- Magnetic lines of force never intersect.
- They will be maximum at the poles than at the equator.
- The tangent drawn at any point on the curved line gives the direction of magnetic field.

Magnetic effect of current

It was on 21st April 1820, Hans Christian Oersted, a Danish Physicist was giving a lecture. He was demonstrating electrical circuits in that class. He had to often switch on and off the circuit during the lecture. Accidentally, he noticed the needle of the magnetic compass that was on the table. It deflected whenever he switched on and the current was flowing through the wire. The compass needle moved only slightly, so that the audience didn't even notice. But, it was clear to Oersted that something significant was happening. He conducted many experiments to find out a startling effect, the magnetic effect of current.

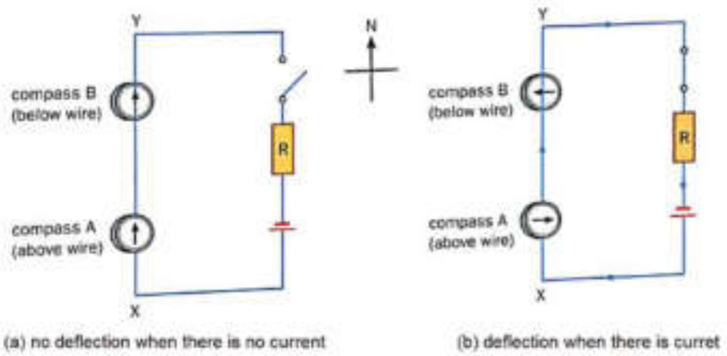
Oersted aligned a wire XY such that they were exactly along the North-South direction. He kept one magnetic compass above the wire at A and another under the wire at B. When the circuit was open and no current was flowing through it, the needle of both the compass was pointing to north. Once the circuit was closed and electric current was flowing, the needle at A pointed to east and the needle at B to the west as shown in Figure 5.5. This showed that current carrying conductor produces magnetic field around it.

The direction of the magnetic lines around a current carrying conductor can be easily understood using the right hand thumb rule. Hold the wire with four fingers of your right hand with thumbs-up position. If the direction of the current is towards the thumb then the magnetic lines curl in the same direction as your other four fingers as shown in Figure 5.6. This shows that the magnetic field is always perpendicular to the direction of current.

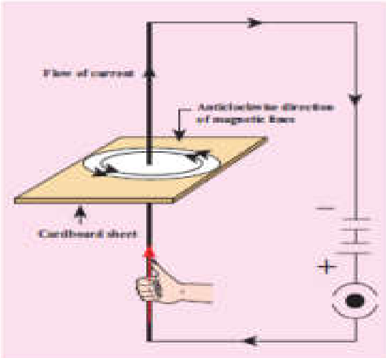
The strength of the magnetic field at a point due to current carrying wire depends on:

I. the current in the wire,
II. distance of the point from the wire,
III. the orientation of the point from the wire and
IV. The magnetic nature of the medium.

The magnetic field lines are stronger near the current carrying wire and it diminishes as you go away from it. This is represented by drawing magnetic field lines closer together near the wire and farther away from the wire.



Current produces magnetic field



Right hand thumb rule

Force on a current carrying conductor in a magnetic field

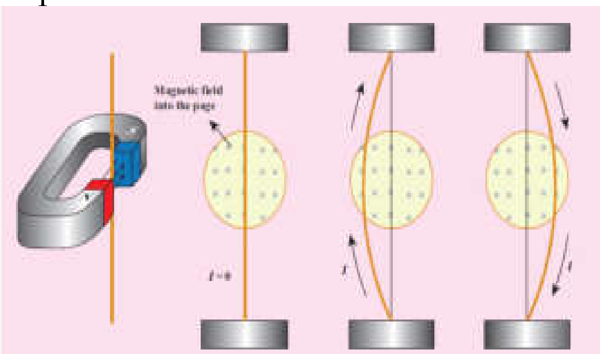
H.A.Lorentz found that a charge moving in a magnetic field, in a direction other than the direction of magnetic field, experiences a force. It is called the magnetic Lorentz force. Since charge in motion constitutes a current, a conductor carrying moving charges, placed in magnetic field other than the direction of magnetic field, will also experience a force and can produce motion in the conductor.

From this activity, we infer that current carrying wire has a magnetic field perpendicular to the wire (by looking at the deflection of the compass needle in the vicinity of a current carrying conductor). The deflection of the needle implies that the current carrying conductor exerts a force on the compass needle. In 1821, Michael Faraday discovered that a current carrying conductor also gets deflected when it is placed in a magnetic field. In Figure 5.7, we can see that the magnetic field of the permanent magnet and the magnetic field produced by the current carrying conductor interact and produce a force on the conductor.

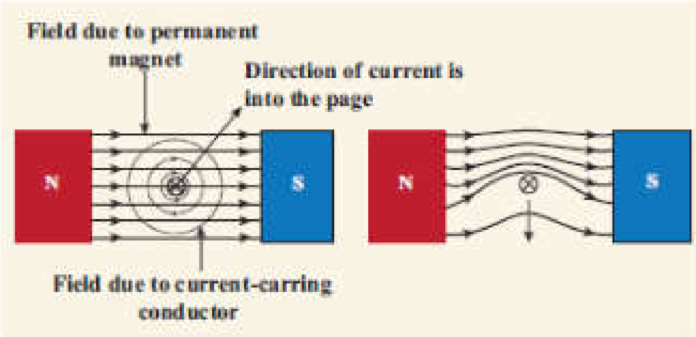
If a current, I is flowing through a conductor of length, L kept perpendicular to the magnetic field B, then the force F experienced by it is given by the equation,

$$F = I\,L\,B$$

The above equation indicates that the force is proportional to current through the conductor, length of the conductor and the magnetic field in which the current carrying conductor is kept.



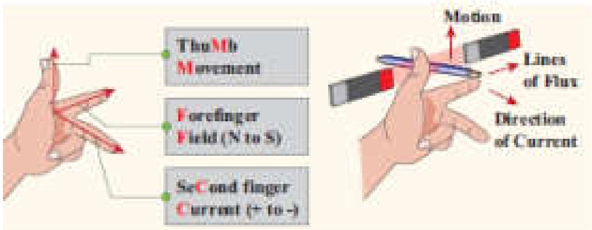
Deflection of current carrying wire in magnetic field



Force on a current carrying
conductor kept in magnetic field

The angle of inclination between the current and magnetic field also affects the magnetic force. When the conductor is perpendicular to the magnetic field, the force will be maximum (=BIL). When it is parallel to the magnetic field, the force will be zero.

The force is always a vector quantity. A vector quantity has both magnitude and direction. It means we should know the direction in which the force would act. The direction is often found using what is known as Fleming's Left hand Rule (formulated by the scientist John Ambrose Fleming).



Fleming's left hand rule

The law states that while stretching the three fingers of left hand in perpendicularmanner with each other, if the direction of the current is denoted by the middle finger of the left hand and the second finger is for direction of the magnetic field, then the thumb of the left hand denotes the direction of the force or movement of the conductor.

Electromagnetic Induction

Experiment 1

In this experiment, two coils were wound on a soft iron ring (separated from each other). The coil on the left is connected to a battery and a switch K. A galvanometer is attached to the coil on the right. When the switch is put 'on', at that instant, there is a deflection in the galvanometer. Likewise, when the switch is put 'off', again there is a deflection – but in the opposite direction. This proves the generation of current.

Experiment 2

In this experiment, current (or voltage) is generated by the movement of the magnetin and out of the coil. The greater the number of turns, the higher is the voltage generated

Experiment 3

In this experiment, the magnet is stationary, but the coil is moved in and out of the magnetic field (indicated by the magnetic lines of force). Here also, current is induced.

All these observations made Faraday to conclude that whenever there is a change in the magnetic flux linked with a closed circuit an emf is produced and the amount of emfinduced varies directly as the rate at which the flux changes. This emf is known as induced emf and the phenomenon of producing an induced emf due to change in the magnetic flux linked with a closed circuit is known as electromagnetic induction.

Note: The direction of the induced current was given by Lenz's law, which states that the induced current in the coil flows in such a direction as to oppose the change that causes it. The direction of induced current can also be given by another rule called Fleming's Right Hand Rule.

Michael Faraday (22nd Sep,1791–25th Aug, 1867) was a British Scientist who contributed to the study of electromagnetism and electrochemistry. His main discoveries include the principles underlying e l e c t r o m a g n e t i c induction, diamagnetism and electrolysis.

Fleming's Right Hand Rule

Stretch the thumb, fore finger and middle finger of your right hand mutually perpendicular to each other. If the fore finger indicates the direction of magnetic field and the thumb indicates the direction of motion of the conductor, then the middle finger will indicate the direction of induced current. Fleming's Right hand rule is also called 'generator rule'.

Electric generator

An alternating current (AC) generator, as shown in Figure 5.18, consists of a rotating rectangular coil ABCD called armature placed between the two poles of a permanent magnet. The two ends of this coil are connected to two slip rings S1 and S2. The inner sides of these rings are insulated. Two conducting stationary brushes B1 and

B2 are kept separately on the rings S1 and S2 respectively. The two rings S1 and S2 are internally attached to an axle. The axle may be mechanically rotated from outside to rotate the coil inside the magnetic field. Outer ends of the two brushes are connected to the external circuit.

When the coil is rotated, the magnetic flux linked with the coil changes. This change in magnetic flux will lead to generation of induced current. The direction of the induced current, as given by Fleming's Right Hand Rule, is along ABCD in the coil and in the outer circuit it flows from B2 to B1. During the second half of rotation, the direction of current is along DCBA in the coil and in the outer circuit it flows from B1 to B2. As the rotation of the coil continues, the induced current in the external circuit is changing its direction for every half a rotation of the coil.

To get a direct current (DC), a split ring type commutator must be used. With 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. The generator is thus called a DC generator .

Transformer

Transformer is a device used for converting low voltage into high voltage and high voltage into low voltage. It works on the principle of electromagnetic induction. It consists of primary and secondary coil insulated from each other. The alternating current flowing through the primary coil induces magnetic field in the iron ring. The magnetic field of the iron ring induces a varying emf in the secondary coil.

Depending upon the number of turns in the primary and secondary coils, we can step-up or step-down the voltage in the secondary coil as shown in Figure 5.20.

Step up transformer:

The transformer used to change a low alternativing voltage to a high alternating voltage is called a step up transformer. ie Vs >Vp. In a step up transformer, the number of turns in the secondary coil is more than the number of turns in the primary coil (Ns > Np).

Step down transformer:

The transformer used to change a high alternating voltage to a low alternating voltage is called a step down transformer (Vs <Vp). In a step down transformer, the number of turns in the secondary coils are less than the number of turns in the primary coil (Ns < Np).

The formulae pertaining to the transformers are given in the following equations.

Number of primary turns Np Primary voltage Vp
Number of secondary turns Ns = Secondary voltage Vs

Number of secondary turns Ns Primary current Ip
Number of primary turns Np = Secondary current Is

A step up transformer increases the voltage but it decreases the current and vice versa. Basically there will be loss of energy in a transformer in the form of heat, sound etc.

A transformer cannot be used with the direct current (DC) source because, current in the primary coil is constant (ie. DC). Then there will be no change in the number of magnetic field lines linked with the secondary coil and hence no emf will be induced in the secondary coil.

Applications of Electromagnets

Electromagnetism has created a great revolution in the field of engineering applications. In addition, this has caused a great impact on various fields such as medicine, industries, space etc.

Speaker Inside the speaker, an electromagnet is placed in front of a permanent magnet. The permanent magnet is fixed firmly in position whereas the electromagnet is mobile. As pulses of electricity pass through the coil of the electromagnet, the direction of its magnetic field is rapidly changed. This means that it is in turn attracted to and repelled from the permanent magnet vibrating back and forth. The electromagnet is attached to a cone made of a flexible material such as paper or plastic which amplifies these vibrations, pumping sound waves into the surrounding air towards our ears.

Magnetic Levitation Trains

Magnetic levitation (Maglev) is a method by which an object is suspended with no support other than magnetic fields. In maglev trains two sets of magnets are used, one set to repel and push the train up off the track, then another set to move the floating train ahead at great speed without friction. In this technology, there is no moving part. The train travels along a guideway of magnets which controls the train's stability and speed using the basic principles of magnets. Figure.

Medical System

Nowadays electromagnetic fields play a key role in advanced medical equipments such as hyperthermia treatments for cancer, implants and magnetic resonance imaging (MRI). Sophisticated equipments working based on electromagnetism can scan even minute details of the human body. Figure 5.22 MRI Scanning machine Many of the medical equipments such as scanners, x-ray equipments and other equipments also use the principle of electromagnetism for their functioning.

12^{th} Physics

3^{rd} lesson

MAGNETISM AND MAGNETIC EFFECTS OF ELECTRIC CURRENT

Earth's magnetic field and magnetic elements

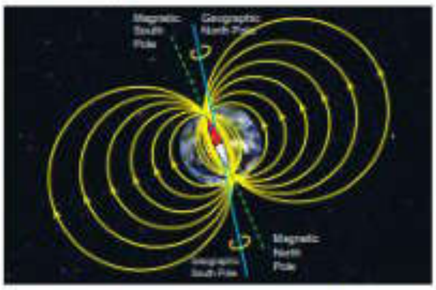


Figure 3.3 Earth's magnetic field

From the activities performed in lower classes, you might have noticed that the needle in a magnetic compass or freely suspended magnet comes to rest in a position which is approximately along the geographical northsouth direction of the Earth.

The north pole of magnetic compass needle is attracted towards the magnetic south pole of the Earth which is near the geographic north pole (Figure 3.3). Similarly, the south pole of magnetic compass needle is attracted towards the magnetic north-pole of the Earth which is near the geographic south pole. **The branch of physics which deals with the Earth's magnetic field is called Geomagnetism or Terrestrial magnetism.**

There are three quantities required to specify the magnetic field of the Earth on its surface, which are often called as the elements of the Earth's magnetic field. They are

(a) magnetic declination (D)
(b) magnetic dip or inclination (I)
(c) the horizontal component of the Earth's magnetic field (B_H)

Day and night occur because Earth spins about an axis called geographic axis. A vertical plane passing through the geographic axis is called geographic meridian and a great circle perpendicular to Earth's geographic axis is called geographic equator.

The straight line which connects magnetic poles of Earth is known as magnetic axis.

A vertical plane passing through magnetic axis is called magnetic meridian and a great circle perpendicular to Earth's magnetic axis is called magnetic equator.

When a magnetic needle is freely suspended, the alignment of the magnet does not exactly lie along the geographic meridian as shown in. **The angle between magnetic meridian at a point and geographical meridian is called the declination or magnetic declination** (D). At higher latitudes, the declination is greater whereas near the equator, the declination is smaller. In India, declination angle is very small and for Chennai, magnetic declination angle is –1o 16′ (which is negative (west)).

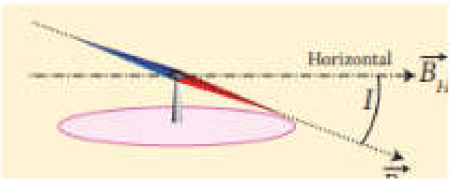
The angle subtended by the Earth's total magnetic field ρ B with the horizontal direction in the magnetic meridian is called dip or magnetic inclination (I) at that point (Figure 3.5). For Chennai, inclination angle is 14^{o} 28′. **The component of Earth's magnetic field along the horizontal direction in the magnetic meridian is called horizontal component of Earth's magnetic field, denoted by B_H.**

Let BE be the net Earth's magnetic field at any point on the surface of the Earth. BE can be resolved into two perpendicular components.

Horizontal component $B_H = B_E \cos I$

Vertical component $B_V = B_E \sin I$

Dividing equation, we get $\tan I = \frac{B_V}{B_H}$



Inclination angle

(i) At magnetic equator

The Earth's magnetic field is parallel to the surface of the Earth (i.e., horizontal) which implies that the needle of magnetic compass rests horizontally at an angle of dip, $I = 0^{o}$.This implies that the horizontal component is maximum and vertical component is zero at the equator.

$$B_H = B_E$$
$$B_V = 0$$

(ii) At magnetic poles

The Earth's magnetic field is perpendicular to the surface of the Earth (i.e., vertical) which implies that the needle of magnetic compass rests vertically at an angle of dip, I = 90o . Hence,

$$B_H = 0$$
$$B_V = B_E$$

This implies that the vertical component is maximum at poles and horizontal component is zero at poles.

EXAMPLE

The horizontal component and vertical component of Earth's magnetic field at a place are 0.15 G and 0.26 G respectively. Calculate the angle of dip and resultant magnetic field. (G-gauss, cgs unit for magnetic field 1G = 10^{-4} T)

Solution:

BH = 0.15 G and BV = 0.26 G

$$\tan I = \frac{0.26}{0.15} \Rightarrow I = \tan^{-1}(1.732) = 60^{\circ}$$

The resultant magnetic field of the Earth is

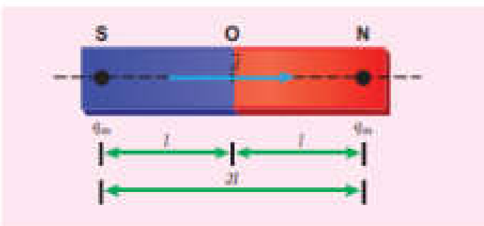
$$B = \sqrt{B_H^2 + B_V^2} = 0.3G$$

Basic properties of magnets

Some basic terminologies and properties used in describing bar magnet.

a) Magnetic dipole moment

Consider a bar magnet as shown. Let q_m be the pole strength of the magnetic pole and let l be the distance between the geometrical centre of bar magnet O and one end of the pole. The magnetic dipole moment is defined as the product of its pole strength and magnetic length. It is a vector quantity, denoted by ρ pm.



A bar magnet

$$\dot{P_m} = q_m \dot{d}$$

Where $\overline{d}$ is the vector drawn from south pole to north pole and its magnitude $\left|\overline{d}\right|$ = 2.

The magnitude of magnetic dipole moment is $p_m=2q_ml$

The SI unit of magnetic moment is Am^2. The direction of magnetic moment is from south pole to north pole.

b) Magnetic field

Magnetic field is the region or space around every magnet within which its influence will be felt by keeping another magnet in that region. **The magnetic field ρ B at a point is defined as a force experienced by the bar magnet of unit pole strength.**

$$\dot{B} = \frac{1}{q_m}\dot{F}$$

Its unit is $N\ A^{-1}\ m^{-1}$.

c) Types of magnets

Magnets are classified into natural magnets and artificial magnets. For example, iron, cobalt, nickel, etc. are natural magnets. Strengths of natural magnets are very weak and the shapes of the magnet are irregular. Artificial magnets are made in order to have desired shape and strength. If the magnet is in the form of rectangular shape or cylindrical shape, then it is known as bar magnet.

Properties of magnet

The following are the properties of bar magnet,

1. A freely suspended bar magnet will always point along the north-south direction.

2. A magnet attracts or repels another magnet or magnetic substances towards itself. The attractive or repulsive force is maximum near the end of the bar magnet. When a bar magnet is dipped into iron filling, they cling to the ends of the magnet.

3. When a magnet is broken into pieces, each piece behaves like a magnet with poles at its ends.

4. Two poles of a magnet have pole strength equal to one another.

5. 5. The length of the bar magnet is called geometrical length and the length between two magnetic poles in a bar magnet is called magnetic length. Magnetic length is always slightly smaller than geometrical length. The ratio of magnetic length and geometrical length is 5/6.

$$\frac{Magnetic\,length}{Geometrical\,length} = \frac{5}{6} = 0.833$$

EXAMPLE

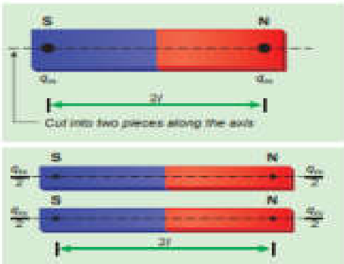
Let the magnetic moment of a bar magnet be P_m whose magnetic length is d = 2l and pole strength is q_m. Compute the magnetic moment of the bar magnet when it is cut into two pieces

(a) along its length

(b) Perpendicular to its length.

Solution

(a) a bar magnet cut into two pieces along its length



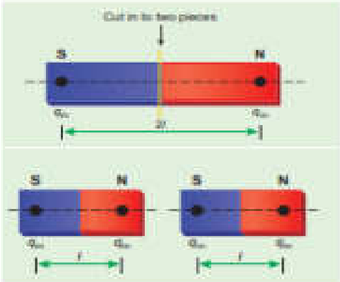
When the bar magnet is cut along the axis into two pieces, new magnetic pole strength is but magnetic length does not change. So, the magnetic moment is

$$P'_m = q'_m 2l$$

$$P'_m = \frac{q'_m}{2} 2l = \frac{1}{2}\left(q_m 2l\right) = \frac{1}{2} P_m$$

In vector notation, $P'_m = \frac{1}{2}\overline{P_m}$

(c) a bar magnet cut into two pieces perpendicular to the axis:
(d)



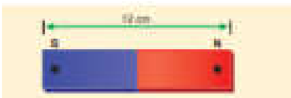
When the bar magnet is cut perpendicular to the axis into two pieces, magnetic pole strength will not change but magnetic length will be halved. So the magnetic moment is

$$P'_m = q_m \times \frac{1}{2}(2l) = \frac{1}{2}(q_m.2l) = \frac{1}{2}P_m$$

In vector notation, $\overline{P'}_m = \frac{1}{2}\overline{P_m}$

EXAMPLE

Compute the magnetic length of a uniform bar magnet if the geometrical length of the magnet is 12 cm. Mark the positions of magnetic pole points.



Solution

Geometrical length of the bar magnet is 12 cm Magnetic

Magnetic length = 5/6 × (geometrical length)

=5/6×12 = 10 Cm

In this figure, the dot implies the pole points.

Magnetic field lines

1. Magnetic field lines are continuous closed curves. The direction of magnetic field lines is from North pole to South pole outside the magnet and from South pole to North pole inside the magnet.

2. The direction of magnetic field at any point on the curve is known by drawing tangent to the magnetic field lines at that point.

3. Magnetic field lines never intersect each other. Otherwise, the magnetic compass needle would point towards two different directions, which is not possible.

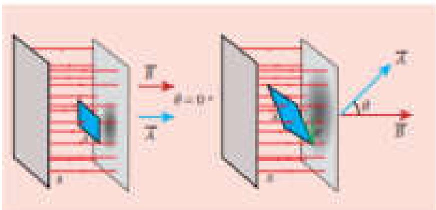
4. The degree of closeness of the field lines determines the relative strength of the magnetic field. The magnetic field is strong where magnetic field lines crowd and weak where magnetic field lines are well separated.

(d) Magnetic flux

The number of magnetic field lines crossing any area normally is defined as magnetic flux Φ_B through the area. Mathematically, the magnetic flux through a surface of area $\vec{A}$ in a uniform magnetic field $\vec{B}$ is defined as

$$\Phi_B = \vec{B}.\vec{A} = BA\cos\theta = B_{\perp}A$$

Where θ is the angle between $\vec{B}$ and $\vec{A}$ as shown in



Magnetic flux

Special cases

(a) When $\vec{B}$ is normal to the surface i.e., θ = 0°, the magnetic flux is Φ_B = BA (maximum).

(b) When $\vec{B}$ is parallel to the surface i.e., θ = 90°, the magnetic flux is $\Phi_B = 0$.

Suppose the magnetic field is not uniform over the surface, the equation (3.6) can be written as

$$\Phi_B = \int \vec{B} \cdot d\vec{A}$$

Magnetic flux is a scalar quantity. The SI unit for magnetic flux is weber, which is denoted by symbol Wb. Dimensional formula for magnetic flux is $[ML^2T^2A^1]$. The CGS unit of magnetic flux is maxwell.

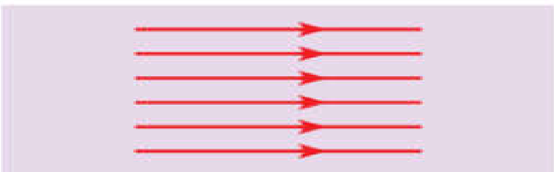
1 weber -10^8maxwell

The magnetic flux density is defined as the number of magnetic field lines crossing per unit area kept normal to the direction of lines of force. Its unit is Wb m^{-2} or tesla (T).

(e) Uniform magnetic field and Nonuniform magnetic field

Uniform magnetic field

Magnetic field is said to be uniform if it has same magnitude and direction at all the



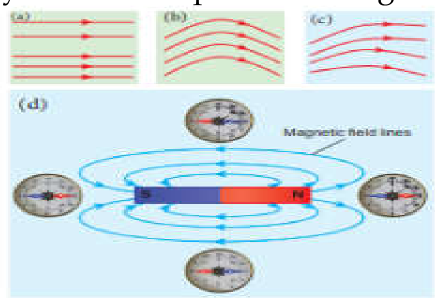
Uniform magnetic field

points in a given region. Example, locally Earth's magnetic field is uniform.

The magnetic field of Earth has same value over the entire area of your school!

Non-uniform magnetic field

Magnetic field is said to be non-uniform if the magnitude or direction or both vary at different points in a region. Example: magnetic field of a bar magnet

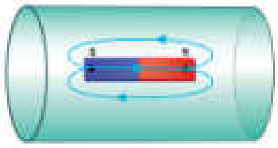


Non-uniform magnetic field

(a) direction is constant
(b) direction is not a constant
(c) both magnitude and direction are not constant
(d) magnetic field of a bar magnet

EXAMPLE

Calculate the magnetic flux coming out from closed surface containing magnetic dipole (say, a bar magnet) as shown in figure.



Solution

The total flux emanating from the closed surface S enclosing the dipole is zero. So,

$$\Phi_B = \oint \vec{B}.d\vec{A} = 0$$

Here the integral is taken over closed surface. Since no isolated magnetic pole (called magnetic monopole) exists, this integral is always zero,

$$\oint \vec{B}.d\vec{A} = 0$$

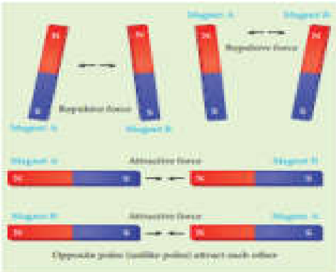
This is similar to Gauss's law in electrostatics.

COULOMB'S INVERSE SQUARE LAW OF MAGNETISM

Consider two bar magnets A and B as shown in Figure 3.11. When the north pole of magnet A and the north pole of magnet B or the south pole of magnet A and the south pole of magnet B are brought closer, they repel each other.

On the other hand, when the north pole of magnet A and the south pole of magnet B or the south pole of magnet A and the north pole of magnet B are brought closer, their poles attract each other.

This looks similar to Coulomb's law for static charges studied in Unit I (opposite charges attract and like charges repel each other). So analogous to Coulomb's law in electrostatics, we can state Coulomb's law for magnetism as follows:



Magnetic poles behave like electric charges – like poles repel and unlike poles attract

The force of attraction or repulsion between two magnetic poles is directly proportional to the product of their pole strengths and inversely proportional to the square of the distance between them.

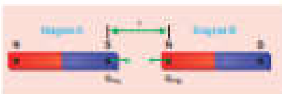
Mathematically, we can write

$$\overline{F} \propto \frac{q_{m_A} q_{m_B}}{r^2} \hat{r}$$

Where q_{m_A} and q_{m_B} are pole strengths of two poles and r is the distance between two magnetic poles.

$$\overline{F} = k \frac{q_{m_A} q_{m_B}}{r^2} \hat{r}$$

Where k is a proportionality constant whose value depends on the surrounding medium. In SI unit, the value of k for free space is $k = \frac{\mu_\circ}{4\pi} \approx 10^{-7}$ H m^{-1}, where μ_o is theabsolute permeability of free space (air or vacuum) and H stands for henry.



Coulomb's law – force between two magnetic poles

EXAMPLE

The repulsive force between two magnetic poles in air is 9 × 10–3 N. If the two poles are equal in strength and are separated by a distance of 10 cm, calculate the pole strength of each pole.

