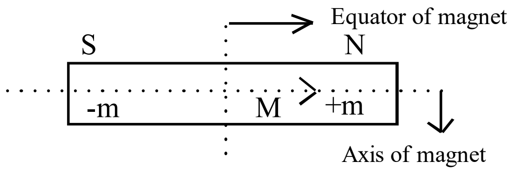
MAGNETISM

INTRODUCTION :

We have learnt in the earlier standards that certain substances possess the property of attracting small pieces of iron. This property of attracting small pieces of iron is called as magnetism. The substances possessing this property is called as magnet. The property was known even to the ancient people that certain ore of iron possesses the property of attracting small pieces of iron. This ore is called as magnetite (Fe_3O_4), as it was found near Magnesia distant in Asia Minor. These ores are used for navigational purposes. For this reason, magnetite was also called leading stone or lode stone.

If we cut bar magnet into pieces, we find that each piece, however small it may be, is still a magnetic dipole. Magnetic monopoles do not exist i.e. "Isolated magnetic poles cannot be obtained. The magnetic poles of a bar magnet are fictitious (Pseudo)".



Consider a magnet of length 2a formed by two poles namely North pole (N) and South pole (S). Then magnetic dipole moment (M) is given by

Magnetic dipole moment = Pole strength x Distance between two poles

Magnetic dipole moment = Pole strength x Magnetic length

$M = m \times 2a$

Remark : magnetic length is a vector quantity.

Pole strength is a scalar quantity

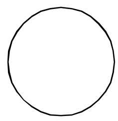
Magnetic dipole moment is a vector quantity whose direction is from South pole Northpole Consider a coil of n number of turns carrying current I. Let A be the area of coil. Then the magnetic moment of the current carrying circular coil is given by **M = nIA**

The direction of magnetic dipole moment of a current carrying coil is along its axis. It is given by right handed screw rule.

Unit : 1) Magnetic dipole Moment = Ampere m^2

Dimension : $[M^0L^2T^0A]$

2) Pole strength = Ampere m



M = nIA

3) Magnetic length = $\frac{5}{6}$ x Geometric length

= 84% of its geometric length

DEFINITION :

1) **Magnetic Dipole :** Magnetic dipole is a pair of equal and opposite magnetic poles separated by small (finite) distance.

The two poles of a magnet are of equal strength

2) **Magnetic dipole moment :** Magnetic dipole moment is defined as product of strength of one of the poles and magnetic length (distance between two poles)

Example 1 :

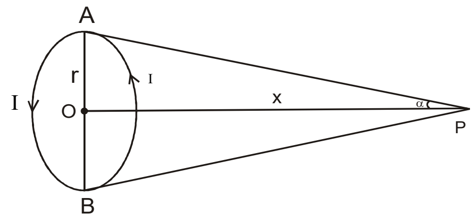
Circular coil of 300 turns and diameter 14 cm arries a current of 15 A. What is the magnitude of magnetic moment associated with the coil ?

$n = 300$ turns D = 14 cm $r = 7\times10^{-2} m$ $I = 15A$ m = ?

$M = nIA$ $= nI\pi r^2$ $300\times15\times3.14\times\left(7\times10^{-2}\right)^2$

$\boxed{M = 69.237\,Am^2}$

Q. Show that magnetic moment 'M' is analogous to electrostatic dipole moment 'P' and magnetic field is analogous to electrostatic field.



We know that magnetic induction at a point on axis at distance x from centre of circular coil of radius 'r' carrying current I is

$$B = \frac{n\mu_0 I r^2}{2(r^2 + x^2)^{3/2}} \qquad \text{(i)}$$

This magnetic induction is directed along the axis of the coil and perpendicular to the plane of coil

For x >>> r, we may neglect the term r^2. We have

$$B = \frac{\mu_0 I r^2}{2\,x^3} \qquad \text{(ii)}$$

But the area of the loop $A = \pi r^2$ (iii)

$\therefore\ r^2 = A/\pi$

$$B = \frac{\mu_0 I\,A}{2\,\pi\,x^3} \qquad \text{(iv)}$$

We know that magnetic moment M is the product of current (I) flowing through the loop of area (A)

$M = IA$ ....(v)

$$\text{Hence } B = \frac{\mu_0 M}{2\,\pi\,x^3} \qquad \therefore\ B = \left(\frac{\mu_0}{4\pi}\right)\times\frac{2M}{x^3} \qquad \text{... (vi)}$$

Electric field of a dipole is $E = \dfrac{1}{4\pi\varepsilon_0}\left(\dfrac{2p}{x^3}\right)$ ...(vii)

From equation (vi) and (vii) μ_0 is analogous to $\dfrac{1}{\varepsilon_0}$

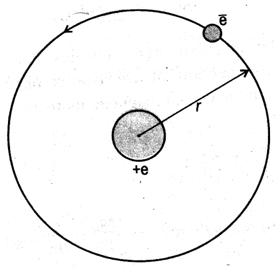
b) Magnetic dipole moment M is analogous to electrostatic dipole moment P.

c) Magntic field (B) is analogous to electrostatic field (E).

MAGNETIC DIPOLE MOMENT OF A REVOLVING ELECTRON : An atom consists of positively charged heavy nucleus around which negatively charged electrons are revolving in circular orbit.

