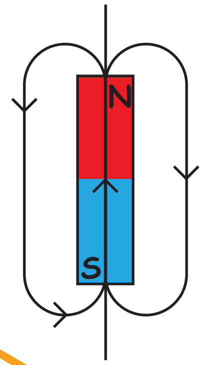
# PHYSICS WALLAH

# MAGNETISM AND MATTER

## THE MAGNETIC FIELD LINES




1. The magnetic field lines of a magnet form continous closed loops
2. The tangent to the field lines at a given point represents the direction of the net magnetic field B at that point
3. The larger no.of field lines $\longrightarrow$ stronger $\vec{B}$
4. Do not intersect

## CUTTING OF BAR MAGNET

**LENGTHWISE / TRANSVERE**

$\leftarrow l \rightarrow$

$l/2$ $l/2$

Pole strength $\longrightarrow$ same

length $\rightarrow$ reduce to half

$M_{new} = \frac{ml}{2}$

**HORIZONTAL**

$\leftarrow l \rightarrow$

Pole strength $\longrightarrow$ reduce to half

length $\rightarrow$ same

$M_{new} = \frac{ml}{2}$

## FACTS

A) Magnetic monopoles does not exist

B) A solenoid and bar magnet produce similar magnetic fields

## POTENTIAL AT ANY GENERAL POINT

$V = \frac{1}{4\pi\varepsilon_0}\frac{P\cos\theta}{r^2}$ $\qquad$ $V_m = \frac{\mu_0}{4\pi}\frac{M\cos\theta}{r^2}$

## TORQUE

1) $F_{net}=0$ $\qquad$ 1) $(F_m)_{net}=0$

2) $\vec{\tau}=\vec{p}\times\vec{E}=pE\sin\theta$ $\qquad$ 2) $\vec{\tau}=\vec{M}\times\vec{B}=MB\sin\theta$

## WORK DONE IN ROTATING A DIPOLE

1. $W=PE(\cos\theta_1-\cos\theta_2)$ $\qquad$ 1. $W_B=MB(\cos\theta_1-\cos\theta_2)$

Maximum work done is from $\theta_1=0^\circ$ to $\theta_2=180^\circ$

## POTENTIAL ENERGY

$U=-\vec{P}.\vec{E}$ $\qquad$ $U_B=-\vec{M}.\vec{B}$

$\theta_1=0^\circ$ Stable position; $\theta=180^\circ$ Unstable position

## APPARENT ANGLE OF DIP

Inclination of magnetic needle in plane other than magnetic meridian

$\tan\delta' = \frac{\tan\delta}{\cos\theta}$

$\delta'$ Apparent angle of dip

$\delta$ true angle of dip

$\theta$ Angle between MM and the plane other than MM

## RELATION BETWEEN TWO FALSE ANGLE OF DIPS ($\delta_1$&$\delta_2$) IN MUTUALLY PERPENDICULAR PLANES AND TRUE ANGLE OF DIP ($\delta$)

$\cot^2\delta_1+\cot^2\delta_2=\cot^2\delta$

## MAGNETIC DIPOLE MOMENT ($\vec{M}$)

$\vec{M}=m\vec{l}$

$m \rightarrow$ pole strength

$l \rightarrow$ Straight line distance b/w poles

Direction from southpole to N pole

Unit of $M \rightarrow Am^2$

Unit of $m \rightarrow Am$

## THE ELECTROSTATIC ANALOG

(Help from electrostatics to magnetism)

**SHORT ELECTRIC DIPOLE**

'q' $\vec{p}$ d

$\vec{p}=q\vec{d}$

**SHORT MAGNETIC DIPOLE**

'm' l

$\vec{M}=m\vec{l}$

## COULOMB'S LAW

$F=\frac{1}{4\pi\varepsilon_0}\frac{q_1q_2}{r^2}$ $\qquad$ $F_m=\frac{\mu_0}{4\pi}\frac{m_1m_2}{r^2}$

