4 MAGNETIC EFFECTS OF ELECTRIC CURRENT

4.1 INTRODUCTION

It was found that magnetism and electricity are related to each other. This means that electricity can be used for the generation of electromagnetic effect and this effect is called electromagnetism. Similarly changing magnetic field can produce electricity, this is called electromagnetic induction.

Question based on basic knowledge required to understand this chapter

1. A charge whenever in motion has
(A) only magnetic field linked with it
(B) only electric field linked with it
(C) Both electric and magnetic field linked with it
(D) only gravitational field linked with it.

2. Magnetic forces
(A) are always attractive (B) are always repulsive
(C) may be attractive or repulsive (D) none of these

3. Magnetic field is generated by
(A) stone (B) mud
(C) magnet (D) iron piece

4. A magnetic needle comes to rest in
(A) geographic east-west direction
(B) geographic North-South direction
(C) Vertical direction
(D) In North-East direction

5. The device used for producing electric current is called
(A) generator (B) galvanometer
(C) ammeter (D) motor

6. 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

7. A magnet can be demagnetised by

(A) Hammering the magnet (B) Putting it in the water

(C) Cooling it (D) Putting in contact with iron

8. Which one of the following is the magnetic substance

(A) Mercury (B) Iron (C) Gold (D) Silver

9. Generally permanent magnets are prepared from

(A) Gold (B) Silver (C) Iron (D) Steel

10. If iron filings are sprinkled around a bar magnet then they arrange in a fixed pattern which is

(A) magnetic field lines pattern (B) Electric field lines pattern

(C) Faraday's electric field lines pattern. (D) None of these

4.2 MAGNET

A substance which attracts small pieces of iron, nickel, cobalt and steel and points in North-South direction when freely suspended (or hanged freely) is known as a magnet.

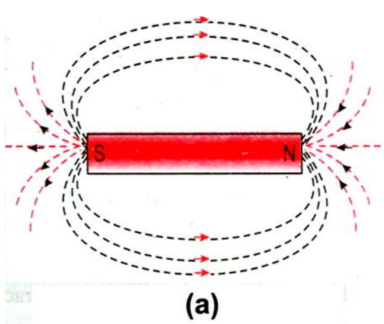
Natural magnets are irregular in shape, moreover they are weak magnets. An iron bar can be made a magnet by rubbing it with a natural magnet. Such a magnet is known as Man made or artificial magnet. Like magnetic poles (i.e. North and North or South and South) repel each other while unlike magnetic poles attract each other.

Try yourself

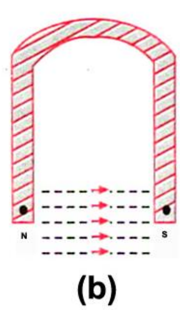
1. What is a magnet?
2. Can the poles of a bar magnet be separated?

4.3 MAGNETIC FIELD AND MAGNETIC FIELD LINES

Magnetic Field: It is the space surrounding a magnet upto which its influence i.e., (force of attraction) can be felt.



(Magnetic field of bar magnet)



(Magnetic field of horse shoe magnet)

Magnetic field of a bar magnet is Non-Uniform which can be represented by curved lines or unequidistant parallel lines as shown in above figure (a). If we sprinkle some iron filings around the bar magnet iron filings arrange themselves as shown in figure along the field lines. Magnetic field between pole pieces of a horse shoe-magnet is uniform as represented by equidistant parallel lines as shown in figure (b) (near the pole N and S).

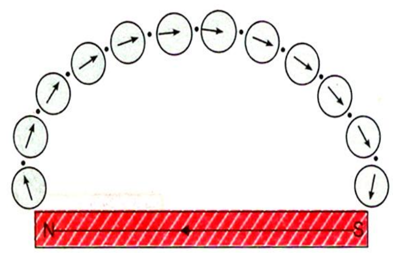
Magnetic lines of force: These are defined as the lines (straight or curved), along which a hypothetical free unit N-pole moves.

4.3.1 Plotting of magnetic field lines of a bar magnet

These can be traced on paper by using a small magnetic compass.

(i) Fix a white paper on drawing board with drawing pins.

(ii) Place the bar magnet in the middle and draw its boundary.



(Plotting of magnetic lines of bar magnet with compass)

(iii) Place the magnetic compass at one end say N-pole and mark dots at the ends of compass needle as shown in figure till it reaches the other end (S-Pole of magnet). Join all these points with dotted lines. It is the curved line of force of bar magnet. In this way we can draw more lines. These lines will represent the field of bar magnet as shown in figure given above.

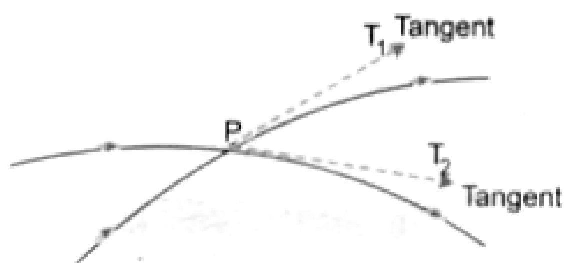
This magnetic field is non-uniform and changes its magnitude and direction at all points.

4.3.2 Properties of Magnetic Lines of Force

(i) These start normally from north pole and converge (or enter) at south pole.

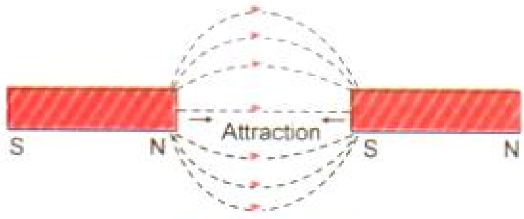
(ii) These are continuous closed curves and inside the bar magnet these are directed from S-pole to N-pole.

(iii) Two lines of force can never intersect each other because if they do so, then at the point of intersection there will be two directions of magnetic intensity at the same point 'P' along PT_1 and PT_2 (as shown in figure below). which is not possible.



(Two magnetic lines can't Intersect)

(iv) These behave like a stretched bow and have a tendency to contract length wise, which shows attraction between two opposite poles as shown in figure given.



(v) Lines of force exert a lateral force of repulsion on each other which explains repulsion between two similar poles as shown in figure below. (No line of force exists in the region between two similar poles.

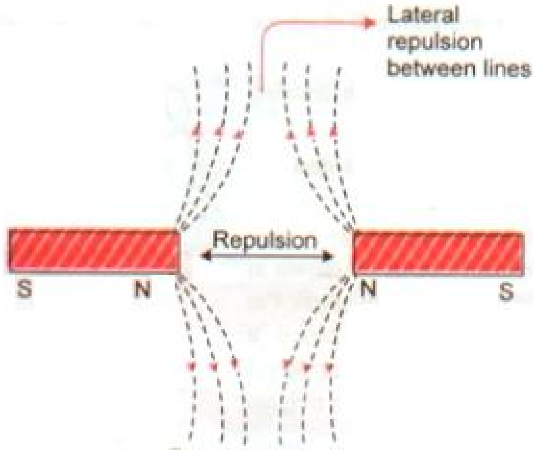


Illustration 1

What is neutral region in a magnetic field.