The electron of charge (-e) performs U.C.M. around a stationary nucleus with period of revolution T. If r be the radius of the orbit of revolution of the electron and v is the orbital velocity then

$$\text{Period of revolution} = \frac{\text{circumference}}{\text{velocity}}$$



$$T = \frac{2\pi r}{v} \qquad \text{(i)}$$

Circulating current $I = e/T$ (ii)

$$I = \frac{e}{\frac{2\pi r}{v}} = \frac{ev}{2\pi r} \qquad \text{(iii)}$$

Magnitude of magnetic moment associated with circular current is

$$M_0 = IA = \frac{ev}{2\pi r} \times \pi r^2 \qquad \text{(iv)}$$

$$\therefore M_0 = \frac{evr}{2} \qquad \text{(v)}$$

The direction of this magnetic moment is into the plane of paper. Negatively charged electron is moving in anticlockwise direction, leading to a clockwise current. Multiplying and dividing the right hand side of equation (v) by the mass of electron, m_e then

$$M_0 = \frac{e}{2m_e}(m_e v r) \qquad \text{(vi)}$$

$$M_0 = \frac{e}{2m_e} \times L_0 \qquad \text{(vii)}$$

Here $L_0 = m_e v r$ = angular momentum of the electron revolving round the nucleus.

In vector, $\vec{M}_0 = -\frac{e}{2m_e}\vec{L}_0$ (viii)

The negative sign indicates that the orbital angular momentum of electron is opposite in the direction to the orbital magnetic moment.

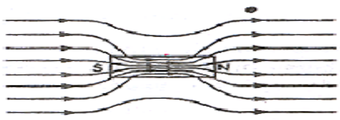
The ratio of magnetic dipole moment with angular momentum of revolving electron is called the gyromagnetic ratio.

$$\text{Gyromagnetic ratio} = \frac{M_0}{L_0} = \frac{e}{2m_e} = \text{constant} = 8.8 \times 10^{10}\ \text{C/kg}$$

SOME IMPORTANT TERMS USED IN MAGNETISM :

I) MAGNETIC INDUCTION $\left(\vec{B}\right)$:

When a piece of any substance is placed in an external magnetic field, the substance becomes magnetised. The magnetism so produced in the substance is called 'induced magnetism' and this phenomenon is called 'magnetic induction'



The number of magnetic lines of induction inside a magnetised substance crossing unit area normal to their direction is called the magnitude of magnetic induction, or magnetic flux density, inside the substance. It is denoted by B. Infact, magnetic induction is a vector $\left(\vec{B}\right)$ whose direction at any point is the direction of mangetic line of induction at the that point. The SI unit of magnetic induction is tesla (T) or weber/ meter^2 $\left(Wb-m^{-2}\right)$ or newton (ampere-meter)

$\left(NA^{-1}m^{-1}\right)$. The CGS unit is 'gauss' $\boxed{B=\frac{F}{m}}$

II) MAGNETIZATION OR INTENSITY OF MAGNETISATION $\left(\vec{I}\right)$:

The intensity of magnetisation , or simply magnetisation of a magnetised substance represents the extent to which the substance is magnetised. It is defined as the magnetic moment per unit volume of the magnetised substance. It is denoted by I. Its SI unit is apere/meter $\left(Am^{-1}\right)$ $\left[M^0L^{-1}T^0I^1\right]$.

Numerically (I = Magnetic moment/volume =M/V)

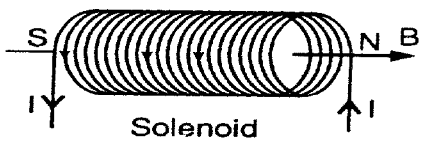
In case of a bar magnet, if m be the pole strength of the magnet, $2l$ its magnetic length and A its area of cross section, then.

$$I=\frac{M}{V}=\frac{m\times 2\ell}{A\times 2\ell}=\frac{m}{A}$$

Thus, magnetisation may also be defined as pole-strength per unit area of cross-section

iii) Consider a long solenoid (or toroid) having n turns per unit length and carrying a current i. The **magnetic field (B_0) inside the solenoid** is given by

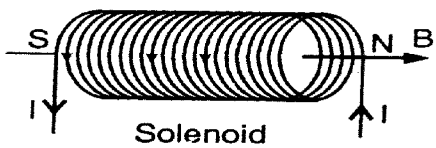
$\boxed{B_0=\mu_0 nI}$ ....(i)

A) 

(No medium)

Now suppose a **material is inserted into solenoid,** the magnetic field now becomes

$\boxed{B=\mu nI}$ ....(ii)

B) 

(With medium)

IV) MAGNETIC INTENSITY OR MAGNETIZING FIELD INTENSITY (H) :

The ratio of magnetic field $\left(\vec{B}_0\right)$ to the permeability of free space $\left(\mu_0\right)$ is called magnetic intensity $\left(\vec{H}\right)$ i.e. $\boxed{\vec{H} = \frac{\vec{B}_0}{\mu_0}}$ ....(iii)

OR

Magnetic intensity (H) is also define as magnetic field produced by a current (in amp)flowing in number of turns/meter of solenoid i.e., $\boxed{H = nI}$ ....(iv)

Where n is the nubmer of turns per meter of solenoid

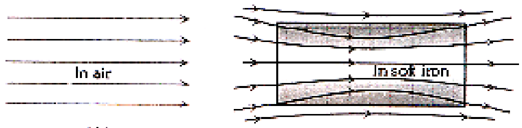
Magnetic intensity (H) has same unit and dimension as that of intensity of magnetisation (I)

i.e., unit $\rightarrow$ A/m, dimensions are $\boxed{M^0L^{-1}T^0A^1}$

From (I) & (II)_ $B_0 = \mu_0 H$ $\qquad B = \mu H$

V) MAGNETIC PERMEABILITY (μ) :

It is the degree or extent to which magnetic lines of force can enter a substance and it denoted by μ .
Or characteristic of a medium which allows magnetic flux to pass through it is called it's permeability.
e.g. permeability of soft iron is 1000 times greater than that of air. $\mu_{iron} = 1000 \quad \mu_{air}$



(A) (B)

From II $B = \mu nI$ $\qquad$ From IV $\qquad H = nI$ $\qquad$ Hence, $B = \mu H \quad OR \quad \boxed{\mu = \frac{B}{H}}$