## AXIAL & EQUITORIAL LINE OF DIPOLE

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

$E_{eq}=\frac{1}{4\pi\varepsilon_0}\frac{P}{r^3}$ $\qquad$ $B_{eq}=\frac{\mu_0}{4\pi}\frac{M}{r^3}$

$\vec{E}_{axial}=-2\vec{E}_{eq}$ $\qquad$ $\vec{B}_{axial}=-2\vec{B}_{eq}$

## MAGNETISM AND GAUSS' LAW

"The net magnetic flux through any closed surface is zero" $\qquad$ $\oint\vec{B}.\vec{ds}=0$

NOTE: "The simplest magnetic element is a magnetic dipole or a current loop." Magnetic monopoles do not exist.

## FACTS

1. Declination is greater at poles and smaller near equator
2. Angle of dip is maximum at poles and minimum at equator

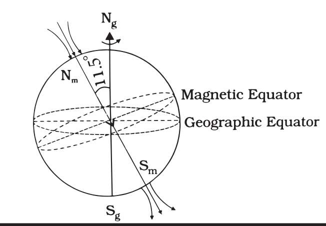
## BAR MAGNET TO DIFFERENT SHAPES

$M_{new}=\frac{M\sin(\frac{\theta}{2})}{(\frac{\theta}{2})}$ $\qquad$ $l'=\frac{l\sin(\frac{\theta}{2})}{(\frac{\theta}{2})}$

## RESULTANT DIPOLE MOMENT

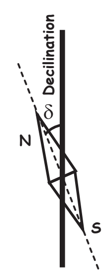
$M_{net}=\sqrt{M_1^2+M_2^2+2M_1M_2\cos\theta}$

## THE EARTH'S MAGNETISM




### MAGNETIC ELEMENTS OF EARTH

**Magnetic declination** $-\delta$



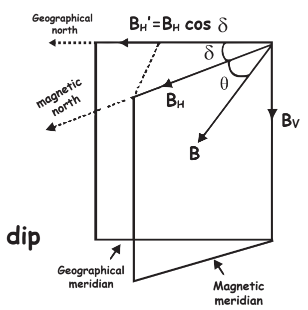

Angle between geographic meridian & magnetic meridian (MM)

**Inclination or Dip** $-\theta$

True angle of dip

$\tan\theta=\frac{B_V}{B_H}$

**Horizontal component** $-B_H$




## COMPASS NEEDLE AND DIP NEEDLE

1. A compass needle at the North pole can point along any direction.
2. A dip needle at the north pole points down and at South pole points straight up.

## TIME PERIOD

of a magnetic dipole in uniform magnetic field

$T=2\pi\sqrt{\frac{I}{MB}}$

I - Moment of Inertia of the body

M - Magnetic dipole moment

B - Magnetic field

Frequency $\nu=\frac{1}{2\pi}\sqrt{\frac{MB}{I}}$

To find B, $B=\frac{4\pi^2 I}{MT^2}$

# Magnetism

## MAGNETIC PROPERTIES

**1) Magnetic Permeability**

Absolute Permeability of air or free space $\mu_0 = 4\pi \times 10^{-7} \frac{\text{Tesla metre}}{\text{Ampere}} \left[\frac{Tm}{A}\right]$

Relative Permeability of medium $\mu_r = \frac{\mu_{medium}}{\mu_0}$

**2) Intensity of magnetizing field ($\vec{H}$)**

$\vec{H} = \frac{B_{ext}}{\mu_0}$ vector quantity

SI unit $\rightarrow \frac{A}{M}$ CGS unit $\rightarrow$ Oersted

**3) Magnetisation ($\vec{M}$)**

$\vec{M} = \frac{\vec{M}_{net}}{V} \rightarrow \left[\frac{\text{Induced dipole moment}}{\text{volume}}\right]$ also, $\vec{M} = \frac{\vec{B}_{ind}}{\mu_0}$

