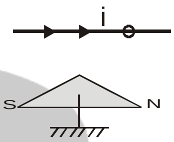
8. ELECTROMAGNETISM

Synopsis :

MAGNETIC EFFECTS OF CURRENT:

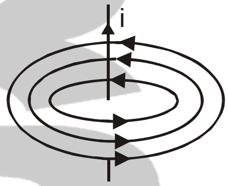
1. Electromagnetism is the branch of physics which deals with relation between electricity and magnetism.
2. A static charge produces only electric field but moving charge produces both electric field and magnetic field in space.
3. Moving charge current is the source of magnetic field.
4. Oersted in 1820 AD observed that magnetic field is produced by a current carrying conductor.
5. Ampere established relationship between the current in the conductor and strength of the magnetic field around the conductor.
6. Oersted's experiment : A magnetic compass needle placed in the vicinity of a conductor carrying conductor aligned perpendicular to the conductor.
7. The direction of deflection of north pole of magnetic needle is given by Ampere's swimming rule.
8. Ampere's swimming rule : Imagine that a man is swimming along the conductor in the direction of the current facing a magnetic needle the north pole of the needle will deflect towards his left hand.



9. The magnetic lines of force around a current carrying conductor are concentric circles with their center lying on the conductor.
10. The direction of magnetic field around the current carrying conductor is given by

    a) Maxwell's cork screw rule

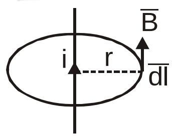
    b) Right hand thumb rule



    Maxwell's cork screw rule : Imagine a right hand screw is advancing in the direction of current in a conductor. Then the direction of rotation of the screw gives the direction of magnetic lines of induction.

    Right hand thumb rule : Imagine that a current carrying conductor is held in the right hand palm such that the direction of current is indicated by the thumb. Then the other fingers indicate the direction of magnetic lines of induction.

11. **Ampere's law** : Ampere's law states that the line integral of $\vec{B}.\vec{dl}$ along a closed path round the current carrying conductor is equal to $\mu_0 i$ where i is the current through the surface bounded by the closed path and μ_0 permeability of free space.



$$\oint \vec{B}.\vec{dl} = \mu_0 i$$

$$B\,2\pi\,r = \mu_0 i$$

$$B = \frac{\mu_0 i}{2\pi r}$$

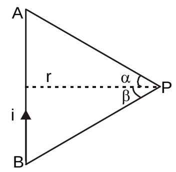
12. **Biot-Savart's law** : The magnetic induction at a point near a current carrying conductor is directly proportional to the length of the conductor, the strength of the current and sine of the angle made by the line joining the point with the conductor and inversely proportional to the square of the distance of the point

$$dB = \frac{\mu_0}{4\pi}.\frac{i.dl.\sin\theta}{r^2}; \quad d\vec{B} = \frac{\mu_0}{4\pi}.\frac{i}{r^3}d\vec{l}\times\vec{r}$$

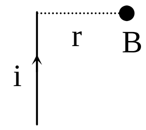
The direction of magnetic induction is given by the vector ($d\vec{l} \times \vec{r}$). This law is valid only for small current segments.

13. Ampere's law and Biot-Savart law are equivalent but Ampere's law is more useful in some symmetrical conditions.

14. The magnetic induction at a point P due to a conductor of finite length is $\vec{B} = \frac{\mu_0 i}{4\pi r}(\sin\alpha + \sin\beta)$



15. The magnetic field induction due to the current carrying conductor of infinite length is given by $\vec{B} = \frac{\mu_0}{4\pi} \cdot \frac{2i}{r}$ or $\vec{B} = \frac{\mu_0 i}{2\pi r}$



Magnetic field at one end of infinite long conductor is $B = \frac{\mu_0 i}{4\pi r}$

16. The magnetic field induction due to the long current carrying cylindrical conductor is $\vec{B} = \frac{\mu_0}{2\pi} \cdot \frac{ir}{(R+r)^2}$

Where R is the radius of the conductor and r is the distance of the point from the surface of the conductor at which the value of B is given. However if r>>R, then $\vec{B} = \frac{\mu_0 i}{2\pi r}$

17. The magnetic field induction at a point along the axis of a circular coil is

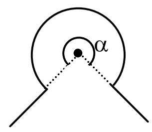
$\vec{B} = \frac{\mu_0}{4\pi} \cdot \frac{2\pi n i r^2}{(r^2 + x^2)^{3/2}}$ where n = number of turns, i = current in the coil, r = radius and x = the distance of the point from the centre of the coil.

