Chapter 5: Magnetism and Matter.

Properties of magnet:

1. A freely suspended magnet always points in earth's geographic N-S direction.

2. A magnet has 2 ends:
end that points towards geographic north → North Pole
end that points towards geographic south → South Pole.

3. Like poles repel, unlike poles attract

4. Magnetic monopoles do not exist.

5. Magnetism can be induced in iron and its alloys.

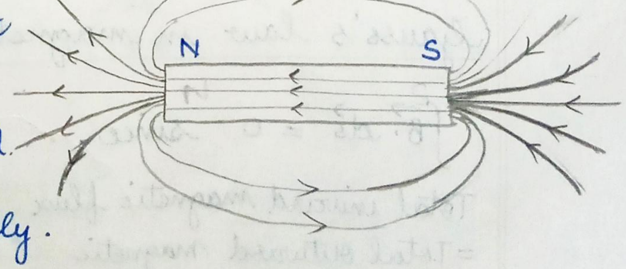
Magnetic field:

Region around a magnet where its force of attraction or repulsion is felt is called magnetic field.

Magnetic field lines:

Imaginary lines drawn around a magnet shows the direction of force on a unit north pole kept at that point.

Properties of magnetic field lines:

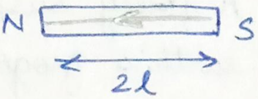


- Field lines orignate at the north pole and end at south pole externally, and from south pole to north pole internally.
- Tangent drawn to the field line at given point shows the direction of magnetic field at that point.
- No of field lines crossing unit area ∝ Mag. field strength
- They do not intersect, they form closed loops.

Pole strength (q_m): It indicates the strength of the pole of the magnet.

SI unit : Am.

Magnetic dipole moment ($\vec{m}$):



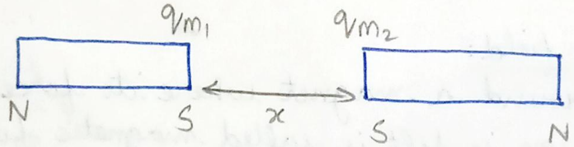
It is defined as the product of pole strength and the distance of separation between them.

$$\vec{m} = q_m \cdot 2\vec{l} \quad = NIA$$

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

SI unit : Am^2

Coulomb's law in magnetism:



$$F \propto q_{m_1} q_{m_2}$$

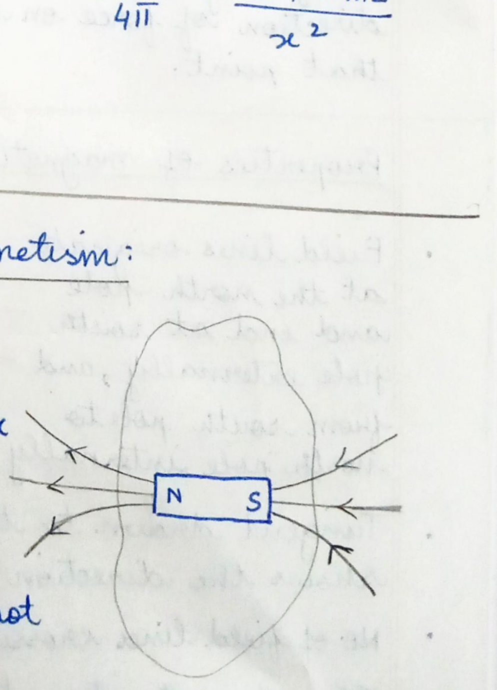
$$F \propto 1/x^2 . \qquad F = \frac{\mu_0}{4\pi} \times \frac{q_{m_1} q_{m_2}}{x^2}$$

$$F \propto \frac{q_{m_1} q_{m_2}}{x^2}$$

Gauss's law in magnetism:

