Magnetism and Matter

5

INTRODUCTION

In nature, first time iron ore was found which had a property to attack small pieces of iron, nickel and cobalt etc. And this property of attracting small pieces of material such as iron, nickel and cobalt etc. by a piece of material is called magnetism.

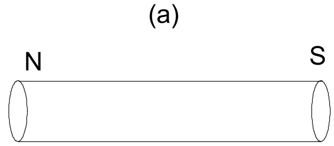
There are two types of magnets. One which are found in nature are called natural magnets. These are of distorted shape.

Second which are artificially manufactured are called artificial magnets. These are of defined shape and size i.e. bar magnets.

BAR MAGNET

A system composed of two poles, equal in magnitude but opposite in polarity, placed at a small displacement apart is known as a bar magnet. It is also known as a magnetic dipole.

(a)



(b)

BASIC PROPERTIES OF MAGNETS

1. A magnet attracts magnetic substances such as nickel, cobalt, iron etc.
2. When a magnet is suspended with the help of unspum thread, its two end, which are called poles come to rest in north south direction.
3. Poles exists always in pair and having equal strength i.e. magnetic monopoles do not exist.
4. Like poles repel each other and unlike poles attract each other.
5. North and south pole of magnet are a little inwards from geometrical end. The magnetic length of magnet is about 0.84 times the geometrical length.
6. The force of attraction or repulsion between two magnetic poles is directly proportional to product of pole strengths (m_1, m_2) and inversely proportional to square of distance (r) between their centres

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

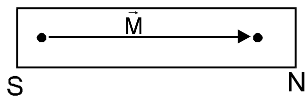
$$\frac{\mu_0}{4\pi} = 1 \text{ in CGS units} \qquad = 10^{-7}\ \text{wbA}^{-1}\text{m}^{-1}$$

where μ_0 is absolute permeability of free space.

MAGNETIC DIPOLE AND It's MOMENT

It has two unlike poles of equal strength separated by a definite small distance.

Unit of pole strength is ampere meter or Newton/Tesla. Magnetic dipole moment ($\vec{M}$) is defined as the product of pole strength denoted by m and distance between the two poles, called magnetic length, represented by $2\vec{\ell}$



$$\vec{M} = m(2\vec{\ell})$$

It is a vector quantity and its direction is from south to north pole.

Its unit is ampere meter^2 or Joule/Tesla

MAGNETIC FIELD

(a) The space around a magnet in which a torque acts on a magnetic needle is known as magnetic field.

(b) The space around a magnet in which a net force acts on a magnetic test pole is known as magnetic field.

(c) The space around a magnet in which its effect is experienced is known as magnetic field.

(d) There are four types of magnetic field :

(i) **Uniform magnetic field:**

(a) The magnetic field, in which the intensity of magnetic field is same at all points, is known as uniform magnetic field.

(b) In such a magnetic field the magnetic lines of force are parallel and equidistant. e.g. the magnetic dines of force of earth's magnetic field.

(ii) **Non-uniform magnetic field:**

(a) The magnetic field, in which the intensity of magnetic field at different points is different, is known as non-uniform magnetic field.

(b) It is represented by non-parallel lines of force.

(iii) **Varying magnetic field:**

(a) The magnetic field, which keeps on changing with respect to time is known as a variable magnetic field.

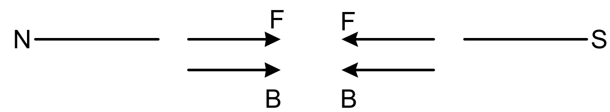
(b) Example :– $B = B_0 \sin \omega t$ or $B = B_0 \cos \omega t$

(iv) **Non-varying magnetic field:**

(a) The magnetic field which does not change with time is known as a constant magnetic field.

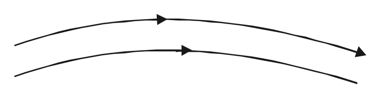
(b) The direction of magnetic field is that in which a force acts on a unit test pole.

(c) It can be produced by moving charges, current carrying loops, and variations in electric currents.



MAGNETIC LINE OF FORCES AND THEIR PROPERTIES

As electric field lines of forces we also have imaginary magnetic field lines to represent magnetic field in any region. These are closed lines when electric field lines are open lines.



direction of magneticfield at point A is towards AB.

To draw magnetic lines we use a magnetic dipole i.e. small compose needle.

The direction of magnetic field at a point is same as direction of tangent at the point.

PROPERTIES :

1. No two magnetic lines can cut each other.
2. These are closed lines whose direction outside magnet is from north to south pole and inside from south to north pole.
3. Tangent at a point of magnetic line give direction of field at that point.
4. Crowding of magnetic lines of force represent stronger magnetic field.
5. There is always tension in magnetic field line and repulsion between two lines.

MAGNETIC FIELD STRENGTH DUE TO BAR MAGNET

(i) **End-on position :** In this position point lies on the axis of magnet.