$\vec{B} = \frac{\mu_0}{4\pi} \cdot \frac{2niA}{(r^2 + x^2)^{3/2}}$

If x >> r, then $\vec{B} = \frac{\mu_0}{4\pi} \cdot \frac{2niA}{x^3}$

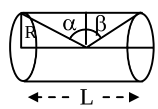
i.e., $\vec{B} = \frac{\mu_0}{4\pi} \cdot \frac{2M}{x^3}$ where M = magnetic moment of the current loop.

18. (a) The magnetic field induction at the centre of a circular coil of n turns is given by relation $\vec{B} = \frac{\mu_0}{2} \cdot \frac{ni}{r}$



(b) Magnetic field induction at the centre of an arc is $B = \frac{\mu_0 i \alpha}{4\pi r}$

19. For a solenoid of finite length at any point on the axis $B = \frac{\mu_0 N i}{2}[\sin\alpha + \sin\beta]$;



N is number of turns per unit length.

20. A solenoid consists of closely wounded helical coil. Inside the solenoid the field is almost uniform. The magnetic induction at the centre of the solenoid is $\vec{B} = \frac{\mu_0 n i}{l}$ where l is the axial length and n is total number of turns in length l of the solenoid. The equation holds good only when the radius of the turns is very small when compared with the length.

21. When current is passed through a helical spring, it contracts due to mutual attraction between consecutive turns.

Force on a moving charge in a magnetic field :

22. An electric charge moving in a uniform magnetic field experiences a force (F).

    $\vec{F} = q(\vec{v} \times \vec{B})$ or $\vec{F} = qvB \sin\theta$

23. The direction of force is obtained by right hand grip rule. When the charge enters into a uniform magnetic field perpendicular to its direction, then F = qvB. If it enters along the direction of the field, F = 0.
24. The force can only change the direction in which the charge is moving but not its speed. Hence no work is done by it.
25. When a charged particle moves in a uniform magnetic field at right angles to the direction of the field.

    i) the trajectory of motion changes and

    ii) the speed and energy of a particle remain the same.

26. When a charged particle moves in an electric field, work is done and hence its kinetic energy increases.
27. If we assume that the earth's magnetic field is due to a long circular loop of current in the interior of the earth, then the plane of the loop will be east-west and the current passes in clockwise direction when seen from earth's north pole.
28. An electron is moving vertically downwards at a certain place. The direction of force on it due to the horizontal component of the earth's magnetic field is towards west.
29. The force acting on a charged particle when it enters a uniform magnetic field of induction B, with velocity v at right angles to the field will provide the necessary centripetal force and make the charged particle move along a circular path of radius 'r'.

    $F = \frac{mv^2}{r} = qvB$; $r = \frac{mv}{qB}$ or $\frac{v}{r} = \frac{qB}{m}$

    since $T = \frac{2\pi}{\omega}$, we have $T = \frac{2\pi m}{qB}$

    Thus time period is independent of the particle-speed. Hence the faster particles move in bigger circles and slower particles move in smaller circles such that the period of revolution T is the same.

30. The frequency $(\nu) = \frac{qB}{2\pi m}$ and is called cyclotron frequency.
31. If a charged particle enters a uniform magnetic field along the line of the field, it goes undeviated. If it enters at an angle of inclination other than 90^o to the field, its path is helical.
32. When both the electric and magnetic fields are present, the total force on q is

    $\vec{F} = q\vec{E} + q\vec{v} \times \vec{B}$. This force is known as Lorentz force.

33. The frequency of a charged particle in a uniform magnetic field is known as cyclotron frequency as the particles in a circular accelerator, called cyclotron, move with this frequency.
34. Cyclotron is a device used to accelerate charged particles to high speed for nuclear reaction. It was invented by Lawrence.

