SPECTRUM
CAREER INSTITUTE
JEE/NEET EXPERT

PHYSICS

BY

Dr. ANOOP DIXIT

B.Tech (Mech) M.Tech (P&I)
PhD(NIT Kurukshetra)

MAGNETISM (SP-14)

Student's Name: ______________________

Batch: ______________________

Magnetism

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CHAPTER

JEE/ NEET Syllabus

Current loop as a magnetic dipole and its magnetic dipole moment. Bar magnet as an equivalent solenoid, magnetic field lines; Earth's magnetic field and magnetic elements. Para-, dia- and ferro- magnetic substances. Magnetic susceptibility and permeability, Hysteresis, Electromagnets and permanent magnets

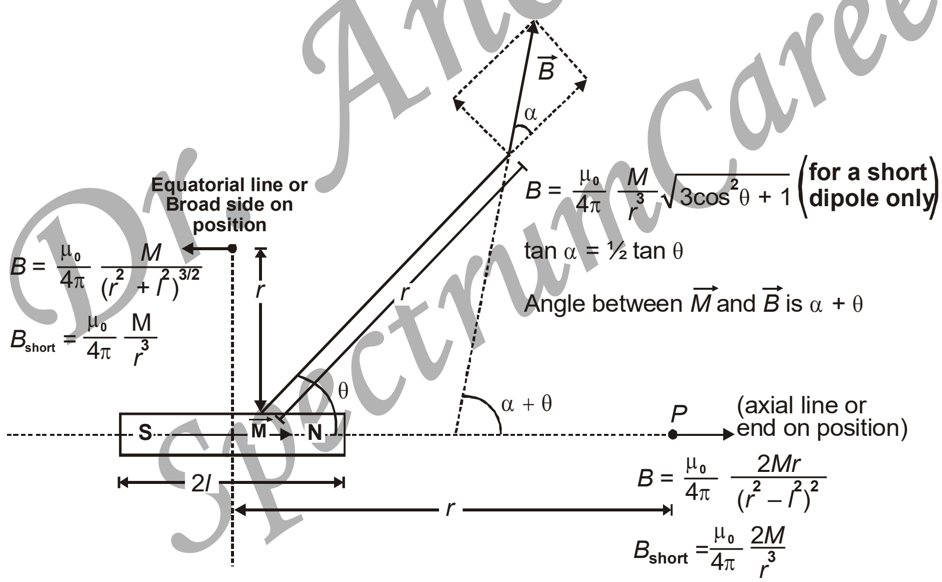
THIS CHAPTER COVERS :

- Bar Magnet
- Field lines
- Torque on a Bar Magnet in Magnetic field
- Oscillation of Bar Magnet in Magnetic field
- Earth's Magnetic field
- Para, Dia and Ferromagnetism
- Magnetic Susceptibility
- Diamagnetic substance
- Curie Law

BAR MAGNET

Properties

1. Geometric length = $2l$.
2. Magnetic length = **0.8** geometric length
3. $\vec{M} = m \times \vec{2l}$ where 'm' is pole strength.



4. $\vec{B}_{axial}$ is parallel to $\vec{M}$.
5. $\vec{B}_{equatorial}$ is antiparallel to $\vec{M}$.
6. $\vec{B} \perp \vec{M}$ when $\theta + \alpha = 90°$ *i.e.*, $\theta = 90° - \alpha$

as $\tan\alpha = \frac{1}{2}\tan\theta \Rightarrow \cot\theta = \frac{1}{2}\tan\theta$ or $\tan\theta = \sqrt{2}$.

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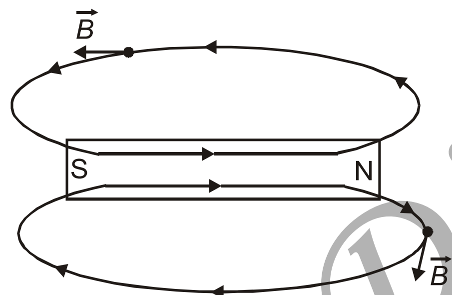
FIELD LINES

Properties

1. They are used to represent magnetic field in a region.
2. They are closed continuous curves.
3. Tangent drawn at any point gives the direction of magnetic field.
4. They can not intersect.
5. Out side a magnet, they are directed from north to south pole and inside a magnet they are directed from south to north.