Solution

The region in the magnetic field where magnetic field lines do not exist is called neutral region.

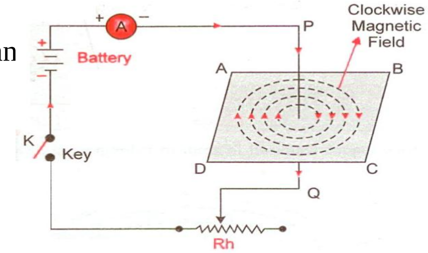
Try yourself

3. What do you mean by magnetic lines of force?
4. At what angle magnetic lines of force lie w.r.t. a bar magnet.
5. What is the use of a magnetic compass?

4.4 MAGNETIC FIELD OF A CURRENT CARRYING CONDUCTOR

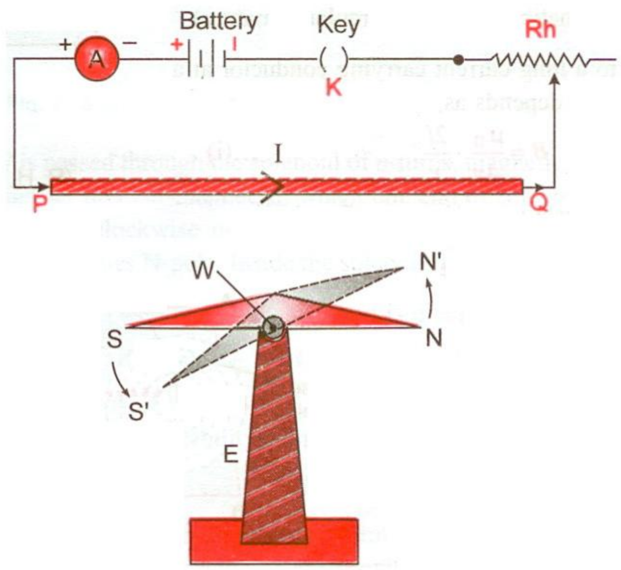
4.4.1 Oersted Experiment:

From his experiments Oersted came to the conclusion that when an electric current is passed through a conductor, a magnetic field is produced surrounding it and hence there is intimate relation between Electricity and Magnetism.



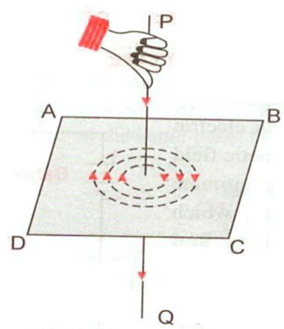
(a)

As shown in figure (a) and (b) when current 'I' is passed through a conductor PQ with battery, key, rheostat (to varry current), then the magnetic field lines around the conductor are circular around the wire in perpendicular plane to the current. Direction of magnetic field lines of straight conductor due to current are given by following rule.



(b)

Right Hand Thumb Rule: If the fingers of right hand are curled around the conductor carrying current (without touching it), with thumb pointing in the direction of current then the direction of curled fingers gives the direction of magnetic field as shown in figure given below. The direction of magnetic field is shown by arrow as shown in figure below:



(R. H. Thumb rule)

***Magnetic field** $\vec{B}$ due to a long current carrying conductor at a distance 'r' in air from conductor depends as,

B $\propto$ 1/r and B $\propto$ i $\Rightarrow$ $B = \frac{\mu_0}{4\pi} \cdot \frac{2l}{r}$

When $\mu_0 = 4\pi \times 10^{-7}$ Tesla meter/Ampere (T-mA^{-1})

Illustration 2

At what distance will a straight conductor carrying current of 2A will produce a magnetic field of 10^{-5} Tesla? (Given: $\mu_o = 4\pi \times 10^{-7}$ Tm/A)

Solution

B = 10^{-5} T, I = 2A, then r = ?

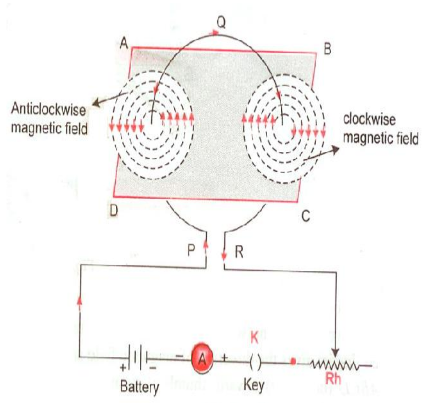
$$B = \frac{\mu_o}{2\pi}\left(\frac{2I}{r}\right)$$

$$r = \frac{\mu_o}{4\pi}\frac{2I}{B} = \frac{4\pi \times 10^{-7}}{4\pi} \times \frac{2 \times 2}{10^{-5}} = 4 \text{ cm}$$

Try yourself

6. What type of magnetic lines of force exist around a straight conductor carrying current.
7. A straight conductor is carrying a current of 2A then find the magnetic field strength due to it at a distance of 1 cm.

4.5 MAGNETIC FIELD PATTERN DUE TO A CIRCULAR COIL CARRYING CURRENT



To study the pattern of magnetic field, we take a long wire, bent in the form of circular coil with 20 - 30 turns, passed through a cardboard, (kept in horizontal position) with half of circular coil above and half of it below the cardboard piece. On passing current of a few ampere through this coil by a battery and magnetic lines of force are plotted around wire on white paper fixed on cardboard with the help of a small magnetic compass. It is seen that lines of force are concentric circle. (Shown in figure).

Direction of magnetic field inside and outside the coil can be obtained by applying right hand thumb rule.

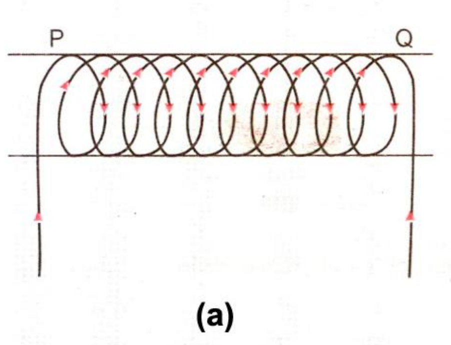
4.5.1 Magnetic field $|\vec{B}|$ at the centre of coil,

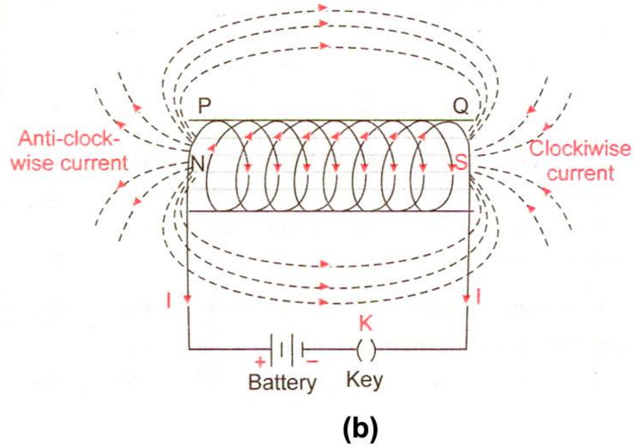
$$B = n\left(\frac{\mu_0 I}{2r}\right)$$

where r = radius of coil, n = no of turns, I = current flowing through the coil.