Thus, magnetic permeability is also defined as ratio of magnetic field in medium (B) to magnetic internsity (H)

VI) RELATIVE MAGNETIC PERMEABILITY (μ_r) :

permeability of various magnetic substances can be compared with one another in terms of relative permeability.
Relative permeability of a material is define as ratio of magnetic field in any medium (B) to magnetic field in vaccum (B_0)

$\boxed{\mu_r = \frac{B}{B_0}}$ from I and II $\boxed{\mu_r = \frac{\mu}{\mu_0}}$

Relative magnetic permeability may also define as ratio of magnetic permeability of material (μ) to magnetic permeability of free space (μ_0)

μ_r has no unit and no dimensions

μ_r =1 for vaccum (by definition) for air μ_r =1.0000004

μ_r <1 (diamagnetic substance), μ_r >1 (paramagnetic substance),

μ_r >>1(ferro magnetic substance)

(VII) MAGNETIC SUSCEPTIBILITY :

(χ_m) : It is the property which determines how easily a specimen (material) can be magnetised. Susceptibility indicates that by what amount the substance gets magnetised because of influence of external magnetic field

Susceptibility of a magnetic material is ratio of intensity magnetisation (I) to magnetic field intensity (H) $\chi_m = \frac{I}{H}$

It means that more is the intensity of magnetisation (I), more is susceptibility

It has no unit and no dimensions. (because I and H have same unit)

We can classify substance in terms of χ_m. Substance with positive values of χ_m are paramagnetic and those with negative values of χ_m are diamagnetic. For ferromagnetic substance, χ_m is positive and very large. However, for them, $\vec{I}$ is not accurately proportional to $(\vec{H})$, and so χ_m is not strictly constant.

Q. Give relation between magnetic permeability and magnetic susceptibility.

Ans : When a magnetic material is placed in a magnetising field of magnetic intensity $\vec{H}$, the material gets magnetised. The total magnetic induction $\vec{B}$ in the material is sum of the magnetic induction $\vec{B}_0$ in vacuum produced by magnetic intensity and magnetic induction $\vec{B}_m$ due to magnetisation of material.

$\vec{B} = \vec{B}_0 + \vec{B}_m$ .....(i) $\quad \vec{B}_0 = \mu_0 \vec{H}$ .....(ii) $\quad$ and $\quad \boxed{\vec{B}_m = \mu_0 \vec{I}}$ ......(iii) , $Bm = \mu_0 I$

From equation (i), (ii) and (iii)

$\vec{B} = \mu_0 \vec{H} + \mu_0 \vec{I} \qquad B = \mu_0 (\vec{H} + \vec{I})$ .....(iv) $\qquad \chi_m = \frac{I}{H} \qquad \therefore \qquad I = \chi_m H$

From equation (iv)

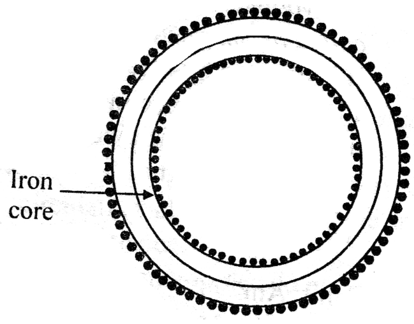
$\vec{B} = \mu_0 (\vec{H} + \chi_m \vec{H}) \qquad \vec{B} = \mu_0 \vec{H} (1 + \chi_m)\ \mu \vec{H} = \mu_0 \vec{H} (1 + \chi_m)$

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

Q. Discuss magnetization of a ferromagnetic material with help of Rowland ring.

Ans : Magnetisation of a ferromagnetic material by Rowland ring :

1) The magnetization of a ferromagnetic material such as iron can be studied using rowland ring. Rowland ring is similar in shape of the toroid.



2) The material is formed into a thin toroidal core of circular cross section. A toroidal coil having n turns per unit length is wrapped around the core and carries current I.

3) The coil is long solenoid bent into a circle, if iron core were not present, the magnitude of the magnetic field inside the coild would be $B_0 = \mu_0 nI$ where μ_0 is the permeability of vacuum.

4) If iron core were present, the magnetic field $\vec{B}$ inside the coil is greater than $\vec{B}_0$. We can write magnitude of this field as $B = B_0 + B_M$ ....(i) Where B_M is the magnetic field contributed by the iron core.

5) Additional field B_M is directly proportional to the magnetization I of the iron.

$B_M = \mu_0 I$ ....(ii)

6) Also, $B_0 = \mu_0 H$ ....(iii)

From equation (i), (ii) and (iii) $B = \mu_0 (H+I)$

Magnetization and magnetic intensity is mathematically expressed as

$I = \chi H$ Hence $B = \mu_0 (H + \chi H)$ $\quad B = \mu_0 (1+\chi)H$

$B = \mu_0 \mu_r H$

Example : 2

A bar magnet made of steel has magnetic moment of 2.5 Am^2 and a mass of $6.6\times10^3 kg$. If the density of steel is $7.9\times10^3 kg/m^3$, find th eintensity of magnetisation of the magnet.

Soln : $M = 2.5Am^2$ $\quad$ mass = 6.6×10^3 kg $\quad \rho = 7.9\times10^3 kg/m^3 \quad I = ?$

$$I = \frac{M}{V} \qquad Mass = V\times\rho$$

$$V = \frac{mass}{\rho} = \frac{6.6\times10^3}{7.9\times10^3} = \frac{6.6}{7.9}$$

$$I = \frac{2.5}{6.6}\times7.9 = \frac{19.75}{6.6} \qquad \boxed{I = 2.99A/m}$$

Example : 3

Find the magnetisation of a bar magnet of length 5 cm, cross sectional area $2cm^2$, if magnetic moment is $1Am^2$

Soln : $M = 1Am^2$, $\quad A = 2cm^2 = 2\times10^{-4}m^2 \quad L = 5cm = 5\times10^{-2}m$

Volume $V = AL = 2\times10^{-4}\times5\times10^{-2} = 10\times10^{-6}m^3$

$$\text{Megnetization} = \frac{M_{net}}{V} = \frac{1}{10\times10^{-6}} = 1\times10^5 A/m$$

Example : 4

The susceptibility of annealed iron at saturation is 5500. Find the permeability of annealed iron at saturation.

