Chapter-5: Magnetism and Matter-Formulae

1. Uniform magnetic field:-

a) At a given place, magnetic field of the earth can be considered uniform.

b) Magnetic field acting in plane of paper is represented by equidistant parallel lines.

$$\longrightarrow$$
$$\longrightarrow \quad \vec{B}$$

a) Magnetic field acting perpendicular to the plane of paper and directed outwards is represented by dot. ⊙ (North pole) ⊙ ⊙ ⊙ ⊙

b) Magnetic field acting perpendicular to the plane of paper and directed inwards is represented by cross. (south pole) ⊗ ⊗ ⊗ ⊗

2. **Bar magnet as a dipole**:

a) A small current loop carrying a current I, produces a magnetic field at an axial point is-

$$\vec{B} = \frac{\mu_0}{4\pi}\left(\frac{2\vec{M}}{x^3}\right)$$

b) $\vec{M} = I\vec{A}$ is the magnetic dipole moment of the current loop.

c) A current loop placed in a magnetic field $\vec{B}$ experiences a torque $\vec{\tau} = \vec{M} x \vec{B}$

d) There are two types of magnetic charges, positive magnetic charge and negative magnetic charge.

e) A magnetic charge m placed in a magnetic field $\vec{B}$ experiences a force $\vec{F} = m\vec{B}$

f) The force on a positive magnetic charge is along the field and force on a negative magnetic charge is opposite to the field.

g) A magnetic charge m produces a magnetic field $B = \frac{\mu_0}{4\pi}\left(\frac{m}{r^2}\right)$

h) Coulomb's law of magnetic force

$$F = \frac{\mu_0}{4\pi}\left(\frac{m_1 m_2}{r^2}\right)$$

i) Magnetic dipole and magnetic dipole moment: An arrangement of equal and opposite magnetic poles separated by a small distance is called a magnetic dipole.

-m 2 l +m $\vec{M} = m(\overrightarrow{2l})$

Where m is the pole strength and 2l is the magnetic length. It is a vector quantity and represented from south to north pole.

3. Magnetic field of a bar magnet at an axial point (end on position) (x-direction)

$$B_{axial} = B_1 + B_2 = \frac{\mu_0}{4\pi}\left(\frac{4xml}{(x^2 - l^2)^2}\right) \; if \; x \gg l, then \; B_{axial} = \frac{\mu_0}{4\pi}\left(\frac{2M}{x^3}\right)$$

In vector form, $\vec{B}_{axial} = \frac{\mu_0}{4\pi}\left(\frac{2\vec{M}}{x^3}\right) = \frac{\mu_0}{4\pi}\left(\frac{4ml}{x^3}\right)\hat{\imath}$

4. Magnetic field of a bar magnet at an equatorial point (broad on position) (y-direction)

$$B_{equitorial} = \frac{\mu_0}{4\pi}\left(\frac{M}{y^3}\right) \; or \; \vec{B}_{equitorial} = \frac{\mu_0}{4\pi}\left(\frac{\vec{M}}{y^3}\right) = \frac{\mu_0}{4\pi}\left(\frac{2ml}{y^3}\right)(-\hat{\imath})$$

5. **Some Important Definitions**:

a) The number of magnetic lines of induction inside a magnetic substance crossing unit area normal to their direction is called the magnitude of magnetic induction, or magnetic flux density inside the substance.'' It is denoted by $\vec{B}$. Its unit is tesla (T) or weber/meter^2 (Wb/m^2). The CGS unit is gauss (G). 1 Wb/m^2 = 1 T = 10^4 G

b) Intensity of Magnetisation$(\vec{I})$: It is defined as magnetic moment per unit volume of the magnetised substance. This basically represents the extent to which the substance is magnetised. Thus, $I = \frac{M}{V}$, The S I unit is Amp/m.

c) Magnetic Intensity or magnetic field strength$(\vec{H})$: When a substance is placed in an external magnetic field, the actual magnetic field inside the substance is the sum of external magnetic field and the field due to its magnetisation (or intensity of magnetisation). $\vec{B} = \vec{B}_0 + \vec{B}_M \Rightarrow \vec{B} = \mu_0\vec{H} + \mu_0\vec{I}$

d) The capacity of magnetising field to magnetise the substance is expressed by means of a vector$(\vec{H})$, called the magnetic intensity of the field.