Solution:

The magnitude of the force between two poles is given by

$$\overline{F} = k\frac{q_{m_A} q_{m_B}}{r^2}$$

Given:

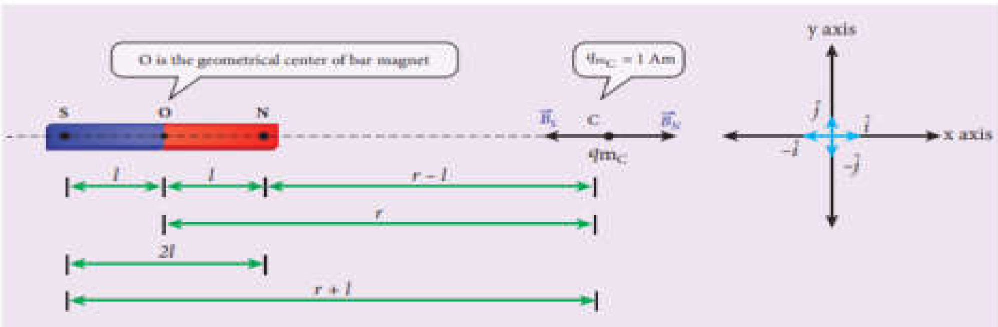
F = 9 × 10^{-3}N, r = 10 cm = 10 × 10^{-2} m

Since $qm_A = qm_B = qm$, we have

$$9 \times 10^{-3} = 10^{-7} \times \frac{q_m^2}{\left(10 \times 10^{-2}\right)} \Rightarrow q_m = 30\, NT^{-1}$$

Magnetic field at a point along the axial line of the magnetic dipole (bar magnet)

Consider a bar magnet NS as shown. Let N be the north pole and S be the south pole of the bar magnet, each of pole strength qm and are separated by a distance of 2l. The magnetic field at a point C (lies along the axis of the magnet)



Magnetic field at a point along the axial line due to magnetic dipole

at a distance r from the geometrical centre O of the bar magnet can be computed by keeping unit north pole (q_{m_c} = 1 Am) at C.

The magnetic field at C due to the north pole is

$$\vec{B}_N = \frac{\mu_0}{4\pi} \frac{q_m}{\left(r-l\right)^2} \hat{i}$$

Where (r – l) is the distance between north pole of the bar magnet and unit north pole at C.

The magnetic field at C due to the south pole is

$$\vec{B}_S = \frac{\mu_0}{4\pi} \frac{q_m}{\left(r+l\right)^2} \hat{i}$$

Where (r + l) is the distance between south pole of the bar magnet and unit north pole at C.

The net magnetic field due to the magnetic dipole at point C

$$\overline{B} = \overline{B}_N + \overline{B}_S$$

$$\overline{B} = \frac{\mu_0}{4\pi}\frac{q_m}{(r-l)^2}\hat{i} + \left(\frac{\mu_0}{4\pi}\frac{q_m}{(r+l)^2}\hat{i}\right)$$

$$\overline{B} = \frac{\mu_0 q_m}{4\pi}\left(\frac{1}{(r-l)^2} - \frac{1}{(r+l)^2}\right)\hat{i}$$

$$\overline{B} = \frac{\mu_0 2r}{4\pi}\left(\frac{q_m.(2l)}{(r^2-l^2)^2}\right)\hat{i}$$

Since the magnitude of magnetic dipole moment is $\left|\overline{P}_m\right| - P_m - q_m.2l$, the magnetic field at a point C can be written as

$$\overline{B}_{axial} = \frac{\mu_0}{4\pi}\left(\frac{2rp_m}{(r^2-l^2)^2}\right)\hat{i}$$

If the distance between two poles in a bar magnet is small (looks like short magnet) when compared to the distance between geometrical centre O of bar magnet and the location of point C (r >>l),

$$(r^2-l^2)^2 \approx r^4$$

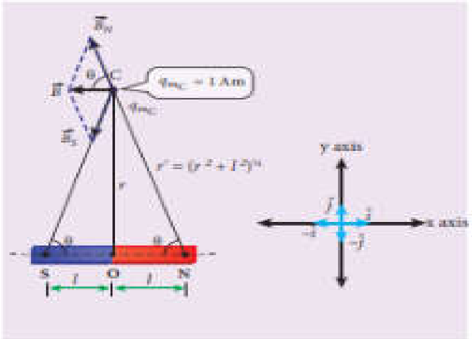
Therefore, using equations

$$\dot{B}_{axial} = \frac{\mu_0}{4\pi}\left(\frac{2p_m}{r^3}\right)\hat{i} = \frac{\mu_0}{4\pi}\frac{2}{r^3}\dot{p}_m$$

Where $\dot{P}_m = p_m\hat{i}$.

Magnetic field at a point along the equatorial line due to a magnetic dipole (bar magnet)

Consider a bar magnet NS as shown. Let N be the north pole and S be the south pole of the bar magnet, each with pole strength q_m and separated by a distance of 2l. The magnetic field at a point C (lies along the equatorial line) at a distance r from the geometrical centre O of the bar magnet can be computed by keeping unit north pole (q_{m_c} = 1 A m) at C.



Magnetic field at a point along the equatorial line due to a magnetic dipole

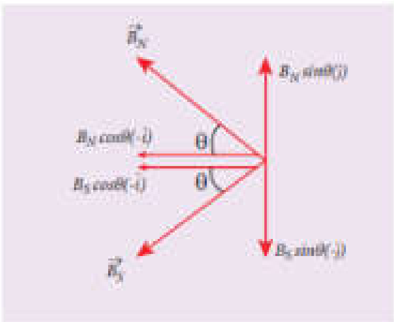
The magnetic field at C due to the north pole is

$$\vec{B}_N = -B_N \cos\theta \hat{i} + B_N \sin\theta \hat{i}$$

Where $B_N = \frac{\mu_\circ}{4\pi} \frac{q_m}{r'^2}$

Here $r' = \left(r^2 + l^2\right)^{\frac{1}{2}}$

The magnetic field at C due to the south pole is



Components of magnetic field

$$\vec{B}_S = -B_S \cos\theta \hat{i} + B_S \sin\theta \, j$$

Where, $B_S = \frac{\mu_\circ}{4\pi} \frac{q_m}{r'^2}$

From equations, the net magnetic field at point C due to the dipole is $\overline{B} = \overline{B}_N + \overline{B}_S$.

$$\dot{B} = -\left(B_N + B_S\right)\cos\theta\,\hat{i} \quad Since, B_N = B_S$$

$$\overline{B} = -\frac{2\mu_\circ}{4\pi}\frac{q_m}{r^{12}}\cos\theta\,\hat{i} = -\frac{2\mu_\circ}{4\pi}\frac{q_m}{\left(r^2 + l^2\right)}\cos\theta\,\hat{i}$$

In a right angle triangle NOC as shown

$$\cos\theta = \frac{adjacent}{hypotenuse} = \frac{l}{r^{'}} = \frac{l}{\left(r^2 + l^2\right)^{\frac{1}{2}}}$$

Substituting equation, we get

$$\dot{B} = -\frac{\mu}{4\pi}\frac{q_m \times (2l)}{\left(r^2 + l^2\right)^{\frac{1}{2}}}\hat{i}$$

Since, magnitude of magnetic dipole moment is $\left|\overline{P}_m\right| = P_m = q_m.2l$ and substituting in equation, the magnetic field at a point C is

$$\dot{B}_{equatorial} = -\frac{\mu}{4\pi}\frac{q_m \times (2l)}{\left(r^2 + l^2\right)^{\frac{3}{2}}}\hat{i}$$

If the distance between two poles in a bar magnet is small (looks like short magnet) when compared to the distance between geometrical centre O of bar magnet and the location of point C (r >>l),

$$\left(r^2 + l^2\right)^{\frac{3}{2}} \approx r^3$$

Therefore, using equation

$$\overline{B}_{equatorial} = -\frac{\mu_\circ}{4\pi}\frac{p_m}{r^3}\hat{i}$$

Since $p_m\hat{i} = \dot{P}_m$, the magnetic field at equatorial point is given by

$$\dot{B}_{equatorial} = -\frac{\mu_\circ}{4\pi}\frac{\dot{p}_m}{r^3}\hat{i}$$

Note that magnitude of B_{axial} is twice that of magnitude of $B_{equatorial}$ and the direction of B_{axial} and $B_{equatorial}$ are opposite.

EXAMPLE

A short bar magnet has a magnetic moment of 0.5 J T^{-1}. Calculate magnitude and direction of the magnetic field produced by the bar magnet which is kept at a distance of 0.1 m from the centre of the bar magnet along (a) axial line of the bar magnet and (b) normal bisector of the bar magnet.

Solution

Given magnetic moment = 0.5 J T^{-1} and distance r = 0.1 m

(a) When the point lies on the axial line of the bar magnet, the magnetic field for short magnet is given by

$$\vec{B}_{axial} = \frac{\mu_\circ}{4\pi}\left(\frac{2p_m}{r^3}\right)\hat{i}$$

$$\overline{B}_{axial} = 10^{-7} \times \left(\frac{2 \times 0.5}{(0.1)^3}\right)\hat{i} = 1 \times 10^{-4}\,\hat{i}\,T$$

Hence, the magnitude of the magnetic field along axial is
$B_{axial} = 1 \times 10^{-4}$ T and direction is towards South to North.

(b) When the point lies on the normal bisector (equatorial) line of the bar magnet, the magnetic field for short magnet is given by

$$\overline{B}_{equatorial} = -\frac{\mu_\circ}{4\pi}\frac{p_m}{r^3}\hat{i}$$

$$\overline{B}_{axial} = -10^{-7} \times \left(\frac{0.5}{(0.1)^3}\right)\hat{i} = -0.5 \times 10^{-4}\,\hat{i}\,T$$

Hence, the magnitude of the magnetic field along axial is
$B_{equatorial} = 0.5 \times 10^{-4}$ T and direction is towards North to South.

Note that magnitude of B_{axial} is twice that of magnitude of $B_{equatorial}$ and the direction of B_{axial} and $B_{equatorial}$ are opposite.

MAGNETIC PROPERTIES

All materials are not magnetic in nature. Further, all the magnetic materials will not behave identically. So, in order to differentiate one magnetic material from another, some basic parameters are used. They are:

(a) **Magnetising field**

The magnetic field which is used to magnetize a sample or specimen is called the magnetising field. Magnetising field is a vector quantity and is denoted by $\dot{H}$ and its unit is A m^{-1}.

(b) **Magnetic permeability**

The magnetic permeability is the measure of ability of the material to allow the passage of magnetic field lines through it or measure of the capacity of the substance to take magnetisation or the degree of penetration of magnetic field through the substance.

In free space, the permeability (or absolute permeability) is denoted by μ_0 and for any other medium it is denoted by μ. **The relative permeability μ_r is defined as the ratio between absolute permeability of the medium to the permeability of free space.**

$$\mu_r = \frac{\mu}{\mu_0}$$

Relative permeability is a dimensionless number and has no units. For free space (air or vacuum), the relative permeability is unity i.e., $\mu_r = 1$.

(c) **Intensity of magnetisation**

Any bulk material (any object of finite size) contains a large number of atoms. Each atom consists of electrons which undergo orbital motion. Due to orbital motion, electron has magnetic moment which is a vector quantity. In general, these magnetic moments orient randomly, therefore, the net magnetic moment is zero per unit volume of the material.

When such a material is kept in an external magnetic field, atomic dipoles are induced and hence, they will try to align partially or fully along the direction of external field. **The net magnetic moment per unit volume of the material** is known **as intensity of magnetisation.** It is a vector quantity. Mathematically,

$$\dot{M} = \frac{Magnetic\,moment}{Volume} = \frac{\dot{p}_m}{V}$$

The SI unit of intensity of magnetisation is ampere metre^{-1}. For a bar magnet of pole strength q_m, length 2l and area of cross-section A, the magnetic moment of the bar magnet is $\dot{p}_m = q_m 2\dot{i}$ and volume of the bar magnet is $V = A\left|\overline{2i}\right| = 2l\,A$. The intensity of magnetisation for a bar magnet is

$$\dot{M} = \frac{Magnetic\,moment}{Volume} = \frac{q_m 2\dot{i}}{2l\,A}$$

In magnitude, equation

$$\left|\overline{M}\right| = M = \frac{q_m \times 2l}{2l \times A} \Rightarrow M = \frac{q_m}{A}$$

This means, for a bar magnet the intensity of magnetisation can be defined as the pole strength per unit area (face area). (d) Magnetic induction or total magnetic field When a substance like soft iron bar is placed in a uniform magnetising field ρ H, the substance gets magnetised. The magnetic induction (total magnetic field) inside the specimen ρ B is equal to the sum of the magnetic field ρ Bo produced in vacuum due to the magnetising field and the magnetic field ρBm due to the induced magnetism of the substance.

$$\dot{B} = \dot{B}_o + \dot{B}_m = \mu\,\dot{H} + \mu_{.}\dot{M}$$

$$\Rightarrow \overline{B} = \overline{B}_o + \overline{B}_m = \mu_{\circ}\left(\overline{H} + \overline{M}\right)$$

(e) Magnetic susceptibility

When a substance is kept in a magnetising field ρ H, magnetic susceptibility gives information about how a material responds to the external (applied) magnetic field. In other words, the magnetic susceptibility measures how easily and how strongly a material can be magnetised. It is defined as the ratio of the intensity of magnetisation ($\dot{M}$) M induced in the material to the magnetising field ($\dot{H}$)

$$x_m = \frac{\left|\dot{M}\right|}{\left|\dot{H}\right|}$$

It is a dimensionless quantity. Magnetic susceptibility for some of the isotropic substances is given.

Magnetic susceptibility for various materials

Material	Magnetic susceptibility (X_m)
Aluminium	2.5×10^{-5}
Copper	-0.98×10^{-5}
Diamond	-2.2×10^{-5}
Gold	-3.6×10^{-5}
Mercury	-3.2×10^{-5}
Silver	-2.6×10^{-5}
Titanium	7.06×10^{-5}
Tungsten	6.8×10^{-5}
Carbon dioxide (1 atm)	-2.3×10^{-9}
Oxygen (1 atm)	2090×10^{-9}

EXAMPLE

Compute the intensity of magnetisation of the bar magnet whose mass, magnetic moment and density are 200 g, 2 A m^2 and 8 g cm^{-3}, respectively.

Solution

Density of the magnet is

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \Rightarrow \text{Volume} = \frac{\text{Mass}}{\text{Density}}$$

$$\text{Volume} = \frac{200\times10^{-3}\,kg}{\left(8\times10^{-3}\,kg\right)\times10^{6}\,m^{-3}}$$

$= 25\times10^{-6} m^3$

Magnitude of magnetic moment $p_m = 2Am^2$

Intensity of magnetization,

$$M = \frac{Magnetic\,moment}{Volume} = \frac{2}{25\times10^{-6}}$$
$$M = 0.8\times10^{5}\,Am^{-1}$$

EXAMPLE

Using the relation $M = \overline{B} = \mu_{\cdot}\left(\overline{H} + \overline{M}\right)$, show that $\chi_m = \mu_r - 1$.

Solution

$$M = \overline{B} = \mu_0 \left(\overline{H} + \overline{M} \right)$$

Hence, $\dot{B} = \mu_0 \left(\chi_m + 1 \right) \dot{H} \Rightarrow \dot{B} = \mu \dot{H}$

Where, $\mu = \mu_0 \left(\chi_m + 1 \right) \Rightarrow \chi_m + 1 = \dfrac{\mu}{\mu_0} = \mu_r$

$$\Rightarrow \chi_m = \mu_r - 1$$

EXAMPLE

Two materials X and Y are magnetised whose values of intensity of magnetisation are 500 A m^{-1} and 2000 A m^{-1} respectively. If the magnetising field is 1000 A m^{-1}, then which one among these materials can be easily magnetized.

Solution

The susceptibility of material X is

$$\chi_{m,X} = \frac{|\overline{M}|}{|\overline{H}|} = \frac{500}{1000} = 0.5$$

The susceptibility of material Y is

$$\chi_{m,Y} = \frac{|\overline{M}|}{|\overline{H}|} = \frac{2000}{1000} = 2$$

Since, susceptibility of material Y is greater than that of material X, which implies that material Y can be easily magnetized.

CLASSIFICATION OF MAGNETIC MATERIALS

The magnetic materials are generally classified into three types based on their behaviour in a magnetising field. They are diamagnetic, paramagnetic and ferromagnetic materials.

(a) Diamagnetic materials

The orbital motion of electrons around the nucleus produces a magnetic field perpendicular to the plane of the orbit. Thus each electron orbit has finite orbital magnetic dipole moment. Since the orbital planes of the other electrons are oriented in random manner, the vector sum of magnetic moments is zero and there is no resultant magnetic moment for each atom.

In the presence of a uniform external magnetic field, some electrons are speeded up and some are slowed down. The electrons whose moments were anti-parallel are speeded up according to Lenz's law and this produces an induced magnetic moment in a direction opposite to the field. The induced moment disappears as soon as the external field is removed.

When placed in a non-uniform magnetic field, the interaction between induced magnetic moment and the external field creates a force which tends to move the material from stronger part to weaker part of the external field. It means that diamagnetic material is repelled by the field.

This action is called diamagnetic action and such materials are known as diamagnetic materials. Examples: Bismuth, Copper and Water etc.

The properties of diamagnetic materials are

i) Magnetic susceptibility is negative.
ii) Relative permeability is slightly less than unity.
iii) The magnetic field lines are repelled or expelled by diamagnetic materials when placed in a magnetic field.
iv) Susceptibility is nearly temperature independent.

(b) Paramagnetic materials

In some magnetic materials, each atom or molecule has net magnetic dipole moment which is the vector sum of orbital and spin magnetic moments of electrons. Due to the random orientation of these magnetic moments, the net magnetic moment of the materials is zero.

In the presence of an external magnetic field, the torque acting on the atomic dipoles will align them in the field direction. As a result, there is net magnetic dipole moment induced in the direction of the applied field. The induced dipole moment is present as long as the external field exists.

When placed in a non-uniform magnetic field, the paramagnetic materials will have a tendency to move from weaker to stronger part of the field. Materials which exhibit weak magnetism in the direction of the applied field are known as paramagnetic materials.

Examples: Aluminium, Platinum, Chromium and Oxygen etc.

The properties of paramagnetic materials are:

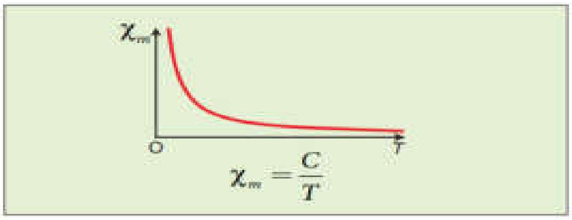
i) Magnetic susceptibility is positive and small.
ii) Relative permeability is greater than unity.
iii) The magnetic field lines are attracted into the paramagnetic materials when placed in a magnetic field.
iv) Susceptibility is inversely proportional to temperature.

Curie's law

When temperature is increased, thermal vibration will upset the alignment of magnetic dipole moments. Therefore, the magnetic susceptibility decreases with increase in temperature. In many cases, the susceptibility of the materials is

$$\chi_m \alpha \frac{1}{T} or \chi_m = \frac{C}{T}$$

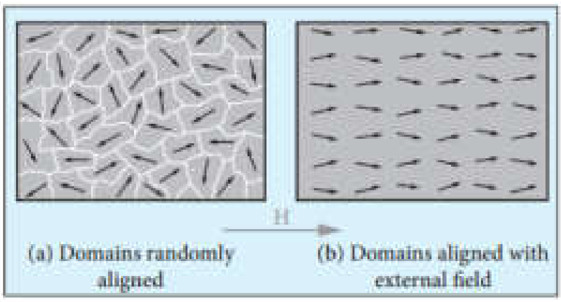
This relation is called Curie's law. Here C is called Curie constant and temperature T is in kelvin. The graph drawn between magnetic susceptibility and temperature is shown in Figure 3.19, which is a rectangular hyperbola.



Curie's law – susceptibility vs temperature

(c) Ferromagnetic materials

An atom or a molecule in a ferromagnetic material possesses net magnetic dipole moment as in a paramagnetic material. A ferromagnetic material is made up of smaller regions, called ferromagnetic domains (Figure 3.20). Within each domain, the magnetic moments are spontaneously aligned in a direction. This alignment is caused by strong interaction arising from electron spin which depends on the inter-atomic distance. Each domain has net magnetisation in a direction. However the direction of magnetisation varies from domain to domain and thus net magnetisation of the specimen is zero.



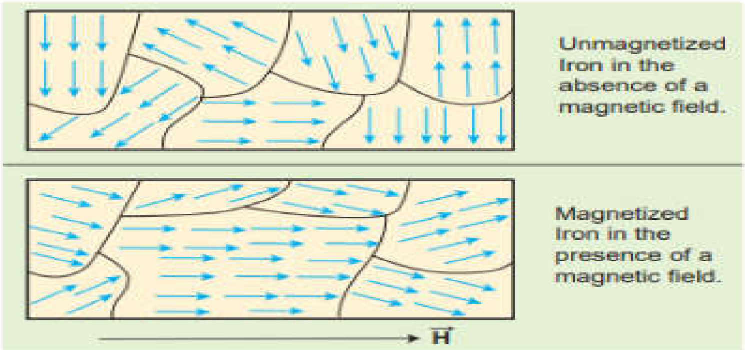
Magnetic domains – ferromagnetic materials

In the presence of external magnetic field, two processes take place

(1) The domains having magnetic moments parallel to the field grow bigger in size (2)

(2) The other domains (not parallel to field) are rotated so that they are aligned with the field.

As a result of these mechanisms, there is a strong net magnetisation of the material in the direction of the applied field.



Processes of domain magnetization

When placed in a non-uniform magnetic field, the ferromagnetic materials will have a strong tendency to move from weaker to stronger part of the field. Materials which exhibit strong magnetism in the direction of applied field are called ferromagnetic materials. Examples: Iron, Nickel and Cobalt.

The properties of ferromagnetic materials are:

i) Magnetic susceptibility is positive and large.

ii) Relative permeability is large.

iii) The magnetic field lines are strongly attracted into the ferromagnetic materials when placed in a magnetic field.

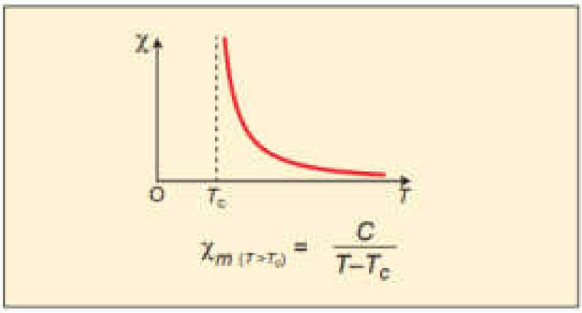
iv) Susceptibility is inversely proportional to temperature.

Curie-Weiss law

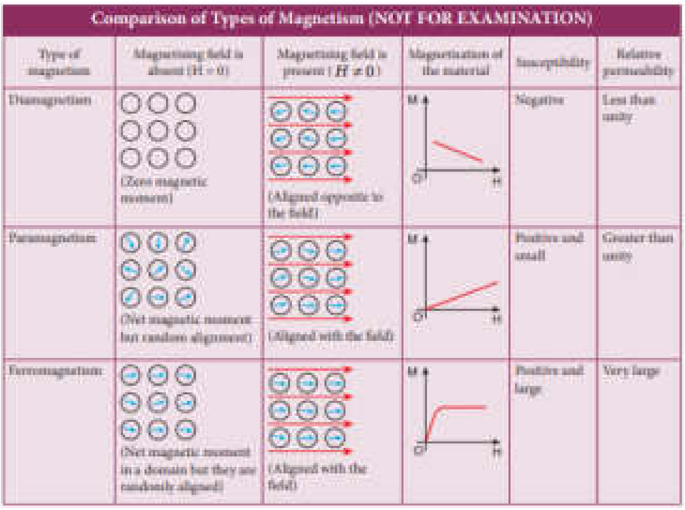
As temperature increases, the ferromagnetism decreases due to the increased thermal agitation of the atomic dipoles. At a particular temperature, ferromagnetic material becomes paramagnetic. This temperature is known as Curie temperature TC. The susceptibility of the material above the Curie temperature is given by

$$\chi_m = \frac{C}{T - T_C}$$

This relation is called Curie-Weiss law. The constant C is called Curie constant and temperature T is in kelvin scale. A plot of magnetic susceptibility with temperature is as shown



Curie-Weiss law – susceptibility vs temperature



Comparison of Types of Magnetism (NOT FOR EXAMINATION)

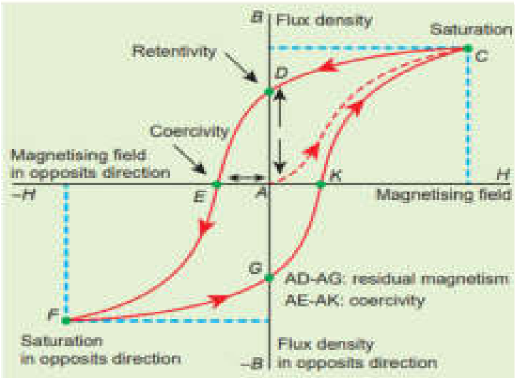
Type of magnetism	Magnetising field is absent ($H = 0$)	Magnetising field is present ($H \neq 0$)	Magnetisation of the material	Susceptibility	Relative permeability
Diamagnetism	(Zero magnetic moment)	(Aligned opposite to the field)		Negative	Less than unity
Paramagnetism	(Net magnetic moment but random alignment)	(Aligned with the field)		Positive and small	Greater than unity
Ferromagnetism	(Net magnetic moment in a domain but they are randomly aligned)	(Aligned with the field)		Positive and large	Very large

HYSTERESIS

When a ferromagnetic material is kept in a magnetising field, the material gets magnetised by induction. An important characteristic of ferromagnetic material is that the variation of magnetic induction $\vec{B}$ with magnetising field $\vec{H}$ is not linear. It means that the ratio $\frac{B}{H} = \mu$ is not a constant. Let us study this behaviour in detail.

A ferromagnetic material (example, Iron) is magnetised slowly by a magnetising field $\vec{H}$. The magnetic induction $\vec{B}$ of the material increases from point A with the magnitude of the magnetising field and then attains a saturation level. This response of the material is depicted by the path AC as shown. Saturation magnetization is defined as the maximum point up to which the material can be magnetised by applying the magnetising field.

If the magnetising field is now reduced, the magnetic induction also decreases but does not retrace the original path CA. It takes different path CD. When the magnetising field is zero, the magnetic induction is not zero and it has positive value. This implies that some magnetism is left in the specimen even when H = 0. The residual magnetism AD present in the specimen is called remanence or retentivity. **Remanence is defined as the ability of the materials to retain the magnetism in them even after the magnetising field disappears**



Hysteresis – plot for B vs H

If the magnetising field is now reduced, the magnetic induction also decreases but does not retrace the original path CA. It takes different path CD. When the magnetising field is zero, the magnetic induction is not zero and it has positive value. This implies that some magnetism is left in the specimen even when H = 0. The residual magnetism AD present in the specimen is called remanence or retentivity. **Remanence is defined as the ability of the materials to retain the magnetism in them even after the magnetising field disappears.**

In order to demagnetise the material, the magnetising field is gradually increased in the reverse direction. Now the magnetic induction decreases along DE and becomes zero at E. The magnetising field AE in the reverse direction is required to bring residual magnetism to zero. **The magnitude of the reverse magnetising field for which the residual magnetism of the material vanishes is called its coercivity.**

Further increase of $\vec{H}$ in the reverse direction causes the magnetic induction to increase along EF until it reaches saturation at F in the reverse direction. If magnetising field is decreased and then increased with direction reversed, the magnetic induction traces the path FGKC. This closed curve ACDEFGKC is called hysteresis loop and it corresponds to one cycle of magnetisation.

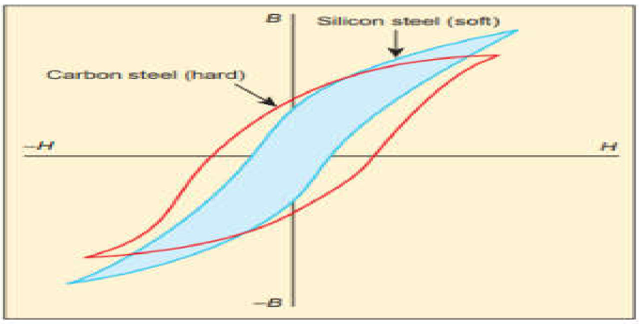
In the entire cycle, the magnetic induction B lags behind the magnetising field H. **This phenomenon of lagging of magnetic induction behind the magnetising field is called hysteresis.** Hysteresis means 'lagging behind'.

