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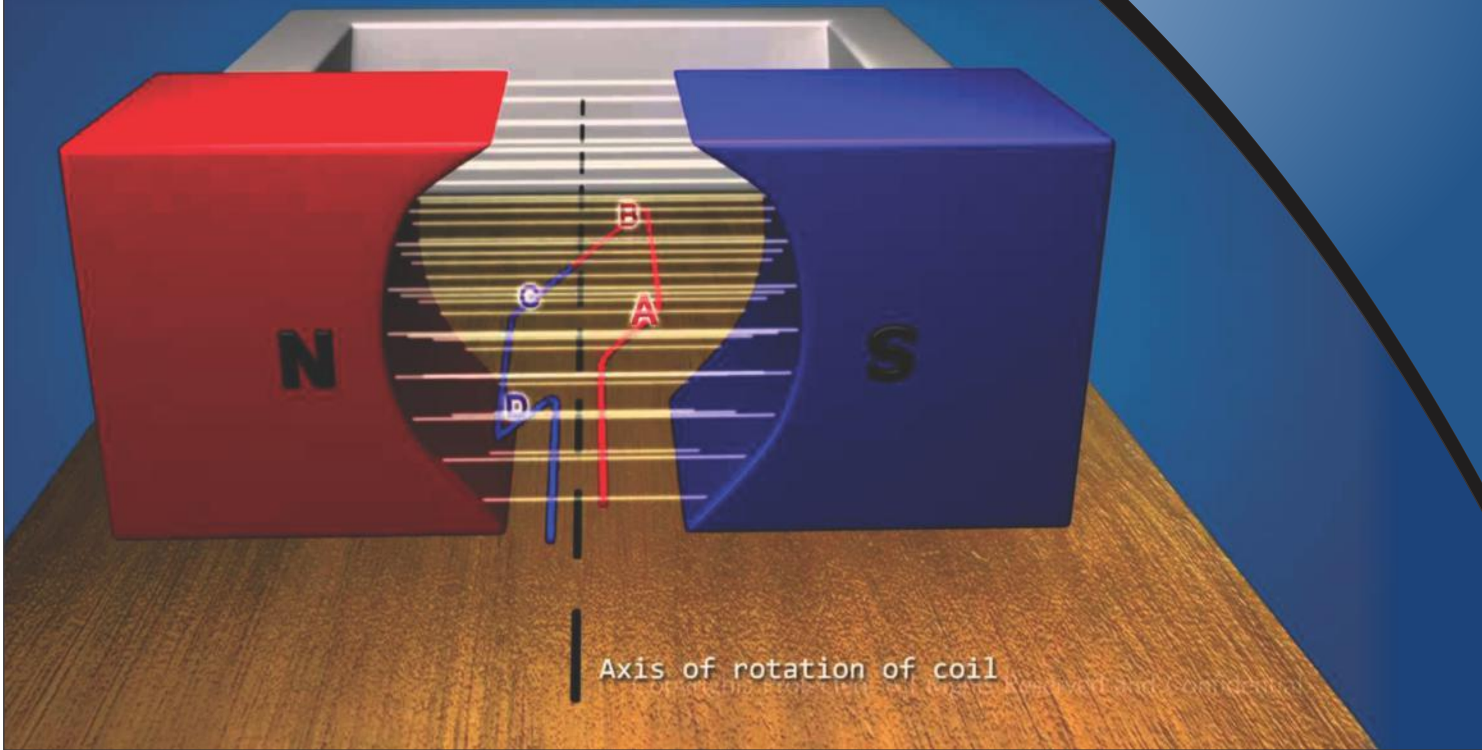
CHAPTER 4

Magnetic Effects of Electric Current



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INTRODUCTION

The term magnetism comes from Magnesia, the name of an ancient city in Asia Minor, where the Greeks found certain very unusual stones more than 2000 years ago. These stones, called lodestones, possess the unusual property of attracting pieces of iron. Such magnets were first fashioned into compasses and used navigation by the Chinese in the twelfth century A.D.

In the sixteenth century, William Gilbert, Queen Elizabeth's physician, made artificial magnets by rubbing pieces of iron against lodestones. He suggested that a compass always points north and south because the earth itself shows the magnetic properties. Later in 1750, John Michaell in England found that magnetic poles obey the inverse-square law, and his results were confirmed by Charles Coulomb. The subjects of magnetism and electricity developed almost independently until 1820, when a Danish physicist named Hans Christian Oersted discovered, in a classroom demonstration, that an electric current affects a magnetic compass. He saw that magnetism was related to electricity. Shortly thereafter, the French physicist Andre Marie Ampere proposed that electric currents are the source of all magnetic phenomena. This chapter is all about how electricity is connected with magnetism. The branch of physics which deals with the magnetism produced due to electric current is called **electromagnetism.**

OERSTED EXPERIMENT

Magnetic effect of electric current means-an electric current flowing in a conductor produces a magnetic field in the space around it. In 1820, **Hans Christian Oersted** Showed that electricity and magnetism are related phenomena.
Oersted discovered a magnetic field around a conductor carrying electric current.

(a) A magnet at rest produces a magnetic field around it while an electric charge at rest produces an electric field around it.
(b) A current carrying conductor has a magnetic field and not an electric field around it. On the other hand, a charge moving with a uniform velocity has an electric as well as a magnetic field around it.
(c) An electric field cannot be produced without a charge whereas a magnetic field can be produced without a magnet.
(d) No poles are produced in a coil carrying current but such a coil shows north and south polarities.

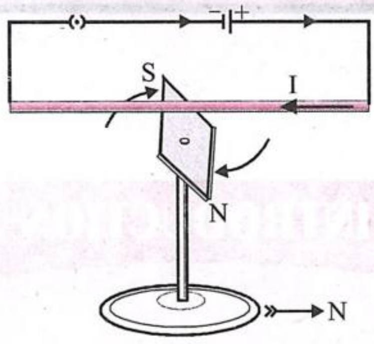
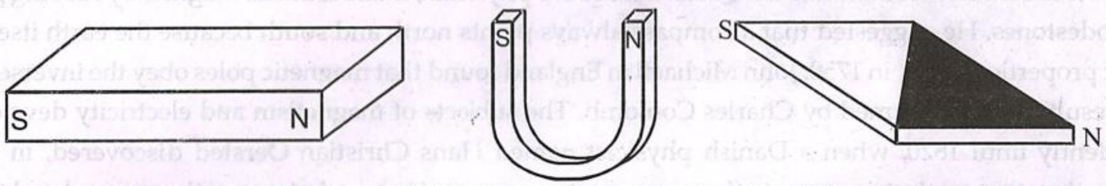


Fig.4.1

(e) All oscillating or an accelerated charge produces E.M. waves also in addition to electric and magnetic fields.

ARTIFICIAL MAGNETS

Magnets produced from magnetic materials are called artificial magnets. They can be made in a variety of shapes and sizes and are used extensively in electrical apparatus.



(a) Bar magnet (b) U-shape or horseshoe magnet (c) Magnetic-needle

Fig. 4.2

Artificial magnets are generally made from special iron or steel alloys which are usually magnetized electrically. The material to be magnetized is inserted into a coil of insulated wire and a heavy flow of electrons is passed through the wire. Magnets can also be produced by stroking a magnetic material with magnetite or with another artificial magnet. The forces causing magnetization are represented by magnetic lines of force.

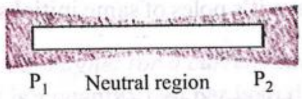
Artificial magnets are usually classified as permanent or temporary, depending on their ability to retain their magnetic properties after the magnetizing force has been removed. Magnets made from substances, such as hardened steel and certain alloys which retain a great deal of their magnetism, are called permanent magnets. These materials are relatively difficult to magnetize because of the opposition offered to the magnetic lines of force as the lines of force try to distribute themselves throughout the material. The opposition that a material offers to the magnetic lines of force is called **reluctance**. All permanent magnets are produced from materials having a high reluctance.

A material with a low reluctance, such as soft iron or annealed silicon steel, is relatively easy to magnetize but will retain only a small part of its magnetism once the magnetizing force is removed. Materials of this type that easily lose most of their magnetic strength are called temporary magnets. The amount of magnetism which remains in a temporary magnet is referred to as its residual magnetism. The ability of a material to retain an amount of residual magnetism is called the **retentivity** of the material. Magnets are also described in terms of the **permeability** of their materials, or the ease with which magnetic lines of force distribute themselves throughout the material. A permanent magnet, which is produced from a material with a high reluctance, has a low permeability. A temporary magnet, produced from a material with a low reluctance, would have a high permeability.

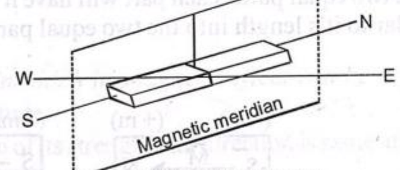
PROPERTIES OF MAGNETS

(1) Attractive property and poles : When a magnet is dipped into iron fillings it is found that the concentration of iron filings, i.e., attracting power of the magnet is maximum at two points near the ends and minimum at the centre. The places in a magnet where its attracting power is maximum are called poles while the place of minimum attracting power is called the neutral region.

(2) Directive property and N-S poles : When magnet is suspended its length becomes parallel to N-S direction. The pole pointing north is called the north (N) pole while the other pointing south is called the south (S) pole.



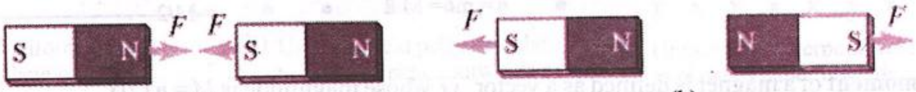
(a) Attractive Property



(b) Directive-Property

Fig. 4.3

(3) Opposite poles (N and S) attract and like poles (N and N, or S and S) repel one another.

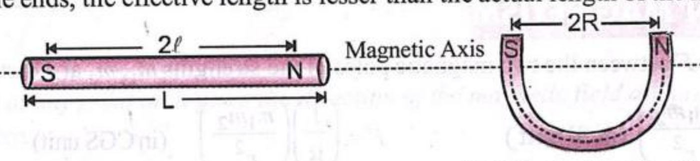


(a) (b)

Fig. 4.4

The line joining the two poles of a magnet is called **magnetic axis** and the vertical plane passing through the axis of a freely suspended or pivoted magnet is called **magnetic meridian.**

Magnetic Length (2ℓ) : The distance between two poles along the axis of a magnet is called its effective or magnetic length. As poles are not exactly at the ends, the effective length is lesser than the actual length of the magnet.



(a) Effective length = $2l$
Actual length = L

(b) Effective length = 2R
Actual length = πR

Fig. 4.5

(4) Poles exist in pairs : In a magnet the two poles are found to be equal in strength and opposite in nature. If a magnet is broken into number of pieces, each piece becomes a magnet with two equal and opposite poles. This shows that monopoles do not exist.

(a) (b)

Fig. 4.6

(5) Repulsion is a sure test of polarity : A pole of a magnet attracts the opposite pole while repels similar pole. A sure test of polarity is repulsion and not attraction, as attraction can take place between opposite poles or a pole and a piece of unmagnetised magnetic material due to 'induction effect'.

(6) Magnetic induction : A magnet attracts certain other substances through the phenomenon of magnetic induction i.e., by inducing opposite pole in a magnetic material on the side facing it as shown in fig.

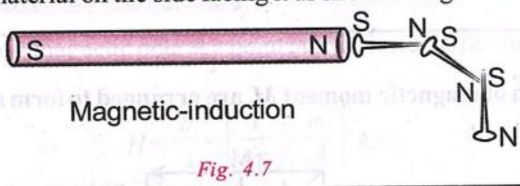


Fig. 4.7

Interesting Fact

Seeds of two tomatoes varieties Rocco and Monza were treated by passing them through an artificial magnetic field (MF) with a constant defined velocity before seeding. The seedlings obtained from MF treated and non MF-treated seeds were planted into the MF treated and non MF-treated plots. They were irrigated by MF-treated and non MF treated water.

Observations were made on early-yield, total-yield, beginning of blooming, and quality of fruit. While significant differences were not observed in Rocco, important MF effects were clearly seen on Monza. Yield increases on Monza in magnet treated plots were around 28–51 percent, especially in early yields, and Monza bloomed three-four days earlier.

CONNECTING TOPIC

POLE STRENGTH AND MAGNETIC MOMENT OF A MAGNET

The strength of attracting a magnetic material by a magnetic pole is measured by pole strength, generally denoted by *m*. The north and south poles of a magnet are said to be associated with the pole strengths $+m$ and $-m$, respectively, each of which is a scalar, having the **dimensional formula** $[M^oLT^oA]$ and **SI unit** Am.

Each pole strength is imagined to be distributed over the entire cross-section of the magnet. Therefore, if the magnet is cut along it's length into the two equal parts, each part will have it's poles of the strengths $+m/2$ and $-m/2$, respectively, and if the magnet is cut perpendicular to it's length into the two equal parts, each part will have it's poles of same initial strengths $+m$ and $-m$, respectively.

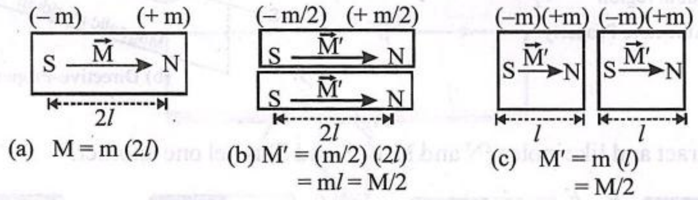


Fig. 4.8

The **magnetic moment** of a magnet is defined as a vector $\overrightarrow{M}$ whose magnitude is $M = n\,(2l)$

where *m* is the pole strength of magnet and $2l$ is the effective length of magnet and whose direction is from the south pole to the north pole. It has the **dimensional formula** $[M^oL^2T^oA]$ and **SI unit** Am^2.

If the magnet is cut along it's length, or perpendicular to its length, into the two equal parts, each part will have it's magnetic moment of magnitude one-half of that of the original magnetic moment, as shown above.

COULOMB'S LAW IN MAGNETISM

This law defines the force *F* between the two magnetic poles of the strengths m_1, m_2 at a distance *r* apart in a medium as

$$F = \left(\frac{\mu}{4\pi}\right)\left(\frac{m_1 m_2}{r^2}\right) \text{ (in SI unit)} \qquad F = \left(\frac{1}{\mu}\right)\left(\frac{m_1 m_2}{r^2}\right) \text{ (in CGS unit)}$$

where μ is the permeability of medium and $\mu = \mu_0 = 4\pi \times 10^{-7}\ N/A^2$ in SI and $\mu = \mu_0 = 1$ (unitless) in CGS. Evidently, the force *F* is directly proportional to the product of the pole strengths and inversely proportional to the square of the distance *r*. It acts along the line joining the two magnetic poles. It is attractive for the unlike magnetic poles and repulsive for the like magnetic poles. It depends on the medium in which the magnetic poles are situated.

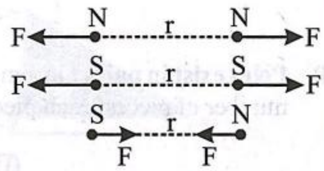


Fig. 4.9

ILLUSTRATION : 4.1

Four identical bar magnets, each of magnetic moment *M*, are arranged to form a square, as shown. Calculate the resultant magnetic moment of the system.

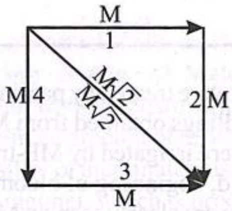


Fig. 4.10

SOLUTION :

The magnetic moments of the given four identical bar magnets are acting along the sides of a square, as shown. The resultant of each of the two pairs of magnetic moments, *i.e.*, (1, 4) and (2, 3), is $M\sqrt{2}$ and it is represented by the same diagonal of the square.

Therefore, the resultant of all the four magnetic moments, taken together, is $2\sqrt{2}M$, which is acting along the diagonal.

MAGNETIC FIELD AND MAGNETIC FIELD LINES

Magnetic Field

The space around a magnet (or a current carrying conductor) in which its magnetic effect can be experienced is called the magnetic field. It is a quantity that has both direction and magnitude.

The magnetic field in a region is said to be uniform if the magnitude of its strength and direction is same at all points in that region.

(a) Uniform field in plane of paper (b) Uniform field perpendicular to plane of paper outwards (c) Uniform field perpendicular to plane of paper inwards

Fig. 4.11

The strength of magnetic field is also known as magnetic induction or magnetic flux density.
The **SI unit** of strength of magnetic field is tesla (T)
1 tesla = 1 newton ampere^{-1} metre^{-1} (NA^{-1}m^{-1}) = 1 weber metre^{-2} (Wb m^{-2})
The **cgs unit** is gauss (G), 1 gauss (G) = 10^{-4} tesla (T).

Magnetic Field Lines

A line such that the tangent at any point on it gives the direction of the magnetic field at that point is called a magnetic field line or magnetic lines of force.

Properties of Magnetic Field Lines

(i) All field lines are closed curves. They come out of the magnet from the side of the north pole and go into it on the side of the south pole. They continue inside the magnet.
(ii) The field lines are close together near the poles and spread out away from them.
(iii) Two field lines never intersect each other.

ACTIVITY: Mapping of Magnetic Lines of Force

- Fix a sheet of white paper on a drawing board using some adhesive material. • Place a bar magnet in the centre of it.
- Sprinkle some iron filings uniformly around the bar magnet. A salt-sprinkler may be used for this purpose.
- Now tap the board gently. The iron filings rearrange themselves in the form of curves.

The curves represent the magnetic lines of force.

MAGNETIC FIELD DUE TO MAGNETIC POLE

In SI, the magnetic induction B due to a magnetic pole at a point at a distance *r* is defined as the force per unit north pole placed there, having the magnitude

$$B=\left(\frac{\mu}{4\pi}\right)\left(\frac{m}{r^2}\right) \text{ tesla} \quad \Rightarrow \quad H=\frac{B}{\mu}=\left(\frac{1}{4\pi}\right)\left(\frac{m}{r^2}\right) \text{ A/m}$$

And direction away for north pole and towards for the south pole.

In CGS, the magnetic field intensity $\vec{H}$ due to a magnetic pole at a point at a distance *r* is defined as the force per unit north pole placed there, having the magnitude

$$H=\left(\frac{1}{\mu}\right)\left(\frac{m}{r^2}\right) \text{ oersted} \Rightarrow B=\mu H=\left(\frac{m}{r^2}\right) \text{ gauss}$$

And direction away for the north pole and towards for the south pole.

FORCE ON MAGNETIC POLE PLACED IN MAGNETIC FIELD

In SI, the force on a magnetic pole of strength *m* placed in a magnetic field $\vec{B}$ is $\vec{F}=\pm m\vec{B}$

where + sign is for the north pole and – sign is for the south pole. Thus, the force is in the direction of $\vec{B}$ for the north pole and in the opposite direction for the south pole

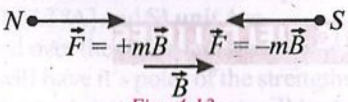


Fig. 4.12

In CGS, the force on a magnetic pole of strength *m* placed in a magnetic field $\vec{H}$ is $\vec{F}=\pm m\vec{H}$

where + sign is for the north pole and – sign is for the south pole. Thus, the force is in the direction of $\vec{H}$ for the north pole and in the opposite direction for the south pole.

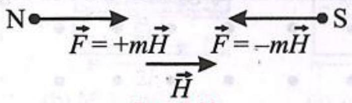


Fig. 4.13

CONNECTING TOPIC

BIOT-SAVART LAW

The Biot-Savart law defines the magnetic field $\vec{B}$ due to a current distribution. Let us consider a line distribution of steady current I confined to a filamentary wire ST. The wire may be imagined to be subdivided into the many elementary parts, each characterised by a vector $d\vec{l}$ whose magnitude is equal to the length of elementary part and whose direction is that of the current, as shown.

The magnetic field at a point P due to an elementary part is $d\vec{B} = \left(\frac{\mu_0 I}{4\pi}\right)\left(\frac{d\vec{l}\times\vec{R}}{R^3}\right)$

where $\vec{R}$ is the position vector of point P with respect to the elementary part. This magnetic field has the magnitude

$dB = \left(\frac{\mu_0 I}{4\pi}\right)\left(\frac{dl\sin\theta}{R^2}\right)$ this is **Biot-savart's law**

And the direction of the cross product $(d\vec{l}\times\vec{R})$, i.e., inwards and perpendicular to the plane of figure, as shown. The magnetic field $\vec{B}$ at the point P due to the complete wire ST is obtained by performing a summation process over all the elementary parts.

The direction of $\vec{B}$ will be the same as that of an elementary magnetic field $d\vec{B}$.

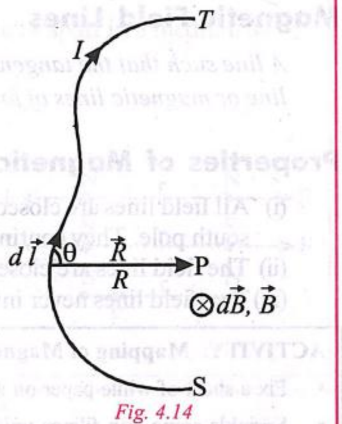


Fig. 4.14

MAGNETIC FIELD DUE TO A CURRENT CARRYING CONDUCTOR

From Oersted experiment followed by Ampere we can conclude that a magnetic field is developed around a conductor when electric current is passed through it. This observation is called magnetic effect of electric current. The presence of a current in a wire near a magnetic compass affect the direction of the compass needle. We now know that current gives rise to magnetic fields, just as electric charge give rise to electric fields.

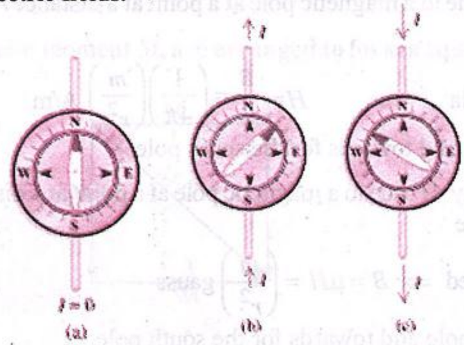


Fig. 4.15 : Compass near a current-carrying wire

Magnetic Field due to a Current Through a Straight Conductor

The magnetic field around a conductor carrying current is in the form of closed circular loops, in a plane perpendicular to the conductor, and is given by right hand thumb rule.

Right Hand Thumb Rule

If we grasp the conductor in the palm of the right hand so that the thumb points in the direction of the flow of current, then the direction in which the fingers curl, gives the direction of magnetic field lines.

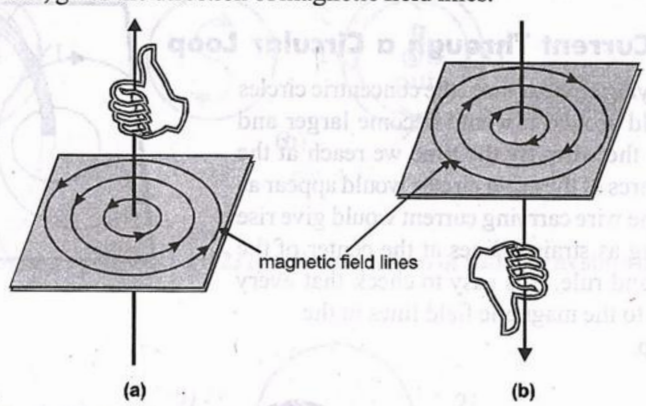


Fig. 4.16

For the current flowing through the conductor in the direction shown in figures (a) or (b), the rule predict that magnetic field lines will be in anticlockwise direction, when seen from above.
This rule is also called Maxwell's corkscrew rule. If we consider ourselves driving a corkscrew in the direction of the current, then the direction of the corkscrew is the direction of the magnetic field.

Ampere's Swimming Rule

Imagine a man swimming along the wire, in the direction of current, (such that the current enters at his feet and leaves him at his head) and facing towards a compass needle placed underneath the wire, then the magnetic field produced is such that the north pole of the compass needle gets deflected towards his left hand.

ILLUSTRATION : 4.2

Compute the magnetic field at a point of 9 cm from the long straight wire carrying a current of 6A.

SOLUTION :

Here, $a = 9\text{ cm} = 9 \times 10^{-2} m, I = 6A, B = ?$

$$B = \frac{\mu_0 I}{2\pi a} = \frac{4\pi \times 10^{-7} \times 6}{2\pi \times 9 \times 10^{-2}} = 1.33 \times 10^{-5}\text{T}$$

Magnetic Field Due to a Current Through a Circular Loop

At every point of a current-carrying circular loop, the concentric circles representing the magnetic field around it would become larger and larger as we move away from the wire. By the time we reach at the centre of the circular loop, the arcs of these big circles would appear as straight lines. Every point on the wire carrying current would give rise to the magnetic field appearing as straight lines at the center of the loop. By applying the right hand rule, it is easy to check that every section of the wire contributes to the magnetic field lines in the same direction within the loop.

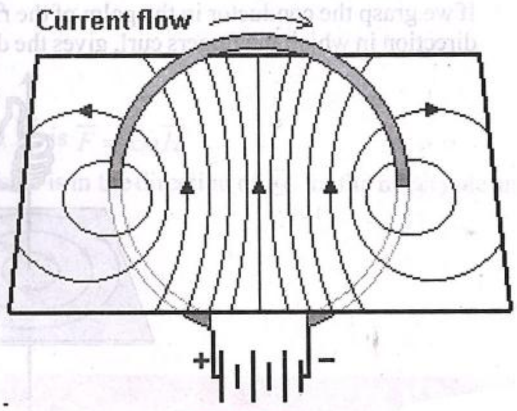


Fig. 4.19

RIGHT HAND PALM RULE

If we hold the thumb of right hand mutually perpendicular to the grip of the fingers such that the curvature of the finger represents the direction of current in the wire loop, then the thumb of the right hand will point in the direction of magnetic field near the centre of the current loop.

