5

MAGNETISM AND MATTER

5.01 Magnetic and non- magnetic substances

Substances which are strongly attracted by a magnet are called magnetic substances.
eg: iron, cobalt, nickel etc.

Substances which are not attracted by a magnet are called non-magnetic substances.

5.02 Basic properties of magnets

- **Attractive property**: A magnet can attract magnetic materials.
- **Directive property**: A freely suspended or pivoted magnet aligns in the north – south direction. The pole of the magnet towards geographical north is North Pole. The other pole which is towards geographical south is South Pole.
- **Like poles repel** each other and **unlike poles attract** each other.
- **Magnetic poles always exist in pairs**. That is monopole does not exist.

5.03 Magnetic field

The space surrounding a magnet where its effect is felt is called magnetic field. Intensity of magnetic field at a point is the force experienced by a unit North Pole kept at that point.

Magnetic flux indicates the total number of magnetic field lines passing through a surface. The number of magnetic field lines passing normally through unit area is called flux density $(\vec{B})$.

- The magnitude of earth's magnetic field is of the order of 10^{-5} T.

The magnetic field of earth changes from place to place on the surface of earth. It changes with time at a given place on the earth.

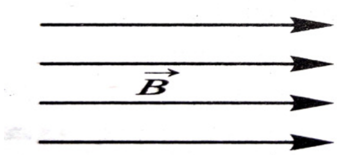
5.03 Uniform magnetic field

Magnetic field is uniform, if it has the same magnitude and direction at all points in the region.
Magnetic field on the surface of the earth is considered as uniform. It extends up to a height of about 5 times the radius of the earth.

Note:
The magnetic field around a bar magnet is non-uniform.

5.04 Representation of uniform magnetic field

Uniform magnetic field is represented by parallel equi-distant lines as shown in figure.



5.05 Geometrical length and Magnetic length

Geometrical length is the distance between two ends of a magnet.
The poles of a magnet are located not exactly at the ends, but slightly inwards. The distance between these two points is called magnetic length.

$$\frac{\text{Magnetic length}}{\text{Geometrical length}} \approx 0.84$$

5.06 Coulomb's law of magnetism

The force of attraction or repulsion between two magnetic poles is directly proportional to the product of their pole strengths and inversely proportional to the square of the distance between them.
If q_{m_1} and q_{m_2} are the pole strengths of poles separated by a distance d, then

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

$$F = \frac{\mu_0}{4\pi} \frac{q_{m_1} q_{m_2}}{d^2}$$

$\mu_0 = 4\pi \times 10^{-7}$ henry/metre or (N/A^2)

If $q_{m_1} = q_{m_2} = 1$ unit and d = 1m then

$$F = \frac{\mu_0}{4\pi} = 10^{-7}\text{N}$$

Thus unit magnetic pole is that pole which when placed at a distance of 1m from an equal and like pole will repel with a force of 10^{-7}N.

5.07 Magnetic dipole and dipole moment

Two equal and opposite magnetic poles separated by a small distance constitute a magnetic dipole. Dipole moment is the product of pole strength and distance between the poles. It is a vector quantity. Its direction is from south pole to north pole.

Dipole moment, $\vec{m} = q_m \times \vec{2l}$. Where $\vec{2l}$ is the magnetic length.
Unit of dipole moment: Am^2 or J/T or Nm/T.

Note:

The natural unit of magnetic moment is Bohr magneton.
Pole strength is also called magnetic charge.
Unit of pole strength is ampere metre or N/T or J/Tm

5.08 Magnetic line of force

Magnetic line of force is the curve whose tangent at any point gives the direction of magnetic field at that point. It is the path of an independent north pole if it is free to do so.

Widely spaced magnetic field lines indicate weak field and closely spaced magnetic field lines indicate strong field.

Electric field lines do not exist within a charged conductor. Magnetic field lines exist within the body of the magnet. i.e. Electric field lines are discontinuous, but magnet field lines are continuous closed loops.