$\oint \vec{B} \cdot \vec{ds} = 0$ since,

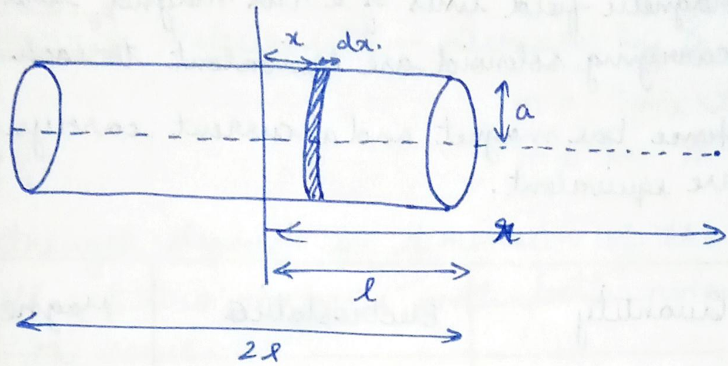
Total inward magnetic flux = Total outward magnetic flux.



~~Reason~~ and magnetic monopoles do not exist.

If monopoles existed, gauss's law can be modified as: $\oint \vec{B} \cdot \vec{ds} = \mu_0 q_m$.

Bar magnet as an equivalent solenoid



let n be no. of turns per unit length.

$$dB = \frac{\mu_0 (n\,dx) I a^2}{2\left[a^2 + (r-x)^2\right]^{3/2}} \qquad B = \frac{\mu_0 N I R^2}{2(R^2+x^2)^{3/2}}$$

$r \ggg x$, $r \ggg a$.

$$\therefore dB = \frac{\mu_0 n\,dx\, I a^2}{2r^3}$$

$$\int dB = \int_0^{2l} \frac{\mu_0 n\,dx\, I a^2}{2r^3}$$

$$B = \frac{\mu_0 n I a^2}{2r^3} \int_0^{2l} dx.$$

$$B = \frac{2l \mu_0 n I a^2}{2r^3} = \frac{\mu_0 n 2l I a^2 \pi}{2\pi r^3}$$

$$B = \frac{\mu_0 m}{2\pi R^2} \times \frac{2}{2} = \boxed{\frac{2\mu_0 \vec{m}}{4\pi r^3} = \vec{B}} \quad \text{— (1)}$$

Axial field of solenoid = Axial field of bar magnet

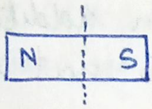
Axial field of a bar magnet is given by

$$\vec{B} = \frac{2\mu_0 \vec{m}}{4\pi r^3} \quad \text{— (2)}$$

- Eq. (1) and (2) are similar.
- Magnetic field lines of a bar magnet and current carrying solenoid are ~~equivalent to each other~~ similar
- Hence bar magnet and a current carrying solenoid are equivalent.

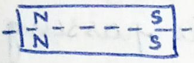
	Quantity	Electrostatics	Magnetism
1.	Constant	$\frac{1}{4\pi\varepsilon_0}$	$\frac{\mu_0}{4\pi}$
2.	Dipole moment	$\vec{p} = q \cdot 2\vec{a}$	$\vec{m} = q_m \cdot 2\vec{l}$
3.	Axial field	$\frac{2k\vec{p}}{x^3}$	$\frac{2\mu_0 \vec{m}}{4\pi r^3}$
4.	Equatorial field	$-\frac{k\vec{p}}{x^3}$	$\frac{\mu_0 m}{4\pi r^3}$
5.	Torque	$\vec{p} \times \vec{E}$	$\vec{m} \times \vec{B}$
6.	WD in rotating a dipole	$PE(\cos\theta_1 - \cos\theta_2)$	$mB(\cos\theta_1 - \cos\theta_2)$
7.	Potential energy	$-\vec{p} \cdot \vec{E}$	$-\vec{m} \cdot \vec{B}$

Q. What happens if a bar magnet is cut into 2 pieces transverse to its length and along its length.
(what happens to pole's strength & magnetic moment ?)

