MAGNETISM

1. Torque on a current carrying loop suspended freely in a magnetic field:

(i) When a loop is suspended freely in a magnetic field and a current is passed through i, we find that the resultant force on the loop is zero but the resultant torque is not zero (in general)

(ii) If normal to the plane of the loop makes an angle θ with the direction of uniform magnetic field B, then torque acting on the loop is given by : $\vec{\tau} = NI\vec{A} \times \vec{B} \quad = \vec{M} \times \vec{B}$

where $\vec{M} = NI\vec{A}$ = magnetic dipole moment of the current carrying coil.

2. Moving coil galvanometer:

(i) It is used for the measurement of current

(ii) The current to be measured is conducted to the coil through the suspension wire. The current deflects the coil in the radial magnetic field between the soft iron cylinder and concave pole pieces. The amount of deflection serves as a measure of current.

(iii) The current I is directly proportional to deflection ϕ

$$\text{At equilibrium,} \quad \tau_{\text{deflecting}} = \tau_{\text{restoring}} \Rightarrow NIAB = C\phi \quad \Rightarrow \phi = \left(\frac{NAB}{C}\right)(I)$$

where C= elastic torsional constant of the suspension wire, N = number of turns in the coil, A = Area per turn of the coil and B = magnetic induction of radial magnetic field.

(iv) The current sensitivity = $S_I = \frac{\phi}{I} = \frac{1}{K} = \frac{NAB}{C}$; The voltage sensitivity = $S_V = \frac{\phi}{V} = \frac{S_I}{R}$

3. Ammeter:

(i) An ammeter is used to measure the current in a circuit. It is connected in series with the ciruit to avoid division of current, but when placed in series with the circuit, it increases the resistance and decreases the current being measured by it. Hence, an ideal ammeter has a zero resistance.

(ii) The resistance of a milliammeter is more than that of an ammeter

(iii) To convert a galvanometer which gives full scale deflection for a current I_g so that it may be used to read a current I, the value of the shunt required is given by: $S = \left[I_g G / \left(I - I_g\right)\right]$

where G = galvanometer resistance

4. Voltmeter:

(i) When a high resistance R is connected in series with a galvanometer of resistance G, it becomes a voltmeter. If I_g represents the minimum current for full scale deflection of the galvanometer, then yhe minimum difference V_g across the terminals of the galvanometer for full scale deflection is given by: $V_g = I_g G$

(ii) Now, the poential difference V across the terminal of the series combination of R and G is given by:

$$V = I_g (R + G) \qquad \text{So,} \qquad \frac{V}{V_g} = \frac{R + G}{G}$$

(iii) To measure potential difference across any element of the circuit we use a voltmeter. A voltmeter is connected in parallel with the element to avoid division of voltage, but when placed in parallel with the element it shares current from the element and decreases the potential difference across the element before measuring it. Hence, an ideal voltmeter has an infinite resistance so that it may not change the current in the element.

5. Magnet and Magnetism

(i) Magnetic poles exists in pairs, i.e., an isolated magnetic pole does not exist.

(ii) The force between magnetic poles obeys inverse square law.

(iii) A freely suspended current carrying solenoid behaves just like a bar magnet.

6. Magnetic lines of force:

(i) The magnetic lines of force are the curves such that the tangent drawn on it at any point indicates the direction of magnetic field.

(ii) The magnetic lines of force form closed curves, emerging from the north pole and entering the south pole.

(iii) These lines of force also never cross each other.

(iv) The intensity of magnetic field at any point in the field is defined as the number of lines of force passing per unit area perpendicular to the lines of force.

7. Other important points concerning a magnet :

(i) When a magnet of length 2l and pole strength m is placed in a magnetic field B, then the couple acting on the bar magnet is given be, $\tau = MB\sin\theta$, where M = m(2l)= magnetic moment of the magnet and θ is the angle between the bar magnet and direction of magnetic field.

(ii) The work done in deflecting the magnet through an angle θ from equilibrium position is given by:

$$W = MB(1-\cos\theta)$$

(iii) (a) If a bar magnet of moment M and pole strength m is cut into two equal halves along its axial line, then pole strength of each part is m/2 and the magnetic moment of each part is M/2.

