# Chapter 3 (c) Magnets & earth's magnetism

## 28 Magnets and Magnetism:-

An iron ore [***black iron oxide*** **($Fe_3O_4$)**] also called ***magnetite*** having the property of attraction of small piece of iron, nickel, cobalt etc is called a magnet & its property of attraction is called magnetism.

## 29 Artificial magnets:-

The natural magnet is weak in strength. So some artificial magnets are formed by the help of iron & some other magnetic materials. These may be of different shapes as

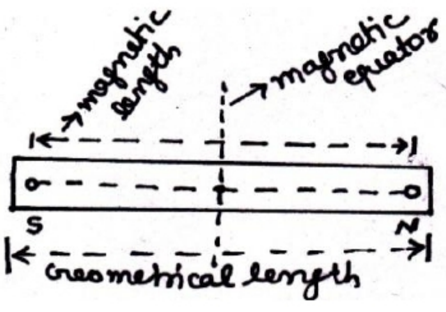
1. Bar magnet: - A magnet in the shape of bar.
2. Magnetic needle: - It is a needle made of magnetic material can rotate at its center.
3. Horse shoe magnet: - A magnet having shape like shores shoe.
4. Ball ended magnet: - A thin bar whose ends are circular.

## 30 Basic properties of magnet:-

1. *Attractive property:* - Magnet attracts small piece of iron nickel, etc.
2. *Directive property:* - Magnets rest in North south direction when suspended freely.
3. *Magnetic poles always exist in pairs;* a single North or South Pole may not exist.
4. Like pole repel each other & unlike pole attract each other.
5. *Magnetic induction:*-A magnetic substance becomes magnetized when placed near to a magnet this property is called magnetic induction.

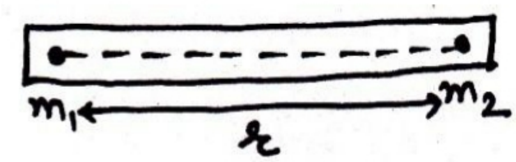
## 31 Some basic definitions connected with magnetism:-

1. Magnetic field: - The space around a magnet in which its magnetic effect can be experienced is called its magnetic field.
2. Magnetic poles: - The region in a magnet where magnetic force is maximum is called magnetic poles.
3. Magnetic axis: - The line passes through the poles of a magnet is called magnetic axis.
4. Magnetic equator: - The line passes through the centre of magnet & perpendicular to magnet axis is called magnetic equator.
5. Magnetic length: - The distance between the two poles of a magnet is called magnetic length.



## 32 Coulomb's Law of Magnetism:-

According to coulomb's Law of magnetism, the force of interaction between two magnetic poles is directly proportional to the pole strength of the poles and inversely proportional to the distance between them.




I,e. $F_m \propto \frac{m_1 m_2}{r^2}$

Or $F_m = k\frac{m_1 m_2}{r^2}$

Where $k = \frac{\mu_0}{4\pi}$ = is constant of proportionality & it value depends upon nature of the medium & system of units taken. Or $F_m = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{r^2}$

Where $\mu_0$ is the permeability of free space & its value is $4\pi \times 10^{-7}$ Henry/meter.

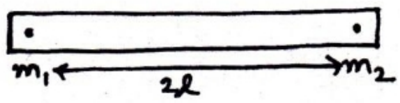
If $m_1 = m_2 = 1\ unit\ \ and\ \ r = 1m$ Then $F_m = \frac{\mu_0}{4\pi} = 10^{-7}$ N

*Hence a unit magnetic pole may be defined as a pole which when placed in vacuum at a distance of one meter from an identical pole repels it by a force of $10^{-7}$ N.*

## 33 Magnetic dipoles & magnetic dipole moment:- m.imp

Magnetic dipoles: - An arrangement of two equal & opposite poles separated by a small distance is called magnetic dipole.

Magnetic dipole moment:-The product of either pole of a magnetic dipole & the distance between the poles is called magnetic dipole moment represented by m .It is a vector quantity having direction from South to North. I,e. $\vec{M} = m \times 2\vec{l}$




S.I unit: Ampere metre$^2$.

## 34 Magnetic field lines:-

The path along which a hypothetical unit north pole moves gives the magnetic lines of forces. The tangent drawn at any point of the line gives the direction of magnetic field at that point.

Properties:-

1. The magnetic lines of forces move from South to north inside the magnet & North to south outside the magnet.
2. Magnetic lines of forces do not intersect each other.
3. The starts & end normally to the surface.
4. Closer the magnetic lines of forces, stronger are the magnetic field.
5. Electrostatic field lines originate at a positive charge and terminate at a negative charge or fade at infinity. Magnetic field lines always form closed loops.

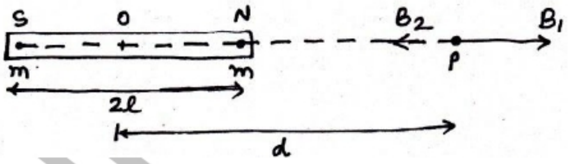
**35 Magnetic field strength at a point due to a bar magnet:-**

**(a ). Magnetic field strength at the axial point of bar magnet:-**

Consider a bar magnet of magnetic strength m & having length $2l$. Now consider a point p having 2d distance from center of the bar magnet. Then magnetic field strength at P due to N pole is

$$B_1 = \frac{\mu_0}{4\pi}\frac{m\times 1}{NP^2} = \frac{\mu_0 m}{4\pi(d-l)^2} \qquad --(1)$$

Similarly magnetic field at P due to S pole is




$$B_2 = \frac{\mu_0}{4\pi}\frac{m\times 1}{SP^2} = \frac{\mu_0 m}{4\pi(d+l)^2} \qquad --(2)$$

So the net magnetic field at P is $B = B_1 - B_2$

Or $$B = \frac{\mu_0}{4\pi}\frac{m}{(d-l)^2} - \frac{\mu_0}{4\pi}\frac{m}{(d+l)^2} = \frac{\mu_0 m}{4\pi}\left[\frac{1}{(d-l)^2} - \frac{1}{(d+l)^2}\right]$$

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

$$= \frac{\mu_0 m.4dl}{4\pi(d^2-l^2)^2} = \frac{\mu_0 m.2d2l}{4\pi(d^2-l^2)^2}$$

**Or** $$\mathbf{B = \frac{\mu_0}{4\pi}\frac{2Md}{(d^2-l^2)^2}}$$

Special case:- If dipole is small then $l^2 << d$ so $l^2$ can be neglected $\Rightarrow$ $B = \frac{\mu_0}{4\pi}\frac{2M}{d^3}$

**(b) When point lies on equatorial point of a bar magnet:-**

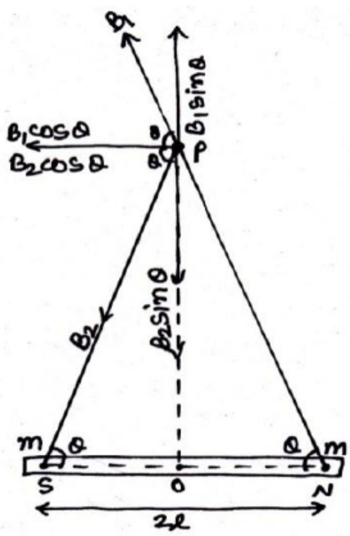
Consider a bar magnet of magnetic strength m & distance $2l$. Again consider a point P lying at the equatorial point of bar magnet having $d$ distance from center of the bar magnet.