e) The SI unit of magnetic intensity is same as that of I that is A/m. The CGS unit is Oersted.

f) Magnetic permeability(μ): It is defined as the ratio of magnetic induction $(\vec{B})$ inside the magnetised substance to the magnetic intensity $(\vec{H})$ of the magnetising field. $\mu = \frac{B}{H}$

g) It is measure of the extent to which material can be penetrated or permeated by a magnetic field. It is basically a measure of conduction of magnetic lines of force through it. The SI unit of magnetic permeability is Wb/A-m.

h) Relative magnetic permeability(μ_r): Permeability of various substances can be compared with one another in terms of relative permeability. It is defined as ratio of permeability of the medium to the permeability of the free space. $\mu_r = \frac{\mu}{\mu_0}$

i) For vacuum, $\mu_r = 1$, It is also defined as ratio of magnetic field B in the substance when placed in magnetic field B_0. Thus, $\mu_r = \frac{B}{B_0}$

j) Magnetic susceptibility (χ_m): It is a measure of how easily a substance is magnetised in a magnetic field. It is defined as the ratio of intensity of magnetisation to the magnetic intensity of the magnetising field. $\chi_m = \frac{I}{H}$

k) Relation between relative permeability and magnetic susceptibility: $\mu_r = 1 + \chi_m$

6. **Hysteresis**: The phenomenon of lagging of magnetic induction (B) behind the magnetising field (H) is called Hysteresis. It is a Greek word, meaning delayed.

7. Hysteresis Loop: The closed curve ABCDEFA which represents a cycle of magnetisation of a ferromagnetic sample is called its hysteresis loop.

8. Significance of the area of hysteresis loop: The product B-H has the dimension of energy per unit volume. $BH = B\left(\frac{B}{\mu}\right) = \frac{B^2}{\mu_0\mu_r} = B^2v^2 = \frac{F^2}{q^2v^2}v^2 = \frac{Energy}{Volume}$

9. Area within the B-H loop represents energy dissipated per unit volume in materials when it is carried through a cycle of magnetisation.
10. Curie's Law: According to Curie's law, magnetic susceptibility of a paramagnetic substance is inversely proportional to the absolute temperature T. $\chi_m \propto \frac{1}{T}$ or $\chi_m = \frac{C}{T}$
11. Curie-Weiss law: The susceptibility of ferromagnetic material decreases with temperature according to $\chi_m = \frac{C}{T-T_C}$

12. **Comparison of magnetic properties of soft iron and steel**:

a) Soft iron has greater permeability (μ) i. e. (B) than steel
b) Soft iron has greater susceptibility ($\chi_m = \mu_r - 1$)
c) Retentivity of soft iron is greater than that for steel
d) Coercivity of soft iron is less than that of steel
e) Soft iron has less hysteresis loss than steel.

13. **Neutral Point**: It is the point where the magnetic field due to a magnet is equal and opposite to the horizontal component of earth's magnetic field. The resultant magnetic field at the neutral point is zero. If a compass needle is placed at such a point, it can stay in any position.

a) Suppose a small bar magnet is placed such that the north pole of the magnet is towards the magnetic south pole of the earth, then neutral points are obtained both sides on the axis of the magnet. If the distance of each neutral point from the middle point of the magnet be r and the magnitude of magnetic moment be M, then $B_H = \frac{\mu_0}{4\pi}\left(\frac{2M}{r^3}\right)$
b) When North Pole of the bar magnet is towards magnetic north pole of the earth, the neutral points are obtained on perpendicular bisectors of the magnet. $B_H = \frac{\mu_0}{4\pi}\left(\frac{M}{r^3}\right)$

14. **Elements of earth's magnetic field**:

a) Magnetic declination (α): The angle between geographical meridian and the magnetic meridian at a place is called the magnetic declination at that place.
b) Angle of dip or magnetic inclination (δ): The angle made by the earth's total magnetic field B with the horizontal direction in the magnetic meridian is called angle of dip.
c) Horizontal component of earth's magnetic field: It is the component of earth's total magnetic $\vec{B}$ in the horizontal direction in the magnetic meridian. If δ be the angle of dip at any place, then $B_H = B \cos\delta$