A: (i) 

Polestrength - constant, $m = q_m \times 2\frac{l}{2}$

$m \downarrow$ by $\frac{1}{2}$

(ii) 

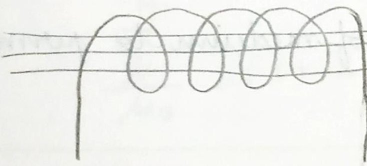
Polestrength - decreases by $\frac{1}{2}$

$m = q_m/2 \cdot 2l$

$m \downarrow$ by $\frac{1}{2}$.

Polestrength depends on dimension of the pole. We will get two magnets with both poles in both the cases.

- Magnetic intensity or magnetising field (H):



$H = nI$

where n = no. of turns per unit length.

I = current through the solenoid.

SI unit : A/m.

- Intensity of magnetisation (M):

When a magnetic material is placed inside a solenoid, it gets magnetised. The total magnetic dipole moment developed per unit volume of the material is called as intensity of magnetisation

$\vec{M} = \frac{\vec{m}}{V}$ (magnetic dipole moment) / (volume)

S.I. unit $= \frac{Am^2}{m^3} =$ A/m.

- Magnetic induction (B):

When a magnetic material is placed in a magnetising field it gets magnetised. So, there are field lines inside it, in addition to the field lines already existing in that region.

The total no. of magnetic field lines passing through the material per unit area is called magnetic induction.

- Permeability of the medium (μ):

Ratio of magnetic induction to magnetising field.

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

- Relative permeability (μ_r)

Ratio of permeability of medium to permeability of free space.

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

- Magnetic susceptibility (χ):

It is found that intensity of magnetisation is directly proportional to magnetising field.

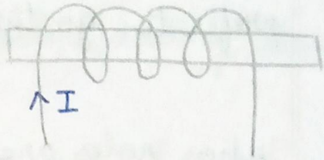
$$M \propto H$$

$$M = \chi H \quad \therefore \chi = \frac{M}{H}.$$

Ratio of intensity of magnetisation to magnetising field is magnetic susceptibility

Relation between μ_r and χ :

Consider a solenoid carrying current I. The magnetic field along the axis of the solenoid is given as:



$$B_0 = \mu_0 n I.$$

When a magnetic material is placed inside a solenoid, it gets magnetised. The total field inside the solenoid is,

$$B = B_0 + \underbrace{B_M}_{\text{due to magnetisation of sample}}$$

$$B = \mu_0 n I = \mu_0 M$$

$$= \mu_0 H + \mu_0 \chi H$$

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

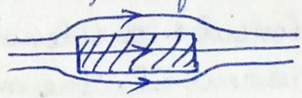
$$\frac{B}{H} = \mu_0 (1+\chi)$$

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

DIAMAGNETIC:

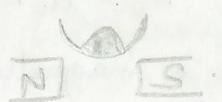
1. Feebly magnetised in a direction opposite to the external field.
2. Moves from strong field region to weak field region.
3. Repelled by external field
4. ~~Net~~ No unpaired e^-s.
5. Net magnetic dipole moment is zero.
6. $\mu_r < 1$
7. $\chi = -ve$ and small.
8. When a diamagnetic rod is placed in a magnetic field, it aligns itself $\perp^r$ to the field.

9. When a diamagnetic material is placed in an external uniform magnetic field, the field lines prefer to go through air



10. When poles are closer

11. When poles are far apart



12. Intensity of magnetisation is independent of temperature.

eg. Cr, H_2O, Pb, Si, NaCl, Bismuth, N at STP.