Soln : $\chi = 5000 \qquad \mu = ?$

The absolute permeability is given by $\mu = \mu_0(1+\chi)$

$= = 4\pi\times10^{-7}(1+5500)$

$= 4\times3.14\times10^{-7}\times5501$

$= 69092.5\times10^{-7}$ $\quad \boxed{\mu = 6.90\times10^{-3}}$

Example : 5

The magnetic field B and the magnetic intensity H in a material are found to be 1.6 T and 1000 A/m respectively. Calculate the relative permeability μ_r and the susceptibility χ of the material

Soln : $B = 1.6T$ $\quad H = 1000 A/m$ $\quad \chi = ?$ $\quad \mu_r = ?$

The magnetic induction is given by $B = \mu_0 (1+\chi) H$

$1.6 = 4\pi \times 10^{-7} (1+\chi) 1000$

$\therefore (1+\chi) = 1273 \qquad \therefore \chi = 1272$

The relative permeability is given as $\mu_r = (1+\chi)$

$\boxed{\mu_r = 1 + 1272 = 1273}$

ORIGIN OF MAGNETISM : In an atom, electron revolves around the nucleus in circular orbit. An electron being charged particle in motion, it constitutes current. Therefore, circulating electron is equivalent to current loop consisting of magnetic moment. Thus, magnetic moment is associated with motion of electron.

Electron has tow types of motion : (1) Orbital Motion (2) Spin Motion

Hence electron has two types of magnetic moment

1) Magnetic moment due to orbital motion 2) Magnetic moment due to spin motion.

Net magnetic moment of electron is vector sum of magnetic moment due to orbital motion and magnetic moment due to spin motion.

DIMAGNETISM

In substance like Gold, Copper, Silver, Water, Hydrogen, Mercuty, Nitrogenetc., magnetic moment of all elecrons in an atom cancel each other. Hence, resultant magnetic moment of atom is equal to zero. Such a substances do not possess any magnetic moment and they are called as dimagnetic substances.

Def. :- "A substance whose atom do not possess any magnetic dipole moment are called as dimagnetic substances". OR Those substances, which are weakly magnetised in the direction opposite to that of the external magnetic field are called as diamagnetic substances. Generally dimagnetic substances doe not exhibit any magnetic property. If dimagnetic substance is placed in external magnetic field, each atom aquires resultant magnetic moment and dimagnetic substance is magnetised. The resultant magnetic moment is opposite to the applied magnetic field and therefore, dimagnetic substance is repelled by magnet and if freely suspended in uniform magnetic field, it sets itself at right angles to direction to magnetic field.

Dimagentic substances when placed in non-uniform magnetic field, it shows moderate tendency to move from strong to weaker magnetic field. There is no effect of a temperature on a diamagnetic substance.

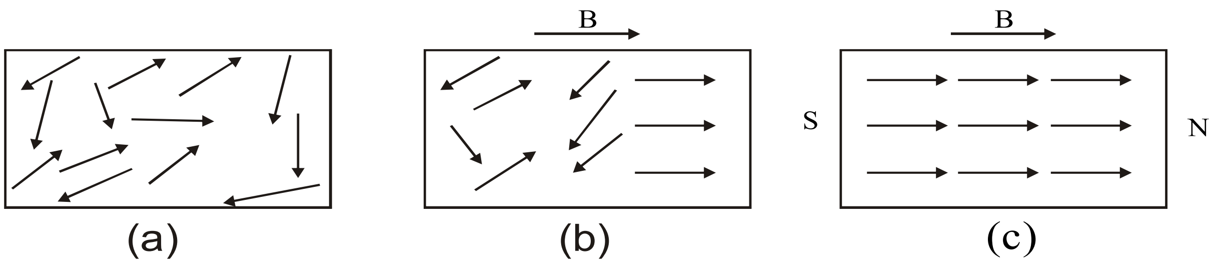
Magnetic susceptibility of diamagnetic substance is small and negative.

Examples : Antimony, Bismuch, Copper, Silver, Gold, Sodium Chloride, Diamond, lead, Silicon, Water, air, H_2, mercury nitrogen.

PARAMAGNETISM

In substance like Manganese, Aluminium, Oxygen, Platinium, Glass, Paper, Sodium etc. magnetic moment of all electrons do not cancel out. hence, each atom has net magnetic moment. Each atom of paramagnetic substances is equivalent to tiny magnetic dipole and called as atomic magnet. Such substance are called as Paramagnetic substances.

Due to thermal motion, atomic magnets are randomly oriented. Hence, net magnetic moment is zero.So that the substance remains in an unmangetised state.
When paramagnetic substance is kept in external magnet field, all atomic magnets are alinged in the direction of external magnetic filed. hence, substance has net magnetic moment and it exhibits some magnetic effect. If external magnetic field is removed, atomic magnets are again randomly oriented and substances losses magnetism. Paramangetic substances has strong magnetism at low temperature and strong field.



(a) Absence of external magnetic field
(b) Weak external magnetic field
(c) Strong external magnetic field
Magnetic susceptibility of paramagnetic substate is small and positive.