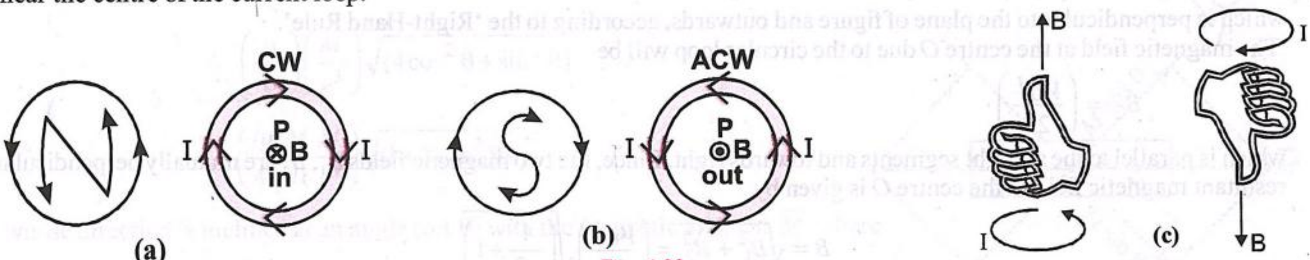


Fig. 4.22

ILLUSTRATION : 4.3

An infinite straight conductor carrying current $2I$ is split into a loop of radius r as shown in figure. The magnetic field at the centre of the coil is

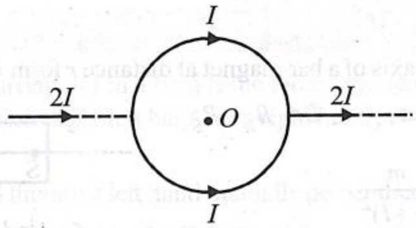


Fig. 4.23

(a) Zero (b) $\frac{\mu_0 I}{2}$ (c) $\mu_0 I$ (d) $2\mu_0 I$

SOLUTION :

(a) Here, the wire does not produce any magnetic field at O because the conductor lies on the line of O. Also, the loop does not produce magnetic field at O.

ILLUSTRATION : 4.4

A current of I ampere flows in a wire forming a circular arc of radius r metres subtending an angle θ at the centre as shown. what will be the magnetic field at the centre O in tesla?

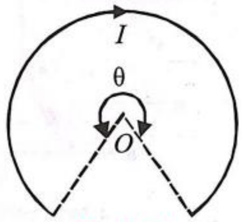


Fig. 4.24

SOLUTION :

Magnetic field at the centre 'O' $B = \frac{\mu_0 I}{2r} \times \frac{\theta}{2\pi} = \frac{\mu_0 I\theta}{4\pi r}$

ILLUSTRATION : 4.5

A long conducting wire, carrying a current I, is arranged in the shape, as shown, with the two straight segments in the plane of figure and the circular loop of radius r perpendicular to the plane of figure. Calculate the magnetic field at the centre O of the circular loop.

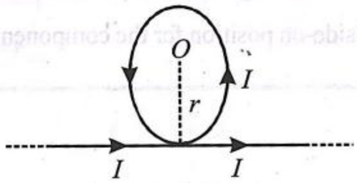


Fig. 4.25

SOLUTION :

The magnetic field at the centre O of the circular loop due to the two straight segments, taken together, will be

$$B_1 = 2\left(\frac{\mu_0 I}{4\pi r}\right)$$

which is perpendicular to the plane of figure and outwards, according to the 'Right-Hand Rule'.

The magnetic field at the centre O due to the circular loop will be

$$B_2 = \left(\frac{\mu_0 I}{2r}\right)$$

which is parallel to the straight segments and towards right. Since, the two magnetic fields B_1, B_2 are mutually perpendicular, the resultant magnetic field at the centre O is given by

$$B = \sqrt{B_1^2 + B_2^2} = \left(\frac{\mu_0 I}{2r}\right)\sqrt{\left(\frac{1}{\pi^2}+1\right)}$$

CONNECTING TOPIC

MAGNETIC FIELD DUE TO A BAR MAGNET

End-on Position

The magnetic field $\vec{B}$ at a point P on the axis of a bar magnet at distance r form it's mid point O is given by

$$\vec{B} = \vec{B}_N + \vec{B}_S \quad \Rightarrow \quad B = B_N - B_S$$

$$= \left(\frac{\mu}{4\pi}\right)\frac{m}{(r-l)^2} - \frac{\mu}{4\pi}\frac{m}{(r+l)^2}$$

$$= \left(\frac{\mu}{4\pi}\right)\frac{2Mr}{(r^2-l^2)^2} \approx \left(\frac{\mu}{4\pi}\right)\left(\frac{2M}{r^3}\right) \text{for } l << r$$

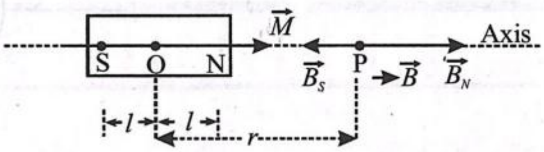


Fig. 4.26

which is having the direction parallel to the magnetic moment $\vec{M}$ of the bar magnet.

Broadside-on Position

The magnetic field $\vec{B}$ at a point P on the equator of the bar magnet at a distance r from it's mid point O is given by

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

$$\Rightarrow \quad B = 2B_N \cos\theta = 2B_s \cos\theta$$

$$= 2\left(\frac{\mu}{4\pi}\right)\frac{m}{(r^2+l^2)}\cdot\frac{l}{\sqrt{(r^2+l^2)}}$$

$$= \left(\frac{\mu}{4\pi}\right)\frac{M}{(r^2+l^2)^{3/2}} \approx \left(\frac{\mu}{4\pi}\right)\left(\frac{M}{r^3}\right) \text{ for } l << r$$

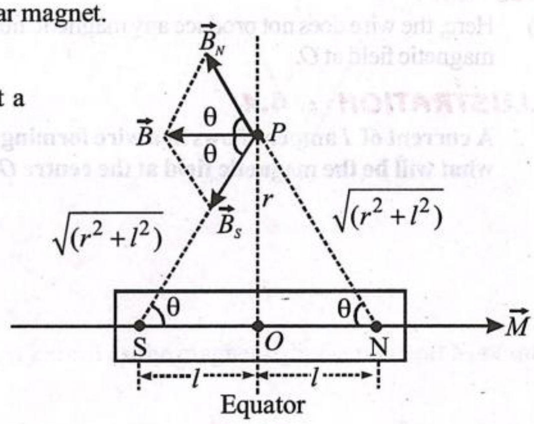


Fig. 4.27

which is having the direction antiparallel to the magnetic moment $\vec{M}$ of the bar magnet. Evidently, the magnetic field at the broadside-on position is one-half of that at the end-on position for the same distance r from the mid point O of the bar magnet.

Any other position

The magnetic moment $\vec{M}$ of bar magnet has the two components, namely, $M\cos\theta$ and $M\sin\theta$, as shown. The point P is neither on the axis nor on the equator of bar magnet but having any other position at a distance r from the mid point O. It's position is end-on for the component $M\cos\theta$ and broadside-on position for the component $M\sin\theta$. Therefore, the magnetic field $\vec{B}$ at the point P is given by

$$\vec{B} = \vec{B}_r + \vec{B}_\theta$$

$$\Rightarrow \quad B = \sqrt{(B_r^2 + B_\theta^2)}$$

$$= \sqrt{\left[\left(\frac{\mu}{4\pi}\right)^2\left(\frac{2M\cos\theta}{r^3}\right)^2 + \left(\frac{\mu}{4\pi}\right)^2\left(\frac{M\sin\theta}{r^3}\right)^2\right]}$$

$$= \left(\frac{\mu}{4\pi}\right)\left(\frac{M}{r^3}\right)\sqrt{(4\cos^2\theta + \sin^2\theta)}$$

$$= \left(\frac{\mu}{4\pi}\right)\left(\frac{M}{r^3}\right)\sqrt{(1+3\cos^2\theta)}$$

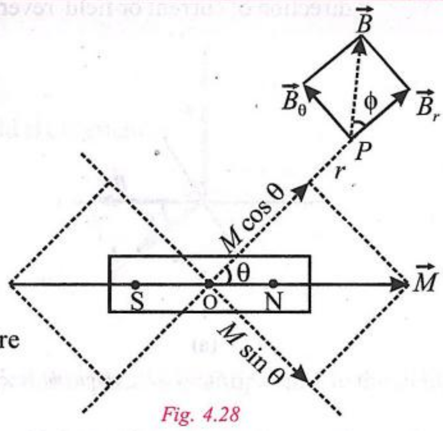


Fig. 4.28

whose direction is inclined at an angle $(\phi + \theta)$ with the magnetic moment $\vec{M}$, where

$$\tan\phi = \frac{B_\theta}{B_r} = \left(\frac{1}{2}\right)\tan\theta$$

FORCE ON A CURRENT CARRYING CONDUCTOR IN A MAGNETIC FIELD

For a conductor of length L carrying a current of I in a field B the force experienced by the conductor $\vec{F} = I\,\vec{L} \times \vec{B}$

Direction of force can be determined by fleming's left hand rule, right hand palm rule or screw rule.

Fleming's Left-Hand Rule

Stretch the fore-finger, central finger and thumb of left hand mutually perpendicular.

Then if the fore-finger points in the direction of field $(\vec{B})$, the central finger in the direction of current (I), the thumb will point in the direction of force Fig. 4.29.

Right-Hand Palm Rule

Stretch the fingers and thumb of right hand at right angles to each other. Then if the fingers point in the direction of field $(\vec{B})$ and thumb in the direction of current I, the normal to palm will point in the direction of force Fig. 4.30.

Screw Rule

Curl right hand finger from current towards magnetic field thumb will give the direction of force as shown in figure 4.31.

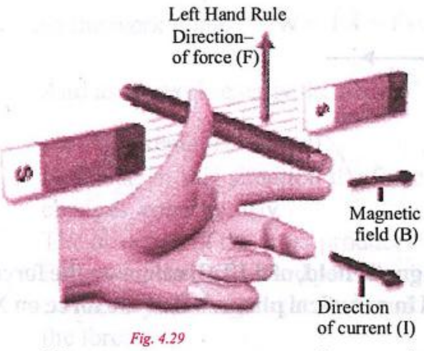


Fig. 4.29

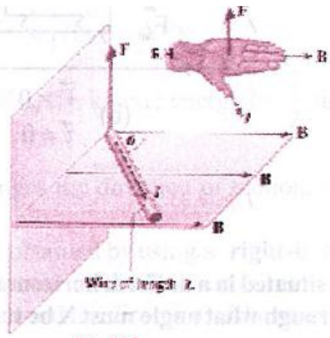


Fig. 4.30

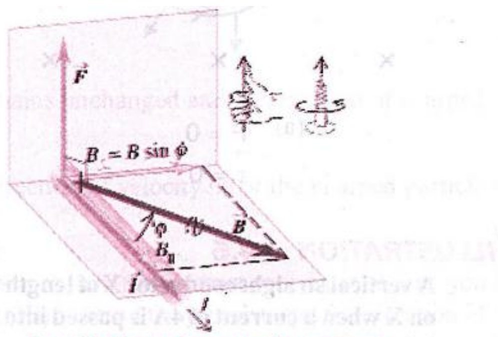


Fig. 4.31 : Magnetic force on straight wire segment.

You can see component of magnetic field perpendicular to current contributes in force on conductor. If current in wire is along external magnetic field force will be zero and if perpendicular to field it will be maximum.

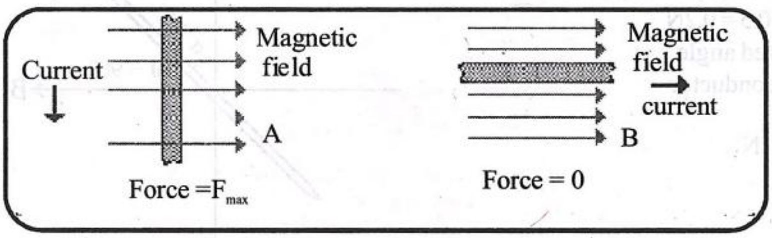


Fig. 4.32

If direction of current or field reverses, direction of force also reverses as shown in figure 4.33

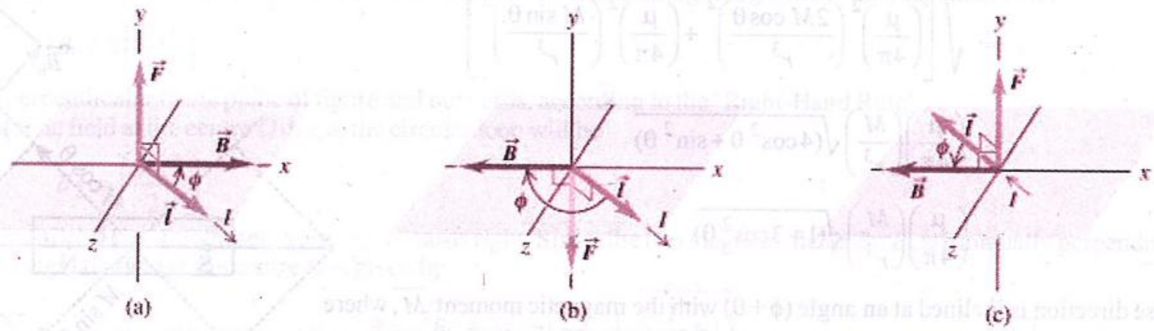


Fig. 4.33 : Magnetic forces - reversing the direction of the field B or the direction of the current I reverses the direction of the force.

Any arbitrary shape in a uniform field experience a force

$$\vec{F} = I\vec{\ell}' \times \vec{B}$$

where $\vec{\ell}'$ is the length vector joining initial and final points of the conductor as shown in figure.

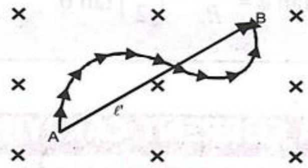


Fig. 4.34

If the current-carrying conductor in the form of a loop of any arbitrary shape is placed in a uniform field, then, $\vec{F} = 0$ i.e., the net magnetic force on a current loop in a uniform magnetic field is always zero as shown in figure 4.35 (a). Here it must be kept in mind that in this situation different parts of the loop may experience elemental force due to which the loop may be under tension or may experience a torque as shown in figure 4.35 (b).

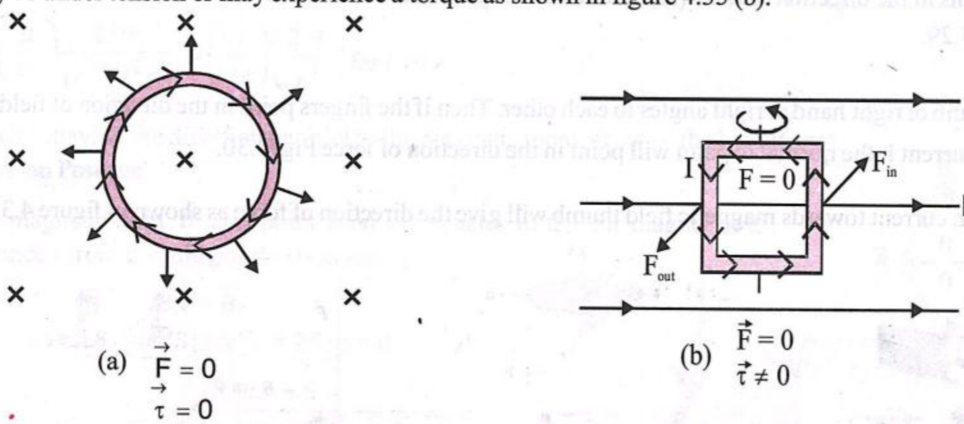


Fig. 4.35

ILLUSTRATION : 4.6

A vertical straight conductor X of length 0.5 m is situated in a uniform horizontal magnetic field, of 0.1 T (i) calculate the force on X when a current of 4A is passed into it (ii) through what angle must X be turned in a vertical plane so that the force on X is halved ?

Solution :

(i) Here, L = 0.5 m, B = 0.1T, I = 4A, F = ?
$F = BIL = 0.1 \times 4 \times 0.5 = 0.2N$

(ii) Let α be the required angle.
The force on the conductor

$$F' = \frac{1}{2}F = \frac{0.2}{2} = 0.1N$$

$$F' = BIL\,Sin\theta$$

or, $\frac{1}{2}BIL = BIL\,Sin(90° - \alpha)$

or, $\frac{1}{2}\cos\alpha$ or $\alpha = \cos^{-1}\left(\frac{1}{2}\right) = 60°$

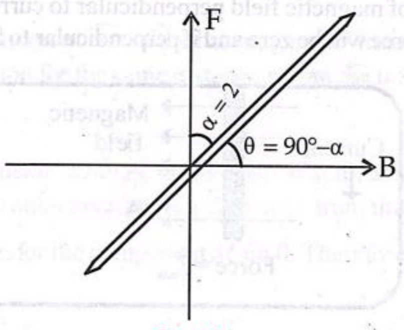


Fig. 4.36

CONNECTING TOPIC

FORCE ON A CHARGED PARTICLE IN A MAGNETIC FIELD

According to Lorentz, charge particle q moving with velocity v in a magnetic field B experiences

Force, $\vec{F} = q(\vec{v} \times \vec{B})$

The force $\vec{F}$ is always perpendicular to both the velocity $\vec{v}$ and the field $\vec{B}$.
A charged particle at rest in a steady magnetic field does not experience any force.

If the charged particle is at rest then $\vec{v} = 0$, so $\vec{v} \times \vec{B} = 0$
A moving charged particle does not experience any force in a magnetic field if its motion is parallel or antiparallel to the field.
i.e., if $\theta = 0°$ or $180°$,

then, $|\vec{F}| = qvB\sin\theta = 0$ $\quad [\because \sin 0° = 0 \text{ and } \sin 180° = 0]$

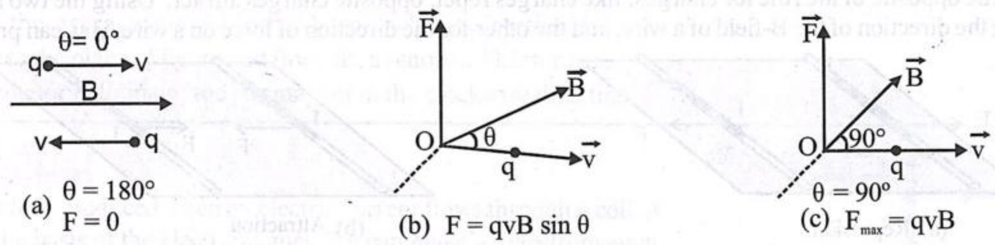


Fig. 4.37

If the particle is moving perpendicular to the field

In this situation all the three vectors $\vec{F}$, $\vec{v}$ and $\vec{B}$ are mutually perpendicular to each other.
Then $\sin\theta = max = 1$, i.e., $\theta = 90°$,
The force will be maximum $F_{max} = qvB$
Work done by force due to magnetic field in motion of a charged particle is always zero.
When a charged particle moves in a magnetic field, then force acts on it is always perpendicular to displacement,

so the work done, $\quad W = \vec{F}.\vec{s} = Fs\cos\theta = 0 \quad (\text{as } \theta = 90°)$,

And as by work-energy theorem $W = \Delta$ KE, the kinetic energy $(= \frac{1}{2}mv^2)$ remains unchanged and hence speed of charged particle v remains constant.
However, in this situation the force changes the direction of motion, so the direction of velocity $\vec{v}$ of the charged particle changes continuously.
The direction of the cross product can be obtained by using a **right-hand rule**:
Fingers of the right hand point in the direction of the first vector (v) in the cross product, then adjust your wrist so that you can bend your fingers (at the knuckles) toward the direction of the second vector (B); extend the thumb to get the direction of the force.

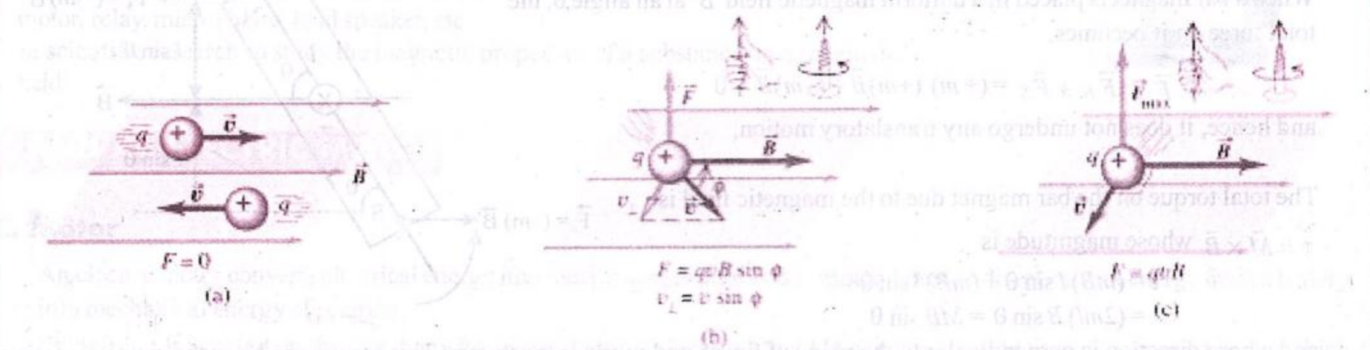


Fig. 6.38 : Magnetic force acting on a moving charge.

A charged particle moving in a plane perpendicular to a magnetic field will move in a circular orbit with the magnetic force playing the role of centripetal force.
The direction of the force is given by the right-hand rule. Equating the centripetal force with the magnetic force and solving for R the radius of the circular path we get,

$mv^2 / R = q\,v\,B$ and $\quad R = m\,v / q\,B$

If charge particle projected at some angle with magnetic field, it will move on helical path.

Fig. 4.39 : Orbit of charged particle in a magnetic field.

FORCE BETWEEN CURRENT CARRYING WIRES

If currents through two wires placed parallel are in the same direction, they attract. If current flow in opposite direction, wires repel. This is the opposite of the rule for charges: like charges repel, opposite charges attract. Using the two right hand rules, one for finding the direction of the B-field of a wire, and the other for the direction of force on a wire, you can predict the results.

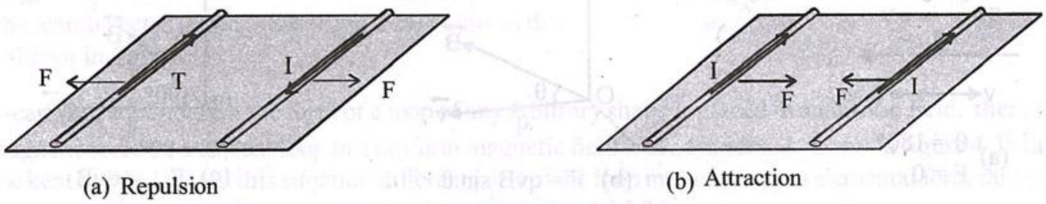


Fig. 4.40

The force per unit length on one wire due to other wire

$\dfrac{F}{\ell} = \dfrac{\mu_0 I_1 I_2}{2\pi d}$ [where I_1, I_2 current in two wires and d = distance between wires]

Definition of Ampere

As, $F = \dfrac{\mu_0}{2\pi}\dfrac{I_1 I_2}{r}$ N/m

When $I_1 = I_2 = 1$ ampere and r = 1m, then $F = \dfrac{\mu_0}{2\pi} = \dfrac{4\pi\times10^{-7}}{2\pi}$ N/m $= 2\times10^{-7}$ N/m

This leads to the following definition of ampere.
One ampere is that current which, if passed in each of two parallel conductors of infinite length and one metre apart in vacuum causes each conductor to experience a force of 2×10^{-7} newton per metre of length of conductor.

FORCE AND TORQUE ON BAR MAGNET PLACED IN MAGNETIC FIELD

Uniform Magnetic Field

When a bar magnet is placed in a uniform magnetic field $\vec{B}$ at an angle θ, the total force on it becomes

$$\vec{F} = \vec{F}_N + \vec{F}_S = (+m)\ (+m)\vec{B} + (-m)\vec{B} = 0$$

and hence, it does not undergo any translatory motion.

The total torque on the bar magnet due to the magnetic field is

$\vec{\tau} = \vec{M} \times \vec{B}$ whose magnitude is

$$\tau = (mB)\, l \sin\theta + (mB)\, l \sin\theta$$
$$= (2ml)\, B \sin\theta = MB \sin\theta$$

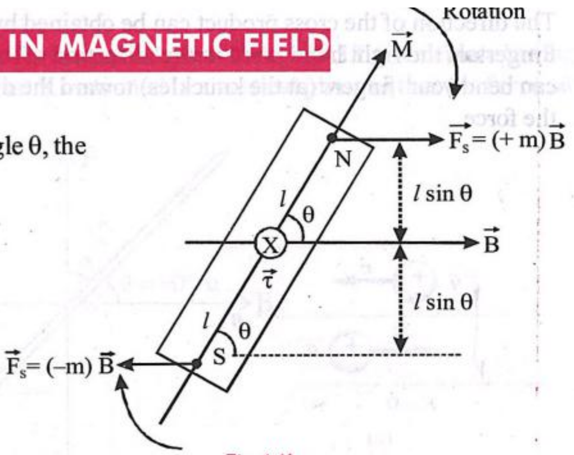


Fig. 4.41

and whose direction is perpendicular to the plane of figure and inwards, as shown. This torque produces the rotatory motion of the bar magnet in the clockwise direction.

Non-uniform Magnetic Field

When the bar magnet is placed in a non-uniform magnetic field $\vec{B}$ at an angle θ, the total force on it becomes

$$\vec{F} = \vec{F}_N + \vec{F}_S$$
$$= (+m)\ \vec{B} + (-m)\vec{B'} = m(\vec{B} - \vec{B'}) \neq 0$$

which produces the translatory motion of the bar magnet in its' direction.