(b) If a bar magnet of magnetic moment M and pole strength m is cut into two equal halves, along its equatorial line, the pole strength of each part is m and magnetic moment is M/2

(iv) (a) The magnetic induction on the axial line (end position) of a bar magnet is given by:

$$B_{axial} = \frac{\mu_0}{4\pi} \times \frac{2Md}{(d^2 - l^2)^2} \qquad (\text{along } S \to N)$$

where B = magnetic induction, d= distance between the centre of the magnet and the given point on the axial line, 2l = length of the magnet. For a short magnet,

$$\boxed{B_{axial} = \frac{\mu_0}{4\pi} \times \frac{2M}{d^3}}$$

(b) The magnetic induction on the equatorial line (broad side on position) is given by:

$$B_{equatorial} = \frac{\mu_0}{4\pi} \times \frac{M}{(d^2 + l^2)^{3/2}} \qquad (\text{parallel to } \overrightarrow{NS})$$

For a short magnet, $\boxed{B_{equatorial} = \frac{\mu_0}{4\pi} \times \frac{M}{d^3}}$ Thus, for a short magnet $\frac{B_{axial}}{B_{equatorial}} = \frac{2}{1}$

(v) The magnetic field induction due to a short bar magnet at a point distant d from the centre of the magnet is given by $\boxed{B = \frac{\mu_0}{4\pi} \times \frac{M}{d^3}\sqrt{1 + 3\cos^3\theta}}$

8. Properties of magnetic materials:

(i) Magnetising force or intensity of magnetisign field H:

(a) The intensity of magnetising field is defined as the force experienced by a unit north pole placed at a point in the field.

(b) The direction of $\vec{H}$ is the same as the direction of $\vec{B} = \mu\vec{H}$, where μ is called the magnetic permeability.

(ii) Intensity of magnetisiation (I)

(a) When a magnetic material is placed in a magnetic field, it is magnetised and it acquires a magnetic dipole moment M. The intensity of magnetisation is defined as the magnetic dipole moment per unit volume, i.e., $I = \frac{M}{V} = \frac{2ml}{A(2l)} = \frac{m}{A}$

where A is the area of cross-section of the material. So intensity of magnetisation may also be defined as pole strength per unit area of cross section.

(iii) Magnetic susceptibility (χ):

(a) Magnetic susceptibility indicates the ease with which a substance can be magnetised.

(b) The susceptibility is defined as the ratio of the intensiy of magnetisation to the magnetising field H in which the material is placed, i.e.,

$\chi = (I/H)$ It has no units.

(iv) Magnetic permeability (μ): The permeability is defined as the ratio of magnetic induciton (B) to the magnetising force (H), i.e. $\mu = (B/H)$

(v) Magnetic induction or flux density (B): The flux density is the total number of lines of force per unit area due to the flux density B_0 in vaccum produced by that magnetising field and flux density B_m due to magnetisation of the material. Thus $B = B_0 + B_m$

9. Diamagnetic mateials:

(i) Materials which are repelled by magnets are known as diamagnetic maerials.

Example : bismuth, zinc, copper, silver, gold, diamond, NaCl, water, nitrogen, hydrogen, etc.

(ii) These material get magnetised in a direction opposite to that of the magnetic field.

(iii) In a non-uniform magnetic field, they move from regions of higher concentration field, they move from regions of higher concentration to regions of lower concentration.

(iv) Relative permeability of these materials is less than one but positive.

10. Paramagnetic material

(i) Materials which are feebly attracted by magnets are known as paramagnetic materials. Examples: aluminium, sodium, platanium, manganese, $CuCl_2$, $FeCl_3$, oxygen, etc.

(ii) These materials get magnetised in the direction of the magnetic field.

(iii) A paramagnetic rod suspended in a uniform magnetic field becomes parallel to the direction of the field.

(iv) In a non-uniform magnetic field, they move towards region of higher field.

(v) Relative permeability of these materials is just greater than one and positive

(vi) The magnetic susceptibility is inversely poportional to absolute temperature. This is called Curie law, $\chi = (C/T)$, where C is called Curie's constant.

11. Ferromagnetic materials:

(i) Subsances which are strongly attracted by magnets are known as feromagnetic substances. Examples: iron, nickel, cobalt, gadolinium.

(ii) A ferromagnetic rod, when suspended in a uniform magnetic field, aligns along the direction of the field.

(iii) In a non-uniform magnetic field, a ferromagnetic material moves towards regions of higher magnetic field.