PARAMAGNETIC

1. Feebly magnetised in a direction along the external field.

2. Moves from ~~strong~~ weak field to strong field region.

3. Attracted by external field

4. Few unpaired e^-s

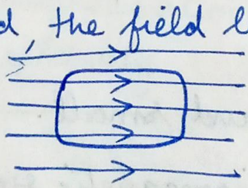
5. No zero net magnetic dipole moment

6. $\mu_r > 1$

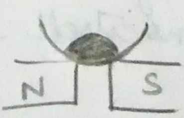
7. χ = +ve & small

8. When a para magnetic rod is placed in external magnetic field it aligns itself parallel to the field.

9. When a paramagnetic material is placed in an external uniform field, the field lines pass through the medium.



10. When poles are closer.



11. When poles are far apart

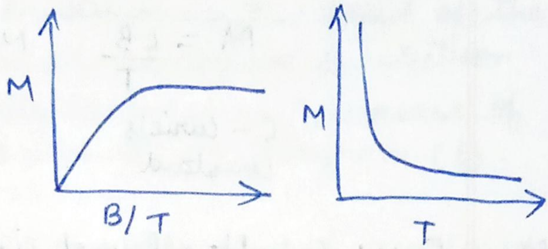
12. Intensity of magnetisation is independent of temp.

Curie's law:

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

$M = \frac{CB}{T}$

$C \rightarrow$ curie's constant



eg. Al, Na, O_2 at STP, $CuCl_2$, Ca.

FERROMAGNETIC:

1. strongly magnetised in a direction along the external field.

2. Moves from weak to strong field region.

3. Strongly attracted by external field

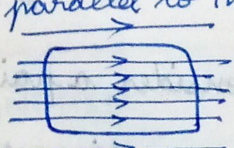
4. Large no. of unpaired e^-s.

5. Large net magnetic dipole moment.

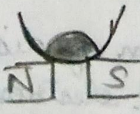
6. $\mu_r >>> 1$

7. χ = +ve & large

8. When a ~~para~~ ferromagnetic rod is placed in external magnetic field it aligns itself parallel to the field.



10. When poles are closer



10. When poles are far apart.

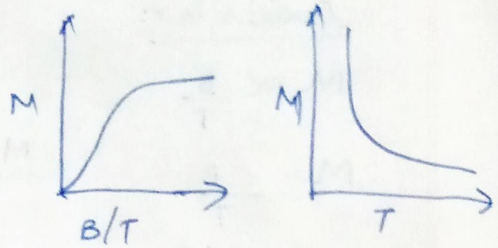
12. Intensity of magnetisation is dependent on temperature.

Curie's law:-

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

$$M = \frac{CB}{T}$$

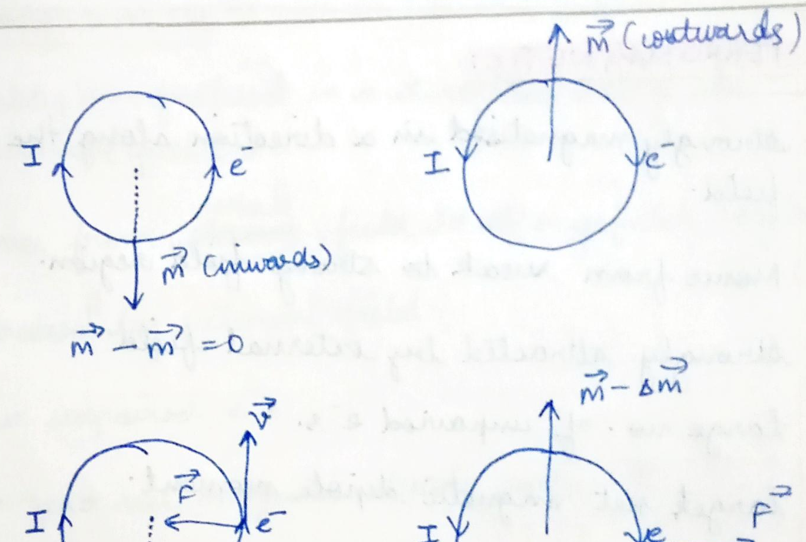
C - Curie's constant



eg. Fe, Ni, Cobalt alloys of iron.