The force on a current carrying conductor in a magnetic field :

35. When a conductor of length l carrying a current i is placed at an angle θ to the direction of the magnetic field of flux density or induction B, the force on the conductor or wire is given by

    $\vec{F} = i(\vec{l} \times \vec{B})$ or $F = ilB \sin\theta$

    Its direction can be determined by using Fleming's left hand rule, whose statement is as follows:
    Stretch the fore finger, middle finger and thumb of the left hand mutually perpendicular to each other. If the fore finger represents the direction of magnetic field, the middle finger that of current, then the thumb will represent the direction of force on the conductor.

Force & torque on current loop or coil in a magnetic field :

36. The total magnetic force on any closed current loop in a uniform magnetic field is zero.

37. Torque or couple on a current carrying rectangular conductor or loop in a uniform magnetic field is given by $\tau = iAB\sin\theta$ where A is the area of the rectangular loop, B is the magnetic induction and θ is the angle between the normal to the plane of the rectangular loop and the field. If there are n turns, then the torque acting on the coil suspended is given by $\tau = niAB\sin\theta$ or $\tau = MB\sin\theta$ where M is the magnetic dipole moment equal to niA and θ is the angle between the magnetic induction and the normal to the plane of the coil i.e., the direction of the magnetic moment. When the plane of the coil makes an angle θ with the field, then the couple acting on the coil is τ = niABCosθ or τ = $MB\cos\theta$.
38. If i_1 and i_2 are the strengths of currents passing through two infinitely long, straight and parallel wires separated by a distance r, the magnetic field induction B, due to the flow of current in the first conductor at a distance r on the second conductor is $\vec{B}_1 = \frac{\mu_0 i_1}{2\pi r}$.

    The force exerted by this induction on a length l on the second conductor is $F = i_2B_1l$

    The force per unit length is $\vec{F} = \frac{\mu_0 i_1 i_2}{2\pi r}$.

    If the current is in the same direction, there will be attraction and if the current is passing in opposite direction, there will be repulsion.
39. An ampere is that steady current when flowing in each of two long straight parallel wires separated by a distance of one metre apart in vacuum causes each wire exert to each other a force of 2×10^{-7} N per each metre length of wire.

    Moving coil galvanometer :
40. A moving coil galvanometer consists of a powerful horse shoe magnet with concave poles to produce

    a uniform radial magnetic field. On a cylindrical soft iron core, a coil is wound and the coil is suspended with a phosphorbronze fibre. The plane of the coil always lies in the direction of the magnetic field because the magnetic field is radial. The whole apparatus is kept inside a brass case provided with a glass window.

    $$i = \frac{C\theta}{NAB} \text{ ampere}$$

    Here C is the couple per unit twist on the suspension fibre, ‘i’ is the current passing through the galvanometer coil and θ is the angle of deflection by the needle.

    C/BAN is a constant (k) is called as galvanometer constant. Deflection is measured more accurately using Lamp and Scale arrangement. The ray reflected onto the scale by the mirror is deflected by 'x'. The distance between the mirror attached to the suspension fibre of the galvanometer and the scale is D, then

    Tan2$\theta \approx 2\theta$ when 2θ is very small

    Then $2\theta = \frac{x}{D}$; $\theta = \frac{x}{2D}$; $i = \frac{C}{BAN}.\frac{x}{2D}$
41. The current sensitivity of a galvanometer is the deflection in mm produced on a scale kept at a distance of one metre by a constant current of one microampere.
42. The reciprocal of the current sensitivity is called figure of merit and is expressed in μA/mm.
43. A current upto 10^{-9}A can be measured using moving coil galvanometer.
44. **Table Galvanometer** : It has a rectangular coil of insulated copper supported on two bearings. The poles of the magnet are concave. It has a light aluminium pointer which moves on a scale. The whole arrangement is kept in an ebonite case with a glass window.
45. **Comparison of MCG with TG :**