4.6 MAGNETIC FIELD PATTERN DUE TO CURRENT CARRYING SOLENOID

Solenoid : It is a long spring, cylindrical, in shape, with large number of turns of insulated copper wire as shown in figure below.



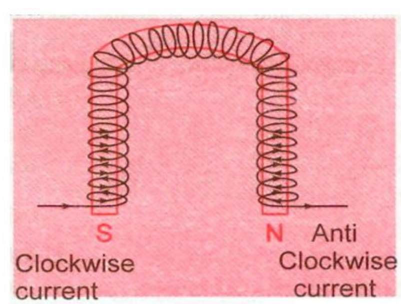


When electric current , I is passed through the solenoid of n-turns, magnetic field set up around it is shown in figure (b) which is just similar to a bar magnet, in which one end of solenoid becomes S-pole and the other N-pole. At the end Q current is clockwise in the coil and it becomes S-pole and at the end P, current is anticlockwise in the coil and it becomes N-pole. Inside the solenoid, magnetic field is uniform (well inside the solenoid) and magnetic field $\left|\vec{B}\right|$ well inside the solenoid is given by

* $B = \mu_0 nI$. (For air core) ($\mu_0 = 4\pi \times 10^{-7}$ T - m A^{-1} magnetic permittivity of free space).

= $\mu nI(\mu = \mu_0 \mu_r)$ Where μ_r is relative magnetic permeability.

4.7 ELECTRO MAGNETS



When soft iron core is used inside a long current carrying cylindrical solenoid, core gets strongly magnetised temporarily for the time current is passed through it. Magnet, so formed is called Electro-magnet. (in the form of a bar-magnet) figure (b) given above But if the iron core is of U-shape, then the electromagnet formed by passing current through Solenoid wound around core is horse Shoe Shaped electro magnet (Shown in figure).

figure (b)

Uses:

These are used in electric bells, Electric horns, telephone receiver, electric relays, etc. When fitted on cranes, these can lift heavy iron pieces, scrap iron etc.

Parmanent Magnets: When steel core is used inside solenoid carrying large current, it forms strong permanent magnet after sometime and current can be switched off after that. Alloys such as Alnico (of AI, Ni, Co) and Fe form even stronger permanent magnets. These are used in Ammeters, Voltmeters, microphones, magnetic compass, loudspeakers, etc.

***Illustration 3**

A solenoid of length 50 cm having 100 turns carries a current of 2.5 A. Find the magnetic field strength inside the solenoid. (Given: $\mu_o = 4\pi \times 10^{-7}$ TmA^{-1})

Solution

Given: $\mu_o = 4\pi \times 10^{-7}$ TmA^{-1}; I = 2.5 A n = number of turns per unit length = 100/0.5 = 200 per metre

$B = \mu_o nI$

$= 4\pi \times 10^{-7} \times 200 \times 2.5 = 6.28 \times 10^{-4}$ T

Illustration 4

A circular coild having 100 turns having a radius of 10 cm is carrying a current of 4A. Find the magnetic field at the centre of the coil. Given: $4\pi \times 10^{-7}$ TmA^{-1};

Solution

Given: n = 100, r = 10×10^{-2} m, I = 4A

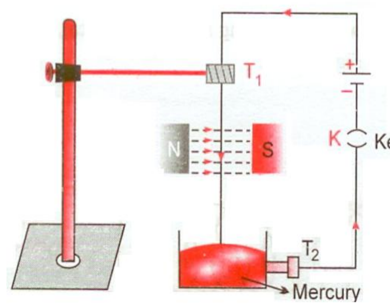
$$B = n\left(\frac{\mu_o I}{2r}\right)$$

$$B = \frac{100 \times 4\pi \times 10^{-7} \times 4}{2 \times 10^{-1}} = 8\pi \times 10^{-4}\ T$$

4.8 MAGNETIC FORCE ON A CURRENT CARRYING CONDUCTOR PLACED IN A MAGNETIC FIELD

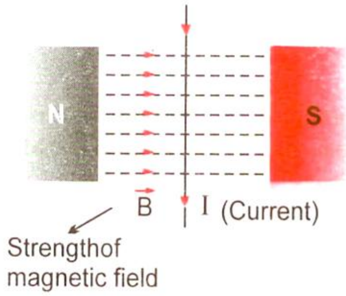
When a magnetic compass is placed close to a straight conductor carrying current, its needle gets deflected due to exertion of force on compass needle by the magnetic field of conductor carrying current.Now if a straight conductor, PQ (free to move when suspended) carrying current due to battery is made to lie inside the magnetic field $\vec{B}$ (Normal to it), then magnetic force $\vec{F}$ acts on the conductor which is normal to both the current and magnetic field as shown in figure.

The wire flies off due to the magnetic force on wire, when the current is switched on by key K.

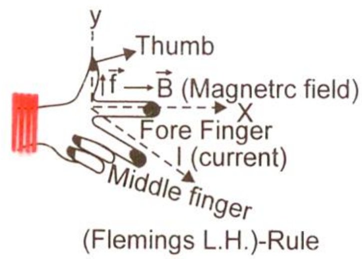


Direction of magnetic force $\vec{F}$, in this experiment is given by Fleming's left hand rule.

FLEMING'S LEFT HAND RULE: it states that if the fore finger, the middle finger and the thumb of left hand are stretched mutually perpendicular to each other , such that fore finger points in the direction of $\vec{B}$ (magnet field), the middle finger in the direction of current (I), then thumb will point in the direction of force on the conductor.(as shown in figure (a) and (b)) $\vec{B}$ is along OX, I along OZ and force $\vec{F}$ along y-axis (represented by thumb).



(a)



(b)

*Magnitude of force $\vec{F}$ acting on a current carrying conductor placed in a magnetic field is found to depend as

$F \propto B$, (Magnitude of the strength of magnetic field)

$\propto I$ (Strength of current)

$\propto l$ (Length of conductor)

$\propto \sin\theta$ (θ = angle between conductor (ie. current I) and magnetic field, $\vec{B}$

$\therefore F \propto BIl\sin\theta$

$= KBIl\sin\theta$, K = Constant of proportionality = 1 (in S.I. system)

$\therefore F = BIl\sin\theta$ (Newtons) (i)

If θ = 0°, Then F = 0

and If θ = 90 then F = maximum = BIl (ii)

or F = $\frac{Bql}{t}$ = BqV $\because$ $\frac{l}{t}$ = V (Velocity of the charges) (iii)

In Equation (ii), direction of $\vec{F}$ is given by Fleming's left-hand rule.

In equation (i) $\vec{F} = I\left(\vec{l} \times \vec{B}\right)$ (Direction of $\vec{F}$ is given by R.H. screw rule) (iv)

or F = BqV sinθ (v)

4.9 THE DIRECT CURRENT ELECTRIC MOTOR

An electric motor is a device that converts electrical energy into mechanical energy. (kinetic energy). There are two kinds of motors that we use in our day to day life.

(i) ac motor that uses ac supply e.g. motor of a fan

(ii) dc motor that uses dc supply e.g. motor of a battery operated toys.