Hysteresis loss

During the magnetisation of the specimen through a cycle, there is loss of energy in the form of heat. This loss is attributed to the rotation and orientation of molecular magnets in various directions. It is found that the energy lost (or dissipated) per unit volume of the material when it is carried through one cycle of magnetisation is equal to the area of the hysteresis loop.

Hard and soft magnetic materials

Based on the shape and size of the hysteresis loop, ferromagnetic materials are classified as soft magnetic materials with smaller area and hard magnetic materials with larger area. The comparison of the hysteresis loops for two magnetic materials is shown. Properties of soft and hard magnetic materials are compared in Table



Comparison of two ferromagnetic materials based on hysteresis loop

S.No.	Properties	Soft ferromagnetic materials	Hard ferromagnetic materials
1	When external field is removed	Magnetisation disappears	Magnetisation persists
2	Area of the loop	Small	Large
3	Retentivity	Low	High
4	Coercivity	Low	High
5	Susceptibility and magnetic permeability	High	Low
6	Hysteresis loss	Less	More

7	Uses	Solenoid core, transformer core and electromagnets	Permanent magnets
8	Examples	Soft iron, Mumetal, Stalloy etc.	Carbon steel, Alnico, Lodestone etc.

Applications of hysteresis loop

The significance of hysteresis loop is that it provides information such as retentivity, coercivity, permeability, susceptibility and energy loss during one cycle of magnetisation for each ferromagnetic material. Therefore, the study of hysteresis loop will help us in selecting proper and suitable material for a given purpose. Some examples:

i) Permanent magnets:

The materials with high retentivity, high coercivity and low permeability are suitable for making permanent magnets. Examples: Carbon steel and Alnico ii)

ii) Electromagnets:

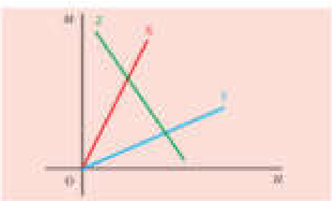
The materials with high initial permeability, low retentivity, low coercivity and thin hysteresis loop with smaller area are preferred to make electromagnets. Examples: Soft iron and Mumetal (Nickel Iron alloy).

iii) Core of the transformer:

The materials with high initial permeability, large magnetic induction and thin hysteresis loop with smaller area are needed to design transformer cores.

Examples:

Soft iron EXAMPLE The following figure shows the variation of intensity of magnetisation with the applied magnetic field intensity for three magnetic materials X, Y and Z. Identify the materials X,Y and Z.



Solution

The slope of M-H graph is a measure of the magnetic susceptibility, which is given by

$$\chi_m = \frac{M}{H}$$

Material X: Slope is positive and larger value. So, it is a ferromagnetic material.

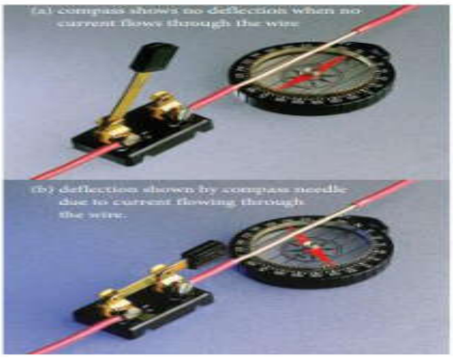
Material Y: Slope is positive and lesser value than X. So, it could be a paramagnetic material.

Material Z: Slope is negative and hence, it is a diamagnetic material.

MAGNETIC EFFECTS OF CURRENT

Oersted experiment

In 1820 Hans Christian Oersted, while preparing for his lecture in physics, noticed that electric current passing through a wire deflects the nearby magnetic needle in the compass. By proper investigation, he observed that the deflection of magnetic needle is due to the change in magnetic field produced around current carrying conductor (Figure 3.25). When the direction of current is reversed, the magnetic needle is deflected in the opposite direction. This lead to the development of the theory 'electromagnetism' which unifies two branches in physics namely, electricity and magnetism.

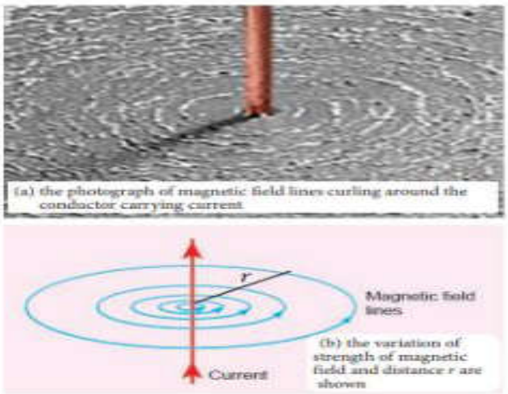


Oersted's experiment - current carrying wire and deflection of magnetic needle

Magnetic field around a straight current-carrying conductor and circular loop

(a) Current carrying straight conductor:

Suppose we keep a magnetic compass near a current-carrying straight conductor, then the needle of the magnetic compass experiences a torque and deflects to align in the direction of the magnetic field at that point. Tracing out the direction shown by magnetic needle, we can draw the magnetic field lines at a distance. For a straight current-carrying conductor, the nature of magnetic field is like concentric circles having their common centre on the axis of the conductor as shown (a).



Magnetic field lines around straight, long wire carrying current

The direction of circular magnetic field lines will be clockwise or anticlockwise depending on the direction of current in the conductor. If the strength (or magnitude) of the current is increased then the density of the magnetic field will also increase. The strength of the magnetic field (B) decreases as the distance (r) from the conductor increases (b).

(b) Circular coil carrying current

Suppose we keep a magnetic compass near a current carrying circular conductor, then the needle of the magnetic compass experiences a torque and deflects to align in the direction of the magnetic field at that point. We can notice that at the points A and B in the vicinity of the coil, the magnetic field lines are circular. The magnetic field lines are nearly parallel to each other near the centre of the loop, indicating that the field present near the centre of the coil is almost uniform.

The strength of the magnetic field is increased if either the current in the coil or the number of turns or both are increased. The polarity (north pole or south pole) depends on the direction of current in the loop.

Right hand thumb rule

The right hand rule is used to find the direction of magnetic field when the direction of current in a conductor is known.

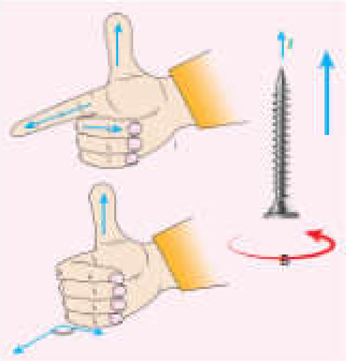
Assume that we hold the current carrying conductor in our right hand such that the thumb points in the direction of current flow, then the fingers encircling the conductor point in the direction of the magnetic field lines produced.

The shows the right hand rule for current carrying straight conductor and circular coil.

Right hand rule – straight conductor and circular loop

Maxwell's right hand cork screw rule

This rule can also be used to find the direction of the magnetic field around the current-carrying conductor. If we rotate a right-handed screw using a screw driver, then the direction of current is same as the direction in which screw advances and the direction of rotation of the screw gives the direction of the magnetic field.



Maxwell's right hand cork screw rule

BIOT - SAVART LAW

Soon after Oersted's discovery, both Jean-Baptiste Biot and Felix Savart in 1819 did quantitative experiments on the force experienced by a magnet kept near current carrying wire and arrived at a mathematical expression that gives the magnetic field at some point in space in terms of the current that produces the magnetic field. This is true for any shape of the conductor.

Definition and explanation of Biot- Savart law

Magnetic field at a point P due to current carrying conductor

Biot and Savart experimentally observed that the magnitude of magnetic field dB ρ at a point P (Figure 3.30) at a distance r from the small elemental length taken on a conductor carrying current varies

(i) directly as the strength of the current I

(ii) directly as the magnitude of the length element $\overline{dl}$

(iii) directly as the sine of the angle θ between $\overline{dl}$ and $\hat{r}$.

(iv) inversely as the square of the distance r between the point P and length element $\overline{dl}$.

This is expressed as

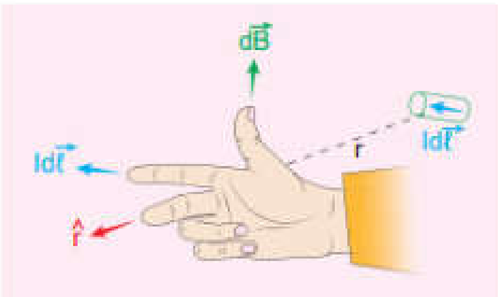
$$dB \alpha \frac{Idl}{r^2}\sin\theta$$

$$dB = k\frac{I\,dl}{r^2}\sin\theta$$

where $k = \frac{\mu_o}{4\pi}$ in SI units.

In vector notation,

Here vector $\overline{dB}$ is perpendicular to both $I\,\vec{dl}$ (pointing the direction of current flow) and the unit vector $\hat{r}$ directed from $\overline{dl}$ toward point P



The direction of magnetic field using right hand rule

The equation (3.34) is used to compute the magnetic field only due to a small elemental length dl of the conductor. The net magnetic field at P due to the conductor is obtained from principle of superposition by considering the contribution from all current elements $I\,\vec{dl}$. Hence integrating equation (3.34), we get

$$\vec{B} = \int d\vec{B} = \frac{\mu_o I}{4\pi}\int \frac{\vec{dl}\times\hat{r}}{r^2}$$

Where the integral is taken over the entire current distribution.

Cases

1. If the point P lies on the conductor, then θ = 0°. Therefore, $|\overline{dB}|$ is zero.

2. If the point lies perpendicular to the conductor, then θ = 90°. Therefore, $\overline{dB}$ is maximum and is given by $d\vec{B} = \frac{\mu_0}{4\pi}\frac{I\,d\vec{l}}{r^2}n$ where n is the unit vector perpendicular to both $I\,d\vec{l}$ and $\hat{r}$

Similarities between electric field (from Coulomb's law) and magnetic field (from Biot-Savart's law)

Electric and magnetic fields

- Obey inverse square law, so they are long range fields.
- Obey the principle of superposition and are linear with respect to source. In magnitude,

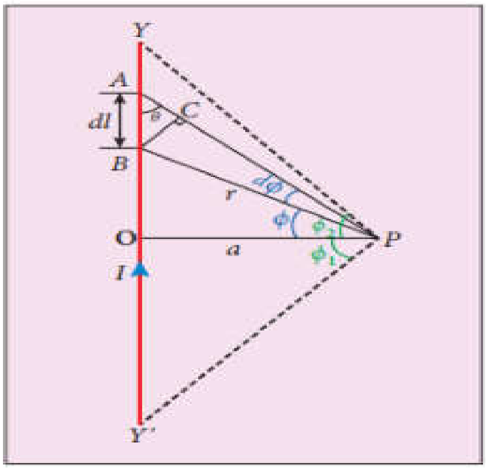
$E \alpha q$
$B \alpha Idl$

Differences between electric field (from Coulomb's law) and magnetic field (from Biot-Savart's law)

S. No.	Electric field	Magnetic field
1	Produced by a scalar source i.e., an electric charge q	Produced by a vector source i.e., current element $I\,d\vec{l}$
2	It is directed along the position vector joining the source and the point at which the field is calculated	It is directed perpendicular to the position vector $\hat{r}$ and the current element $I\,d\vec{l}$

3	Does not depend on angle	Depends on the angle between the position vector $\hat{r}$ and the current element $I\,\vec{dl}$

Magnetic field due to long straight conductor carrying current



Magnetic field due to a long straight current carrying conductor

Let YY' be an infinitely long straight conductor and I be the steady current through the conductor as shown in Figure 3.32. In order to calculate magnetic field at a point P which is at a distance a from the wire, let us consider a small line element dl (segment AB).

The magnetic field at a point P due to current element Idl can be calculated from Biot-Savart's law, which is

$$d\vec{B} = \frac{\mu_\circ}{4\pi}\frac{I\,d\vec{l}\sin\theta}{r^2}n$$

Where n is the unit vector which points into the page at P, θ is the angle between current element Idl and line joining dl and the point P. Let r be the distance between line element at A to the point P.

To apply trigonometry, draw a perpendicular AC to the line BP as shown.

In triangle $\Delta ABC, \sin\theta = \frac{AC}{AB}$

$$\Rightarrow AC = AB\sin\theta$$

But $AB = dl \Rightarrow AC = dl\sin\theta$

Let $d\phi$ be the angle subtended between AP and BP

i.e., $\angle APB = \angle BPC = d\phi$

In a triangle Δ APC, $\sin(d\phi) = \frac{AC}{AP}$

Since, dϕ is very small, $\sin(d\phi) \doteq d\phi$

But AP = r ⇒ AC = rdϕ

$$\therefore AC = dl\sin\theta = rd\phi$$

$$\therefore d\overline{B} = \frac{\mu_\circ}{4\pi}\frac{I}{r^2}(rd\phi).n = \frac{\mu_\circ}{4\pi}\frac{Id\phi}{r}n$$

Let ϕ be the angle between BP and OP

In a ΔOPA, cosϕ = $\frac{OP}{BP} = \frac{a}{r}$

$$\Rightarrow r = \frac{a}{\cos\phi}$$

$$d\overline{B} = \frac{\mu_\circ}{4\pi}\frac{I}{a/\cos\phi}d\phi n$$

$$\Rightarrow d\overline{B} = \frac{\mu_\circ}{4\pi}\frac{I}{a}\cos\phi d\phi n$$

The total magnetic field at P due to the conductor YY' is

$$\overline{B} = \int_{-\phi_1}^{\phi_2} d\overline{B} = \int_{-\phi_1}^{\phi_2}\frac{\mu_\circ}{4\pi}\frac{I}{a}\cos\phi d\phi n$$

$$= \frac{\mu_\circ}{4\pi}\frac{I}{a}\left[\sin\phi\right]_{-\phi_1}^{\phi_2} n$$

$$= \overline{B} = \frac{\mu_\circ}{4\pi}\frac{I}{a}\left(\sin-\phi_1 + \sin\phi_2\right)n$$

For infinitely long conductor,

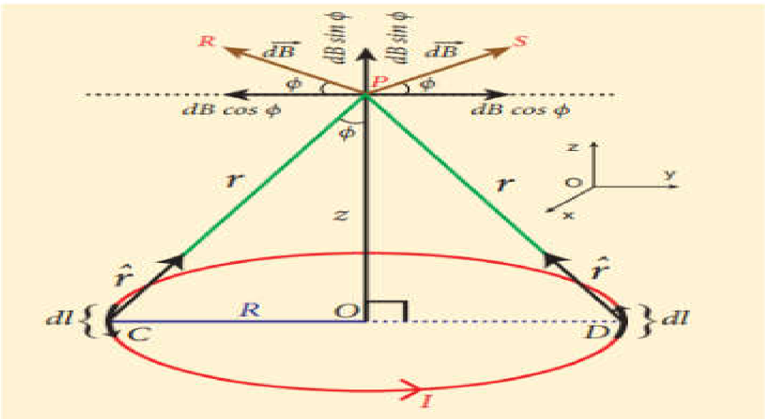
$\phi_1 = \phi_2 = 90°$

$$\overline{B} = \frac{\mu_0}{4\pi}\frac{I}{a} \times 2n \Rightarrow \overline{B} = \frac{\mu_0 I}{2\pi a} n$$

Magnetic field produced along the axis of the current-carrying circular coil

Consider a current carrying circular loop of radius R and let I be the current flowing through the wire in the direction as shown

The magnetic field at a point P on the axis of the circular coil at a distance z from the centre of the coil O is computed by taking two diametrically opposite line elements of the coil each of length $\overline{dl}$ at C and D. Let $\vec{r}$ be the vector joining the current element ($I\,d\vec{l}$) at C and the point P.



Magnetic field due to current-carrying circular loop

According to Biot-Savart's law, the magnetic field at P due to the current element at C is

$$d\vec{B} = \frac{\mu_0}{4\pi}\frac{I\,d\vec{l} \times \hat{r}}{r^2}$$

The magnitude of $d\overline{B}$ is

$$dB = \frac{\mu_0}{4\pi}\frac{Idl\sin\theta}{r^2} = \frac{\mu_0}{4\pi}\frac{Idl}{r^2}$$

Where θ is the angle between $I\,d\vec{l}$ and $\vec{r}$. Here θ = 90°.

The direction of $d\overline{B}$ is perpendicular to the current element $I\,d\vec{l}$ and CP. It is therefore along PR perpendicular to CP.

The magnitude of magnetic field at P due to current element at D is same as that for the element at C because of equal distances from the coil. But its direction is along PS.

The magnetic field $d\overline{B}$ due to each current element is resolved into two components; dBcosϕ along y-direction and dBsinϕ along z-direction. The horizontal components cancel out while the vertical components ($dB\sin\phi k$) alone contribute to the net magnetic field $\dot{B}$ at the point P.

$$\overline{B} = \int d\overline{B} = \int dB\sin\phi k$$

$$= \frac{\mu_{\circ} I}{4\pi}\int \frac{dl}{r^2}\sin\phi k$$

From ΔOCP,

$$\sin\phi = \frac{R}{\left(R^2+z^2\right)^{1/2}} k\left(\int dl\right) \text{and } r^2=R^2+z^2$$

Substituting these in the above equation, we get

$$\overline{B} = \frac{\mu_{\circ} I}{4\pi}\frac{R}{\left(R^2+z^2\right)^{3/2}} k\left(\int dl\right)$$

If we integrate the line element from 0 to 2πR, we get the net magnetic field $\dot{B}$ at point P due to the current-carrying circular loop.

$$\overline{B} = \frac{\mu_{\circ} I}{2}\frac{R^2}{\left(R^2+z^2\right)^{3/2}} k$$

If the circular coil contains N turns, then the magnetic field is

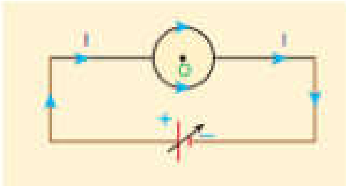
$$\overline{B} = \frac{\mu_{\circ} NI}{2}\frac{R^2}{\left(R^2+z^2\right)^{3/2}} k$$

The magnetic field at the centre of the coil is

$$\overline{B} = \frac{\mu_{\circ} NI}{2R} k \text{ since } z = 0$$

EXAMPLE

What is the magnetic field at the centre of the loop shown in figure?



Solution

The magnetic field due to current in the upper semicircle and lower semicircle of the circular coil are equal in magnitude but opposite in direction. Hence, the net magnetic field at the centre of the loop
(at point O) is zero $\vec{B} = 0$.

Tangent law and Tangent Galvanometer

Tangent galvanometer is a device used to detect very small currents. It is a moving magnet type galvanometer. Its working is based on tangent law.

Tangent law

When a magnetic needle or magnet is freely suspended in two mutually perpendicular uniform magnetic fields, it will come to rest in the direction of the resultant of the two fields.

Right hand thumb rule

In order to determine the direction of magnetic moment, we use right hand thumb rule which states that

If we curl the fingers of right hand in the direction of current in the loop, then the stretched thumb gives the direction of the magnetic moment associated with the loop.

Table 3.3 End rule – polarity with direction of current in circular loop

Current in circular loop	Polarity	Picture
Anti-clockwise current	North Pole	
Clockwise current	South Pole	

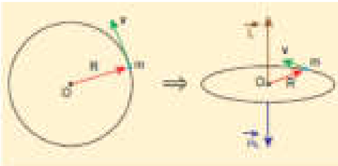
Magnetic dipole moment of revolving electron

Suppose an electron undergoes circular motion around the nucleus as shown. The circulating electron in a loop is like current in a circular loop (since flow of charge constitutes current). The magnetic dipole moment due to current carrying circular loop is

$$\vec{\mu}_L = I\vec{A}$$

In magnitude,

$$\mu_L = IA$$



(a) Electron revolving in a circular orbit (b) Direction of magnetic dipole moment vector and orbital angular momentum vector are opposite

If T is the time period of revolution of an electron, the current due to circular motion of the electron is

$$I = \frac{-e}{T}$$

Where −e is the charge of an electron. If R is the radius of the circular orbit and v is the velocity of the electron in the circular orbit, then

$$T = \frac{2\pi R}{v}$$

Using equationsthe above we get,

$$\mu_L = \frac{e}{\frac{2\pi R}{v}} \pi R^2 = -\frac{evR}{2}$$

Where A = πR2 is the area of the circular loop. By definition, angular momentum of the electron about O is

$$\vec{L} = \vec{R} \times \vec{p}$$

In magnitude,

$$L = Rp = mvR$$

Using equation, we get

$$\frac{\mu_L}{L} = \frac{evR/2}{mvR} = \frac{e}{2m} \Rightarrow \overline{\mu}_L = -\frac{e}{2m}\overline{L}$$

The negative sign indicates that the magnetic moment and angular momentum are in opposite direction.

In magnitude,

$$\frac{\mu_L}{L} = \frac{e}{2m} = \frac{1.60\times10^{-19}}{2\times9.11\times10^{-11}} = 0.0878\times10^{12}Ckg^{-1}$$

$$\frac{\mu_L}{L} = 8.78\times10^{10}C\,kg^{-1} = constant$$

The ratio $\frac{\mu_L}{L}$ is a constant known as gyro-magnetic ratio $\left(\frac{e}{2m}\right)$.It must be noted that the gyro-magnetic ratio is a constant of proportionality which connects angular momentum of the electron and the magnetic moment of the electron.

According to Neil's Bohr quantization rule, the angular momentum of an electron moving in a stationary orbit is quantized which means

$$L = nh = n\frac{h}{2\pi}$$

Where h is the Planck's constant (h = 6.63 x 10–34 J s) and number n is the orbit number, i.e., n = 1,2,3,..... Hence,

$$\mu_L = \frac{e}{2m}L = n\frac{eh}{4\pi m}$$

$$\mu_L = n\times\frac{(1.160\times10^{-19})h}{4\pi m}Am^2$$

$$= n\times\frac{(1.60\times10^{-19})(6.63\times10^{-14})}{4\times3.14\times(9.11\times10^{-10})}$$

$$\mu_L = 9.27\times10^{-24}Am^2$$

The minimum value of magnetic moment can be obtained by substituting n = 1,

$$\mu_L = 9.27\times10^{-24}\,Am^2 = 9.27\times10^{-24}\,JT^{-4}$$
$$= (\mu_L)_{\min} = \mu_a$$

where µ _B ehm = = × − 4 927 10 242 .Amis called Bohr magneton which is used to measure atomic magnetic moments.

AMPÈRE'S CIRCUITAL LAW

Ampère's circuital law is used to calculate magnetic field at a point whenever there is a

symmetry in the problem. This is similar to Gauss's law in electrostatics.

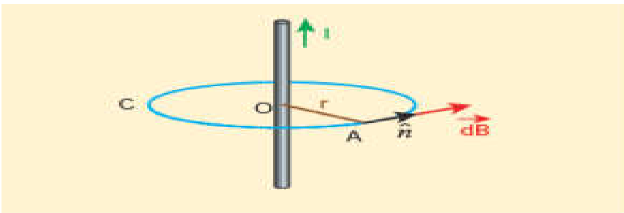
Ampère's circuital law

Ampère's law: The line integral of magnetic field over a closed loop is µ0 times net current enclosed by the loop.

$$\oint_C \vec{B}.\vec{dl} = \mu_o I_{enclosed}$$

Where $I_{enclosed}$is the net current linked by the closed loop C. Note that the line integral does not depend on the shape of the path or the position of the conductor with the magnetic field.

Magnetic field due to the current carrying wire of infinite length using Ampère's law



Ampèrian loop for current carrying straight wire

Consider a straight conductor of infinite length carrying current I andthe direction of magnetic field lines is shown in Figure 3.37. Since the wire is geometrically cylindrical in shape and symmetrical about its axis, we construct an Ampèrian loop in the form of a circular shape at a distance r from the centre of the conductor as shown in Figure 3.37. From the Ampère's law, we get

$$\oint_C \vec{B}.\vec{dl} = \mu_o I$$

Where $\bar{dl}$ is the line element along the Amperian loop (tangent to the circular loop). Hence, the angle between magnetic field vector and line element is zero. Therefore,

$$\oint_C B.dl = \mu_o I$$

Where I is the current enclosed by the Ampèrian loop. Due to the symmetry, the magnitude of the magnetic field is uniform over the Ampèrian loop. Hence

For a circular loop, the circumference is 2πr, which implies,

$$B \int_o^{2\pi r} dl = \mu_o I$$

$$B.2\pi r = \mu_o I$$

$$B = \frac{\mu_o I}{2\pi r}$$

In vector form, the magnetic field is

$$\dot{B} = \frac{\mu_o I}{2\pi r} \hat{n}$$

Where $\hat{n}$ is the unit vector along the tangent to the Ampèrian loop asshown.

EXAMPLE

Compute the magnitude of the magnetic field of a long, straight wire carrying a current of 1 A at distance of 1m from it. Compare it with Earth's magnetic field.

Solution

Given that I = 1 A and radius r = 1 m

But the Earth's magnetic field is $B_{Earth} \sim 10^{-5}$T
So, $B_{straightwire}$is one hundred times smaller than $B_{Earth.}$

Solenoid

A solenoid is a long coil of wire closely wound in the form of helix as shown in Figure 3.38. When electric current is passed through the solenoid, the magnetic field is produced. The magnetic field of the solenoid is due to the superposition of magnetic fields of each turn of the solenoid. The direction of magnetic field due to solenoid is given by right hand palm-rule.

Inside the solenoid, the magnetic field is nearly uniform and parallel to its axis whereas, outside the solenoid the field is negligibly small. Based on the direction of the current, one end of the solenoid behaves like North Pole and the other end behaves like South Pole.

The current carrying solenoid is held in right hand. If the fingers curl in the direction of current, then extended thumb gives the direction of magnetic field of current carrying solenoid. It is shown in

Solenoid

Solenoid as a bar magnet

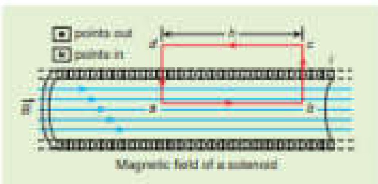
The direction of magnetic field of solenoid

Hence, the magnetic field of a solenoid looks like the magnetic field of a bar magnet.

The solenoid is assumed to be long which means that the length of the solenoid is large when compared to its diameter. The winding need not to be always circular, it can also be in other shapes. We consider here only circularly wound solenoid as shown in Figure 3.40.

Magnetic field due to a long current carrying solenoid

Consider a solenoid of length L having N turns. The diameter of the solenoid is assumed to be much smaller when compared to its length and the coil is wound very closely.



Amperian loop for solenoid

In order to calculate the magnetic field at any point inside the solenoid, we use Ampere's circuital law. Consider a rectangular loop abcd as shown in Figure 3.41. Then from Ampère's circuital law,

$$\oint_c \vec{B}.d\vec{l} = \mu_o I_{enclosed}$$

The left hand side of the equation is

$$\oint_c \bar{B}.\bar{d}l = \int_a^b \bar{B}.\bar{d}l + \int_b^c \bar{B}.\bar{d}l + \int_c^d \bar{B}.\bar{d}l + \int_d^a \bar{B}.\bar{d}l$$

Since the elemental lengths along bc and da are perpendicular to the magnetic fieldwhich is along the axis of the solenoid, the integrals

$$\int_b^c \bar{B}.\bar{d}l = \int_b^c |\bar{B}||\bar{d}l| \cos 90^0 = 0$$

Similarly

$$\int_d^a \bar{B}.\bar{d}l = 0$$

Since the magnetic field outside the solenoid is zero, the integral

$$\int_c^d \bar{B}.\bar{d}l = 0$$

For the path along ab, the integral is

$$\int_a^b \bar{B}.\bar{d}l = B\int_a^b dl \cos 0^0 = B\int_a^b dl$$

Where the length of the loop ab as shown hBut the choice of length of the loop ab is arbitrary. We can take very large loop such that it is equal to the length of the solenoid L. Therefore the integral is

$$\int_a^b \bar{B}.\bar{d}l = BL$$

Let I be the current passing through the solenoid of N turns, then

$$\int_a^b \bar{B}.\bar{d}l = BL = \mu_0 NI \Rightarrow B = \mu_0 \frac{NI}{L}$$

The number of turns per unit length is given by $\frac{N}{L} = n$, Then

$$B = \mu_0 \frac{nLI}{L} = \mu_0 nI$$

Since n is a constant for a given solenoid and μ_0 is also constant. For a fixed current I, the magnetic field inside the solenoid is also a constant.