The susceptibility decreases with rise in temperature. $\left(\chi \propto \frac{1}{T}\right)$

Examples : Manganese, Chromium, Aluminium, Platinum, Oxygen

In 1895, Pierre Curie discovered experimentally that the magnetization of a paramagnetic sample is directly proportional to the external magnetic field and inversely proportional to the absolute temperature.

$$\text{i.e. } M_Z \ \alpha \ B_{ext} \text{ and } M_Z \ \alpha \ \frac{1}{T}$$

$$\therefore \quad M_Z \ \alpha \ \frac{B_{ext}}{T}$$

$$\therefore \quad M_Z = C \times \frac{B_{ext}}{T} \qquad \text{....... (1)}$$

Equation (1) is known as Curie's Law and C is called Curie constant.

Q. What are the ferrmoagnetic substances ? Give its examples.

Ferromagnetic substance : Those substances which are strongly magnetised in the direction of the external magnetic field are called as ferromagnetic substance.
Examples : Steel, Iron, Nickel, Cobalt, Gadolinium, Dysprosium and their alloys.,

FERROMAGNETISM (Domain Theory)

Q. What are Domains ? Explain domain theory of Ferromagnetism

Ans : Domain :- Ferromagnetic material contains large number of small regions such that magnetic dipole moment of all atoms in one region are aligned in the same direction. Such regions are called as domains.
Each domain has resultant magnetic moment.

Domain Theory :- Magnetic moment is associated with atoms of ferromangetic substances. But in ferromagnetic substances, there are large number of small regions called domains. Each domain has net magnetic moment.Magnetic moment of all atoms in one domain are aligned in one direction. The alignment is due to an interaction called exchange coupling. Due to random orientation of domain axis, net magnetic moment is zero.

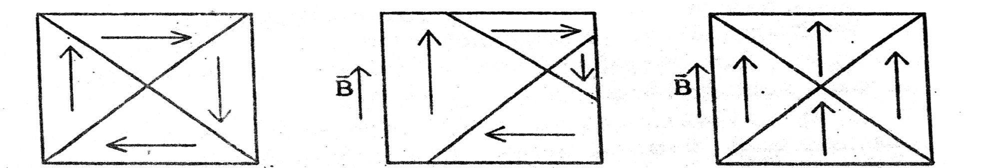
When weak magnetic field is applied to the ferromagnetic substances, atomic magnets are aligned in the direction of external magnetic field. Therefore, size of domain in which atomic magnets are aligned in the direction of external magnetic field increase and hence size of other domain decreases. Substance, therefore, is partially magnetised. If external magnetic field is removed, atomic magnets are again randomly oriented and substance get demagnetised.

When strong magnetic field is applied all atomic magnets turns in the direction of external magnetic field. Now, even after external magnetic field is removed, substance remains permanantly magnetised ie. they do not retains its original position.

Due to heating, coupling between domain wall becomes lose. At a temperature, called as Curie temperature, domain structure is disturbed completely. Substance loses its ferromangetic property and becomes paramagnetic.

Curie temperature of

Iron 770^{0}C,	**Nickel is 360^{0}C**	**and Cobolt is 1150^{0}C**
OR 1043 K	**631 K**	**1423 K**



Without external magnetic field　　Under the influence of Weak magnetic field　　Under the influence of Strong magnetic field

PROPERTIES OF DIMAGNETIC SUBSTANCES :-

1) Dimanetic substance are weakly repelled by magned.
2) When dimagnetic substance placed in non-uniform magnetic field, they exhibit moderate tendency to move from stronger to weaker part of magnetic field.
3) In a absence of external magnetic field, resultant magnetic moment of dimangetic substance is zero.
4) A thin rod of dimangetic substance when suspended in uniform magnetic field, it comes to rest which its length perpendicular to diretion of magnetic field.
5) Dimagneic susbnstance when magnetised, it has magnetic moment in the direction opposite to mangetic field.
6) Magnetic susceptibility of diamagnetic substance is small and negative.
7) The most exotic diamagnetic materials are superconductors. Superconductors are metals and when it is cooled to very low temperature shows both perfect conductivity and perfect diamagnetism. The phenomenon of perfect diamagnetism in super conductor is called **"Meissner effect."**

PROPERTIES OF PARAMAGNETIC SUBSTANCES :-

1) Paramagnetic Substances are weakly attracted by magnet.
2) When paramangetic substances are placed in non-uniform magnetic field, ti exhibits moderate tendency to move from weaker to stronger part of magnetic field.
3) Each atom is paramagnetic substance possesses resultant magnetic moment and they behave like tiny atomic magnets. However, in absence of external magnetic field, all atomic magnets are oriented randomly and hence, resultant magnetic moment becomes zero. Therefore, paramagnetic substance as a whole remains in unmagnetised state.

4) When paramagnetic substance is placed in external weak magnetic field, magnetic moment of some atomic magnets are alinged themselves in the direction of magnetic field. Therefore, specimen of paramangetic substance becomes partially magnetised. If strong magnetic field is applied, atomic magnets are alinged parallel to the field. So that specimen is completely magnetised.
5) When external magnetic field is removed, paramangetic substance loses it magnetism.
6) Paramagnetic substance when magntised, it has magnetic moment in same direction as that of external magnetic field.
7) Magnetic susceptibility of paramagnetic substrate is small and positive.
8) If a thin rod of paramagnetic substance is freely suspended in a uniform magnetic field, it comes slowly to rest with its length parallel to the direction of the field.