Then magnet field at the point P due to N is

$$B_1 = \frac{\mu_0}{4\pi}\frac{m\times 1}{(NP)^2} = \frac{\mu_0}{4\pi}\frac{m}{(l^2+d^2)} \; along \; NP$$

Similarly the magnetic field at P due to S is

$$B_2 = \frac{\mu_0}{4\pi}\frac{m}{(SP)^2} = \frac{\mu_0}{4\pi}\frac{m}{(l^2+d^2)} \; along \; PS$$




As $|\vec{B_1}| = |\vec{B_2}|$ so $B_1\sin\theta$ & $B_2\sin\theta$ components cancel out each other.

So the net magnetic field can be given as

$$B = B_1\cos\theta + B_2\cos\theta = 2B_1\cos\theta \quad (B_1 = B_2)$$

Or $$B = 2 \times \frac{\mu_0}{4\pi}\frac{m}{(l^2+d^2)} \times \frac{l}{\sqrt{l^2+d^2}}$$

or $$B = \frac{\mu_0}{4\pi}\frac{M}{(l^2+d^2)^{3/2}} \qquad (\because M = m2l)$$

Special case:- If magnet is small then $l << d$ .so d can be neglected

$$\Rightarrow \quad B = \frac{\mu_0 M}{4\pi (d^2)^{3/2}} = \frac{\mu_0 M}{4\pi d^3}$$

✸ Also $$\frac{B_{axial}}{B_{equitarial}} = 2$$

**Example9. what is the magnitude of the equatorial and axial fields due to a bar magnet of length 5.0 cm at a distance of 50 cm from its mid-point? The magnetic moment of the bar magnet is 0.40 Am$^2$.**

Solution as $B_{equitarial} = \frac{\mu_0 M}{4\pi d^3} = 3.2 \times 10^{-7} T$ and $B_{axial} = \frac{\mu_0}{4\pi}\frac{2M}{d^3} = 6.4 \times 10^{-7} T$

**Example10. the earth's magnetic field at the equator is approximately 0.4 G Estimate the earth's dipole moment.**

Solution as the equatorial magnetic field is, $B_{equitarial} = \frac{\mu_0 M}{4\pi d^3}$

We are given that $BE \sim 0.4\, G = 4 \times 10^{-5}\, T$. For r, we take the radius of the earth $6.4 \times 10^6$ m.

Hence, $M = \frac{4 \times 10^{-5} \times (6.4 \times 10^6)^3}{10^{-7}} = 1.05 \times 10^{23} Am^2$ this is close to the value $8 \times 10^{22} Am^2$ quoted in geomagnetic texts

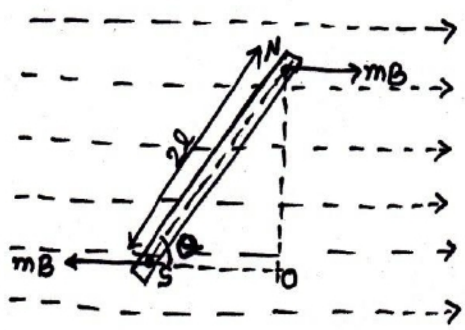
## 36 Torque on a magnetic dipole in magnetic field:-

Consider a bar magnet of length $2l$ placed at angle θ with magnetic field B.

Then force acting at N pole is along B & force acting at S pole is in opposite to magnetic field. These equal & opposite force form a couple & exerts torque given as

$$\tau = force \times perpendicular\ distance$$

$$= mB \times 2l sin\theta = mB2l\, Sin\theta$$




Or $$\tau = MB\, Sin\theta$$

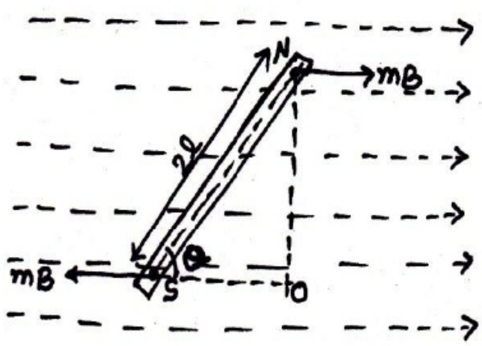
Or $$\vec{\tau} = \vec{M} \times \vec{B}$$

Special case:-

1. When the magnet lies along the direction of magnetic field then θ= 0$^0$ ⇒ sin0 =0
   $\Rightarrow \quad \tau = 0$ *(torque is minimum.)*
2. When the magnet lies perpendicular to the direction of magnetic field then θ =90$^0$ ⇒ sin 90$^0$=1
   $\Rightarrow \quad \tau = MB$ *(torque is maximum)*

## 37 Potential Energy of a magnetic dipole:-

When the magnet dipole is placed in a magnetic field B then the dipole experiences a torque which can be given as $\tau = MB\,Sin\theta$




This torque tends to align the dipole in direction of $\overrightarrow{B}$. Now small work is to be done to turn the dipole at small angle dθ as

$$dW = \tau d\theta = MBsin\theta d\theta$$

If the dipole is rotated from $\theta_1$ to $\theta_2$, then the total work done will be $W = \int dw = \int_{\theta_1}^{\theta_2} MBsin\theta d\theta$

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

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

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

This work done is stored as the potential energy U of the dipole so $\boldsymbol{U = MB[cos\theta_1 - cos\theta_2]}$

**Example11. A short bar magnet placed with its axis at 30° with an external field of 800 G experiences a torque of 0.016 Nm. (a) what is the magnetic moment of the magnet?**