Here we will study a simple dc (direct current) motor.

Principle: It is based on the principle that when a current carrying conductor capable of moving freely is placed in a magnetic field, it experiences a force and begins to move in a direction given by Flemming's left hand rule.

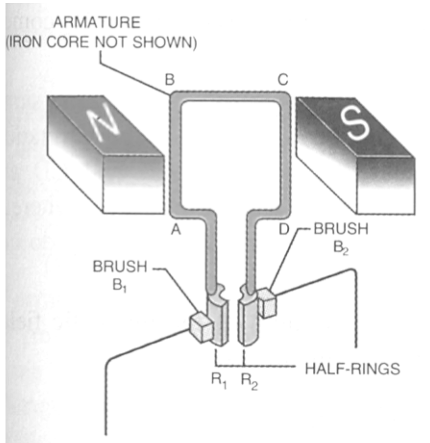


Figure: The basic components of a dc motor

Construction: A dc motor consists of the following components as shown in given figure.

(i) Armature coil : It consists of a large number of turns of a rectangular coil ABCD made of copper wire wound over a soft iron laminated core.

(ii) Strong field magnets: Two poles of permanent magnets between which the armature coil is roated.

(iii) Split rings or half rings: The two ends of the coil are welded to two semicircular metallic rings R_1 and R_2. These rings are called the split rings or half rings. The function of the slip rings is to change the direction of current flowing through the coil after each half rotation.

(iv) Brushes: Two carbon brushes B_1 and B_2 make a contact with the slip rings R_1 and $R_{2\backslash}$

The system of two half rings and the associated brushes are referred to as a split-ring commutator. The function of the commutator is to reverse the direction of the current flowing through the coil after every half turtn of the coil.

Working: The operation of a motor can be understood by considering in figure In figure the current from the battery enters the coil through the left brush B_1 and half-ring R_1, goes around the coil, and then leaves through the right half-ring R_2 and brush B_2.

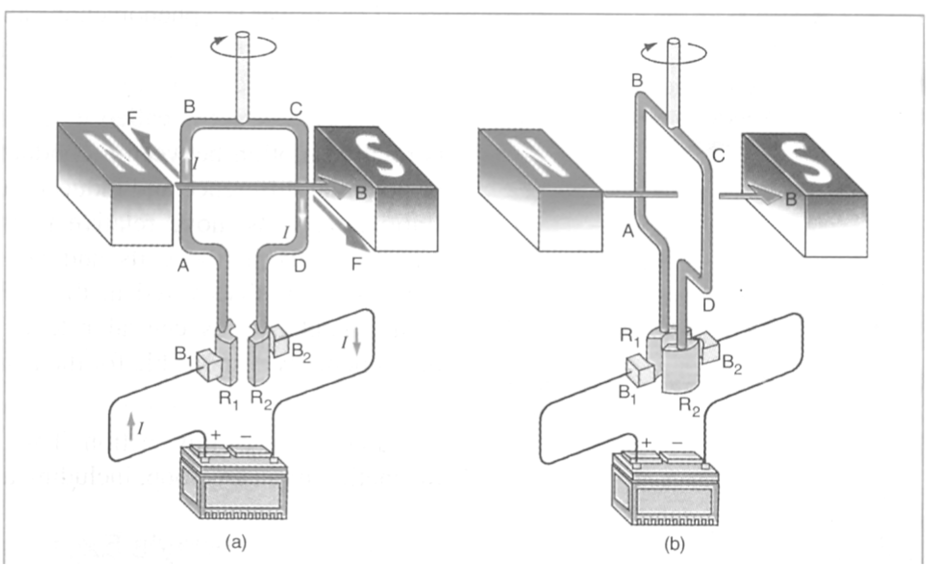


Figure: (a) When a current exists in the coil, the coil experience a torque (pair of forces) (b) Because of its inertia, the coil continues to rotate when there in no current

According to Fleming's left hand rule, the directionsof the forces on the two sides AB and CD of the coil are as shown in the figure. The force on AB acts inwards whereas the force on CD acts outwards. These forces form a couple and hence apply a torque (pair of forces) on the coil that turns it. This is because the direction of current in the two sides is opposite to each other. Eventually the coil reaches the position shown in figure. In this position the half-rings momentarily lose electrical contact with the brushes, so that there is no current in the coil and no applied torque. However, like any moving object, the rotating coil does not stop immediately for its inertia of motion carries it onward. When the half-rings re-establish contact with the brushes, there again is a current in the coil and a magnetic torque again rotates the coil in the same direction. This time the force on AB acts outwards and that on CD acts inwards. But this time the rings are in contact with different brushes. Ring R_1 comes in contact with brush B_2 and ring R_2 comes in contact with brush B_1.

The split ring commutator ensures that the current is always in the same direction to yield a torque (pair of forces) that produces a continuous rotation of the coil. It should be remembered that the two sides AB and CD are perpendicular to the magnetic field, hence they experience a force, whereas the sides BC and DA are parallel to the magnetic field, therefore they do not experience a force.

The speed of the motor depends on the strength of the magnetic field, the current and on the number of turns in the armature oil.

Illustration 5

A charge of +2C enters in a magnetic field perpendicular to the magnetic field of intensity 4T with a velocity of 10 m/s. Find the force acting on the charged particle.

Solution

$F = BqV\sin 90°$

$= 4 \times 2 \times 10 = 80$ N

Illustration 6

A current of 2A is flowing through a wire of length 50 cm. If this wire be placed at a angle of 60° with the direction of a uniform magnetic field of 5×10^{-4} $NA^{-1}m^{-1}$, how much force will act upon the wire?

Solution

$F = B I l \sin\theta$

$F = 2 \times 0.5 \times 5 \times 10^{-4} \times \sin 60°$

$= 4.33 \times 10^{-4}$ N

Try yourself

*8. An electron moving with velocity 5×10^7 m/s enters a magnetic field of 1 Wb/m^2 at an angle of 30° to the field. Calculate the force on the electron

*9. A current of 10A is flowing through a wire. It is kept perpendicular to a magnetic field of 5 Wb/m^2. Find out the force on its (1/10)m length

4.10 ELECTRO-MAGNETIC INDUCTION

4.10.1 Introduction

Oersted experiments revealed that magnetism is associated with electric current flowing through a conductor i.e. production of magnetism from electricity, Faraday, after a series of experiments to final its reverse i.e. production of current from magnetism", found that electric current can be produced in a coil momentarily when a bar magnet is made to move quickly near or away from the coil in closed form without the use of cells. This current produced is called 'Induced current'.