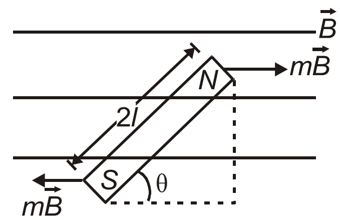
Magnetic Pole Strength

It is represented by *m*. Its unit is A-m. It is equivalent to charge in electrostatics. When a magnetic pole *m* is kept in magnetic field *B*, it experiences a force $m\vec{B}$.

Magnetic Flux : $\phi = \int \vec{B}.d\vec{s}$. Total number of field lines crossing a surface in a direction normal to it.

Gauss Law : $\phi = \oint_s \vec{B}.d\vec{s} = 0$. Total flux linked with a closed body is zero. Reason as magnetic monopoles do not exist, therefore total flux linked with a body is always zero.

TORQUE ON A BAR MAGNET IN MAGNETIC FIELD



$\tau = mB \times 2l \sin\theta$

$= m \times 2l \times B \sin\theta$

$\Rightarrow \tau = MB \sin\theta$

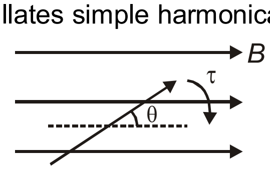
Results :

1. $\tau = \vec{M} \times \vec{B}$ $\tau_{max} = MB$ [when $\theta = 90°$], $\tau_{min} = 0$ [when $\theta = 0$ or $180°$]
2. Net force is zero.
3. $U = -M.B$ $U_{min} = -MB$ at $\theta = 0°$
   $U_{max} = MB$ at $\theta = 180°$
4. Work done in rotating bar magnet from angular position θ_1 to θ_2 is $W = MB [\cos\theta_1 - \cos\theta_2]$
5. A bar magnet kept in a non-uniform magnetic field may experience a net force and also a torque.

Oscillations of a Bar Magnet in Magnetic Field

For small displacements from equilibrium position, bar magnet oscillates simple harmonically such that

Angular frequency $\omega = \sqrt{\dfrac{MB}{I}}$; Time period $T = 2\pi\sqrt{\dfrac{I}{MB}}$



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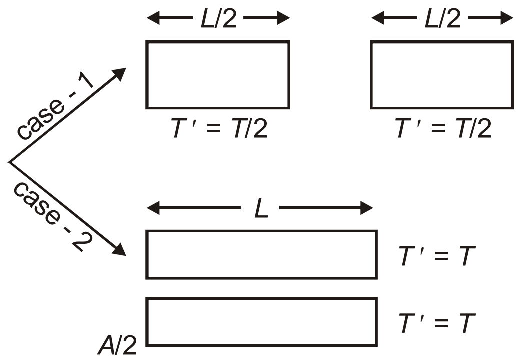
Some important cases are given below “