Magnetic field strength due to south pole

$B_S = \frac{\mu_0}{4\pi} \cdot \frac{m}{(r+\ell)^2}$ along PS

due to north pole. $B_N = \frac{\mu_0}{4\pi} \frac{m}{(r-\ell)^2}$ along NP

Net magnetic field strength at P

$\vec{B}_1 = B_N - B_S$ along NP

$= \frac{\mu_0}{4\pi} \frac{m 4\ell r}{(r^2-\ell^2)^2} = \frac{\mu_0}{4\pi} \frac{2Mr}{(r^2-\ell^2)}$ along NP.

For small magnet $l << r$.

So $\vec{B}_E = \frac{\mu_0}{4\pi} \frac{2M}{r^3}$ along NP.

(ii) **Broad - side - on - position :**

When point lies on equatorial line of magnet.

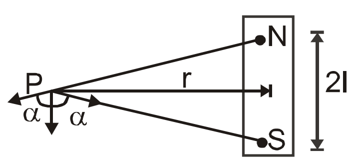
Magnetic field strength at point P.

Due to north pole

$B_N = \frac{\mu_0}{4\pi} \times \frac{m}{(r^2+\ell^2)}$ along NP

Due to south pole

$B_S = \frac{\mu_0}{4\pi} \times \frac{m}{(\ell^2+r^2)}$ along PS



Net magnetic field

$\overrightarrow{B_B} = 2\frac{\mu_0}{4\pi} \times \frac{m}{(\ell^2+r^2)} \cos\alpha$ along PS

$= \frac{\mu_0}{4\pi} \frac{m \times 2\ell}{(r^2+\ell^2)^{3/2}} = \frac{\mu_0}{4\pi} \frac{M}{(r^2+\ell^2)^{3/2}}$

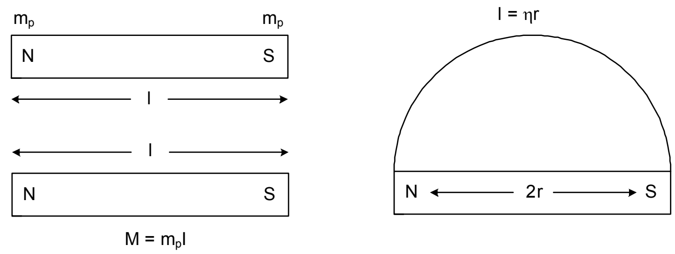
For small magnet $l << r$

$\vec{B}_B = \frac{\mu_0}{4\pi} \frac{M}{r^3}$ along PQ

Note $\frac{B_E}{B_B} = \frac{2}{1}$

MAGNETIC MOMENT (M)

(a) If a magnet of length l and magnetic moment M is bent in the form of a semicircular are then its new magnetic moment will be $M' = \frac{2M}{\pi}$



(b) The magnetic moment of an electron due to its orbital motion is $1\mu_B$ whereas that due to its spin motion it is $\frac{\mu_B}{2}$.

i.e. $M_{orbital} = l\left(\frac{eh}{4\pi m_l}\right) = \left(\frac{\bar{e}h}{2m_l}\right)$

and $M_{spin} = s\left(\frac{eh}{4\pi m_s}\right) = s\left(\frac{\bar{e}h}{2m_s}\right) = s\mu_B = \frac{\mu_B}{2}$

Here μ_B = Bohr magneton

(i) The value of Bohr magneton $\mu B = \frac{eh}{4\pi m}$

(ii) $\mu B = 0.93 \times 10^{-23}$ Amp-m^2

(c) **Other formulae of M:**

(i) $M = ni\pi r^2$

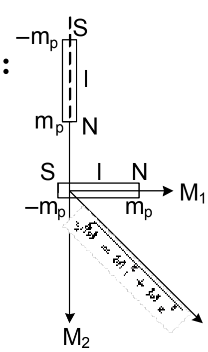
(ii) $M = \frac{eVr}{2} = \frac{er^2\omega}{2} = \frac{er^2 2\pi f}{2} = \frac{er^2\pi}{T}$

(iii) $\frac{e}{2mJ}$

(iv) $M = n\mu_B$

(d) **Resultant magnetic moment :**

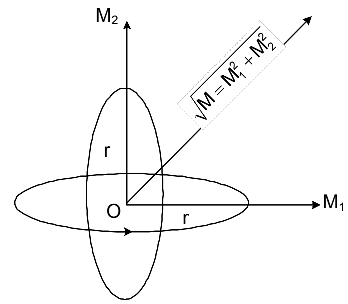
(i) When two bar magnets are lying mutually perpendicular to each other, then



$M = \sqrt{M_1^2 + M_2^2} = \sqrt{2} m_p l$

(ii) When two coils, each of radius r and carrying current i, are lying concentrically with their planes at right angles to each other, then

$$M = \sqrt{M_1^2 + M_2^2} = \sqrt{2}i\pi r^2 \text{ if } M_1 = M_2$$



INTENSITY OF MAGNETISATION (I)

(a) The magnetic moment per unit volume of a material is defined as intensity of magnetisation (I). i.e. $I = \frac{M}{V}$, when $V = 1m^3$ then $I = M$.