EXAMPLE

Calculate the magnetic field inside a solenoid, when

a) the length of the solenoid becomes twice with fixed number of turns
b) both the length of the solenoid and number of turns are doubled
c) the number of turns becomes twice for the fixed length of the solenoid

Compare the results.

Solution

The magnetic field of a solenoid (inside) is

$$B_{L,N} = \mu_0 \frac{NI}{L}$$

(a) length of the solenoid becomes twice with fixed number of turns

L→2L (length becomes twice)

N→N (number of turns remains constant)

The magnetic field is

MRI is Magnetic Resonance Imaging which helps the physicians to diagonise or monitor treatment for a variety of abnormal conditions happening within the head, chest, abdomen and pelvis. It is a non invasive medical test. The patient is placed in a circular opening (actually interior of a solenoid which is made up of superconducting wire) and large current is sent through the superconducting wire to produce a strong magnetic field. So, it uses more powerful magnet, radio frequency pulses and a computer to produce pictures of organs which helps the physicians to examine various parts of the body.

$$B_{2L,N} = \mu_0 \frac{NI}{2L} = \frac{1}{2} B_{L,N}$$

(b) both the length of the solenoid and number of turns are doubled

L→2L (length becomes twice)

N→2N (number of turns becomes twice)

The magnetic field is

(c) the number of turns becomes twice but the length of the solenoid remains same

L→L (length is fixed)

N→2N (number of turns becomes twice)

The magnetic field is

$$B_{L,2N} = \mu_0 \frac{2NI}{L} = 2B_{L,N}$$

From the above results,

$B_{L,2N} > B_{2L,2N} > B_{2L,N}$

Thus, strength of the magnetic field is increased when we pack more loops into the same length for a given current.

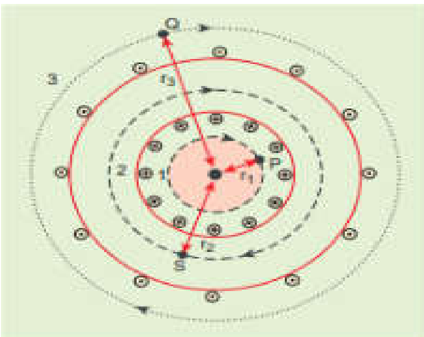
Toroid

A solenoid is bent in such a way its ends are joined together to form a closed ring shape, is called a toroid which is shown in Figure 3.42. The magnetic field has constant magnitude inside the toroid whereas in the interior region (say, at point P) and exterior region (say, at point Q), the magnetic field is zero.

Toroid

(a) Open space interior to the toroid

Let us calculate the magnetic field BP at point P. We construct an Amperian loop 1 of radius r_1 around the point P as shown in



Toroid – Amperian loop

For simplicity, we take circular loop so that the length of the loop is its circumference

$L_1 = 2\pi r_1$

Ampère's circuital law for the loop 1 is

$$\oint_{loop1} \vec{B}_p . \vec{dl} = \mu_0 I_{enclosed}$$

Since the loop 1 encloses no current, $I_{enclosed} = 0$

$$\oint_{loop1} \vec{B}_p . \vec{dl} = 0$$

This is possible only if the magnetic field at point P vanishes i.e.

$$\vec{B}_p = 0$$

(b) Open space exterior to the toroid

Let us calculate the magnetic field *BQ* at point Q. We construct an Amperian loop 3 of radius *r*3 around the point Q as shown in Figure 3.43. The length of the loop is
$L_3 = 2\pi r_3$

Ampère's circuital law for the loop 3 is

$$\oint_{loop3} \vec{B}_Q . \vec{dl} = \mu_0 I_{enclosed}$$

Since in each turn of the toroid loop, current coming out of the plane of paper is cancelled by the current going into the plane of paper Thus, $I_{enclosed} = 0$

$$\oint_{loop3} \vec{B}_Q . \vec{dl} = 0$$

This is possible only if the magnetic field at point Q vanishes i.e.

$$\vec{B}_Q = 0$$

(c) Inside the toroid

Let us calculate the magnetic field *BS* at point S by constructing an Amperian loop 2 of radius *r*2 around the point S as shown in Figure 3.43. The length of the loop is

$L_2 = 2\pi r_2$

Ampere's circuital law for the loop 2 is

$$\oint_{loop2} \vec{B}_S.\vec{dl} = \mu_0 I_{enclosed}$$

Let *I* be the current passing through the toroid and *N* be the number of turns of the toroid, then

$$I_{enclosed} = NI$$

Therefore,

$$\oint_{loop2} \vec{B}_S.\vec{dl} = \oint_{loop2} B_S.dl\cos\theta = B_S 2\pi r_2$$

If the number of turns per unit length $n = \mu_0 \dfrac{NI}{2\pi r_2}$, then the magnetic field at point S is

$$B_S = \mu_0 nI$$

When an electric charge *q* is kept at rest in a magnetic field, no force acts on it. At the same time, if the charge moves in the magnetic field, it experiences a force. This force is different from Coulomb force, studied in unit 1. This force is known as magnetic force. It is given by the equation

$$F = q\left(\bar{\upsilon} \times \bar{B}\right)$$

In general, if the charge is moving in both the electric and magnetic fields, the total force experienced by the charge is given by $F = q\left(\bar{E} + \bar{\upsilon} \times \bar{B}\right)$. It is known as Lorentz force

Force on a moving charge in a magnetic field

When an electric charge *q* is moving with velocity $\vec{\upsilon}$ in the magnetic field $\vec{B}$, it experiences a force, called magnetic force $\vec{F_m}$. After careful experiments, Lorentz deduced the force experienced by a moving charge in the magnetic field $\vec{F_m}$

$$\overline{F_m} = q\left(\bar{\upsilon} \times \bar{B}\right)$$

In magnitude,

$$F_m = q\upsilon B\sin\theta$$

The equations (3.55) and (3.56) imply

1. $\vec{F}_m$ directly proportional to the magnetic field $\vec{B}$

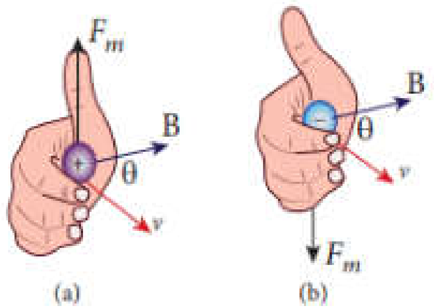
2. $\vec{F}_m$ is directly proportional to the velocity $\vec{\upsilon}$ of the moving charge

LORENTZ FORCE

3. $\vec{F}_m$ is directly proportional to sine of the angle between the velocity and magnetic field

4. $\vec{F}_m$ is directly proportional to the magnitude of the charge q

5. The direction of $\vec{F}_m$ is always perpendicular to $\vec{\upsilon}$ and $\vec{B}$ as $\vec{F}_m$ is the cross product of $\vec{\upsilon}$ and $\vec{B}$



Direction of the Lorentz force on (a) positive charge (b) negative charge

6. The direction of $\vec{F}_m$ on negative charge is opposite to the direction of $\vec{F}_m$ on positive charge provided other factors are identical as shown

7. If velocity $\vec{\upsilon}$ of the charge q is along magnetic field $\vec{B}$ then, $\vec{F}_m$ is zero

Definition of tesla

The strength of the magnetic field is one tesla if a unit charge moving in it with unit velocity experiences unit force.

$$1T = \frac{1NS}{Cm} = 1\frac{N}{Am} = 1NA^{-1}m^{-1}$$

A particle of charge q moves with velocity $\vec{\upsilon}$ along positive y - direction in a magnetic field $\vec{B}$. Compute the Lorentz force experienced by the particle

(a) when magnetic field is along positive y-direction

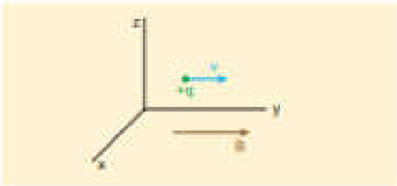
(b) when magnetic field points in positive z - direction

(c) when magnetic field is in zy - plane and making an angle θ with velocity of the particle. Mark the direction of magnetic force in each case.

Solution

Velocity of the particle is $\vec{\upsilon} = \upsilon\hat{j}$

(a) Magnetic field is along positive y - direction, this implies, $\vec{B} = B\hat{j}$

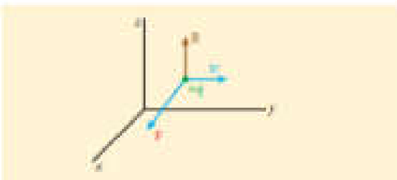


From Lorentz force, $\overline{F_m} = q\left(\upsilon\,\hat{j}\times B\hat{j}\right) = 0$

So, no force acts on the particle when it moves along the direction of magnetic field.

(b) Since the magnetic field points in positive z - direction, this implies,

$$\vec{B} = B\hat{K}$$

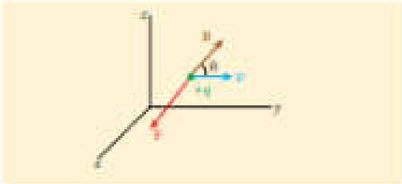


From Lorentz force, $\overline{F_m} = q\left(\upsilon\,\hat{j}\times B\hat{K}\right)$

$= q\upsilon B\hat{i}$

Therefore, the magnitude of the Lorentz force is $q\upsilon B$and direction is along positive x - direction.

c) Magnetic field is in zy - plane and making an angle θ with the velocity of the particle, which implies $\vec{B} = B\cos\theta\,\hat{j} + B\sin\theta\hat{K}$



From Lorentz force,

$$\overline{F_m} = q\left(\upsilon\,\hat{j}\right) \times \left(B\cos\theta\,\hat{j} + B\sin\theta\,\hat{K}\right)$$
$$= q\upsilon B\sin\theta\,\hat{i}$$

EXAMPLE

Compute the work done and power delivered by the Lorentz force on the particle of charge q moving with velocity $\dot{\upsilon}$ Calculate the angle between Lorentz force and velocity of the charged particle and also interpret the result.

Solution

For a charged particle moving on a magnetic field, $\bar{F} = q\left(\bar{\upsilon} \times \bar{B}\right)$

The work done by the magnetic field is

$$W = \int \dot{F}.d\dot{r} = \int \dot{F}\,\dot{\upsilon}\,dt$$
$$W = q\int \left(\bar{\upsilon} \times \bar{B}\right).\bar{\upsilon}\,dt = 0.$$

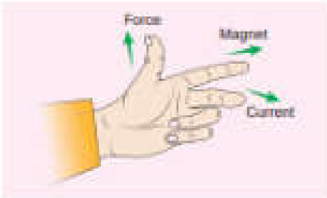
Since $\dot{\upsilon}$ is perpendicular to $\dot{\upsilon}$ and hence $\left(\bar{\upsilon} \times \bar{B}\right)\dot{\upsilon} = \bar{0}$ this means that Lorentz force does no work on the particle. From work-kinetic energy theorem, (Refer section 4.2.6, XI th standard Volume I)

$$\frac{dW}{dt} = P = 0$$

Since, $\dot{F}.\dot{\upsilon} = 0 \Rightarrow \dot{F}$ and $\dot{\upsilon}$ are perpendicular to each other. The angle between Lorentz force and velocity of the charged particle is 90^{o}. Thus Lorentz force changes the direction of the velocity but not the magnitude of the velocity. Hence Lorentz force does no work and also does not alter kinetic energy of the particle.

Fleming's left hand rule

When a current carrying conductor is placed in a magnetic field, the direction of the force experienced by it is given by Fleming's Left Hand Rule (FLHR) as shown.



2 Fleming's Left Hand Rule (FLHR)

Stretch out forefinger, the middle finger and the thumb of the left hand such that they are in three mutually perpendicular directions. If the forefinger points in the direction of magnetic field,the middle finger in the direction of the electric current, then thumb will point in the direction of the force experienced by the conductor.

EXAMPLE

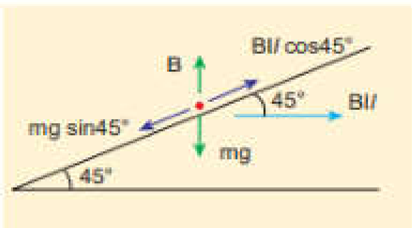
A metallic rod of linear density is 0.25 kg m–1 is lying horizontally on a smooth inclined plane which makes an angle of 45o with the horizontal. The rod is not allowed to slide down by flowing a current through it when a magnetic field of strength 0.25 T is acting on it in the vertical direction. Calculate the electric current flowing in the rod to keep it stationary.

Solution

The linear density of the rod i.e., mass per unit length of the rod is 0.25 kg m^{-1}

$$\Rightarrow \frac{m}{l} = 0.25\, kg\, m^{-1}$$

Let I be the current flowing in the metallic rod. The direction of electric current is into the plane of the paper. The direction of magnetic force BIl is given by Fleming's left hand rule



For equilibrium of the rod,

$$mg \sin 45^o = BIl \cos 45^o$$

$$\Rightarrow I = \frac{1}{B}\frac{m}{l} g \tan 45^o$$

$$= \frac{0.25\,kgm^{-1}}{0.25\,T} \times 1 \times 9.8\,ms^{-2}$$

$$\Rightarrow I = 9.8A$$

So, we need to supply current of 9.8 A to keep the metallic rod stationary.

Definition of ampere

One ampere is defined as that constant current which when passed through each of the two infinitely long parallel straight conductors kept side by side parallelly at a distance of one metre apart in air or vacuum causes each conductor to experience a force of 2 × 10^{-7} newton per metre length of conductor.

Sensitivity of a galvanometer

The galvanometer is said to be sensitive if it shows large scale deflection even for a small current passed through it or a small voltage applied across it.

Current sensitivity

It is defined as **the deflection produced per unit current flowing through galvanometer**

$$I_S = \frac{\theta}{I} = \frac{NAB}{K} \Rightarrow I_S = \frac{1}{G}$$

The current sensitivity of a galvanometer can be increased by

(i) increasing the number of turns, N
(ii) increasing the magnetic induction, B
(iii) increasing the area of the coil, A
(iv) decreasing the couple per unit twist of the suspension wire, K. Phosphor - bronze wire is used as the suspension wire because the couple per unit twist is very small.

Voltage sensitivity

It is defined as **the deflection produced per unit voltage applied across galvanometer**.

$$V_S = \frac{\theta}{V}$$

$$V_S = \frac{\theta}{IR_g} = \frac{NAB}{KR_g} \text{ or}$$

$$V_S = \frac{1}{GR_g} = \frac{I_S}{R_g}$$

Where R_g is the resistance of galvanometer.

EXAMPLE

The coil of a moving coil galvanometer has 5 turns and each turn has an effective area of 2×10^{-2} m^2. It is suspended in a magnetic field whose strength is 4×10^{-2}Wb m^{-2}. If the torsional constant K of the suspension fibre is 4×10^{-9} N m deg^{-1}

(a) Find its current sensitivity in division per micro - ampere.

(b) Calculate the voltage sensitivity of the galvanometer for it to have full scale deflection of 50 divisions for 25 mV.

(c) Compute the resistance of the galvanometer.

Solution

N = 5 turns
A = 2×10^{-2} m^2

B = 4×10^{-2}Wbm^{-2}

K = 4×10^{-9} N m deg^{-1}

(a) Current sensitivity

$$I_S = \frac{NAB}{K} = \frac{5 \times 2 \times 10^{-2} \times 4 \times 10^{-2}}{4 \times 10^{-9}}$$

= 10^6 divisions per ampere

1 μA = 1 microampere = 10^{-6} ampere

Therefore,

$$I_S = 10^6 \frac{div}{A} = 1\frac{div}{10^6 A} = 1\frac{div}{\mu A}$$

$$I_S = 1 div(\mu A)^{-1}$$

(b) Voltage sensitivity

$$V_S = \frac{\theta}{V} = \frac{50div}{25mV} = 2\times10^3 divV^{-1}$$

(c) The resistance of the galvanometer is

$$R_g = \frac{I_S}{V_S} = \frac{10^6 \frac{div}{A}}{2\times10^3 \frac{div}{V}} = 0.5\times10^3 \frac{V}{A} = 0.5k\Omega$$

EXAMPLE

The resistance of a moving coil galvanometer is made twice its original value in order to increase current sensitivity by 50%. Find the percentage change in voltage sensitivity.

Solution

Voltage sensitivity is $V_S = \frac{I_S}{R_g}$

When the resistance is doubled, then new resistance is $R_g' = 2R_g$

Increase in current sensitivity is

$$I_S' = \left(1+\frac{50}{100}\right)I_S = \frac{2}{3}I_S$$

The new voltage sensitivity is

$$V_S' = \frac{\frac{2}{3}I_S}{2R_g} = \frac{3}{4}V_S$$

Hence the voltage sensitivity decreases. The percentage decrease in voltage sensitivity is

$$\frac{V_S - V_S'}{V_S}\times100\% = 25\%$$

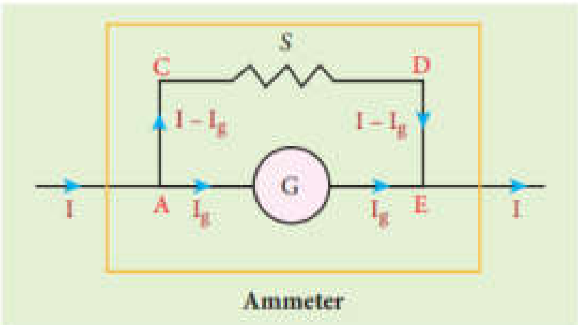
Conversion of galvanometer into ammeter and voltmeter

A galvanometer is very sensitive instrument to detect the current. It can be easily converted into ammeter and voltmeter.

Galvanometer to an Ammeter

Ammeter is an instrument used to measure current flowing in the electrical circuit. The ammeter must offer low resistance such that it will not change the current passing through it. So ammeter is connected in series to measure the circuit current.

A galvanometer is converted into an ammeter by connecting a low resistance in parallel with the galvanometer. This low resistance is called shunt resistance S. The scale is now calibrated in ampere and the range of ammeter depends on the values of the shunt resistance.



Shunt resistance connected in parallel

Let I be the current passing through the circuit as shown. When current I reaches the junction A, it divides into two components. Let I g be the current passing through the galvanometer of resistance R g through a path AGE and the remaining current (I – I_g) passes along the path ACDE through shunt resistance S. The value of shunt resistance is so adjusted that current I g produces full scale deflection in the galvanometer. The potential difference across galvanometer is same as the potential difference across shunt resistance.

$$V_{galvanometer} = V_{shunt}$$

$$\Rightarrow I_g R_g = (I - I_g) S$$

$$S = \frac{I_g}{(I - I_g)} R_g$$

$$I_g = \frac{S}{S + R_g} I$$

Since, the deflection in the galvanometer is proportional to the current passing through it,

$$\theta = \frac{1}{G} I_g \Rightarrow \theta \alpha I_g \Rightarrow \theta \alpha I \text{ so,}$$

the deflection produced in the galvanometer is a measure of the current I passing through the circuit.

Shunt resistance is connected in parallel to galvanometer. Therefore, resistance of ammeter (R_a) can be determined by computing the effective resistance, which is

$$\frac{1}{\mathrm{R}_{eff}} = \frac{1}{R_g} + \frac{1}{S} \Rightarrow \mathrm{R}_{eff} = \frac{R_g S}{R_g + S} = R_a$$

Since, the shunt resistance is a very low resistance and the ratio $\frac{S}{R_g}$ is also small. This means, Ra is also small, i.e., the resistance offered by the ammeter is small. So, when we connect ammeter in series, the ammeter will not change appreciably the current in the circuit. For an ideal ammeter, the resistance must be equal to zero. But in reality, the reading in ammeter is always less than the actual current in the circuit. Let I_{ideal} be the current measured by ideal ammeter and I_{actual} be the actual current in the circuit. Then, the percentage error in measuring a current through an ammeter is

$$\frac{\Delta I}{I} \times 100\% = \frac{I_{ideal} - I_{actual}}{I_{ideal}} \times 100\%$$

Key points

1. An ammeter is a low resistance instrument and it is always connected in series to the circuit

2. An ideal ammeter has zero resistance

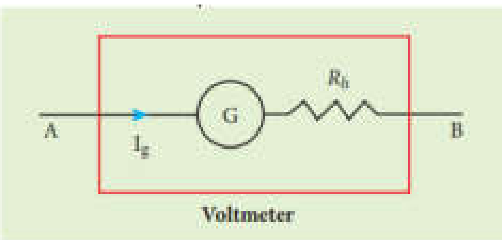
3. In order to increase the range of an ammeter n times, the value of shunt resistance to be connected in parallel is

$$S = \frac{R_g}{n-1}$$

Galvanometer to a voltmeter

A voltmeter is an instrument used to measure potential difference across any two points in the electrical circuits. It should not draw any current from the circuit otherwise the value of potential difference to be measured will change.

Voltmeter must have high resistance and when it is connected in parallel, it will not draw appreciable current so that it will indicate the true potential difference.



High resistance connected in series

A galvanometer is converted into a voltmeter by connecting high resistance R_h in series with galvanometer as shown. The scale is now calibrated in volt and the range of voltmeter depends on the values of the resistance R_h connected in series i.e. the value of resistance is so adjusted so that current I_g produces full scale deflection in the galvanometer.

Let R_g be the resistance of galvanometer and $I_g$be the current with which the galvanometer produces full scale deflection. Since the galvanometer is connected in series with high resistance, the current in the electrical circuit is same as the current passing through the galvanometer.

$$I = I_g$$

$$I = I_g \Rightarrow I_g = \frac{potential\ difference}{total\ resis\tan ce}$$

Since the galvanometer and high resistance are connected in series, the total resistance or effective resistance in the circuit is the sum of their resistances. This gives the resistance of voltmeter. Thus the voltmeter resistance is

$$R_V = R_g + R_h$$

Therefore,

$$I_g = \frac{v}{R_g + R_h}$$

$$R_h = \frac{V}{I_g} - R_g$$

Note that $I_g \alpha V$

The deflection in the galvanometer is proportional to current I_g. But current I_g is proportional to the potential difference. Hence the deflection in the galvanometer is a measure of potential difference. Since the resistance of voltmeter is very large, a voltmeter connected in parallel in an electrical circuit will draw least current in the circuit. An ideal voltmeter is one which has infinite resistance.

Key points

1. Voltmeter is a high resistance instrument and it is always connected in parallel with the circuit element across which the potential difference is to be measured.

2. An ideal voltmeter has infinite resistance

3. In order to increase the range of voltmeter n times the value of resistance to be connected in series with galvanometer is

$$R_h = (n-1)R_g$$

Unit 4 – Magnetism & Magnetic Alternating Current

An anecdote!
Michael Faraday was enormously popular for his lectures as well. In one of his lectures, he demonstrated his experiments which led to the discovery of electromagnetic induction.
At the end of the lecture, one member of the audience approached Faraday and said, "Mr. Faraday, the behaviour of the magnet and the coil of wire was interesting, but what is the use of it?" Faraday answered politely, "Sir, what is the use of a newborn baby?"
Note: We will soon see the greatness of 'that little child' who has now grown as an adult to cater to the energy needs.

Faraday's Law of Electromagnetic

Induction

From the results of his experiments, Faraday realized that whenever the magnetic flux linked with a closed coil changes, an emf (electromotive force) is induced and hence an electric current flows in the circuit. This current is called an induced current and the emf giving rise to such current is called an induced emf. This phenomenon is known as electromagnetic induction.

Based on this idea, Faraday's experiments are understood in the following way. In the first experiment, when a bar magnet is placed close to a coil, some of the magnetic field lines of the bar magnet pass through the coil i.e., the magnetic flux is linked with the coil. When the bar magnet and the coil approach each other, the magnetic flux linked with the coil increases. So this increase in magnetic flux induces an emf and hence a transient electric current flowsin the circuit in one direction

At the same time, when they recede away from one another, the magnetic flux linked with the coil decreases. The decrease in magnetic flux again induces an emf in opposite direction and hence an electric current flows in opposite direction. So there is deflection in the galvanometer when there is a relative motion between the coil and the magnet.

In the second experiment, when the primary coil P carries an electric current, a magnetic field is established around it. The magnetic lines of this field pass through itself and the neighbouring secondary coil S.When the primary circuit is open, no electric current flows in it and hence the magnetic flux linked with the secondary coil is zero.

However, when the primary circuit is closed, the increasing current builds up a magnetic field around the primary coil. Therefore, the magnetic flux linked with the secondary coil increases. This increasing flux linked induces a transient electric current in the secondary coil. When the electric current in the primary coil reaches a steady value, the magnetic flux linked with the secondary coil does not change and the electric current in the secondary coil will disappear.

Similarly, when the primary circuit is broken, the decreasing primary current induces an electric current in the secondary coil, but in the opposite direction. So there is deflection in the galvanometer whenever there is a change in the primary current.

The symbol ε is used for permittivity in unit 1 and for emf in this chapter.

Importance of Electromagnetic Induction!

The application of the phenomenon of Electromagnetic Induction is almost everywhere in the present day life. Right from home appliances to huge factory machineries, from cellphone to computers and internet, from electric guitar to satellite communication, all need electricity for their operation. There is an ever growing demand for electric power.

All these are met with the help of electric generators and transformers which function on electromagnetic induction. The modern, sophisticated human life would not be possible without the discovery of electromagnetic induction.

The conclusions of Faraday's experiments are stated as two laws.

First law

Whenever magnetic flux linked with a closed circuit changes, an emf is induced in the circuit.

Second law

The magnitude of induced emf in a closed circuit is equal to the time rate of change of magnetic flux linked with the circuit.

If the magnetic flux linked with the coil changes by $d\Phi_B$ in a time dt, then the induced emf is given by

$$\varepsilon = -\frac{d\Phi_B}{dt}$$

The negative sign in the above equation gives the direction of the induced current which will be dealt with in the next section.

If a coil consisting of N turns is tightly wound such that each turn covers the samearea, then the flux through each turn will be the same. Then total emf induced in the coil is given by

$$\varepsilon = -N\frac{d\Phi_B}{dt} = -\frac{d(N\Phi_B)}{dt}$$

Here, $N\Phi_B$ is called flux linkage, defined as the product of number of turns N of the coil and the magnetic flux linking each turn of the coil Φ_B.

Lenz's law

A German physicist Heinrich Lenz performed his own experiments on electromagnetic induction and deduced alaw to determine the direction of the induced current. This law is known as Lenz's law.

Lenz's law states that the direction of the induced current is such that it always opposes the cause responsible for its production.

Faraday discovered that when magnetic flux linked with a coil changes, an electric current is induced in the circuit. Here the flux change is the cause while the induction of current is the effect. Lenz's law says that the effect always opposes the cause. Therefore, the induced current would flow in a direction so that it could oppose the flux change.

To understand Lenz's law, let us consider two illustrations in which we find the direction of the induced current in a circuit.

Fleming's right hand rule

When a conductor moves in a magnetic field, the direction of motion of the conductor, the field and the induced current are given by Fleming's right hand rule and is as follows:

The thumb, index finger and middle finger of right hand are stretched out in mutually perpendicular directions. If the index finger points the direction of the magnetic field and the thumb indicates the direction of motion of the conductor, then the middle finger will indicate the direction of the induced current.

Fleming's right hand rule is also known as generator rule.

Eddy Currents

According to Faraday's law of electromagnetic induction, an emf is induced in a conductor when the magnetic flux passing through it changes. However, the conductor need not be in the form of a wire or coil.

Even for a conductor in the form of a sheet or plate, an emf is induced when magnetic flux linked with it changes. But the difference is that there is no definite loop or path for induced current to flow away. As a result, the induced currents flow in concentric circular paths. As these electric currents resemble eddies of water, these are known as Eddy currents. They are also called Foucault currents.

Demonstration

Here is a simple demonstration for the production of eddy currents. Consider a pendulum that can be made to oscillate between the poles of a powerful electromagnet as shown.

First the electromagnet is switched off, the pendulum is slightly displaced and released. It begins to oscillate and it executes a large number of oscillations before stopping. The air friction is the only damping force.

When the electromagnet is switched on and the disc of the pendulum is made to oscillate, eddy currents are produced in it which will oppose the oscillation. A heavy damping force of eddy currents will bring the pendulum to rest within a few oscillations

However if some slots are cut in the disc as shown, the eddy currents are reduced. The pendulum now will execute several oscillations before coming to rest. This clearly demonstrates the production of eddy current in the disc of the pendulum.

