11. Magnetic Materials

* Derive an expression for potential energy of a bar magnet placed in a uniform magnetic field.

Ans i) Consider a bar magnet kept at an angle θ with the direction of magnetic field $\vec{B}$

ii) Torque acting will be

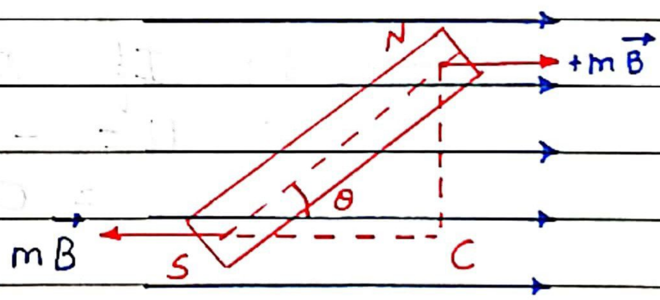
$$\tau = mB\sin\theta$$

where m is magnetic dipole moment.

iii) Due to torque, the bar magnet will undergo rotational motion. So, external torque is applied which rotates magnet from θ_0 to θ.

iv) Since displacement is taking place, work is done.

v) Such work is stored in form of potential energy (U)



$$\therefore U = \int_{\theta_0}^{\theta} \tau \, d\theta$$

$$= \int_{\theta_0}^{\theta} mB\sin\theta \, d\theta$$

$$= mB\int_{\theta_0}^{\theta} \sin\theta \, d\theta$$

$$= mB\left[-\cos\theta\right]_{\theta_0}^{\theta}$$

$$= -mB\left[\cos\theta - \cos\theta_0\right]$$

If $\theta_0 = \pi/2$

$$\therefore U = -mB\left[\cos\theta - \cos\pi/2\right]$$

$$U = -mB\cos\theta$$

* At which positions, the magnet will be most stable and most unstable?

Ans We know, $U = -mB\cos\theta$

Case 1 : If $\theta = 0^\circ$

$\therefore U = -mB\cos 0$

$= -mB$

This is the position where bar magnet possesses minimum P.E. and is the most stable state.

Case 2 : If $\theta = 180^\circ$

$\therefore U = -mB\cos 180$

$= -mB \times -1$

$= mB$

This is the position where bar magnet possesses maximum P.E. and is most unstable state.

Case 3 : If $\theta = 90^\circ$

$U = -mB\cos 90$

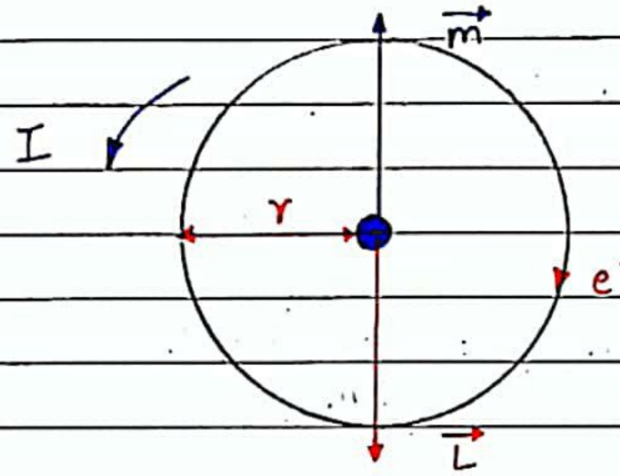
$= 0$

This is the position where bar magnet is perpendicular to direction of magnetic field

* Derive an expression for time period of angular oscillation of a bar magnet.

Ans Already covered in chapter Oscillations.

Q2) v) Obtain an expression for orbital magnetic moment of an electron rotating about the nucleus in an atom.



Consider an electron moving with constant speed v in a circular orbit of radius r about the nucleus.