(b) The unit of intensity of magnetisation is ampere/meter and its dimensions are $M^0L^{-1}T^0A^1$

(c) The pole strength per unit area of cross-section is defined as intensity of magnetisation. i.e. $I = \frac{m_p}{A}$ when $A = 1m^2$ then $A = 1m^2$ then $I = mp$

(d) It is a vector quantity whose direction is along the magnetic field.

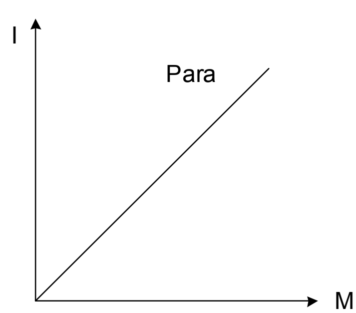
(e) In para- and ferro-magnetic materials its direction is in the direction of H and in dia-magnetic materials it is opposite to that of H.

(f) I is produced in materials due to spin motion of electrons.

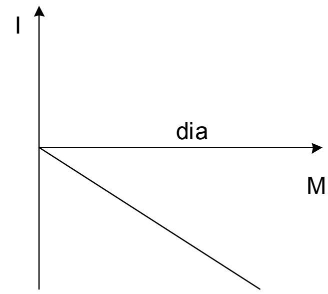
(g) The value of I and its direction in a material depend on the nature of that material.

(h) **I - M curve**

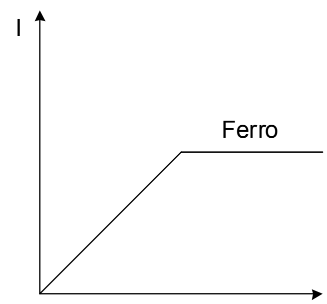
(i) For para magnetic materials



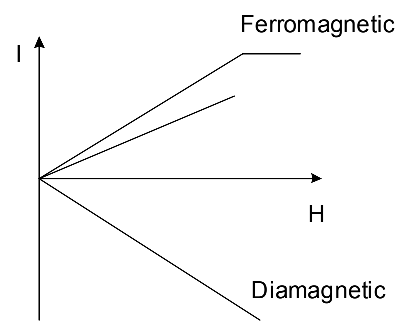
(ii) For diamagnetic materials



(iii) For ferromagnetic materials



(i) **I - H curve**



(j) Its value depends on temperature.

(k) It is produced on account of induction in a material.

(l) For low magnetising field $I \propto H$. i.e. $I \propto H$ or $I = \chi Ht$

(m) χ is a dimensionless constant i.e. it carries no unit.

(n) **Other types of intensity of magnetisation:**

(i) Mass intensity of magnetisation (I_{mass})-

$$I_{mass} \text{ or } I_m = \frac{\text{Intensity of magnetisation}}{\text{density of magnetic material}} = \frac{1}{\rho}$$

(ii) Molar intensity of magnetisation-

$I_{molar} = I_{MW}$ = Mo. Wt.× mass intensity of magnetisation $= M_W \times I_m$

(iii) Molecular intensity of magnetisation-

$$I_{molecular} = I_M = \frac{\text{Molar intensity of magnetisation}}{\text{Avogadro No.}} = \frac{I_{MW}}{N}$$

MAGNETIC SUSCEPTIBILITY OR (OR K)

(a) The ratio intensity of magnetisation (I) in a material and the magnetising field (H) is defined as magnetic susceptibility (χ).

i.e. $\chi = \frac{I}{H}$

When H = 1 Oersted then χ = I.

(b) The intensity of magnetisation induced in a material by unit magnetising field is defined as magnetic susceptibility.

(c) It has no unit and no dimensions.

(d) It is a measure of ease with which a material can be magnetised by a magnetised by a magnetising field (H).

(e) Magnetic susceptibility of various materials-

(i) For diamagnetic materials – χ = low and negative

(ii) For paramagnetic materials – χ = low but positive

(iii) For ferromagnetic materials – χ = high and positive

(f) For paramagnetic substances it is inversely proportional to temperature i.e. $\chi \propto \frac{I}{T}$

(g) For low magnetising field the value of χ is constant.

(h) Different types of magnetic susceptibility-

(i) **Volume susceptibility**

$$\chi_V = \frac{I}{H} = X$$

(ii) **Mass or specific susceptibility** χ_m

$$\chi_m = \frac{\chi_v}{\rho} = \frac{\text{Volume susceptibility}}{\text{density of meterial}}$$

(iii) **Molar susceptibility** χ_{MW}

$$\chi_{MW} = \chi_m \times M_W$$

χ = Specific susceptibility × Mol. Wt.