Drawbacks of Eddy currents

When eddy currents flow in the conductor, a large amount of energy is dissipated in the form of heat. The energy loss due to the flow of eddy current is inevitable but it can be reduced to a greater extent with suitable measures

The design of transformer core and electric motor armature is crucial in order to minimise the eddy current loss. To reduce these losses, the core of the transformer is made up of thin laminas insulated from one another while for electric motor the winding is made up of a group of wires insulated from one another. The insulation used does not allow huge eddy currents to flow and hence losses are minimized.

Application of eddy currents

Though the production of eddy current is undesirable in some cases, it is useful in some other cases. A few of them are

- **Induction stove**
- **Eddy current brake**
- **Eddy current testing**
- **Electromagnetic damping**

Induction stove

Induction stove is used to cook the food quickly and safely with less energy consumption. Below the cooking zone, there is a tightly wound coil of insulated wire. The cooking pan made of suitable material, is placed over the cooking zone. When the stove is switched on, an alternating current flowing in the coil produces high frequency alternating magnetic field which induces very strong eddy currents in the cooking pan. The eddy currents in the pan produce so much of heat due to Joule heating which is used to cook the food.

Note: The frequency of the domestic AC supply is increased from 50–60 Hz to around 20–40 KHz before giving it to the coil in order to produce high frequency alternating magnetic field.

Eddy current brake

This eddy current braking system is generally used in high speed trains and roller coasters. Strong electromagnets are fixed just above the rails. To stop the train, electromagnets are switched on. The magnetic field of these magnets induces eddy currents in the rails which oppose or resist the movement of the train. This is Eddy current linear brake.

In some cases, the circular disc, connected to the wheel of the train through a common shaft, is made to rotate in between the poles of an electromagnet. When there is a relative motion between the disc and the magnet, eddy currents are induced in the disc which stop the train. This is Eddy current circular brake.

Eddy current testing

It is one of the simple non–destructive testing methods to find defects like surface cracks, air bubbles present in a specimen. A coil of insulated wire is given an alternating electric current so that it produces an alternating magnetic field. When this coil is brought near the test surface, eddy current is induced in the test surface. The presence of defects causes the change in phase and amplitude of the eddy current that can be detected by some other means. In this way, the defects present in the specimen are identified.

Electro magnetic damping

The armature of the galvanometer coil is wound on a soft iron cylinder. Once the armature is deflected, the relative motion between the soft iron cylinder and the radial magnetic field induces eddy current in the cylinder. The damping force due to the flow of eddy current brings the armature to rest immediately and then galvanometer shows a steady deflection. This is called electromagnetic damping.

Self – Induction

Introduction

Inductor is a device used to store energy in a magnetic field when an electric current flows through it. The typical examples are coils, solenoids and toroids shown.

Inductance is the property of inductors to generate emf due to the change in current flowing through that circuit (self-induction) or a change in current through a neighbouring circuit with which it is magnetically linked (mutual induction).

Self-induction

An electric current flowing through a coil will set up a magnetic field around it. Therefore, the magnetic flux of the magnetic field is linked with that coil itself. If this flux is changed by changing the current, an emf is induced in that same coil. This phenomenon is known as self-induction. The emf induced is called self-induced emf.

Let ΦB be the magnetic flux linked with each turn of the coil of N turns, then the total flux linked with the coil (flux linkage) is proportional to the current *i*in the coil.

$$N\Phi_B \propto i$$

$$N\Phi_B = Li$$

$$L = \frac{N\Phi_B}{i}$$

The constant of proportionality L is called self-inductance of the coil. It is also referred to as the coefficient of self-induction. If i =1A, then L $N\Phi_B$. Self inductance or simply inductance of a coil is defined as the flux linkage of the coil when 1A current flows through it.

When the current i changes with time, an emf is induced in it. From Faraday's law of electromagnetic induction, this self-induced emf is given by

$$\varepsilon = -\frac{d(N\Phi_B)}{dt} = -\frac{d(Li)}{dt}$$

$$\therefore\ \varepsilon = -L\frac{di}{dt}$$

$$\text{(or)}\ L = \frac{-\varepsilon}{di/dt}$$

The negative sign in the above equation means that the self-induced emf always opposes the change in current with respect to time. If $\frac{di}{dt}$ = 1As $^{-1}$, then L = - ε.

Inductance of a coil is also defined as the opposing emf induced in the coil when the rate of change of current through the coil is 1 A s^{-1}.

Unit of inductance

Inductance is a scalar and its unit is or WbA^{-1} . It is also measured in henry (H).

1H = 1 Wb A^{-1} = 1VsA^{-1}

The dimensional formula of inductance is $ML^2T^{-2}A^{-2}$

If i = 1A and $N\Phi_B$ = 1Wb turns, when L = 1 H

Therefore, the inductance of the coil is said to be one henry if a current of 1 A produces unit flux linkage in the coil.

If $\frac{di}{dt}$ = 1As^{-1} and ε = -1V, then L = 1H

Therefore, the inductance of the coil is one henry if a current changing at the rate of 1 A s^{-1} induces an opposing emf of 1 V in it.

Physical significance of inductance

The inductance plays the same role in a circuit as mass and moment of inertia play in mechanical motion. When a circuit is switched on, the increasing current induces an emf which opposes the growth of current in a circuit. Likewise, when circuit is broken, the decreasing current induces an emf in the reverse direction. This emf now opposes the decay of current.

Thus, inductance of the coil opposes any change in current and tries to maintain the original state.

Mutual induction

When an electric current passing through a coil changes with time, an emf is induced in the neighbouring coil. This phenomenon is known as mutual induction and the emf is called mutually induced emf.

Consider two coils which are placed close to each other. If an electric current i_1 is sent through coil 1, the magnetic field produced by it is also linked with coil 2 as shown.

Let Φ_{21} be the magnetic flux linked with each turn of the coil 2 of N_2 turns due to coil 1, then the total flux linked with coil 2 ($N_2\Phi_{21}$) is proportional to the current i_1 in the coil 1.

$$N_2\Phi_{21} \propto i_1$$

$$N_2\Phi_{21} = M_{21}\, i_1$$

$$\text{(or)}\ M_{21} = \frac{N_2\Phi_{21}}{i_1}$$

$N_2\Phi_{21} \propto i_1$

$N_2\Phi_{21} = M_{21} i_1$

(or) $M_{21} = N_2\Phi_{21}/i_1$

The constant of proportionality M_{21} is the mutual inductance of the coil 2 with respect to coil 1. It is also called as coefficient of mutual induction. If $i_1 = 1A$, then $M_{21} = N_2\Phi_{21}$. Therefore, the mutual inductance M_{21} is defined as the flux linkage of the coil 2 when 1A current flows through coil 1.

When the current i_1 changes with time, an emf ε_2 is induced in coil 2. From Faraday's law of electromagnetic induction, this mutually induced emf ε_2 is given by

$$\varepsilon_2 = -\frac{d(N_2\Phi_{21})}{dt} = -\frac{d(M_{21}i_1)}{dt}$$

$$\varepsilon_2 = -M_{21}\frac{di_1}{dt}$$

$$\text{(or) } M_{21} = \frac{-\varepsilon_2}{di_1/dt}$$

The negative sign in the above equation shows that the mutually induced emf always opposes the change in current i_1 with respect to time.

$$\text{If } di_1/dt = 1A\, s^{-1}$$

Then = M_{21} = - ε_2.

Mutual Inductance M_{21} is also defined as the opposing emf induced in the coil 2 when the rate of change of current through the coil 1 is 1 As^{-1}.

Similarly, if an electric current i_2 through coil 2 changes with time, then emf ε_1 is induced in coil 1. Therefore,

$$M_{12} = \frac{N_1\Phi_{12}}{i_2} \quad \text{and} \quad M_{12} = \frac{-\varepsilon_1}{di_2/dt}$$

where M_{12} is the mutual inductance of the coil 1 with respect to coil 2. It can be shown that for a given pair of coils, the mutual inductance is same.

$$M_{21} = M_{12} = M$$

In general, the mutual induction between two coils depends on size, shape, the number of turns of the coils, their relative orientation and permeability of the medium.

Unit of mutual-inductance

The unit of mutual inductance is also henry (H).

If i_1 = 1A and $N_2\Phi_{21}$ = 1 Wb turns, then M_{21} = 1 H.

Therefore, the mutual inductance between two coils is said to be one henry if a current of 1A in coil 1 produces unit flux linkage in coil 2.

$$\text{If} \quad {}^{di_1}/_{dt} = 1As^{-1} \text{ and } \quad \varepsilon_2 = -1\,V, \quad \text{then}$$

$$M_{21} = 1H.$$

Therefore, the mutual inductance between two coils is one henry if a current changing at the rate of $1As^{-1}$ in coil 1 induces an opposing emf of 1V in coil 2.

Methods of Producing Induced EMF

Introduction

Electromotive force is the characteristic of any energy source capable of driving electric charge around a circuit. We have already learnt that it is not actually a force. It is the work done in moving unit electric charge around the circuit. It is measured in $J\,C^{-1}$ or volt.

Some examples of energy source which provide emf are electrochemical cells, thermoelectric devices, solar cells and electrical generators. Of these, electrical generators are most powerful machines. They are used for large scale power generation.

According to Faraday's law of electromagnetic induction, an emf is induced in a circuit when magnetic flux linked with it changes. This emf is called induced emf. The magnitude of the induced emf is given by

$$\varepsilon = \frac{d\Phi_B}{dt}$$

$$\varepsilon = \frac{d}{dt}(BA\cos\theta)$$

From the above equation, it is clear that induced emf can be produced by changing magnetic flux in any of the following ways.

- By changing the magnetic field B
- By changing the area A of the coil and
- By changing the relative orientation θ of the coil with magnetic field.

Induction of emf by changing the magnetic field

From Faraday's experiments on electromagnetic induction, it was discovered that an emf is induced in a circuit on changing the magnetic flux of the field through it. The change in flux is brought about by (i) relative motion between the circuit and the magnet (First experiment) (ii) variation in current flowing through the nearby coil (Second experiment).

Induction of emf by changing the area of the coil

Consider a conducting rod of length l moving with a velocity towards left on a rectangular metallic framework as shown. The whole arrangement is placed in a uniform magnetic field whose magnetic lines are perpendicularly directed into the plane of the paper.

As the rod moves from AB to DC in a time *dt*, the area enclosed by the loop and hence the magnetic flux through the loop decreases.

The change in magnetic flux in time *dt* is

$d\Phi_B$ = B × change in area

= B × Area ABCD

= *Blvdt*

Since Area ABCD = 1 (*vdt*)

$$\text{(or)}\ \frac{d\Phi_B}{dt} = Blv$$

As a result of change in flux, an emf is generated in the loop. The magnitude of the induced emf is

$$\varepsilon = \frac{d\Phi_B}{dt}$$

$\varepsilon = Blv$

The emf is called motional emf. The direction of induced current is found to be clockwise from Fleming's right hand rule.

Ac Generator

Introduction:

AC generator or alternator is an energy conversion device. It coverts mechanical energy used to rotate the coil or field magnet into electric energy. Alternator produces a large scale electrical power for use in homes and industries. AC generator and its components are shown.

Principle

Alternators work on the principle of electromagnetic induction. The relative motion between a conductor and a magnetic field changes the magnetic flux linked with the conductor which in turn, induces an emf. The magnitude of the induced emf is given by Faraday's law of electromagnetic induction and its direction by Fleming's right hand rule.

Alternating emf is generated by rotating a coil in a magnetic field or by rotating a magnetic field within a stationary coil.
The first method is used for small AC generators while the second method is employed for large AC generators. The rotating-field method is the one which is mostly used in power stations.

Construction

Alternator consists of two major parts, namely stator and rotor. As their names suggest, stator is stationary while rotor rotates inside the stator. In any standard construction of commercial alternators, the armature winding is mounted on stator and the field magnet on rotor.

The construction details of stator, rotor and various other components involved in them are given below.

Stator

The stationary part which has armature windings mounted in it is called stator. It has three components, namely stator frame, stator core and armature winding.

Stator frame

This is the outer frame used for holding stator core and armature windings in proper position. Stator frame provides best ventilation with the help of holes provided in the frame itself.

Stator core

Stator core or armature core is made up of iron or steel alloy. It is a hollow cylinder and is laminated to minimize eddy current loss. The slots are cut on inner surface of the core to accommodate armature windings.

Armature winding

Armature winding is the coil, wound on slots provided in the armature core. One or more than one coil may be employed, depending on the type of alternator.

Two types of windings are commonly used. They are i) single-layer winding and ii) double-layer winding. In single-layer winding, a slot is occupied by a coil as a single layer. But in double-layer winding, the coils are split into two layers such as top and bottom layers.

Rotor

Rotor contains magnetic field windings. The magnetic poles are magnetized by DC source. The ends of field windings are connected to a pair of slip rings, attached to a common shaft about which rotor rotates. Slip rings rotate along with rotor. To maintain connection between the DC source and field windings, two brushes are used which continuously slide over the slip rings.

There are 2 types of rotors used in alternators i) salient pole rotor and ii) cylindrical pole rotor.

Salient pole rotor

The word salient means projecting. This rotor has a number of projecting poles having their bases riveted to the rotor. It is mainly used in low-speed alternators. The salient 2-pole rotor is shown.

Cylindrical pole rotor

This rotor consists of a smooth solid cylinder. The slots are cut onthe outer surface of the cylinder along its length. It is suitable for very high speed alternators.

The frequency of alternating emf induced is directly proportional to the rotor speed. In order to maintain the frequency constant, the rotor must run at a constant speed.

These are standard construction details of alternators. Based on the type of alternator being constructed, the details like number of poles, pole type, number of coils and type of windings would change from one another.

We will discuss the construction and working of two examples, namely single phase and three phase AC generators in the following sections.

Advantages of stationary armature-rotating field alternator

Alternators are generally high current and high voltage machines. The stationary armature-rotating field construction has many advantages. A few of them include:

- The current is drawn directly from fixed terminals on the stator without the use of brush contacts.
- The insulation of stationary armature winding is easier.
- The number of sliding contacts (slip rings) is reduced. Moreover, the sliding contacts are used for low-voltage DC Source.
- Armature windings can be constructed more rigidly to prevent deformation due to any mechanical stress.

Single phase AC generator

In a single phase AC generator, the armature conductors are connected in series so as to form a single circuit which generates a single-phase alternating emf and hence it is called single-phase alternator.

The simplified version of a AC generator is discussed here. Consider a stator core consisting of 2 slots in which 2 armature conductors PQ and RS are mounted to form single-turn rectangular loop PQRS as shown. Rotor has 2 salient poles with field windings which can be magnetized by means of DC source.

Working

The loop PQRS is stationary and is perpendicular to the plane of the paper. When field windings are excited, magnetic field is produced around it. The direction of magnetic field passing through the armature core is shown. Let the field magnet be rotated in clockwise direction by the prime mover. The axis of rotation is perpendicular to the plane of the paper.

Assume that initial position of the field magnet is horizontal. At that instant, the direction of magnetic field is perpendicular to the plane of the loop PQRS. The induced emf is zero. This is represented by origin O in thegraph between induced emf and time angle

When field magnet rotates through 90°, magnetic field becomes parallel to PQRS. The induced emfs across PQ and RS would become maximum. Since they are connected in series, emfs are added up and the direction of total induced emf is given by Fleming's right hand rule.

Care has to be taken while applying this rule; the thumb indicates the direction of the motion of the conductor with respect to field. For clockwise rotating poles, the conductor appears to be rotating anti-clockwise. Hence, thumb should point to the left. The direction of the induced emf is at right angles to the plane of the paper. For PQ, it is downwards and for RS upwards. Therefore, the current flows along PQRS. The point A in the graph represents this maximum emf.

For the rotation of 180° from the initial position, the field is again perpendicular to PQRS and the induced emf becomes zero. This is represented by point B.

The field magnet becomes again parallel to PQRS for 270° rotation of field magnet. The induced emf is maximum but the direction is reversed. Thus the current flows along SRQP. This is represented by point C. On completion of 360°, the induced emf becomes zero and is represented by the point D. From the graph, it is clear that emf induced in PQRS is alternating in nature.

Therefore, when field magnet completes one rotation, induced emf in PQRS finishes one cycle. For this construction, the frequency of the induced emf depends on the speed at which the field magnet rotates.

Phase difference
If two alternating quantities of same frequency do not pass through a particular point, say zero point, in the same direction at the same instant, they are said to have a phase difference. The angle between zero points is the angle of phase difference.

For the graph shown above, the phase difference between ε and i is given by OA = ϕ.

Three-phase AC generator

Some AC generators may have more than one coil in the armature core and each coil produces an alternating emf. In these generators, more than one emf is produced. Thus they are called poly-phase generators.

If there are two alternating emfs produced in a generator, it is called two-phase generator. In some AC generators, there are three separate coils, which would give three separate emfs. Hence they are called three-phase AC generators.

In the simplified construction of three- phase AC generator, the armature core has 6 slots, cut on its inner rim. Each slot is 60° away from one another. Six armature conductors are mounted in these slots. The conductors 1 and 4 are joined in series to form coil 1. The conductors 3 and 6 formcoil 2 while the conductors 5 and 2 form coil 3. So, these coils are retangular in shape and are 120° apart from one another

The initial position of the field magnet is horizontal and field direction is perpendicular to the plane of the coil 1. As it is seen in single phase AC generator, when field magnet is rotated from that position inclockwise direction, alternating emf in coil 1 begins a cycle from origin O. This is shown.
The corresponding cycle for alternating emf in coil 2 starts at point A after field magnet has rotated through 120°. Therefore, the phase difference between and is 120°. Similarly, emf in coil 3 would begin its cycle at point B after 240° rotation of field magnet from initial position. Thus these emfs produced in the three phase AC generator have 120° phase difference between one another.

Advantages of three-phase alternator

Three-phase system has many advantages over single-phase system. Let us see a few of them.

- For a given dimension of the generator, three-phase machine produces higher power output than a single-phase machine.
- For the same capacity, three-phase alternator is smaller in size when compared to single phase alternator.
- Three-phase transmission system is cheaper. A relatively thinner wire is sufficient for transmission of three-phase power.

Transformer

Transformer is a stationary device used to transform electrical power from one circuit to another without changing its frequency. The applied alternating voltage is either increased or decreased with corresponding decrease or increase of current in the circuit.

If the transformer converts an alternating current with low voltage into an alternating current with high voltage, it is called step-up transformer. On the contrary, if the transformer converts alternating current with high voltage into an alternating current with low voltage, then it is called step-down transformer.

Construction and working of transformer

Principle

The principle of transformer is the mutual induction between two coils. That is, when an electric current passing through a coil changes with time, an emf is induced in the neighbouring coil.

Construction

In the simple construction of transformers, there are two coils of high mutual inductance wound over the same transformer core. The core is generally laminated and is made up of a good magnetic material like silicon steel. Coils are electrically insulated but magnetically linked via transformer core.

The coil across which alternating voltage is applied is called primary coil P and the coil from which output power is drawn out is called secondary coil S. The assembled core and coils are kept in a container which is filled with suitable medium for better insulation and cooling purpose.

Working

If the primary coil is connected to a source of alternating voltage, an alternating magnetic flux is set up in the laminated core. If there is no magnetic flux leakage, then whole of magnetic flux linked with primary coil is also linked with secondary coil. This means that rate at which magnetic flux changes through each turn is same for both primary and secondary coils.

As a result of flux change, emf is induced in both primary and secondary coils. The emf induced in the primary coil ε_p is almost equal and opposite to the applied voltage υ_p and is given by

$$\upsilon_p = \varepsilon_p = -N_p \frac{d\Phi_B}{dt}$$

The frequency of alternating magnetic flux in the core is same as the frequency of the appliedvoltage. Therefore, induced emf in secondary will also have same frequency as that of applied voltage. The emf induced in the secondary coil ε_s is given by

$$\varepsilon_s = -N_s \frac{d\Phi_B}{dt}$$

Where N_p and $N_s$are the number of turns in the primary and secondary coil respectively. If the secondary circuit is open, then $\varepsilon_s = \upsilon_s$where υ_s is the voltage across secondary coil.

$$\upsilon_s = \varepsilon_s = -N_s \frac{d\Phi_B}{dt}$$

$$\frac{\upsilon_s}{\upsilon_p} = \frac{N_s}{N_p} = K$$

P = 2 MW; R = 40 Ω; V = 100 kV

$$\therefore \text{Current, } I = \frac{P}{V}$$

$$= \frac{2\times10^6}{100\times10^3} = 20A$$

Power loss = I^2R

$$= (20)^2 \times 40 = 0.016\times10^6 W$$

$$\text{\% of power loss} = \frac{0.016\times10^6}{2\times10^6}\times100\%$$

$$= 0.008\times100\% = 0.8\%$$

Thus it is clear that when an electric power is transmitted at higher voltage, the power loss is reduced to a large extent.

Alternating Current

Introduction

We have seen that when the orientation of the coil with the magnetic field is changed, an alternating emf is induced and hence an alternating current flows in the closed circuit. An alternating voltage is the voltage which changes polarity at regular intervals of time and the direction of the resulting alternating current also changes accordingly.

An alternating voltage source is connected to a resistor R in which the upper terminal of the source is positive and lower terminal negative at an instant. Therefore, the current flows in clockwise direction. After a short time, the polarities of the source are reversed so the current now flows in anti – clockwise direction. This current which flows in alternate directions in the circuit is called alternating current.

Sinusoidal alternating voltage

If the waveform of alternating voltage is a sine wave, then it is known as sinusoidal alternating voltage which is given by the relation.

$$\upsilon = V_m \sin \omega t$$

Where v is the instantaneous value of alternating voltage; V_m is the maximum value (amplitude) and w is the angular frequency of the alternating voltage. When sinusoidal alternating voltage is applied to a closed circuit, the resulting alternating current is also sinusoidal in nature and its relation is

$$i = I_m \sin wt$$

where I_m is the maximum value (amplitude) of the alternating current. The direction of sinusoidal voltage or current is reversed after every half – cycle and its magnitude is also changing continuously as shown.

Mean or Average value of AC

The current and voltage in a DC system remain constant over a period of time so that there is no problem in specifying their magnitudes. However, an alternating current or voltage varies from time to time. Then a question arises how to express the magnitude of an alternating current or voltage. Though there are many ways of expressing it, we limit our discussion with two ways, namely mean value and RMS (Root Mean square) value of AC.

ELECTRICITY

6^{th}Std (Term- II)

Unit – 2 . Electricity

Sources of Electricity
Thermal Power stations

- In thermal power stations, the thermal energy generated by burning coal, diesel or gas is used to produce steam. The steam thus produced is used to rotate the turbine. While the turbine rotates, the coil of wire kept between the electromagnet rotates. Due to electromagnetic induction electricity is produced. Here heat energy is converted into electrical energy.

Hydel power stations

- In hydel power stations, the turbine is made to rotate by the flow of water from dams to produce electricity. Here kinetic energy is converted into electrical energy. Hydel stations have long economic lives and low operating cost.

Atomic power stations

- In atomic power stations, nuclear energy is used to boil water.The steam thus produced is used to rotate the turbine. As a result, electricity is produced. Atomic power stations are also called as nuclear power stations. Here nuclear energy is converted into mechanical energy and then electrical energy.

Wind mills

- In wind mills, wind energy is used to rotate the turbine to produce electricity. Here kinetic energy is converted into electrical energy.

Cell
A device that converts chemical energy into electrical energy is called a cell.

- A chemical solution which produces positive and negative ions is used as electrolyte. Two different metal plates are inserted into electrolyte as electrodes to form a cell. Due to chemical reactions, one electrode gets positive charge and the other gets negative charge producing a continuous flow of electric current.

Depending on the continuity of flow of electric current cells are classified in to two types. They are primary cells and secondary cells.

Primary Cells

- They cannot be recharged. So they can be used only once. Hence, the primary cells are usually produced in small sizes.

Examples

- cells used in clocks, watches and toys etc., are primary cells.

Secondary Cells

- A cell that can be recharged many times is called secondary cell**.** These cells can be recharged by passing electric current. So they can be used again and again. The size of the secondary cells can be small or even large depending upon the usage. While the secondary cells used in mobiles are in the size of a hand, the cells used in automobiles like cars and buses are large and very heavy.

Examples

- Secondary Cells are used in Mobile phones, laptops, emergency lamps and vehicle batteries.

Battery

- Often, we call cells as 'batteries'. However only when two or more cells are combined together they make a battery. A cell is a single unit that converts chemical energy into electrical energy, and a **battery is a collection of cells.**

Electric Circuits

- Grandfather asked Selvi to bring torchlight. While taking the torchlight, it fell down and the cells came out. She puts the cells back and switched it on (Fig. A)

Fig: A

- The torchlight did not glow. She thought the torchlight was worn out. She was afraid that grandfather might scold her. She started crying. Her uncle came there and asked the reason for crying. She conveyed the matter. Her uncle removed the cells and reversed them (Fig B)

- Now, the torch glows. Selvi's face also glows. Uncle told her the reason and explained her about electric circuits.

Fig: B

Inside view of torch

- An electric circuit is the continuous or unbroken closed path along which electric current flows from the positive terminal to the negative terminal of the battery. A circuit generally has:

- ❖ **A cell are battery- a source of electric current**
- ❖ **Connecting wires- for carrying current**
- ❖ **A bulb- a device that consumes the electricity**
- ❖ **A key or a switch- this may be connected anywhere along the circuit to stop or allow the flow of current.**

a. Open Circuit

- In a circuit if the key is in open (off) condition, then electricity will not flow andthe circuit is called an open circuit. The bulb will not glow in this circuit.

b. Closed Circuit

- In a circuit if the key is in closed (on) condition, then electricity will flow and the circuit is called a closed circuit. The bulb will glow in this circuit.

- Can you make a simple switch own by simple things available to you?

Types of Circuits

- ❖ **Simple Circuit**
- ❖ **Series Circuit**
- ❖ **Parallel Circuits**

1. Simple Circuit

- A circuit consisting of a cell, key, bulb and connecting wires is called a simple circuit.

2. Series Circuit

- If two or more bulbs are connected in series in a circuit, then that type of circuit is called series circuit. If any one of the bulbsisdamageddisconnected, the entire circuit will not work.

3. Parallel Circuit

- If two or more bulbs are connected in parallel in a circuit, then that type of circuit is called parallel circuit.

ymbols of Electric Components

- In the circuits discussed above, we used the figures of electric components. Using electric components in complicated circuits is difficult. So, symbols of the components are used instead of figures. If these symbols used in electric circuits, even complicated circuits can be easily understood.

- If any one of the bulb is damaged or disconnected the other part of the circuit will work. So parallel circuits are used in homes.

- Electric Eel is a kind of fi sh which is able to produce electric current. This fish can produce an electric shock to safeguard itself from enemies and also to catch its food.

More to Know

- Ammeter is an instrument used in electric circuits to find the quantity of current flowing through the circuit. This is to be connected in series.

Conductors and Insulators

Will electric current pass throw all materials?

- If an electric wire is cut, we could see a metal wire surrounded by another material. Do you know why it is so?

Conductors

The rate of flow of electric charges in a circuit is called electric current. The materials which allow electric charges to pass through them are called conductors. Examples: Copper, iron, aluminium, impure water, earth etc.

Insulators (Non-Conductors)

The materials which do not allow electric charges to pass through them are called insulators or non- conductors.

Safety measures to safeguard a person from electric shock

- Switch off the power supply.
- Remove the connection from the switch.
- Push him away using non - conducing materials.
- Give him first aid and take him to the nearest health centre.

More to Know

Thomas Alva Edison (February 11, 1847 – October 18, 1931) was an American inventor. He invented more than 1000 useful inventions and most of them are electrical appliances used in homes. He is remembered for the invention of electric bulb.

7th std (Term –II)
Unit - 2. Electricity

Electric Current

- The flows of electric charges constitute anelectric current. For an electricalapplianceto work, electric current must flow through it.An electric current ismeasured by the amountof electric charge moving per unit time at anypoint in thecircuit. The conventional symbolfor current is 'I'.

Unit of Electric Current

- The SI unit for measuring an electric current isthe ampere, which is the flowof electric chargeacross a surface at the rate of one coulomb persecond.

$$I = q / t$$

Where	I	⇒	current (in Ampere - A)
	q	⇒	charge (in coulomb - c)
	t	⇒	time taken (in seconds - s)

Conventional Current and Electron Flow

- Before the discovery of electrons, scientists believed that an electric current consisted of moving positive charges.

- This movement of positive charges is calledconventionalcurrent.After the electrons were discovered, itwas known that electron flow actuallytakesplace from the negative terminal to the positiveterminal of the battery. Thismovementisknown as electron flow.Conventional current is in thedirection opposite to electron flow.

