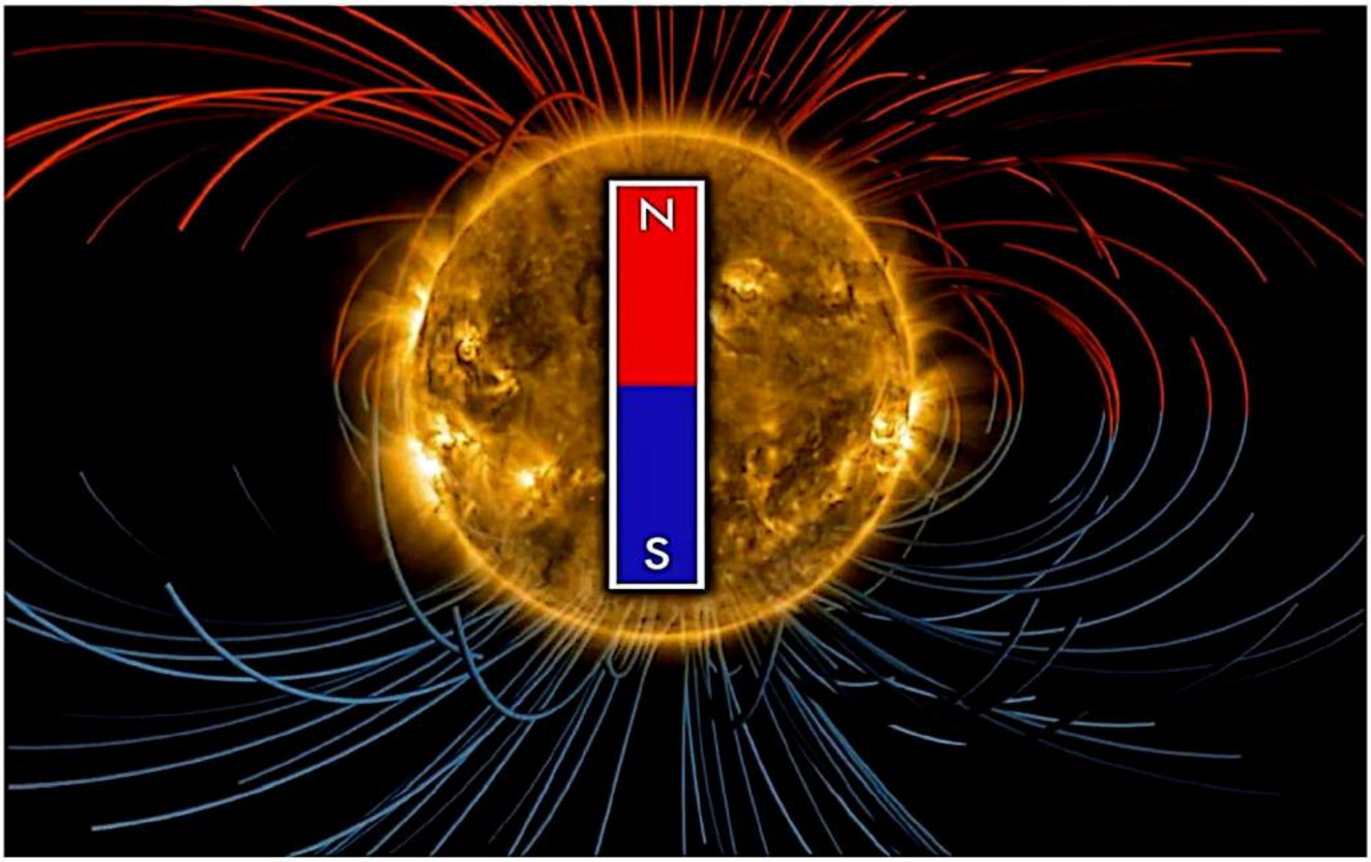
Chapter–5

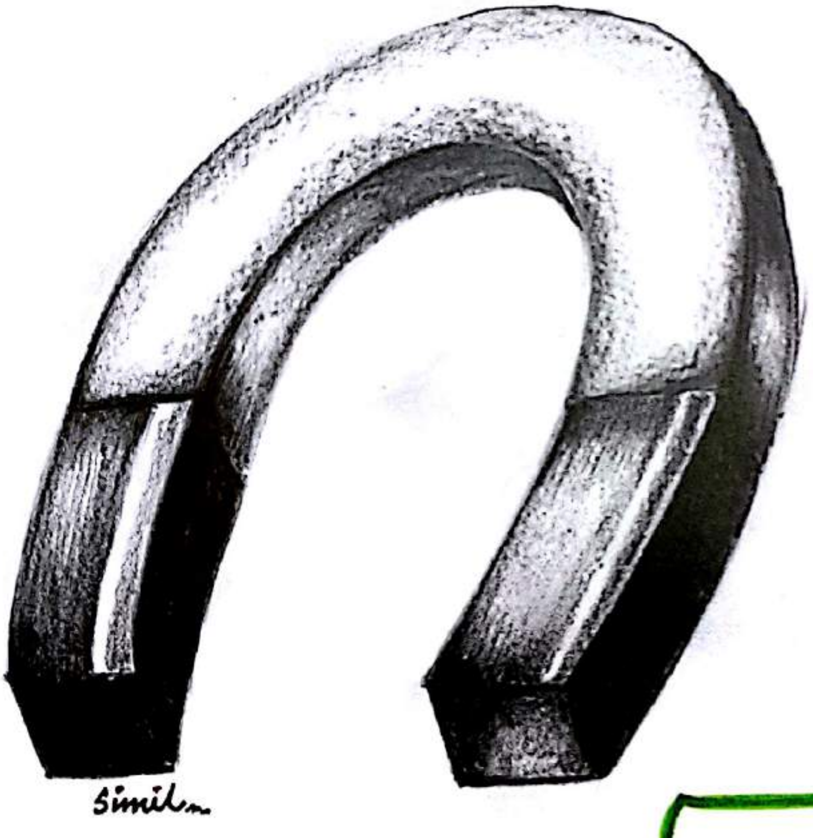
Magnetism and Matter



CBSE CLASS XII NOTES

Dr. SIMIL RAHMAN

Magnetism



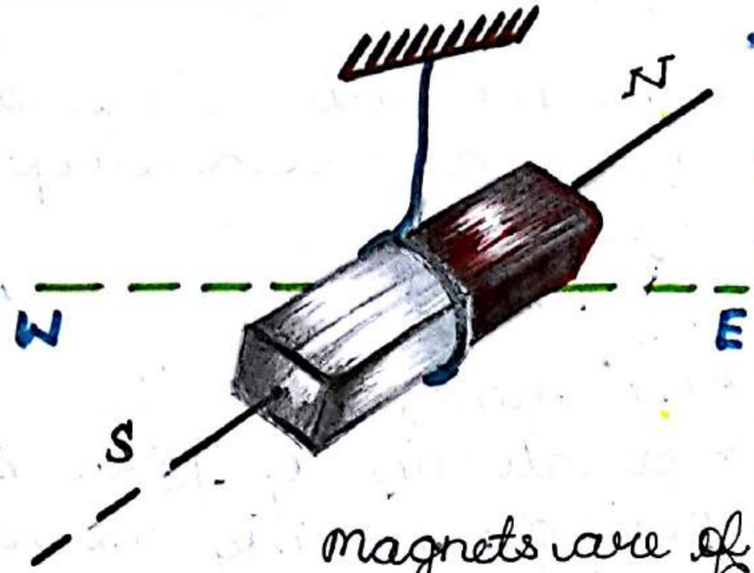
CBSE **CLASS NOTES**

SIMIL RAHMAN

MSc Phy, D.*Electrical Electronics Engineering*, M.Eng ,B.Ed,SET, PhD(*Doing*)

M.E.S Doha,Qatar

Magnetism and Matter.



magnets are of two types

(1) **Artificial magnets:-**

They can be made out of iron and steel by rubbing them with a magnet eg. bar magnet, magnetic needle, horse shoe magnet.

(2) **Natural magnets**

Naturally occuring eg, Fe_3O_4 [Magnetite]

Properties of magnets

(1) Attractive property
(2) Directive property
(3) No manopoles
(4) unlike poles attract
(5) like poles repel.

Magnetic Dipole

Two magnetic poles of equal and opposite strength, seperated by a small distance.

magnetic length (2l)

N |←--2l--→| S. The distance between two poles of a bar magnet. It is represented by $2\vec{l}$.

magnetic dipole moment