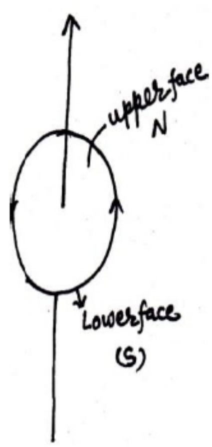
**(b) The bar magnet is replaced by a solenoid of cross-sectional area 2 × $10^{-4}$m² and 1000 turns, but of the same magnetic moment. Determine the current flowing through the solenoid.**

Solution (a) as $\tau = m\,B\,sin\,\theta, \theta = 30^0$,hence $sin\theta = \frac{1}{2}$. $Thus$ $0.016 = m \times 800 \times 10^{-4}T \times \frac{1}{2} \Rightarrow m = 160 \times \frac{2}{800} = 0.40\,A\,m^2$

(b) As $m_s$ = NIA. From part (a), $m_s = 0.40\,A\,m^2 \Rightarrow 0.40 = 1000 \times I \times 2 \times 10^{-4} \Rightarrow I = 0.40 \times \frac{10^4}{1000 \times 2} = 2A$

## 38 Current loop as a magnetic dipole:- m.imp

Consider a current carrying loop having current I flowing through it. Looking at upper face, the current is anti clock wise so act as North Pole & in lower face current is clockwise so act as South Pole. Hence we can say a current carrying coil behave as a magnetic dipole. The electric field at the axial point of loop is $\vec{E} = \frac{1}{4\pi\varepsilon_0}\frac{2\vec{P}}{r^3}$ -- (1)




& the magnetic field at the axial point of the loop is $\vec{B} = \frac{\mu_0}{4\pi}\frac{2\overrightarrow{IA}}{r^3}$ — (2)

Comparing eqⁿ 1 & 2 we can see that both $\vec{E}$ & $\vec{B}$ have same distance dependence nature, same direction so $\overrightarrow{IA}$ should be magnetic dipole moment. So we can say that magnetic dipole moment of circular loop is $\boldsymbol{\overrightarrow{M} = \overrightarrow{IA}}$**……………………….(3)**

*Hence current loop behave as a magnetic dipole.*

**Example12. A 100 turn closely wound circular coil of radius 10 cm carries a current of 3.2 A. (a) What is the field at the centre of the coil?**

**(b) What is the magnetic moment of this coil? The coil is placed in a vertical plane and is free to rotate about a horizontal axis which coincides with its diameter. A uniform magnetic field of 2T in the horizontal direction exists such that initially the axis of the coil is in the direction of the field. The coil rotates through an angle of 90º under the influence of the magnetic field.**

**(c) What are the magnitudes of the torques on the coil in the initial and final position?**

Solution (A) Here, N = 100; I = 3.2 A, and R = 0.1 m. Hence,

$$B = \frac{\mu_0 nI}{2r} = \frac{4\times 3.14\times 10^{-7}\times 100\times 3.2}{2\times 0.1} = \frac{4\times 10^{-5}\times 10}{2\times 10^{-1}} = 2\times 10^{-3} T \text{ (Using } \pi\times 3.2 = 10)$$

(b) The magnetic moment is given by $m = NIA = NI\pi r^2 = 100 \times 3.2 \times 3.14 \times 10^{-2} = 10\, A\, m^2$.

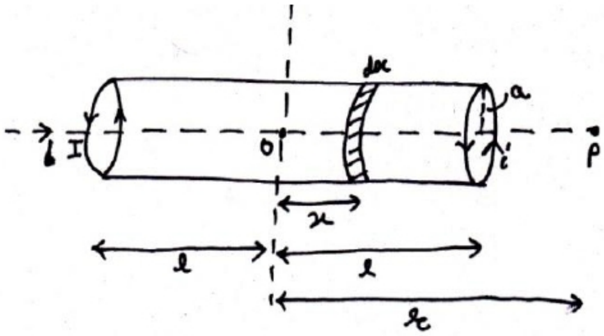
(c) $\tau = \vec{m} \times \vec{B} = mB\sin\theta$

Initially, θ = 0. Thus, initial torque $\tau_i = 0$. Finally, $\theta = \frac{\pi}{2}$ $(or\ 90^0)$ Thus, final torque $\tau_f = m B = 10 \times 2 = 20\, N\, m$

## <u>39 BAR MAGNET AS A SOLENOID:-</u> or solenoid as a bar magnet.

Suppose a solenoid of radius a, length $2l$ & n number of turns. Suppose I is the amount of current passing through the solenoid. Now we have to calculate magnetic field at point P having r distance from the center of the solenoid. Consider a small length $dx$ of the solenoid at distance $x$ from 0.

Then total number of turn in $dx = ndx$




As we know magnetic field at the axis of circular loop is

$$dB = \frac{\mu_0 I a^2 n dx}{2r^3} \quad \text{(remember it from 3 (a))}$$

As $x$ varies from $-l$ to $l$

So total magnetic field B = $\frac{\mu_0}{2r^3} nIa^2 \int_{-l}^{l} dx = \frac{\mu_0}{2r^3} nIa^2 [x]_{-l}^{l} = \frac{\mu_0}{2r^3} nIa^2 .2l$

Now if m is the magnetic dipole moment of the solenoid then

$$M = number\ of\ turn \times current \times area$$
$$= n(2l)I\pi a^2$$
$$\Rightarrow \quad B = \frac{\mu_0}{4\pi} \frac{2n(2l)I\pi a^2}{r^3}$$
$$\Rightarrow \quad B = \frac{\mu_0}{4\pi} \frac{2M}{r^3}$$

Which is the magnetic field at the axis of bar magnet hence we can say that a solenoid act as a bar magnet.

## 40 Gauss Theorem In Magnetism:- m.imp

As we know Gauss theorem in electrostatic states that the surface integral of electric field over a closed surface is $\frac{1}{\varepsilon o}$ the total charge inclosed by the surface

As $$\oint E.ds = \frac{q}{\varepsilon o}$$

But if there is an electric dipole then the gauss theorem is

$$\oint \boldsymbol{E}.\boldsymbol{ds} = 0$$ (Because the net Electric field around electric dipole is zero.)

Now *Gauss theorem in magnetism states that the surface integral magnetic field over a closed path is always zero.*

I,e. $$\oint \boldsymbol{B}.\boldsymbol{ds} = 0$$

Because a magnet always exists in pair as magnetic dipole, i.e. no single pole exists.