11) The susceptibility of paramagnetic susbstance decreases with rise in temperature. $\left(\chi \propto \frac{1}{T}\right)$

12) Examples : Manganese, Chromium, Aluminium, Platinum, Oxygen

PROPERTIES OF FERROMAGNETIC SUBSTANCES
1) Ferromagnetic susbtances are strongly attracted by magnet.
2) Each atom of ferromagnetic substances has magnetic dipole moment (Atomic magnets) having resultant magnetic moment.
3) Ferromagnetic substances are composed of domains. Each domain contains large number of atoms having their magnetic moment aligned in same direction. All domains are randomly oriented. Therefore, resultant magnetic moment of substances as a whole is zero and substance remains in unmagnetised state.
4) When external strong magnetic field is removed, ferromagnetic substances do not lose its magnetism and substance retains its magnetism permanantly.
5) Ferromangetic substances when magnetised, magnetic moment of ferromagnetic substane lies in the direction of external magnetic field.
6) Magnetic susceptibility of ferromagnetic material is positive and very high.
7) In a thin rod of ferromagnetic substance is freely suspended in a uniform magnetic field, it comes quickly to rest with its length parallel to the direction of the field.
8. When placed in non uniform magnetic field, they shows a strong tendency to move from the weaker to the stronger part of the field.
9. Liquid and gases do not show ferromagnetism.
10. When heated above the Curie temperature, they become paramagnetic.
Note : (i) Liquid and gases never show ferromagnetic properties. (ii) Ferromagnetism depends inversely on the temperature of the substance.

Q. Explain, why Ferromagnetic substance cannot be magnetised beyond certain limit?

Ans : When ferromagnetic substance is placed in weak external magneic field, some of the domains rotates and the magnetic moments are oriented in the direction of external magnetic field. Therefore, substance is partially magnetised. if the strength of external magnetic field is gradually increased, more and more domains gets aligned in the direction of external magnetic field and magnetisation of substance goes on increasing. Finally, when all domains are aligned in the direction of external field, the substance becomes completely magnetised.
If the strength of external magnetic field is increased still further, the magnetisation of the substance cannot increase, because there are no domain left for alignment. Thus, there is a limit beyond which ferromangetic substance cannot be magnetised.

Q. What is Curie temperature ? What happens above the Curie temperature ?

It is observed that when ferromagnetic substance is heated its magnetisation decreases with temperature. At a particular temperature, it looses its magnetisation completely, because at this temperature its domain structure completely vanishes.

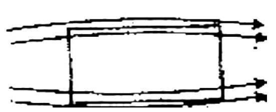
Curie temperature : The temperature at which the domain structure gets destroyed and ferromagnetic substance is converted into paramagnetic is called as Curie temperature. With increase in the temperature, the thermal vibrations of the atoms in the given ferromagnetic substance increases and as a result, the inter atomic coupling becomes weak.

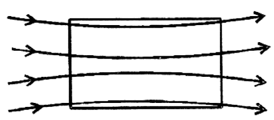
At a higher temperature, the exchange coupling between the atomic magnets in each domain breaks completely and all the atomic dipoles get randomly oriented, destroying the domain structure.The Curie temperature is different for different substance.

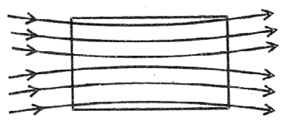
PARAMAGNETISM	FERROMAGNETISM
1) Every atom has resultant magnetic moment	1) Every atom has resultant magnetic moment
2) Magnetic moment of all atoms are randomly oriented, there are no domain	2) Ferromagnetic substance consist of domain. All atomic magnets in one domain are aligned in one direction. Magnetic moment of all atomic magnets cancel each other.
3) Paramagnetic substances loses magnetism when external magnetic field (strong or weak) is removed.	3) They retain magnetism ever after external strong magnetic field is removed
4) Paramagnetic substances cannot be converted into ferromagnetic	4) Ferromagnetic substances can be converted into paramagnetic when heated above Curie temperature.
eg. Maganese, Aluminium, Oxygen, Platinum Sodium, Glass, Paper	eg. Iron, Cobalt Nickel etc.

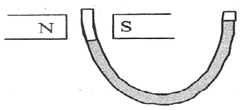
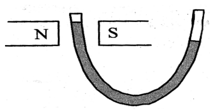
DIMAGNETISM	PARAMAGNETISM
1) Magnetic moment of every atom is zero.	1) Every atom has resultant magnetic moment
2) Ordinarily, dimagnetic substance remain in unmagnetised state.	2) Ordinarily, Magnetic moment of all atoms are random and hence substance remains in unmagnetised state.
3) They are weakly repelled by magnet	3) They are weakly attracted by magnet
4) When placed in non uniform magnetic field, they tend to move from stronger to weaker magnetic field.	4) When placed in non-uniform magnetic field, they tend to move from weaker to stronger.
5) In an external magnetic field, they get weakly magnetised in an direction opposite	5) In an external magnetic field, they get weakly magnetised in the same direction as that of external magnetic field.
eg. Bismath, Copper, Gold, Mercury, Water etc	eg. Manganese,Aliminium,Oxygen, Platinum.

Diamagnetic Substances	Paramagnetic Substances	Ferromagnetic Substances
1. Repelled by magnet	Feebly(weakly) attracted by magnets	Strengly attracted by magnets
2. Resultant magnetic moment of these substance is zero.	These substances have a permanent magnetic moment.	These substances also have a permanant magnetic moment
3. In there substances the less magnetic lines of forces pass than in air.	In these substances little more magnetic lines of forces passes than in air.	In these substances more magnetic lines of forces passes than in air.