The product of strength of either of the poles and the magnetic length is called magnetic dipole mament

$$\boxed{\vec{M} = m \times 2\vec{l}}$$

* S.I unit = $A.m^2$

A → Amperes

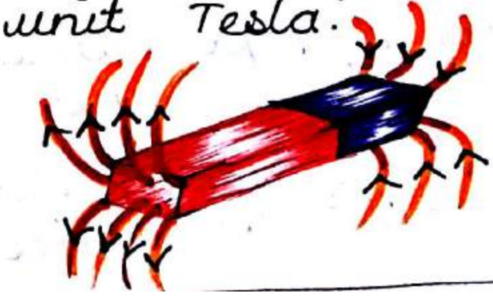
or J/T JT^{-1}

J - Joule
T - Tesla

Magnetic Field

The space around the magnet in which magnetic force can be experienced is called the magnetic field.

S.I unit Tesla.



$\boxed{B = \frac{F}{m}}$

note :- $\boxed{E = \frac{F}{q}}$ in electrostatics

magnetic field lines

path in which unit north pole moves freely in magnetic field.

properties of magnetic field lines

* form closed, continuous loop
* Never Intersect
* Tangent drawn at any point gives the direction of magnetic field
* Inside magnet
  from south to North
* outside magnet
  from North to south

coulomb's law in magnetism

$$\boxed{F = \frac{\mu_0}{4\pi} \frac{m_1 m_2}{r^2}}$$

m_1 and m_2 → pole strengths

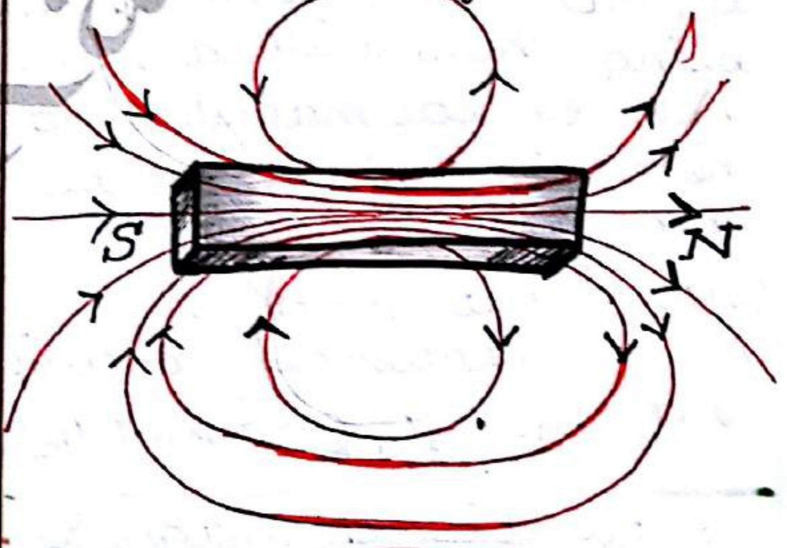
note: $\boxed{F = \frac{1}{4\pi\varepsilon_0} \frac{q_1 q_2}{r^2}}$ in electrostatics.