Consequence of Gauss theorem:-

- The magnetic poles always exist as unlike pairs of equal strength.
- The number of magnetic lines of forces entering a surface equal to number of magnetic lines leaving the surface.
- An isolated monopole does not exist in magnets.
- Magnetic lines of forces forms continuous closed curves.

## 41 Magnetic field of the earth:-

Earth is a powerful natural magnet. Its magnetic field is present everywhere near the surface of earth. It is supposed that a huge magnetic field exist at the center of earth.

*There is some evidence in support of earth's magnetism:-*

(i) A freely suspended bar magnets always rest in North South direction which suggest that earth behave as a magnet.

(ii) An iron piece buried in the earth becomes weak magnet due to earth's Magnetism.

(iii) Existence of neutral point near a bar magnet that there is magnet in Earth which cancel the magnetic field of bar magnet.

## 42 Origin of Earth's magnetic field:-

*There are many theories given to prove earth's magnetic field as.*

(i) In 1600 William Gilbert suggested that at the center of earth there is a permanent magnetic material due to which earth shows magnetism. But at the center of earth, it is very hot, no magnetism may exist.

(ii) According to prof. Blackett earth's magnetism is due to its rotation. As when earth rotates so every substance rotates, as all substances are made up of electrons & protons so due to circular motion of ions current produces due to which magnetism are shown by earth.

(iii) According to Bullard & W.M Elaster at the center of earth there is magnetic material like iron, nickel etc are in the molten state. These circulating ions in the conducting medium form *circular current loop* which cause earth's magnetism. *This theory is somewhat acceptable because moon which has no molten core have no magnetic field.*

- The exact cause of earth's magnetism is yet not known.

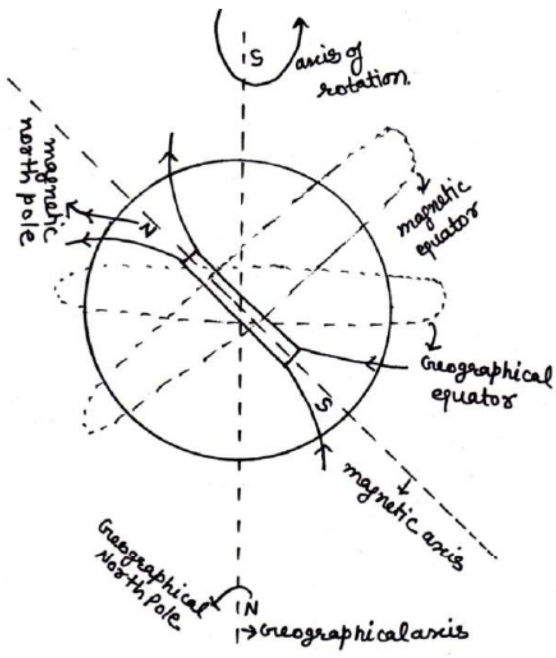
## 43 Some definitions in connection with Earth's magnetism:- [m.imp]

### (1) Geographic axis:-

The straight line passing through the geographical north and South Pole of earth is called Geographical axis.

### (2) Magnetic axis: -

The straight line passing through the magnetic north and South Pole of earth is called magnetic axis.




### (3) Magnetic equator:-

The great circle on the Earth, perpendicular to the magnetic axis called magnetic equator.

### (4) Magnetic meridian:-

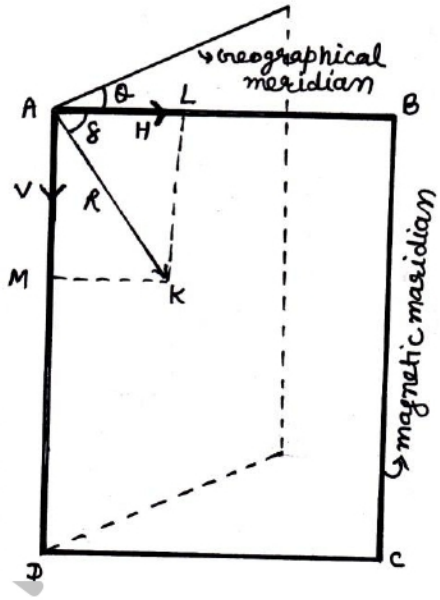
The vertical plane passing through the magnetic axis is called magnetic meridian.

### (5) Geographical meridian:-

The vertical plane passing through the geographical axis is called Geographical meridian.

## 44 ELEMENT OF EARTH'S MAGNETIC FIELD:- m.imp

The earth's magnetic field at a point can be completely described by three elements called elements of earth's magnetic field. Which are




1. Magnetic declination:-

The small angle between magnetic meridian and Geographical meridian is called magnetic declination. It is represented by θ.

2. Magnetic inclination:-

The angle between the directions of total magnetic field of earth with the horizontal line in magnetic meridian is called magnetic inclination. It is denoted by $\delta$ .

3. Horizontal component:-

It is the component of earth's total magnetic field $\vec{B}$ in the horizontal direction in the magnetic meridian. The horizontal components of earth's magnetic field $\vec{B}$ at a place is given by

$$B_H = B\ cos\delta$$

## 45 Relation between elements of earth magnetic field:-

The horizontal & vertical components of earth's magnetic field can be given as

$$B_H = B\ cos\delta \ \ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$and \quad B_v = B\ sin\delta \quad \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Dividing $\frac{B_v}{B_H} = \frac{B\ sin\delta}{B\ cos\delta} = \frac{sin\delta}{cos\delta} = tan\delta$

Also squaring and adding (1) & (2)

$$B_H^2 + B_v^2 = B^2(cos^2\delta + sin^2\delta\ )$$

Or $$\boldsymbol{B = \sqrt{B_H^2 + B_v^2}}$$

**Example13. In the magnetic meridian of a certain place, the horizontal component of the earth's magnetic field is 0.26G and the dip angle is 60°. What is the magnetic field of the earth at this location?**

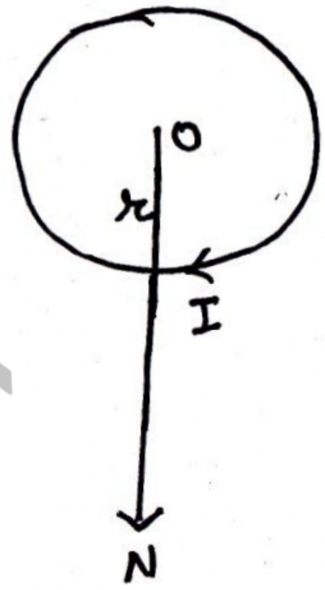
Solution it is given that $H_E\ =\ 0.26\ G$. Also we have $cos60^0 = \frac{H_E}{B_E} \Rightarrow B_E = \frac{H_E}{cos\ 60^0} = \frac{0.26}{0.5} = 0.52G$