The current $I = \frac{e}{T}$ where e is charge of electron

put $T = \frac{2\pi}{\omega}$ where ω is angular speed

$$\therefore I = \frac{e}{\frac{2\pi}{\omega}} = \frac{e\omega}{2\pi}$$

put $\omega = \frac{v}{r}$

$$\therefore I = \frac{ev}{2\pi r}$$

We know, orbital magnetic moment $M_{orb} = IA$

$$\therefore M_{orb} = \frac{ev}{2\cancel{\pi}\cancel{r}} \times \cancel{\pi} r^2$$

$$\therefore m_{orb} = \frac{evr}{2}$$

Multiplying num & deno by m_e

$$m_{orb} = \frac{evr}{2} \times \frac{m_e}{m_e}$$

put $m_e v r = L$ (angular momentum)

$$\therefore m_{orb} = \left(\frac{e}{2m_e}\right) \times L$$

* what is gyromagnetic ratio?

Ans The ratio of magnetic dipole moment with angular momentum is called gyromagnetic ratio.

$$\text{Gyromagnetic ratio} = \frac{m_{orb}}{L} = \frac{e}{2m_e}$$

* What is Bohr magneton?

Ans According to Bohr's theory, angular momentum (L) of electron is an integral multiple (n) of $\frac{h}{2\pi}$, where h is planck's constant.

$$\therefore L = \frac{nh}{2\pi} \quad \text{— (1)}$$

We know, $m_{orb} = \frac{e}{2m_e} \times L$

$$= \frac{e}{2m_e} \times \frac{nh}{2\pi} \quad \text{— \{from eqn 1\}}$$

$$\therefore m_{orb} = n\left(\frac{eh}{4\pi m_e}\right)$$

For 1st orbit $n = 1$

$$\therefore m_{orb} = \frac{eh}{4\pi m_e}$$

The quantity $\frac{eh}{4\pi m_e}$ is called Bohr magneton

Its value is $9.274 \times 10^{-24}\ Am^2$

* What is magnetization and magnetic Intensity? What is the relation between them.

Ans The ratio of magnetic moment to the volume of the material is called magnetization.

$$M = \frac{m_{net}}{volume}$$

The ratio of strength of magnetising field to permeability of free space is called magnetic Intensity.

$$H = \frac{B}{\mu_0} = nI$$

Relation between M & H is

$$M = \chi H$$

* What is magnetic Susceptibility (χ)?

Ans It is a measure of magnetic behaviour of the material in external applied magnetic field.

It is ratio of Magnetization to that of magnetic Intensity.

$\chi = \frac{M}{H}$. It is dimensionless constant.

* Define magnetic permeability and relative permeability.

Ans The ratio of total magnetic field Inside the material to that of magnetic intensity is called magnetic permeability (μ).

$$\mu = \frac{B}{H}$$

The ratio of magnetic permeability (μ) of material to magnetic permeability of free space (μ_0) is called relative permeability (μ_r)

$$\mu_r = \frac{\mu}{\mu_0}$$

Also, $\mu_r = 1 + \chi$

* Explain the net magnetic field for a rod placed in a solenoid.

Ans Consider a rod with some net magnetization, placed in a solenoid carrying current I.

Magnetic field inside the solenoid is
$B_0 = \mu_0 n I$

put $nI = H$ (magnetic Intensity)

$\therefore B_0 = \mu_0 H$

Now, magnetic field due to rod kept inside the solenoid is B_m

$$\therefore B_m = \mu_0 M$$

where M is magnetization

$\therefore$ Net magnetic field is

$$B = B_0 + B_m$$

$$B = \mu_0 H + \mu_0 M$$

$$B = \mu_0 (H + M) \quad - (1)$$

$$\therefore \frac{B}{\mu_0} = H + M$$

$$\therefore H = \frac{B}{\mu_0} - M$$

We know, $M = \chi H$

put in eqn (1)

$$\therefore B = \mu_0 (H + \chi H)$$

$$= \mu_0 H (1 + \chi)$$

put $\mu_r = 1 + \chi$

$$\therefore B = \mu_0 H \mu_r$$

put $\mu_0 \mu_r = \mu$

$$\therefore \quad B = \mu H$$

where μ is magnetic permeability of the material.

μ_r is relative permeability of substance
χ is magnetic Susceptibility.

* Discuss the classification of materials based on their behaviour in magnetic field.