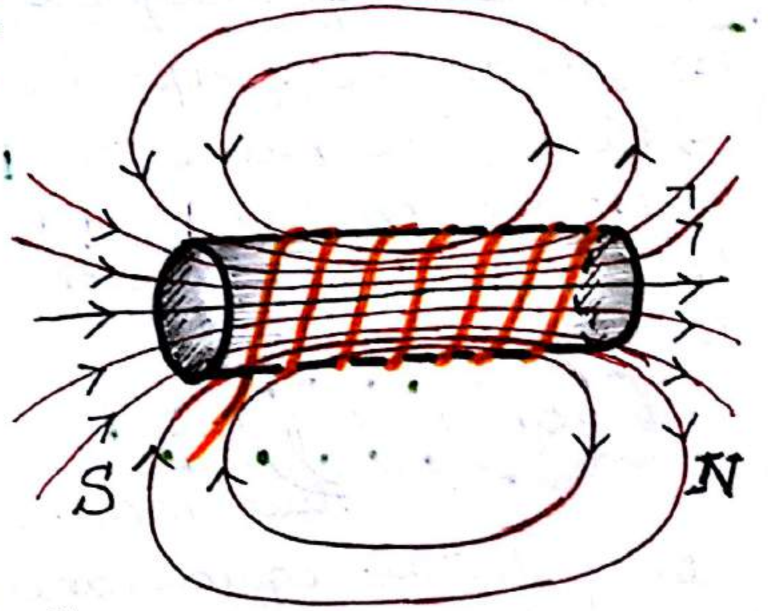
Gauss's law in magnetism

* The net magnetic flux over a closed surface = 0
* $\boxed{\oint_s \vec{B} \cdot \vec{ds} = 0}$
* No monopoles exist
* so all lines of force entering = leaving the surface.

Patterns of field lines

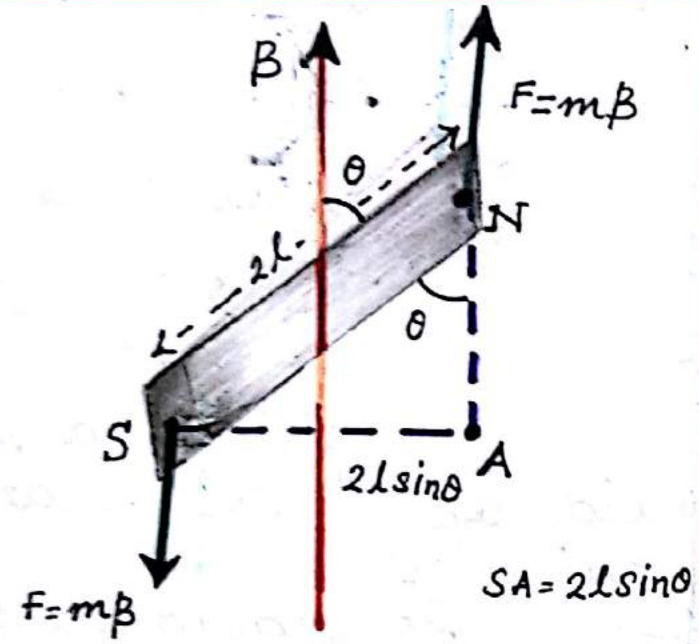
(a) Bar magnet.





(b) solenoid

Torque acting on a magnetic Dipole



consider a magnetic dipole of dipole length $2\vec{l}$ placed in a uniform magnetic field $\vec{B}$. as shown in figure.

- * force on north pole is $= mB$ in the direction of $\vec{B}$
- * Force on south pole is $= mB$ opposite direction of B.
- * These equal and opposite forces constitute a couple tending to rotate it.

Torque = Force × ⊥r distance

$$\tau = F \times SA$$
$$= mB \times 2l \sin\theta.$$

$$\boxed{\tau = MB\sin\theta}.$$

$M = m\cdot 2l$

$$\boxed{\tau = \vec{M}\times\vec{B}}$$

special cases

(1) when $\theta = 90^\circ$, $\sin\theta = 1$

$\tau = MB$

$\tau \rightarrow$ maximum

(2) when $\theta = 30^\circ$, $\sin 30^\circ = 1/2$

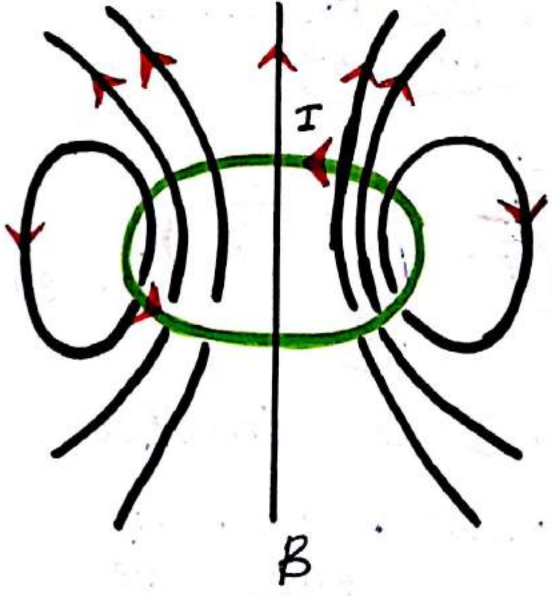
$\tau = \frac{MB}{2}$ $\tau \rightarrow$ half the maximum

(3) when $\theta = 0^\circ$ or $\theta = 180^\circ$

$\sin\theta = 0$

$\tau = 0$ (minimum)

show that the circular coil behaves as a magnetic dipole or a bar magnet.



