

Magnetism And Matter

Bar Magnet

- It consists of a magnetic dipole.
- The two poles of a magnet point to the North and South Poles of the Earth when the magnet is suspended freely.
- Properties of magnetic poles:
 - Like poles repel each other and unlike poles attract each other.
 - They can never be separated.
- Magnetic length is the distance between the two poles of a magnet.
- Magnetic dipole moment is the product of either pole strength and magnetic length of a magnet.
- Magnetic dipole moment is a vector quantity. Its SI unit is joule/tesla or ampere-metre².
- A current-carrying coil behaves like a magnetic dipole whose one face represents the North Pole and the other face represents the South Pole.
- The magnetic moment of a current-carrying coil is given by $M = nIA$.
- The magnetic moment of a bar magnet is equal to the magnetic moment of an equivalent solenoid that produces the same magnetic field.
- The magnetic field of a small bar magnet along the axial line is given by $B = \frac{\mu_0}{4\pi} \frac{2Mr^3}{r^4}$
- The magnetic field of a small bar magnet along the equatorial line is given by $B = \frac{\mu_0}{4\pi} \frac{Mr^3}{r^4}$.

Magnetic Field Lines

- A magnetic field line is an imaginary curve the tangent to which at any point gives the direction of magnetic field at that point.
- Magnetic field lines move from the South Pole to the North Pole within the magnet's material and from the North Pole to the South Pole outside it.
- Magnetic field lines do not intersect each other.

Magnetic dipole in a uniform magnetic field

- Equal and opposite forces act on the poles, which constitute a couple on the bar magnet.
- The net torque(τ) acting on the magnetic dipole,

Here, M is the magnetic moment of the dipole and B is the magnitude of the magnetic field.

Electrostatic Analogue

- The equations for magnetic field $\vec{B}$ due to a magnetic dipole can be obtained from the equation of an electric field $\vec{E}$ due to an electric dipole, by making the following changes:

$$\vec{E} \rightarrow \vec{B}$$

$$\vec{p} \rightarrow \vec{M}$$

$$\frac{1}{4\pi\epsilon_0} \rightarrow \frac{\mu_0}{4\pi}$$

- Magnetic induction due to a bar magnet at any point on the axis,

$$B = \frac{\mu_0}{4\pi} \frac{2Mr}{(r^2 - l^2)^2} \quad B = \frac{\mu_0}{4\pi} \frac{2Mr}{r^2 - l^2}$$

Here, M = magnetic moment of the bar magnet

r = distance of the points where the magnetic field is to be calculated along the axis of the dipole.

- Magnetic induction due to a bar magnet at any point on the equator,

$$B = \frac{\mu_0}{4\pi} \frac{M}{(r^2 + l^2)^{3/2}} \quad B = \frac{\mu_0}{4\pi} \frac{M}{r^2 + l^2}$$

Here, M = magnetic moment of the bar magnet
 r = distance of the points where the magnetic field is to be calculated along the equatorial line of the dipole

Gauss' law for magnetism

- This law suggests that the number of magnetic field lines leaving any closed surface is always equal to the number of magnetic field lines entering it.
- According to Gauss' law for magnetism, the net magnetic flux ($\oint \vec{B} \cdot d\vec{s}$) through any closed surface is always zero.

$$\oint \vec{B} \cdot d\vec{s} = 0 \quad \oint \vec{B} \cdot d\vec{s} = 0$$

- No magnetic monopole (isolated magnetic poles) can exist.

Earth's Magnetism

- **Dynamo effect** – According to this the earth's magnetic field is due to electrical currents produced by convective motion of metallic fluids in the outer core of the earth.

Magnetic elements

- **Magnetic declination**(θ) – It is the angle between the geographic meridian and magnetic meridian.
- **Magnetic inclination or dip**(δ) – It is defined as the angle made by the direction of the earth's total magnetic field with the horizontal direction.
- **Horizontal component of earth's magnetic field** – It is the component of earth's magnetic field along the horizontal direction. It is denoted by B_H .
 $B \sin \delta B \cos \delta = B V B H \tan \delta = B V B H$

- **Magnetic Intensity:** It is given by
 $H = B_0 \mu_0 H = B_0 \mu_0$
- **Intensity of magnetisation** – It is defined as the magnetic moment developed per unit volume when a magnetic specimen is subjected to magnetising field. It is denoted by I .
 $I = M V I = M V$
- **Magnetic Induction** – It is defined as the number of magnetic lines of induction crossing per unit area through the magnetic substance. It is denoted by B .

$$B = \mu_0 (H + I)$$

- **Magnetic susceptibility** – The magnetic susceptibility of a magnetic substance is defined as the ratio of the intensity of magnetisation to the magnetic intensity. It is denoted by χ_m .

$$\chi_m = I H \chi_m = I H$$

- **Magnetic permeability** – The magnetic permeability of a magnetic substance is defined as the ratio of the magnetic induction to the magnetic intensity. It is denoted by μ .
 $B H = \mu_0 (1 + \chi_m) B H = \mu_0 (1 + \chi_m)$
or,
 $\mu = \mu_0 (1 + \chi_m) \mu = \mu_0 (1 + \chi_m)$

Relation between magnetic intensity (H) and magnetic field (B):

$$B = \mu_0 (1 + \chi) H$$

Where, χ is the magnetic susceptibility

Classification of magnetic materials:

- **Diamagnetic substances:** When such substances are placed in an external magnetic field, they get feebly magnetised in the direction opposite to the field.
- **Paramagnetic substances:** When such substances are placed in an external magnetic field, they get feebly magnetised in the direction of the field.
- **Ferromagnetic substances:** When such substances are placed in an external magnetic field, they get strongly magnetised in the direction of the field.

Permanent magnets

- Those substances which remain ferromagnetic at room temperature for a long period of time are called permanent magnets.
- Methods of making permanent magnets:
 - Holding a steel rod and striking it with a permanent magnet.
 - Placing a ferromagnetic substance in a solenoid and passing current through it.
- The material used to make a permanent magnet should have high retentivity and high coercivity.

Electromagnets

- The soft iron core in the solenoid acts as an electromagnet.
- The core of an electromagnet should have high permeability and low retentivity.
- The most suitable material for making an electromagnet is soft iron.
- Electromagnets are used in various devices such as electric bells, loud speakers and telephone diaphragms.
- An electromagnet must have:
 - high value of saturation magnetisation
 - low retentivity and coercivity
 - low hysteresis loss