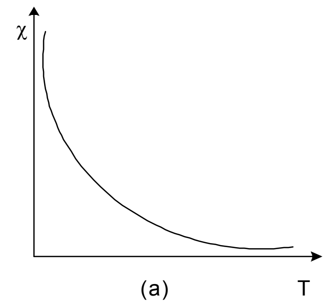
(iv) **Molecular susceptibility** χ_m

χm = Atomic wt. × specific susceptibility

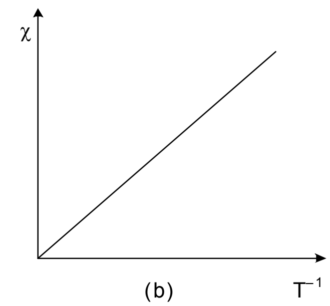
$$= A\ \chi_m = \frac{AI}{\rho H}$$

(i) χ–T curve

(j) $\chi - \frac{1}{T}$:



For paramagnetic substances



For paramagnetic substances

ABSOLUTE MAGNETIC PERMEABILITY (M)

(a) The ratio of magnetic induction (B) to magnetising field (H) is defined as magnetic permeability (μ).

(b) The extent to which magnetic permeability of that medium.

(c) It is the characteristic property of a magnetic material because it represents the amplification of magnetising field in that material.

(d) Its value is always positive and is different for different materials.

(e) For materials its value can be greater or less than μ_0.

(f) Its value depends on H and T.

(h) $\mu = \mu_0\,[1 + \chi]$

(i) $\mu = \mu_0\mu_r$

(j) (i) For feeromagnetic materials μ = high

(ii) For paramagnetic materials μ = low

(iii) For diamagnetic materials μ = very low

(k) The unit of magnetic permeability is Weber per ammere-meter or Henry per meter and its dimensions are $M^1L^0T^{-2}A^{-2}$.

RELATIVE PERMEABILITY (M_R)

(a) The ratio of magnetic permeability of medium (μ) to the magnetic permeabiliy of free space (μ_0) is defined as relative permeability (μ_r). i.e. $\mu_r = \frac{\mu}{\mu_0}$

(b)

$$\mu_r = \frac{\text{Number of lines of force passing through unit area in medium}}{\text{Number of lines of force passing through unit area in vacuum}}$$

(c) $\mu_r = \frac{\text{magnetic flux density in medium}}{\text{Magnetic flux density in vacuum}}$

(d) The limit unto which a magnetic field penetrates matter, is known as relative permeability of that material.

(e) It has no unit and no dimensions.

(f) $\mu_r = 1 + \chi$

(g) Relative permeability of various substances-

(i) For diamagnetic substances the value of μ_r is slightly less than one i.e. $\mu_r < 1$.

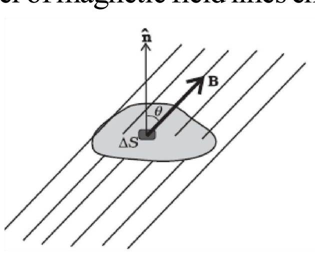
(ii) For paramagnetic substances the value of μ_r is slightly greater than one i.e. $\mu_r > 1$.

(iii) For ferromagnetic substance the value of μ_r is much greater than one i.e. $\mu_r >> 1$.

MAGNETISM AND GAUSS'S LAW

According to Gauss's law for magnetism, the net magnetic flux (ϕ_s) through any closed surface is always zero.

The law implies 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's law for magnetism.

Magnetic flux

$$\phi_B = \sum_{all} \Delta\phi_B = \sum_{all} \vec{B}.\vec{\Delta S} = 0 \qquad \text{-----(1)}$$

We can write

$$\phi_B = \oint_S \vec{B}.\vec{dS} = 0 \qquad \text{-----(2)}$$

Compare (2) with Gauss's law in electrostatics electric flux through closed surface. S is given by

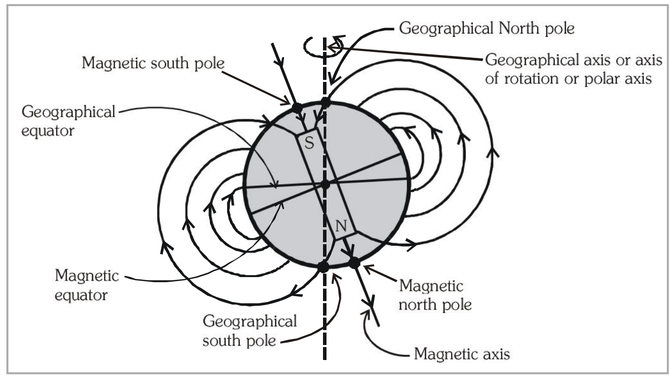
$$\phi_\varepsilon = \oint_S \vec{E}.\vec{ds} = \frac{q}{E_0} \qquad \text{-----(3)}$$

'q' is electric charge enclosed by the surface Gauss's law for magnetism is :

The net magnetic flux through any closed surface zero.

THE EARTH'S MAGNETISM

The branch of physics which deals with the study of earth's magnetic field is called geomagnetism.