Magnetic moment

$M \propto I$

$M \propto A$

$M = KIA$ $\{k = 1\}$

If 'N' no of turns

$$\boxed{M = NIA}$$

$$B_{axial} = \frac{\mu_0 \cdot NIR^2}{2(R^2+x^2)^{3/2}}$$

if $x >>> R$ neglect R

$$\boxed{B = \frac{\mu_0 NIR^2}{2x^3}} \quad \ldots ①$$

① × $\frac{\pi}{\pi}$

$$① \Rightarrow B = \frac{\mu_0 NI \, \pi R^2}{2\pi x^3}$$

$$B = \frac{\mu_0 NI A}{2\pi x^3}.$$

$M = NIA$

$$\boxed{B = \frac{\mu_0 M}{2\pi x^3}}$$

$$\boxed{B = \frac{\mu_0}{2\pi} \frac{M}{x^3}} \quad \ldots ②$$

② × $\frac{2}{2}$

$$\boxed{B = \frac{\mu_0}{4\pi} \cdot \frac{2M}{x^3}} \quad \ldots ③$$

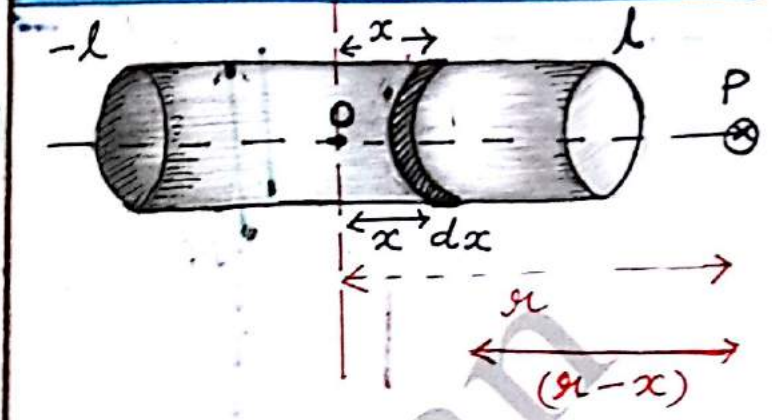
eqtn ③ is similar to

$$E_{axial} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2P}{r^3}$$

∴ circular coil behaves as magnetic dipole.

S.T the solenoid behaves as bar magnet?

Bar magnet as equivalent solenoid.



consider a solenoid of length '2l' and radius 'a'.

To evaluate the magnetic field at a point P at a large distance r from the centre consider a circular element of thickness 'dx' of the solenoid at a distance 'x' from the centre.

$$n = \frac{\text{No of turns}}{\text{unit length}} = \frac{N}{dx}$$

$$\boxed{\therefore N = n\,dx.} \qquad \because R = a$$

$$B_{axial} = \frac{\mu_0 NIR^2}{2(R^2+x^2)^{3/2}}$$

dB due to 'dx' at a distance $(r-x)$

$$dB = \frac{\mu_0 (n\,dx) I a^2}{2(a^2+(r-x)^2)^{3/2}}$$

If $r >>> a$, $r >>> l$ neglect 'a' and 'x' in denometor

$$d\beta = \frac{\mu_0 n I a^2 dx}{2r^3}$$

$$\int d\beta = \frac{\mu_0 n I a^2}{2r^3} \cdot \int_{-l}^{l} dx$$

$$\beta = \frac{\mu_0 n I a^2}{2r^3} \cdot [x]_{-l}^{l}$$

$$\beta = \frac{\mu_0 n I a^2}{2r^3} [l - (-l)]$$

$$\beta = \frac{\mu_0 \underline{n} I a^2 \underline{2l}}{2r^3}$$

$\therefore N = n2l$

$$\beta = \frac{\mu_0 N I a^2}{2r^3} \quad \text{......} ①$$

$$① \times \frac{2\pi}{2\pi}$$

$$\beta = \frac{\mu_0}{\underline{4\pi}} \cdot \frac{\underline{2} N I \underline{\pi} a^2}{r^3}$$

$\therefore \pi a^2 = A$

$$\beta = \frac{\mu_0}{4\pi} \cdot \frac{2NIA}{r^3}$$

$$\boxed{\therefore \beta = \frac{\mu_0}{4\pi} \frac{2M}{r^3}}$$

$\therefore \boxed{M = NIA}$

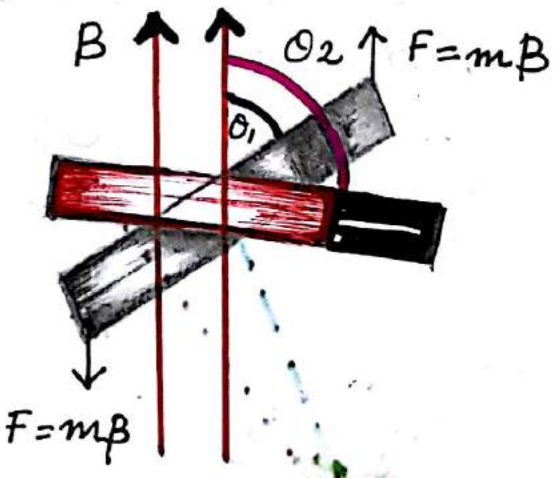
This equation is similar to E axial

$$E_{axial} = \frac{1}{4\pi\varepsilon_0} \cdot \frac{2P}{r^3}$$

$\therefore$ solenoid behaves as a bar magnet or magnetic dipole.

Potential Energy (U)

consider a magnetic dipole placed in a uniform magnetic field. Inorder to find the P.E of the dipole, it is enough to find the work done to rotate the dipole from θ_1 to θ_2. The small amount of work done to rotate the dipole through a small angle '$d\theta$'.



$$dw = \tau \, d\theta$$

$$dw = MB \sin\theta \, d\theta$$

$$\int dw = MB \int_{\theta_1}^{\theta_2} \sin\theta \, d\theta$$

$$w = MB [-\cos\theta]_{\theta_1}^{\theta_2}$$

$W = -MB[\cos\theta_2 - \cos\theta_1]$

$$\boxed{W = MB[\cos\theta_1 - \cos\theta_2]}$$

special cases

if $\theta_1 = 90^\circ$, $\theta_2 = \theta$.

$U = W = MB[0 - \cos\theta]$

$U = -MB\cos\theta$

$$\boxed{U = -\vec{M}\cdot\vec{B}}$$

- * stable equilibrium when $\theta = 0^\circ$
- * unstable equilibrium when $\theta = 180^\circ$.