The total torque on the bar magnet due to the magnetic field is

$\vec{\tau} = \vec{M} \times \vec{B}_{av}$ whose magnitude is

$$\tau = (mB)\, l \sin\theta + (mB')\, l \sin\theta$$
$$= (2ml)\left(\frac{B + B'}{2}\right)\sin\theta = MB_{av} \sin\theta$$

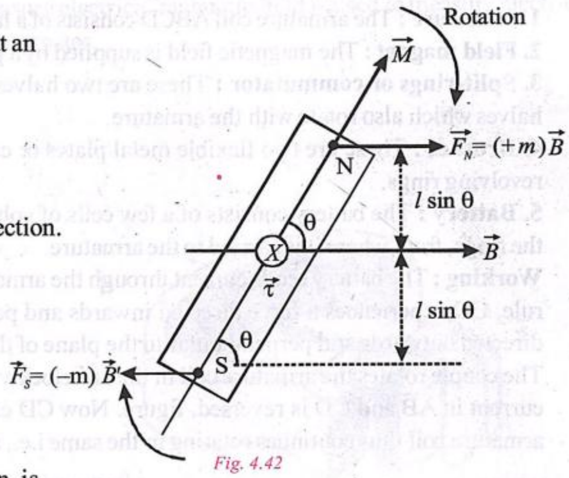


Fig. 4.42

where B_{av} is the average magnetic field, and whose direction is perpendicular to the plane of figure and inwards, as shown. This torque produces the rotatory motion of the bar magnet in the clockwise direction.

ELECTROMAGNET

A magnetic field is produced when an electric current flows through a coil of wire. This is the basis of the electromagnet. We can make an electromagnet stronger by doing these things:

- Adding more turns to the coil.
- Increasing the current flowing through the coil.

The magnetic field around an electromagnet is just the same as the one around a bar magnet. It can, however, be reversed by turning the battery around. Unlike bar magnets, which are permanent magnets, the magnetism of electromagnets can be turned on and off just by closing or opening the switch. Electromagnets are temporary magnets.

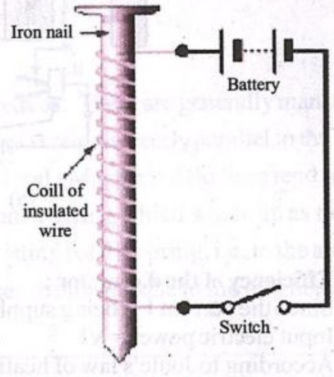


Fig. 4.43 : A simple electromagnet.

Uses of Electromagnet

1. For lifting and transporting large masses of iron scrap, girders, plates etc., especially to places where it is not convenient to take the help of human labour. Electromagnets are used to lift as much as 20-22 tonnes of iron in a single lift. To unload the magnet at the desired place, the current in the electromagnet is switched off so that the load drops.
2. For loading furnaces with iron.
3. For separating magnetic substances such as iron from other debris (e.g. for separating iron from the crushed copper ore in copper mines).
4. For removing pieces of iron from wounds.
5. In several electrical devices such as electric-bell, telegraph, electric tram, electric motor, relay, microphone, loud speaker, etc.
6. In scientific research to study the magnetic properties of a substance in a magnetic field.

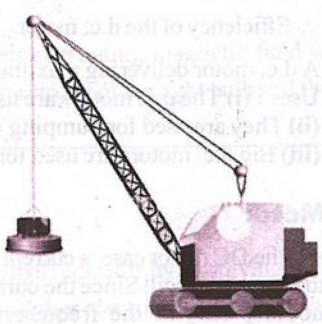


Fig. 4.44 : Electric Crane.

DC AND AC ELECTRIC MOTOR

D.C. Motor

An electric motor converts electrical energy into mechanical energy. A d.c. **motor** converts direct current energy from a battery into mechanical energy of rotation.

Principle : It is based on the fact that when a coil carrying current is held in a magnetic field, it experiences a torque, which rotates the coil.

Construction : It consists of the five parts.

1. Armature : The armature coil ABCD consists of a large number of turns of insulated copper wire wound over a soft iron core.

2. Field magnet : The magnetic field is supplied by a permanent magnet NS.

3. Split-rings or commutator : These are two halves of the same ring. The ends of the armature coil are connected to these halves which also rotate with the armature.

4. Brushes : These are two flexible metal plates or carbon rods B_1 and B_2, which are so fixed that they constantly touch the revolving rings.

5. Battery : The battery consists of a few cells of voltage V connected across the brushes. The brushes convey the current to the rings, from where it is carried to the armature.

Working : The battery sends current through the armature coil in the direction shown in figure. Applying Fleming's Left Hand rule, CD experiences a force directed inwards and perpendicular to the plane of the coil. Similarly, AB experiences a force directed outwards and perpendicular to the plane of the coil. These two forces being equal, unlike and parallel form a couple. The couple rotates the armature coil in the anticlockwise direction. After the coil has rotated through 180°, the direction of the current in AB and CD is reversed, figure. Now CD experiences an outward force and AB experiences an inward force. The armature coil thus continues rotating in the same i.e., anticlockwise direction.

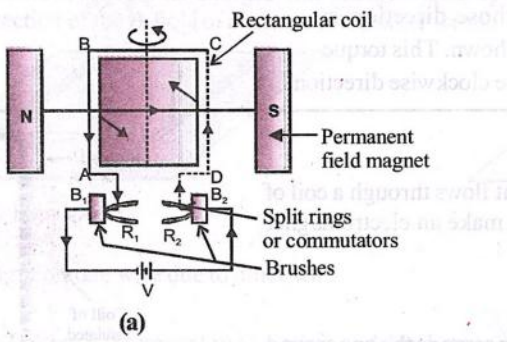


Fig. 4.45

Efficiency of the d.c. motor :

Since the current I is being supplied to the armature coil by the external source of e.m.f. V, therefore,

Input electric power = VI

According to Joule's law of heating, Power lost in the form of heat in the coil = $I^2 R$

If we assume that there is no other loss of power, then Power converted into external work i.e.,

Output mechanical power = $VI - I^2 R = (V - IR) I = EI$

$\therefore$ Efficiency of the d.c. motor, $\eta = \dfrac{\text{Output mechanical power}}{\text{Input electric power}}$

A d.c. motor delivering maximum output has an efficiency of only 50%.

Uses : (i) The d.c. motors are used in d.c. fans (exhaust, ceiling or table) for cooling and ventilation.

(ii) They are used for pumping water.

(iii) Big d.c. motors are used for running tram-cars and even trains.

A.C. Motor

As in the DC motor case, a current is passed through the coil, generating a torque on the coil. Since the current is alternating, the motor will run smoothly only at the frequency of the *sine* wave. It is called a synchronous motor. More common is the induction motor, where electric current is induced in the rotating coils rather than supplied to them directly.

One of the drawbacks of this kind of AC motor is the high current which must flow through the rotating contacts. Sparking and heating at those contacts can waste energy and shorten the lifetime of the motor. In common AC motors the magnetic field is produced by an electromagnet powered by the same AC voltage as the motor coil. The coils which produce the magnetic field are sometimes referred to as the "stator", while the coils and the solid core which rotates is called the "armature". In an AC motor the magnetic field is sinusoidally varying, just as the current in the coil varies.

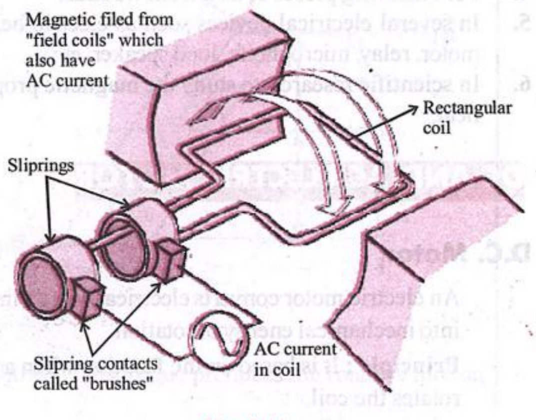


Fig. 4.46

Galvanometer

The torque on a current loop in a uniform magnetic field is used to measure electrical magnetic field is used to measure electrical currents. This current measuring device is called a moving coil galvanometer.

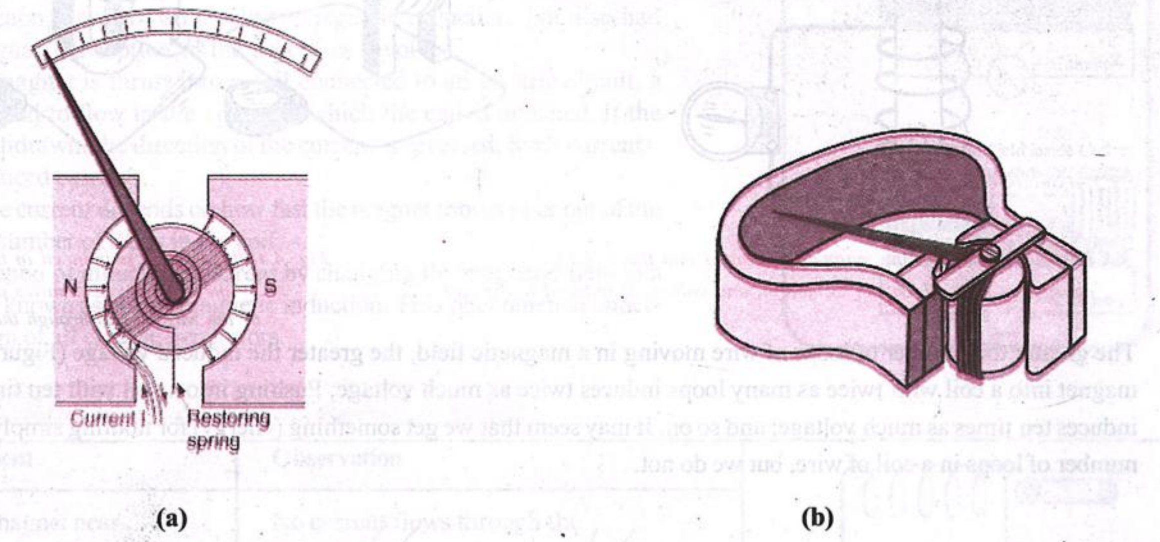


Fig. 4.47

The galvanometer consists of a coil of wire often rectangular, carrying the current to be measured. There are generally many turns in the coil to increase its sensitivity. The coil is placed in a magnetic field such that the lines of B remain nearly parallel to the plane of wire as it turns. This is achieved by having a soft iron cylinder placed at the center of the coil. Magnetic field lines tend to pass through the iron cylinder, producing the field configuration. The moving coil is hung from a spring which winds up as the coil rotates; this winding up produces a restoring torque proportional to the winding up (or twisting) of the spring, i.e. to the angular deflection of the coil. The coil comes to equilibrium when this restoring torque k balances the torque due to the magnetic field balances the torque due to the magnetic field.

ELECTROMAGNETIC INDUCTION

In the early 1800s, the only current-producing devices were voltaic cells, which produced small currents by dissolving metals in acids. These were the forerunners of our present-day batteries. The question arose as to whether electricity could be produced from magnetism. The answer was provided in 1831 by two physicists, Michael Faraday in England and Joseph Henry in the United States—each working without knowledge of the other. Their discovery changed the world by making electricity common-place—powering industries by day and lighting up cities at night.

Faraday and Henry both discovered that electric current could be produced in a wire simply by moving a magnet into or out of a coil of wire. (Figure 4.48(a)). No battery or other voltage source was needed—only the motion of a magnet in a wire loop. They discovered that voltage is caused, or *induced,* by the relative motion between a wire and a magnetic field. Whether the magnetic field moves near a stationary conductor or vice versa, voltage is induced either way (Figure 4.48(b)).

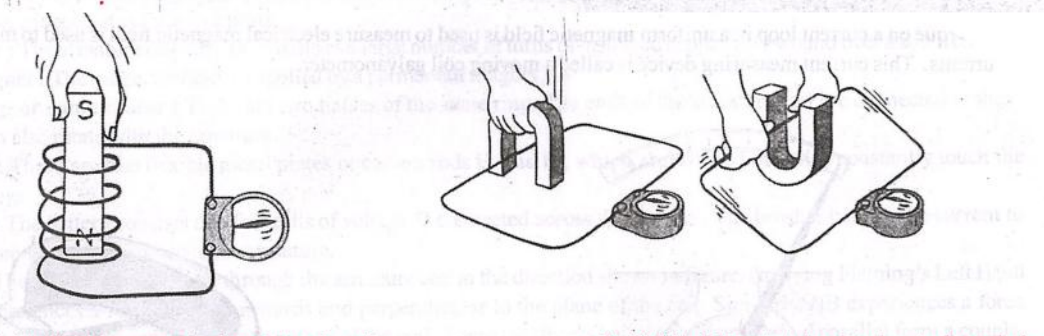


Fig. 4.48 (a), When the magnet is plunged into the coil, charges in the coil are set in motion, and voltage is induced in the coil.

Fig. 4.48(b), Voltage is induced in the wire loop whether the magnetic field moves past the wire or the wire moves through the magnetic field.

The greater the number of loops of wire moving in a magnetic field, the greater the induced voltage (Figure 4.49). Pushing a magnet into a coil with twice as many loops induces twice as much voltage; Pushing into a coil with ten times as many loops induces ten times as much voltage; and so on. It may seem that we get something (energy) for nothing simply by increasing the number of loops in a coil of wire, but we do not.

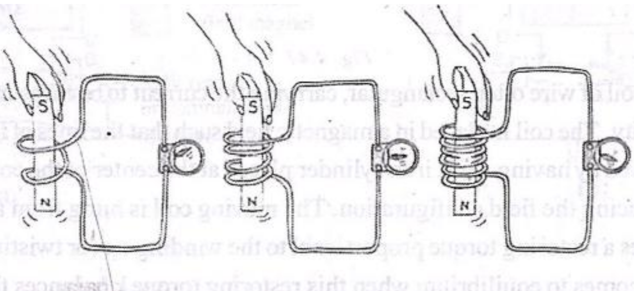


Fig. 4.49, When a magnet is plunged into a coil with twice as many loops as another, twice as much voltage is induced. If the magnet is plunged into a coil with three times as many loops, three times as much voltage is induced.

We find that it is more difficult to push the magnet into a coil made up of more loops. This is because the induced voltage produces a current, which makes an electromagnet, which repels the magnet in our hand. So we must do more work against this "back force" to induce more voltage (Figure 4.50).

Fig. 4.50, It is more difficult to push the magnet into a coil with many loops because the magnetic field of each current loop resists the motion of the magnet.

The amount of voltage induced depends on how fast the magnetic field lines are entering or leaving the coil. Very slow motion produces hardly any voltage at all. Rapid motion induces a greater voltage. This phenomenon of inducing voltage by changing the magnetic field in a coil of wire is called **electromagnetic induction.**

FARADAY'S EXPERIMENT

In 1831, Michael Faraday carried out numerous experiments in his attempt to prove that electricity could be generated from magnetism. Within the course of a few weeks, the great experimentalist not only had clearly demonstrated this phenomenon, now known as electromagnetic induction, but also had developed a good conception of the processes involved.

When a bar magnet is thrust into a coil connected to an electric circuit, a current is caused to flow in the circuit to which the coil is attached. If the magnet is withdrawn, the direction of the current is reversed. Such currents are called induced currents.

The size of the current depends on how fast the magnet moves in or out of the coil, and the number of loops in the coil.

The phenomenon of inducing a current by changing the magnetic field in a coil of wire is known as electromagnetic induction. This phenomenon underpins the design of all electric generators.

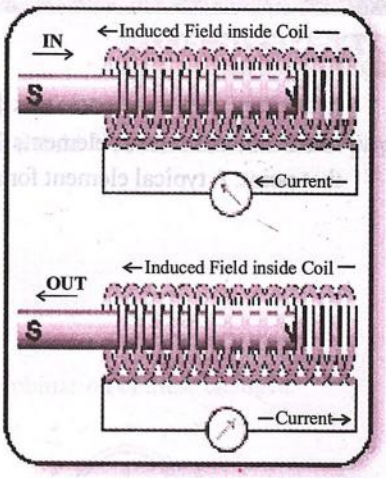
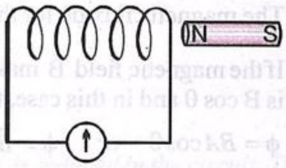
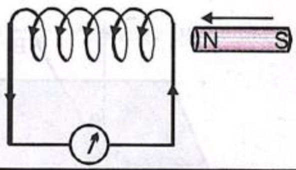
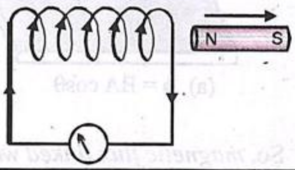
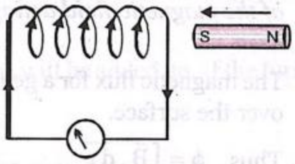
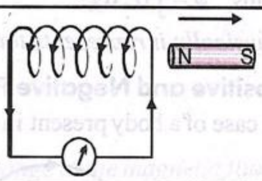


Fig. 4.51

FARADAY'S EXPERIMENT AND OBSERVATION

S. No.	Experiment	Observation	
1.	Place a magnet near a conducting loop with a galvanometer in the circuit	No current flows through the galvanometer	

2.	Move the magnet towards the loop	The galvanometer register a current	
3.	Reverse the direction of motion of the magnet	The galvanometer deflection reverses	
4.	Reverse the polarity of the magnet and move the magnet towards the loop	The galvanometer deflection reverses	
5.	Keep magnet fixed and move the coil towards the magnet	The galvanometer register a current	
6.	Increases the speed of the magnet	The deflection in the galvanometer increases	
7.	Increase the strength of the magnet	The deflection in the galvanometer increases	
8.	Increase the diameter of the coil	The deflection in the galvanometer increases	
9.	Fix the speed of the magnet but repeat the experiment with the magnet closer to the coil.	The deflection in the galvanometer increases	
10.	Move the magnet at an angle to the plane of the coil.	Deflection decreases, it is maximum when the magnet moves perpendicular to the plane of the coil and is zero when the magnet moves parallel to the plane of the coil.	
11.	Increase the number of turns of the coil	Magnitude of current increases.	

CONNECTING TOPIC

MAGNETIC FLUX

In analogy with the electric flux ϕ_E, a magnetic flux ϕ_B of the magnetic field for a surface is defined. Imagine dividing a surface into infinitesimal area elements. The direction of an area element d_A at a point on the surface is perpendicular to the surface at that point. A typical element for a surface is shown in fig. along with the magnetic field B at a point P.

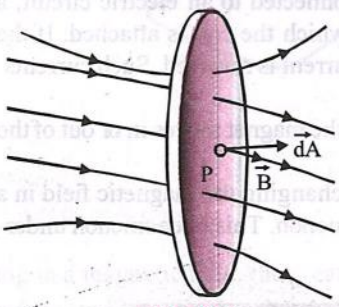


Fig. 4.52

The magnetic flux $d\phi$ for the area element "d_A" is $d\phi = \vec{B}.\vec{d_A}$.

If the magnetic field $\vec{B}$ makes an angle θ with the normal to the surface as shown in fig. then the normal component of the field is B cos θ and in this case, the magnetic flux is given by

$\phi = BA\cos\theta$ or $\phi = \vec{B}.\vec{A}$

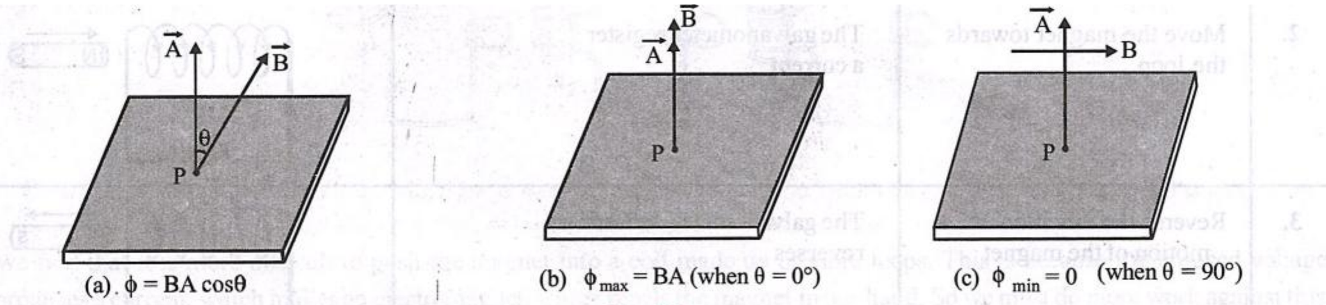


Fig. 4.53

So, *magnetic flux linked with a closed surface may be defined as the product of the surface area and the normal component of the magnetic field acting on that area. It may also be defined as the dot or scalar product of magnetic field and surface area.*

The magnetic flux for a general surface is obtained by integrating (summing) the contributions $d\phi$ as the area element dA ranges over the surface.

Thus, $\phi = \int \vec{B} \cdot \vec{d_A}$

Physically it represents total lines of force passing through a given area.

Positive and Negative Flux

In case of a body present in a field, either uniform or non-uniform outward flux is taken to be positive while inward negative.

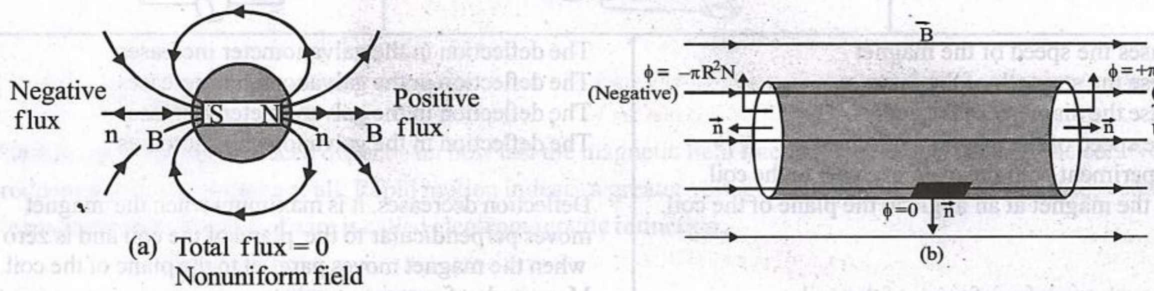


Fig. 4.54

If the normal drawn on the surface is in the direction of the field, then the flux is taken as positive. In this case, θ is 0° or $\theta < 90°$. If the normal on the surface is opposite to the direction of the field, then $\theta = 180°$. In this case, the magnetic flux is taken as negative.

Magnetic flux density, $B = \dfrac{\phi}{A}$

Lines of force are imaginary, but as magnetic flux associated with elemental area $\vec{d_A}$ in a field $\vec{B}$, so flux is a real scalar physical quantity

S.I. unit of magnetic flux (ϕ) is weber (Wb)

The unit of magnetic field is tesla (T) or wb/m^2

Different Ways Which can Vary the Magnetic Flux

Magnetic flux in planar area $\vec{A}$ due to an uniform magnetic field $\vec{B}$, $\phi = BA\cos\theta$

So, flux linked with a circuit will change only if field B, area A, orientation θ or any combination of these changes.

(1) By varying the magnetic field $\vec{B}$ with time.

(2) By varying the area of the conducting loop $\vec{A}$ with time.

(3) Loop entering or leaving a finite region of magnetic field.

(4) Loop rotating in and out of a finite region of magnetic field.

(5) Effect of time varying angle between the area vector and the magnetic field vector.

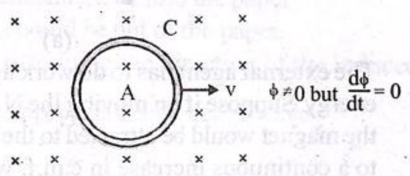


Fig. 4.55

FARADAY'S LAWS OF ELECTROMAGNETIC INDUCTION

Faraday gave two laws of electromagnetic induction.

First law : *Whenever there is change in the magnetic flux associated with a circuit, an e.m.f. is induced in the circuit. This is also known as Neumann's law*

Second law : *The magnitude of the induced e.m.f. (e) is directly proportional to the time rate of change of the magnetic flux through the circuit.*

i.e., $e \propto \frac{\Delta\phi}{\Delta t}$ or, $e = k\frac{\Delta\phi}{\Delta t}$

In the limit, $\Delta t \to 0$, $e = \frac{d\phi}{dt}$

k = const. of proportionality depending upon the system of units used.

In the **S.I. system**, emf 'e' is measured in volt and $\frac{d\phi}{dt}$ in Wb/sec.

In MKS or SI system, these units are so chosen that k = 1, and 1 volt = 1 Wb/sec

Induced current or e.m.f. lasts only for the time for which the magnetic flux is changing.

If the coil has N turns, then the emf will be induced in each turn and the emf's of all the turns will be added up. If the turns of coil are very close to each other, the magnetic flux passing through each turn will be same.

So, *the induced emf in the whole coil* $e = N\frac{\Delta\phi}{\Delta t}$

$N\phi$ = number of 'flux linkages' in the coil.

LENZ'S LAW AND CONSERVATION OF ENERGY

According to Lenz's law, *the direction of the induced current is such that it opposes the change in the magnetic flux that causes the induced current or e.m.f.* i.e., induced current tries to maintain flux.

On combining Lenz's law with Faraday's laws $e = -\frac{d\phi}{dt}$

–ve sign indicating that the induced e.m.f. opposes the change in the magnetic flux. The direction of the induced current or e.m.f. is given by Lenz's law. **The Lenz's law is consistent with the law of conservation of energy.**

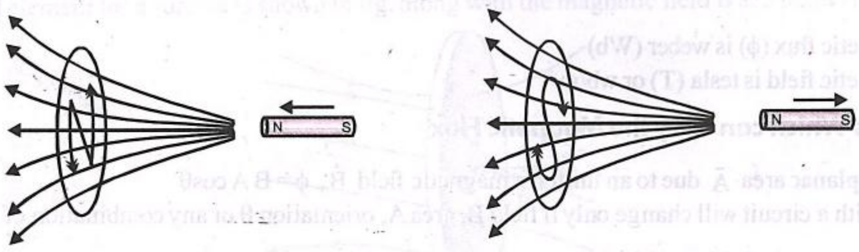
The induced e.m.f. is produced at the cost of mechanical work done by an external agent. In the magnet and coil experiment when the N-pole of the magnet is moved towards the coil, the face of the coil facing the north pole acts like a north pole. (This can be found by Flemings' Right Hand Rule).