## 3(d) Classification of magnetic materials

### 46 Bohr magneton or magnetic dipole moment of revolving electron m.imp

As electron revolves in circular path in an atom, constitute current. Due to this current the atom behaves as a magnetic dipole. I,e. $I = \frac{e}{T}$

Here $T = \frac{2\pi}{\omega}$ = Time period of e revolution. $\Rightarrow I = e\frac{\omega}{2\pi}$




If $A = \pi r^2$ = area of conductor .Then magnetic dipole moment

$$M = IA = \frac{e\omega}{2\pi} \times \pi r^2 = \frac{1}{2}e(\omega r^2) \text{ ------- } (1)$$

From Bohr Theory $mvr = \frac{nh}{2\pi}$

Or $m(r\omega)r = \frac{nh}{2\pi}$

Or $mr^2\omega = \frac{nh}{2\pi} \Rightarrow r^2\omega = \frac{nh}{2\pi m}$.......... .(2)

Putting in (1) $\Rightarrow M = \frac{1}{2}e\frac{nh}{2\pi m}$

$\Rightarrow M = n\frac{eh}{4\pi m} = n\mu_b$

$\Rightarrow \boldsymbol{M = n\mu_b}$

Here $\mu_b = \frac{eh}{4\pi m} = \frac{(1.6\times10^{-19})\times(6.67\times10^{-34})}{4\times3.14\times(9.1\times10^{-31})} = 9.27 \times 10^{-24}\ Am^2$

Here $\mu_b = 9.27 \times 10^{-24}\ Am^2$ called Bohr magneton

Hence *Bohr Magneton is the minimum magnetic dipole moment associated with an atom due to orbital motion of an electron, in the first stationary orbit of atom.*

### 47 Some important terms used in magnetism:- m.imp

1. Magnetic permeability :-( $\mu$)

The degree or extent to which magnetic field can penetrate a magnetic material is called magnetic permeability. It is represented by$\mu$.

It is defined as the ratio of magnetic induction to the magnetizing force.

I,e. $\mu = \frac{B}{H}$

Unit: - $Hm^{-1} = WbA^{-1}m^{-1} = (Tm^2)\ A^{-1}m^{-1} = TmA^{-1}$

Relative magnetic permeability

It is defined as the ratio of magnetic permeability of the material ($\mu$) and the magnetic permeability of free space ($\mu_0$)

I,e. $\mu_r = \frac{\mu}{\mu_0}$

Unit: - unit less

2.Magnetic induction or magnetic flux density:-(B) or magnetic field strength:-

It is defined as the amount of force experienced by a unit +ve charge moving with unit velocity in a direction perpendicular to magnetic field. It is also defined as the sum of external magnetizing field ($B_0$) and the additional magnetic field produced due to magnetization of the material ($B_m$), is called magnetic induction B.

I,e. $\vec{B} = \vec{B}_0 + \vec{B}_m$

Unit:- Wb/$m^2$ or Tesla (T). The c.g.s. unit is Gauss [1 Gauss =$10^{-4}$Tesla]

3.Megnetising force or Magnetizing intensity ($\vec{H}$)

The degree up to which a magnetic field can magnetize a material is represented in terms of magnetizing force or magnetizing intensity ($\vec{H}$), its magnitude may be defined as the number of ampere turn ($nI$) flowing around the unit length of the solenoid required to produce the given magnetizing field.

Thus $H = nI$

Also $B_0 = \mu_0 nI = \mu_0 H$

Or $H = \frac{B_0}{\mu_0}$

Unit: - $Am^{-1} = Nm^{-2}T^{-1}$

4. Intensity of magnetization :-( I)

It tells about the extent to which a specimen is magnetized when placed in a magnetizing field.

In magnitude, it is defined as the magnetic moment per unit volume of the material

I,e. $I = \frac{\text{magnetic moment}}{\text{volume}} = \frac{M}{V}$

\or $I = \frac{m \times 2l}{a \times 2l} = \frac{m}{a}$

Hence intensity of magnetization may be defined as the pole strength per unit area of cross -section of the material.

Unit – $Am^{-1}$ same as that of H

5. Magnetic susceptibility ($\chi_m$)

It tells that how easily a specimen can be magnetized. It is defined as the ratio of intensity of magnetization (I) induced material when magnetizing force is applied on it. It is represented by $\chi_m$.

$$\chi_m = \frac{I}{H}$$

It is also called volume susceptibility of the material.

Unit: - It is unit less.

**48 Relation between magnetic permeability and magnetic susceptibility:-**

If a magnetic material is placed in magnetizing field (H) then intensity of magnetization (I) induces in the material. Then magnetic induction possessed by material is

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

$$\text{But } B = \mu H$$

$$\Rightarrow \mu H = \mu_0 (H + I) \quad \Rightarrow \mu = \mu_0 \left(\frac{H}{H} + \frac{I}{H}\right)$$

$$\Rightarrow \mu = \mu_0 (1 + \chi_m)$$

$$\Rightarrow \frac{\mu}{\mu_0} = \mu_r = (1 + \chi_m)$$

So $$\boldsymbol{\mu_r = (1 + \chi_m)}$$

**Example14. A solenoid has a core of a material with relative permeability 400. The windings of the solenoid are insulated from the core and carry a current of 2A. If the number of turns is 1000 per metre, calculate (a) H, (b) M, (c) B and (d) the magnetizing current $I_m$.**

Solution (a) the field H is dependent of the material of the core, and is $H = nI = 1000 \times 2.0 = 2 \times 10^3\ A/m$.