1 **Important definitions :**

(a) **Geographic axis** : It is a straight line which passes through the geographical poles of the earth. It is also called axis of rotation or polar axis of the earth.

(b) **Geographic Meridian (GM)** : It is a vertical plane which passes through geographical axis of the earth.

(c) **Geographic equator** : It is a great circle on the surface of the earth, in a plane perpendicular to the geographic axis. All the points on the geographic equator are at equal distance from the geographic poles.

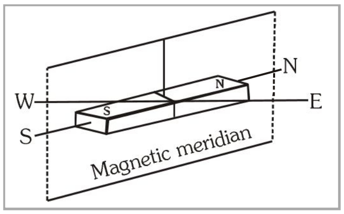
A great plane which passes through geographic equator and perpendicular to the geographic axis called **geographic equatorial plane**. This plane cuts the earth in two equal parts, a part has geographic north called **northen hemisphere** (NHS) and another part has geographic south called **southern hemi sphere** (SHS).

(d) **Magnetic axis** : It is a straight line which passes through magnetic poles of the earth. It is inclined to the geographic axis at nearly 17°.

(e) Magnetic Meridian (MM) :

(i) It is a vertical plane which passes through magnetic axis of the earth.

(ii) At a particular place it is a vertical plane, which passes through axis of free suspended bar magnet or magetic needle.



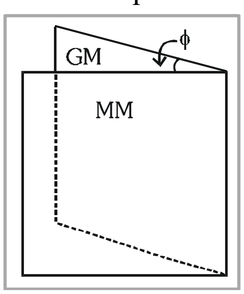
(iii) At a particular place it is a vertical plane, which contains all the field lines of earth's magnetic field.

(f) Magnetic equator : It is a great circle on the surface of the earth, in a plane perpendicular to the magnetic axis. All the points on the magnetic equator are at equal distance from the magnetic poles.

2 Main elements of earth's magnetic field :

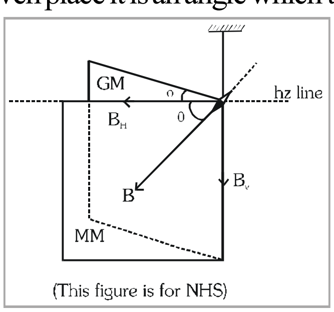
13.2.1 Angle of declination (ϕ) :–

At a given place the acute angle between geographic meridian and the magnetic meridian is called angle of declination, i.e. at a given place it is the angle between the geographical north-south direction and the direcation indicated by a magnetic compass needle in its equillibrium.



Angle of dip (θ) :–

(i) At a given place it is an angle which the direction of resultant magnetic field of the earth substends with respect to horizontal in magnetic meridian.



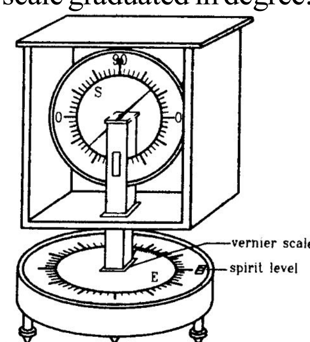
(ii) At a given place it is an angle which the axis of freely suspended magnetic needle substends with respect to horizontal in magnetic meridian.

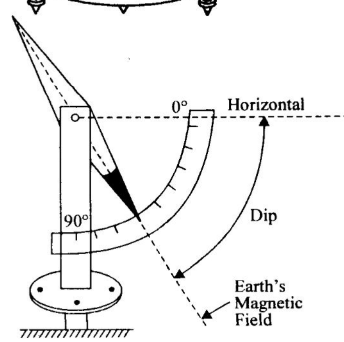
Note :-

In NHS, north pole of freely suspended magnetic needle will dip downwards i.e. towards the earth surface.

In SHS, south pole of freely suspended magnetic needle will dip downwards i.e. towards the earth surface.

Dip circle : Angle of dip is measured by the instrument called 'Dip-circle' in which a magnetic needle is free to rotate in vertical plane about horizontal axis. The ends of the needle move over a vertical scale graduated in degree.





Horizontal component of earth magnetic field (B_H) :–

At a given place horizontal component of earth magnetic field is the component of resultant magnetic field of the earth along the horizontal line in magnetic meridian.

$B_H = B\cos\theta$ and $B_v = B\sin\theta$ ....(1)

so that $\tan\theta = \dfrac{B_V}{B_H}$ and $B = \sqrt{B_H^2 + B_V^2}$ ....(2)

Note 1 :

* At magnetic poles $\Rightarrow \theta = 90°$

B_H = O (min)

B_V = B (max) (fully)

* At magnetic equator $\Rightarrow \theta = 0°$

B_H = B (max) (fully)

B_V = O (min)

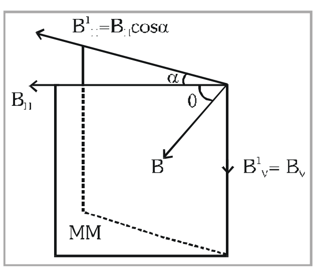
Note 2 :

ϕ decides the plane in which magnetic field lies at any place, (ϕ) and (θ) decides the direction of magnetic field and (θ) and (B_H) decides the magnitude of the field.