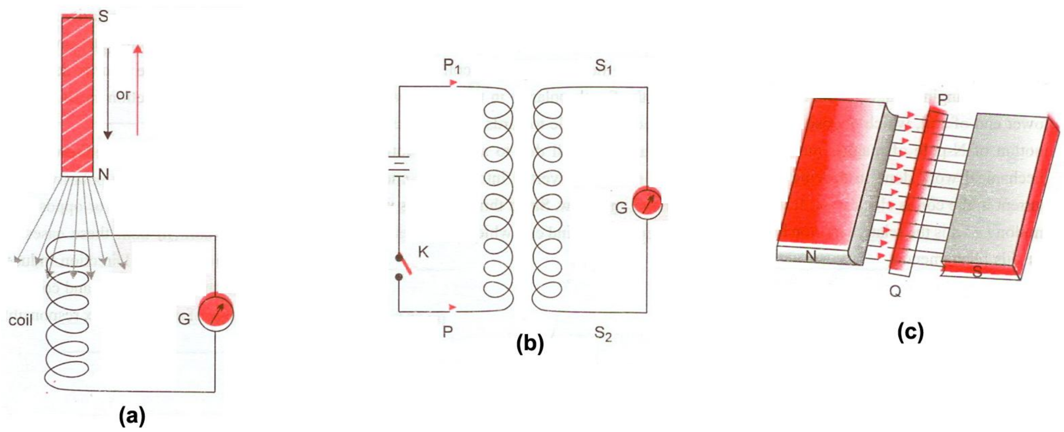
4.10.2 Electro magnetic induction (E.M.I.)

It is the phenomenon of production of induced current in a coil by changing magnetic field crossing the coil, which lasts as long as the magnetic field actually changes, crossing the coil.

4.10.3 Faraday's Experiments

As shown in figures (a) (b) and (c) the changing magnetic field is produced in figure (a) by moving magnet near or away from coil quickly, in figure (b) by changing current in the neighbouring coil, in figure (c) by moving a straight conductor in between the pole pieces of a permanent magnet, respectively.

In all these figures, magnetic field crossing the coil is changing. Galvanometer shows momentary deflection and it does not give deflection when the field near the coil is not crossed or changed by stopping the motion of magnet in figure (a) or in conductor in figure (c) or when key is off in figure (b). More greater speed of changing magnetic field, more is the deflection in galvanometer (or current).



***Conclusions of these experiments** are put in the form of two laws of Electromagnetic induction.

First Law : It states that whenever a magnetic field or flux linked with a coil changes, induced e.m.f. is set up in it, which lasts so long as the change in magnetic flux crossing the coil continues.

Second Law: Magnitude of induced e.m.f in the coil is directly proportional to the rate of change of magnetic flux linked with it.

$$e \propto \frac{\varphi_2 - \varphi_1}{t}$$ Where $\phi_2 - \phi_1$ = change in magnetic flux in time t.

or $$e \propto \frac{d\phi}{dt}$$ ($d\phi$ = small change in magnetic flux in small time dt.)

or $$e = K\left(\frac{\varphi_2 - \varphi_1}{t}\right) = \frac{\varphi_2 - \varphi_1}{t}$$ K = Constant of proportionality = 1 (i) or $e = K \times \frac{d\varphi}{dt} = -\frac{d\varphi}{dt}$ (include e.m.f.) (ii)

(In the coil of resistance, R) Induced current $I = \frac{e}{R} = -\frac{1}{R}.\frac{\varphi_2 - \varphi_1}{t} = -\frac{1}{R}\frac{d\varphi}{dt}$.

–ve sign in 'e' and 'I' shows that induced e.m.f. and current are of opposing nature.

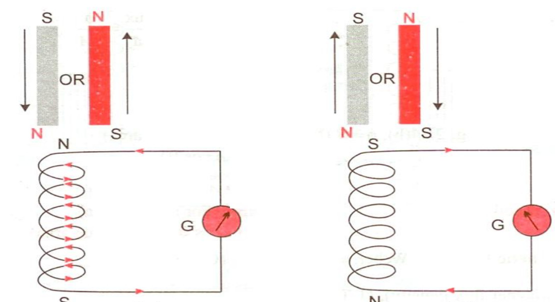
***Lenz's Law :** gives the explanation of direction of induced current in the coil.

It states that direction of induced current in the coil is always such as to opposes the very cause of its production (i.e. it opposes the motion of magnet or coil or conductor or it opposes the changing current, responsible for change of magnetic flux linking the coil)

Lenz's law is according to law of conservation of energy (i.e. energy can neither be created no destroyed but it changes from one form to another in the figure (a) and (b) it can be explained as follows.

In figure (a) When N pole of magnet is moved towards the coil or S pole of magnetismoved away from the coil, the end of coil near the magnet acquires North (N) polarity and the other end South (S) polarity so that it opposes N pole of magnet tending to move towards coil or it opposes the S pole of magnet tending to move away from coil. Hence, work (Mechanical energy) has to be done for moving the magnet against the polarity developed in coil. This mechanical energy is converted into electrical energy. Direction of induced current in this coil is anticlockwise.

In Figure (b) When N pole of magnet is moved away from coil or S pole of magnet is moved towards the coil, the changing magnetic flux induces the south polearity in the upper end of coil and North polarity on the lower end of coil, which opposes the motion of S pole towards the coil due to repulsion by coil or opposes the motion of N pole of magnet moving away from coil due to attractive force of coil. In both these cases the mechanical work done in moving the magnet is converted into electric energy in the coil. Direction of induced current in the coil is clock wise. It verifies Lenz's law. Same thing happens when magnet is at rest and coil is in motion i.e. it is the relative motion between magnet and coil which produces change of magnetic flux responsible for this phenomenon.



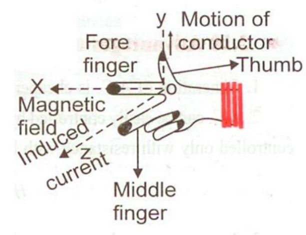
(a) (b)

Hence : Lenz's Law does not violate the law of conservation of energy.

Direction of induced current

Direction of induced current in a conductor can be found from Fleming's right hand rule (or Dynamo Rule)

Stretch the fore finger, middle finger and thumb of right hand mutually perpendicular to each other such that fore finger points in the direction of magnetic field and the thumb points in the direction of motion of conductor, then middle (or central) finger

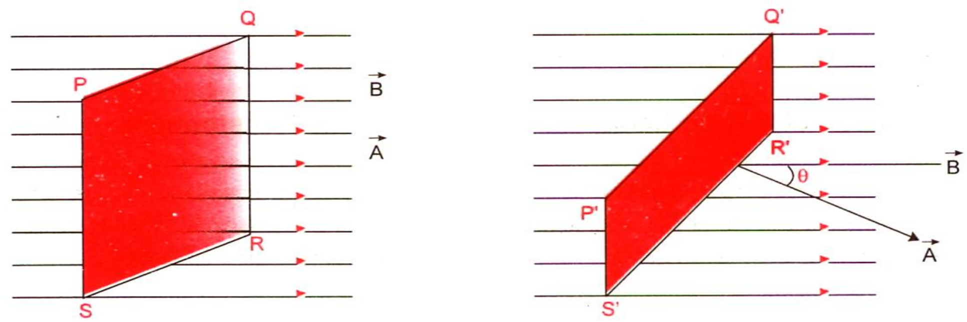


points in the direction of induced current. (as shown in figure).

This rule is the practical form of Lenz's law.

*Magnetic Flux, ϕ it is the total number of magnetic lines of force crossing the surface, held in a magnetic field $\vec{B}$.