vector quantity

SI unit $\rightarrow \frac{A}{m}$ $[M] \rightarrow [L^{-1}A]$

**4) Magnetic Susceptibility ($\chi_m$)**

$\chi_m = \frac{M}{H}$ Also $\chi = \frac{B_{ind}}{B_{ext}}$

scalar quantity
no unit
no dimension

**5) Relation between relative permeability and susceptibility**

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

**6) Relation between B, M and H**

$B = \mu_m H$ $M = \chi H$

## MAGNETIC MATERIALS

**1. Diamagnetic**

a. Weakly repelled by a magnet
b. Eg: Cu, Ag, Au, NaCl, $H_2O$ etc.
c. Superconductors - Perfect conductivity
perfect diamagnetism
$\chi = -1, \mu_r = 0$
d. Perfect diamagnetism in superconductors is called as MEISSNER EFFECT
e. Important $\boxed{\begin{array}{l} -1 \le \chi < 0 \\ 0 \le \mu_r < 1 \\ \mu < \mu_0 \end{array}}$
f. Individual atoms do not possess permanent magnetic dipole moment
g. No effect of temperature on magnetisation

**2. Paramagnetic substances**

a. Weakly attracted by a magnet
b. Eg : Al, Mn, Pt, Na, $CuCl_2$, $O_2$, Crown glass
c. Individual atom possesses permanent dipole moment
d. Curie's law
Magnetisation of a paramagnetic material is inversely proportional to the absolute temperature

$$\left.\begin{array}{l} M = C\frac{B_0}{T} \\ \chi = C\frac{\mu_0}{T} \end{array}\right\} \text{Curie's law}$$

e. Important

$\boxed{\begin{array}{l} 0 < \chi < \varepsilon \\ 1 < \mu_r < 1+\varepsilon \ (\varepsilon \rightarrow \text{Small positive number}) \\ \mu > \mu_0 \end{array}}$

f. Graph


**3. Ferromagnetic substances**

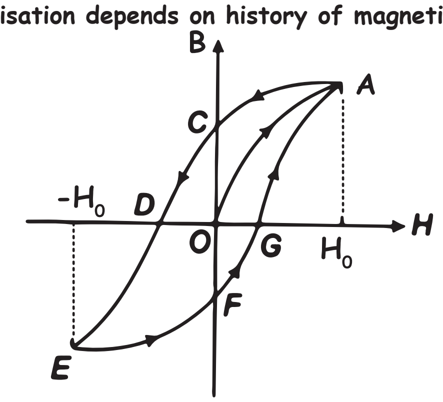
a. Strongly attracted by a magnet
b. Eg : Fe, Co, Ni, Cd, $Fe_3O_4$
c. Individual atoms possess permanent magnetic moment and magnetic moments of neighbouring atoms tend to align due to a force called exchange coupling
d. Due to exchange coupling, atoms form domains inside which magnetic moments are aligned in the same direction
e. Important $\boxed{\begin{array}{l} \chi >>> 1 \\ \mu_r >> 1 \\ \mu >> \mu_0 \end{array}}$
f. At high temperature, a ferromagnetic substance becomes paramagnetic

Curie's temperature

$$\chi = \frac{C}{T-T_c} \ (T > T_c)$$

## HYSTERESIS CURVE / B-H CURVE

Magnetisation depends on history of magnetisation




**Important terms**
Retentivity - OC - Residual magnetism
Coercivity -OD-Demagnetising process
1. High coercivity - Hard substance - Steel
2. Low coercivity - Soft substance - Soft iron

**Important result**
B-H curve signifies the energy loss/heat loss in the process and is proportional to the area of the loop.

Area of hysteresis loop
- Smaller for soft iron
- Higher for steel

**Permanent magnets**

should have
1. High retentivity
2. High coercivity
3. High permeability

Steel is used for making permanent magnets

| Steel | soft iron |
|---|---|
| Smaller retentivity<br>High coercivity | Higher retentivity than steel<br>Smaller coercivity than steel |

## ELECTROMAGNETS

Materials should have
high permeability
low retentivity
Soft iron is used

Used in electric bells, Loudspeakers, telephone diaphragms, heavy cranes to lift machinery

PHYSICS WALLAH