As the magnet is moved towards the coil, the magnetic flux linked with the coil increases.

To oppose this increase in flux, e.m.f. induced in the coil has to be in such a direction as to reduce the increase in flux.

The external agent has to do some work against this force of repulsion between the two N-poles.

Similarly, if the magnet with its N-pole is moved away from the coil, then the face of the coil acts like a South pole and hence the flux linked with the coil tends to decrease. The induced current or e.m.f. must now be in a direction so as to increase the flux as shown in figure.



(a) *Fig. 4.56* (b)

The external agent has to do work against this force of attraction between the N and S pole and this is converted into electrical energy. Suppose if on moving the N pole of the magnet towards the coil, a south polarity is induced on the face of the coil, then the magnet would be attracted to the coil, and there would be a continuous increase in magnetic flux linked with the coil leading to a continuous increase in e.m.f. without any expenditure of energy and this would violate the principle of conservation of energy.

Induced Current and Induced Charge

If in a coil of N turns the rate of change of magnetic flux be $\Delta\phi/\Delta t$, then the induced emf in the circuit is $e = -N(\Delta\phi/\Delta t)$.

If the coil be closed and the total resistance of its circuit be R, then the induced current in the circuit will be

$$I = \frac{e}{R} = \frac{N}{R}\frac{\Delta\phi}{\Delta t}$$

It is clear from this equation that the induced current in the circuit depends upon the resistance, whereas the induced emf is independent of resistance.

The charge flowing through the circuit in time-interval Δt

$q = I \times \Delta t$

or $q = \frac{N}{R}\frac{\Delta\phi}{\Delta t} \times \Delta t = \frac{N}{R}\Delta\phi$

$= \frac{Number\ of\ turns \times change\ in\ magnetic\ flux}{Resistance}$

The induced charge does not depend upon the time-interval.

Whether the change in magnetic flux be rapid or slow, the charge in the circuit will remain the same.

Fleming's Right Hand Rule

Fleming's right hand rule gives the direction of the induced e.m.f. and current in a straight conductor moving perpendicular to the direction of magnetic field.

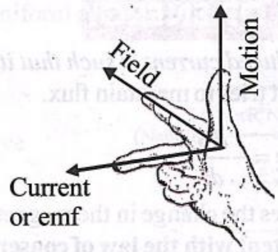


Fig. 4.57

Statement : Stretch out the thumb, fore finger and middle finger of the right hand mutually perpendicular to each other. If the fore finger points in the direction of magnetic field, the thumb in the direction of motion of the conductor, then the middle finger will point out the direction of induced current or induced e.m.f.

Determination of the Direction of the Induced Current in a Circuit (Using Lenz's Law)

The Lenz's law can be systematically applied as follows to determine the direction of induced current.

(1) Identify the loop in which the induced current is to be determined.

(2) Determine the direction of the magnetic field in this loop (i.e., in or out of the loop).

(3) The direction of flux is the same as the direction of the magnetic field. Determine if the flux through the loop is increasing or decreasing due to change in area, or change in magnetic field.

(4) Choose the appropriate current in the loop that will oppose the change in flux i.e.,

(i) If the flux is into the paper and increasing, the flux due to the induced current should be out of the paper.

(ii) If the flux is into the paper and decreasing, the flux due to the induced current should be into the paper.

(iii) If the flux is out of the paper and increasing, the flux due to the induced current should be into the paper.

(iv) If the flux is out of the paper and decreasing, the flux due to induced current should be out of the paper.

The above description is the physical interpretation of Lenz's law. We can determine the direction of the induced current mathematically by simply applying Lenz's law, $e_{ind} = -\frac{d\phi_B}{dt}$ with the appropriate sign conventions.

The **Right Hand Sign Convention :**

- Counter clockwise current/emf is +ve
- Clockwise current/emf is –ve
- Magnetic flux out of the paper is +ve
- Magnetic flux into the plane of the paper is –ve
- The rate of change of an increasing positive flux is +ve
- The rate of change of a decreasing positive flux is –ve
- The rate of change of an increasing negative flux is –ve
- The rate of change of a decreasing negative flux is +ve

SELF INDUCTION

The phenomenon of induction of e.m.f. in a coil due to change in current or magnetic flux linked with the coil is called self induction.

When a current I flows through a coil, the magnetic flux ϕ linked with the coil is $\phi = LI$, where **L is coefficient of self induction** or self inductance of the coil. On differentiating, we get

$$\frac{d\phi}{dt} = L\frac{dI}{dt} = -e$$

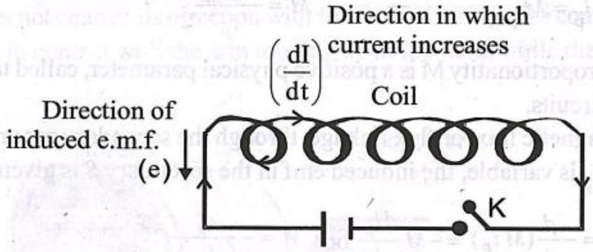


Fig. 4.58

If dI/dt = 1; L = – e.

Hence self inductance of a coil is equal to e.m.f. induced in the coil when rate of change of current through the same coil is unity. Coefficient of self induction of a coil is also defined as the magnetic flux linked with a coil when 1 ampere current flows through the same coil. The value of L depends on geometry of the coil and is given by $L = \frac{\mu_0 N^2 A}{\ell}$.

Where ℓ is length of the coil (solenoid), N is total number of turns of solenoid and A is area of cross section of the solenoid. The **S.I. unit** of L is henry. Coefficient of self induction of a coil is said to be one henry when a current change at the rate of 1 ampere/sec in the coil induces an e.m.f. of one volt in the coil.

MUTUAL INDUCTION

The mutual induction is another kind of electromagnetic induction in which a changing current i_p in one circuit called the primary, induces an emf e_s and , in turn, may induce a current i_s in another nearby circuit, called the secondary S. Out of the two circuits involved in the mutual induction process, any one can be taken as primary, or secondary. However, the two circuits constitute a mutual inductor.

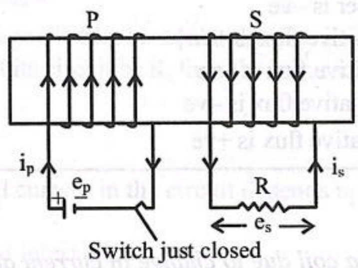


Fig. 4.59

When a constant, or variable current i flows through the primary P, then the total magnetic flux through each turn of the secondary S is Φ_{ms} and the total magnetic flux, or flux linkage, through all the N_s turns, assumed identical, of secondary S is

$$N_s \Phi_{ms} \propto i_p = Mi_p \quad \Rightarrow \quad M = \frac{N_s \phi_{ms}}{i_p}$$

where the constant of proportionatity M is a positive physical parameter, called the **mutual inductance**, or **coefficient of mutual induction**, of the two circuits.

Evidently, M is total magnetic flux, or flux linkage, through the secondary per unit current in the primary.

If the primary current i_p is variable, the induced emf in the secondary S is given by

$$e_s = -\frac{d}{dt}(Ns\phi_{ms}) = -\frac{d}{dt}(M\,i_p) = -M\frac{di_p}{dt} \quad \text{or,} \quad M = \frac{e_s}{\left(\frac{di_p}{dt}\right)}$$

which means that the mutual inductance M is the induced emf in the secondary per unit rate of change of current in the primary. The mutual inductance M depends on the geometry of two circuits and their proximity. It's SI unit is the same as that of the self inductance L, i.e., henry (H).

ELECTRIC GENERATOR

The large generators present in hydroelectric power plants depend on magnets for their operation. They convert the kinetic energy in moving water into electricity. Generators in fossil-fueled and nuclear-fueled power plants harness the kinetic energy in moving steam in the same way.

Electrical current can be generated by moving a metal wire through a magnetic field. This applies both to alternating current (AC) and direct current (DC) electricity.

Principle : When a coil of conducting wire is rotated in a magnetic field, electromagnetic induction results in an induced current flowing through the loop. In this way, mechanical energy is converted to electrical energy.

The device is called a generator or dynamo.

The generator will produce an electromotive force that will vary sinusoidally with the angle made by the coil and the applied field. Thus the direction of the current will vary and the current so produced is called an alternating current. A better name for the device is alternator.

Electric motor is analogous to an electric motor: the motor converts electrical energy into mechanical energy, while the alternator converts mechanical energy into electrical energy. The alternator does not create electricity out of nothing.

Working of generator : An electric generator, consists of a rotating rectangular coil ABCD placed between the two poles of a permanent magnet. The two ends of this coil are connected to the two rings R_1 and R_2. The inner side of these rings are made insulated. The two conducting stationary brushes B_1 and B_2 are kept pressed separately on the rings R_1 and R_2, respectively. The two rings R_1 and R_2 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 galvanometer to show the flow of current in the given external circuit. When the axle attached to the two rings is rotated such that the arm AB moves up (and the arm CD moves down) in the magnetic field produced by the permanent magnet. Let us say the coil ABCD is rotated clockwise in the arrangement. By applying Fleming's right-hand rule, the induced currents are set up in these arms along the directions AB and CD. Thus an induced current flows in the direction ABCD. If there are larger numbers of turns in the coil, the current generated in each turn adds up to give a large current through the coil. This means that the current in the external circuit flows from B_2 to B_1.

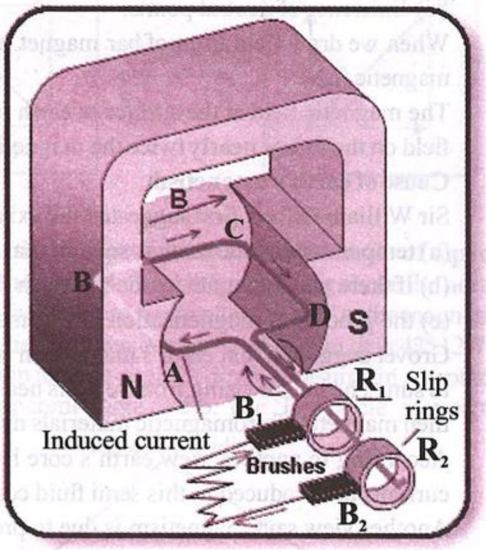


Fig. 4.60 : AC generator

After half a rotation, arm CD starts moving up and AB moving down. As a result, the directions of the induced currents in both the arms change, giving rise to the net induced current in the direction DCBA.

The current in the external circuit now flows from B_1 to B_2. Thus after every half rotation the polarity of the current in the respective arms changes. Such a current, which changes direction after equal intervals of time, is called an alternating current (abbreviated as AC). This device is called an AC generator.

To get a direct current (DC, which does not change its direction with time), 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.

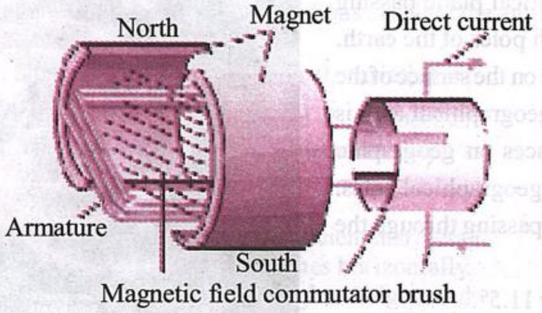


Fig. 4.61 : Split-ring type commutator.

The difference between the direct and alternating currents is that the direct current always flows in one direction, whereas the alternating current reverses its direction periodically. Most power stations constructed these days produce AC. In India, the AC changes direction after every 1/100 second, that is, the frequency of AC is 50 Hz. An important advantage of AC over DC is that electric power can be transmitted over long distances without much loss of energy.

CONNECTING TOPIC

TERRESTERIAL MAGNETISM

William Gilbert suggested that earth itself behaves like a huge magnet. This magnet is so oriented that its S pole is towards geographic north and N pole is towards the geographic south.

The earth behaves as a magnetic dipole inclined at small angle 11.5° to the earth's axis of rotation with its south pole pointing geographic north.

The idea of earth having magnetism is supported by following facts.

(i) A freely suspended magnet always comes to rest in N-S direction.

(ii) A piece of soft iron buried in N-S direction inside the earth acquires magnetism.

(iii) Existence of neutral points.

When we draw field lines of bar magnet we get neutral points where magnetic field due to magnet is neutralized by earth's magnetic field.

The magnetic field at the surface of earth ranges from nearly 30 μT near equator to about 60 μT near the poles. The magnetic field on the axis is nearly twice the magnetic field on the equatorial line.

Cause of earth's magnetism

Sir William Gilbert first suggested the existence of a powerful magnet inside the earth. This is not possible because

(a) temperature inside earth is so high that it will not be possible for magnet to retain magnetism.

(b) if there was a magnet inside the earth then position of earth's magnetic poles would have not changed.

(c) the process of magnetisation of this magnet is not understood.

Grover suggested that earth's magnetism is due to flow of current near outer surface of earth. These currents are produced due to sun. The hot air rising from regions near equator while going towards north and south hemispheres gets electrifield. These then magnetise ferromagnetic materials near the surface of earth.

According to another view earth's core has many conducting materials like iron and nickel in molten state. Conventional currents are produced in this semi fluid core due to rotation of earth about its axis which generates magnetism.

Another view says magnetism is due to presence of ionised gases in atmosphere. The high energy sun rays ionize gas atoms in upper layer of atmosphere. The radioactivity of atmosphere and cosmic rays also ionize the gases. Strong electric currents flow due to rotation of earth producing magnetism.

Thus most likely cause of earth's magnetism is the motion and distribution of charged materials in and outside the earth.

Some Definitions

Geographic Axis : It is straight line passing through the geographic poles of the earth. It is the axis of rotation of the earth. It is known as polar axis

.

Geographic Meridian : It is a vertical plane passing through geographic north and south poles of the earth.

Geographic Equator : A great circle on the surface of the earth in a plane perpendicular to geographical axis is called geographic equator. All places on geographic equator are at equal distances from geographical poles.

Magnetic Axis : It is a straight line passing through the magnetic poles of the earth. It is inclined to geographic axis at nearly 11.5°.

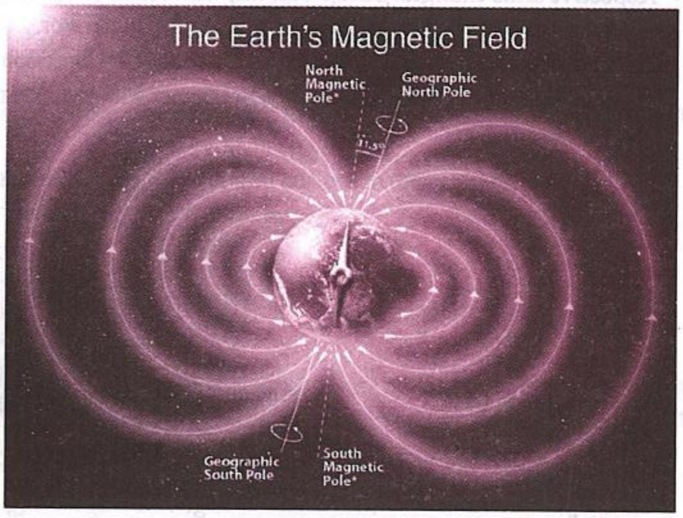


Fig. 4.62

Magnetic Meridian : It is a vertical plane passing through the magnetic north and south poles of the earth.

Magnetic Equator : A great circle on the surface of the earth in a plane perpendicular to magnetic axis is called magnetic equator. All places on magnetic equator are at equal distance from magnetic poles.

COMPONENTS OF EARTH'S MAGNETIC FIELD

The resultant magnetic field $\vec{B}$ of earth at a place has the two components, namely, the vertical component B_V and horizontal component B_H. The component B_V has the vertical direction which is downwards in the northern hemisphere and upwards in the southern hemisphere. The component B_H has the horizontal direction which is from the south to the north everywhere.

Vertical component of earth's magnetic field, $B_V = B \sin\theta$

Horizontal component of earth's magnetic field, $B_H = B\cos\theta$

Resultant magnetic field $B = \sqrt{\left(B_V^2 + B_H^2\right)}$

$$\frac{B\sin\theta}{B\cos\theta} = \tan\theta = \frac{B_V}{B_H}$$

The vertical component $B_V = 0$ at the magnetic equator and the horizontal component $B_H = 0$ at the magnetic north and south poles of earth. At Delhi, $B_H = 35\ \mu T = 0.35 G$.

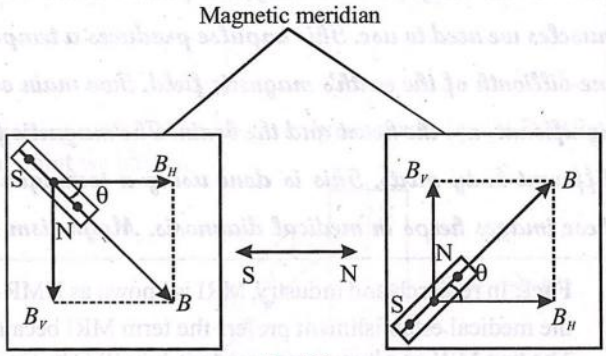


Fig. 4.63

Angle of Dip or Inclination, θ

At a place, the angle θ which the resultant magnetic field $\vec{B}$ of earth makes with the horizontal is called the angle of dip, or inclination. A freely-suspended magnet will keep it's axis at this angle θ with the horizontal, the south pole being above the north pole in the northern hemisphere and the south pole being below the north pole in the southern hemisphere. It is 0° at the magnetic equator and 90° at the magnetic north and south poles of earth. At other places, it lies between 0° and 90°. At Delhi, it is 42° 12.7′. The angle of dip θ measured in the magnetic meridian is called the true angle of dip and the angle of dip θ′ measured in any other vertical plane inclined at an angle ϕ with the magnetic meridian is called the apparent angle of dip. The 'Dip circle' is used to measure the angle of dip in any vertical plane.

$$\tan\theta = \frac{B_V}{B_H},$$

$$\tan\theta' = \frac{B_V}{B_H'} = \frac{B_V}{B_H\cos\phi}$$

$$\Rightarrow \quad \tan\theta' = \left(\frac{1}{\cos\phi}\right)\tan\theta$$

$$\Rightarrow \quad \theta' > \theta$$

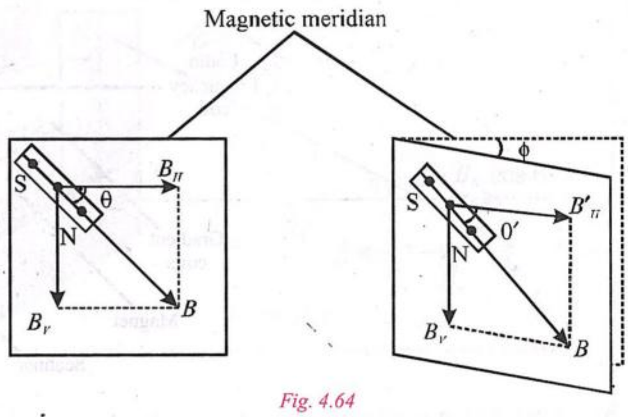


Fig. 4.64

Angle of Declination, α

At a place, the angle between the magnetic and geographic meridians is called the angle of declination. It is 0° at Delhi.

Magnetic Elements of Earth

The three parameters, namely, the angle of dip or inclination θ, variation or declination α and horizontal component B_H of earth's magnetic field $\vec{B}$, are together called the magnetic elements of earth. These elements completely define the earth's magnetism.

Magnetic Compass:

Present day magnetic compasses use the same forces that guided ancient mariners. A magnetized needle, in conjunction with a compass card, rotates horizontally. Present day compasses are superior to the ancient ones through a heightened knowledge of magnetic laws and greater precision in construction.

The Earth's magnetic lines of force provide the directional information needed to navigate. A compass detects and converts the energy from these magnetic lines of force into a directional display. In order to understand the operation of a ship's compass, it is first necessary to understand some basic information about the Earth's magnetic field.

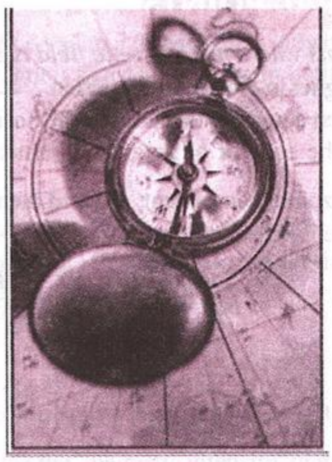


Fig. 4.65

Fact: In research and industry, MRI is known as NMR – Nuclear Magnetic Resonance. It's more or less the same process, but the medical establishment prefers the term MRI because some patients are scared off by the word nuclear.
The first MRI on a human was made in July 1977 by Dr. Raymond Damadian of New York. MRI patients are sometimes injected with gadolinium, a contrast agent that can make abnormalities such as tumors clearer due to the element's special magnetic properties.

MRIs are most commonly used for cancer patients (about 35 percent of all scans) and patients with spinal problems (about 30%).

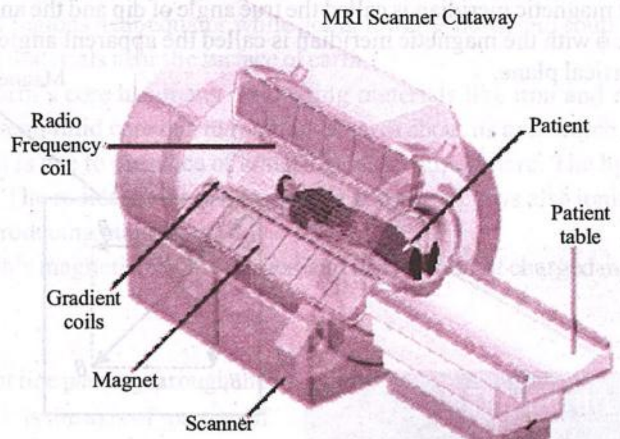


Fig. 4.66

NEUTRAL POINTS

Points where net magnetic field is zero are called neutral points.

Magnet in Horizontal Position

When a magnet is placed in the horizontal position with it north pole facing the north, we get the two neutral points P_1 and P_2 on the equator of magnet, symmetrically placed with respect to the magnet, as shown. At the neutral points, the earth's horizontal component $\vec{B}_H$ and the magnetic field $\vec{B}$ of magnet balance each other so that the resultant magnetic field is zero there. Therefore,

$$B_H = B = \left(\frac{\mu}{4\pi}\right)\frac{M}{(r^2+l^2)^{3/2}}$$

$$\approx \left(\frac{\mu}{4\pi}\right)\frac{M}{r^3} \quad \text{for } l << r$$

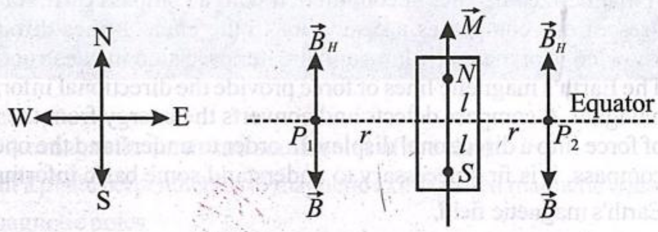


Fig. 4.67

When the magnet is placed in the horizontal position with it's north pole facing the south, we get the two neutral points P_1 and P_2 on the axis of magnet, symmetrically placed with respect to the magnet, as shown. At the neutral points, we have

$$B_H = B = \left(\frac{\mu}{4\pi}\right)\frac{2Mr}{(r^2-l^2)^2}$$

$$\approx \left(\frac{\mu}{4\pi}\right)\frac{2M}{r^3} \quad \text{for } l << r$$

Magnet in Vertical Position

When the magnet is placed in the vertical position with it's north pole resting on the table, we get only one neutral point P on the south of magnet in the plane of the table top, as shown. At the neutral point we have

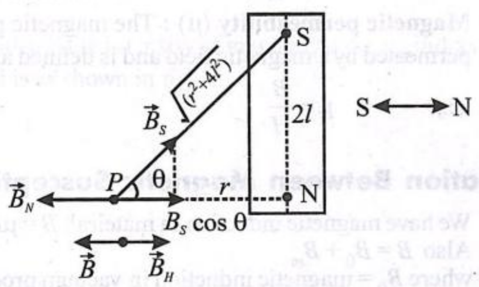
$$B_H = B = B_N - B_S\cos\theta \quad \text{(for short magnet)}$$

$$\approx B_N \quad \text{(for long magnet, i.e., } l >> r)$$

where,

$$B_N = \left(\frac{\mu}{4\pi}\right)\frac{m}{r^2}$$

$$B_S = \left(\frac{\mu}{4\pi}\right)\frac{m}{(r^2+4l^2)}$$



are the magnetic fields due to the two poles, taken separately.

When the magnet is placed in the vertical position with it's south pole resting on the table, we get only one neutral point P on the north of magnet in the plane of the table top, as shown. At the neutral point, we have

$$B_H = B = B_S - B_N \cos\theta \text{ (for short magnet)}$$

$$\cong B_S \text{ (for long magnet, i.e., } l >> r)$$

where $B_N = \left(\frac{\mu}{4\pi}\right)\frac{m}{(r^2+4l^2)}$

and $B_S = \left(\frac{\mu}{4\pi}\right)\frac{m}{r^2}$

are the magnetic fields due to the two poles.

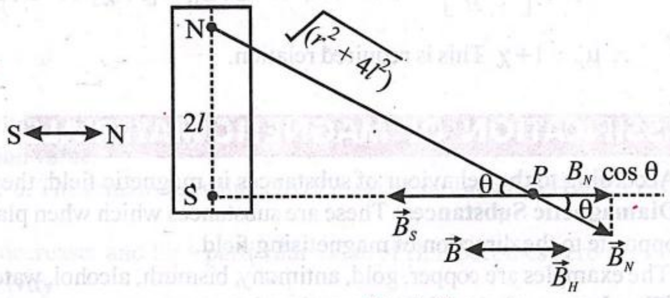


Fig. 4.69

MAGNETIC MATERIALS

Certain materials, when placed in a magnetic field $\vec{B}_0$, i.e., in a magnetising field intensity $\vec{H} = \vec{B}_0/\mu_0$, get magnetised. Such materials are called the magnetic materials. Some materials get magnetised very strongly, e.g., ferromagnetics and others get magnetised very feebly, e.g., diamagnetics and paramagnetics.