*4.11 MAGNETIC FLUX DENSITY OR MAGNETIC FIELD INTENSITY



(a) (b)

$$\vec{B} = \frac{magnetic\ flux}{Normal\ area} = \frac{\phi}{\perp A}$$

In figure (a)

For normal area PQRS.

ϕ = BA (i)

For oblique area (A) in figure (b), $\phi = B\,(A\cos\theta)$

For n turns of coil, ϕ = nBA (for normal area) (ii)

and ϕ = nBA cos θ (for oblique area) (iii)

S.I. unit of magnetic flux, ϕ = weber = 10^8 Maxwell (C.G.S. system)

S.I. unit of $\vec{B}$ (Magnet flux density), (tesla)

$$B = \frac{\phi}{A} = \frac{1weber}{1m^2} = \frac{10^8\,Maxwells}{(100cm)^2}$$

$$= 10^4 \frac{Maxwells}{cm^2} = 10^4 \text{ Gauss} \qquad \text{(C.G.S. system)}$$

Illustration 7

A coil having 100 turns and area 0.20 m² is placed normally in a magnetic field. The field changes from 0.20 Wb m⁻² to 0.60 Wb m⁻² uniformly over a period of 0.01 s. Calculate the emf induced in the coil.

Solution

The magnetic flux through each turn of a coil of area A placed perpendicular to a magnetic field of magnitude of B is given by

$\Phi_B = B\,A$

The change in flux due to a change in B is

$$\Phi_B = (\Delta B)\,A = (0.60 - 0.20)\ \text{Wb m}^{-2} \times 0.20\ \text{m}^2 = 0.08\ \text{Wb}$$

By Faraday's law, the magnitude of the induced emf is

$$|e| = N\frac{\Delta\Phi_B}{\Delta t} = \frac{100 \times 0.08\ \text{Wb}}{0.01\ \text{s}} = 800\ \text{V}$$

***Illustration 8**

A coil has an area of 0.04 m² and has 1,000 turns. It is suspended in a magnetic field of 5 × 10⁻⁵ Wb m⁻², perpendicular to the field. The coil is rotated through an angle of 90° in 0.2 second. Calculate the maximum magnetic flux associated with the coil, and the average emf induced in the coil due to its rotation.

Solution

The magnetic flux passing through each turn of a coil of area A, perpendicular to a magnetic field of magnetic B is given by

$$\Phi_B = B\,A$$

Here $B = 5 \times 10^{-5}$ Wb m^{-2} and $A = 0.04$ m^2

$$\Phi_B = (5.0 \times 10^{-5}) \times 0.04 = 2 \times 10^{-6}\ \text{Wb}$$

On rotating the coil through 90° the magnetic flux passing through it will become zero. Thus, the change in magnetic flux is

$$\Delta\Phi_B = 0 - \Phi_B = 0 - (2 \times 10^{-6}\ \text{Wb}) = -2 \times 10^{-6}\ \text{Wb}$$

The time taken for this change is $\Delta t = 0.2$ s

Therefore, according to Faraday's law the emf induced in the coil is

$$e = -N\frac{\Delta\Phi_B}{\Delta t} = -1000 \times \frac{(-2\times 10^{-6}\ \text{Wb})}{0.2\,\text{s}} = 0.01\ \text{V}$$

***Illustration 9**

The area of a coil of 25 turns is 1.6 cm². This coil is inserted in 0.3 second in a magnetic field of 1.8 Wb m⁻² such that its plane is perpendicular to the flux-lines of the field. What will be the induced emf in the coil? If the resistance of the wire of the coil be 10 ohm, how much total charge will flow through it?

Solution

The magnetic flux passing through each turn of a coil of area A, placed perpendicular to a magnetic field of magnitude B is

$$\Phi_B = B\,A$$

Before the coil was inserted in the magnetic field, the flux was zero. On inserting it in the field in 0.3 second, the flux becomes

$$\Phi_B = B\,A = 1.8\ \text{Wb m}^{-2} \times (1.6 \times 10^{-4}\ \text{m}^2) = 2.88 \times 10^{-4}\ \text{Wb}$$

So, the change in magnetic flux is

$$\Delta\Phi_B = \Phi_B - 0 = 2.88 \times 10^{-4}\ \text{Wb}$$

According to Faraday's law, the emf of the induced in the coil

$$e = -N\frac{\Delta\Phi_B}{\Delta t} = -25\times\frac{2.88\times10^{-4}\,Wb}{0.3s} = -2.4\times10^{-2}\,V$$

The negative sign indicates that the induced emf oppsses the increase in magnetic flux.

The resistance of the coil is R, = 10Ω. Hence, the current induced in the coil is

$$i = \frac{e}{R} = \frac{2.4\times10^{-2}\,V}{10\Omega} = 2.4\times10^{-3}\,A$$

This current persists only during the flux-change (0.3 s). Hence the charge passed through the coil is

$q = i \times \Delta t = 2.5 \times 10^{-2}\ A \times 0.3\ s = 7.2 \times 10^{-4}\ C.$

Try yourself

*10. A rectangular loop, 0.040 m × 0.050 m is situated in a uniform vertical magnetic field of 0.80 Wb m^{-2}. Find the magnetic flux passing through the loop, when the plane of the loop is (i) horizontal (ii) vertical.

*11. A rectangular loop of area 20 cm × 30 cm is placed in a magnetic field of 0.3 T with its plane (i) normal to the field (ii) inclined 30° to the field, (iii) parallel to the field. Find the flux linked with the coil in each case.

*12. The magnetic flux associated with a coil of 100 turns changes from 0.5 weber to 0.3 weber in 0.1 second. Find the potential difference induced at the ends of the coil.

4.12 ADVANTAGES OF A.C.OVER D.C.

1. Generation of A.C. is cheaper than that of D.C.
2. A.C. can be easily controlled by using chokes, transformes, etc, without much power loss but D.C. can be controlled only with resistance with large power loss.

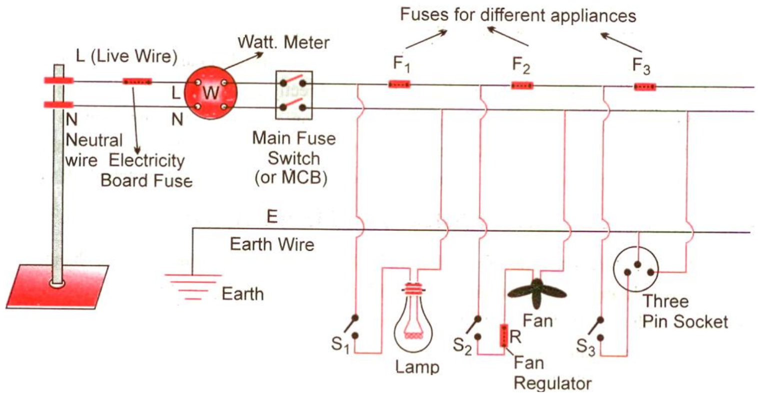
   $H = I^2.R.t$
3. A.C. can be easily transmitted to longer distances by usning transformers.
4. A.C. can be easily converted into D.C. by using Rectifiers, Battery eliminators, etc.