Earths Magnetism

Earth acts a huge magnet

* Earths magnetic south is near geographic north and magnetic north is is near geographic south

* A suspended magnet always point 'N' towards geographic North and 'S' towards geographic south.

* Magnetic Meridian

Vertical plane passing through earths magnetic axis

* Geographic meridian

Vertical plane passing through geographic axis.

Magnetic Elements

used to determine intensity of total earths magnetic field

(1) magnetic declination

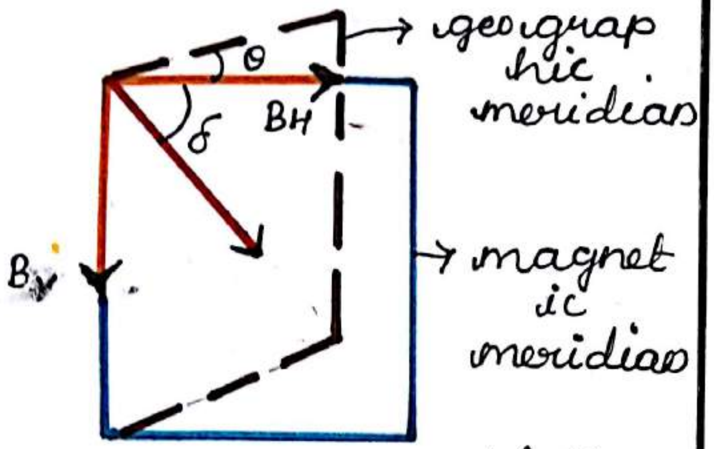
(2) magnetic Inclination or dip

(3) Horizontal component of earths magnetic field (B_H)

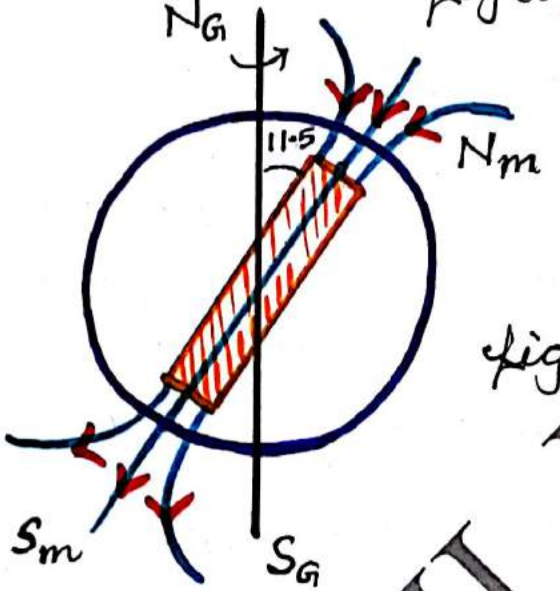
(1) magnetic Declination (θ)

It is the angle

between geographic and magnetic meridian.



fig(i)



fig(ii)

* The vertical plane passing through the geographic axis of earth is called geographic meridian.

* The verticle plane passing through a freely (axis of) suspended magnet is called magnetic meridian.

Magnetic Inclination or dip (δ)

Dip at a place is defined as the angle made by the earths magnetic field with the horizontal.

from fig(i)

$$B_H = B\cos\delta \quad \ldots ①$$

$$B_V = B\sin\delta \quad \ldots ②$$

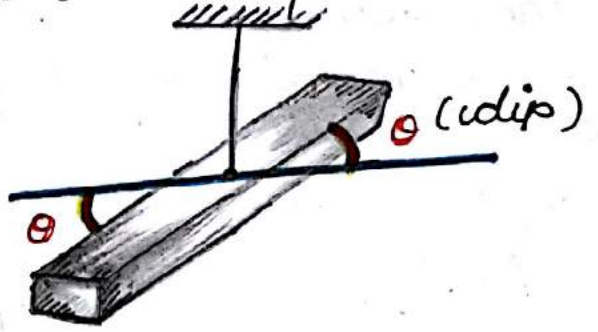
$$\frac{②}{①} \quad \boxed{\frac{B_V}{B_H} = \frac{B\sin\delta}{B\cos\delta} = \tan\delta}$$

or

* The angle b/w the freely suspended magnet and horizontal axis of earth is called angle of dip.

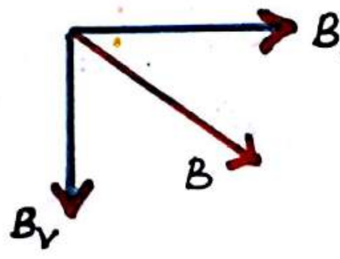
* It is 0° at the equator

* 90° at the poles.



Horizontal component (B_H)

It is the component of magnetic field along the horizontal direction.



$$B = \sqrt{B_V^2 + B_H^2}$$

Dynamo effect

Earths magnetic field is believed to arise from the electrical currents produced by convective motion of metallic fluid. (mostly molten iron and Nickel) in the outer core of the earth. This effect is known as dynamo effect.

Definitions

(a) Magnetic Intensity or Magnetising force (H)

The ratio of magnetising field $\vec{B_0}$ to the permeability of free space is called intensity of magnetising field.

$$\boxed{\vec{H} = \frac{\vec{B_0}}{\mu_0}} \quad \text{or} \quad \boxed{\vec{B_0} = \mu_0 \vec{H}}$$

S.I unit Am^{-1}

(b) Intensity of magnetisation (I_m)

$$I = \frac{\text{magnetic moment}}{\text{volume}}$$

$$\boxed{I = \frac{M}{V}} = \boxed{\frac{m \times 2l}{a \times 2l} = \frac{m}{a}}$$

(c) magnetic flux.

The no of field lines passing normally through the surface.

* scalar Quantity

* $\boxed{\phi = \vec{B} \cdot \Delta\vec{S}}$ $\boxed{\phi = \vec{B} \cdot \vec{ds}}$

* S.I unit is weber.