Terms Related to Magnetism

Magnetic intensity $(\vec{H})$ **:** When a magnetic material is placed in a magnetic field, it becomes magnetised. The capability of the magnetic field to magnetise a material is expressed by means of a magnetic vector $\vec{H}$, called the 'magnetic intensity' of the field.

The relation between magnetic induction B and magnetising field $\vec{H}$ is $B = \mu H$, μ being permeability of medium.

Intensity of magnetisation (I_m) : When a material is placed in a magnetising field, it acquires magnetic moment M. The intensity of magnetisation is defined as the magnetic moment per unit volume i.e., $I_m = \frac{M}{V}$, V being volume of mateiral.

If the material is in the form of a bar of cross-sectional area A, length $2l$ and pole strength m, then

$$M = m \times 2\ell;\ V = A \times 2\ell \qquad \therefore I_m = \frac{M}{V} = \frac{m.2\ell}{A.2\ell} = \frac{m}{A}$$

Magnetic susceptibility (χ) **:** The magnetic susceptibility is defined as the intensity of magnetisation per unit magentising field

i.e., $\chi = \frac{I_m}{H}$.

Magnetic permeability (μ) **:** The magnetic permeability of a material is the measure of degree to which the material can be permeated by a magnetic field and is defined as the ratio of magnetic induction (B) in the material to the magnetising field

i.e., $\mu = \frac{B}{H}$

Relation Between Magnetic Susceptibility and Permeability

We have magnetic induction in mateiral, $B = \mu H$

Also $B = B_0 + B_m$

where B_0 = magnetic induction in vacuum produced by magnetising field

B_m = magnetic induction due to magnetisation of material.

But $B_0 = \mu_0 H$ and $B_m = \mu_0 I_m \Rightarrow B = \mu_0[H + I_m]$

$\therefore B = \mu_0 H\left[1 + \frac{I_m}{H}\right] = B_0\ [1+\chi]$; $\therefore B/B_0 = [1+\chi]$ $\therefore B/B_0 = \frac{\mu H}{\mu_0 H} = \mu/\mu_0$, the relative magnetic permeability

$\therefore \mu_r = 1 + \chi$ This is required relation.

CLASSIFICATION OF MAGNETIC MATERIALS

According to the behaviour of substances in magnetic field, they are classified into three categories

(I) **Diamagnetic Substances:** These are substances which when placed in a strong magnetic field acquire a feeble magnetism opposite to the direction of magnetising field.

The examples are copper, gold, antimony, bismuth, alcohol, water, quartz, hydrogen, etc.

The characteristics of diamagnetic substances are:

(a) They are feebly repelled by a strong magnet
(b) Their susceptibility is negative (i.e. $\chi < 0$)
(c) Their relative permeability is less than 1 (i.e. $\mu_r < 1$)
(d) Their susceptibility is independent of magnetising field and temperature (except for Bismuth at low temperature)

(II) Paramagnetic Substances: These are the materials which when placed in a strong magnetic field acquire a feeble magnetism in the same sense as the applied magnetic field. The examples are platinum, aluminium, chromium, manganese, $CuSO_4$, O_2, air, etc.

The characteristics of paramagnetic substances are:
(a) They are attracted by a strong magnet
(b) Their susceptibility is positive but very small ($\chi > 0$)
(c) Their relative permeability is slightly greater than unity. ($\mu > 1$)
(d) Their susceptibility and permeability do not change with the variation of magnetising field.
(e) Their susceptibility is inversely proportional to temperature, $\left(\text{i.e. } \chi \alpha \frac{1}{T}\right)$
(f) Found in those material which have atoms containing odd number of electrons

(III) Ferromagnetic Substances: These are the substances which are strongly magnetised by relatively weak magnetising field in the same sense as the magnetising field. The examples are Ni, Co, iron and their alloys.

The characteristics of ferromagnetic substances are :
(a) They are attracted even by a weak magnet.
(b) The susceptibility is very large and positive. ($\chi >> 0$)
(c) The relative permeability is very high (of the order of hundreds and thousands). ($\mu >> 1$)
(d) The intensity of magnetisation is proportional to the magnetising field H for smaller values, varies rapidly for moderate values and attains a constant value for larger values of H.
(e) The susceptibility of a ferromagnetic substance is inversely proportional to temperature

i.e., $\chi \propto 1/T \Rightarrow \chi = \frac{C}{T}$; C = curie constant.

This is called **Curie law**. At a temperature called **curie temperature**, ferromagnetic substance becomes paramagnetic. The curie temperatures for Ni, Fe and Co are 360°C, 740°C and 1100°C respectively.
(f) Found in those material which have domains and can be converted into strong magnets

HYSTERESIS

When a bar of ferromagnetic material is magnetised by a varying magnetic field and the intensity of magnetisation I_m induced is measured for different values of magnetising field H, the graph of I versus H is as shown in fig.

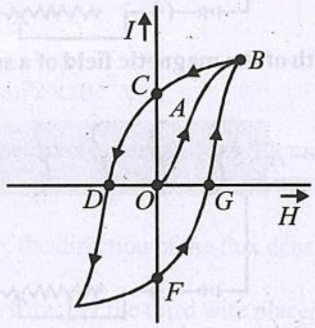


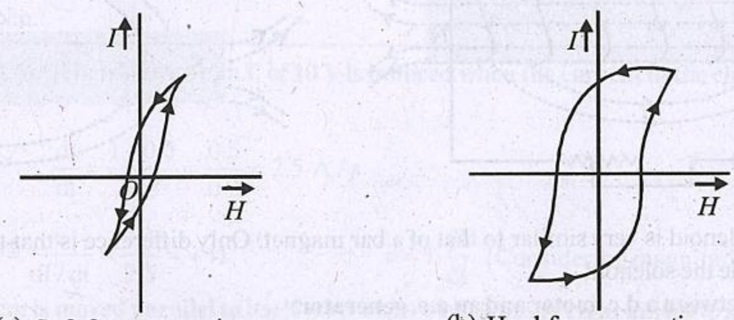
Fig. 4.70

The graph shows
(i) When magnetising field is increased from O the intensity of magnetisation I_m increases and becomes maximum (i.e. point A). This maximum value is called the **saturation value**.
(ii) When H is reduced, I_m reduces but is not zero when H = 0. The remainder value OB of magnetisation when H = 0 is called the residual magnetism or **retentivity**. OB is retentivity.
(iii) When magnetic field H is reversed, the magnetisaiton decreases and for a particular value of H, it becomes zero i.e., for H = OC, I = 0. This value of H is called the **coercivity**.
(iv) When field H is further increased in reverse direction, the intensity of magnetisation attains saturation value in reverse direction (i.e., point D).
(v) When H is decreased to zero and changed direction in steps, we get the part DFGA.

Properties of Soft Iron and Steel

For soft iron, the susceptibility, permeability and retentivity are greater while coercivity and hysteresis loss per cycle are smaller than those of steel.

Permanent magnets are made of steel and cobalt while electromagnets are made of soft iron.

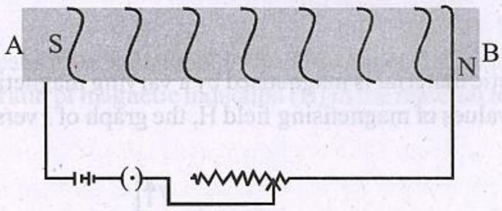


(a) Soft ferromagnetics (b) Hard ferromagnetics

Fig. 4.70

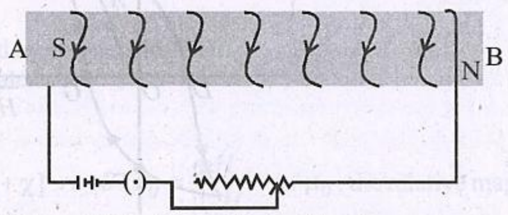
MISCELLANEOUS SOLVED EXAMPLES

1. (a) **Fig. below shows a solenoid. Copy the diagram and mark on it :**
   (i) **The direction of flow of current.**
   (ii) **The magnetic polarity at ends A and B.**



(b) **Suggest three ways of increasing, strength of the magnetic field of a solenoid.**

Sol. (a) The complete diagram is shown in Fig.



(i) Current flows from end A of the solenoid to end B in the clockwise direction.
(ii) As current at the end A is in clockwise direction, it develops south pole; and the current at end B is in anticlockwise direction, it develops a north pole.

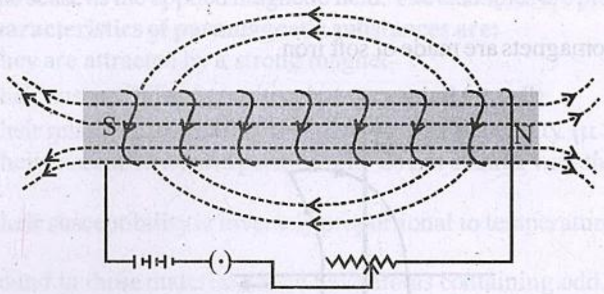
(b) The strength of the magnetic field can be increased by:
(i) increasing the current.
(ii) increasing number of turns of wire.
(iii) inserting a soft iron core along the axis of the solenoid.

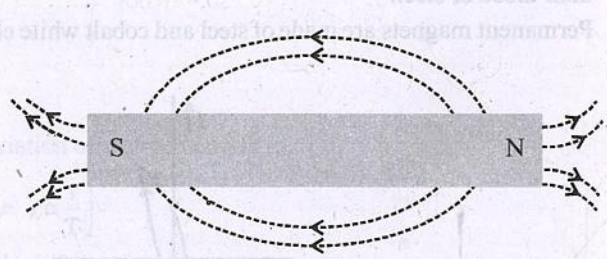
2. **Why is soft iron generally used as the core of the electromagnet?**

Sol. (a) Soft iron has less retenitvity. So it acquires the magnetic properties only when the current flows through the coil wound on it and loses the magnetic properties as the current is switched off.
(b) The soft iron intensifies the magnetic field of the electromagnet because of its high permeability.

3. **Draw the magnetic lines of force in case of:**
   (a) a solenoid and **(b) a bar magnet.**

Sol. (a) Magnetic lines of force in case of a solenoid. (b) Magnetic lines of force in case of a bar magnet.





The magnetic field of a solenoid is very similar to that of a bar magnet. Only difference is that the magnetic lines of force are parallel to each other inside the solenoid.

4. State two dissimilarities between a d.c. motor and an a.c. generator.

Sol. (i) A d.c. motor converts electrical energy to mechnical energy, whereas an a.c. generator converts mechanical energy to electrical energy.

(ii) A d.c. motor uses a split ring commutator, whereas an a.c. generator uses a pair of slip rings.

SOLVED EXAMPLES BASED ON CONNECTING TOPICS

5. A horizontal straight wire 5 cm long weighing $1.2\ g^{-1}$ is placed perpendicular to a uniform horizontal magnetic field of the flux density 0.6T. If the resistance of the wire is $3.8\ \Omega\ m^{-1}$ calculate the potential difference that has to be applied between the ends of the wire to make it just supporting ($g = 9.8\ ms^{-1}$)

Sol. Here, $l = 5cm = 5\times10^{-2}m$

Mass of the wire, m = mass per unit length × length of the wire.

$= 1.2\times10^{-3}\ kg\ m^{-1}\times5\times10^{-2}m = 6\times10^{-5}\ Kg,$

$B = 0.6T$

Resistance of the wire R = (Resistance per unit length x length of the wire)

$= 3.8\times5\times10^{-2} = 0.19\,\Omega$

Let V be the P.d. applied between the ends of the wire, for the wire to be self supporting:

$$mg = BI\,l = B\frac{V}{R}l$$

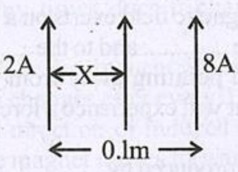
$$\therefore V = \frac{mg\times R}{B\ell} = \frac{6\times10^{-5}\times9.8\times0.19}{0.6\times5\times10^{-2}} = 3.72\times10^{-3}\ V$$

6. Two long parallel conductors carry respectively currents of 12 and 8A in the same direction. If the wires are 10 cm apart, find where the third parallel wire also carrying a current must be placed so that the force experienced by it shall be zero.

Sol. For the force on the third conductor to be zero, the direction of the flux density due to the current flowing in the two wires must be opposite in the position of the wire.

∴ The third wire must be placed between the wire. Let the third wire placed at a distance *x m* from the wire carrying 12A, then, $B_1 = B_2$

$$\frac{\mu_0 I_1}{2\pi x} = \frac{\mu_0 I_2}{2\pi(0.1-x)}$$



or $\frac{12}{x} = \frac{8}{0.1-x}$ or $\frac{3}{x} = \frac{2}{0.1-x}$

or $0.3 = 5x$ or, $x = \frac{0.3}{5} = 0.06\ m$

7. A narrow vertical rectangular coil is suspended from the middle of its upper side with its plane parallel to a uniform horizontal magnetic field of 0.02 T. The coil has 10 turns and the lengths of its vertical and horizontal sides are 0.1 m and 0.05 m respectively. Calculate the torque on the coil when a current of 5A is passed into it. What would be the new value of the torque if the plane of the vertical coil was initially at 60° to the magnetic field and a current of 5A was passed into the coil.

Sol. Given: $B = 0.02\ T, N = 10$ turns

$A = 1\times b = 0.1\times0.05 = 0.005\ m^2 : I = 5A$

Torque $= BINA = 0.02\times5\times10\times0.005 = 0.005\ Nm = 5\times10^{-3}Nm$

New value of the torque when the plane of the vertical coil was at 60° to the magnetic field

$= BINA\cos\theta = 5\times10^{-3}\cos60^\circ$

$= 5\times10^{-3}\times½ = 2.5\times10^{-3}\ Nm.$

8. Find the self inductance of a coil in which an e.m.f. of 10 V is induced when the current in the circuit changes uniformly from 1 A to 0.5 A in 0.2 sec.

Sol. Given : e = 10 V and $\frac{dI}{dt} = \frac{1-0.5}{0.2} = \frac{0.5}{0.2} = 2.5\ A/s$

Self inductance of coil $L = \frac{e}{dI/dt} = \frac{10}{2.5} = 4\ H$ $\because$ $e = L\frac{dI}{dt}$ (Considering magnitude only)

9. A conductor of length 10 cm is moved parallel to itself with a speed of 10 m/s at right angles to a uniform magnetic induction 10^{-4} Wb/m². What is the induced e.m.f. in it?

Sol. Given : $\ell = 10\ cm = 0.1\ m$, $v = 10\ m/s$

$B = 10^{-4}\ Wb/m^2$

e.m.f. induced in conductor $e = B\ell V = 10^{-4} \times 0.1 \times 10 = 10^{-4}\ V$

1 EXERCISE

Fill in the Blanks :

DIRECTIONS : *Complete the following statements with an appropriate word / term to be filled in the blank space(s).*

1. A compass needle is a .... magnet.
2. Field lines are used to represent a ....
3. Field lines are shown closer together where the magnetic field is ....
4. A metallic wire carrying an electric current has associated with it a .... field.
5. The field lines about the wire consist of a series of concentric circles whose direction is given by the .... rule.
6. The magnetic lines of force are the lines drawn in a magnetic field along which a .... pole would move.
7. An electric current can be used for making temporary magnets known as ....
8. The unit of magnetic field is ....
9. The S.I. unit of magnetic flux ....
10. The force between currents is called the .... force.
11. The N-pole of a compass points to the .... pole of a permanent magnet.
12. The force that a magnetic field exerts on a current is always perpendicular to the .... and to the ....
13. In a magnetic field pointing away from you, an electron traveling to the right will experience a force in the .... direction.
14. Magnetic fields are produced by ....
15. You are looking into a solenoid, at its S-pole, along its axis. From your view point, the direction of the current in the solenoid is ....
16. Crowding the wires of a solenoid more closely together will .... the strength of the field inside it.
17. A paramagnet magnet behaves like a solenoid because both contain currents in the form of ....
18. Magnetic field lines emerge from the .... pole of a solenoid or a permanent magnet.
19. You are looking down the axis of a solenoid, and the current from your position is clockwise. The end of the solenoid facing you is a .... pole.
20. A generator converts mechanical energy into .... energy. It works on the basis of ....
21. In our houses we receive AC electric power of .... with a frequency of ....
22. The frequency for A.C. (alternating current) in USA is ....
23. The armature in a motor rotates within a(n) .... field.
24. To produce DC, the output of a generator must be fed through a (n) ....
25. In any generator, the current in the armature is of the .... type.
26. The phenomenon of production of back e.m.f. in a coil due to flow of varying current through it is called.............
27. The unit of self-inductance in SI system is ....
28. An e.m.f. is induced in a coil when .... linked with it changes.
29. In an AC generator, maximum number of lines of force pass through the coil when the angle between the plane of coil and lines of force is ....

True / False :

DIRECTIONS : *Read the following statements and write your answer as true or false.*

1. Energy associated with an electric field is analogous to potential energy whereas the energy associated with the magnetic field is analogous to kinetic energy.
2. No net force acts on a rectangular coil carrying a steady current when suspended freely in a uniform magnetic field.
3. An electron and a proton move in a uniform magnetic field with same speed perpendicular to the magnetic field. They experience forces in opposite directions differing by a factor of 1840.
4. A positive charge projected along the axis of a current carrying solenoid moves undeviated from its original path.
5. There is no change in the energy of a charged particle moving in a magnetic field although a magnetic force is acting on it.
6. An electron does not suffer any deflections while passing through a region. This makes sure that there is no magnetic field in that region.
7. The field at the centre of a long circular coil carrying current will be parallel straight lines.
8. A magnetic field exists in the region surrounding a magnet, in which the force of the magnet can be detected.
9. The pattern of the magnetic field around a conductor due to an electric current flowing through it depends on the shape of the conductor.
10. A current-carrying conductor when placed in a magnetic field always experiences a force.
11. The direction of force on a current carrying conductor placed in a magnetic field can be reversed by reversing the direction of current flowing in the conductor.
12. The direction of force on a current carrying conductor placed in a magnetic field cannot be reversed by reversing the direction of magnetic field.
13. Two magnetic lines of force never intersect each other.
14. The field lines inside the infinite solenoid are in the form of parallel straight lines.
15. An electric generator works on the principle of electromagnetic induction.
16. In a DC electric motor a pair of split rings is used as commutator.

17. The induced e.m.f. depends only the turns of the coil
18. The magnitude of induced current can be increased by decreasing the speed of rotation of coil.
19. The magnitude of induced current can be decreased by increasing the area of cross section of coil.

Match the Following :

DIRECTIONS : *Each question contains statements given in two columns which have to be matched. Statements (A, B, C, D) in column I have to be matched with statements (p, q, r, s) in column II.*

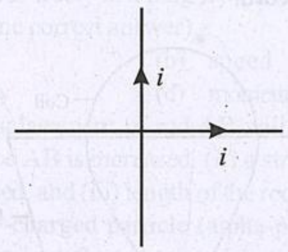
1.

Column I	Column II
(A) An electric motor works on	(p) to a battery
(B) An electric motor is also	(q) direct current
(C) A commutator is used to	(r) reverse the direction of flow of current.
(D) Commutator rings are connected	(s) known as DC MOTOR

2. Column II gives approximate values of magnetic fields due to source given in column I

Column I	Column II
(A) At surface of neutron star	(p) 10^{-10} T
(B) Near big electromagnet	(q) 1.5 T
(C) At earth surface	(r) 10^{8} T
(D) In interstellar space	(s) 10^{-4} T

3. Equal currents i flow in two wires along x and y axis as shown. Match the following :

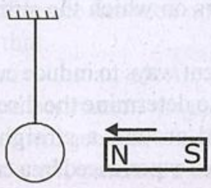


Column I	Column II
(A) Magnetic field in first quadrant	(p) inwards
(B) Magnetic field in second quadrant	(q) outwards
(C) Magnetic field in third quadrant	(r) may be inwards or outwards
(D) Magnetic field in fourth quadrant	

Very Short Answer Questions:

DIRECTIONS : *Give answer in one word or one sentence.*

1. Why does a compass needle get deflected when brought near a bar magnet?
2. A current through a horizontal power line flows in east to west direction. What is the direction of magnetic field at a point directly below it and at a point directly above it ?
3. Why don't two magnetic lines of force intersect each other?
4. Consider a circular loop of wire lying in the plane of the table. Let the current pass through the loop clockwise. Apply the right-hand rule to find out the direction of the magnetic field inside and outside the loop.
5. List three sources of magnetic fields.
6. When is the force experienced by a current–carrying conductor placed in a magnetic field largest?
7. What do you conclude from Oersted's experiment?
8. Name the types of electromagnets commonly used.
9. When can an electric charge give rise to a magnetic field?
10. Why is soft iron used as the core of the electromagnet used in electric bell ?
11. How will the direction of force be changed, if the current is reversed in the conductor placed in a magnetic field?
12. Describe a set up for plotting the magnetic lines of force in a straight conductor.
13. What is the direction of magnetic field at the centre of a coil carrying current in (i) clockwise (ii) anticlockwise direction?
14. Why does a current carrying, freely suspended solenoid rest along a particular direction ?
15. What constitutes the field of a magnet?
16. Name the physical quantity whose S.I. unit is Wb - m^2. Is it a scalar quantity or vector quantity?
17. Name the rule used to find the direction of force on a current carrying conductor.
18. State Fleming's right hand rule.
19. Does the A.C. generator have any slip ring ?
20. An alternating electric current has a frequency of 50 Hz. How many times does it change its direction in one second?
21. What will be the frequency of an alternating current if its direction changes after every 0.01 s?
22. Give the direction of induced current in the wire loop, when the magnet moves forward as shown in the figure.



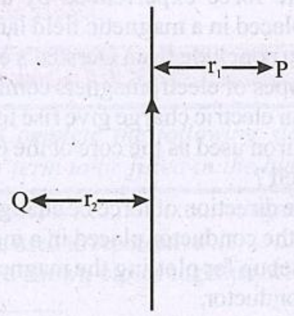
Short Answer Questions :

DIRECTIONS : *Give answer in 2-3 sentences.*

1. State two ways through which the strength of an electromagnet can be increased.
2. State three factors on which, the magnitude of force on a current carrying conductor placed in a magnetic field, depends. Can this force be zero for some position of the conductor?
3. What do you mean by an electromagnet ? With the help of diagrams show the two types of electromagnets. Give two uses of electromagnets.
4. How will you experimentally show that a current-carrying conductor experiences a force when kept in a magnetic field?
5. Under what conditions permanent electromagnet is obtained

if a current carrying solenoid is used? Support your answer with the help of a labelled circuit diagram.

6. AB is a current carrying conductor in the plane of the paper as shown in Figure. What are the directions of magnetic fields produced by it at points P and Q? Given $r_1 > r_2$, where will the strength of the magnetic field be larger?

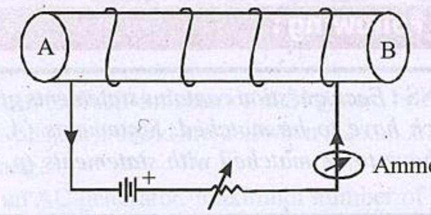


7. What does the divergence of magnetic field lines near the ends of a current carrying straight solenoid indicate?
8. List the properties of magnetic lines of force.
9. What is the magnetic field that exerts a force of 2.4×10^{-4} newtons on a current of 12 amperes in a wire 30 cm long set perpendicular to the field ?
10. A wire carrying 1.5 amp has a length of 20 cm in a magnetic field of 40 milliteslas. If the wire is perpendicular to the field, how much force does the field exert on the wire ?
11. What is the direction of the force that a vertical magnetic field, directed upward, will exert on an electron traveling eastward in it.
12. What is the shape of magnetic field lines around a circular current carrying conductor?
13. What is Solenoid?
14. Why is soft iron generally used as the core of the electromagnet?
15. State four factors on which the strength of electromagnet depends.
16. Explain different ways to induce current in a coil.
17. State the rule to determine the direction of a (i) magnetic field produced around a straight conductor-carrying current, (ii) force experienced by a current-carrying straight conductor placed in a magnetic field which is perpendicular to it, and (iii) current induced in a coil due to its rotation in a magnetic field.
18. Explain the underlying principle of an electric generator. What is the function of brushes?
19. What is electromagnetic induction ? Describe one experiment to demonstrate the phenomenon of electromagnetic induction.

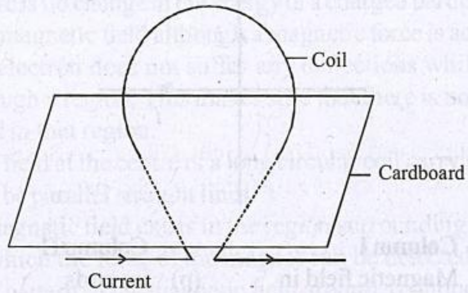
Long Answer Questions :

DIRECTIONS : *Give answer in 4 to 5 sentences.*

1. What is the nature of magnetic field produced by a straight current carrying conductor? Explain with the help of an experiment.
2. Diagram below shows a circuit containing a coil wound over a long and thin hollow carboard tube. Copy the diagram (i) Show the polarity acquired by each face of the solenoid. (ii) Draw the magnetic field lines of force inside the coil and also show their direction. (iii) Mention two methods to increase the strength of the magnetic field inside the coil.