A bar magnet of length L is,

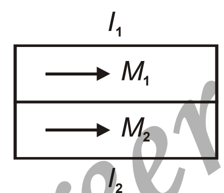
1. Cut into two halves



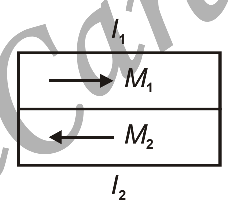
where $T = 2\pi\sqrt{\dfrac{I}{MB}}$

2. Two bar magnets having magnetic moments M_1, M_2 and moment of inertias I_1, I_2 are joined as shown.

(a) $T_1 = 2\pi\sqrt{\dfrac{I_1 + I_2}{(M_1 + M_2)B}}$



(b) $T_2 = 2\pi\sqrt{\dfrac{I_1 + I_2}{(M_1 - M_2)B}}$

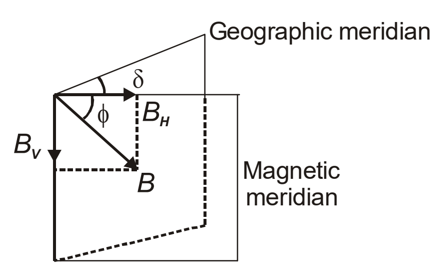


$\Rightarrow \dfrac{T_2^2 + T_1^2}{T_2^2 - T_1^2} = \dfrac{M_1}{M_2}$

EARTH’S MAGNETIC FIELD

The basic components of earth’s magnetic field at a place are shown

1. δ = Angle of declination
2. ϕ = Angle of dip



3. $B_H = B \cos \phi$
4. $B_V = B \sin \phi$
5. $B_H^2 + B_V^2 = B^2$

Note : *The needle of a vertical compass in magnetic meridian points toward B.*

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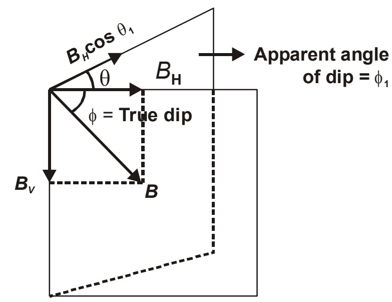
6. $\tan\phi = \dfrac{B_V}{B_H}$



7. $\tan\phi_1 = \dfrac{B_V}{B_H\cos\theta_1}$ (apparent dip)

$\Rightarrow \quad \tan\phi_1 = \dfrac{\tan\phi}{\cos\theta}$

PARA, DIA AND FERROMAGNETIC SUBSTANCES

All the elements of the nature are studied under the action of magnetic field, and then classified into three parts according to following properties.

1. **Magnetic Intensity (Magnetising Force) :** $H = \dfrac{B_o}{\mu_o}$

   B_0 is magnetic field in vacuum

   SI units = A/m

2. **Intensity of magnetisation :** Magnetic moment developed/volume

   $I = \dfrac{M}{V}$ (Units A/m or oersted)

   $\Rightarrow \quad I = \dfrac{\text{Pole strength}}{\text{area}} \qquad \begin{bmatrix} \because M = m \times l \\ \because V = A \times l \end{bmatrix}$

3. **Magnetic Induction or Magnetic Flux Density (B) :** Number of magnetic field lines crossing per unit area normally through a magnetic substance.

   $B = B_0 + \mu_0 I$

   $B = \mu_0 H + \mu_0 I \qquad \begin{bmatrix} B_0 = \text{applied magnetic field} \\ \mu_0 I = \text{magnetic fielddue to magnetisation} \end{bmatrix}$

   $B = \mu_0 (H + I)$

4. **Magnetic Susceptibility :** $\chi_m = \dfrac{I}{H}$ (no units)

5. **Magnetic Permeability :** $\mu = \dfrac{B}{H} \Rightarrow B = \mu H$

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

   $\Rightarrow \quad \mu H = \mu_0 (H + I)$

   $\dfrac{\mu}{\mu_0} = 1 + \dfrac{I}{H}$

   $\mu_r = 1 + \chi_m$ where μ_r = relative permeability.

Properties of Diamagnetic Substance

1. Diamagnetism is universal property of the substances.
2. χ_m is small and negative
3. $\mu_r < 1$.
4. As $\chi_m = \dfrac{I}{H} \quad \Rightarrow I$ is small and opposite to H.

   $\therefore$ They are magnetised weakly and opposite to applied magnetic field.

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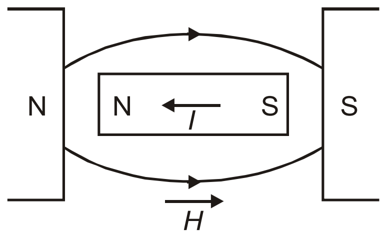
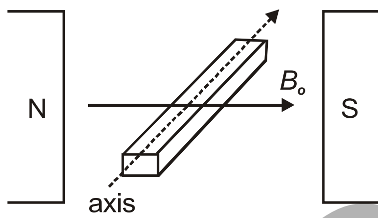
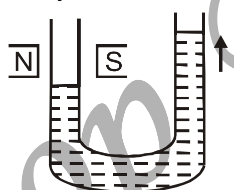
5. Magnetic field lines do not cross through diamagnetic materials.