(d) Magnetic Induction or magnetic flux density [ϕ]

No of magnetic lines crossing per unit area normally.

$$\boxed{\beta = \frac{\phi}{A}}$$

*S.I unit wb/m^2

(e) magnetic susceptibility χ

* It is the ratio of magnetization to the magnetic Intensity.

$$\boxed{\chi = \frac{I}{H}}$$

* how easily a specimen can be magnetised.

(f) magnetic permiability

$$\boxed{\mu = \frac{B}{H}}$$

Distinguish b/w dia, para and ferromagnetic materials?

Property	Diamagnetic	Paramagnetic	Ferromagnetic.
1, Nature of force	feeble repulsion	feeble attraction	strong attraction
2, Alignment in uniform β	$\perp$r to β	Aligns in the direction of β	Aligns in the direction of β.
3, Dependence on temperature	does Not depend	Depends	Depends
4, Susceptibility	negative and small $-1 \leq \chi < 0$	+ve & small $0 < \chi < 1$	$\chi >>> 1$
5, permeability μ_r	$0 \leq \mu_r < 1$	$1 < \mu_r < 1+\varepsilon$ $\varepsilon \to$ small +ve no	$\mu_r >>> 1$
6, Examples	Cu, Si	Al, Na	Co, Ni, Fe

Diamagnetic substances

The substances which are feebly magnetised in a direction opposite to that of magnetising field are known as diamagnetic substances.

eg; Gold, copper, water, alcohol, NaCl, air etc.

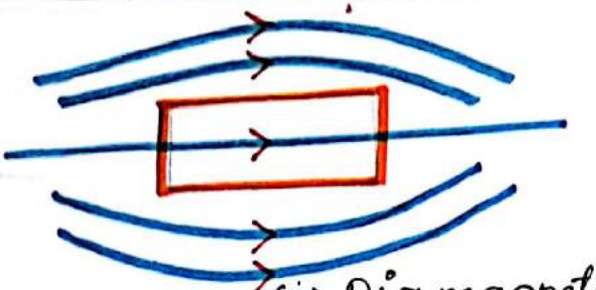
Paramagnetic substances.

The substances which are feebly magnetised in the direction of magnetic field are known as paramagnetic substances.

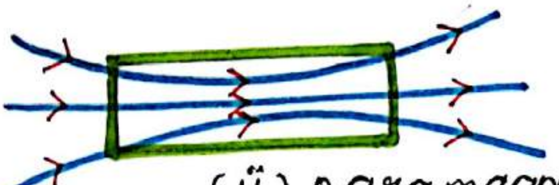
eg; Al, Na.

Ferro magnetic substances.

The substances which are strongly magnetised in the direction of magnetising field. eg; Fe, Ni, Alnico etc.



(i) Diamagnetic



(ii) paramagnetic.

(iii) Ferromagnetic

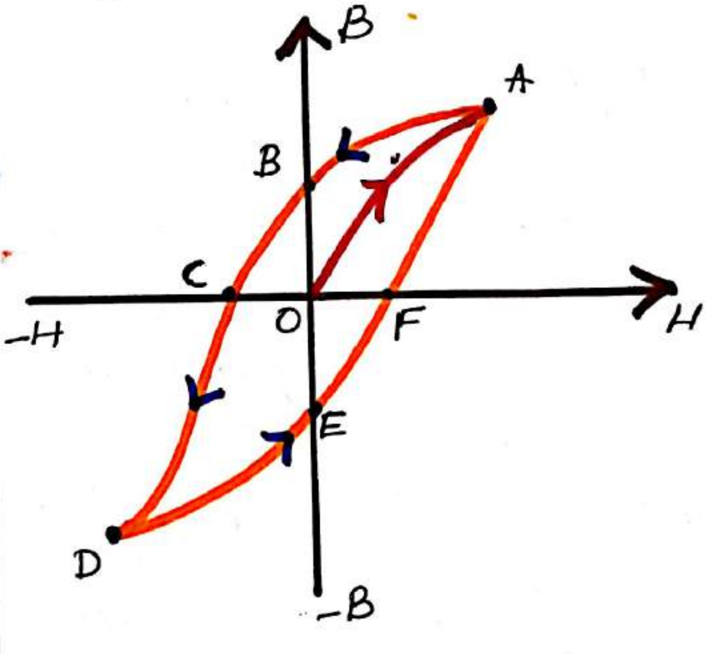
Magnetic Hysterisis

The lagging of magnetic Induction (B) behind the magnetising field (H) during the process of magnetisation and demagnetisation of a ferromagnetic material is called hysterisis.

When a magnetic material is kept in the magnetic field which is produced with the help of electromagnet, the magnetisation increases till it reaches saturation value represented by A.

When the applied field is decreased in steps, the magnetisation does not decrease proportionally. It follows a different path and when magnetising field is reduced to zero, the intensity of magnetisation remains as a non-zero positive value (OB).

Retentivity :- It is defined as the value of intensity of magnetisation of a material when the magnetising field is reduced to zero. (OB)



When the current is made to flow in opposite direction, the magnetising field gets reversed.

The Intensity

of magnetisation reduces to zero for certain negative value of magnetising field. (OC)

This negative magnetisation field required to nullify the intensity of magnetisation is know as coercivity.

On increasing the magnetising field, a different path is followed to form a complete loop. This loop is known as hysterisis loop.

note:

* It is found that the area of hysteresis loop is directly proportional to the energy wasted in the form of heat by the magnetic material.

* The core of electro magnet is made up of ferromagnetic materials having high permeability and low retentivity

* Permanent magnet should have high retentivity and high coercivity.

* steel is favoured for making permanent magnets though it has slightly smaller retentivity than soft iron core because it has large coercivity compared to soft iron.

curie's law.

The magnetic susceptibility of paramagnetic substance is inversely proportional to the absolute temperature. This is called curies law in magnetism.