3. A 0.4m wire, stretched horizontally, carries an electric current of 15A from east to west, in a magnetic field whose magnetic field intensity is 0.1 N/Am, directed vertically downwards. What is
(a) the magnitude of the magnetic deflecting force on the wire, and
(b) its direction?
4. A straight conductor passes vertically through a cardboard sprinkled with iron filings. Show the setting of the iron filings when a weak current is passed in the downward direction. What changes occur if,
(i) the strength of the current is increased.
(ii) the single conductor is replaced by several parallel conductors with current flowing in the same. direction.
5. The diagram shows a current carrying coil passing through a sheet of stiff cardboard. Draw three lines of magnetic field on the cardboard.



State two factors on which the magnitude of magnetic field at the centre of coil, depends.
6. Draw a labelled diagram to make an electromagnet from a soft iron bar. Mark the polarity at its ends. What precaution would you observe ?
7. What is an electric motor? With the help of diagram, explain its principle, construction and working.
8. What is D.C. generator? Explain its principle, construction and working with diagram.
9. What does the direction of thumb indicate in the right hand thumb rule. In what way this rule is different from Fleming's left-hand rule?
10. Explain with the help of a diagram, the principle and working of an a.c. generator.

2 EXERCISE

Text-Book Questions :

1. Why does a compass needle get deflected when brought near a bar magnet ?
2. Draw magnetic field lines around a bar magnet.
3. List the properties of magnetic lines of force.
4. Why don't two magnetic lines of force intersect each other ?
5. Consider a circular loop of wire lying in the plane of the table. Let the current pass through the loop clockwise. Apply the right-hand rule to find out the direction of the magnetic field inside and outside the loop.
6. The magnetic field in a given region is uniform. Draw a diagram to represent it.
7. Choose the correct option?
   The magnetic field inside a long straight solenoid-carrying current
   (a) is zero.
   (b) decrease as we move towards its end.
   (c) increases as we move towards its end.
   (d) is the same at all points.
8. Which of the following property of a proton can change while it moves freely in a magnetic field? (There may be more than one correct answer).
   (a) mass (b) speed
   (c) velocity (d) momentum
9. How the displacement of rod AB will be affected if (i) current in rod AB is increased, (ii) a stronger horse-shoe magnet is used, and (iii) length of the rod AB is increased?
10. A positively-charged particle (alpha-particle) projected towards west is deflected towards north by a magnetic field. The direction of magnetic field is
    (a) towards south (b) towards east
    (c) downward (d) upward
11. State Fleming's Left hand rule.
12. What is the principle of an electric motor?
13. What is the role of the split ring in an electric motor.
14. Explain the different ways to induce current in a coil.
15. State the principle of an electric generator.
16. Name some sources of direct current.
17. Which sources produce alternating current.
18. Choose the correct options?
    A rectangular coil of copper wires is rotated in a magnetic field. The direction of the induced current changes once in each
    (a) two revolutions (b) one revolution
    (c) half revolution (d) one-fourth revolution
19. Name two safety measures commonly used in electric circuits and appliances.
20. An electric oven of 2 kW power rating is operated in a domestic circuit (220 V) that has a current rating of 5 A. What result do you expect ? Explain.
21. What precaution should be taken to avoid the overloading of domestic electric circuits?

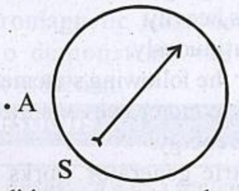
Text-Book Exercise :

1. Which of the following correctly describes the magnetic field near a long straight wire?
   (a) The field consists of straight lines perpendicular to the wire.
   (b) The field consists of straight lines parallel to the wire.
   (c) The field consists of radial lines originating from the wire.
   (d) The field consists of concentric circles centred on the wire.
2. The phenomenon of electromagnetic induction is
   (a) the process of charging a body.
   (b) the process of generating magnetic field due to a current passing through a coil.
   (c) producing induced current in a coil due to relative motion between a magnet and the coil.
   (d) the process of rotating a coil of an electric motor.
3. The device used for producing electric current is called a
   (a) generator (b) galvanometer
   (c) ammeter. (d) motor.
4. The essential difference between an AC generator and a DC generator is that
   (a) AC generator has an electromagnet while a DC generator has permanent magnet.
   (b) DC generator will generate a higher voltage.
   (c) AC generator will generate a higher voltage.
   (d) AC generator has slip rings while the DC generator has a commutator.
5. At the time of short circuit, the current in the circuit
   (a) reduces substantially.
   (b) does not change.
   (c) increases heavily.
   (d) very continuously.
6. State whether the following statements are true or false.
   (a) An electric motor converts mechanical energy into electrical energy.
   (b) An electric generator works on the principle of electromagnetic induction.
   (c) The field at the centre of a long circular coil carrying current will be parallel straight lines.
   (d) A wire with a green insulation is usually the live wire of an electric supply.

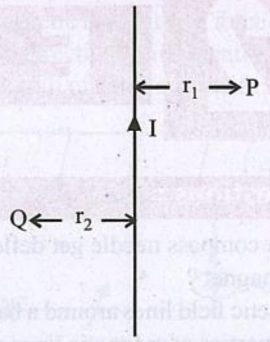
7. List three sources of magnetic fields.
8. How does a solenoid behave like a magnet? Can you determine the north and south poles of a current-carrying solenoid with the help of a bar magnet? Explain.
9. When is the force experienced by a current-carrying conductor placed in a magnetic field largest?
10. Imagine that you are sitting in a chamber with your back to one wall. An electron beam, moving horizontally from back wall towards the front wall, is deflected by a strong magnetic field to your right side. What is the direction of magnetic field?
11. Draw a labelled diagram of an electric motor. Explain its principle and working. What is the function of a split ring in an electric motor?
12. Name some devices in which electric motors are used.
13. A coil of insulated copper wire is connected to a galvanometer. What will happen if a bar magnet is (i) pushed into the coil (ii) withdrawn from inside the coil (iii) held stationary inside the coil?
14. Two circular coils A and B are placed close to each other. If the current in the coil A is changed, will some current be induced in the coil B? Give reason.
15. State the rule to determine the direction of a (i) magnetic field produced around a straight conductor carrying current, (ii) force experienced by a current carrying straight conductor placed in a magnetic field which is perpendicular to it, and (iii) current induced in a coil due to its rotation in a magnetic field.
16. Explain the underlying principle and working of an electric generator by drawing a labelled diagram. What is the function of brushes?
17. When does an electric short circuit occur?
18. What is the function of an earth wire? Why is it necessary to earth metallic appliances?

Exemplar Questions :

1. A magnetic compass needle is placed in the plane of paper near point A as shown in Figure. In which plane should a straight current carrying conductor be placed so that it passes through A and there is no change in the deflection of the compass? Under what condition is the deflection maximum and why?



2. Under what conditions permanent electromagnet is obtained if a current carrying solenoid is used? Support your answer with the help of a labelled circuit diagram.
3. AB is a current carrying conductor in the plane of the paper as shown in Figure. What are the directions of magnetic fields produced by it at point P and Q? Given $r_1 > r_2$, where will the strength of the magnetic field be larger?



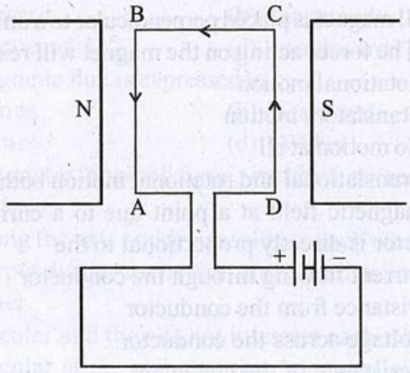
4. It is established that an electric current through a metallic conductor produces a magnetic field around it. Is there a similar magnetic field produced around a thin beam of moving (i) alpha particles, (ii) neutrons? Justify your answer.
5. What is the difference between a direct current and an alternating current? How many times does AC used in India change direction in one second?
6. Why does a magnetic compass needle pointing North and South in the absence of a nearby magnet get deflected when a bar magnet or a current carrying loop is brought near it. Describe some salient features of magnetic lines of field concept.

HOTS Questions :

1. Consider a circular loop of wire lying in the plane of the table. Let the current pass through the loop clockwise. Apply the right-hand rule to find out the direction of the magnetic field inside and outside the loop.
2. A current through a horizontal power line flows in east to west direction. What is the direction of magnetic field at a point directly below it and at a point directly above it ?
3. When is the force experienced by a current–carrying conductor placed in a magnetic field largest?
4. An electron in passing through a field but no forces acting on it. Under what condition it is possible, that the motion of the electron will be in the (i) electric field (ii) magnetic field?
5. A loop of irregular shape carrying current is located in an external magnetic field. If the wire is flexible, why does it change to a circular shape?
6. An electron does not suffer any deflection while passing through a region. Are you sure that there is no magnetic field? Is the reverse definite ?
7. Why is pure iron not used for making permanent magnets? Name one materials used for making permanent magnets. Describe how permanent magnets are made electrically. State two examples of electrical instruments made by using permanent magnets.
8. How does the strength of the magnetic field at the centre of a circular coil of wire depend on :
   (i) the radius of the coil
   (ii) the number of turns of wire in the coil
   (iii) the strength of current flowing in the coil ?

9. How will the magnetic field intensity at the centre of a circular coil carrying current change, if the current through the coil is doubled and the radius is halved?

10. A rectangular coil ABCD is placed between the pole pieces of a horse-shoe magnet as shown in figure.

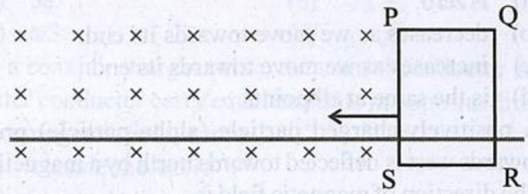


(i) What is the direction of force on each arm?
(ii) What is the effect of the forces on the coil?
(iii) How is the effect of force on the coil changed if the terminals of the battery are interchanged ?

11. If your metal car moves over a wide, closed loop of wire embedded in a road surface, will the magnetic field of the earth within the loop be altered? Will this produce a current pulse? Can you think of a practical application for this at a traffic intersection?

12. At the security area of an airport, you walk through a weak AC magnetic field inside a large coil of wire. What is the result of a small piece of metal on person that slightly alters the magnetic field in the coil?

13. The closed loop PQRS is moving into a uniform magnetic field acting at right angles to the plane of the paper as shown in the following figure. State the direction in which the induced current flows in the loop.



3 EXERCISE

Single Option Correct :

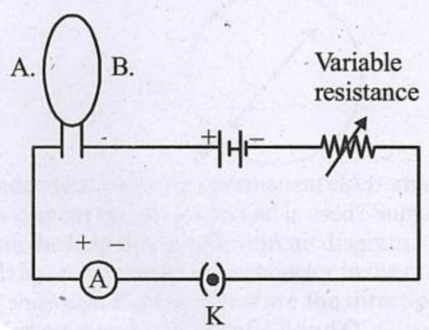
DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. Choose the correct option(s).
The magnetic field inside a long straight solenoid-carrying current
(a) is zero.
(b) decreases as we move towards its end.
(c) increases as we move towards its end.
(d) is the same at all points.

2. A positively-charged particle (alpha-particle) projected towards west is deflected towards north by a magnetic field. The direction of magnetic field is
(a) towards south (b) towards east
(c) downward (d) upward

3. Which of the following correctly describes the magnetic field near a long straight wire?
(a) The field consists of straight lines perpendicular to the wire.
(b) The field consists of straight lines parallel to the wire.
(c) The field consists of radial lines originating from the wire.
(d) The field consists of concentric circles centred on the wire.

4. A circular loop placed in a plane perpendicular to the plane of paper carries a current when the key is ON. The current as seen from points A and B (in the plane of paper and on the axis of the coil) is anti clockwise and clockwise respectively. The magnetic field lines point from B to A. The N-pole of the resultant magnet is on the face close to
(a) A
(b) B
(c) A if the current is small, and B if the current is large
(d) B if the current is small and A if the current is large



5. A small magnet is placed perpendicular to a uniform magnet field. The forces acting on the magnet will result in
(a) Rotational motion
(b) Translatory motion
(c) No motion at all
(d) Translational and rotational motion both

6. The magnetic field at a point due to a current carrying conductor is directly proportional to the
(a) current flowing through the conductor
(b) Distance from the conductor
(c) Voltage across the conductor
(d) Resistance of the conductor

7. Which one of the following substances is the magnetic substances?
(a) Mercury (b) Iron
(c) Gold (d) Silver

8. Magnetic lines do not intersect on one-another because
(a) they are at a distance
(b) they are in the same direction
(c) they are parallel to another
(d) at the point intersection there will be two direction of the magnetic force which is impossible

9. Instrument can be shielded from outside magnetic effects by surrounding them with
(a) Rubber shield (b) Glass shield
(c) Iron shield (d) Brass shield

10. By removing the inducing magnet, the induced magnetism is
(a) Finished after some time
(b) Finished just after
(c) Not finished for a long time
(d) Not changed

11. The effective length of the magnet is
(a) the complete length of the magnet
(b) the distance between the two poles of the magnet
(c) the half of the length of the magnet
(d) the square of the length of the magnet

12. When the bars of bismuth are placed between the magnetic poles they set their length
(a) perpendicular to the lines of force
(b) along the lines of force
(c) neither perpendicular nor along the lines of force
(d) In any direction

13. Which of the following processes will not produce new magnetic poles?
(a) cutting a bar magnet in half
(b) turning on a current in a solenoid
(c) running a current through a straight wire
(d) placing an iron rod in contact with a magnet

14. A tesla is equivalent to a
(a) newton per coulomb
(b) newton per ampere-meter
(c) ampere per newton
(d) newton per ampere-second

15. A vertical wire carries a current upward. The magnetic field north of the wire will be directed
(a) upward (b) eastward
(c) westward (d) northward

16. The magnetic flux is expressed in
(a) dynes (b) Oerested
(c) Gauss (d) Weber

17. The magnetic lines of force, inside a current carrying solenoid, are
(a) along the axis and are parallel to each other
(b) perpendicular to the axis and equidistance from each other
(c) circular and they do not intersect each other
(d) circular at the ends but they are parallel to the axis inside the solenoid.

18. Which of the following is not true
(a) Induction precedes attraction
(b) We cannot isolate a single pole
(c) We can magnetise an iron ring
(d) A permanent magnet retains its magnetism even when heated on a flame.

19. Which of the following statement is not correct about two parallel conductors carrying equal currents in the same direction?
(a) Each of the conductors will experience a force
(b) The two conductors will repel each other.
(c) There are concentric lines of force around each conductor
(d) Each of the conductors will move if not prevented from doing so

20. Which of the following determines the direction of magnetic field due to a current carrying conductor?
(a) Faraday's laws of electromagnetic induction
(b) Fleming's left-hand rule
(c) Lenz's rule
(d) Maxwell's cork screw rule

21. Along the direction of current carrying wire, the value of magnetic field is ?
(a) Zero
(b) Infinity
(c) Depends on the length of the wire
(d) Uncertain

22. To obtain maximum intensity of magnetic field at a point the angle between position vector of point and small elements of length of the conductor is
(a) 0 (b) $\pi/4$
(c) $\pi/2$ (d) π

23. The value of magnetic field due to a small element of current carrying conductor at a distance r and lying on the plane perpendicular to the element of conductor is
(a) zero
(b) maximum
(c) inversely proportional to the current
(d) none of the above

24. The value of intensity of magnetic field at a point due to a current carrying conductor depends
(a) Only on the value of current
(b) Only on a small part of length of conductor
(c) On angle between the line joining the given point to the mid point of small length and the distance between the small length of the point
(d) On all of the above

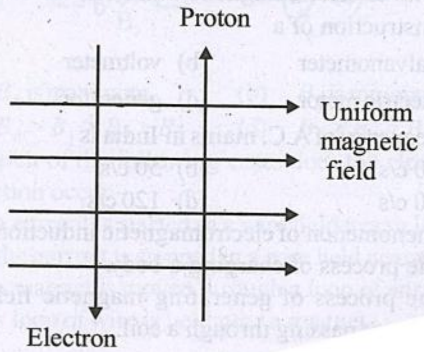
25. An electric current i is flowing in a circular coil of radius a. At what distance from the center of the axis of the coil will the magnetic field be 1/8th of its value at the centre ?
(a) 3a (b) $\sqrt{3}$ a
(c) a/3 (d) $a/\sqrt{3}$

26. In a coaxial, straight cable, the central conductor and the outer conductor carry equal currents in opposite direction. The magnetic field is zero-
(a) outside the cable
(b) inside the inner conductor
(c) inside the outer conductor
(d) in between the two conductors

27. When the number of turns in a toroidal coil is doubled, the value of magnetic flux density will become
(a) four times (b) eight times
(c) half (d) double

28. By a current carrying toroid, whose area of cross-section is fixed, the magnetic induction produced will be -
(a) maximum at inner end
(b) maximum at outer end
(c) maximum at center of area of cross-section
(d) equal at whole area of cross-section

29. A uniform magnetic field exists in the plane of paper pointing from left to right as shown in Figure. In the field an electron and a proton move as shown. The electron and the proton experience
(a) forces both pointing into the plane of paper
(b) forces both pointing out of the plane of paper
(c) forces pointing into the plane of paper and out of the plane of paper, respectively
(d) force pointing opposite and along the direction of the uniform magnetic field respectively



30. When an electron beam is moving in a magnetic field, then the work done is equal to the
(a) charge of electron
(b) magnetic field
(c) product of electronic charge and the magnetic field
(d) zero

31. Which of the following rays are not deflected by a magnetic field -
(a) α-rays (b) β-rays
(c) γ-rays (d) positive rays

32. Two parallel beams of electron moving in the same direction will
(a) repel each other
(b) attract each other
(c) not interact with each other
(d) annihilate each other

33. An inverse square law of distance is obeyed by-
(a) the force per unit length between two long straight parallel current-carrying conductors in vacuum.
(b) the electric field intensity outside an isolated charged sphere
(c) the magnetic flux density outside a long straight current-carrying wire
(d) the electrostatic potential

34. A current carrying loop lying in a magnetic field behaves like a.
(a) A magnetic dipole (b) magnetic pole
(c) magnetic material (d) non-magnetic material

35. Two identical coaxial circular loops carry a current i each circulating in the same direction. If the loops approach each other, you will observe that
(a) the current in each increases,
(b) the current in each decreases,
(c) the current in each remains the same,
(d) the current in one increases whereas that in the other decreases

36. An induced e.m.f. is produced when a magnet is plunged into a coil. The strength of the induced e.m.f. is independent of
(a) the strength of the magnet
(b) number of turns of coil
(c) the resistivity of the wire of the coil
(d) speed with which the magnet is moved

37. The laws of electromagnetic induction have been used in the construction of a
(a) galvanometer (b) voltmeter
(c) electric motor (d) generator

38. The frequency of A.C. mains in India is
(a) 30 c/s (b) 50 c/s
(c) 60 c/s (d) 120 c/s

39. The phenomenon of electromagnetic induction is –
(a) the process of charging a body.
(b) the process of generating magnetic field due to a current passing through a coil.
(c) producing induced current in a coil due to relative motion between a magnet and the coil.
(d) the process of rotating a coil of an electric motor.

40. The device used for producing electric current is called a
(a) generator (b) galvanometer
(c) ammeter (d) motor

41. The direction of induced current is obtained by
(a) Fleming's left hand rule
(b) Right hand thumb rule
(c) Biot and Savart rule
(d) Fleming's right hand rule

42. In an electric motor, conversion takes place of
(a) Chemical energy into electrical energy
(b) Electrical energy into mechanical energy
(c) Electrical energy into light
(d) Electrical energy into chemical energy

43. The current in a generator armature is AC because
(a) the magnetic field reverses at intervals
(b) the current in the field coils is AC
(c) the rotation of the armature causes the field through it to reverse
(d) the commutator feeds current into it in opposite directions every half cycle

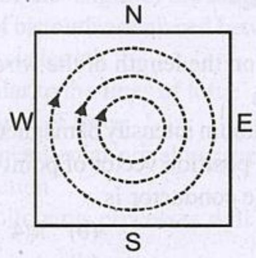
44. The current in the armature of a motor is reversed every half cycle due to the action of a(n)
(a) armature (b) field coil
(c) brush (d) commutator.

45. In an electric motor, the energy transformation is
(a) from electrical to chemical
(b) from chemical to light
(c) from mechanical to electrical
(d) from electrical to mechanical

46. The direction of induced current is obtained by
(a) Fleming's left hand rule
(b) Maxwell's cork-screw rule
(c) Ampere's rule
(d) Fleming's right hand rule

47. Direction of induced e.m.f. is determined by -
(a) Fleming's left hand rule
(b) Fleming's right hand rule
(c) Maxwell's rule
(d) Ampere's rule of swimming

48. A metal sheet is placed in a variable magnetic field which is increasing from zero to maximum. Induced current flows in the directions as shown in figure. The direction of magnetic field will be -



(a) normal to the paper, inwards
(b) normal to the paper, outwards
(c) from east to west
(d) from north to south

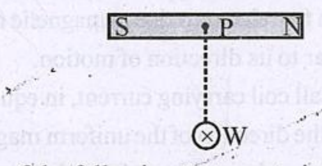
More than One Option Correct :

DIRECTIONS : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

1. Which of the following is/are valid for a current carrying circular coil?
(a) To induce magnetic induction of constant magnitude (at the centre of the coil), current required in it is directly proportional to its radius
(b) Induction of inducted magnetic field at the centre is inversely proportional to the radius of the coil
(c) Induction of the inducted magnetic field at the centre is directly proportional to the current flowing through the coil
(d) None of the above

2. A current flows along the length of a long thin cylindrical shell:
(a) magnetic field at all the points lying inside the shell is zero
(b) magnetic field at any point outside the shell varies inversely with distance from the surface of the shell
(c) magnetic field strength is maximum just outside the shell
(d) none of the above

3. Figure shows a bar magnet and a long straight wire W carrying current into the plane of the paper. Point P is the point of inersection of axis of the magnet and the line of the shortest distance between the magnet and the wire.



Which of the following statements is/are correct?
(a) If P is the midpoint of the magnet, the magnet experiences no torque
(b) If P is on the left of the midpoint of the magnet, the magnet experiences a leftward force as well as a torque
(c) If P is the midpoint of the magnet, the magnet experience a force along the line of the shortest distance
(d) None of the above

4. A straight conductor carries a current. Assume that all free electrons in the conductor move with the same drift velocity v. A and B are two observers on a straight line XY parallel to the conductor. A is stationary. B moves along XY with a velocity v in the direction of the free electrons.
(a) A and B observe the same magnetic field
(b) A observes a magnetic field, B does not
(c) A and B observe magnetic fields of the same magnitude but opposite directions
(d) A and B do not observe any electric field

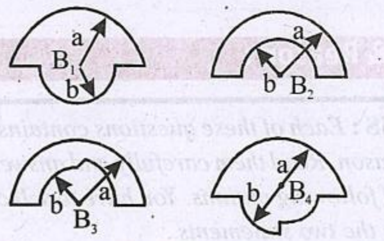
5. A charged particle enters into a space and continues to move undeflected. Then in that space:
(a) a uniform horizontal electric field and a vertical magnetic field may be present
(b) a vertical electric field alone may be present
(c) uniform electric and magnetic fields, both directed vertically downwards, may be present
(d) a uniform horizontal magnetic field alone may be present

6. A flat circular coil carrying a current has a magnetic moment μ:
(a) μ has only magnitude; it does not have direction
(b) the direction of μ is along the normal to the plane of the coil
(c) the direction of μ depends on the direction of current flow
(d) the direction of μ does not change if the current in the coil is reversed

7. A current carrying ring is placed in a magnetic field. The direction of the field is perpendicular to the plane of the ring:
(a) there is no net force on the ring
(b) the ring will tend to expand
(c) the ring will tend to contract
(d) either (b) or (c) depending on the directions of the current in the ring and the magnetic field

8. A solenoid is connected to a source of constant e.m.f. for a long time. A soft iron piece is inserted into it. Then:
(a) self-inductance of the solenoid gets increased
(b) flux linked with the solenoid increases; hence, steady state current gets decreased
(c) energy stored in the solenoid gets increased
(d) magnetic moment of the solenoid gets increased

9. In the loops shown in figure all curved sections are either semicircles or quarter circles. All the loops carry the same current. The magnetic fields at the centres have magnitudes B_1, B_2, B_3 and B_4:



(a) B_4 is maximum (b) B_3 is minimum
(c) $B_4 > B_1 > B_2 > B_3$ (d) $B_1 > B_4 > B_3 > B_2$

10. In which of the following cases does the electromagnetic induction occur –
(a) a current is started in a wire held near a loop of wire
(b) the current is stopped in a wire held near a loop of wire
(c) a magnet is moved through a loop of wire
(d) a loop of wire is held near a magnet

Passage Based Questions :

DIRECTIONS : *Study the given paragraph(s) and answer the following questions.*

Passage - I

Take a tightly-wound solenoid of radius a and length ℓ. the number of turns per unit length in it is n. It carries current i. Consider a small element of length dx of the solenoid at a distance x from one end. This contains ndx turns and can be assumed as a current carrying loop. The magnetic field due to whole solenoid will be the sum of magnetic field due to such elements.