Ans The behaviour of material in external magnetic field classifies materials broadly into diamagnetic, paramagnetic & ferromagnetic materials.

Diamagnetic materials are weakly repelled by a magnet.
Paramagnetic materials are weakly attracted by a magnet.
Ferromagnetic materials are strongly attracted by a magnet.

* Explain origin of diamagnetism on the basis of its atomic structure.

Ans i) In diamagnetic Substance, magnetic dipole moments of all the electrons in atom cancel each other. Hence, there is no net magnetic dipole moment.

ii) when orbiting electron or current loop is placed in external magnetic field then the field induces current as per Lenz's law.

iii) As per lenz's law, direction of current is opposite to the direction of external magnetic field.
iv) Out of pair of electrons, for one loop, direction of induced current will increase the magnetic dipole moment.
v) For opposite spin electron, direction of induced current will decrease the magnetic dipole moment
vi) This results in net magnetic dipole moment opposite to direction of applied external magnetic field. Hence, diamagnetic materials are repelled by magnet.

* Explain origin of Paramagnetism on the basis of its atomic structure.

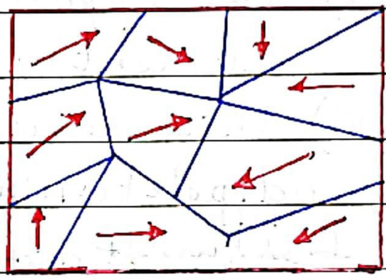
Ans i) Paramagnetic materials have presence of unpaired electrons. This results in net magnetic dipole moment of atom/molecule.
ii) But due to thermal agitation, these atoms/molecules are randomly oriented.
iii) Hence, magnetic dipole moment of all atoms cancel each other.
iv) The net magnetic dipole moment of paramagnetic material is zero in absence of external magnetic field.
v) when paramagnetic materials are placed in strong magnetic field, most of atoms align themselves in direction of applied field; and shows temporary magnetism.

* Explain ferromagnetism on the basis of its domain theory.

Ans i) According to domain theory, a ferromagnetic material contains a large number of small regions or domains.

ii) Domain size can be a fraction of a millimetre and contains about $10^{10} - 10^{17}$ atoms.

iii) In umagnetized state, different domains are oriented randomly; it results in net magnetic moment of whole material as zero.

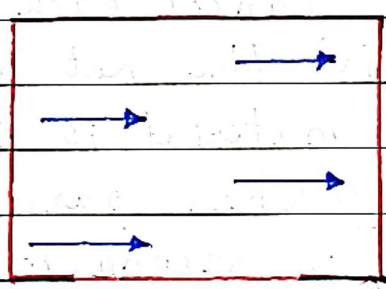


iv) when an external magnetic field is applied, domains try to align themselves along the direction of applied magnetic field.

v) This process is referred to as flipping or domain rotation.

vi) when sufficiently high magnetic field is applied, all the domains coalesce together to form a giant domain. as shown in figure

vii) when high magnetic field is removed, it does not set back domain boundaries to original position & ferromagnetic material is said to retain magnetization. Such materials are used in preparing permanent magnets.



Q2) ii) what happens to a ferromagnetic material when its temperature increases above curie temperature?

Ans i) As the temperature of ferromagnetic material is increased, the domain structure starts distorting.
ii) At a certain temperature, the domain structure collapses totally and material behaves like paramagnetic material. This temperature is called Curie temperature (T_c)
iii) So, above curie temperature, ferromagnetic material transforms into a paramagnetic material.

Q2.iv) Discuss the curie law for paramagnetic material.