Measurement of electric current

- Electric current is measuredusing a device called ammeter.The terminals ofanammeterare marked with + and -sign. An ammeter must beconnected in seriesin a circuit.Instruments used to measure smallercurrents, in the milli ampere ormicroampererange, are designated as milli ammeters ormicro ammeters.

1 Milliampere (mA)	= 10_{-3} ampere.
	= 1/1000 ampere
1 Microampere (μA)	= 10_{-6} ampere
	= 1/1000000 ampere

Potential difference (v)

- Electrical charges need energy to push themalong a circuit.Wateralwaysflowsfromhigher to lower ground.Similarly an electric chargealways flows from apointathigher potential to a point atlower potential.

- An electric current can flow only when there isa potential difference (V) or P.D.

- The potential difference between anytwo points in the circuit is the amount ofenergy needed to move one unit of electriccharge from one point to the other.

Unit of potential difference

- Did you ever notice the precautionaryboard while crossing the railway trackand the electrical transformer? What does theword high voltage denotes?

- The term mentioned in the board volt isthe measurement for the electricpotentialdifference.

- The SI unit of potential difference is volt (V).Potential difference between twopointsismeasured by using a device called voltmeter.

- The electric current flow from the higher potential level to the lower potential level is just like the water flow.

Electrical conductivity and Resistivity
Resistance (R)

- An electrical component resists or hinders theflow of electric charges, when itis connected ina circuit. In a circuit component, the resistanceto the flow of chargeis similar to how a narrowchannel resists the flow of water.

- The higher the resistance in a component, thehigher the potential difference neededtomoveelectric charge through the component. We canexpress resistance as a ratio.

- Resistance of a component is the ratio of thepotential difference across it to thecurrentflowing through it. R=$\frac{V}{I}$

- The S.I unit of resistance is ohmGreater the ratio of V to I, the greater is theresistance

Electrical conductivity (σ)

- Electrical conductivity or specific conductanceis the measure of a material'sability to conductan electric current. It is commonly representedby the Greek letterσ (sigma) The S.I Unit ofelectrical conductivity is Siemens/meter(S/m)

Electrical resistivity (ρ)

- Electrical resistivity (also known as specificelectrical resistance or volumeresistivity)is a fundamental property of a material thatquantifies how strongly thatmaterialopposesthe flow of electric current. The SI unit ofelectrical resistivity is the ohm-metre (Ω m).

Material	**Resistivity (ρ) ($\Omega\ m$) at 20°C**	**Conductivity (σ) (S/m) at 20°C**
Silver	1.59x10-8	$6.30x10^{7}$
Copper	1.68x10-8	5.98x107
Annealed copper	$1.72x10^{-8}$	$5.80x10^{7}$
Aluminium	$2.82x10^{-8}$	$3.5x10^{7}$

Analogy of Electric Current with Water Flow

- An electric current is a flow of electrons througha conductor (like a copperwire). We can't seeelectrons; however, we can imagine the flow ofelectric current ina wire like the flow of waterin a pipe.

- Let us see the analogy of flow of electric current with the water flow. Water flowing through pipes is pretty good mechanical system that is a lot like an electrical circuit. This mechanical system consists of a pump pushing water through a closed pipe.

- Imagine that the electrical current is similar to the water flowing through the pipe. The following parts of the two systems are related

  - The pipe is like the wire in the electric circuit and the pump is like the battery.
  - The pressure generated by the pump drives water through the pipe.
  - The pressure is like the voltage generated by the battery which drives electrons through the electric circuit.
  - Suppose, there are some dust and rust that plug up the pipe and slow the flow of water, creating a pressure difference from one end to the other end of the pipe. In similar way, the resistance in the electric circuit resists the

flow of electrons and creates a voltage drop from one end to the other. Energy loss is shown in the form of heat across the resistor.

Sources of Electric current -Electro chemical cells or electric cells

- An electric cell is something that provideselectricity to different devices thatare not fed directly or easily by the supplyof electricity.

- In addition to electro chemical, we use electrothermal source for generatingelectricityforlarge scale use.It has two terminals. When electric cells areused, achemical reaction takes place inside thecells which produces charge in the cell.

Types of cell – primary cell and secondary cell

- In our daily life we are using cells and batteriesfor the functioning of aremote, toys cars, clock,cellphone etc. Event Hough all the devicesproduceselectrical energy, some of the cellsare reusable and some of them are of single use.Do you know the reason why? Based on theirtype they are classified into two types namely –primary cell and secondary cell.

Primary cell

- The dry cell commonly used in torches is anexample of a primary cell. Itcannot be rechargedafter use.

Secondary cells

- Secondary cells are used in automobiles andgenerators. The chemical reactioninthemand be reversed, hence they can be recharged.Lithium cylindrical cells,button cells andalkaline cells are the other types that are in use.

PRIMARY CELL	SECONDARY CELL
1. The chemical reaction inside the primary cell is irreversible.	The chemical reaction inside the secondary cell is reversible
2. It cannot be recharged	It can be recharged
3. Examples of secondary cells are lead accumulator, Edison accumulator and Nickle – Iron accumulator	It is used to operate devices such as mobile phones, cameras, computers and emergency lights
4. Example – Simple Voltalic cell, Daniel cell, and Lechananche cell and dry cell	Examples of secondary cells are lead accumulator, Edison accumulator and Nickle – Iron accumulator.

Primary cell – simply Dry cell

- A dry cell is a type of chemical cellcommonly used in the common formbatteriesfor many electrical appliances. It is a convenientsource of electricityavailable in portable andcompact form. It was developed in 1887 by YeiSakizoofJapan.

- Dry cells are normally used in small devicessuch as remote control for T.V., torch, cameraand toys.
- A dry cell is a portable form of a leclanchecell.It consists of zinc vessel whichacts as a negativeelectrode or anode. The vessel contains a moistpaste of saw dustsaturated with a solution ofammonium chloride and zinc chloride.Theammoniumchloride acts as an electrolyte.Electrolytes are substances that becomeionsinsolution and acquire the capacityto conduct electricity.

- The purpose of zinc chloride is to maintainthe moistness of the paste beinghighlyhygroscopic. The carbon rod covered with abrass cap is placed in the middleof the vessel. Itacts as positive electrode or cathode.

- It is surrounded by a closely packed mixtureof charcoal and manganese dioxide (MnO2) ina muslin bag. Here MnO2 acts as depolarizer.The zinc vessel issealed at the top with pitch orshellac. A small hole is provided in it to allowthegases formed by the chemical action toescape. The chemical action inside the cell is thesame as in leclanche cell.

Batteries

- Batteries are a collection of one or more cellswhose chemical reactions create aflowofelectrons in a circuit. All batteries are made upof three basic components: ananode (the '+'side), a cathode (the '–' side), and some kindof electrolyte. Electrolyteis a substance thatchemically reacts with the anode and cathode.

Invention of the Battery

- One fateful day in 1780,Italian physicist, physician,biologist, andphilosopher, LuigiGalvani, was dissecting a frogattached to a brass hook. As hetouched the frog's leg with an iron scapel, theleg twitched.

- Galvani theorized that the energy came fromthe leg itself, but his fellow scientist,AlessandroVolta, believed otherwise.Volta hypothesized thatthe frog's legimpulseswereactually caused by differentmetals soaked in a liquid.He repeated the experiment using cloth soakedin brine instead of a frog corpse, whichresultedin a similar voltage. Volta published his findingsin 1791 and later createdthe first battery, thevoltaic pile, in 1800.The invention of the modernbatteryisoften attributed toAlessandro Volta. It actuallystarted with a surprising accidentinvolving the dissection of a frog.

Do you know?
All muscles of our bodies move in response to electrical impulses generated naturally in our bodies

Do you know?
Short circuit

- You mighth a v eobservedthespark in the electric polelocated nearby yourhouse. Do you knowthe cause of this electric spark? This is dueto the shortcircuiting of electricity along itspath.A short circuit is simply a low resistanceconnection between the two conductorssupplying electrical power to any circuit.Arc welding is a common example of thepractical application of the heating due toashort circuit.

Conductors and Insulators

- Based on the property ofconductance of electricity,substances are classifiedinto two types, namely,Conductors and Insulators(or) bad conductors of electricitythe electrons of different types of atoms havedifferent degrees of freedom to movearound.With some types of materials, such as metals,the outermost electrons in theatoms are looselybound and they chaotically move in the spacebetween the atomsof that material. Becausethese virtually unbound electrons are free toleavetheirrespective atoms and float aroundin the space between adjacent atoms, they areoften called as free electrons.

- Let's imagine that we have a metal in the form ofa wire. When a voltage isconnected across theends of the metal wire, the free electrons drift inone direction.

- So, a really good conductor is one that has lots offree charges while those whodon't have enough'free charges' would not be good at conductingelectricity or wecan say that they would be'poor conductors' of electricity.

Conductors

- Conductors are the materials whose atoms haveelectrons that are looselybound and are free tomove through the material. A material that is agoodconductor gives very little resistance to theflow of charge (electron) on theapplicationofexternal voltage. This flow of charge (electron)is what constitutes anelectric current. A goodconductor has high electrical conductivity intheaboveactivity.In general, more the free electrons, the betterthe material will conduct (for acertainappliedvoltage).

Insulators

- Those materials which don’t have enough‘free electrons’ are not good atconductingelectricity or we can say that they would be‘poor conductors’ ofelectricity and they are called insulators

Do you know? • This is the material used in SIM Cards, Computers, and ATM cards. Do you know by which material I am made up off? • The chips which are used in SIM Cards, Computers, and ATM cards are made up of semiconductors namely, silicon and germanium because of their electrical conductivity lies between a conductor and an insulator.

- An insulator gives a lot of resistance to the flowof charge (electron). Duringthe drift of theelectrons in an object when an external voltageis applied, collisionsoccur between the freeelectrons and the atoms of the material alsoaffectthemovement of charges. These collisionsmean that they get scattered. It is acombinationof the number of free electrons and how muchthey are scattered thataffects how well themetal conducts electricity. The rubber eraserdoes not allowelectric current to pass throughit. So rubber is a non-conductor of electricity.Rubber is an insulator Most of the metals are good conductors of electricity while most of the non-metals are poor conductors of electricity.

Do you know? • Wires made of copper, anelectrical conductor, havevery low resistance. Copperwires are used to carrycurrent in households. These wires are inturn enclosed inelectrical insulators, ormaterials of highelectricalresistance.These materials areusually made offlexible plastic.

Effects of Electric Current

- You performed manyexperiments with electricityin Class 6 and learned quitea few interesting facts. Forexample, you saw that abulb can be made to light up bymakingelectricity flow through it. The light of thebulb is thus one of the effects ofelectricity.There are several other important effectsof electricity. We shall studysome of theseeffects in this chapter. There are 3 maineffects of electricity as,

  - Heating effect
  - Magnetic effect (Magnetism)
  - Chemical effect

Heating effect

- When an electric current passes through a wire,the electrical energy is converted to hear. Inheating appliances, the heating element is madeupofmaterials with high melting point. An example of such a material is nichrome (an alloy of nickel, iron and chromium).

- The heating effect of electric current has manypractical applications. Theelectric bulb, geyser,iron box, immersible water heater are based onthiseffect.These appliances have heating coilsof high resistance.Generation of heat due toelectriccurrent is known as the heating effect ofelectricity.

Factors affecting Heating Effect of current

1. Electric Current
2. Resistance
3. Time for which current flows

Electric Fuse

- Electric fuse isa safety devicewhich is usedinhouseholdwiringandinmanyappliances. Electric fuse has a body made ofceramic and two points for connectingthefusewire. The fuse wire melts whenever there isoverload of the current in thewire. This breaksthe circuit and helps in preventing damage tocostlyappliancesand to the wiring. In electricaldevices, a glass fuse is often used. This is a smallglasstube, in which lies the fuse wire.

MCBs (Miniature Circuit Breaker)

- MCBs have been replacing electric fuse fromwirings at most of the places. Theelectricfusehas a big practical problem. Whenever the wirefuses, one needs toreplace the wire to resumeelectric supply. More often than not, this provesto be acumbersome task. Miniature circuitbreakers break the circuit automatically. Onejust needs to switch it on to resume the electricsupply. Many models of MCBs havea built inmechanism by which the electric supply isautomatically resumed.

Magnetic Effect of electricity

- The next effect of electric current is Magnetism.In 1819, Hans ChristianOersteddiscoveredthe electricity that has a magnetic effect.The experiment inactivity-5 will help youunderstand the magnetic effect of electriccurrent.

Application of magnetic effect of electric current - Electromagnet

- Magnetic effect of electric current has beenused in making powerfulelectromagnets.Electromagnets are also used to removesplinters of steel or iron inhospitalsdealingwith eye injuries.Electro magnets are used in many appliancesthat we use in our day to day life, namely, electricbell, cranes and telephone. Let usknow how themagnetic effect of electric current is applied intelephones.

Telephone

In telephones, a changing magnetic effect causesa thin sheet of metal(diaphragm) to vibrate.The diaphragm is made up a metal that can beattractedtomagnets.

1. The diaphragm is attached to spring that isfixed to the earpiece.
2. When a current flows through the wires, thesoft – iron bar becomes anelectromagnet.
3. The diaphragm becomes attracted to theelectromagnet.
4. As the person on the other end of the linespeaks, his voices cause the current inthecircuit to change. This causes the diaphragmin the earpiece to vibrate,producing sound.

Chemical Effects of Electricity

- Chemical reactions happen, when electricitypasses through variousconducting liquids. Thisis known as chemical effects of electricity. Youwilllearnchemical effect of electricity in yourhigher classes.

8^{th}std (Term – 2)
Unit – 2 Electricity

Charges

- Charge or electric charge is the basic property of matter that causes objects to attract or repel each other. It is carried by the subatomic particles like protons and electrons. Charges can neither be created nor be destroyed. There are two types of charges: positive charge and negative charge. Protons carry positive charge and the electrons carry negative charge. There is a force of attraction or repulsion between the charges. Unlike charges attract each other and like charges repel each other.

- Electric charge is measured in coulomb (C). Small amount of charge that can exist freely is called elementary charge (e). Its value is 1.602 × 10-19 C. This is the amount of charge possessed by each proton and electron. But, protons havepositive elementary charge (+e) and electrons have negative elementarycharge (-e). Since protons and electrons are equal in number, an atom is electrically neutral.

Transfer of Charges

- As we saw earlier, electrons (negative electric charges) in the outermost orbit of an atom can be easily removed. They can be transferred from one substance to another. The substance which gains electrons become negatively charged and the substance which looses electrons becomes positively charged. Transfer of charges takes place in the following three ways.

    - Transfer by Friction
    - Transfer by Conduction
    - Transfer by Induction

Transfer by Friction

- Comb rubbed with hair gains electronsb from the hair and becomes negatively charged. These electrons are accumulated on the surface of the comb. When a piece of paper is teared into bits, positive and negative charges are present at the edges of the bits. Negative charges in the comb attract positive charges in the bits. So, the paper bits are moving towards the comb. While combing hair charges are transferred from the hair to comb due to friction. If the hair is wet, the friction between the hair and the comb reduces which will reduce the number of electrons transferring from hair to comb. Hence, rubbing certain materials with one another can cause the build-up of electrical charges on the surfaces. From this it is clear that charges are transferred by friction.

- A neutral object can become positively charged when electrons get transferred to another object; not by receiving extra positive charges.

- Similar effect can be seen when we rub few materials with one another. When a glass rod is rubbed with a silk cloth the free electrons in the glass rod are transferred to silk cloth. It is because the free electrons in the glass rod are less tightly bound as compared to that in silk cloth. Since the glass rod looses electrons, it has a deficiency of electrons and hence acquires positive charge. But, the silk cloth has excess of electrons. So, it becomes negatively charged.

- When an ebonite rod (rod made by vulcanized rubber) is rubbed with fur, the fur transfers electrons to the ebonite rod because the electrons in the outermost orbit of the atoms in fur are loosely bound as compared to the ebonite rod. The ebonite rod which has excess electrons becomes negatively charged and the fur which has deficiency of electrons is positively charged.

- From these we know that when two materials are rubbed together, some electrons may be transferred from one material to the other, leaving them both with a net electric charge.

- If a negatively charged glass rod is brought near another glass rod, the rods will move apart as they repel each other. If a positively charged glass rod is brought close to a negatively charged ebonite rod, the rods will move toward each other as they attract. The force of attraction or repulsion is greater when the charged objects are closer.

Transfer by Conduction

- When the ebonite rod is rubbed with woollen cloth, electrons from the woolen cloth are transferred to the ebonite rod. Now ebonite rod will be negatively charged. When it is brought near the paper cylinder, negative charges in the rod are attracted by the positive charges in the cylinder. When the cylinder is touched by the rod, some negative charges are transferred to the paper. Hence, the negative charges in the rod are repelled by the negative charges in the cylinder. Thus, we can say that charges can be transferred to on object by bringing it in contact with a charged body. This method of transferring charges from one body to other body is called transfer by conduction.

- The materials which allow electric charges to pass through them easily are called conductors of electricity. For example, metals like aluminium, copper are good conductors of electricity. Materials which do not allow electric charges to pass through them easily are called insulators. Rubber,wood and plastic are insulators

Transfer by Induction

- We saw that we can charge an uncharged object when we touch it by a charged object. But, it is also possible to obtain charges in a body without any contact with other charges. The process of charging an uncharged body by bringing a charged body near to it but without touching it is called induction. The uncharged body acquires an opposite charge at the near end and similar charge at the farther end.

- Bring a negatively charged plastic rod near a neutral rod. When the negatively charged plastic rod is brought close to the neutral rod, the free electrons move away due to repulsion and start piling up at the farther end. The near end becomes positively charged due to deficit of electrons. When the neutural rod is grounded, the negative charges flow to the ground. The positive charges at the near end remain held due to attractive forces and the electrons inside the metal is zero. When the rod is removed from the ground, the positive charge continues to be held at the near end. This makes the neutral rod a positively charged rod

- Similarly, when a positively charged rod is brought near an uncharged rod, negatively charged electrons are attracted towards it. As a result there is excess of electrons at nearer end and deficiency of electrons at the farther end. The nearer end of the uncharged rod becomes negatively charged and far end is positively charged.

Flow of Charges

- Suppose you have two metallic spheres; one having more negative charge (excess of electrons) and the other having more positive charge (deficiency of electrons). When you connect them both with the help of a metallic wire, excess electrons from the negatively charged sphere will start flowing towards the positively charged sphere. This flow continues till the number of electrons in both the sphere is equal. Here, the positively charged sphere is said to be at higher potential and the negatively charged sphere is said to be at lower potential. Hence, electrons flow from lower potential to higher potential. This is known electric current (flow of electrons). The difference between these potentials is known as potential difference, commonly known as voltage.

Before the discovery of electrons it was considered that electric current is due to the flow of positive charges. Flow of positive charge is called conventional current. Conventional current flows from higher potential to lower potential.

Electroscope

- An electroscope is a scientific instrument used to detect the presence of electric charge on a body. In the year 1600, British physician William Gilbert invented the first electroscope. It is the first electrical instrument. There are two types of electroscope: pith-ball electroscope and gold leaf electroscope. An electroscope is made out of conducting materials, generally metal. It works on the principle that like charges repel each other. In a simple electroscope two metal sheets are hung in contact with each other. They are connected to a metal rod that extends upwards, and ends in a knob at the end.

- The first electroscope developed in 1600 by William Gilbert was called versorium. The versorium was simply a metal needle allowed to pivot freely on a pedestal. The metal would be attracted to charged bodies brought near.

- If you bring a charged object near the knob, electrons will either move out of it or into it. This will result in charges on the metal leaves inside the electroscope. If a negatively charged object is brought near the top knob of the electroscope, it causes free electrons in the electroscope to move down into the leaves, leaving the top positive. Since both the leaves have negative charge, they repel each other and move apart.If a positive object is brought near the top knob of the electroscope, the free electrons in theelectroscope start to move up towards the knob. This means that the bottom has a net positive charge. The leaves will spread apart again.

Gold leaf electroscope

- The gold-leaf electroscope was developed in 1787 by a British scientist named Abraham Bennet. Gold and silver are used in electroscope because they are the best conductors of electric current.

Structure of Electroscope

- It is made up of a glass jar. A vertical brass rod is inserted into the jar through a cork. The top of the brass rod has a horizontal brass rod or a brass disc. Two gold leaves are suspended from the brass rod inside the jar.

Working of Electroscope

- When the brass disc of the electroscope is touched by a charged object, electric charge gets transferred to the gold leaf through the rod. This results in the gold leaves moving away from each other. This happens because both the leaves have similar charges.

Charging

- Transfer of charge from one object to another is called charging. In case of the gold leaves charge is transferred through the brass rods.

Electrical Discharge

- The gold leaves resume their normal position after some time. This happens because they lose their charge. This process is called electrical discharge. The gold leaves would also be discharged when someone touches the brass rod with bare hands. In that case, the charge is transferred to the earth through the human body.

Lighting and Thunder

- Getting a shock from a doorknob after rubbing your foot on a carpet floor, results from discharge. Discharge occurs when electronson the hand are quickly pulled to the positively charged doorknob. This movement of electrons, which is felt as a shock, causes the body to lose negative charge. Electric discharge takes place in a medium, mostly gases. Lightning is another example of discharge that takes place in clouds.

- Lightning is produced by discharge of electricity from cloud to cloud or from cloud to ground. During thunderstorm air is moving upward rapidly. This air which moves rapidly carries small ice crystals upward. At the same time, small water drops move downward. When they collide, ice crystals becomepositively charged and move upward and the water drops become negatively charged and move downward. So the upper part of the cloud is positively charged and the lower part of the cloud is negatively charged. When they come into contact, electrons in the water drops are attracted by the positive charges in the ice crystals. Thus, electricity is generated and lightning is seen.

- Sometimes the lower part of the cloud which is negatively charged comes into contact with the positive charges accumulated near the mountains, trees and even people on the earth. This discharge produces lot of heat and sparks that results in what we see as lightning. Huge quantities of electricity are discharged in lightning flashes and temperatures of over 30,000°C or more can be reached. This extreme heating causes the air to expand explosively fast and then they contract. This expansion and contraction create a shock wave that turns into a booming sound wave, known as thunder.

- Lightning's extreme heat will vaporize the water inside a tree, creating steam that may burn out the tree.

Sometimes lightning may be seen before the thunder is heard. This is because the distance between the clouds and the surface is very long and the speed of light is much faster than the speed of sound.

- During lightning and thunder, we should avoid standing in ground and open spaces. You should make yourself as small as possible by squating. It is however safe to stay inside a car because the car acts as a shield and protects us from the electric field generated by the storm.

Earthing

- A safety measure devised to prevent people from getting shocked if the insulation inside electrical devices fails is called Earthing. Electrical earthing can be defined as the process of transferring the discharge of electrical energy directly to the Earth with the help of low-resistance wire.

- We get electrical energy from different sources. Battery is one such source. We use it in wall clocks, cell phones etc. For the working of refrigerators, air conditioners, washing machines, televisions, laptops and water heaters we use domestic power supply. Usually an electric appliance such as a heater, an iron box, etc. are fitted with three wires namely live, neutral and earth. The earth wire is connected to the metallic body of the appliance. This is done to avoid accidental shock.

- Suppose due to some defect, the insulation of the live wire inside an electric iron is burnt then the live wire may touch the metallic body of the iron. If the earth wire is properly connected to the metallic body, current will pass into the Earth through earth wire and it will protect us from electric shock. The Earth, being a good conductor of electricity, acts as a convenient path for the flow of electric current that leaksout from the insulation.

Lightning Arresters

- Lightning arrestor is a device used to protect buildings from the effects of lightning. Lightning conductor consists of a metallic lightning rod that remains in air at the top of the building. Major portion of the metal rod and copper cable are installed in the walls during its construction. The other end of the rod is placed deep into the soil. When lightning falls, it is attracted by the metallic rods at the top of the building. The rod provides easy route for the transfer of electric charge to the ground. In the absence of lightning arrestors, lightning will fall on the building and the building will be damaged.

Effects of Current

- When current is flowing through a conductor it produces certain effects. These are known as effects of electric current. These effects result in conversion of electrical energy into different forms of energies such as heat energy, mechanical energy, magnetic energy, chemical energy and so on.

Chemical Effect of Current

- We saw that electricity is conducted by metals. This activity shows that liquids also conduct electricity. When electric current is passed through a conducing solution, some chemical reactions take place in the solution. This chemical reactions produce electrons which conduct electricity. This is called chemicaleffect of electric current. The decomposition of molecules of a solution into positive and negative ions on passing an electric current through it, is called electrolysis. Electrolysis has a number of applications. It is used in extraction and purification of metals. The most general use of electrolyte is electroplating.

Electroplating

- Electroplating is one of the most common applications of chemical effects of electric current. The process of depositing a layer of one metal over the surface of another metal by passing electric current in called electroplating.

- Electro plating is applied in many fields. We use iron in bridges and automobiles to provide strength. However, iron tends to corrode and rust. So, a coating of zinc is deposited on iron to protect it from corrosion and formation of rust. Chromium has a shiny appearance. It does not corrode. It resists scratches. But, chromium is expensive and it may not be economical to make the whole object out of chromium. So, the objects such as car parts, bath taps, kitchen gas burners, bicycle handlebars, wheel rims are made from a cheaper metal and only a coating of chromium is deposited over it.

Heating Effect of Current

- When electric current passes through a conductor, there is a considerable 'friction' between the moving electrons and the molecules of the conductor. During this process, electrical energy is transformed to heat energy. This is known as heating effect of electric current. The heat produced depends on the amount ofresistance offered by the wire.

- Copper wire offers very little resistance and does not get heated up quickly. On the other hand, thin wires of tungsten or nichrome which are used in bulbs offer high resistance and gets heated up quickly. This is the reason why tungsten wire is used in the filaments of the bulbs and nichrome wire is used as a heating element in household heating appliances. Heating effect of electric current can be seen in many devices. Some ofthem are given below.

Fuse

- Fuse is a strip of alloy wire which is made up of lead and tin with a very low melting point. This can be connected to the circuit. The fuse is usually designed to take specific amount of current. When current passing through the wire exceeds the maximum limit, it gets heated up. Due to low melting point it melts quickly disconnecting the circuit. This prevents damage to the appliances.

Electric cookers

- Electric cookers turn red hot when electric current is passed through the coil. The heat energy produced is absorbed by the cooking pot through conduction.

Electric kettles

- The heating element is placed at the bottom of the kettle which contains water. The heat is then absorbed by the liquid and distributed throughout the liquid by convection.

Electric irons

- When current flows through the heating element, the heat energy developed is conducted to the heavy metal base, raising its temperature. This energy is then used to press clothes.

9th std
UNIT-4 Electric charge and Electric current

Electric current

- When the charged object is provided with a conducting path, electrons start to flow through the path from higher potential to lower potential region. Normally, the potential difference is produced by a cell or battery. When the electrons move, we say that an electric current is produced. That is, an electric current is formed by moving electrons.

Direction of current

- Before the discovery of the electrons, scientists believed that an electric current consisted of moving positive charges. Although we know this is wrong, the idea is still widely held, as the discovery of the flow of electronsdid not affect the basic understanding of the electric current. The movement of the positive charge is called as 'conventional current'. The flow of electrons is termed as 'electron current'.

- In electrical circuits the positive terminal is represented by a long line and negative terminal as a short line.

Measurement of electric current

- We can measure the value of current and express it numerically. Current is the rate at which charges flow past a point on a circuit. That is, if q is the quantity of charge passing through a cross section of a wire in time t, quantity of current (I) is represented as,

$$I = q/t$$

- The standard SI unit for current is ampere with the symbol A. Current of 1 ampere means that there is one coulomb (1C) of charge passing through a cross section of a wire every one second (1 s).

1 ampere = 1 coulomb / 1 second (or)
$$1\ A = 1\ C / 1\ s = 1Cs^{-1}$$

- Ammeter is an instrument used to measure the strength of the electric current in an electric circuit.

- The ammeter is connected in series in a circuit where the current is to be found. . The current flows through the positive (+) red terminal of ammeter and leaves from the negative (–) black terminal.

Electromotive force (e.m.f)

- Imagine that two ends of a water pipe filled with water are connected. Although filled with water, the water will not move or circle around the tube on its own. Suppose, you insert a pump in between and the pump pushes the water, then the water will start moving in the tube. Now the moving water can be used to produce some work. We can insert a water wheel in between the flow and make it to rotate and further use that rotation to operate machinery.