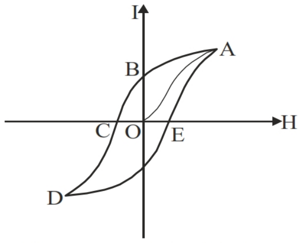
(iv) The relative permeability of these materials is very large (10^2 to 10^6)

(v) The magnetic susceptibiliy of these materials is positive and very high (10^2 to 10^6)

(vi) Ferromagnetism is due to the existence of magnetic domains. Ferromagnetic materials exhibit hysteresis.

12. Hysteresis loop

(i) Hysteresis loop or cycle is a plot a intensity of magnetisation (I) against magnetising field (H) over closed loop ABCDEA.



(ii) Retentivity: The residual magnetism present inside the speciment even when the external magnetising foce is made zero is called retentivity, or Retentivity is the capacity of the material to retain its magnetism when the magnetising force is removed. The intercept OB is a measure of retentivity.

(iii) Coercivity: Coercivity is the capacity of the material to reain its magnetism inspite of any demagnetising process. The intercept OC is a measure of retentivity.

(iv) The area of the hysteresis loop is a measure of work done or energy dissipation or hysteresis loop.

(v) (a) For soft iron: Coercivity is less, reentivity is more, hysteresis loss is less, susceptibility is more and permeability is more

(b) For steel: Coercivity is more, retentivity is less, hystersis loss is more, susceptibility is less and permeability is less.

(vi) Soft iron is used in transformers, moving coil galvanometers, electromagnets, etc., while steel is used for permanent magnets.

13. Earth's magnetic field:

(i) An imaginary vertical plane passing through magnetic north and magnetic north and magnetic south of a freely suspended magnet is called the magnetic meridian.

(ii) An imaginary vertical plane passing through north and south poles of the earth at a place is called as geographical meridian.

(iii) Declination: (θ)

(a) Declination is the angle between magnetic meridian and geographical meridian at a given place.

(b) The value of declination at equator is $17°$. Declination varies from place to place.

(c) The lines joining the places of equal declination are called isogonal lines

(d) The lines joining the places of zero declination are called agonal lines.

(v) Dip or inclination (δ):

(a) The angle made by the earth's magnetic field with the horizontal at a place is called dip or inclination at that place.

(b) Dip circle is the instrument used to measure the dip

(c) It varies beween 0° and 90°. At the magnetic equator it is zero and 90° at poles

(d) The lines joining the places of equal dip are called isoclinal lines.

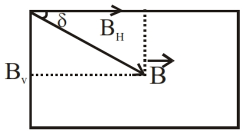
(e) The lines joining the places of zero dip are called aclinal lines.

(vi) Horizontal component (B_H)

(a) The component of the total induction of the earth's magnetic field (B) along the horizontal direction is called the horizontal component.

(b) The horizontal component can be measured with the help of a deflection magnetometer.

(c) If θ is the dip, i.e., the angle between total magnetic induction of the earth's magnetic field B and horizontal component B_H then



(I) horizontal component $B_H = B\cos\delta$

(II) vertical component $B_V = B\sin\delta$

(III) $B = \sqrt{B_H^2 + B_V^2}$ and $\tan\delta = (B_V / B_H)$

(d) B_H is zero at magnetic poles and maximum at the magnetic equator.

14. Vibration magnetometer

(i) If a magnet of dipole moment M oscillates in a uniform induction field B, then the time period of vibration magnetometer is :

$T = 2\pi\sqrt{\frac{I}{MB}}$ where $I = m\left[\frac{l^2 + b^2}{12}\right]$ is the moment of inertia of the magnet abou the axis of oscillation.

(ii) If two magnets of dipole moments M_1 and M_2 of same dimensions and same mass are oscillating in the same field, then $\frac{T_1}{T_2} = \sqrt{\frac{M_2}{M_1}}$

(iii) A magnet is oscillating in a magnetic field and its time period is T sec. If another identical magnet is placed over that magnet with similar poles togehter, then the time period remains unchagned $(\because I' = 2I \,\&\, M' = 2M)$

(iv) Two magnents of magnetic moments M_1 and M_2 ($M_1 > M_2$) are placed one over the other parallel. If T_1 is the time period when like poles touch each other and T_2 is the time period when unlike poles touch each other, then $\frac{M_1}{M_2} = \frac{T_2^2 + T_1^2}{T_2^2 - T_1^2}$