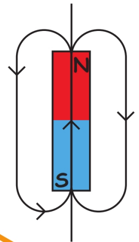
MAGNETISM AND MATTER

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 ⟶ stronger $\vec{B}$
4. Do not intersect

CUTTING OF BAR MAGNET

LENGTHWISE / TRANSVERE

Pole strength ⟶ same

length ⟶ reduce to half

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

HORIZONTAL

Pole strength ⟶ reduce to half

length ⟶ 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 $\theta_1 = 0^0$ to $\theta_2 = 180^0$

POTENTIAL ENERGY

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

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

APPARENT ANGLE OF DIP

Inclination of magnetic needle in plane other than magnetic meridian

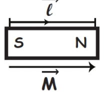
$\tan\delta' = \frac{\tan\delta}{\cos\theta}$

δ' Apparent angle of dip

δ true angle of dip

θ Angle between MM and the plane other than MM

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



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

m ⟶ pole strength

l ⟶ Straight line distance b/w poles

Direction from southpole to N pole

Unit of M ⟶ Am^2

Unit of m ⟶ Am

THE ELECTROSTATIC ANALOG

(Help from electrostatics to magnetism)

SHORT ELECTRIC DIPOLE — 'q', $\vec{p} = q\vec{d}$

SHORT MAGNETIC DIPOLE — 'm', $\vec{M} = m\vec{l}$

COULOMB'S LAW

$F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$ $\qquad F_m = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{r^2}$

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.

RELATION BETWEEN TWO FALSE ANGLE OF DIPS (δ_1&δ_2) IN MUTUALLY PERPENDICULAR PLANES AND TRUE ANGLE OF DIP (δ)

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

FACTS

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

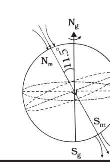
BAR MAGNET TO DIFFERENT SHAPES

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

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 – δ

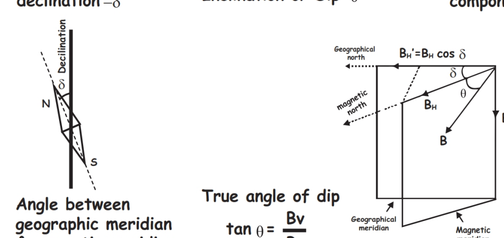
Angle between geographic meridian & magnetic meridian (MM)

Inclination or Dip – θ

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 $\mu_0 = 4\pi \times 10^{-7} \dfrac{\text{Tesla metre}}{\text{Ampere}} \left[\dfrac{Tm}{A}\right]$

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

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

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

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

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

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

vector quantity

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

4) Magnetic Susceptibility (χ_m)

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

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
$-1 \leq \chi < 0$
$0 \leq \mu_r < 1$
$\mu < \mu_0$
f. Individual atoms do not possess permanent magnetic dipole moment
g. No effect of temperature on magnetisation

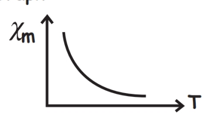
2. Paramagnetic substances

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

$M = C\dfrac{B_0}{T}$, $\chi = C\dfrac{\mu_0}{T}$ } Curie's law

e. Important
$0 < \chi < \varepsilon$
$1 < \mu_r < 1+\varepsilon$ ($\varepsilon \rightarrow$ Small positive number)
$\mu > \mu_0$

f. Graph



3. Ferromagnetic substances

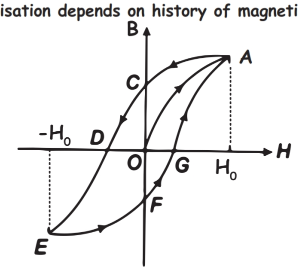
a. Strongly attracted by a magnet
b. Eg : Fe, Co, Ni, Cd, Fe_3O_4
c. Individual atoms possess permanent magnetic moment and magnetic moments of neighbouring atoms tend to align due to a force called exchange coupling
d. Due to exchange coupling, atoms form domains inside which magnetic moments are aligned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

Curie's temperature

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

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 High coercivity	Higher retentivity than steel 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