Moving Coil Galvanometer	Tangent Galvanometer
MCG is a moving coil type galvanometer and the coil rotates in a magnetic field when current is passed through the coil.	TG is a moving magnet type galvanometer. The magnetic needle rotates when current is passed through the coil.
The plane of the coil need not be aligned in magnetic induction.	The plane of the coil must be in magnetic meridian.
The current flowing through the coil is directly proportional to the deflection.	The current flowing in the coil is proportional to the tangent of deflection.
It is accurate and can be used to measure the currents of order 10^{-9} A with proper design.	Tan values are not so accurate and can be used to measure the currents of the order 10^{-6} A.
The galvanometer constant does not depend on earth's magnetic field.	The galvanometer reduction factor depends on earth's magnetic field which is different at different places.
Stray magnetic fields have no effect on it and can be used for the measurement of the currents even in mines.	External fields have effect on it and therefore TG cannot be used in mines.

Tangent Galvanometer :

46. a) It is portable and minimum measurable current is of the order of 10^{-6} A.

b) works on the principle of Tangent law $B = B_H \tan\theta$

Here B = Magnetic induction due to passage of current in the coil = $\frac{\mu_0 i}{2r}$

c) current measured by Tangent galvanometer is $i = \left(\frac{2rB_H}{\mu_0 n}\right)$ $\tan\theta = K\tan\theta$

r = Radius of coil
n = number of turns of coil

d) Reading is more accurate when $\theta = 45°$ since relative error $\frac{di}{i} \alpha \frac{1}{\sin 2\theta}$ and it is minimum for 45°

e) Sensitiveness is maximum when $\theta = 0°$ since sensitiveness $\frac{d\theta}{di} \alpha \cos 2\theta$, which is maximum for $\theta = 0°$.

f) During experiment, plane of the coil should be along the magnetic meridian [to fulfill the requirement of tangent law]

47. **Shunt :**

a) A low resistance connected in parallel to galvanometer to protect it from large current is known as shunt.

b) $i = i_g + i_s$

c) $i_g = \frac{i(S)}{G+S}$

d) $i_s = \frac{i(G)}{G+S}$

e) $\frac{i_g}{i_s} = \frac{S}{G+S} = \frac{1}{n}$

f) effective resistance of circuit = $\frac{GS}{G+S}$

g) If the range of galvanometer is increased to n times, $1/n^{th}$ of main current passes through galvanometer. Hence sensitiveness decrease by n times.

48. **Ammeter :**

a) It is a device used to measure current in electrical circuits.

b) Galvanometer can be converted in to Ammeter by connecting low resistance parallel to it.

c) To increase the range by 'n' times or to decrease the Sensitiveness by 'n' times , shunt to be connected across Galvanometer.

$S = \frac{ig(G)}{i - ig} = \frac{G}{(n-1)}$

Here n = $\frac{i}{i_g} = \frac{\text{new range}}{\text{old range}} = \frac{\text{old dividisions / A}}{\text{new divisions / A}}$

d) Resistance of Ammeter = $\frac{GS}{G+S}$

e) Resistance of ideal Ammeter is zero and its conductivity is infinity

f) Ammeter must be always connected in series to the conductor.

g) Among low range and high range Ammeter, low range Ammeter has more resistance.

h) As shunt value decreases sensitivity decreases, accuracy increases.

49. **Voltmeter :**

a) Voltmeter is a device used to measure P.D. across the conductor in electric circuits.

b) Galvanometer is converted into voltmeter by connecting high resistance in series to it.

c) Voltmeter is always connected in parallel to the conductor [P.D. across which is to be measured]

d) Resistance of voltmeter = G +R = $\frac{V}{ig}$

e) Here 'V' is range of voltmeter (e) resistance of ideal voltmeter is infinity and conductivity is zero.

f) Among low range and high range voltmeters, high range voltmeter has more resistance.

g) P.D. across the ends of voltmeter is, $V = i_g + (G+R)$

h) Resistance to be connected in series to galvanometer to convert into voltmeter is $R = \frac{V}{i_g} - G$.

i) To increase the range by n times,

$$n = \frac{\text{new range}V_2}{\text{old range}V_1}$$

$$= \frac{i_g(G+R)}{i_g(G)}$$

$$= 1 + \frac{R}{G}$$

Hence resistance to be connected in series to galvanometer is R = G(n-1).

j) As series resister value increases sensitivity decreases, accuracy increases