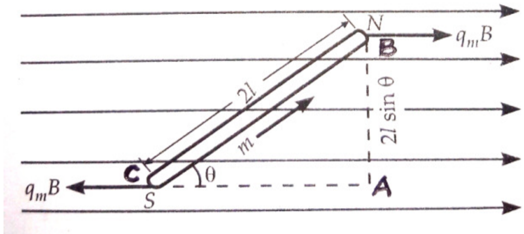
Note:
Magnetite Stone is known as lodestone (leading stone) as it was used by ancient navigators to find direction.
Compass used in ships are known as **gyrocompass**.
The strength of a magnet decreases on heating or hammering.

5.09 Properties of magnetic field lines

- Magnetic field lines of a magnet form continuous closed loops.
- The tangent at any point on the field line gives the direction of magnetic field at that point.
- The larger the number of field lines crossing a unit area, the stronger is the magnetic field.
- Magnetic field lines do not intersect each other. If they intersect it means that at the point of intersection there are two directions for the field which is impossible.
- Magnetic field lines prefer to pass through magnetic materials.

5.10 Torque on a magnetic dipole kept in a magnetic field

Consider a magnetic dipole of pole strength q_m and length $2l$ which is kept in a uniform magnetic field. The axis of the dipole makes an angle θ with the field.



The force on north pole = Bq_m (in the direction of $\vec{B}$)

The force on south pole = Bq_m (in the opposite direction of $\vec{B}$)

These two equal and opposite forces constitute a couple. Moment of couple is called torque.

Torque = One of the forces × Perpendicular distance between their line of action

= Bq_m × AB

In ΔABC , Sinθ= $\frac{AB}{2l}$ Or AB = $2l$ Sinθ

Torque τ = $Bq_m \times 2l$ Sinθ But $2l \times q_m = \vec{m}$, dipole moment

$\therefore \tau$ = m B Sinθ OR $\vec{\tau} = \vec{m} \times \vec{B}$ which is the torque acting on the dipole kept in a uniform field.

5.11 Time period of oscillation of a freely suspended magnetic needle kept in a magnetic field

When the magnetic needle is kept in a magnetic field, it experiences a torque.
τ = mB Sinθ where τ is the torque and θ is the angle between the axis of dipole and magnetic field.

When the magnetic needle is turned, it oscillates and comes in equilibrium position. In the equilibrium state,
$I\frac{d^2\theta}{dt^2} = -mBSin\theta$ where I is the moment of inertia. –ve sign shows that restoring torque is in the opposite direction of deflecting torque.

or $I\frac{d^2\theta}{dt^2} + mBSin\theta = 0$

$$\frac{d^2\theta}{dt^2} + \frac{mBSin\theta}{I} = 0$$

If θ is small , $Sin\theta \rightarrow \theta$ $\therefore$ $\frac{d^2\theta}{dt^2} + \frac{mB\theta}{I} = 0$

This is similar to the equation of SHM $\frac{d^2x}{dt^2} + \omega^2 x = 0$

Hence the oscillations of the magnetic needle are simple harmonic.

$\omega^2 = \frac{mB}{I}$ OR $\omega = \sqrt{\frac{mB}{I}}$

$$\omega = 2\pi\vartheta = \frac{2\pi}{T}$$

Or Time Period, $T = \frac{2\pi}{\omega}$

$T = \frac{2\pi}{\sqrt{\frac{mB}{I}}} = 2\pi\sqrt{\frac{I}{mB}}$ which is expression for the time period of oscillation of the magnetic needle.

Squaring, $T^2 = 4\pi^2\frac{I}{mB}$

Strength of field $B = 4\pi^2\frac{I}{mT^2}$

5.12 Potential energy of a magnetic dipole which is kept in an external field

When a magnetic dipole is kept in an external field, it experiences a torque τ = mBSinθ
When turned through an angle dθ, work done dw = τ dθ
Work done in turning through an angle θ is $W = \int \tau\, d\theta$
$W = \int m\,B\,Sin\theta\, d\theta = m\,B \int Sin\theta\, d\theta$
$W = mB\,[-Cos\,\theta]$
$W = -mB\,Cos\,\theta$

This work is stored as potential energy.
$\therefore$ Potential energy, $U = -mB\,Cos\theta$
When dipole is perpendicular to field, $\theta = 90^0$
$\therefore$ U = 0
When $\theta = 0^0$
U = −mB (potential energy is minimum). This is the most stable position.
When $\theta = 180^0$

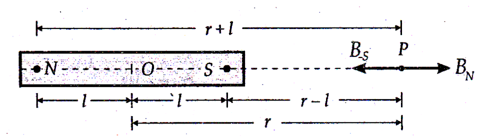
$U = -mB\,Cos\,180^0$

$U = -mB \times -1$

U = mB (potential energy is maximum). This is the most unstable position.