4.	In non uniform magnetic field the diamagnetic rod is placed then it moves from strong to weaker magnetic field.	If paramagnetic material rod is placed in non uniform magnetic field it moves from weaker to stronger field.	If paramagnetic material rod is placed in non uniform magnetic field it moves from weaker to stronger field.
5.	Substance gets slightly magnetised in a direction opposite to the field $\rightarrow$ H M $\leftarrow$	Substance gets magnetised in the direction to the field. $\rightarrow$ H M $\rightarrow$	Substance gets easily magnetised in the direction to the field. $\rightarrow$ H M $\rightarrow$
6.	A thin bar of this material suspended suspended in magnetic field comes to rest in the direction perpendicular to the field.  	A thin bar of this material suspended in magentic field comes to rest in the direction of the field.  	A thin bar of this material suspended in magnetic field comes to rest in the direction of the field. 
7.	Example antinolty,bismath, copper, hydrogen, water, air,gold, silver,zinc,sodium, chloride diamond, mercury nitrogen, lead helium, neon.	Aluminium managenes, oxygen, platinum,chromium,sodium, $CuCl_2$, $FeCl_3$, potassium magnesium	Ion,cobalt, nickel, steel, gadolonium alnico, Fe_3O_4.
8.	A diamagnetic liquid in a U tube depressed in the limb which is placed between the poles of a strong magnet.  	A paramagnetic liquid rises in the limb of U-tube when the limb is placed between the poles of a strong magnet.  	No liquid state

Question Bank

1. Derive an expression for magnetic dipole moment of a revolving electron.
2. In a hydrogen atom, an electron of charge 'e' revolves in an orbit of radius r with speed v. Prove that the magnetic moment associated with the electron is given by $\frac{evr}{2}$
3. Show that current loop produces a magnetic field and behaves like a magnetic dipole.
4. Define (i) Magnetization (ii) Magnetic intensity.
5. Discuss magnetization of a ferromagnetic material with the help of Rowland ring.
6. Distinguish between diamagnetic and paramagnetic substances.
7. Distinguish between ferromagnetic and diamagnetic substances.
8. Explain ferromagnetism on the basis of domain theory.
9. What is Curie temperature ? What happens above curie temperature?
10. Discuss the classification of materials based on their behaviour in magnetic field.
11. Explain origin of diamagnetism on the basis of its atomic structure.
12. Explain origin of paramagnetism on the basis of its atomic structure.

Assignment

1. In a H-atom electron revolves in circular orbit of radius $0.53 A^0$ with velocity 2.2×10^6 m/s. Find equivalent magnetic moment. (Ans : 0.932×10^{-23} Am^2)

2. In a hydrogen atom an electron revolves around nucleus in circular orbit of radius $0.53 A^0$ in 1.5×10^{-16} sec. What is the magnetic moment of electron in that orbit.

   (Ans : $M = 0.937 \times 10^{-23}$ Am^2)

3. The space within a current carrying toroid is filled with material of susceptibility 5×10^{-3}. What is the percent increase in the magnetic field B.(Ans : 0.5)

4. The susceptibility of material at 400 K is 2×10^{-5}. At what temperature will susceptibility increases to 3×10^{-5}. (Ans : T = 266.66K)

5. Find the magnetization of a bar magnet of length 5 cm and cross sectional area 2 cm^2. The magnetic moment is 1 Am^2. (Ans : 1×10^5 A/m)

6. An electron in an atom revolves around the nucleus in an orbit of radius 0.53Å. If the frequency of revolution of an electron is 9×10^9 MHz, calculate the orbital angular momentum

   [Given : Charge on an electron = $1.6 \times 10^{-19} C$ Gyromagnetic ratio = $8.8 \times 10^{10} C/kg; \pi = 3.142$] **(Ans :** $L_0 = 0.1443 \times 10^{-33} kgm^2/s$) **(March - 2017)**

7. The susceptibility of magnesium at 200 K is 1.8×10^{-5}. At what temperature will the susceptibility decrease by 6×10^{-6}? (Ans : 300K) **(March 2016)**

8. An iron rod of area of cross section $0.1 m^2$ is subjected to a magnetic field of 1000 A/m. Calculate the magnetic permeability of the iron rod. [Magnetic susceptibility of iron = 59.9, [Magnetic permeability of vacuum = $4\pi \times 10^{-7}$ S.I. unit.]

   (Ans : $= 7.654 \times 10^{-5}$ wb/A-m) **(October - 2015)**

9. A circular coil of 300 turns and average area 5×10^{-3} m^2. carries a curent of 15 A. Calculate the magnitude of magnetic moment associated with the coil. **(Ans :** $= 22.5 A - m^2$)

   (February-2015)

10. The magnetic moment of a magnet of dimensions 5cm $\times$ 2.5 cm $\times$ 1.25 cm is 3 Am^3. Calculate the intensity of magnetization. (Ans : $1.920 \times 10^5 A/m$) **(Oct. 2014)**

11. The susceptibility of magnesium at 300 K is 2.4×10^{-5}. At what temperature will the susceptibility increases to 3.6×10^{-5}? **(Ans :** $T_2 = 200 K$ **)** **(Feb. 2014)**

Multiple Choice Questions

1. A circular coil of radius R carrying current I has 'n' turns, its magnetic dipole moment is given by

a) $n^2I\pi R^2$ b) $nI\pi R^2$ c) $\frac{n^2}{I\pi R^2}$ d) $n^2I\pi R$

2) An electron revolving around nucleus has angular momentum L and magnetic dipole moment 'M'.The correct relation

a) $\frac{M}{L}=\frac{e}{2}$ b) $\frac{M}{L}=\frac{-e}{m}$ c) $\frac{M}{L}=\frac{2}{1}$ d) $\frac{M}{L}=\frac{e}{2m}$

3) An electron revolves around nucleus in circular orbit gives angular momentum 'L' and magnetic dipole moment 'M', they are

a) in same direction b) opposite to each other
c) at 45^0 to each other d) at 90^0 to each other

4) If electron revolves with time period T in a circular orbit. After transition of electron of other orbit time period increases then current in new orbit

a) decreases b) increases c) remains same d) becomes ∞

5) A circular loop of radius R, carries a current of I. If another circular loop of radius 2R carries same current I, then ratio of magnetic dipole moment is

a) 9 : 4 b) 4 : 9 c) 1 : 4 d) 4 : 1

6) A circular coil of 100 turns and radius 10 cm carrying a current of 5A. The magnitude of magnetic moment of coil is

a) 5π b) 7π c) 5 d) 10π

7) A current loop placed perpendicular to a uniform field behaves like a

a) magnetic dipole b) magnetic substance c) magnetic pole d) both 'b' and 'c'