1. The magnetic field due to this solenoid at the centre of its axis is :
   (a) $\frac{\mu_0 i}{2a}$ (b) $\frac{\mu_0 n i}{2a}$
   (c) $\frac{\mu_0 ni}{\sqrt{1+\frac{a^2}{\ell^2}}}$ (d) $\frac{\mu_0 n i}{\sqrt{1+\frac{4a^2}{\ell^2}}}$
2. The magnetic field due to the solenoid at the centre of its axis in the situation $a >> \ell$ is :
   (a) $\frac{\mu_0 n i}{2}$ (b) $\mu_0 ni$
   (c) $\frac{\mu_0 ni\ell}{2a}$ (d) $\frac{\mu_0 ni\ell}{a}$
3. The magnetic field due to the solenoid at the centre of its axis in the situation a << ℓ is :
   (a) zero (b) $\frac{\mu_0 n i}{2}$
   (c) $\mu_0 ni$ (d) infinite

Assertion & Reason :

DIRECTIONS : *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

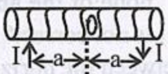
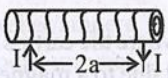
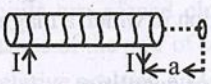
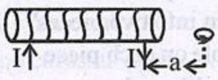
(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) **If Assertion is correct but Reason is incorrect.**
(d) **If Assertion is incorrect but Reason is correct.**

1. **Assertion :** A direction current flows through a metallic rod, produced magnetic field only outside the rod.
   Reason : There is no flow of charge carriers inside the rod.
2. **Assertion :** Force experienced by moving charge will be maximum if direction of velocity of charge is perpendicular to applied magnetic field.
   Reason : Force on moving charge is independent of direction of applied magnetic field.
3. **Assertion :** A neutral body may experience a net nonzero magnetic force.
   Reason : The net charge on a current carrying wire is zero, but it can experience a force in a magnetic field.
4. **Assertion :** There is no change in the energy of a charged particle moving in a magnetic field although a magnetic force is acting on it.
   Reason : Work done by centripetal force is always zero.
5. **Assertion:** When two long parallel wires, hanging freely are connected in series to a battery, they come closer to each other.
   Reason : Wires carrying current in opposite direction repel each other.
6. **Assertion :** A solenoid tends to expand, when a current passes through it.
   Reason : Two straight parallel metallic wires carrying current in same direction attract each other.
7. **Assertion :** In a conductor, free electrons keep on moving but no magnetic force acts on a conductor in a magnetic field.
   Reason: Force on free electrons due to magnetic field always acts perpendicular to its direction of motion.
8. **Assertion :** A small coil carrying current, in equilibrium, is perpendicular to the direction of the uniform magnetic field.
   Reason : Torque is maximum when plane of coil and direction of the magnetic field are parallel to each other.
9. **Assertion :** Basic difference between an electric line and magnetic line of force is that former is discontinuous and the later is continuous or endless.
   Reason : No electric lines of force exist inside a charged body but magnetic lines do exist inside a magnet.
10. **Assertion :** No net force acts on a rectangular coil carrying a steady current when suspended freely in a uniform magnetic field.
    Reason : Force on coil in magnetic field is always non-zero.
11. **Assertion :** An induced current has a direction such that the magnetic field due to the current opposes the change in the magnetic flux that induces the current.
    Reason : Above statement is in accordance with conservation of energy.

Multiple Matching Questions :

DIRECTIONS : *Following question has four statements (A, B, C and D) given in Column I and four statements (p, q, r and s) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

1. In column I, the positions of small current carrying loops have been shown and in column II information related to force experienced by coil is given. Match the entries of column I with the entries of column II. (Assume solenoid radius to be small as compared to its length)

Column-I	Column-II
A. 	(p) Attractive
B. 	(q) Repulsive
C. 	(r) Zero
D. 	(s) Initially zero, then starts increasing

	A	B	C	D
(a)	p	q	r	s
(b)	p, q	t	s	r
(c)	r	p	p	s
(d)	t	q, r	p, s	q

Integer/ Numeric Questions :

DIRECTIONS : *Following are integer based/Numeric based questions. Each question, when worked out will result in one integer or numeric value.*

1. The energy of a charged particle moving in a uniform magnetic field does not change. Explain
2. The flow of a current in a circular loop of wire creates a magnetic field at its centre. How may existence of this field be detected? State the rule which helps to predict the direction of this magnetic field.
3. A force of 1N is exerted on a conductor of length 3 m carrying a current of 2A when placed in a magnetic field. Find the strength of field?
4. A coil of radius 22 cm has 14 turns. Find strength of field if 5A current is flowing through the coil?
5. A circular coil of wire of radius 0.05 m having 500 turns carries a current of 1A. Calculate the magnetic field at the centre of the coil?
6. Find magnetic field in air 0.01 m away from an infinitely long wire that carries a current of 2A?
7. The radius of a circular coil having 20 turns is 15 cm. If a current of 60A is flowing through this circular coil, calculate the magnetic field produced at its centre?
8. A wire of length 0.04 m is placed perpendicular to a uniform magnetic field of magnitude 0.30 T? Calculate the force on the wire when the current flowing through it is 5A.
9. A particle having a charge of 1.6×10^{-19} coulomb is moving with a speed of 3.5×10^7 m/s in a magnetic field of 4T. Calculate the force experienced by this moving charged particle?

4 ADVANCE EXERCISE
BASED ON CONNECTING TOPICS

DIRECTIONS (Qs. 1-23) : *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONLY ONE is correct.*

1. A magnet is placed vertically on a paper. Then the number of neutral points obtained on the paper is
(a) zero (b) one
(c) two (d) three

2. A charge of 1.6×10^{-19} coulomb enters in the magnetic field of 2 weber/m² normally with a velocity of 10^5 m/sec. The force on the charge will be
(a) 3.2×10^{-14} N (b) 3.2×10^{-19} N
(c) 1.6×10^{-14} N (d) zero

3. The vertical plane which passes through the magnetic axis of a freely suspended magnet at rest is called
(a) Magnetic meridian (b) Geographical meridian
(c) North meridian (d) South meridian

4. The similar magnets of steel are .... than the magnets of soft iron
(a) stronger (b) of equal strength
(c) weaker (d) none of the above

5. A bar of soft iron is placed flat on the table. A bar magnet is taken and its south pole is placed on one end of the bar of soft iron. The magnet is held almost vertically. The bar is stroked from one end to the other with magnet. On the other end of the bar, magnet is lifted and again placed on the first end and the bar is again stroked. The end of the bar where the magnet is lifted will be
(a) south pole
(b) no pole
(c) south and north both type
(d) north pole

6. The angle of decilination at a place is the angle
(a) between the vertical plane and the geographical meridian
(b) between the vertical plane and the magnetic meridian
(c) between the geographical meridian and the magnetic meridian
(d) between the geographical meridian and horizontal plane

7. The magnetism in a magnet is mainly due to
(a) The orbital motion of the electrons
(b) The spin motion of the electrons
(c) The nuclear charge
(d) None of the above

8. When the north pole of a strong magnet is brought near to the north pole of a weak magnet then they will
(a) Attract each other
(b) repel each other
(c) first attract and then repel
(d) first repel and then attract

9. The angle of inclination of the axis of the magnetic needle to the horizontal plane when suspended freely and is at rest is known as
(a) angle of inclination (b) angle of variation
(c) angle of declination (d) none of the above

10. Which of the following statement is not correct?
(a) The dip angle is the angle between the horizontal and earth's total magnetic field.
(b) Neutral points are obtained where the earth's magnetic field is perpendicular to that due to a magnet
(c) A magnetic field is a region in which a magnetic force can be detected.
(d) Magnetic fields are vector quantities

11. When a bar magnet is broken into two pieces?
(a) we will have a single pole on each piece
(b) each piece will have two like poles
(c) each piece will have two unlike poles
(d) each piece will be lose magnetism

12. The permanent magnets are kept with soft iron pieces at ends as keepers
(a) to magnetise the soft iron pieces
(b) to increase the strength of the magnets
(c) to avoid self demagnetisation
(d) for physical safety of the magnets

13. The vertical component of the earth's magnetic field is
(a) zero at the magnetic pole
(b) zero at the geographic pole
(c) same everywhere
(d) zero at the magnetic equator

14. A small piece of a substance gas repelled when it is brought near a powerful magnet. The substance can be
(a) dimagnetic (b) paramagnetic
(c) ferromagnetic (d) non-magnetic

15. Whenever the magnetic flux linked with a coil changes, an induced e.m.f. is produced in the circuit. The e.m.f. lasts
(a) for a short time
(b) for a long time
(c) for ever
(d) so long as the change in flux takes place

16. A magnet is moved towards a coil (i) quickly (ii) slowly, then the induced e.m.f. is
(a) larger in case (i)
(b) smaller in case (i)
(c) equal in both the cases
(d) larger or smaller depending upon the radius of the coil

17. Lenz's law is a consequence of the law of conservation of
(a) charge (b) mass
(c) energy (d) momentum

18. The laws of electromagnetic induction have been used in the construction of a
(a) galvanometer (b) voltmeter
(c) electric motor (d) generator

19. Whenever, current is changed in a coil, an induced e.m.f. is produced in the same coil. This property of the coil is due to
(a) mutual induction (b) self induction
(c) eddy currents (d) hysteresis

20. If N is the number of turns in a coil, the value of self inductance varies as
(a) N^0 (b) N
(c) N^2 (d) N^{-2}

21. The SI unit of inductance, henry, can be written as
(a) weber/ampere (b) volt second/ampere
(c) joule/ampere^2 (d) all of these

22. Two coils are placed close to each other. The mutual inductance of the pair of coils depends upon
(a) relative position and orientation of the two coils.
(b) the materials of the wires of the coils.
(c) the currents in the two coils
(d) the rates at which currents are changing in the two coils

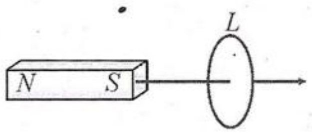
23. The current in a generator armature is AC because
(a) the magnetic field reverses at intervals
(b) the current in the field coils is AC
(c) the rotation of the armature causes the field through it to reverse
(d) the commutator feeds current into it in opposite directions every half cycle

DIRECTIONS (Qs. 24-27): *This section contains multiple choice questions. Each question has 4 choices (a), (b), (c) and (d) out of which ONE OR MORE may be correct.*

24. A proton moving with a constant velocity passes through a region of space without any change in its velocity. If E and B represent the electric and magnetic fields repectivelmy, this region of space may have:
(a) $E=0, B=0$ (b) $E=0, B\neq 0$
(c) $E\neq 0, B=0$ (d) $E\neq 0, B\neq 0$

25. In which of the following cases does the electromagnetic induction occur –
(a) a current is started in a wire held near a loop of wire
(b) the current is stopped in a wire held near a loop of wire
(c) a magnet is moved through a loop of wire
(d) a loop of wire is held near a magnet

26. Figure shows a loop model (loop L) for a diamagnetic material.



(a) The net dipole moment of the loop directed towards the magnet
(b) The net dipole moment of the loop directed away from the loop
(c) The loop gets attracted towards the magnet
(d) The loop gets repelled by the magnet.

27. Which of the following statements are true about the magnetic susceptibility χ_m of paramagnetic substance
(a) value of χ_m is inversely proportional to the absolute temperature of the sample
(b) χ_m is positive at all temperature
(c) χ_m is negative at all temperature
(d) χ_m does not depend on the temperature of the sample

DIRECTIONS (Qs. 28-33) : *Study the given paragraph(s) and answer the following questions.*

Passage - I

In a television tube, each of the electrons in the beam has a kinetic energy of 12.0 keV. The tube is oriented so that the electrons move horizontally from geomagnetic south to geomagnetic north. The vertical component of earth's magnetic field points down and has a magnitude of 55.0 μT.

28. The direction in which beam deflects :
(a) east (b) west
(c) north-east (d) south-west

29. The acceleration of any electron due to the magnetic field is :
(a) $3.14\times 10^{14}\,m/s^2$ (b) $4.28\times 10^{14}\,m/s^2$
(c) $5.56\times 10^{12}\,m/s^2$ (d) $6.28\times 10^{14}\,m/s^2$

30. The transverse deflection of the beam after travelling 20.0 cm through the television tube :
(a) 1.96 mm (b) 2.98 mm
(c) 4.24 mm (d) none of these

Passage II

Modern Trains are based on Maglev technology in which trains are magnetically leviated, which runs its EDS Maglev System. These are coils on both sides of wheels. Due to motion of train current induces in the coil of track which levitate it. This is in accordance with Lenz's law. If trains lower down, then due to Lenz's law a repulsive force increases due to which train gets uplifted and if it goes much high then there is a net downward force due to gravity. The advance of Maglev train is that there is no friction ebtween the trains and the track, thereby reducing power consumption and enabling the train to attain very high speeds. Disadvantage of Maglev train is that as it slows down the electromagnetic force decreases and it become difficult to keep it leviated and as it moves forwards, according to Lenz's law there is an electromagnetic drop force.

31. What is the advantage of this system?
(a) No friction, hence no power consumption
(b) No electric power is used
(c) Gravitation force is zero
(d) Electrostatic force draws the train

32. What is the disadvantage of this system?
(a) Train experiences an upward force according to Lenz's law
(b) Friction force creates a drag on the train
(c) Retardation
(d) By Lenz's law, train experiences a drag

33. Which force causes the train to elevate up?
(a) Electrostatic force
(b) Time varying electric field
(c) Magnetic force
(d) Induced electric field

DIRECTIONS (Qs. 34-37): *Each of these questions contains an Assertion followed by reason. Read them carefully and answer the question on the basis of following options. You have to select the one that best describes the two statements.*

(a) If both **Assertion** and **Reason** are **correct** and Reason is the **correct explanation** of Assertion.
(b) If both **Assertion** and **Reason** are correct, but Reason is **not the correct explanation** of Assertion.
(c) **If Assertion is correct but Reason is incorrect.**
(d) **If Assertion is incorrect but Reason is correct.**

34. **Assertion :** A proton moves horizontally towards a vertical long conductor having an upward electric current. It will deflect vertically downward.
Reason : Seeing the proton and the conductor from the side of the proton, the magnetic field at the site of the proton will be towards right. Hence the force $\vec{F} = q\vec{v} \times \vec{B}$ will deflect the proton vertically downward.

35. **Assertion :** An induced e.m.f. appears in any coil in which the current is changing.
Reason : Self induction phenomenon obeys Faraday's law of induction.

36. **Assertion :** Lenz's law violates the principle of conservation of energy.
Reason : Induced e.m.f. always opposes the change in magnetic flux responsible for its production.

37. **Assertion :** When number of turns in a coil is doubled, coefficient of self-inductance of the coil becomes 4 times.
Reason : This is because $L \propto N^2$.

DIRECTIONS (Qs. 38-39) : *Following question has four statements (A, B, C and D) given in Column I and four statements (p, q, r and s) in Column II. Any given statement in Column I can have correct matching with one or more statement(s) given in Column II. Match the entries in column I with entries in column II.*

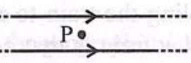
38. In magnetic field, for a charged particle, match the entries of column I with the entries of column II.

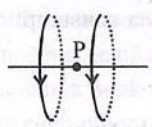
Column I	**Column II**
(A) Acceleration	(p) may be zero
(B) Velocity	(q) is zero
(C) Speed	(r) may be constant
(D) Kinetic energy	(s) is constant

	A	B	C	D
(a)	p	r	s	s
(b)	s	p	q	r
(c)	p, q	s	r, s	q
(d)	q, s	q, r	s	s

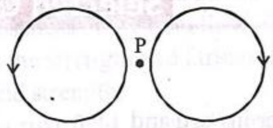
39. Two wires each carrying a steady current I are shown in four configurations in Column I. Some of the resulting effects are described in Column II. Match the statements in Column I with the statements in column II

Column I	**Column II**
(A) Point P is situated midway between the wi es.	(p) The magnetic fields (B) at P due to the currents in the wires are in the same direction.
(B) Point P is situated at the mid-point of the line joining the centers of the circular wires, which have same radii.	(q) The magnetic fields (B) at P due to the currents in the wires are in opposite directions.



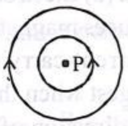


(C) Point P is situated at the mid-point of the line joining the centers of the circular wires, which have same radii.



(r) There is no magnetic field at P.

(D) Point P is situated at the common center of the wires.



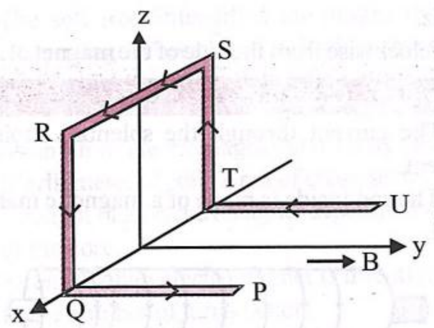
(s) The wires repel each other.

	A	B	C	D
(a)	p, r	r, s	q, s	s
(b)	s	p	q	r
(c)	q, r	p	q, r	q, s
(d)	q, s	q, r	s	s

DIRECTIONS (Qs. 40-45): *Following are integer based/Numeric based questions. Each question, when worked out will result in one integer or numeric value.*

40. At a certain position, earth's magnetic field of 39 μT is horizontal and directed due north. Suppose the net field is zero exactly 8.0 cm above a long, straight, horizontal wire that carries a constant current. What are (a) the magnitude and (b) the direction of the current ?

41. A wire PQRSTU (with each side of length L) bent as shown in figure and carrying a current I is placed in a uniform magnetic field B parallel to positive y direction. What is the force experienced by the wire?



42. An electron is projected with a velocity of 10^5 m/s at right angles to a magnetic field of 0.019G . Calculate the radius of the circular path described by the electron, if charge of electron $e = 1.6 \times 10^{-19}$ C, and mass of electron $m = 9.1 \times 10^{-31}$ kg.

43. Find the self inductance of a coil in which an e.m.f. of 10 V is induced when the current in the circuit changes uniformly from 1 A to 0.5 A in 0.2 sec.

44. The mutual inductance of a pair of coils is 0.75 H. If current in the primary coil changes from 0.5 A to zero in 0.01 s find average induced e.m.f. in secondary coil.

45. An AC generator of 220 V having internal resistance $r = 10\Omega$ and external resistance $R = 100\Omega$. What is the power developed in the external circuit?

SOLUTIONS

Brief Explanations of Selected Questions

1 EXERCISE

Fill in the Blanks :

1.	small	2.	magnetic field
3.	greater.	4.	magnetic
5.	right-hand	6.	north magnetic
7.	electromagnets	8.	tesla
9.	Weber	10.	magnetic
11.	S	12.	field, current
13.	downward	14.	currents
15.	clockwise	16.	increase
17.	circles	18.	None
19.	south		
20.	electrical, electromagnetic induction.		
21.	220 V, 50 Hz.	22.	60 Hz
23.	magnetic	24.	commutator
25.	A.C	26.	self-induction
27.	henry	28.	the magnetic flux
29.	90		

True / False :

1. True	2. True	3. False	4. True
5. False	6. True	7. True	8. True
9. True	10. False	11. True	12. False
13. True	14. True	15. True	16. True
17. False	18. False	19. False	

Match the Following :

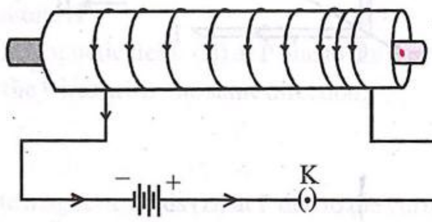
1. (A) $\to$ q, (B) $\to$ s, (C) $\to$ r, (D) $\to$ p
2. (A) $\to$ r, (B) $\to$ q, (C) $\to$ s, (D) $\to$ p
3. (A) $\to$ r, (B) $\to$ q, (C) $\to$ r, (D) $\to$ p

Very Short Answer Questions :

1. A compass needle gets deflected when brought near a bar magnet because magnetic force is exerted by the bar magnet on the compass needle, which is itself a tiny pivoted magnet.
2. The current is in the east-west direction. Applying the right-hand thumb rule, we get that the direction of magnetic field at a point below the wire is from north to south. The direction of magnetic field at a point directly above the wire is from south to north.
3. Two magnetic lines of force never intersect each other. If the lines intersect, then at the point of intersection there would be two directions (the needle would point towards two directions) for the same magnetic field, which is not possible.
4. Direction of magnetic field inside the loop – Perpendicular to the plane of paper inward and
Direction of magnetic field outside the loop – Perpendicular to the plane of paper outward.
5. (a) Natural and artificial magnets. (b) Electromagnets (c) A current carrying conductor produces magnetic field.
6. The force experienced by a current-carrying conductor placed in a magnetic field is largest when the direction of current is at right-angles to the direction of the magnetic field.
7. Oersted's experiment demonstrates the magnetic effect of current. It showed experimentally that the current flowing through a conductor produces a magnetic field.
8. (i) Bar type (ii) Horse shoe type
13. (i) Along the axis of the coil inwards
(ii) Along the axis of the coil outwards.
15. Magnetic field lines at any point constitute the field of a magnet indicating that a north pole experiences a force at that point.
16. Magnetic field. It is a vector quantity.
17. Fleming's left hand rule.
18. M, B, I are represented by thumb, forefinger and middle finger of the right hand.
19. The A.C. generator has two slip rings.
20. Frequency of an alternating current is 50 Hz. It changes the direction after every sec. i.e. the direction of current change 100 times per second.
21. 50 Hz.
22. Anticlockwise from the side of the magnet.

Short Answer Questions :

5. (i) The current through the solenoid should be direct current.
(ii) The rod inside is made of a magnetic material such as steel.



6. Into the plane of paper at P and out of it at Q. The strength of the magnetic field is larger at the point located closer i.e. at Q.
7. The divergence, that is, the falling degree of closeness of magnetic field lines indicates the fall in strength of magnetic field near and beyond the ends of the solenoid.

8. (i) The direction of the magnetic field is indicated by the arrow in the line at any point (Tangent).
(ii) The field lines come out of the north pole and get into the south pole (closed loops are formed).
(iii) The strength of magnetic field is indicated by the closeness of the field lines. Closer the lines, more will be the strength and farther the lines, lesser will be the field strength.
(iv) No two field lines will intersect each other if they intersect there will be two different directions for field at the same point which is not impossible.

9. The current is perpendicular to the field, $B = \frac{F}{I\ell}$

Therefore, $B = \frac{2.4\times10^{-4}\,N}{(12A)\,(0.30m)} = 6.7\times10^{-5}\,N/A.m$

Since 1mT is 10^{-3} N/A.m, the answer can be written as 0.067 mT

10. With the wire perpendicular to the field,

$F = I\ell B = (1.5A)\,(0.20m)\,(0.040T) = 0.012\ N$

11. Point you left fingers upward, since your are dealing with a negative charge. Rotate your hand until the thumb points east. Your palm will point northward, and that is the direction of the force.

12. Concentric lines around the two ends of the conductor and straight lines at the centre of the conductor.

13. A cylindrical coil of many tightly wound turns of insulated wires with generally diameter of the coil smaller than its length is called a solenoid.

14. (i) Soft iron has less retentivity so it acquires the magnetic properties only when the current flows through the coil wound on it and loses the magnetic properties as the current is switched off.
(ii) The soft iron intensifies the magnetic field of the electromagnet because of its high permeability.

15. Factors on which the strength of an electromagnet depends are:
(1) Strength of electromagnet is directly proportional to the diameter of coil (Area of cross-section).
(2) Strength of an electromagnet depends upon the nature of the core.
(3) Strength of an electromagnet is directly proportional to the number of turns in coil.
(4) Strength of electromagnet is directly proportional to current.

16. (i) A current is induced in a coil when a magnet is moved relative to the fixed coil.
(ii) A current is also induced in a coil when it is moved relative to a fixed magnet.
(iii) Not any current is induced in a coil when the coil and magnet both are stationary relative to one another.
(iv) When the direction of motion of magnet or coil is reversed, the direction of current induced in the coil also gets reversed.

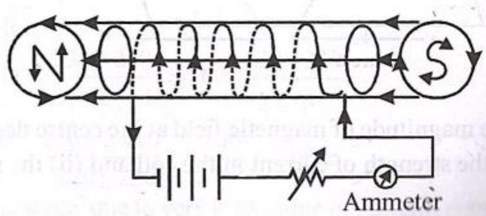
17. (i) The direction of magnetic field produced around a current-carrying conductor is given by right hand thumb rule. If the conductor carrying current is held in the right hand in such a way that the thumb points in the direction of current, then direction of curl of fingers gives the direction of the magnetic field.
(ii) The direction of force experienced by a straight conductor carrying-current placed in a magnetic field, which is perpendicular to it determined by Fleming's left hand rule. Hold the thumb and first two fingers of the left hand at right angles to each other with the first finger pointing the direction of the field and the second finger in the direction of the current, then the thumb points in the direction of the motion.
(iii) The direction of current induced in a circuit by changing magnetic flux due to motion of a magnet is determined by Fleming's right-hand rule. If we stretch our right hand in such a way that the thumb, forefinger and central finger remain perpendicular to echo other, so that the forefinger indicates the direction of the magnetic field and the thumb in the direction of motion of conductor. Then the central finger indicates the direction of induced current.

18. Principle : It is based on the principle of electromagnetic induction, which is the process of producing induced current in a coil by relative motion between a magnet and the coil.
Function of brushes : The brushes carry the contact from rings to external load resistance.

Long Answer Questions :

1. The magnetic field produced around a straight current carrying conductor is in the form of concentric circles with the centre lying on the straight conductor.
Take a copper wire AB. Pass it through a cardboard. Connect the wire to a battery through a key. Sprinkle some iron filings on the cardboard. Switch on the key and tap the cardboard gently. You will find that the iron filings arrange themselves in the form of concentric circles. Reverse the direction of current by changing the polarity of the battery. You will find that this time too, the iron filings arrange themselves in concentric circle but in opposite direction.
Hence, the magnetic field lines of force around a straight conductor carrying electric current are concentric circles with the conductor at the centre. The direction of magnetic field changes if the direction of current is reversed.

2. (i) The polarity acquired by the two ends is as shown below. (A shows North and B shows South polarity
(ii)

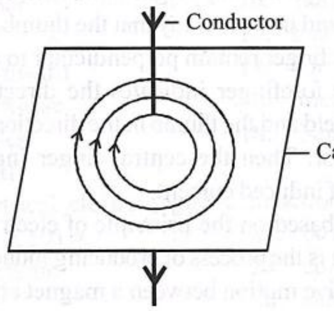


(iii) Increase the strength of current, increase the number of turns in the coil, insert soft iron rod in the coil.

3. (a) Given : Length of the wire (ℓ) = 0.4 m
Current (I) = 15A
Magnetic induction (B) = 0.1 N/Am
To calculate : (i) Force (F) = ? (ii) Direction = ?
Formula to be used : $F = BI\ell$
Substituting the given values,
$F = 0.1 \times 15 \times 0.4 = 0.6\,N$.