- Likewise if you take a circular copper wire, it is full of free electrons. However, they are not moving in a particular direction. You need some force to push the electrons to move in a direction.
- Devices like electric cells and other electrical energy sources act like pump, 'pushing' the charges to flow through a wire or conductor. The 'pumping' action of the electrical energy source is made possible by the 'electromotive force, (e.m.f). The electromotive force is represented as (ε). The e.m.f of an electrical energy source is the work done (W) by the source in driving a unit charge (q) around the complete circuit.

- $\varepsilon = W/q$ where, W is the work done. The SI unit of e.m.f is joules per coulomb (JC-1) or volt (V). In other words the e.m.f of an electrical energy source is one volt if one joule of work is done by the source to drive one coulomb of charge completely around the circuit.

Potential difference (p.d)

- One does not just let the circuit connect one terminal of a cell to another. Often we connect, say a bulb or a small fan or any other electrical device in an electric circuit and use the electric current to drive them. This is how a certain amount of electrical energy provided by the cell or any othersource of electrical energy is converted into other form of energy like light, heat, mechanical and so on. For each coulomb of charge passing through the light bulb (or any appliances) the amount of electrical energy converted to other forms of energy depends on the potential difference across the electrical device or any electrical component in the circuit. The potential difference is represented by the symbol V.

$$V = W/q$$

- where, W is the work done, i.e., the amount of electrical energy converted into other forms of energy measured in joule and q is amount of charge measured in coulomb. The SI unit for both e.m.f and potential difference is the same i.e., volt (V).

- Voltmeter is an instrument used to measure the potential difference. To measure the potential difference across a component in a circuit, the voltmeter must be connected in parallel to it. Say, you want to measure the potential difference across a light bulb, you need to connect the voltmeter.

- Note the positive (+) red terminal of the voltmeter is connected to the positive side of circuit and the negative (–) black terminal is connected to the negative side of the circuit across a component (light bulb in the above illustration).

Resistance

- The Resistance (R) is the measure of opposition offered by the component to the flow of electric current through it. Different electrical components offer different electrical resistance.

- Metals like copper, aluminium etc., have very much negligible resistance. That is why they are called good conductors. On the other hand, materials like nicrome, tin oxide etc., offer high resistance to the electric current. We also have a category of materials called insulators; they do not conduct electric current at all (glass, polymer, rubber and paper). All these materials are needed in electrical circuits to have usefulness and safety in electrical circuits.

- The SI unit of resistance is ohm with the symbol (Ω). One ohm is the resistance of a component when the potential difference of one volt applied across the component drives a current of one ampere through it.

- We can also control the amount of flow of current in a circuit with the help of resistance. Such components used for providing resistance are called as 'resistors'. The resistors can be fixed or variable.

- Fixed resistors have fixed value of resistance, while the variable resistors like rheostats can be used to obtain desired value of resistance.

Electric circuit diagram

- To represent an electrical wiring or solve problem involving electric circuits, the circuit diagrams are made.
- The four main components of any circuits namely,

(i) cell,
(ii) connecting wire,
(iii) switch and
(iv) resistor or load are given above.

- In addition to the above many other electrical components are also used in an actualcircuit. A uniform system of symbols has been evolved to describe them. It is like learning a sign language, but useful in understanding circuit diagrams. Some common symbols in the electrical circuit.

Different electrical circuits

- Look at the two circuits, shown in Figure 4.11. In Figure A two bulbs are connected in series and in Figure B they are connected in parallel. Let us look at each of these separately.

Series circuits

- Let us first look at the current in a series circuit. In a series circuit the components are connected one after another in a single loop. In a series circuit there is only one pathway through which the electric charge flow. From the above we can know that the current I all along the series circuit remain same. That is in a series circuit the current in each point of the circuit is same.

Parallel circuits

- In parallel circuits, the components are connected to the e.m.f source in two or more loops. In a parallel circuit there is more than one path for the electric charge to flow. In a parallel circuit the sum of the individual current in each of the parallel branches is equal to the main current flowing into or out of the parallel branches. Also, in a parallel circuit the potential difference across separate parallel branches are same.

Effects of electric current

- When current flows in a circuit it exhibits various effects. The main effects are heating, chemical and magnetic effects.

- When the flow of current is 'resisted' generally heat is produced. This is because the electrons while moving in the wire or resistor suffer resistance. Work has to be done to overcome the resistance which is converted in to heat energy. This conversion of electrical energy into heating energy is called 'Joule heating' as this effect was extensively studied by the scientist Joule. This forms the principle of all electric heating appliances like iron box, water heater, toaster etc. Even connecting wires offer a small resistance to the flow of current. That is why almost all electrical appliances including the connecting wires are warm when used in an electric circuit.

- So far we have come across the cases in which only the electrons can conduct electricity. But, here when current passes through electrolyte like copper sulphate solution, both the electron and the positive copper ion conduct electricity. The process of conduction of electric current through solutions is called 'electrolysis'. The solution through which the electricity passes is called 'electrolyte'. The positive terminal inserted in to the solution is called 'anode' and the negative terminal 'cathode'. In the above experiment, copper wire is anode and carbon rod is cathode.

- Extremely weak electric current is produced in the human body by the movement of charged particles. These are called synaptic signals. These signals are produced by electro-chemical process. They travel between brain and the organs through nervous system.

Magnetic effect of electricity

- A wire or a conductor carrying current develops a magnetic field perpendicular to the direction of the flow of current. This is called magnetic effect of current. The discovery of the scientist Oersted and the 'right hand thumb rule' are detailed in the chapter on Magnetism and Electromagnetism in this book.

Direction of current is shown by the right hand thumb and the direction of magnetic field is shown by other fingers of the same right hand.

Types of current

- There are two distinct types of electric currents that we encounter in our everyday life: direct current (dc) and alternating current (ac).

Direct current

- We know current in electrical circuits is due to the motion of positive charge from higher potential to lower potential or electron from lower to higher electrical potential. Electrons move from negative terminal of the battery to positive of the battery. Battery is used to maintain a potential difference between the two ends of the wire. Battery is one of the sources for dc current. The dc is due to the unidirectional flow of electric charges. Some other sources of dc are solar cells, thermocouples etc.

- Many electronic circuits use dc. Some examples of devices which work on dc are cell phones, radio, electric keyboard, electric vehicles etc.

Alternating current

- If the direction of the current in a resistor or in any other element changes its direction alternately, the current is called an alternating current. The alternating current varies sinusoidally with time. This variation is characterised by a term called as frequency. Frequency is the number of complete cycle of variation, gone through by the ac in one second. In ac, the electrons do not flow in one direction because the potential of the terminals vary between high and low alternately. Thus, the electrons move to and fro in the wire carrying alternating current. It is diagrammatically represented.

- Domestic supply is in the form of ac. When we want to use an electrical device in dc, then we have to use a device to convert ac to dc. The device used to convert ac to dc is called rectifier. Colloquially it is called with several names like battery eliminator, dc adaptor and so on. The device used to convert dc into ac is called inverter.

Advantages of ac over dc

- The voltage of ac can be varied easily using a device called transformer. The ac can be carried over long distances using step up transformers. The loss of energy while distributing current in the form of ac is negligible. Direct current cannot be transmitted as such. The ac can be easily converted into dc and generating ac is easier than dc. The ac can produce electromagnetic induction which is useful in several ways.

Advantage of dc

- Electroplating, electro refining and electrotyping can be done only using dc. Electricity can be stored only in the form of dc.

- In India, the voltage and frequency of ac used for domestic purpose is 220 V and 50 Hz respectively where as in United States of America it is 110 V and 60 Hz respectively.

Dangers of electricity and precautions to be taken

- The following are the possible dangers as for as electric current is concerned.

Damaged insulation:

- Do not touch the bare wire. Use safety glows and stand on insulating stool or rubber slippers while handling electricity.

Overload of power sockets:

- Do not connect too many electrical devices to a single electrical socket.

Inappropriate use of electrical appliances:

- Always use the electrical appliances according to the power rating of the device like ac point, TV point, microwave oven point etc.

Environment with moisture and dampness:

- Keep the place, where there is electricity, out of moisture and wetness as it will lead to leakage of electric current.

Beyond the reach of children:

- The electrical sockets are to be kept away from the reach of little children who do not know the dangers of electricity.

- Resistance of a dry human body is about 1,00,000 ohm. Because of the presence of water in our body the resistance is reduced to few hundred ohm. Thus, a normal human body is a good conductor of electricity. Hence, precautions are required while doing electrical work.

10th Std

Unit-4-Electricity

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ELECTRIC CURRENT

- The motion of electric charges (electrons) through a conductor (e.g., copper wire) will constitute an electric current. Th is is similar to the flow of water through a channel or flow of air from a region of high pressure to a region of low pressure. In a similar manner, the electric current passes from the positive terminal (higher electric potential) of a battery to the negative terminal (lower electric potential) through a wire as shown in the Figure 4.1.

Definition of electric Current

- Electric current is oft en termed as 'current' and it is represented by the symbol 'I'. It is defined as the rate of flow of charges in a conductor. Th is means that the electric current represents the amount of charges fl owing in any cross section of a conductor (say a metal wire) in unit time. If a net charge 'Q' passes through any cross section of a conductor in time 't', then the current fl owing through the conductor is

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

SI unit of electric current

- The SI unit of electric current is ampere (A). Th e current fl owing through a conductor is said to be one ampere, when a charge of one coulomb flows across any cross-section of a conductor, in one second.

$$\text{Hence, 1 ampere} = \frac{1\text{coulomb}}{1second}$$

Solved Problem-1

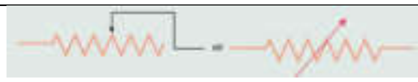
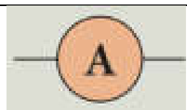
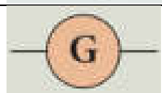
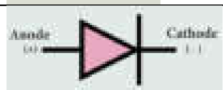
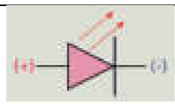
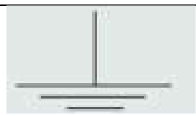
- A charge of 12 coulomb flows through a bulb in 5 second. What is the current through the bulb?

Solution:

Charge Q = 12 C, Time t = 5 s. Therefore,
current $I = \frac{Q}{t} = \frac{12}{5} = 2.4$ A

ELECTRIC CIRCUIT

- An electric circuit is a closed conducting loop (or) path, which has a network of electrical components through which electrons are able to flow. Th is path is made using electrical wires so as to connect an electric appliance to a source of electric charges (battery). A schematic diagram of an electric circuit comprising of a battery, an electric bulb, and a switch is given in Figure 4.2.

COMPONENT	USE OF THE COMPONENT	SYMBOL USED
Resistor	Used to fix the magnitude of the current through a circuit	
Variable resistor or Rheostat	Used to select the magnitude of the current through a circuit.	
Ammeter	Used to measure the current	
Voltmeter	Used to measure the potential diff erence.	
Galvanometer	Used to indicate the direction of current.	
A diode	A diode has various uses, which you will study in higher classes.	
Light Emitting Diode (LED)	A LED has various uses which you will study in higher classes.	
Ground connection	Used to provide protection to the electrical components. It also serves as a reference point to measure the electric potential.	

- In this circuit, if the switch is 'on', the bulb glows. If it is switched off, the bulb does not glow. Therefore, the circuit must be closed in order that the current passes through it. The potential difference required for the flow of charges is provided by the battery. The electrons flow from the negative terminal to the positive terminal of the battery.

❖ ***By convention, the direction of current is taken as the direction of flow of positive charge (or) opposite to the direction of flow of electrons.***

- Thus, electric current passes in the circuit from the positive terminal to the negative terminal.

Electrical components

- The electric circuit given in Figure 4.2 consists of different components, such as a battery, a switch and a bulb. All these components can be represented by using certain symbols. It is easier to represent the components of a circuit using their respective symbols.

The symbols that are used to represent some commonly used components are given in Table 4.1. The uses of these components are also summarized in the table.

OHM'S LAW

- A German physicist, Georg Simon Ohm established the relation between the potential difference and current, which is known as Ohm's Law. This relationship can be understood from the following activity.

- According to Ohm's law, at a constant temperature, the steady current 'I' flowing through a conductor is directly proportional to the potential difference 'V' between the two ends of the conductor.

$$I \propto V. \text{ Hence, } \frac{I}{V} = \text{constant}.$$

The value of this proportionality constant is found to be , $\frac{1}{R}$

Therefore, $I = \frac{1}{R} V$

$$V = I R$$

- Here, R is a constant for a given material (say Nichrome) at a given temperature and is known as the **resistance** of the material. Since, the potential difference V is proportional to the current I, the graph between V and I is a straight line for a conductor, as shown in the Figure 4.5.

RESISTANCE OF A MATERIAL

- In Figure 4.4, a Nichrome wire was connected between X and Y. If you replace the Nichrome wire with a copper wire and conduct the same experiment, you will notice a different current for the same value of the potential difference across the wire. If you again replace the copper wire with an aluminium wire, you will get another value for the current passing through it. From equation (4.3), you have learnt that V/I must be equal to the resistance of the conductor used. The variations in the current for the same values of potential difference indicate that the resistance of different materials is different. Now, the primary question is, "what is resistance?"

- Resistance of a material is its property to oppose the flow of charges and hence the passage of current through it. ***It is different for different materials***.

From Ohm's Law, $\frac{V}{I}$=R

- The resistance of a conductor can be defined as the ratio between the potential difference across the ends of the conductor and the current flowing through it.

Unit of Resistance

- The SI unit of resistance is ohm and it is represented by the symbol Ω.
- Resistance of a conductor is said to be one ohm if a current of one ampere flows through it when a potential difference of one volt is maintained across its ends.

1 ohm =, $\frac{1volt}{1ampre}$

Solved Problem-3

- Calculate the resistance of a conductor through which a current of 2 A passes, when the potential difference between its ends is 30 V.

Solution:

Current through the conductor I = 2 A, Potential Difference V = 30 V
From Ohm's Law: R = $\frac{V}{I}$. Therefore, R = $\frac{30}{2}$= 15 Ω

ELECTRICAL RESISTIVITY & ELECTRICAL CONDUCTIVITY
Electrical Resistivity

- You can verify by doing an experiment that the resistance of any conductor 'R' is directly proportional to the length of the conductor 'L' and is inversely proportional to its area of cross section 'A'.

R $\propto$ L, R $\propto$ $\frac{1}{A}$,
Hence , R $\propto$ $\frac{L}{A}$

Therefore, R = ρ $\frac{L}{A}$

- Where, ρ (rho) is a constant, called as electrical resistivity or specific resistance of the material of the conductor.

From equation ρ = $\frac{Ra}{L}$
If L = 1 m, A = 1 m2 then, from the above equation ρ = R

- Hence, the electrical resistivity of a material is defined as the resistance of a conductor of unit length and unit area of cross section. Its unit is ohm metre.

- Electrical resistivity of a conductor is a measure of the resisting power of a specified material to the passage of an electric current. It is a constant for a given material.

Nichrome is a conductor with highest resistivity equal to 1.5 × 10–6 Ω m. Hence, it is used in making heating elements.

Conductance and Conductivity

- Conductance of a material is the property of a material to aid the flow of charges and hence, the passage of current in it. The conductance of a material is mathematically defined as the reciprocal of its resistance (R). Hence, the conductance 'G' of a conductor is given by

$$G = \frac{1}{R} \quad (4.5)$$

Its unit is ohm–1. It is also represented as 'mho'.

- The reciprocal of electrical resistivity of a material is called its electrical conductivity.

$$\sigma = \frac{1}{\rho} \quad (4.6)$$

- Its unit is ohm–1 metre–1. It is also represented as mho metre–1. The conductivity is a constant for a given material. Electrical conductivity of a conductor is a measure of its ability to pass the current through it. Some materials are good conductors of electric current. Example: copper, aluminium, etc. While some other materials are non-conductors of electric current (insulators). Example: glass, wood, rubber, etc.
- Conductivity is more for conductors than for insulators. But, the resistivity is less for conductors than for insulators. The resistivity of some commonly used materials is given in Table 4.2.

NATURE OF THE MATERIAL	MATERIAL	RESISTIVITY (Ω m)
Conductor	Copper	1.62×10^{-8}
	Nickel	6.84×10^{-8}
	Chromium	12.9×10^{-8}
Insulator	Glass	10^{10} to 10^{14}
	Rubber	10^{13} to 10^{16}

Solved Problem-4

- The resistance of a wire of length 10 m is 2 ohm. If the area of cross section of the wire is 2 × 10–7 m2, determine its (i) resistivity (ii) conductance and (iii) conductivity

Solution:

Given: Length, L = 10 m, Resistance, R = 2 ohm and Area, A = 2 × 10–7 m2

Resistivity, $\rho = \frac{RA}{L} = \frac{2\times 2 \times 10{-}7}{10} =$

$= 4 \times 10^{-8}\ \Omega$ m

Conductance, $G = \frac{1}{R} = \frac{1}{2} = 0.5$ mho

Conductivity, $\sigma = \frac{1}{\rho} = \frac{1}{4 \times 10{-}8} = 0.25 \times 10{-}8$ mho m–1

SYSTEM OF RESISTORS

- So far, you have learnt how the resistance of a conductor affects the current through a circuit. You have also studied the case of the simple electric circuit containing a single resistor. Now in practice, you may encounter a complicated circuit, which uses a combination of many resistors. This combination of resistors is known as 'system of resistors' or 'grouping of resistors'. Resistors can be connected in various combinations. The two basic methods of joining resistors together are:

a) Resistors connected in series, and b) Resistors connected in parallel.

- In the following sections, you shall compute the effective resistance when many resistors having different resistance values are connected in series and in parallel.

Resistors in series

- A series circuit connects the components one after the other to form a 'single loop'. A series circuit has only one loop through which current can pass. If the circuit is interrupted at any point in the loop, no current can pass through the circuit and hence no electric appliances connected in the circuit will work. Series circuits are commonly used in devices such as flashlights. Thus, if resistors are connected end to end, so that the same current passes through each of them, then they are said to be connected in series.

- Let, three resistances R1, R2 and R3 be connected in series (Figure 4.6). Let the current flowing through them be I. According to Ohm's Law, the potential differences V1, V2 and V3 across R1, R2 and R3 respectively, are given by:

$V_1 = I\,R_1$
$V_2 = I\,R_2$
$V_3 = I\,R_3$

- The sum of the potential differences across the ends of each resistor is given by:

$$\mathbf{V = V_1 + V_2 + V_3}$$

Using equations (4.7), (4.8) and (4.9), we get

$$\mathbf{V = I\,R_1 + I\,R_2 + I\,R_3 \quad (4.10)}$$

- The effective resistor is a single resistor, which can replace the resistors effectively, so as to allow the same current through the electric circuit. Let, the effective resistance of the series-combination of the resistors, be R_S. Then,

$V = I\,R_S$ (4.11)

Combining equations (4.10) and (4.11), you get,

$$\mathbf{I\,R_S = I\,R_1 + I\,R_2 + I\,R_3}$$
$$\mathbf{R_S = R_1 + R_2 + R_3 \quad (4.12)}$$

- Thus, you can understand that when a number of resistors are connected in series, their equivalent resistance or effective resistance is equal to the sum of the individual resistances. When ‘n’ resistors of equal resistance R are connected in series, the equivalent resistance is ‘n R’.

i.e., $R_S = n\,R$

- ***The equivalent resistance in a series combination is greater than the highest of the individual resistances***.

Solved Problem-5

- Three resistors of resistances 5 ohm, 3 ohm and 2 ohm are connected in series with 10 V battery. Calculate their effective resistance and the current flowing through the circuit.

Solution:

$R_1 = 5\ \Omega$, $R_2 = 3\ \Omega$, $R_3 = 2\ \Omega$, $V = 10$ V
$Rs = R_1 + R_2 + R_3$, $Rs = 5 + 3 + 2 = 10$, hence $Rs = 10\ \Omega$
The current, $I = \frac{V}{Rs} = \frac{10}{10} = 1$ A

Resistances in Parallel

- A parallel circuit has two or more loops through which current can pass. If the circuit is disconnected in one of the loops, the current can still pass through the other loop(s). The wiring in a house consists of parallel circuits.

- Consider that three resistors R1, R2 and R3 are connected across two common points A and B. The potential difference across each resistance is the same and equal to the potential difference between A and B. This is measured using the voltmeter. The current I arriving at A divides into three branches I1, I2 and I3 passing through R1, R2 and R3 respectively.

According to the Ohm's law, you have,

$I1 = \frac{V}{R1}$ R_1R_2 R_3

$I2 = \frac{V}{R2}$

$I3 = \frac{V}{R3}$

The total current through the circuit is given by

$I = I_1 + I_2 + I_3$

Using equations (4.13), (4.14) and (4.15), you get

$I = \frac{V}{R1}+\frac{V}{R2}+\frac{V}{R3}$

Let the effective resistance of the parallel combination of resistors be RP. Then,

$I = \frac{V}{Rp}$

Combining equations (4.16) and (4.17), you have

$\frac{V}{Rp}= \frac{V}{R1}+\frac{V}{R2}+\frac{V}{R3}$

$\frac{1}{Rp}= \frac{1}{R1}+\frac{1}{R2}+\frac{1}{R3}$

- Thus, when a number of resistors are connected in parallel, the sum of the reciprocals of the individual resistances is equal to the reciprocal of the effective or equivalent resistance. When 'n' resistors of equal resistances R are connected in parallel, the equivalent resistance is $\frac{R}{n}$.

$\frac{1}{Rp} = \frac{1}{R} + \frac{1}{R} + \frac{1}{R} ... + \frac{1}{R} = \frac{n}{R}$.

Hence, $R_p = \frac{R}{n}$

- ***The equivalent resistance in a parallel combination is less than the lowest of the individual resistances.***

Series Connection of Parallel Resistors

- If you consider the connection of a set of parallel resistors that are connected in series, you get a series – parallel circuit. Let R1 and R2 be connected in parallel to give an effective resistance of RP1. Similarly, let R3 and R4 be connected in parallel to give an effective resistance of RP2. Then, both of these parallel segments are connected in series (Figure 4.8).

Using equation (4.18), you get

$\frac{1}{Rp1} = \frac{1}{R1} + \frac{1}{R2}$

$\frac{1}{Rp} = \frac{1}{R3} + \frac{1}{R4}$

Finally, using equation (4.12), the net effective resistance is given by Rtotal= RP1 + RP2

Parallel Connection of Series Resistors

- If you consider a connection of a set of series resistors connected in a parallel circuit, you get a parallel-series circuit. Let R1 and R2 be connected in series to give an effective resistance of RS1. Similarly, let R3 and R4 be connected in series to give an effective resistance of RS2. Then, both of these serial segments are connected in parallel (Figure 4.9).

S.no	CRITERIA	SERIES	PARALLEL
1	Equivalent resistance	More than the highest resistance.	Less than the lowest resistance.
2	Amount of current	Current is less as effective resistance is more.	Current is more as effective resistance is less.
3	Switching ON/OFF	If one appliance is disconnected, others also do not work.	If one appliance is disconnected, others will work independently.

Using equation (4.12), you get

RS1 = R1 + R2, RS2 = R3 + R4

Finally, using equation (4.18), the net effective resistance is given by

$$\frac{1}{Rtotal} = \frac{1}{Rs1} + \frac{1}{Rs2}$$

Comparison between series and parallel connections

- The difference between series and parallel circuits may be summed as follows in Table 4.3

HEATING EFFECT OF CURRENT

- Have you ever touched the motor casing of a fan, which has been used for a few hours continuously? What do you observe? The motor casing is warm. This is due to the heating effect of current. The same can be observed by touching a bulb, which was used for a long duration. Generally, a source of electrical energy can develop a potential difference across a resistor, which is connected to that source. This potential difference constitutes a current through the resistor. For continuous drawing of current, the source has to continuously spend its energy. A part of the energy from the source can be converted into useful work and the rest will be converted into heat energy. Thus, the passage of electric current through a wire, results in the production of heat. This phenomenon is called heating effect of current. This heating effect of current is used in devices like electric heater, electric iron, etc.

Joule's Law of Heating

- Let 'I' be the current flowing through a resistor of resistance 'R', and 'V' be the potential difference across the resistor. The charge flowing through the circuit for a time interval 't' is 'Q'.

- The work done in moving the charge Q across the ends of the resistor with a potential difference of V is VQ. This energy spent by the source gets dissipated in the resistor as heat. Thus, the heat produced in the resistor is:

H = W = VQ

- You know that the relation between the charge and current is Q = I t. Using this, you get

H = V I t (4.19)

- From Ohm's Law, V = I R. Hence, you have

H = I2 R t (4.20)

- This is known as Joule's law of heating.

Joule's law of heating states that the heat produced in any resistor is:

- ✓ directly proportional to the square of the current passing through the resistor.
- ✓ directly proportional to the resistance of the resistor.
- ✓ directly proportional to the time for which the current is passing through the resistor.

Applications of Heating Effect

1. Electric Heating Device:

- The heating effect of electric current is used in many home appliances such as electric iron, electric toaster, electric oven, electric heater, geyser, etc. In these appliances Nichrome, which is an alloy of Nickel and Chromium is used as the heating element. Why? Because:

(i) it has high resistivity, (ii) it has a high melting point, (iii) it is not easily oxidized.

2. Fuse Wire:

- The fuse wire is connected in series, in an electric circuit. When a large current passes through the circuit, the fuse wire melts due to Joule's heating effect and hence the circuit gets disconnected. Therefore, the circuit and the electric appliances are saved from any damage. The fuse wire is made up of a material whose melting point is relatively low.

3. Filament in bulbs:

- In electric bulbs, a small wire is used, known as filament. The filament is made up of a material whose melting point is very high. When current passes through this wire, heat is produced in the filament. When the filament is heated, it glows and gives out light. Tungsten is the commonly used material to make the filament in bulbs.

Solved Problem-6

An electric heater of resistance 5 Ω is connected to an electric source. If a current of 6 A flows through the heater, then find the amount of heat produced in 5 minutes.

Solution:

- Given resistance R = 5 Ω, Current I = 6 A, Time t = 5 minutes = 5 × 60 s = 300 s

Amount of heat produced, H = I2Rt, H = 62 × 5 × 300. Hence, H = 54000 J

ELECTRIC POWER

- In general, power is defined as the rate of doing work or rate of spending energy. Similarly, the electric power is defined as the rate of consumption of electrical energy. It represents the rate at which the electrical energy is converted into some other form of energy.

Suppose a current 'I' flows through a conductor of resistance 'R' for a time 't', then the potential difference across the two ends of the conductor is 'V'. The work done 'W' to move the charge across the ends of the conductor is given by the equation (4.19) as follows:

$$W = V\ I\ t, \text{ Power } P = \frac{work}{\text{Time}} = \frac{VIt}{t}$$

P = V I (4.21)

- Thus, the electric power is the product of the electric current and the potential difference due to which the current passes in a circuit.

Unit of Electric Power

- The SI unit of electric power is watt. When a current of 1 ampere passes across the ends of a conductor, which is at a potential difference of 1 volt, then the electric power is

P = 1 volt × 1 ampere = 1 watt

- Thus, one watt is the power consumed when an electric device is operated at a potential difference of one volt and it carries a current of one ampere. A larger unit of power, which is more commonly used is kilowatt.

HORSE POWER:
The horse power (hp) is a unit in the foot-pound-second (fps) or English system, sometimes used to express the electric power. It is equal to 746 watt.

Consumption of electrical energy

- Electricity is consumed both in houses and industries. Consumption of electricity is based on two factors: (i) Amount of electric power and (ii) Duration of usage. Electrical energy consumed is taken as the product of electric power and time of usage. For example, if 100 watt of electric power is consumed for two hours, then the power consumed is 100 × 2 = 200 watt hour. Consumption of electrical energy is measured and expressed in watt hour, though its SI unit is watt second. In practice, a larger unit of electrical energy is needed. This larger unit is kilowatt hour (kWh). One kilowatt hour is otherwise known as one unit of electrical energy. One kilowatt hour means that an electric power of 1000 watt has been utilized for an hour. Hence,

1 kWh = 1000 watt hour = 1000 × (60 × 60) watt second = 3.6 × 106 J

DOMESTIC ELECTRIC CIRCUITS

- The electricity produced in power stations is distributed to all the domestic and industrial consumers through overhead and underground cables. The diagram, which shows the general scheme of a domestic electric circuit, is given in Figure 4.10.