3 Apparent angle of dip (θ') :

When the plane of vertical scale of dip circle is in the magnetic meridian, the needle stays in the direction of earth's magnetic field. The angle made by the needle with respect to horizontal is called true dip or actual dip. If the plane of vertical scale of dip circle not kept in magnetic meridian, then the needle will not indicate the correct direction of earth magnetic field. In this situation the angle made by the needle with respect to horizontal is called the apparent angle of dip.

Suppose the dip circle is set at an angle α to the magnetic



meridian. Effective horizontal component in this plane will be $B_H \cos\alpha$ and vertical component B_V remains same.

App. angle of dip $\tan\theta' = \dfrac{B'_V}{B'_H} \Rightarrow \tan\theta' = \dfrac{B_V}{B_H \cos\alpha}$

[from (2)]

$$\boxed{\tan\theta' = \frac{\tan\theta}{\cos\alpha}}$$

Note 1 :

* For a vertical plane other than magnetic meridian $\alpha > 0 \Rightarrow \cos\alpha < 1 \Rightarrow \tan\theta' > \tan\theta \Rightarrow \theta' > \theta$, so apparent angle of dip is always more than actual angle of dip at any place.

Note 2 :

* For a vertical plane which is perpendicular to magnetic meridian $\alpha = 90° \Rightarrow \tan\theta' = \dfrac{\tan\theta}{\cos 90°} = \infty$

$\theta' = 90°$, so in a plane which is perpendicular to magnetic meridian dip needle becomes just verticle.

Magnetic field of long Bar magnet :

(i) At Axial position :–

Magnetic field at point 'P' due to north pole :–

$B_1 = \dfrac{\mu_0}{4\pi}\dfrac{m}{(r-\ell)^2}$ ..... (1) (away from north pole)

Magnetic field at point 'P' due to south pole :–

$B_2 = \dfrac{\mu_0}{4\pi}\dfrac{m}{(r+\ell)^2}$ .... (2) (towards north pole)

Net magnetic field at point 'P'

$B_{axis} = B_1 - B_2$, ($\because B_1 > B_2$)

$$= \frac{\mu_0 m}{4\pi}\left[\frac{1}{(r-\ell)^2} - \frac{1}{(r+\ell)^2}\right] = \frac{\mu_0 m}{4\pi}\left[\frac{4r\ell}{(r^2-\ell^2)^2}\right]$$

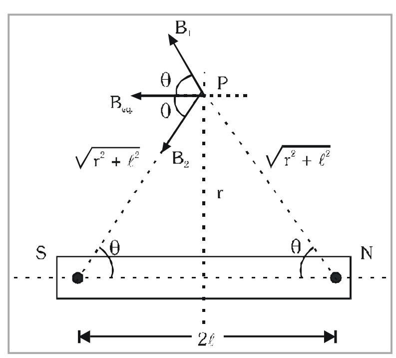
$\boxed{B_{axis} = \dfrac{\mu_0}{4\pi}\dfrac{2Mr}{(r^2-\ell^2)^2}}$, where $M = m(2\ell)$

Note : If magnet is short $r >> \ell$, then $\boxed{B_{axis} \simeq \dfrac{\mu_0}{4\pi}\dfrac{2M}{r^3}}$

(ii) At equatorial position :

Magnetic field at point 'P' due to north pole :–

$B_1 = \dfrac{\mu_0}{4\pi}\dfrac{m}{\left(\sqrt{r^2+\ell^2}\right)^2}$ ..... (1) (along NP line)



Magnetic field at point 'P' due to south pole :–

$$B_2=\frac{\mu_0}{4\pi}\frac{m}{\left(\sqrt{r^2+\ell^2}\right)^2} \quad ..... (2) \text{ (along PS line)}$$

From equation (1) & (2) $B_1 = B_2 = \frac{\mu_0}{4\pi}\cdot\frac{m}{r^2+\ell^2}$

$= B$ (Let)

Net magnetic field at point 'P'

$B_{eq} = 2 B \cos\theta$

$= 2\cdot\frac{\mu_0}{4\pi}\frac{m}{(r^2+\ell^2)}\cos\theta$, where $\cos\theta = \frac{\ell}{\sqrt{(r^2+\ell^2)}}$

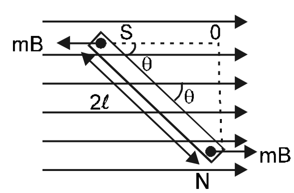
$= 2\cdot\frac{\mu_0}{4\pi}\frac{m}{(r^2+\ell^2)}\frac{\ell}{\sqrt{(r^2+\ell^2)}}$

$\boxed{B_{eq.} = \frac{\mu_0}{4\pi}\cdot\frac{M}{(r^2+\ell^2)^{3/2}}}$, where $M = m(2\ell)$

Note : If magnet is short $r >> \ell$, then $\boxed{B_{eq.} \simeq \frac{\mu_0}{4\pi}\cdot\frac{M}{r^3}}$

TORQUE ON A MAGNET IN MAGNETIC FIELD

When a bar magnet of pole strength m and magnetic length $2l$ is placed at an angle θ with a uniform magnetic field $\vec{B}$.