(b) The magnetic field B is given by $B = \mu_r \mu_0 H = 400 \times 4\pi \times 10^{-7} \times 2 \times 10^3 = 1.0\,T$

(c) Magnetization is given by $M = \frac{B - \mu_0 H}{\mu_0} = \frac{\mu_r \mu_0 H - \mu_0 H}{\mu_0} = (\mu_r - 1)H = 399 \times H \cong 8 \times 10^5 A/m$

(d) The magnetizing current $I_M$ is the additional current that needs to be passed through the windings of the solenoid in the absence of the core which would give a B value as in the presence of the core. Thus B = $\mu_r\, n_0\, (I + I_M)$.

$$Using\ I = 2A, B = 1\,T, we\ get\ I_M = 794\ A.$$

**49 Classification of magnetic materials:-**

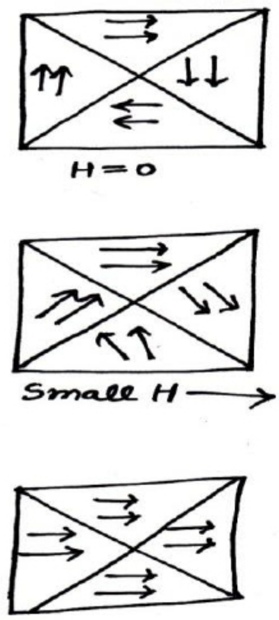
There may be three types of magnetic materials

1. Diamagnetic substances:- Those substances which are feebly (weakly) repelled by external magnetic field are called diamagnetic substance. E.g. -> Hg, $H_2O$, Au, Cu, Diamond, Zn, Quartz, Antimony, Bismuth, Air, $H_2$, $N_2$, All inert gasses etc.
2. Paramagnetic Substances:-Those substances which are feebly attracted by external magnetic field are called paramagnetic substances. E,g:-Al, Cr, Mn, Li, Mg, Na, K, $O_2$, etc.
3. Ferromagnetic substances:-Those substances which are strongly attracted by the external magnetic field are called ferromagnetic substances e.g. Fe, Ni, Co, Gadolinium etc.

**50 Explanation of ferromagnetism:-** m.imp

Ferromagnetism is explained by the **Weiss** on the basis of domain theory.

**Domain:-** A set of atoms which have the same direction of magnetic dipole moment or we can say a set of atoms which are aligned in the same direction in a small piece of ferromagnetic material called domain. There may be thousand of domain and each may contains thousand of electrons or atoms.




**Domain theory:-**When there is no any external magnetic field is applied on ferromagnetic materials then set of domains are in such a way that the net magnetization is zero. But when small external magnetizing field is applied then due to displacement of boundaries & rotation of the domains the material acquires some net magnetization in direction of H.

And when strong magnetizing force is applied then all the items in domains align in direction of external magnetizing field & the material becomes magnetized, which remains for a long time even after removal of H.

*Hence ferromagnetic materials can be used to make permanent magnets.*

**Example15. a domain in ferromagnetic iron is in the form of a cube of side length 1μm. Estimate the number of iron atoms in the domain and the maximum possible dipole moment and magnetization of the domain. The molecular mass of iron is 55 g/mole and its density is 7.9 g/cm$^3$. Assume that each iron atom has a dipole moment of $9.27\times10^{-24}$A m$^2$.**

Solution The volume of the cubic domain is $V = (10^{-6}\,m)^3 = 10^{-18}\,m^3 = 10^{-12}\,cm^3$

Its mass is $volume \times density = 7.9\,g\,cm^{-3} \times 10^{-12}\,cm^3 = 7.9 \times 10^{-12} g$

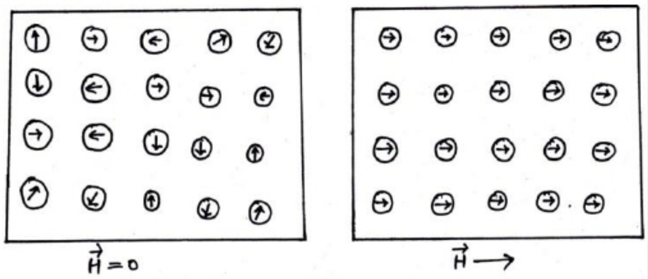
It is given that Avagadro number $(6.023 \times 10^{23})$ of iron atoms have a mass of 55 g. Hence, the number of atoms in the domain is $N = \frac{7.9 \times 10^{-12} \times 6.023 \times 10^{23}}{55} = 8.65 \times 10^{10}$ atoms

The maximum possible dipole moment $m_{max}$ is achieved for the (unrealistic) case when all the atomic moments are perfectly aligned. Thus, $m_{max} = (8.65 \times 10^{10}) \times (9.27 \times 10^{-24}) = 8.0 \times 10^{-13} A\,m^2$

The consequent magnetization is $m_{max} = \frac{m_{max}}{Domain\ \ volume} = 8.0 \times 10^{-13}/10^{-18} = 8.0 \times 10^5 Am^{-1}$

**51 Explanation of Para magnetism or Langevin's theory of Para magnetism:-**

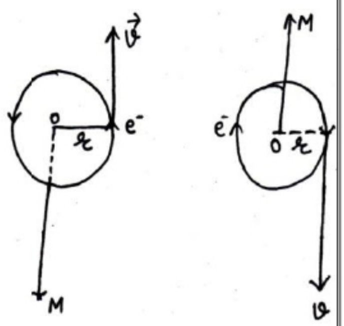
In paramagnetic materials every atom have some permanent magnetic moment, in the absence of external magnetic field, the net magnetic moment is zero. But when external field is applied, then atoms align in the direction of external magnetic field, which remain till the field is applied and disappear when field is removed. Hence under the effect of external magnetic field the paramagnetic material shows magnetism.




Para magnetism decreases with rise in temp.

**52 Explanation of diamagnetism:-**

In case of some elements like Bi, Cu, Pb which have fully filled electronic configuration, the electrons exist in pairs and revolves in opposite direction. Then the net magnetic moment of atom become zero. When such a atom is placed in external magnetic field $\vec{B}$, then the speed of one e increase and that of second decrease. The magnetic moment of former electron increase to $\vec{M} + \Delta\vec{M}$ & that of latter electron decrease to $\vec{M} - \Delta\vec{M}$. So electron pair get a net magnetic moment - 2 $\Delta\vec{M}$ in opposite to external magnetic field. Due to this magnetic moment diamagnetic material repels the external magnetic field.




**53 Curie law in magnetism:-** m.imp

According to curie law the intensity of magnetization (I) of a material is directly proportional to magnetic induction (B) & inversely proportional to temperature (T) of the material.

I,e. $I \propto B$

& $I \propto \frac{1}{T}$

$\Rightarrow \quad I \propto \frac{B}{T}$

But $B \propto H \Rightarrow \quad I \propto \frac{H}{T}$

Or $\frac{\mathrm{I}}{\mathrm{H}} \propto \frac{1}{\mathrm{T}} \qquad (\because \chi_m = \frac{\mathrm{I}}{\mathrm{H}})$

Or $\chi_m \propto \frac{1}{\mathrm{T}}$

Or $\chi_m = \frac{\mathrm{C}}{\mathrm{T}}$ Where C is called curie constant

**Curie temperature:-** *The minimum temperature below which no any substance behaves as magnet called Curie temperature*

- ✓ For paramagnetic material $\chi_m$ & $\mu_r$ *not* only depend on material but also on temperature.
- ✓ *At very high field & low temperature the magnetization approaches to its maximum value.*
- ✓ A thermometer based on curie law can measure temperature < 1 K.