6. When freely suspended, they align perpendicular to $\vec{B}_o$.



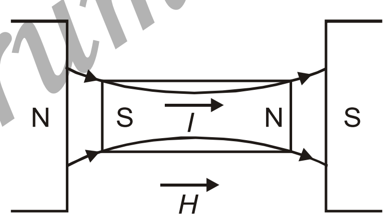
7. They are repelled by magnetic field, so they move from stronger to weaker regions of magnetic field.



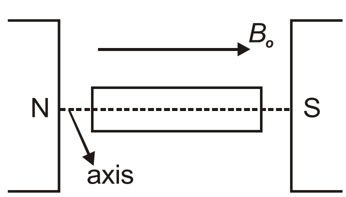
Some examples of diamagnetic substances are Cu, Zn, Bi, Ag, Au, Glass, NaCl.

Paramagnetic and Ferromagnetic Substances

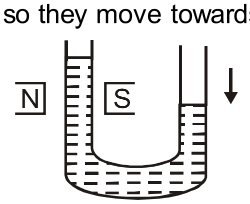
1. For paramagnetic, χ_m is small and positive, $\mu_r > 1$.
2. For ferromagnetic, χ_m is large and positive, $\mu_r >> 1$.
3. Both get magnetised in the direction of applied field.
4. Magnetic field lines cross through them.



5. When freely suspended, they align along the applied field.



6. They are attracted by magnetic field, so they move towards stronger region of magnetic field.



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Some examples are given below :

(a) Paramagnetic - Al, Na, Sb, Pt.

(b) Ferromagnetic - Fe, Ni, Co

Curie Law

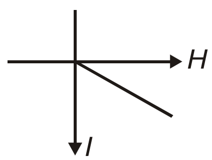
Magnetic susceptibility of paramagnetic material is inversely proportional to its absolute temperature.

$\chi_m \propto \frac{1}{T}$ or $\chi_m = \frac{C}{T}$ The magnetisation is directly proportional to magnetic intensity and inversely proportional to absolute temperature.

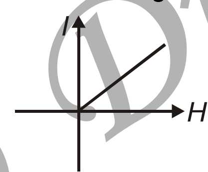
> **Note:** (a) *Diamagnetic material is independent of temperature.*
>
> (b) *Magnetic susceptibility of a ferromagnetic substance also decreases with increase in temperature. At a particular temperature T_C called 'CURIE POINT', a ferromagnetic substance is converted into paramagnetic.*

Variation of *I* with *H*

1. Diamagnetic



2. Paramagnetic

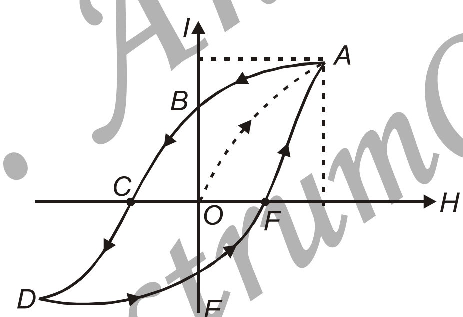


3. Ferromagnetic (Hysteresis)

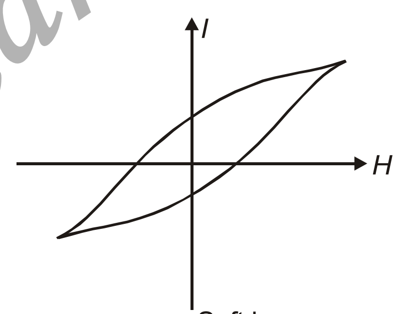
OB = Retentivity (residual magnetism even after magnetising field is reduced to zero)

OC = Coercivity (reverse magnetic field required to reduce residual magnetism to zero)

Area *ABCDEFA* = Energy loss/cycle during magnetisation and demagnetisation.



Steel
(High coercivity, high retentivity)



Soft iron
(Low coercivity, low retentivity)

> **Note :** (a) *Steel is used for making permanent magnets.*
>
> (b) *Soft iron is used for temporary magnets (Electromagnet).*

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