15. **Tangent Galvanometer**: Tangent law: This law states that if a freely suspended small magnet is acted upon by two uniform mutually perpendicular magnetic fields B_1 and B_2 simultaneously, then the magnets comes to rest in such a position that the tangent of the angle θ that the magnet makes with B_1 is equal to the ratio B_2 /B_1 of the two fields. That is, $\tan\theta = \frac{B_2}{B_1}$
16. **Time period** of oscillation of freely suspended magnet is $T = 2\pi\sqrt{\frac{I}{MB}}$
17. **Difference between magnetic dipole and electric dipole**

a) **Magnetic Dipole**:
    i. Current coil loop, solenoid etc. Are just like a magnetic dipole whose dipole moment M = NIA

ii. Direction of Magnetic dipole moment $(\vec{M})$: It is from south pole (S) to north pole (N).

iii. The behaviour of magnetic dipole (may be a bar magnet) is similar to electric dipole. The only difference is that the electric dipole moment $\vec{p}$ is replaced by magnetic dipole moment $\vec{M}$, charge q is replaced by pole strength m, $\vec{E}$ by $\vec{B}$ and the constant $\frac{1}{4\pi\epsilon_0}$ is replaced by $\frac{\mu_0}{4\pi}$

18. Comparative study of properties of para, dia and ferromagnetic materials

Parameters	Paramagnetic	Diamagnetic	Ferromagnetic
Effects of magnets	Feebly attracted by magnets	Feebly repelled by magnets	Strongly attracted by magnets
In external magnetic field	Acquires feeble magnetism in the direction of magnetizing field	Acquires feeble magnetism in the opposite direction of magnetizing field	Acquires strong magnetism in the direction of magnetic field
In non uniform magnetic field	Tends to move slowly from weaker to stronger	Tends to move slowly stronger to weaker	Tends to move quickly from weaker to stronger
In uniform magnetic field	Freely suspended rod aligns itself parallel to field	Freely suspended rod aligns perpendicular to field	Freely suspended rods aligns parallel to field
μ_r	>1	< 1 or $0 \le \chi_m < 0$	>> 1 or $\mu_{r>}$>1000
X_m	Slightly positive	Slightly negative, or $-1 \le \chi_m < 0$	Positive and very large, or $\chi_m > 1000$
μ	$\mu > \mu_0$	$\mu < \mu_0$	$\mu >> \mu_0$
Effect of temperature	Inversely as temp.	Independent of temp.	$\chi_m \propto \frac{1}{T-T_C}$, $T > T_C$
Removal of magnetising field	As soon as magnetising field is removed, magnetism is lost	Magnetisation lasts as long as magnetising field is applied	Magnetisation is retained even after magnetising field is removed
Variation of I with H	I changes linearly with H and attains saturation	I changes linearly with I	I changes non linearly with H and ultimately attains saturation
Hysteresis effect	Shows no hysteresis	Shows no hysteresis	Shows hysteresis
Physical state of material	Solid, liquid or gas	Solid, liquid or gas	Normally solids only

19. **Moving coil galvanometer**:

a) The moving coil is a device used to measure an electric current.

b) Principle: Action of moving coil galvanometer is based upon the principle that when a current carrying coil is placed in a magnetic field, it experiences a torque whose magnitude depends on the magnitude of current. $Current\ I \propto Deflection\ (\varphi)$

c) In the equilibrium, torque experienced in a magnetic field = Spring torque, that is

$\tau = MB\sin\theta = (NIA)B\sin\theta = k\varphi$ where k is the torsional or spring constant.

d) $Galvanometer\ constant = \frac{k}{NAB}$

20. $Current\ sensitivity = \frac{\varphi}{I} = \frac{NAB}{k} Voltage\ sensitivity = \frac{\varphi}{V} = \frac{\varphi}{IR} = \frac{NBA}{kR}$ of galvanometer
21. Conversion of galvanometer into voltmeter, $V = I(R_g + R_s)$, $R_V = R_g + R_s \gg R_g$
22. Conversion of galvanometer into ammeter, $I_g = I\frac{R_{sh}}{R_{sh}+R_g}$, $R_A = \frac{R_g R_{sh}}{R_g+R_{sh}} < R_{sh}$

23. Magnetic dipole moment of a revolving electron in terms of Bohr's magneton

a) Magnetic dipole moment $M = \frac{eL}{2m}$ where $L = mvr = \frac{nh}{2\pi}\ or\ M = \frac{e}{2m}\left(\frac{nh}{2\pi}\right) = nM_{min}$

b) Bohr magneton = $M_{min} = \frac{eh}{4\pi m}$