(b) By Fleming's left hand rule, forefinger (magnetic field) points vertically downwards, the middle finger (current) points west and the thumb (force) points towards the south.

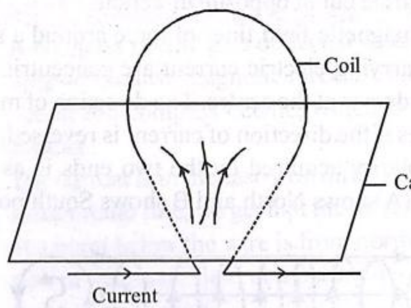
4. Figure shows the setting of the iron filings.



(i) The shape of distribution of iron filings remains unchanged but they get arranged upto a larger distance from the conductor when the strength of current is increased. This is because on increasing the strength of current, the strength of the magnetic field is increased and it is effective upto a larger distance from the conductor.

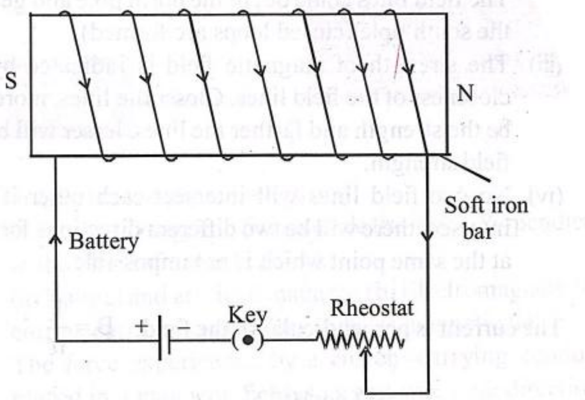
(ii) Magnetic field strength is increased so the iron filings get arranged upto a larger distance.

5. Figure represents the magnetic lines of force due to current carrying coil.



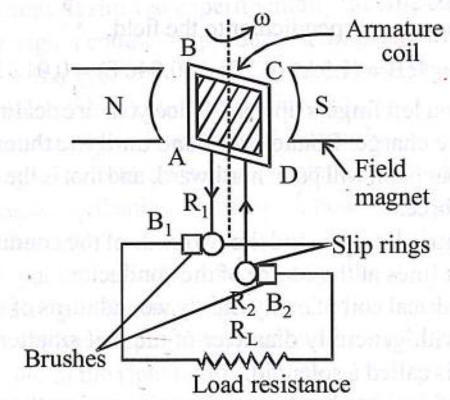
The magnitude of magnetic field at the centre depends on (i) the strength of current in the coil and (ii) the radius of coil.

6. The labelled diagram is shown in figure.



Precaution : The source of current must be the d.c. source.

10.



Principle: A dynamo or generator is a device which converts mechanical energy into electrical energy. It is based on the principle of electromagnetic induction.
Construction: It consists of four main parts-

(i) Field magnet: It produces the magnetic field. For a low power dynamo, the magnetic field in generated by a permanent magnet but for a large power dynamo, the magnetic field is produced by an electromagnet.

(ii) Armature: It consists of a large number of turns of insulated copper wire on a soft iron core. It can revolve round the axis between the two poles of the field magnet. The soft iron core provides support to the coils and increases the magnetic field through the coil.

(iii) Slip rings: The slip rings R_1 and R_2 are two metal rings to which the ends of the armature coil are connected. These rings are fixed to the shaft which rotates the armature coil so that the rings also rotate along with the armature.

(iv) Brushes (B_1 and B_2): These are flexible metal plates or carbon rods which are fixed and constantly touch the revolving rings. The output current in external load resistance R_1 is taken through these brushes.

Working: When the armature coil is rotated in the strong magnetic field, the magnetic flux linked the coil changes and the current is induced in the coil. The direction of current is given by Flemming's left hand rule. It remains same during the first half turn of the armature. During the second half revolution, the direction of current is reversed.

If N is the number in the coil, f is the frequency of rotation, A is the area of the coil and B is the magnetic field intensity then induced e.m.f..

$$e = -\frac{d\phi}{dt} = \frac{d}{dt}(NBA\cos 2pft) = 2pNBAf\sin 2pft$$

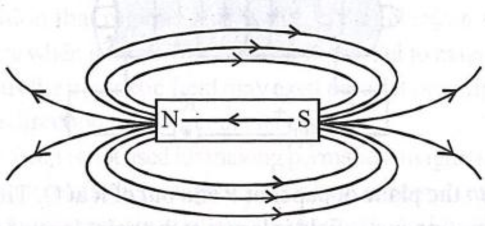
Therefore, the e.m.f. produced is alternating in nature and the current is also alternating.

Current produced in a.c. generator can not be measured by moving coil galvanometer, because average value of a.c. over full cycle is zero.

2 EXERCISE

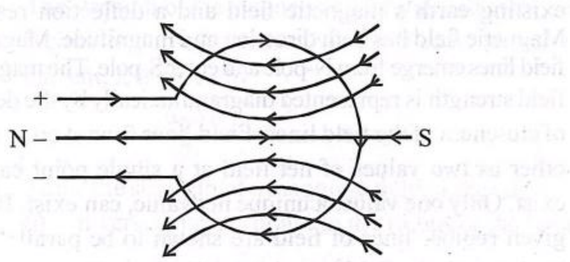
Text-Book Questions :

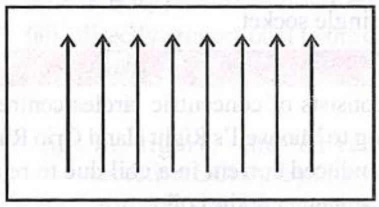
1. Compass needle is a tiny magnet, so due to force of repulsion or attraction between the poles of a magnet, there is a deflection in the compass needle.

2. 

3. Magnetic field lines emerge from N-pole and enter S-pole. The magnetic field strength is represented diagrammatically by the degree of closeness of the field lines. Field lines cannot cross each other as two values of net field at a single point cannot exist. Only one value, a unique net value, can exist. If in a given region, lines of field are shown to be parallel and equispaced, the field is understood to be uniform.

4. Because we cannot have two directions of the magnetic field at the same point.

5. 

6. 

Magnetic field lines are parallel straight lines for a uniform field. The lines are closer for a strong field and for away for a weak one.

7. (d)

8. (b, c, d)

9. We know that when a current carrying conductor is kept in a magnetic field, the force acting on it is given by

$F = BIL$

(i) $F \propto I$ I increases then force increases, hence, displacement is more

(ii) $F \propto B$ B increases then force increases, hence, displacement is more

(iii) $F \propto L$ L increases then force increases, hence, displacement is more

10. (d) upward, according to the Fleming's Right Hand Thumb Rule.

11. Refer to theory.

12. Refer to theory.

13. The split ring acts as a commutator. The reversal of current also reverses the direction of force acting on the arms of the coil. At this stage, the commutator reverses the direction of current.

14 (a) Either coil or a magnet should be in motion relative to each other.

(b) If there is a relative motion between a current carrying coil and a coil without current.

15. Refer to Theory.

16. (i) Electro chemical cells (ii) Lead accumulator (iii) D.C. Generator.

17. A.C. generator, hydropower stations, etc.

18. (c) half revolution

19. (a) A fuse of proper rating should be used to avoid damages due to short circuiting and overloading.

(b) Earthing should be provided to avoid shocks when the live wire touches the body of the appliances.

20. $P = \frac{V^2}{R}$

$$2\times10^3 = \frac{220\times220}{R} \Rightarrow R = \frac{220\times220}{2\times10^3}$$

$$I = \frac{V}{R} = \frac{220\times2\times10^3}{220\times220} = \frac{100}{11} = 9.09A$$

At this stage, due to very high value of current, oven will be damaged.

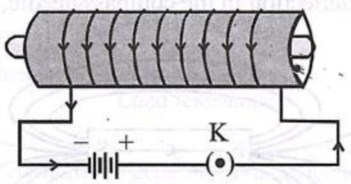
21. We can avoid overloading by not connecting too many appliances to a single socket.

Text-Book Exercise :

1. (d) The field consists of concentric circles centred on the wire according to Maxwell's Right Hand Grip Rule.
2. (c) Producing induced current in a coil due to relative motion between a magnet & the coil.
3. (a) Generator. It is also called alternator.
4. (d) AC generator has slip rings while the DC generator has a commutator.
5. (c) Increases heavily
6. (a) F, (b) T, (c) T, (d) F.
7. (i) A natural manget (ii) A current carrying conductor (iii) A solenoid.
8. A coil of many circular turns of insulated copper wire in the shape of a cylinder is called a solenoid. One end of a solenoid behaves like north pole and the other end as south pole. The field lines inside the solenoid are in the form of parallel lines. So, the field is uniform inside the solenoid.
   Yes, If we bring the north pole of a bar magnet near one end of a current carrying solenoid and if it is attracted, then this end behaves as south pole & the other end is north pole.
9. We know that the force experienced by a current carrying conductor in a magnetic field is
   $F = BIL \sin \theta$.
   So, if θ (i.e., angle between the direction of magnetic field and current carrying conductor) is maximum i.e., 90°, then the force is maximum.
10. The magnetic field is perpendicular to the plane containing the beam of electrons and the force acting on it.
11. Refer to theory.
12. (a) Fan (b) Motor cycle
    (c) Cooler (d) Air conditioner.
13. (i) When a bar magnet with its north pole facing the coil is moved towards the coil, the galvanometer shows a deflection.
    (ii) When a bar magnet is moved away from the coil galvanometer again shows deflection but now in opposite direction.
    (iii) When the bar magnet is stationary near the coil, no deflection in the galvanometer is observed.
14. Yes, we know that larger the current, stronger will be the magnetic field. As there is change in current in coil A, there is a decrease in the number of magnetic field lines passing through coil B and hence, due to change in the number of magnetic field lines, there is an induced current in coil B.
15. (i) Maxwell's Right Hand Thumb Rule
    (ii) Fleming's Left Hand Rule
    (iii) Fleming's Right Hand Rule
16. Refer to theory.
17. Electric short circuit occurs when
    (i) a current of value more than its rating passes through a wire;
    (ii) the live wire touches with the earth or neutral-wire;
    (iii) the insulation of the wires is weak;
    (iv) over load is provided in the circuit.
18. The earth wire is a wire which connects a given appliance to the earth. It is used as a safety measure especially for electric appliances having a metallic body. Whenever the live wire touches the body of the appliance, the current passes to the earth and the user doesn't suffer a severe electric shock.

Exemplar Questions :

1. In the plane of the paper itself. The axis of the compass is vertical and the field due to the conductor is also vertical. It could result in a dip of compass needle which is not possible in this case (dips result only if axis of compass is horizontal). The deflection is maximum when the conductor through A is perpendicular to the plane of paper and the field due to it is maximum in the plane of the paper.
2. (i) The current through the solenoid should be direct current.
   (ii) The rod inside is made of a magnetic material such as steel.



3. *Into* the plane of paper at P and *out* of it at Q. The strength of the magnetic field is larger at the point located closer i.e., at Q.
4. (i) Yes, Alpha particles being positively charged constitutes a current in the direction of motion. (ii) No. The neutrons being electrically neutral constitute no current.
5. Direct current always flows in one direction but the alternating current reverses its direction periodically. The frequency of AC in India is 50 Hz and in each cycle it alters direction twice. Therefore AC changes direction 2 × 50 = 100 times in one second.
6. Current carrying loops behave like bar magnets and both have their associated lines of field. This modifies the already existing earth's magnetic field and a deflection results. Magnetic field has both direction and magnitude. Magnetic field lines emerge from N-pole and enter S-pole. The magnetic field strength is represented diagrammatically by the degree of closeness of the field lines. Field lines cannot cross each other as two values of net field at a single point cannot exist. Only one value, a unique net value, can exist. If in a given region, lines of field are shown to be parallel and equispaced, the field is understood to be uniform.

Hots Questions :

1. Direction of magnetic field inside the loop is perpendicular to the plane of paper inward and direction of magnetic field outside the loop is perpendicular to the plane of paper outward.
2. The current is in the east-west direction. Applying the right-hand thumb rule, we get that the direction of magnetic field at a point below the wire is from north to south. The direction of magnetic field at a point directly above the wire is from south to north.
3. The force experienced by a current-carrying conductor placed in a magnetic field is largest when the direction of current is at right-angles to the direction of the magnetic field.
4. (i) In electric field, there is always a force on the moving electron opposite to the direction of field. Thus the force will be zero only if field is zero.
   (ii) In magnetic field, the force acting on a moving electron is $F = q v B \sin\theta$, it is zero if $\theta = 0°$ or $180°$ i.e., the electron is moving parallel to the direction of magnetic field.
5. It assumes circular shape with its plane normal to the field to maximize flux, since for a given perimeter, a circle encloses greater area than any other shape.
6. If electron passing through a certain region does not suffer any deflection, then we are not sure that there is no magnetic field in that region. This is due to that electron suffers no force when it moves parallel or antiparallel to magnetic field. Thus the magnetic field may exist parallel or antiparallel to the direction of motion of electron.
7. Pure iron is not used for making permanent magnets because it cannot retain their magnetism for long time and used only for electromagnet since alloys of iron and steel have strongly magnetised and have a capacity to hold it for a longer time period, they are used for permanent magnets.
   Material used for permanent magnet–ALNICO. Formation of a permanent magnet electrically. Permanent magnets can be formed by placing a hard steel rod in the strong uniform magnetic field produced by the solenoid. Steels have the quality to retain its magnetism after switch off the solenoid current.
   Permanent magnets are used in
   (i) Galvanometer
   (ii) Ammeter.
8. The strength of the magnetic field produced at the centre of a circular coil of radius r, having N turns and carrying a current, I, is given by
   $$B = \frac{\mu_0 N I}{2r} \text{ testla}$$
   Thus, the strength of a magnetic field in the coil is
   (i) inversely proportional to the radius of the loop.
   $$\left(B \propto \frac{1}{r}\right)$$
   (ii) directly proportional to the number of turns. $(B \propto N)$
   (iii) directly proportional to the current passing through it. $(B \propto I)$
9. Four times
10. (i) In figure, the current in the coil is in direction DCBA. By Fleming's left hand rule, on the arm AB, the force is outward at right angles to the plane of the coil. On the arm BC no force acts. On the arm CD, the force is inwards perpendicular to the plane of the coil. On the arm DA, no force acts.
    (ii) The force on the arms AB and CD are equal in magnitude, but opposite in direction. They form a clockwise couple. So the coil will rotate clockwise with the arm AB coming out and the arm CD going in.
    (iii) On interchanging the terminals of the battery, the coil will rotate anticlockwise.
11. Yes, our metal cars moving over a wide, closed loop of wire embedded in a road surface, change the magnetic field of the earth within the loop.
    This change in the magnetic field induces currents in the wire loops and a current pulse is produced.
    At a traffic intersection, the color of the traffic light changes as a result of these current pulses.
12. As soon as the piece of metal changes the magnetic field in the coil, voltage is induced which sounds an alarm and the security personnel detect the metal.
13. The direction of induced current will be anti-clockwise i.e. along PSRQP. This is given by Flemming's right hand rule.

3 EXERCISE

Single Option Correct :

1.	(d)	2.	(d)	3.	(d)	4.	(a)	5.	(a)
6.	(a)	7.	(b)	8.	(d)	9.	(c)	10.	(b)
11.	(b)	12.	(a)	13.	(c)	14.	(b)	15.	(c)
16.	(d)	17.	(a)	18.	(d)	19.	(b)	20.	(d)
21.	(a)	22.	(c)	23.	(b)	24.	(d)	25.	(b)
26.	(a)	27.	(d)	28.	(d)	29.	(c)	30.	(d)
31.	(c)	32.	(b)	33.	(b)	34.	(a)	35.	(b)
36.	(c)	37.	(d)	38.	(b)	39.	(c)	40.	(a)
41.	(d)	42.	(b)	43.	(c)	44.	(d)	45.	(d)
46.	(d)	47.	(b)	48.	(b)				

More Than One Option Correct :

1.	(a, b, c)	2.	(a, c)	3.	(a, b, c)	4.	(a, d)
5.	(b, c, d)	6.	(b, c)	7.	(a, d)	8.	(a, c, d)
9.	(a, b, c)	10.	(a, b, c)				

Passage Based Questions :

1. (d) 2. (c) 3. (c)

Assertion & Reason :

1. (b) In the case of metallic rod, the charge carries flow through whole of the cross section. Therefore, the

magnetic field exists both inside as well as outside. However magnetic field inside the rod will go no decreasing as we go towards the axis.

2. (c) From equation F = qvB sin θ. Force on moving charge will be maximum if direction of velocity of charge is perpendicular to direction of magnetic field (when θ = 90°)

3. (a)

4. (a) Magnetic force is always perpendicular to the direction of motion of charged particle, i.e., work done on the charge particle moving on a circular path in magnetic field is zero.

5. (b) The wires are parallel to each other but the direction of current in it is in same direction so they attract each other. If the current in the wire is in opposite direction then wires repel each other. When the currents are in opposite directions, the magnetic forces are reversed and the wires repels each other

6. (d) When current flows through a solenoid, the currents in the various turns of the solenoid are parallel and in the same direction. Since the currents flowing through parallel wires in the same direction lead to force of attraction between them, the turns of the solenoid will also attract each other and as a result the solenoid tends to contract.

7. (c) In a conductor, the average velocity of electrons is zero. Hence no current flows through the conductor. Hence, no force acts on this conductor.

8. (b) The torque acting on a coil is given by,

$$\tau = NIAB \sin\theta$$

where θ is the angle between the plane of the coil and the direction of magnetic field. When θ = 90°, then τ = 0. The coil tries to orient itself in this position. Thus in equilibrium, the coil acquires a position, such that its plane makes an angle 90° with the direction of magnetic field.

9. (a) In case of the electric field of an electric dipole, the electric lines of force originate from positive charge and, end at negative charge. Since, isolated magnetic lines are closed continuous loops extending throughout the body of magnet, hence they from endless curves.

10. (c) Force acting on each pair of the opposite sides of the coil are eq.

11. (a)

Muliple Matching Question:

1. (c) A → r; B → p; C → p; D → s

The force experienced by a coil in a magnetic field is given by $F = P_m \frac{\partial B}{\partial r}$, where $\frac{\partial B}{\partial r}$ is the increment of B along magnetic dipole moment of contour. You can write the expression for magnetic field due to solenoid at a general point and then differentiate it. From this information, you can have the results. Whether the force is attractive or repulsive can also be found by using the concept of nature of poles induced on the solenoid and coil.

The force comes out to be zero at centre and as we approach it from some outside point, its value increases.

For D: The coil first rotates to allign itself in such a manner so as to link the maximum flux and then the case would be same as that of C.

Integer/Numeric Question:

1. When a charged particle is moving in a uniform magnetic field it experiences a force in a direction, perpendicular to its direction of motion. Due to which the speed of the charged particle remains unchanged and work done on it is zero, hence its kinetic energy remains same.

2. To detect the presence of the magnetic field created by the current in a circular loop at the centre, one can draw the magnetic field lines with the help of compass needle. The magnetic field lines appear as a straight line at the centre and other lines appear in the same direction without the loop.

Direction of field is given by the right hand thumb's rule. Right hand thumb rule. Hold the wire in your right hand with your extended thumb pointing in the direction of current. Your folded fingers will indicate the direction of magnetic field around the wire.

3. B = ?, I = 2 A, L = 3 m

F = 1 N

F = B I L

$1 = 2 \times 3 \times B \Rightarrow \frac{1}{6} = B$

B = 0.16 Tesla

4. r = 22 cm = 0.22 m, n = 14, I = 5A, $\mu_0 = 4\pi \times 10^{-7}$ Tm/A

$$B = n \times \frac{\mu_0 I}{2r} = 14 \times \frac{4\pi \times 10^{-7} \times 5 \times 10^2}{2 \times 122}$$

$$= 14 \times 2 \times \frac{22}{7} \times \frac{10^{-5} \times 5}{22} = 20 \times 10^{-5} \text{ Tesla.}$$

5. r = 0.05 m., n = 500, I = 1 A,

$\mu_0 = 4\pi \times 10^{-7}$ Tm/A

$$B = \frac{\mu_0 In}{2r} = \frac{4\pi \times 10^{-7} \times 1 \times 500}{2 \times 0.05}$$

$= 6.28 \times 10^{-3}$ T.

6. r = 0.01 m., $\mu_0 = 4\pi \times 10^{-7}$ Tm/A, I = 2A

$$B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7} \times 2}{2 \times \pi \times 0.01} = 4 \times 10^{-5} \text{ T}$$

7. $\mu_0 = 4\pi \times 10^{-7}$ Tm/A; r = 15 cm = 0.15 m; I = 60A

n = 20 turns

$B = \frac{n\mu_0 I}{2r} = \frac{20 \times 4\pi \times 10^{-7} \times 60}{2 \times 0.15} = 5 \times 10^{-3}$ T

8. $I = 5A, L = 0.04$ m, $B = 0.30$ T
$F = B \times I \times L = 0.30 \times 5 \times 0.04 = 0.06$ N

9. $B = 4$ T, $Q = 1.6 \times 10^{-19}$ C, $V = 3.5 \times 10^7$ m/s
$F = B \times Q \times V = 4 \times 1.6 \times 10^{-19} \times 3.5 \times 10^7$
$= 2.24 \times 10^{-11}$ N

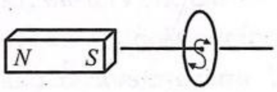
4 ADVANCED EXERCISE
BASED ON CONNECTING TOPICS

1.	(b)	**2.**	(a)	**3.**	(a)	**4.**	(c)
5.	(d)	**6.**	(c)	**7.**	(b)	**8.**	(a)
9.	(a)	**10.**	(b)	**11.**	(c)	**12.**	(c)
13.	(d)	**14.**	(a)	**15.**	(d)	**16.**	(a)
17.	(c)	**18.**	(d)	**19.**	(b)	**20.**	(c)
21.	(d)	**22.**	(a)	**23.**	(c)		

24. (a, d)

25. (a, b, c)

26. (b, d) The near face of the loop behaves like south pole and far face as north pole. So loop will be repelled by the magnet.



27. (a, b) $\chi_m = \frac{C}{(T - T_C)}$.

28. (a) **29.** (d) **30.** (b)

31. (a) **32.** (d) **33.** (c)

34. (a)

35. (b)

36. (a) Lenz's law (that the direction of induced e.m.f. is always such as to oppose the change that cause it) is direct consequence of the law of conservation of energy.

37. (b)

38. (a) Work done by magnetic force is zero. From work-energy theorem, its speed or kinetic-energy is constant.

39. (c) **A : q, r**

The magnetic field at P due to current flowing in AB is perpendicular to the plane of paper acting vertically downward. And the magnetic field at P due to current flowing in CD is perpendicular to the plane of paper acting vertically upwards.

Therefore, q is correct.

As P is the mid point, the two magnetic fields, cancel out each other. Therefore, r is correct.

B : p

The magnetic field at P due to current in loop A is along the axial line towards right. Similarly, the magnetic field at P due to current in loop B is also along the axial line towards right.

C : q, r

The magnetic field due to current in loop A at P is equal and opposite to the magnetic field due to current in loop B at P.

D : q, s

The direction of magnetic field at P due to current in loop A is perpendicular to the plane of paper directed vertically upwards.

The direction of magnetic field at P due to current in loop B is perpendicular to the plane of paper directed vertically downward.

Since the current are in opposite direction the wires repel each other.

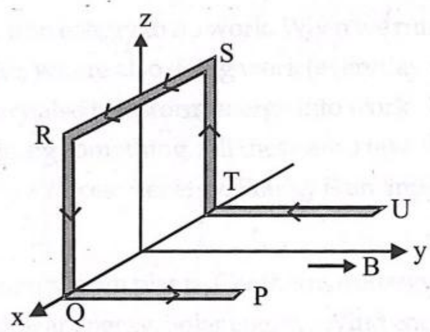
40. The magnetic field of earth at that point becomes zero, when wire produces equal and opposite field. So

$$\frac{\mu_0}{2\pi}.\frac{i}{r} = B_H$$

$$\therefore \quad i = \frac{B_H r}{(\mu_0/2\pi)} = \frac{(39 \times 10^{-6}) \times 0.08}{2 \times 10^{-7}}$$

$$\approx 16 \text{ A from west to east}$$

41. If we join P to U by a straight conductor it will become a closed loop and as in case of closed loop in a uniform magnetic field,



If $\vec{F}_W$ is the force on the given network of wires and $\vec{F}'$ on the wire PU, then

$\vec{F}_W + \vec{F}' = 0$ i.e., $\vec{F}_W = -\vec{F}'$

But as $\vec{F}' = BIL \sin 90°$ along negative z-axis,

so, $\vec{F}_W = BIL$ along z-axis

42. Given : $v = 10^5$ m/s ; $e = 1.6 \times 10^{-19}$ C;
$m = 9.1 \times 10^{-31}$ kg; $B = 0.019$ G $= 0.019 \times 10^{-4}$ T

$$r = \frac{m\,v}{B\,e} = \frac{9.1\times10^{-31}\times10^{5}}{0.019\times10^{-4}\times1.6\times10^{-19}} = 0.299\,m$$

43. Given : $e = 10$ V and $\frac{dI}{dt} = \frac{1-0.5}{0.2} = \frac{0.5}{0.2} = 2.5$ A / s

Self inductance of coil $L = \frac{e}{dI/dt} = \frac{10}{2.5} = 4$ H

$\because\ e = L\frac{dI}{dt}$ (considering magnitude only)

44. Given : $M = 0.75$ H and $\frac{dI}{dt} = \frac{0.5-0}{0.01} = 50$ A / s

$\therefore$ Average induced e.m.f. in secondary coil

$$e = M\frac{dI}{dt} = 0.75\times50 = 37.5\text{ V}$$

45. $= 220V;\ r = 10\Omega$

$R' = 10 + 100\Omega = 110\Omega$

$I = \frac{V}{R'} = \frac{220}{110} = 2A$

$P = I^2R = 4\times100 = 400\,W$