5.13 Magnetic field on the axial line of a bar magnet

Consider a bar magnet of pole strength q_m and magnetic length $2l$. P is a point on the axial line at a distance r from the centre of the magnet.



Intensity of magnetic field at P due to north pole is,

$\overrightarrow{B_N} = \frac{-\mu_0}{4\pi} \frac{q_m}{(r+l)^2} \hat{m}$ where $\hat{m}$ is a unit vector in the same direction of $\vec{m}$.

Intensity of magnetic field at P due to south pole is,

$\overrightarrow{B_s} = \frac{\mu_0}{4\pi} \frac{q_m}{(r-l)^2} \hat{m}$ where $\hat{m}$ is a unit vector in the same direction of $\vec{m}$.

Total intensity

$$\vec{B} = \frac{\mu_0}{4\pi} \frac{q_m}{(r-l)^2} \hat{m} + \frac{-\mu_0}{4\pi} \frac{q_m}{(r+l)^2} \hat{m} = \frac{\mu_0 q_m}{4\pi} \left[\frac{1}{(r-l)^2} - \frac{1}{(r+l)^2}\right] \hat{m} = \frac{\mu_0 q_m}{4\pi} \left[\frac{(r+l)^2-(r-l)^2}{(r-l)^2\ (r+l)^2}\right] \hat{m}$$

$$= \frac{\mu_0 q_m}{4\pi} \left[\frac{(r^2+2rl+l^2)-(r^2-2rl+l^2)}{(r^2-l^2)^2}\right] \hat{m} = \frac{\mu_0 q_m}{4\pi} \left[\frac{4rl}{(r^2-l^2)^2}\right] \hat{m}$$

But $q_m \times 2l = \vec{m}$

$$\therefore \quad \vec{B} = \frac{\mu_0}{4\pi} \frac{2\vec{m}r}{(r^2-l^2)^2} \hat{m}$$ (in the same direction of dipole moment)

Since $l \ll r$, l^2 is neglected.

$$\therefore \vec{B} = \frac{\mu_0}{4\pi} \frac{2\vec{m}r}{r^4} \hat{m}$$

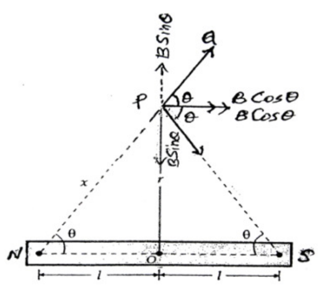
OR

$$\vec{B} = \frac{\mu_0}{4\pi} \frac{2\vec{m}}{r^3} \hat{m}$$

5.14 Magnetic field on the equatorial line of a bar magnet

Consider a bar magnet of pole strength q_m and length $2l$. P is a point on the equatorial line at a distance r from the centre of the magnet. The distance from each pole to P is x. The magnetic intensity at P due to North Pole is

$B_N = \frac{\mu_0}{4\pi} \frac{q_m}{x^2}$ along PQ.



The magnetic intensity at P due to South Pole is,

$B_S = \frac{\mu_0}{4\pi}\frac{q_m}{x^2}$ along PS. $B_N = B_S$ = B

The field along PQ is resolved into two components : B cosθ along x direction and B sinθ along y direction.

The field along PS is resolved into two components : B cosθ along x direction and B sinθ along –Y direction.

The Y components cancel each other as they are equal and opposite. The x components add up.

The total field at P is B = 2B Cosθ = $2\frac{\mu_0}{4\pi}\frac{q_m}{x^2} \times \frac{l}{x}$

But $q_m \times 2l = \vec{m}$ dipole moment.