Force on N-pole = mB along $\vec{B}$

Force on S-pole = mB opposite $\vec{B}$

These forces are equal in magnitude and opposite in since

so they will form couple.

Torque $\tau = mB \times ON = MB\,2l \sin\theta = MB \sin\theta$

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

The direction $\vec{\tau}$ is perpendicular to plane containing $\vec{M}$ and $\vec{B}$, and is given by right hand screw rule

Solved Examples

Ex.1 The length of a bar magnet is 10 cm and its pole strength is 10^{-3} Weber. It is placed in a magnetic field of induction $4\pi \times 10^{-3}$ Tesla in a direction making an angle of 30º with the field direction. The value of torque acting on the magnet will be

(A) $2\pi \times 10^{-7}$ N-m (B) $2\pi \times 10^{-5}$ N-m

(C) 0.5×10^{2} N-m (D) None of these

Sol. $\tau = MB\sin\theta = m\ell B\sin\theta$

$= 10^{-3} \times 0.1 \times 4\pi \times 10^{-3} \times 0.5$

$= 2\pi \times 10^{-7}$ N-m

SOME TERMS RELATED TO MAGNETISM

(A) Magnetic permeability : It is the ability of material to permit the passage of magnetic lines through it. If it denoted by μ. Its unit is weber/ammeter.

Relative magnetic permeability (μ_r), is a factor by which the magnetic field B is increased when a material is brought in the field. μ_r is unitless.

$$\mu_r = \frac{\mu}{\mu_0} = 1 + \chi$$

where μ_0 is permeability of vaccum and χ is susceptibly of material.

(B) Intensity of magnetization (I) : It is defined as magnetic moment per unit volume.

$$\vec{I} = \frac{\text{magnetic moment}}{\text{volume}} = \frac{\vec{m}}{V}$$

$$I = \frac{m}{V} = \frac{2m\ell}{A(2\ell)} = \frac{m}{A}$$

For bar magnet of pole strength m, length x and area of cross-section A.

(C) Magnetic susceptibility : For paramagnetic and diamagnetic substances, the intensity of magnetization ($\vec{I}$) of a material is directly proportional to magnetic in intensity ($\vec{H}$)

Thus $\vec{I} = \chi\vec{H}$

The proportionality content χ is called susceptibility. It is a dimensionless quantity.

For vaccum $\chi = 0$.

Note : $\mu_r = 1 + \chi$ (in M.K.S. system)

$\mu_r = 1 + 4\pi\chi$ (in C.G.S system)

(D) **Magnetic Intensity :** The actual magnetic field inside the material is the sum of the applied magnetic field and magnetic field due to magnetization.

Hence $\vec{H} = \frac{\vec{B}}{\mu_0} - I = \frac{\vec{B}}{\mu}$

where $\vec{B}$ is the resultant magnetic field, and μ permeability of the material and $\vec{I}$ intensity of magnetization. The quantity $\vec{H}$ is called magnetic field intensity or magnetizing field intensity. Unit of it is ampere/meter.

Solved Examples

Ex.2 The magnetic susceptibility of a paramagnetic substance is 3×10^{-4}. It is placed in a magnetising field of 4×10^4 amp/m. The intensity of magnetisation will be

(A) 3×10^8 A/m (B) 12×10^8 A/m

(C) 12 A/m (D) 24 A/m

Sol. $I = XH = 3 \times 10^{-4} \times 4 \times 10^3 = 12$ A/m

Ex.3 The horizontal component of flux density of earth's magnetic field is 1.7×10^{-5} tesla. The value of horizontal component of intensity of earth's magnetic field will be ?

(A) 24.5 A/m (B) 13.5 A/m

(C) 0.135 a/m (D) 1.35 A/m

Sol. $H = \frac{B}{\mu_0} = \frac{1.7 \times 10^{-5}\ Wb/m^2}{4\pi \times 10^{-7}\ Wb/A-m} = 13.5$ A/m

Hence the correct answer will be (B).

Ex.4 A magnetising field of 2×10^3 amp/m produces a magnetic flux density of 8π Tesla in an iron rod. The relative permeability of the rod will be

(A) 10^2 (B) 10^0

(C) 10^4 (D) 10^1

Sol. $\because\ \mu_r = \frac{\mu}{\mu_0} = \frac{B}{H\mu_0}$

or $\mu_r = \frac{8\pi}{2 \times 10^3 \times 4\pi \times 10^{-7}} = 10^4$

Ex.5 A bar magnet made of steel has a magnetic moment of 2.5 A-m^2 and a mass of 6.6×10^3 kg. If the density of steel is 7.9×10^9 kg/m^3, find the intensity of magnetization of the magnet.

