

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 $B = \frac{\mu_0}{4\pi} \frac{2Mr}{r^3}$.
- The magnetic field of a small bar magnet along the equatorial line is given by $B = \frac{\mu_0}{4\pi} \frac{M}{r^3}$.

Magnetic Field Lines

- A magnetic field line is an imaginary curve the tangent to which at any point gives the direction of magnetic field $\vec{B}$ with rightwards arrow on top 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,

o

τ with rightwards arrow on top equals M with rightwards arrow on top cross times B with rightwards arrow on top

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,

$$B = \frac{\mu_0}{4\pi} \frac{2Mr}{r^3}$$

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,

$$B = \frac{\mu_0}{4\pi} \frac{M}{r^3}$$

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 ($\oint \mathbf{B} \cdot d\mathbf{s}$) through any closed surface is always zero.

$$\oint \mathbf{B} \cdot d\mathbf{s} = 0$$

- 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 .

$$B \sin \delta = B_H \quad B \cos \delta = B_V \quad B_H \tan \delta = B_V$$

Magnetic Intensity: It is given by

$$H = \frac{B}{\mu_0}$$

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 .

$$I = \frac{M}{V}$$

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 .

$$\chi_m = I/H$$

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 .

$$B/H = \mu_0(1 + \chi_m)$$

or,

$$\mu = \mu_0(1 + \chi_m)$$

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