4.13 DISADVANTAGES OF A.C.OVER D.C.

1. A.C. is more dangerous than D.C. because shock of A.C. is attractive, while that of D.C. is repulsive. shock of A.C. of same voltage as D.C. is more severe than that of D.C.
2. A.C. can't be used for laboratory purposes such as in electrolysis, electroplating. etc.

4.14 DOMESTIC (OR HOUSE HOLD) ELECTRICITY

A.C. elecrticity generated at power station is transmitted to long distances using transformers. In cities and village households it is used at 220 volts (For factories 440 volts is used). Household appliances make use of vast variety from electric bulbs, fans, fluoresant tubes to desert coolers, Referegerators, air conditioners, washing machines, mixers, grinders, T.V., Computer, etc.



As shown in figure electric power is supplied to houses and factories through overhead wires and underground cables from main electric poles through transformers of various loads. Three wires are used for all houshold, electricity inputs, one is known as phase wire (or Live-wire) red in colour, second is Neutral wire (N), Potential difference between, Live wire and Neutral wire is kept 220 volts, w.r.t. each other, third wire, known as Earth wire, (E) green colour in line wires, maintained at zero potential by connecting it from power station to deep inside the earth with large metal blocks. Electricity board puts a fuse F before the meter.

Through fuse, the leads enter the Electricity Meter (Watt-metter W) and through main switch to various electricity houshold appliances all connected in parallel thorugh different switches S1, S2, S3, etc, shown in fig. Every appliance gets two insulated wires L and N through respective switches in parallel so that if one is switehed off, other may work at the same time. Earth wire is meant only for safety and has no connection with power supply wire L and N. Wiring in different rooms with various apppliances to be used is done systtematically through various fuses F1, F2, F3, etc. switches of different ampers and total load of the appliances should be kept well below the marked load on watt meter. If somehow a short circuit or over loading appear in one part of the circuit, it will melt that fuse and other connections or mains continue to work untill the main fuse burns. Watt meter records the number of units consumed by the house and respective bills are paid.

4.15 FUSE SAFELY DEVICE

It is a safety device made of thin wires of material having low melting point, put in series with Live wire for commercial purpose a special piece of wire of an alloy of 63 % tin and lead (37%) which has a very low m.pt. is used. But in house holds Cu wires (having low m.pt) of proper thickness may be used for different loads. Fuse wire is fixed between two U shaped metallic strips fixed on porcelain holder with cut outs and different ratings like 3A, 5A, 15A, 25A, etc. for different appliances of various loads. Due to either overloading or short circuiting large current flows in the fuse circuit and melts the fuse, keping the appliance safe and out of the circuit.

4.16 EARTHING OF ELECTRICAL APPLIANCES

Electric iron, Heater, Toaster, Referegerators, Geysers etc. having metallic bodies are touched by bare hands frequently. if by chance the insulation on Live wire melts or it is improper, then live wire may touch the body of apliance and we may receive a severe shock. To avoide dangerous effects of electricity, metallic bodies of all appliances must be earthed through the third pin in the socket (thicker) and green lead of all appliances is connected to this pin which connects the appliance to earth directly and seves us from severe shock as current prefers to pass through low resistance (metallic wires having low resistance in comparison to human flesh), to deep into earth through earth wire. Large current will flow through this earth wire in comparison to Human body and it may melt the fuse wire in the circuit and electric appliance may get switchen off automatically.

Solved Examples

***Example 1**

An electron is projected normally, with a velocity of 3×10^7 ms^{-1} in a magnetic field of strength 10 Wb m^{-2}. Calculate the magnetic force on the electron and compare it with the weight of the electron. Electronic charge is 1.6×10^{-19} C and electronic mass is 9.1×10^{-31} kg (g = 9.8 ms^{-2})

Solution

The magnetic force on a charged particle moving with velocity v in a magnetic field B is given by

$F = q\,v\,B \sin\theta$

where q is the charge and θ is the angle between the magnetic field B and the velocity v of the charged particle.

Here $q = e = 1.6 \times 10^{-19}$ C; $v = 3 \times 10^7$ ms^{-1}, B = 10 Wb m^{-2} (or 10 N A^{-1} m^{-1}) and θ = 90° (or sinθ = 1)

$\therefore \quad F = (1.6 \times 10^{-19}) \times (3 \times 10^7) \times 10 \times 1 = 4.8 \times 10^{-11}$ N

The weight of the electron is

$W = mg = (9.1 \times 10^{-31}) \times 9.8 = 8.9 \times 10^{-30}$ N

The magnetic force is 5.4×10^{18} times the weight of the electron.

***Example 2**

A proton moving with a speed of 3.4×10^7 ms^{-1} enters a magnetic field in a direction perpendicular to the field. The intensity of magnetic field is 2 Wb m^{-2}. Calculate the force acting on the proton and the acceleration produced in it. (Mass of the proton = 1.67×10^{-27} kg, fundamental charge, e = 1.6×10^{-19} C)

Solution

A proton has a positive charge equal to the fundamental charge. We know that a charged particle moving in a magnetic field B with velocity v experiences a force F given by

$F = q\,v\,B \sin\theta$

where q is the charge on the particle and θ is the angle between the magnetic field B and the direction of motion of the particle.

Here $q = e = 1.6 \times 10^{-19}$ C; $v = 3.4 \times 10^7$ ms^{-1}, B = 2 N A^{-1} and θ = 90° (or sinθ = 1)

$\therefore \quad F = (1.6 \times 10^{-19}) \times (3.4 \times 10^7) \times 2\ \text{NA}^{-1} \times 1 = 1.09 \times 10^{-11}$ N

Mass of proton = 1.67×10^{-27} kg. Hence the acceleration of the proton is

$$a = \frac{F}{m} = \frac{1.09 \times 10^{-11}\,\text{N}}{1.67 \times 10^{-27}\,\text{kg}} = 6.5 \times 10^{15}\ \text{N kg}^{-1}\ (\text{or ms}^{-2})$$

***Example 3**

A current of 2 A is flowing through a wire of length 50 cm. If this wire be placed at an angle of 60° with the direction of a uniform magnetic field of 5×10^{-4} NA^{-1}m^{-1}, how much force will act upon the wire?

Solution

The magnetic force on a current carrying wire of length L placed in a magnetic field B at an angle θ with the field is given by

$F = i\,L\,B \sin\theta$

Here $B = 5 \times 10^{-4}$ N A^{-1} m^{-1}, i = 2 A, L = 50 cm = 0.50 m and θ = 60°

$\therefore \quad F = 2 \times 0.50 \times (5 \times 10^{-4}) \times \sin 60° (=0.866) = 4.33 \times 10^{-4}$ N

According to Fleming's left-hand rule, this force will act perpendicular to both the wire and the magnetic field

EXERCISE-I

1. What is a solenoid?
2. Name the unit of magnitude of magnetic field.
3. What is the relation between a tesla, an ampere and a meter.
4. An alternating electric current has frequency of 50 Hz. How many times does it change its direction in one second?
5. How can it be shown that a magnetic field exists around a wire through which a direct current is passing?
6. How is the strength of the magnetic field at a point near a wire related to the strength of the electric current flowing in the wire?
7. Where do we connect a fuse : with live wire or with neutral wire?
8. Why is a fuse wire made of tin-lead alloy?
9. What type of current is used in household supply?