8) An electron in an atom revolves around the nucleus in an orbit of radius 2.12×10^{-10}m. If frequency of revolution of electron is 6.28×10^{16} Hz, then the equivalent magnetic moment is

a) 14.18×10^{-22} Am^2 b) 14.18×10^{22} Am^2 c) 14.18×10^{-26} Am^2 d) 14.18×10^{-24} Am^2

9) The equivalent magnetic dipole moment of electron in a H-atom is 9.1×10^{-3} Am^2. The angular momentum of electron in the orbit is

a) 0.103×10^{-12} kgm^2/s b) 10.3×10^{-12} kgm^2/s c) 10.3×10^{-15} kgm^2/s d) 0.103×10^{-15} kgm^2/s

10) A wire of length L is bent into a circle of radius R, when I current flows through wire. The magnetic dipole moment will be

a) $\frac{IL^2}{4\pi}$ b) $\frac{IL}{4\pi}$ c) $\frac{IL^2}{2\pi}$ d) $\frac{IL}{2\pi}$

11) A circular loop of radius 10 cm, lies in a horizontal plane. It carries a current of 7 A in clockwise direction. magnetic moment of the loop is

a) 0.42 Am^2 b) 0.22 Am^2 c) 0.46 Am^2 d) 0.29 Am^2

12) A circular coil of radius 15 cm having 35 turns. It carries a current of 0.7A. The value of magnetic moment of coil is

a) 7.73 J/T b) 2.73 J/T c) 1.73 J/T d) 5.73 J/T

13) Circular coil of radius 0.8 m has dipole moment is 6.28 J/T, when it carries current of 3.12 A. The number of turns of coil is

a) 4 b) 3 c) 2 d) 1

14) The magnetic moment of an electron with spin magnetic moment of $\overline{M}_S$ and orbital magnetic moment $\overline{M}_0$ can be given as

a) $M = M_0 + M_S$ b) $\overline{M} = \overline{M}_0 + \overline{M}_S$ c) $\overline{M} = \overline{M}_0 - \overline{M}_S$ d) $M = M_0 - M_S$

15) Maximum matter shows the following magnetic properties

a) diamagnetism b) ferromagnetism c) paramagnetism d) both 'a' and 'b'

16) The root cause of all magnetic properties is

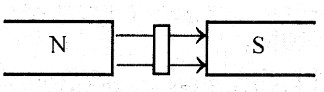
a) orbital motion of an electron b) orbital and spin motion of an electron

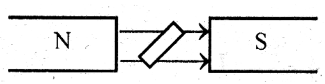
c) spin motion of proton d) orbital and spin motion of a proton

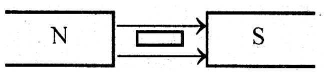
17) If the net magnetic moment of the atoms of a substance is zero, the substance is called

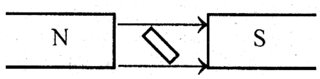
a) diamagnetic b) paramagnetic c) ferromagnetic d) antiferromagnetic

18) A rod of paramagnetic substance such as aluminium is suspended in a uniform strong magnetic field. How will it align itself in the field

a) 

b) 

c) 

d) 

19) Liquid and gases never show

a) diamagnetic properties b) paramangetic properties

c) ferromagnetic properties d) diamagnetic and paramagnetic properties

20) A ferromagnetic material is heated above its curie temperature. Which one is a correct statement

a) ferromagnetic domains are perfectly arranged

b) ferromagnetic domains get destroyed.

c) ferromagnetic domains are not influenced.

d) ferromagnetic material changes into diamagnetic material

21) Which of the following is ferromagnetic

a) quartz b) nickel c) bismuth d) aluminium

22) A wire carrying current 1 of length 'L' bent into circle of radius R having magnetic dipole moment M, if same wire bent into square then dipole moment will become

a) $\frac{\pi}{4}M$ b) $\frac{4}{\pi}M$ c) 4 M d) 4π

23) The dimensions of magnetization are .....

a) $[L^1M^0T^0I^1]$ b) $[L^{-1}M^0T^0I^1]$ c) $[L^{-1}M^0T^0I^{-1}]$ d) $[L^1M^0T^0I^{-1}]$

24) The magnetic dipole moment for circular coil having n turns and carrying current I is "nIA". The factor .... in this expression is called ampere turns

a) nI b) nA c) IA d) n

25) The permeabilities of paramagnetic materials are .....

a) zero b) equal to unity c) less than unity d) greater than unity

26) A magnet of pole strength 50 Am has magnetic moment 10Am^2. The geometric length of magnet is

a) 20 cm b) 10 cm c) 24 cm d) 20 m

27) The magnetic dipole moment is a vector directed from

a) S pole to N pole b) N pole to S pole c) perpendicular to dipole d) none of these

28) Indicate the group containing only diamagnetic substances :

a) Ar, Al, Ag, Ni Co, Na, Cu

b) Fe, Co, Ni, Gd, Fe_3O_4

c) Al, Mn, Pt, Na, O_2, $CuCl_2$, Crown glass

d) Argon, Copper, Silver, Bismuth, Water, Air, Diamond, Antimony, NaCl, Au

29) When a material produces a magnetic field, which opposes the applied magnetic field. This material is called :

a) Diamagnetic b) Paramagnetic c) Ferromagnetic d) Non magnetic

30) A permanent magnet can be made from which on the following substances ?

a) soft iron b) ferromagnetic c) diamagnetic d) paramagnetic