Ans Curie law :- Magnetization M in a paramagnetic material is directly proportional to applied magnetic field B and inversely proportional to absolute temperature T of the material.

$$M \propto B \quad \ldots (i)$$

$$M \propto \frac{1}{T} \quad \ldots (ii)$$

Combining (i) & (ii)

$$M \propto \frac{B}{T}$$

$$M = C \frac{B}{T}$$

where C is curie constant

put $B = \mu_0 H$

$$\therefore M = C \times \frac{\mu_0 H}{T}$$

$$\frac{M}{H} = C \frac{\mu_0}{T}$$

Put $\frac{M}{H} = \chi$

$\therefore \chi = \frac{C \mu_0}{T}$

Put $\chi = \mu_r - 1$

$\therefore \mu_r - 1 = \frac{C \mu_0}{T}$

* Distinguish between Diamagnetic and paramagnetic Substances

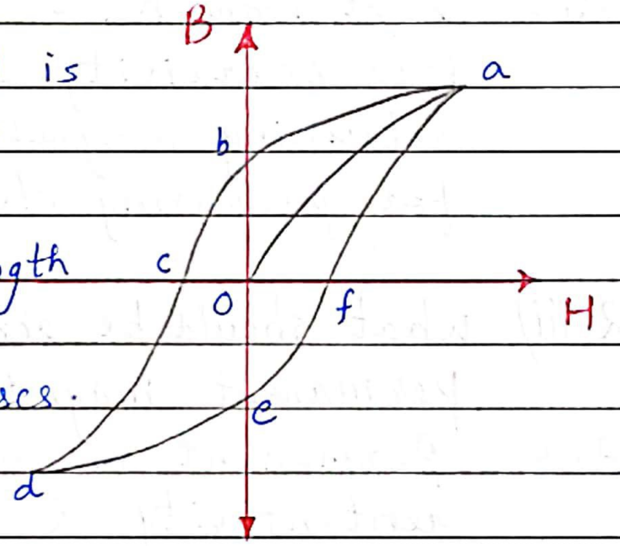
Ans

	Diamagnetic	Paramagnetic
i)	These materials are repelled by a magnet.	These materials are attracted by a magnet.
ii)	Magnetic Susceptibility is negative	Magnetic Susceptibility is positive but small.
iii)	when placed in non uniform magnetic field, it moves from stronger to weaker part of the field.	when placed in non uniform magnetic field, it moves from weaker to stronger part of the field.
iv)	If magnetic field is applied to diamagnetic liquid in one arm of U-tube then the liquid is pushed in the other arm.	If magnetic field is applied to paramagnetic liquid in one arm of U-tube then the liquid level rises in that arm.
v)	Copper, gold, bismuth, glass, water, wood, plastics etc.	Magnesium, lithium, molybdenum, oxygen etc. are examples.

Q2) vi) What does the hysteresis loop represents?

Ans i) Hysteresis loop is a closed curve which shows the behaviour of the material as it is taken through one cycle of magnetisation.

ii) Hysteresis loop is a graph of magnetic field B against magnetic intensity H.



iii) At point O, the material is in non-magnetised state.

iv) From point O, as strength of magnetic intensity H is increased, B also increases. But, the increase is non-linear.

v) Near point a, B reaches its maximum value. If H is increased further, there is no increase in B.

vi) This process is not reversible. If H is reduced, then earlier path of graph is not retraced.

vii) When H = 0, we do not get B = 0. The value of B existing when H = 0 is called retentivity or remanence. This is point b.

viii) When H is increased in reverse direction, point C is reached in graph where B = 0. This value of H existing when B = 0 is called coercivity

ix) If H is now further increased in reverse direction, B increases and again reaches its maximum value. This is point d.

x) The path of defa is being traced in same manner as abcd was traced and the loop is complete.

xi) Area inside the hysteresis loop represents the hysteresis loss per unit volume.

Q2 i) Which property of soft iron makes it useful for preparing electromagnet?

Ans Soft iron have properties like high permeability, low coercivity and small amount of retaining magnetization. This makes it useful for preparing electromagnet.

Q2 iii) What should be retentivity & coercivity of permanent magnet?

Ans Permanent magnets should have high retentivity & high coercivity.

Q2 vii) Explain one application of electromagnet.

Ans i) Electromagnets are used in cranes to lift heavy loads made of iron

ii) Electromagnets are mounted on a crane.

iii) On passing the current through electromagnet, the magnetic field increases thousand folds.

iv) Due to this, electromagnet attracts heavy loads of iron and crane operator transports heavy loads to designated place.

v) The current is then cut off; the magnetism disappears and load of iron is dropped down.

vi) This way electromagnets are used to transport heavy loads of iron using cranes.