EXERCISE-II

1. 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 the current flowing in the coil?
2. Draw the pattern of field lines due to a solenoid carrying electric current. Mark the north and south poles in the diagram.
3. Draw the pattern of field lines due to a bar magnet. Mention any two properties of the magnetic field lines.
4. A coil of copper wire is connected to a galvanometer. What would happen if a bar magnet is:

   (i) pushed into the coil with north pole entering first (ii) pulled out of the coil (iii) held stationary inside the coil?
5. Explain what is short-circuiting in electric supply.
6. Why is pure iron not used for making permanent magnets? Name one material used for making permanent magnets. Describe how permanent magnets are made electrically. State two examples of elecrical instruments made by using permanenet magnets.
7. State fleming's left hand rule. With a labelled diagram describe the working of an electric motor. What is the function of split ring commutator in a motor?

EXERCISE-III

SECTION-A

- **Fill in the blanks**

1. Magnetic effect of current was discovered by______________.
2. The ______________ materials are those which are attracted in magnetic field.
3. Like poles ______________each other, unlike poles______________each other.

SECTION-B

- **Multiple choice question with one correct answers**

1. A vertical wire is carrying current in the upward direction. Then the direction of magnetic field in the west direction will be
   (A) towards south (B) towards east (C) towards west (D) towards north
2. A charge of 1.6×10^{-19} C enters in the magnetic field of 3 tesla normally with a velocity of 10^6 m/s. The force on the charge will be
   (A) 4.8×10^{-12} m/s (B) 4.8×10^{-13} m/s (C) 4.8×10^{-14} m/s (D) 2×10^{-19} m/s
3. The magnetic field due to an infinitely long wire carrying a current of 2A at a distance of 10 m from it is
   (A) 2×10^{-8} T (B) 4×10^{-8} T (C) $4\pi \times 10^{-8}$ T (D) 2×10^{-6} T
4. The device used for producing electric current is called a
   (A) generator (B) galvanometer (C) ammeter (D) motor

SECTION-C

- **Assertion & Reason**

Instructions: In the following questions as Assertion (A) is given followed by a Reason (R). Mark your responses from the following options.

(A) Both Assertion and Reason are true and Reason is the correct explanation of ‘Assertion’
(B) Both Assertion and Reason are true and Reason is not the correct explanation of ‘Assertion’
(C) Assertion is true but Reason is false
(D) Assertion is false but Reason is true

1. **Assertion:** A magnetic field is produced around a current carrying conductor.
   Reason: This was experimentally proved by Oersted.
2. **Assertion:** A changed particle (+vely charged) when enters normally to the magnetic field follows an elliptical path
   Reason: The magnetic force on the charged particle provides the necessary centripetal force

SECTION-D

- **Match the following (one to one)**

Column-I and **column-II** contains **four** entries each. Entries of column-I are to be matched with some entries of column-II. Only One entries of column-I may have the matching with the same entries of column-II and one entry of column-II Only one matching with entries of column-I

1.

Column I	**Column II**
(A) $B = \frac{\mu_o}{4\pi}\frac{2I}{r}$	(P) Force on a charged particle q moving with a velocity v in a magnetic field

(B) $F = Bqv \sin\theta$ (Q) Fleming's left-hand rule

(C) Force on a current carrying conductor in a magnetic field (R) $r = \frac{mv}{qB}$

(D) Radius of the circular path of a charged particle in a magnetic field (S) Magnetic field due to an infinitely long wire.

EXERCISE-IV

SECTION-A

- **Multiple choice question with one correct answers**

1. When North pole of magnetic approaches a circular coil, then the current in the coil as seen from the magnet side is
   (A) clockwise (B) anticlockwise (C) parallel (D) antiparallel
2. 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
3. The magnetic flux is expressed in
   (A) dyne (B) Oested (C) Gauss (D) Weber

SECTION-B

- **Multiple choice question with one or more than one correct answers**

1. The magnetic field lines have which of the following properties
   (A) They are closed curves (B) Field lines don't intersect
   (C) The are discontinuous (D) None of the above
2. Which of the following are magnetic materials?
   (A) Gold (B) Iron (C) Steel (D) Silver
3. Magnetic field due to a current carrying solenoid on its axis is
   (A) constant (B) variable
   (C) $B = \mu_o nI$ (D) At ends $B = \frac{\mu_o nI}{2}$
4. Lenz's law explains the following
   (A) direction of induced emf (B) direction of induced current
   (C) conservation of energy (D) direction of induced magnetic field

SECTION-C

- **Comprehension**

A man instals a horizontal wire carrying current from west to east. A charged particle of charged 2C is moving normally to the field in the North direction with a speed of 10 m/s. If the current in the wire is 10^7A and the point in the North lies at a distance of 1 m then answer the following questions.

1. The strength of magnetic field at given distance in the North is

(A) 1 Tesla (B) 3 Tesla (C) 2 Tesla (D) 4 Tesla

2. The force on the charged particle is

(A) 40N (B) 30 N (C) 10 N (D) 5 N

3. The direction of magnetic field is

(A) Downwards (B) Upwards (C) Towards north (D) towards south

SECTION-D

- **Match the following (one to many)**

Column-I and **column-II** contains **four** entries each. Entries of column-I are to be matched with some entries of column-II. One or more than one entries of column-I may have the matching with the same entries of column-II and one entry of column-II may have one or more than one matching with entries of column-I

1.

Column-I	**Column-II**
(Devices)	***(Components used in given devices)***
(A) Electric motor	(P) Current carrying conductors
(B) Electromagnet	(Q) Magnets
(C) AC Generator	(R) Commutator
(D) Loud speakers	(S) Brushes

*****

Answers

KNOWLEDGE BASE QUESTIONS

1.	(C)	2.	(C)	3.	(C)	4.	(B)	5.	(A)
6.	(B)	7.	(A)	8.	(B)	9.	(D)	10.	(B)

TRY YOURSELF

8. 4×10^{-12} N
9. 5N
10. (i) 1.6×10^{-3} Wb (ii) zero
11. (i) 1.8×10^{-2} Wb (ii) 0.9×10^{-2} Wb (iii) zero
12. 200 volt

EXERCISE-III

SECTION-A

1. Oersted
2. Magnetic
3. repel, attract

SECTION-B

1.	(A)	2.	(B)	3.	(B)	4.	(A)

SECTION-C

1.	(A)	2.	(D)

SECTION-D

1. (A)-(S), (B)-(P),(C)-(Q),(D)-(R)

EXERCISE-IV

SECTION-A

1.	(B)	2.	(C)	3.	(D)

SECTION-B

1.	(A,B)	2.	(B,C)	3.	(A,C,D)	4.	(A,B,C)

SECTION-C

1.	(C)	2.	(A)	3.	(A)

SECTION-D

1. (A)-(PQRS), (B)-(P), (C)-(QS), (D)-(PQ)

*****