**54 Difference between Para, Ferro & diamagnetic substances: m.imp -**

| S. No. | Paramagnetic materials | Ferromagnetic materials | Diamagnetic materials |
|---|---|---|---|
| 1 | Those substances which are feebly attracted by external magnetic field are called paramagnetic substances e,g. Na, K, Al etc. | Those substances which are strongly attracted by external magnetic field are called ferromagnetic substance e,g. iron, Ni, Co, etc. | Those substances which are feebly repelled by the external magnetic field are called Diamagnetic substance e.g, All inert gasses, $N_2, H_2$, etc. |
| 2 | These substances tend to move slowly from weaker magnetic field to stronger magnetic field. | These substances tend to move from weaker magnetic field to stronger magnetic field fastly. | These substances tend to move from stronger magnetic field to weaker magnetic field. |
| 3 | A freely suspended paramagnetic material aligns itself in direction of external magnetic field. | A freely suspended Ferro magnetic material aligns in direction of external magnetic field. | A freely suspended diamagnetic material aligns itself perpendicular to external magnetic field. |
| 4 | The relative permeability value is slightly greater than 1. $1<\mu_r<1+E$ | The relative permeability value is of order of 1000. $\mu_r > 1000$ | The relative permeability value is slightly less than one. $O<\mu_r<1$ |
| 5 | The susceptibility varies inversely as temperature $\chi_m \propto \frac{I}{T}$ | Susceptibility decreases with temp. In complex manner. $\chi_m \propto \frac{1}{T-tc}$ (t> tc) | Susceptibility does not depends on temperature |
| 6 | As soon as the H is removed I disappear | Magnetization remains even after removal of H. | Magnetization lasts as long as the magnetizing field is applied |
| 7 | B- Vector shows no hysteresis. | B – Vector shows the hysteresis loop. | B vector shows no hysteresis. |
| 8 | These may be solid, liquid or gas. | These are normally solids. | These may be solid, liquid or gasses. |

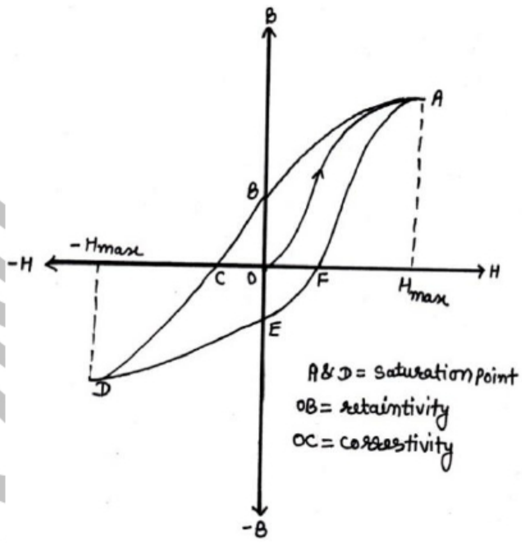
**55 Hysteresis:- m.imp**

The world hysteresis is a Greek word which means ***delayed***. In case of ferromagnetic materials, *the phenomenon of lagging of magnetic induction behind the magnetizing field is called* ***hysteresis loop***.

Suppose an iron piece is placed in external magnetic field H. Then initially with increase of H, B also increases up to point A. At A magnetic induction becomes maximum, this point is called saturation point.

After saturation point if we decrease magnetizing field then at H=0 there remains some amount of magnetism in substance called **retaintivity or residual magnetism**.

Now to do B = 0 if we increase H in reverse direction than at C, B becomes zero, here *oc* is called correstivity. Now by increasing more H, the substance get starts magnetized in reverse direction & follow the path CDEFA. The formed loop is called hysteresis loop.




***Saturation point: -*** *The value of magnetizing forces H at which intensity of magnetization I becomes constant called saturation point.*

***Retaintivity or remainence or residual magnetism:-*** *The magnetic induction left behind in the sample after the removal of magnetizing field is called retaintivity.*

***Coercivity:-*** *The value of reverse magnetizing field at which the residual magnetic field of sample because zero is called is called Coercivity.*

<u>Significance of area under hysteresis loop:-</u>

- ✓ The product of B-H has the dimensions of energy per unit volume; hence the area under hysteresis loop represents the energy dissipated per unit volume in the materials when magnetization is done.
- ✓ It also helps to make electromagnets of desired strength.

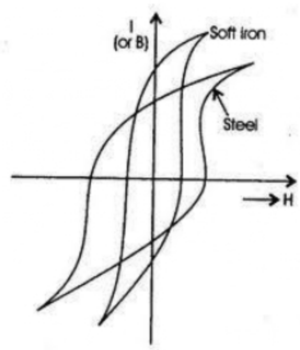


**<u>56 Types of Ferromagnetic materials</u>**

1. **<u>Soft ferromagnetic materials:-</u>**

These are those ferromagnetic materials in which magnetism disappear after removal of external magnetic field, e.g, iron, mu, metals, alloy etc.

2. **<u>Hard ferromagnetic materials:-</u>**




These are those ferromagnetic materials in which magnetism remains even after removal of magnetizing field. E.g. steel, alnico, Iodostone etc

***Q. Which one is better to make permanent magnet an iron or steel?***

The hysteresis loop of both iron and steel are as shown in fig.

Here we can see that the retaintivity of iron is larger than that of steel. Means iron can be easily magnetized. But the Coercivity of steel is much larger than that of iron, means if once steel is magnetized, then magnetism remains for a long time. Thus *steel is better than iron to make a permanent magnet.*

**57 Uses of ferromagnetic materials:-** m.imp

Ferromagnetic materials are used to make permanent magnets, electromagnetic Transformer cores etc explained below.

**(a).Permanent magnets :-**

The magnetic material having ability to maintain their magnetic properties for a long time after removal of magnetizing field are called permanent magnets. For making permanent magnets the material should have high retaintivity high Coercivity & high permeability.

Steel is preferred to make permanent magnets, other are **cobalt steel** (52% iron, 36% cobalt, 7%tungsten, 4%chromium, 0.5% manganese & 0.5% carbon) **carbon steel** (98% Iron, 0.86% Carbon and 0.9% Manganese) **Alloy alnico** (55% Iron, 10% Aluminum , 17% Nickel,12% Cobalt & 6% Copper)

To magnetize a ferromagnetic material, a rod of material is placed in a current carrying solenoid which magnetizes the rod.