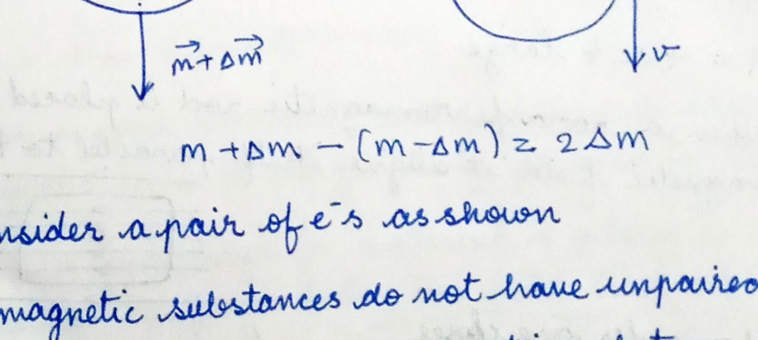
THEORY OF DIAMAGNETISM

(a)



$$\vec{m} - \vec{m} = 0$$

(b)



$$m + \Delta m - (m - \Delta m) = 2\Delta m$$

Consider a pair of e^-s as shown

Diamagnetic substances do not have unpaired e^-s. Consider an atom of diamagnetic substance in which the paired electrons are revolving in opposite direction. This produces a magnetic moment which cancel each other as shown in diagram (a)

When external magnetic field is applied, each e^- experiences a force given by :

$$\vec{F} = -e(\vec{v} \times \vec{B})$$

$$\vec{F} = e(\vec{B} \times \vec{v})$$

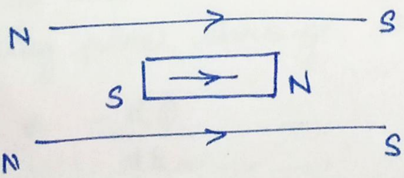
This force increases or decreases the speed of the electron depending on the direction of electron movement. This results in increase / decrease of magnetic moment as shown in diagram (b).

Hence there is a net magnetic moment developed opposite to the external magnetic field. Hence diamagnetic substance gets magnetised opposite to the external field.

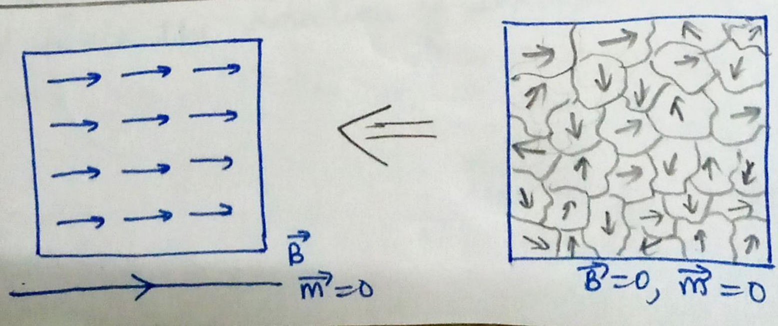
(no unpaired e^- $\Rightarrow$ net $\vec{m} = 0$).

THEORY OF PARAMAGNETISM

These substance have few unpaired electrons. Hence each atom has net magnetic dipole moment when placed in an external uniform magnetic field, the atoms will align their magnetic moment along the external field. This orientation increases with increase in the strength of external field, but is opposed by temperature as given by curie's law. Hence the sample gets magnetised along the external field.



THEORY OF PERROMAGNETISM



In ferromagnetic substances there are large no. of unpaired e^-s due to which the atoms have high magnetic dipole moment. As sample of ferromagnetic substance can be divided into small regions called "domains". Each domain is 1mm in size, containing about 10^{11} atoms. Different domains have their magnetic moment oriented in random possible direction. Hence the total magnetic moment of the sample is 0 in the absence of external magnetic field, all the domains align their magnetic moment along the external field. Hence the sample gets magnetised along the external field direction.