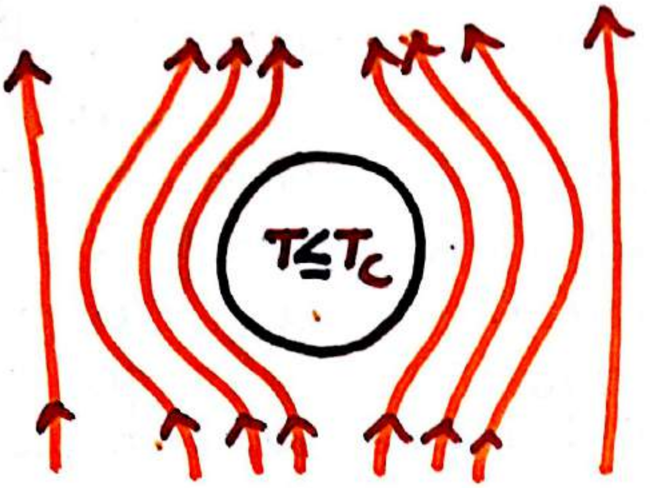
i.e, $\chi \propto \frac{1}{T}$

curie temperature

The temperature at which (or above) a ferromagnetic material becomes paramagnetic is known as curie temperature / curie point.

meissner effect .

The phenomenon of perfect diamagnetism in superconductors is called meissner effect.



* Derive $\mu_r = 1+\chi$?

place an unmagnetised material in external field B_0 set up in vaccum. The magnetic field induced in it is

$$B = B_0 + \mu_0 I$$

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

$$B = \mu_0 H\left[1 + \frac{I}{H}\right]$$

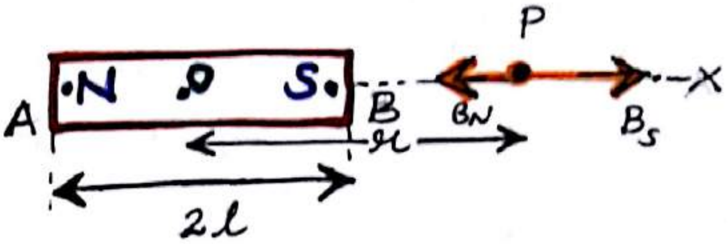
$$\frac{B}{H} = \mu_0[1+\chi]$$

$$\mu = \mu_0[1+\chi]$$

$$\therefore \frac{\mu}{\mu_0} = [1+\chi]$$

$$\boxed{\mu_r = 1+\chi}$$

** magnetic field at a point on the axial line of a magnetic dipole.



consider a bar magnet AB, having south pole 'S' and north pole 'N' respectively. each of pole strength 'm', of moment 'M' and of length '2l' with centre at 'O'.

Magnetic field at P due to 'N' of the magnet is

$$B_N = \left(\frac{\mu_0}{4\pi}\right) \times \frac{m}{(r+l)^2} \text{ along } NP.$$

magnetic field strength at 'P' due to south pole 'S' of the magnet is

$$B_S = \left(\frac{\mu_0}{4\pi}\right) \times \frac{m}{(r-l)^2} \text{ along } PS.$$

∴ net magnetic field

$$B = B_S - B_N \quad \text{since } B_S > B_N$$

$$B = \frac{\mu_0}{4\pi}\left\{\left(\frac{m}{(r-l)^2}\right) - \frac{m}{(r+l)^2}\right]$$

$$B = \frac{\mu_0 m}{4\pi}\left[\frac{(r+l)^2 - (r-l)^2}{(r^2-l^2)^2}\right]$$

$$B = \frac{\mu_0}{4\pi} m\left[\frac{\cancel{r^2}+\cancel{l^2}+2rl-\cancel{r^2}-\cancel{l^2}+2rl}{(r^2-l^2)}\right]$$

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

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

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

In vector form

$$\vec{B} = \frac{\mu_0}{4\pi} \frac{2\vec{M} r}{(r^2-l^2)^2} \text{ along OX.}$$

for very short dipole:

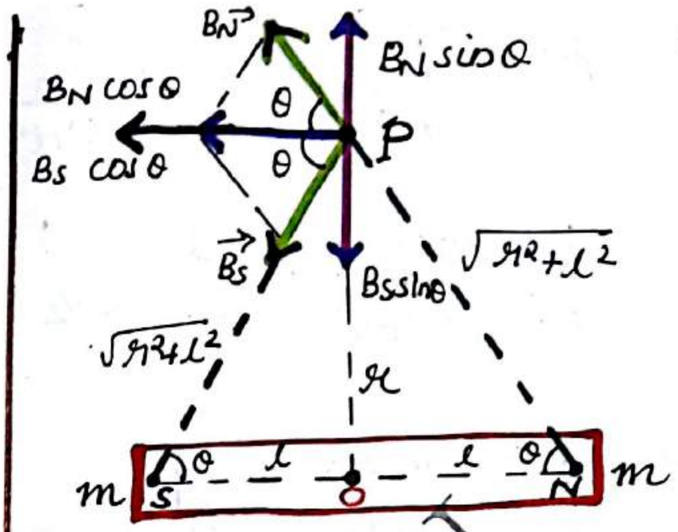
$l << r$

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

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

Magnetic field at a point on the equatorial line of magnetic dipole

consider a magnetic dipole length $2\vec{l}$. let 'P' be a point at a distance 'r' from the centre of the dipole ~~at~~ on the ⊥r bisector.



magnetic field at 'P' due to m at S

$$\boxed{\vec{B_S} = \frac{\mu_0}{4\pi} \frac{m}{(r^2+l^2)}} \text{ along PS.}$$

magnetic field at 'P' due to m at N

$$\boxed{\vec{B_N} = \frac{\mu_0}{4\pi} \frac{m}{(r^2+l^2)}} \text{ along NP}$$

$\vec{B_S}$ & $\vec{B_N}$ can be resolved into two components.

$B_S \sin\theta$ along PO

$B_S \cos\theta$

$B_N \sin\theta$

$B_N \cos\theta$.

since $|\vec{BN}| = |\vec{Bs}|$, the components $B_N \sin\theta$ and $B_S \sin\theta$ are equal and opposite hence they cancel out each other.