**b. Electromagnetic:-**

An electromagnetic is made from materials which have high permeability & low retaintivity. A soft iron is preferred to make electromagnets. When soft iron is placed in current carrying solenoid then it magnetize quickly & after removal of field demagnetize quickly due to low retaintivity.

**c. Transformer core:-**

The material used for making transformer care must have high initial permeability, low hysteresis lose, low resistivity these condition are found in iron, so soft iron is preferred for making transformer cores and telephone diaphragms.

## -: SOME IMPORTANT MCQ:-

**(1). Force on a charge particle will be zero when it is moving**

(a) Parallel to magnetic field
(b) Anti-parallel to magnetic field
(c) At right angle to magnetic field
**(d) both a & b**

**(2). If a charged particle is moving parallel to magnetic field than magnetic force on charged particle will be**

(a) Maximum
(b) Minimum
**(c) Zero**
(d) Constant

**(3). Earth magnetic field on its surface is nearly**

(a) $3.5 \times 10^{5}$ T
**(b) $3.5 \times 10^{-5}$ T**
(c) $5.3 \times 10^{5}$ T
(d) $5.3 \times 10^{-5}$ T

**(4). Magnetic field at the centre of circular coil is**

(a) $\frac{\mu_0 I}{2\pi r}$
**(b) $\frac{\mu_0 I}{2r}$**
(c) $\frac{\mu_0 I}{4\pi r}$
(d) $\frac{\mu_0 I}{2\pi}$

**(5). Time period of revolution of particle in the magnetic field will be**

(a) $\frac{2\pi m}{Bq}$
(b) $\frac{2\pi v}{Bq}$
**(c) $\frac{2\pi B}{qm}$**
(d) $\frac{2\pi q}{Bm}$

**(6). To convert galvanometer into ammeter which one of the following is connected with the coil**

(a) High resistance wire in series
(b) Low resistance wire in parallel
**(c) High resistance wire in parallel**
(d) Low resistance wire in series

**(7). The sensitivity of a moving coil galvanometer can be increased by decreasing**

**(a) The number of turns in the coil**
(b) The area of the coil
(c) The magnetic field
(d) the couple per unit twists of the suspension

**(8). Which of the following is responsible for earth's magnetic field**

(a) Connective current in earth's core
(b) Diversive current in earth's core
(c) Rotational motion of earth
(d) Revolution of earth around sun

**(9). A magnetic dipole moment is a vector quantity directed from**

(a) South to North
(b) North to South
(c) East to West
(d) West to East

**(10). S.I. unit of magnetic pole strength is**

(a) $Ampere\ meter^{-1}$
(b) $Ampere\ meter^{-2}$
(c) $Ampere\ meter$
(d) $Ampere\ meter^{2}$

**(11) Gauss's law in magnetism conclude that**

(a) Poles of a magnet can be isolated
**(b) Monopoles do not exist**
(c) There is a counter part of charge in magnetism
(d) none of the above

**(12). What is the value of angle of dip at the magnetic equator**

**(a) 0°**
(b) 90°
(c) 45°
(d) Nearly 30°

**(13). What is the angle of dip at a place where the horizontal component of the earth's magnetic field is equal to the vertical component**

(a) 0°
(b) 30°
**(c) 45°**
(d) 90°

**(14). Which of the following independent quantity is not used to specify the earth's magnetic field**

(a) Magnetic declination (b) Magnetic dip

(c) Horizontal component of earth's magnetic field **(d) Vertical component of earth's magnetic field**

**(15). The vertical component of earth's magnetic field at a place is √3 times the horizontal component, the value of angle of dip is**

(a) 30° (b) 45° **(c) 60°** (d) 90°

**(16). The value at horizontal component of earth's magnetic field on the surface of earth is of order of**

**(a) $3.2 \times 10^{-5}$ Tesla** (b) $3.2 \times 10^{-6}$ Tesla (c) $4.2 \times 10^{-5}$ Tesla (d) $4.2 \times 10^{-6}$ Tesla

**(17). The small angle between magnetic axis and geographic axis a place is called**

(a) Magnetic inclination (b) Magnetic dip **(c) Magnetic declination** (d) None of the above

**(18). Which of the following parameter is used to assess the magnetic ability of material**

(a) Magnetic flux density (b) Magnetization (c) Magnetic dipole moment **(d) Magnetic susceptibility**

**(19). For a diamagnetic material, which of the following statement is correct**

**(a) Magnetic susceptibility $\chi_m < 0$** (b) $\chi_m > 0$ (c) $\chi_m = 0$ (d) $\chi_m = 1$

**(20). For a diamagnetic material, which of the following statement is correct**

(a) $\mu_r = 0$ **(b) $\mu_r < 1$** (c) $\mu_r > 1$ (d) $\mu_r = 1$

**(21). For a paramagnetic material which of the following is correct**

(a) $\chi_m < 0$ **(b) $\chi_m > 0$** (c) $\chi_m = 0$ (d) $\chi_m = -1$

**(22). For a paramagnetic substance**

**(a) $\mu_r > 1$** (b) $\mu_r < 1$ (c) $\mu_r = 0$ (d) $0 < \mu_r < 1$

**(23). with increase in temperature magnetic susceptibility of paramagnetic substance**

**(a) Decrease** (b) Increase (c) Remains constant (d) First increase than decrease

**(24). With increase in temperature magnetic susceptibility of ferromagnetic substance**

(a) Increase **(b) Decrease** (c) Remains constant (d) First decrease then increase

**(25). Magnetic susceptibility of a super conductor**

(a) $\chi_m = 1$ **(b) $\chi_m = -1$** (c) $\chi_m = 0$ (d) $\chi_m = \infty$

**(26). Curie temperature is the temperature above which**

**(a) A ferromagnetic material becomes paramagnetic** (b) A paramagnetic material becomes ferromagnetic

(c) A ferromagnetic material becomes diamagnetic (d) A paramagnetic material becomes ferromagnetic

**(27). The susceptibility in independent of temperature in which material**

(a) Paramagnetic (b) Ferromagnetic **(c) Diamagnetic** (d) Both paramagnetic & diamagnetic

**(28). The material suitable for making electromagnet should have**

(a) High retaintivity and high Coercivity **(b) Low retaintivity and low Coercivity**

(c) High retaintivity and low Coercivity (d) Low retaintivity and high Coercivity