- In our homes, electricity is distributed through the domestic electric circuits wired by the electricians. The first stage of the domestic circuit is to bring the power supply to the main-box from a distribution panel, such as a transformer. The important components of the main-box are: (i) a fuse box and (ii) a meter. The meter is used to record the consumption of electrical energy. The fuse box contains either a fuse wire or a miniature circuit breaker (MCB). The function of the fuse wire or a MCB is to protect the house hold electrical appliances from overloading due to excess current.

- You have learnt about a fuse wire in section 4.8.2. An MCB is a switching device, which can be activated automatically as well as manually. It has a spring attached to the switch, which is attracted by an electromagnet when an excess current passes through the circuit. Hence, the circuit is broken and the protection of the appliance is ensured. represents a fuse and an MCB.

- The electricity is brought to houses by two insulated wires. Out of these two wires,one wire has a red insulation and is called the 'live wire'. The other wire has a black insulation and is called the 'neutral wire'. The electricity supplied to your house is actually an alternating current having an electric potential of 220 V. Both, the live wire and the neutral wire enter into a box where the main fuse is connected with the live wire. After the electricity meter, these wires enter into the main switch, which is used to discontinue the electricity supply whenever required. After the main switch, these wires are connected to live wires of two separate circuits. Out of these two circuits, one circuit is of a 5 A rating, which is used to run the electric appliances with a lower power rating, such as tube lights, bulbs and fans. The other circuit is of a 15 A rating, which is used to run electric appliances with a high power rating, such as air-conditioners, refrigerators, electric iron and heaters.

- It should be noted that all the circuits in a house are connected in parallel, so that the disconnection of one circuit does not affect the other circuit. One more advantage of the parallel connection of circuits is that each electric appliance gets an equal voltage.

In India, domestic circuits are supplied with an alternating current of potential 220/230V and frequency 50 Hz. In countries like USA and UK, domestic circuits are supplied with an alternating current of potential 110/120 V and frequency 60 Hz.

Overloading and Shortcircuiting

- The fuse wire or MCB will disconnect the circuit in the event of an overloading and short circuiting. Over loading happens when a large number of appliances are connected in series to the same source of electric power. This leads to a flow of excess current in the electric circuit.

- When the amount of current passing through a wire exceeds the maximum permissible limit, the wires get heated to such an extent that a fire may be caused. This is known as overloading. When a live wire comes in contact with a neutral wire, it causes a 'short circuit'. This happens when the insulation of the wires get damaged due to temperature changes or some external force. Due to a short circuit, the effective resistance in the circuit becomes very small, which leads to the flow of a large current through the wires. This results in heating of wires to such an extent that a fire may be caused in the building.

Earthing

- In domestic circuits, a third wire called the earth wire having a green insulation is usually connected to the body of the metallic electric appliance. The other end of the earth wire is connected to a metal tube or a metal electrode, which is buried into the Earth. This wire provides a low resistance path to the electric current. The earth wire sends the current from the body of the appliance to the Earth, whenever a live wire accidentally touches the body of the metallic electric appliance. Thus, the earth wire serves as a protective conductor, which saves us from electric shocks.

LED BULB

- An LED bulb is a semiconductor device that emits visible light when an electric current passes through it. The colour of the emitted light will depend on the type of materials used. With the help of the chemical compounds like Gallium Arsenide and Gallium Phosphide, the manufacturer can produce LED bulbs that radiates red, green, yellow and orange colours. Displays in digital watches and calculators, traffic signals, street lights, decorative lights, etc., are some examples for the use of LEDs.

Seven Segment Display

- A 'Seven Segment Display' is the display device used to give an output in the form of numbers or text. It is used in digital meters, digital clocks, micro wave ovens, etc. It consists of 7 segments of LEDs in the form of the digit 8.These seven LEDs are named as a, b, c, d, e, f and g (Figure 4.12). An extra 8th LED is used to display a dot.

Merits of a LED bulb

1. As there is no filament, there is no loss of energy in the form of heat. It is cooler than the incandescent bulb.
2. In comparison with the fluorescent light, the LED bulbs have significantly low power requirement.
3. It is not harmful to the environment.
4. A wide range of colours is possible here.
5. It is cost-efficient and energy efficient.
6. Mercury and other toxic materials are not required.
One way of overcoming the energy crisis is to use more LED bulbs.

LED TELEVISION

- LED Television is one of the most important applications of Light Emitting Diodes. An LED TV is actually an LCD TV (Liquid Crystal Display) with LED display. An LED display uses LEDs for backlight andan array of LEDs act as pixels. LEDs emitting white light are used in monochrome (black and white) TV; Red, Green and Blue (RGB) LEDs are used in colour television. The first LED television screen was developed by James P. Mitchell in 1977. It was a monochromatic display. But, after about three decades, in 2009, SONY introduced the first commercial LED Television.

Advantages of LED television

- ❖ It has brighter picture quality.
- ❖ It is thinner in size.
- ❖ It uses less power and consumes very less energy.
- ❖ Its life span is more.
- ❖ It is more reliable.

Electronics

Unit – 10 COMMUNICATION SYSTEMS

MODULATION

The transmission of information through short distances does not require complicated techniques. The energy of the information signal is sufficient enough to be sent directly. However if the information, for example, audio frequency (20 to 20,000 Hz) needs tobe transmitted to long distances across the world, certain techniques are required to transmit the information without any loss. **For long distance transmission, the low frequency baseband signal (input signal) is superimposed onto a high frequency radio signal by a process called modulation.** In the modulation process, a very high frequency signal called carrier signal (radio signal) is used to carry the baseband signal. As the frequency of the carrier signal is very high, it can be transmitted to long distances with less attenuation. The carrier signal is usually a sine wave signal. Also, the carrier signal will be more compatible with the communication medium like free space and can propagate with greater efficiency.

A sinusoidal carrier wave can be represented as $e_c = E_c \sin (2\pi \nu_c t + \phi)$, where E_c is the amplitude, ν_c is the frequency and ϕ is the initial phase of the carrier wave at any instant of time t. Three characteristics in the carrier signal can be modified by the baseband signal during the process of modulation: amplitude, frequency and phase of the carrier signal. There are 3 types of modulation based on which parameter is modified. They are
(i) amplitude modulation,
(ii) frequency modulation and
(iii) phase modulation.

ITUDE MOD LATION (AM)

If t he amp itude of he car ier sig al is od fied in roortion to he ins antaneous amp itude of he bas band UNIsignal, then it is called amplitude modulation. Here the frequency and the phase of the carrier signal remain constant. Amplitude modulation is used in radio and TV broadcasting. The signal shown in Figure 10.1(a) is the baseband signal that carries information. Figure 10.1(b) shows the high-frequency carrier signal and Figure 10.1(c) gives amplitude modulated signal. We can see that amplitude of the carrier is modified in proportion to the amplitude of the baseband signal.

Advantages of AM

i) **Easy transmission and reception**
ii) Lesser bandwidth requirements
iii) Low cost
Limitations of AM

i) Noise level is high
ii) Low efficiency
iii) Small operating range

FREQUENCY MODULATION (FM)

The frequency of the carrier signal is modified in proportion to the instantaneous amplitude of the baseband signal in frequency modulation. Here the amplitude and the phase of the carrier signal remain constant. Increase in the amplitude of the baseband signal increases the frequency of the carrier signal and vice versa. This leads to compressions and rarefactions in the frequency spectrum of the modulated wave as shown in Figure 10.2. Louder signal leads to compressions and relatively weaker signals to rarefactions.

When the amplitude of the baseband signal is zero in Figure 10.2(a), the frequency of the modulated signal is the same as the carrier signal. The frequency of the modulated wave increases when the amplitude of the baseband signal increasesin the positive direction (A, C). The increase in amplitude in the negative half cycle (B, D) reduces the frequency of the modulated wave (Figure 10.2(c)).

When the frequency of the baseband signal is zero (no input signal), there is no change in the frequency of the carrier wave. It is at its normal frequency and is called as **centre frequency or resting frequency.** Practically this is the allotted frequency of the FM transmitter.

Advantages of FM

i) Large decrease in noise. This leads to an increase in signal-noise ratio.
ii) The operating range is quite large.
iii) The transmission efficiency is very high as all the transmitted power is useful.
iv) FM bandwidth covers the entire frequency range which humans can hear. Due to this, FM radio has better quality compared to AM radio.

Limitations of FM

i) FM requires a much wider channel.
ii) FM transmitters and receivers are more complex and costly.
iii) In FM reception, less area is covered compared to AM.

PHASE MODULATION (PM)

In phase modulation, the instantaneous amplitude of the baseband signal modifies the phase of the carrier signal keeping the amplitude and frequency constant (Figure 10.3). This modulation is used to generate frequency modulated signals. It is similar to frequency modulation except that the phase of the carrier is varied instead of varying frequency.

The carrier phase changes according to increase or decrease in the amplitude of the baseband signal. When the modulating signal goes positive, the amount of phase lead increases with the amplitude of the modulating signal. Due to this, the carrier signal is compressed or its frequency is increased.

On the other hand, the negative half cycle of the C baseband signal produces a phase lag in the carrier signal. This appears to have stretched the frequency of the carrier wave. Hence similar to frequency modulated wave, phase modulated wave also comprises of compressions and rarefactions. When the signal voltage is zero (A, C and E) the carrier frequency is unchanged.

„ If a square wave is used as the baseband signal, then phase reversal takes place in the modulated signal. FM and PM waves are completely different for square wave modulating signal.

The frequency shift in carrier wave frequency exists in phase modulation as well. The frequency shift depends on

(i) amplitude of the modulating signal and
(ii) the frequency of the signal.

Advantages of PM

i) FM signal produced from PM signal is very stable.
ii) The centre frequency called resting frequency is extremely stable.

Comparison between FM and PM
PM wave is similar to FM wave. PM generally uses a smaller bandwidth than FM. In other words, in PM, more information can be sent in a given bandwidth. Hence, phase modulation provides high transmission speed on a given bandwidth.

THE ELEMENTS OF AN ELECTRONIC COMMUNICATION SYSTEM

Electronics plays a major role in communication. Electronic communicationis nothing but the transmission of sound, text, pictures, or data through a medium. Long distance transmission uses free space as a medium. This section provides sufficient information on how voice signal is transmitted by a transmitter through space and received by the receiver at the receiving end.

Elements of an electronic communication system

The elements of the basic communication system are explained with the block diagram shown in Figure 10.4.

1. Information (Baseband or input signal)

Information can be in the form of speech, music, pictures, or computer data.This information is given as input to the input transducer.

2. Input transducer

A transducer is a device that converts variations in a physical quantity (pressure, temperature, sound) into an equivalent electrical signal or vice versa. In communication system, the transducer converts the information which is in the form of sound, music, pictures or computer data into corresponding electrical signals. **The electrical equivalent of the original information is called the baseband signal.** The best example for the transducer is the microphone that converts sound energy into electrical energy.

3. Transmitter

It feeds the electrical signal from the transducer to the communication channel. It consists of circuits such as amplifier,oscillator, modulator and power amplifier. The transmitter is located at the broadcasting station.

Amplifier: The transducer output is very weak and is amplified by the amplifier.

Oscillator: It generates high-frequency carrier wave (a sinusoidal wave) for long distance transmission into space. As the energy of a wave is proportional to its frequency, the carrier wave has very high energy.

Modulator: It superimposes the baseband signal onto the carrier signal and generates the modulated signal.

Power amplifier: It increases the power level of the electrical signal in order to cover a large distance.

4. Transmitting antenna

It radiates the radio signal into space in all directions. It travels in the form of electromagnetic waves with the velocity of light (3 × 108 m s–1).

5. Communication channel

Communication channel is used to carry the electrical signal from transmitter to receiver with less noise or distortion. The communication medium is basically of two types: wireline communication and wireless communication.

Wireline communication (point to point communication) uses mediums like wires, cables and optical fibers. These systems cannot be used for long distance transmission as they are connected physically. Examples are telephone, intercom and cable TV.

Wireless communication uses free space as a communication medium. The signals are transmitted in the form of electromagnetic waves with the help of a transmitting antenna. Hence wireless communication is used for long distance transmission. Examples are mobile, radio or TV broadcasting and satellite communication.

6. Noise

It is the undesirable electrical signal that interferes with the transmitted signal. Noise attenuates or reduces the quality of the transmitted signal. It may be man-made (automobiles, welding machines, electric motors etc.) or natural (lightning, radiation from sun and stars and environmental effects). Noise cannot be completely eliminated. However, it can be reduced using various techniques.

7. Receiver

The signals that are transmitted through the communication medium are received by a receiving antenna which converts em waves into RF signals and are fed into the receiver. The receiver consists of electronic circuits like demodulator, amplifier, detector etc. The demodulator extracts the basebandsignal from the modulated signal. Then the baseband signal is detected and amplified using amplifiers. Finally, it is fed to the output transducer.

8. Repeaters

Repeaters are used to increase the range or distance through which the signals are sent. It is a combination of transmitter and receiver. The signals are received, amplified and retransmitted with a carrier signal of different frequency to the destination. The best example is the communication satellite in space.

9. Output transducer

It converts the electrical signal back to its original form such as sound, music, pictures or data. Examples of output transducers are loudspeakers, picture tubes, computer monitor, etc.

10. Attenuation

The loss of strength of a signal while propagating through a medium is known as attenuation.

11. Range

It is the maximum distance between the source and the destination up to which the signal is received with sufficient strength.

BANDWIDTH

The frequency range over which the baseband signals or the information signals such as voice, music, picture etc is transmitted is known as bandwidth. Each of these signals has different frequencies.
The type of communication system depends on the nature of the frequency band for a given signal. Bandwidth gives the difference between the upper and lower frequency limits of the signal. It can also be defined as the portion of the electromagneticare the lower and upper-frequency limits of a signal, then the bandwidth, BW = $\nu 2 - \nu 1$.

BANDWIDTH OF TRANSMISSION SYSTEM

The range of frequencies required to transmit a piece of specified information in a particular channel is called channel bandwidth or the bandwidth of the transmission system. This corresponds to the spectrum that is assigned to be used by the system. For example, amplitude modulation system requires a channel bandwidth of 10 kHz to transmit a 5 kHz signal, whereas a single side-band system requires only a 5 kHz channel bandwidth for the same 5 kHz signal. This is because in amplitude modulation, the channel bandwidth is twice the signal frequency. Therefore, it is required to reduce the channel bandwidth to accommodate more number of channels in the available electromagnetic spectrum. In some applications, modulation is selected based on this.

ANTENNA SIZE

Antenna is used at both transmitter and receiver end. Antenna height is an important parameter to be discussed. The height of the antenna must be a multiple of$\frac{\lambda}{4}$.

$$\mathbf{h} = \frac{\lambda}{4}$$

where is wavelength ($\lambda = \frac{c}{v}$), c is the velocity of light and v is the frequency of thEsignal to be transmitted.

An example

Let us consider two baseband signals. One signal is modulated and the other is not modulated.

The frequency of the original baseband signal is taken as $\nu = 10\ kHz$ while the modulated signal is $\nu = 1\ MHz$.
The height of the antenna required to transmit the original baseband signal of frequency $\nu = 10\ kHz$ is

$$h_1 = \frac{\lambda}{4} = \frac{c}{4\nu} = \frac{3\times10^8}{4\times10\times10^3} = 7.5\,km$$

The height of the antenna required to transmit the modulated signal of frequency ν = 1 *MHz* is

$$h_2 = \frac{\lambda}{4} = \frac{c}{4\nu} = \frac{3\times10^8}{4\times1\times10^6} = 75\,m$$

PROPAGATION OF ELECTROMAGNETIC WAVES

Comparing equations (10.2) and (10.3), we can infer that it is practically feasible to construct an antenna of height 75 m while the one with 7.5 km is not possible. It clearly manifests that modulated signals reduce the antenna height and are required for long distance transmission.
The information signal modulated with the carrier wave (radio wave) is transmitted by an antenna. This travels through space and is received by the receiving antenna at the other end. The frequencies from 2 kHz to 400 GHz are transmitted through wireless communication. The strength of the electromagnetic wave keeps decreasing while traveling from transmitter to the receiver. The electromagnetic wave transmitted by the transmitter travels in three different modes to reach the receiver according to its frequency range:

- Ground wave propagation (or) surface wave propagation (nearly 2 kHz to 2 MHz)
- Sky wave propagation (or) ionospheric propagation (nearly 3 MHz to 30 MHz)
- Space wave propagation (nearly 30 MHz to 400 GHz)

GROUND WAVE PROPAGATION

If the electromagnetic waves transmitted by the transmitter glide over the surface of the earth to reach the receiver, then the propagation is called ground wave propagation. The corresponding waves are called ground waves or surface waves. The pictorial representation is shown in Figure 10.5(a).

Both transmitting and receiving antennas must be close to the earth. The size of the antenna plays a major role in deciding the efficiency of the radiation of signals.
During transmission, the electrical signals are attenuated over a distance. Some reasons for attenuation are as follows:

- **Increasing distance**: The attenuation of the signal with distance depends on (i) power of the transmitter (ii) frequency of the transmitter and (iii) condition of the Earth surface.

- **Absorption of energy by the Earth**: When the transmitted signal in the form of EM wave is in contact with the Earth, it induces charges in the Earth and constitutes a current. Due to this, the Earth behaves like a leaky capacitorwhich leads to the attenuation of the wave.

• **Tilting of the wave:** As the wave progresses, the wavefront starts gradually tilting according to the curvature of the Earth. This increase in the tilt decreases the electric field strength of the wave. Finally at some distance, the surface wave dies out due to energy loss.The frequency of the ground waves is mostly less than 2 MHz as high frequency waves undergo more absorption of energy at the earth's atmosphere. The medium wave signals received during the day time use surface wave propagation.

It is mainly used in local broadcasting, radio navigation, for ship-to-ship, ship- to-shore communication and mobile communication.

SKY WAVE PROPAGATION

The mode of propagation in which the electromagnetic waves radiated from an antenna, directed upwards at large angles, gets reflected by the ionosphere back to earth is called sky wave propagation or ionospheric propagation. The corresponding waves are called sky waves (Figure 10.5(b)).

The frequency range of EM waves in this mode of propagation is 3 to 30 MHz. EM waves of frequency more than 30 MHz can easily penetrate through the ionosphere and does not undergo reflection. It is used for short wave broadcast services. Medium and high frequencies are for long-distance radio communication. Extremely long-
distance communication is also possible as the radio waves can undergo multiple reflections between the earth and the ionosphere. A single reflection helps the radio waves to travel a distance of approximately 4000 km.

Ionosphere acts as a reflecting surface. It is at a distance of approximately 50 km and spreads up to 400 km above the Earth surface. Due to the absorption ofultraviolet rays, cosmic ray, and other high energy radiations like α, β rays from sun, the air molecules in the ionosphere get ionized. This produces charged ions and these ions provide a reflecting medium for the reflection of radio waves or communication waves back to Earth within the permitted frequency range. The phenomenon of bending the radio waves back to earth is nothing but the total internal reflection.

This is the reason why the EM waves are transmitted at a critical angle to ensure that the waves undergo total reflection and reaches the ground without escaping into space.

The shortest distance between the transmitter and the point of reception of the sky wave along the surface is called as the skip distance shown in Figure 10.5(b).

The electromagnetic waves are transmitted from the ground at particular angles. When the angle of emission increases, the reception of ground waves decreases. At one point, there will be no reception due to ground waves and marked as A in the Figure 10.5(b). If the angle of emission is increased further, the reception of sky waves starts at point B in the Figure 10.5(b). **There is a zone (in between A and B) where there is no reception of electromagnetic waves neither ground nor sky, called as skip zone or skip area.**

The higher the frequency, higher is the skip distance and for a frequency less than the critical frequency, skip distance is zero.

SPACE WAVE PROPAGATION

The process of sending and receiving information signal through space is called space wave communication (Figure 10.5(c)). **The electromagnetic waves of very high frequencies above 30 MHz are called as space waves.** These waves travel in a straight line from the transmitter to the receiver. Hence, it is used for a line of sight communication (LOS).

For high frequencies, the transmission towers must be high enough so that the transmitted and received signals (direct waves) will not encounter the curvature of the Earth and hence travel with less attenuation and loss of signal strength. Certain waves reach the receiver after getting reflected from the ground.

The communication systems like television telecast, satellite communication and RADAR are based on space wave propagation. Microwaves having high frequencies (super high frequency band) are used against radio waves due to certain advantages: larger bandwidth, high data rates, better directivity, small antenna size, low power consumption, etc.

The range or distance (d) of coverage of the propagation depends on the height (h) of the antenna given by the equation,

$$d = \sqrt{2Rh}$$

where R is the radius of the Earth and it is 6400 km.
The distance of coverage is shown pictorially in Figure 10.6.

EXAMPLE 10.1

A transmitting antenna has a height of 40 m and the height of the receiving antenna is 30 m. What is the maximum distance between them for line-of-sight communication? The radius of the earth is 6.4×106 m.

Solution:

The total distance d between the transmitting and receiving antennas will be the sum of the individual distances of coverage.

$$d = d_1 + d_2$$
$$= \sqrt{2Rh_1} + \sqrt{2Rh_2}$$
$$= \sqrt{2R}\left(\sqrt{h_1} + \sqrt{h_2}\right)$$
$$= \sqrt{2 \times 6.4 \times 10^6} \times \left(\sqrt{40} + \sqrt{30}\right)$$
$$= 16 \times 10^2 \sqrt{5} \times (6.32 + 5.48)$$
$$= 42217\, m = 42.217\, km$$

SATELLITE COMMUNICATION

The satellite communication is a mode of communication of signal between transmitter and receiver via satellite. The message signal from the Earth station is transmitted to the satellite on board via an uplink (frequency band 6 GHz), amplified by a transponder and then retransmitted to another Earth station via a downlink (frequency band 4 GHz) (Figure 10.7).

The high-frequency radio wave signals travel in a straight line (line of sight) may come across tall buildings or mountains or even encounter the curvature of the earth. A communication satellite relays and amplifies such radio signals via transponder to reach distant and far off places using uplinks and downlinks. It is also called as a radio repeater in sky. The applications are found to be in all fields and are discussed below.

Applications

Satellites are classified into different types based on their applications. Some satellites are discussed below.

i) **Weather Satellites:** They are used to monitor the weather and climate of Earth. By measuring cloud mass, these satellites enable us to predict rain and dangerous storms like hurricanes, cyclones etc.

ii) **Communication satellites:** They are used to transmit television, radio, internet signals etc. Multiple satellites are used for long distances.
iii) **Navigation satellites:** These are employed to determine the geographic location of ships, aircrafts or any other object.

FIBRE OPTIC COMMUNICATION

The method of transmitting information from one place to another in terms of light pulses through an optical fiber is called fiber optic communication. It works under the principle of total internal reflection.Light has very high frequency (400 THz – 790 THz) than microwave radio systems. The fibers are made up of silica glass or silicon dioxide which is highly abundant on Earth.

Now it has been replaced with materials such as chalcogenide glasses, fluoroaluminate crystalline materials because they provide larger infrared wavelength and better transmission capability.
As fibers are not electrically conductive, it is preferred in places where multiple channels are to be laid and isolation is required from electrical and electromagnetic interference.

Applications

Optical fiber system has a number of applications namely, international communication, inter-city communication, data links, plant and traffic control and defense applications.

Merits

i) Fiber cables are very thin and weigh lesser than copper cables.
ii) This system has much larger band width. This means that its information carrying capacity is larger.
iii) Fiber optic system is immune to electrical interferences.
iv) Fiber optic cables are cheaper than copper cables.

Demerits

i) Fiber optic cables are more fragile when compared to copper wires.
ii) It is an expensive technology.

Fiber optic cables provide the fastest transmission rate compared to any other form of transmission. It can provide data speed of 1 Gbps for homes and business. Multimode fibers operate at the speed of 10 Mbps. Recent developments in optical communication provide the data speed at the rate of 25 Gbps

Most transatlantic telecommunication cables between the United States of America and Europe are fiber optic.

RADAR AND APPLICATIONS

Radar basically stands for Radio Detection and Ranging System. It is one of the important applications of communication systems and is mainly used to sense, detect, and locate distant objects like aircraft, ships, spacecraft, etc. The angle, range or velocity of the objects that are invisible to the human eye can be determined.

Radar uses electromagnetic waves for communication. The electromagnetic signal is initially radiated into space by an antenna in all directions. When this signal strikes the targeted object, it gets reflected or reradiated in many directions. This reflected (echo) signal is received by the radar antenna which in turn is delivered to the receiver. Then, it is processed and amplified to determine the geographical statistics of the object. The range is determined by calculating the time taken by the signal to travel from RADAR to the target and back.

Applications

Radars find extensive applications in almost all fields. A few are mentioned below.

i) In military, it is used for locating and detecting the targets.
ii) It is used in navigation systems such as ship borne surface search, air search and missile guidance systems.

iii) To measure precipitation rate and wind speed in meteorological observations, Radars are used.

iv) It is employed to locate and rescue people in emergency situations.

MOBILE COMMUNICATION

Mobile communication is used to communicate with others in different locations without the use of any physical connection like wires or cables. It allows the transmission over a wide range of area without the use of the physical link. It enables the people to communicate with each other regardless of a particular location like office, house etc. It also provides communication access to remote areas.

It provides the facility of roaming – that is, the user may move from one place to another without the need of compromising on the communication. The maintenance and cost of installation of this communication network are also cheap.

Applications

i) It is used for personal communication and cellular phones offer voice and data connectivity with high speed.
ii) Transmission of news across the globe is done within a few seconds.
iii) Using Internet of Things (IoT), it is made possible to control various devices from a single device. Example: home automation using a mobile phone.
iv) It enables smart classrooms, online availability of notes, monitoring student activities etc. in the field of education.

Recently, the mobile communication technology has evolved through various stages like 2G, 3G, 4G, 5G, WiMAX, Wibro, EDGE, GPRS and many others. This helps to increase the speed of communication and the range of coverage. The connectivity issues have decreased with reliable and secure connections. The GPS (Global Positioning System) and GSM (Global System for Mobile communication) technology play an important role in mobile communication. This increases the utilization of bandwidth of the network, sharing of the networks, error detections, etc. Many methods like digital switching, TDMA, CDMA have been used to ease the communication process.

INTERNET

Internet is a fast growing technology in the field of communication system with multifaceted tools. It provides new ways and means to interact and connect with people. Internet is the largest computer network recognized globally that connects millions of people through computers. It finds extensive applications in all walks of life.

To store all the information available on the internet, you would need over 1 billion DVDs or 200 million Blu-ray discs.

Applications:

i) **Search engine:** The search engine is basically a web-based service tool used to search for information on World Wide Web.
ii) **Communication:** It helps millions of people to connect with the use of social networking: emails, instant messaging services and social networking tools.
iii) **E-Commerce:** Buying and selling of goods and services, transfer of funds are done over an electronic network.

GLOBAL POSITIONING SYSTEM

GPS stands for Global Positioning System. It is a *global* navigation satellite system that offers geolocation and time information to a GPS receiver anywhere on or near the Earth.

GPS system works with the assistance of a satellite network. Each of these satellites broadcasts a precise signal like an ordinary radio signal. These signals that convey the location data are received by a low-cost aerial which is then translated by the GPS software. The software is able to recognize the satellite, its location, and the time taken by the signals to travel from each satellite. The software then processes the data it accepts from each satellite to estimate the location of the receiver.

Applications

Global positioning system is highly useful many fields such as fleet vehicle management (for tracking cars, trucks and buses), wildlife management (for counting of wild animals) and engineering (for making tunnels, bridges etc).

APPLICATION OF INFORMATION AND COMMUNICATION TECHNOLOGY IN AGRICULTURE, FISHERIES AND MINING

(i) Agriculture

The implementation of information and communication technology (ICT) in agriculture sector enhances theproductivity, improves the living standards of farmers and overcomes the challenges and risk factors.

a) ICT is widely used in increasing food productivity and farm management.

b) It helps to optimize the use of water, seeds and fertilizers etc.

c) Sophisticated technologies that include robots, temperature and moisture sensors, aerial images, and GPS technology can be used.

d) Geographic information systems are extensively used in farming to decide the suitable place for the species to be planted.

(ii) Fisheries

a) Satellite vessel monitoring system helps to identify fishing zones.
b) Use of barcodes helps to identify time and date of catch, species name, quality of fish.

(iii) Mining

a) ICT in mining improves operational efficiency, remote monitoring and disaster locating system.

b) Information and communication technology provides audio-visual warning to the trapped underground miners.

c) It helps to connect remote sites.