The net magnetic field at P

$$B = B_S \cos\theta + B_N \cos\theta$$

$$B = 2B_S \cos\theta \quad \because \{B_S = B_N\}$$

$$\beta = 2 \times \frac{\mu_0}{4\pi} \frac{m}{(r^2+l^2)} \times \frac{l}{\sqrt{r^2+l^2}}$$

$$\beta = \frac{\mu_0}{4\pi} \frac{m}{(r^2+l^2)} \frac{2l}{(r^2+l^2)^{1/2}}$$

$$\beta = \left[\frac{\mu_0}{4\pi} \frac{m \times 2l}{(r^2+l^2)^{3/2}}\right]$$

$$M = m2l$$

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

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

special case

for a short dipole

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

$$\therefore B_{axial} = 2 B_{equatorial}$$

* what should be the nature of permanent magnets and electromagnets?

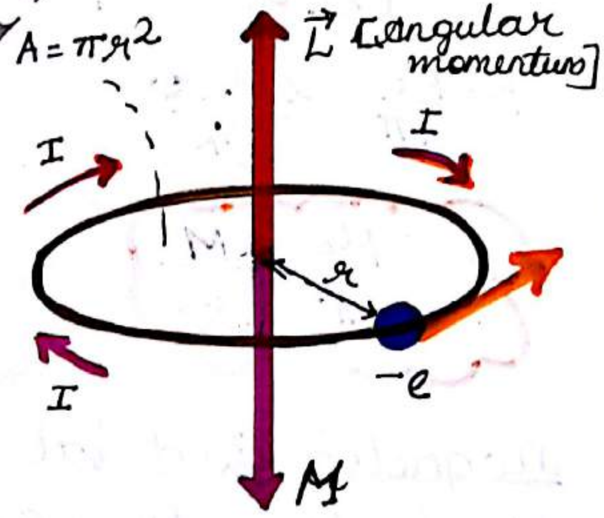
permanent magnets: (i) high retentivity
(ii) high coercivity
(iii) high permeability
(iv) high saturation magnetisation

eg; Alnico.

Electromagnets:
(i) low retentivity
(ii) low coercivity
(iii) high saturation magnetisation
(iv) high permeability

eg; soft iron.

Bohr Magneton



$$M = IA = \frac{q}{T} A = \frac{e}{T} A$$

$$M = \frac{e}{\frac{2\pi}{\omega}} A = \frac{e\omega}{2\pi} \cdot A$$

$$M = \frac{e\omega}{2\pi} \cdot \pi r^2$$

$$V = r\omega$$

$$M = \frac{e\omega r^2}{2} = \frac{eVr}{2} \quad \ldots ①$$

According to bohr's theory $\bar{e}$ can revolve only in non-radiating orbits where

$$L = \frac{nh}{2\pi}$$

$$I\omega = \frac{nh}{2\pi}$$

$$mr^2\omega = \frac{nh}{2\pi}$$

$$r^2\omega = \frac{nh}{2\pi m} \quad \ldots ②$$

sub ② in ①

$$M = \frac{e}{2}\,\frac{nh}{2\pi m} = \frac{neh}{4\pi m}$$

$$\therefore \boxed{M = n\mu_B}$$

where μ_B is Bohr magneton

$$\boxed{\mu_B = \frac{eh}{4\pi m}}$$

** Extra:

Velocity selector/filter

If a charged particle moves in a ⊥r electric and magnetic field, they can move without any deflection if

Electric force = Magnetic force.

$$F_E = F_B$$

$$qE = BqV$$

$$\boxed{V = \frac{E}{B}}$$

∴ If the particle move with velocity $V = \frac{E}{B}$ it can go without deflection.

Application

spectrometer

Electron theory - Diamagnetism

* Atoms have even number of electrons
* magnetic dipole moment due to e spin motion = 0.
* M due to orbital motion = 0.
* Net dipole moment in absence of external magnetic field = 0

In external B

* ē with dipole moment in the same direction of B slows down
* ē with dipole moment opposite to B speeds up result is feeble repulsion.

Paramagnetism - electron theory.

* Atoms have unpaired ē's.
* have net dipole moment even in absence of B_{ext}
* In external magnetic field (B_{ext}), align in the direction of B.

Ferromagnetism - Domain Theory.

* --- have spontaneous magnetic dipole moment.
* Dipole moments have strong Interaction with neighbours in the domain.
* In the Absence of B_{ext}.

  All dipole moments oriented in such a way that net dipole moment = 0.
* In the presence of external magnetic field.

  All dipole moments in all domains align themselves.

5 MARK QUESTIONS

(1) DRAW THE LABELLED DIAGRAM OF A MOVING COIL GALVANOMETER. STATE THE PRINCIPLE ON WHICH IT WORKS?

CBSE 2007, 05, 2013
2004, 2009(F)

(2) DERIVE EXPRESSION FOR TORQUE ACTING ON A RECTANGULAR CURRENT CARRYING LOOP KEPT IN A UNIFORM MAGNETIC FIELD B. INDICATE THE DIRECTION OF TORQUE ACTING ON THE LOOP?

(3) STATE AND EXPLAIN BIOT-SAVART LAW. USE IT DERIVE AN EXPRESSION FOR THE MAGNETIC FIELD PRODUCED AT A POINT NEAR A LONG CURRENT CARRYING WIRE.

[2008, 2002C]

HOW DOES A CIRCULAR LOOP BEHAVE AS A MAGNET?

[2011, 2013 CBSE]
[2006, 05, 02]

(4) DERIVE AN EXPRESSION FOR THE FORCE PER UNIT LENGTH BETWEEN TWO LONG STRAIGHT PARALLEL CURRENT CARRYING CONDUCTORS. HENCE DEFINE SI unit of current?

[2012, 2010, 2009, 2006 CBSE]

(5) AMPERE'S CIRCUITAL LAW
→ APPLICATIONS [CBSE 2010, 2013 2004C]