Sol. The volume of the bar magnet is

$$V = \frac{\text{mass}}{\text{density}} = \frac{6.6 \times 10^{-3}\,kg}{7.9 \times 10^3\,kg/m^3} = 8.3 \times 10^{-7}\ m^3.$$

The intensity of magnetization is

$$I = \frac{M}{V} = \frac{2.5\ A-m^2}{8.3 \times 10^{-7}\ m^2} = 3.0 \times 10^6\ A/m$$

MAGNETIC BEHAVIOUR OF ATOM

If an electron having charge e is revoling in an orbit of radius r having uniform angular velocity ω. Then Magnetic moment of atom contributed by the electron $M = \frac{1}{2} e\,\omega\, r^2$ and magnetic field $B = \frac{eh}{4\pi m} = 9.27 \times 10^{-24}$. ampere meter^2

If source as the unit of atomic magnetic dipole moment. Where h is plank's constant.

MOLECULAR / ATOMIC THEORY OF MAGNETIZATION

According to this theory

(i) Every molecule/atom of a magnetic substance has north pole as well as south pole of equal strength, so it is a magnetic dipole.

(ii) In unmagnetized condition, atomic dipoles are randomly oriented and they cancel dipole moment of one another.

(iii) After applying magnetic field, atomic dipoles align in its direction.

(iv) Extent of magnetization depends on extent of realignment of the molecular dipoles.

(v) On heating magnetization reduces or vanish completely.

On the basis of this theory magnetic materials are classified into three categories

(a) **Paramagnetic substances :** Every molecules / atoms of these substances has its own dipole moment. When we place such substances in magnetic field tries to align every individual molecule / atom in its direction e.g. chromium, CuSO4 , crown glass, aluminimium, platinum, manganese, solution of salts of iron and nickel are paramagnetic substances.

Permeability of paramagnetic substance is greater than unity. Susceptibility of paramagnetic substances varies inversely to the temperature of substance.

(b) **Diamagnetic substances :** Molecules / atoms of this type of substances do not have dipole moment individually. When they are kept in any magnetic field, magnetic moment induces but it is in opposite direction to the applied magnetic field. e.g. copper, gold, mercury , quart, antimony and Bismoth etc.

Permeability of diamagnetic substances is always less than unity.

Susceptibility of diamagnetic substances does not change with temperature.

(c) **Ferromagnetic substances :** In these substance each individual atom/molecule has magnetic moment. They have strong tendency to align themselves so they make domain. In a domain, a large no. of atoms/ molecules align in same direction.

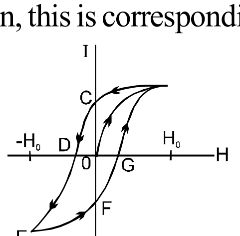
Different domains have different directions of magnetic moment hence, the material remains un magnetized.

When a magnetic field is applied, the domains which are aligned along the direction of the field grown in size and those opposite to it get reduced. iron nickel and cobalt etc. are examples of such materials.

HYSTERESIS

As shown in adjacent curve, as we change field intensity, magnetization changes.

In the beginning , the field is zero and sample has no magnetization, this is corresponding to point O.



As we increase field intensity, magnetization point A corresponds to saturation magnetization. As value of and direction of field intensity varies, magnetization along path ACDEFGA is followed.

Hence as field intensity increased or decreased, magnetization does not return to its initial value. This fact is called hysteresis. The curve ACDEFGA is called hysteresis loop. This are of the hysteresis loop is proportional to the thermal energy developed per unit volume of the material as it goes through the hysteresis cycle.

Hysteresis loop for soft iron is narrow and large, whereas hysteresis loop for steel is wide and short.

Solved Examples

Ex.6 The mass of a speciment of a ferromagnetic material is 0.6 kg. and its density is 7.8 x 10^3 kg/m^3. If the area of hysteresis loop of alternating magnetising field of frequency 50Hz is 0.722 MKS units then the hysteresis loss per second will be –

(A) 277.7×10^{-5} Joule (B) 277.7×10^{-6} Joule
(C) 277.7×10^{-4} Joule (D) 277.7×10^{-4} Joule

Sol. $W_H = VAft = \frac{m}{d} Aft$

or $W_H = \frac{0.6}{7.8 \times 10^3}$ x 0.722 x 50

= 277.7 x 10^{-5} Joule

CURIE LAW

According to this law, intensity of magnetization (I) of a magnetic material is directly proportional to magnetic induction (B) and inversely proportional to the temperature of magnetic material.

$I \alpha \frac{B}{T}$ we know $B \alpha H$

So $\frac{I}{H} \alpha \frac{1}{T}$ $\frac{I}{H} = \chi = \frac{C}{T}$

where χ is susceptibility of material and C is a constant called curie constant.

The variation of I with graph it is clear that saturation is reached when H/T exceeds a certain limit. Magnetic thermometers are based on curie law and filled with paramagnetism substance (e).