$\therefore B = \frac{\mu_0}{4\pi}\frac{m}{x^3}$

From figure, $x^2 = r^2 + l^2$

$x = (r^2 + l^2)^{1/2}$

$x^3 = (r^2 + l^2)^{3/2}$

$\therefore$ B = $\frac{\mu_0}{4\pi}\frac{m}{(r^2+l^2)^{3/2}}$ (parallel to the axis of magnet)

Vectorially $\vec{B} = \frac{-\mu_0}{4\pi}\frac{m}{(r^2+l^2)^{3/2}}\hat{m}$ where $\hat{m}$ is a unit vector in the same direction of dipole moment.

l<< r $\therefore l^2$ is neglected. $\therefore \vec{B} = \frac{-\mu_0}{4\pi}\frac{m}{(r^2)^{3/2}}\hat{m}$ OR $\vec{B} = \frac{-\mu_0}{4\pi}\frac{m}{r^3}\hat{m}$

Note : For a short dipole , B_{axial} = $2B_{equatorial}$

Magnetic field at any point = $\frac{\mu_0}{4\pi}\frac{m}{r^3}\sqrt{1 + 3cos^2\theta}$

For axial point $\theta = 0^0$ and for equatorial point $\theta = 90^o$.

5.15 Comparison between electrostatics and magnetism

Magnetism	**Electrostatics**
B	E
$\frac{\mu_o}{4\pi}$	$\frac{1}{4\pi\varepsilon_0}$
m	P

Equatorial field for a short dipole

$\frac{-\mu_o}{4\pi}\frac{m}{r^3}$	$\frac{-1}{4\pi\varepsilon_0}\frac{P}{r^3}$

Axial field for a short dipole

$\frac{\mu_o}{4\pi}\frac{2m}{r^3}$	$\frac{1}{4\pi\varepsilon_0}\frac{2P}{r^3}$

Torque, $\vec{m} \times \vec{B}$ $\vec{P} \times \vec{E}$

5.16 Gauss's law in magnetism

Surface integral of magnetic field over a closed surface is zero.

$$\oint \vec{B}.\vec{dS} = 0$$

Or The net magnetic flux though any closed surface is zero
Gauss's law in magnetism can be applied to both closed and open surfaces.

Differential form of Gauss's theorem

$$\frac{d\,B_x}{dx} + \frac{d\,B_y}{dy} + \frac{d\,B_z}{dz} = 0$$

5.17 Consequences of Gauss's law in magnetism

- By Gauss's law there is no point where the magnetic field lines start or end. Hence magnetic monopoles do not exist.
- Magnetic poles exists like unlike pairs of equal strength.
- The number of magnetic lines of force entering a closed surface is equal to the number of lines of force leaving the surface.

5.18 Show that a current carrying loop behaves as a magnetic dipole. Obtain the expression for its magnetic moment.

Consider a circular loop of current whose radius is r which carries a current i.

The magnetic field along its axis, $B = \frac{\mu_0}{4\pi} \frac{2\pi i r^2}{(r^2+x^2)^{3/2}}$

For $r \gg x$ $B = \frac{\mu_0}{4\pi} \frac{2\pi i r^2}{(r^2)^{3/2}} = \frac{\mu_0}{4\pi} \frac{2\pi i r^2}{r^3}$

πr^2 = A, the area of the loop

$$\therefore \quad B = \frac{\mu_0}{4\pi} \frac{2iA}{r^3} \quad \text{........................ (1)}$$

The electric field on the axial line of a dipole is $E = \frac{1}{4\pi\varepsilon_0} \frac{2P}{r^3}$ ....(2)

On comparing (1) and (2) we find that $\vec{B}$ and $\vec{E}$ have the same distance dependence $\frac{1}{r^3}$.
Also they have the same direction.
This shows that the circular loop acts as a magnetic dipole of magnetic moment. m = iA

Vectorially $\vec{m} = i\,\vec{A}$.

The result is valid for planar loop of any shape. The direction of $\vec{m}$ is normal to the plane of loop as given by **right hand thumb rule.**

5.19 Current carrying solenoid as bar magnet

Solenoid can be taken as the combination of circular loops arranged side by side. Each turn of the current carrying solenoid acts as a magnetic dipole. The number of dipoles is equal to the number of turns in the solenoid. The north pole of one loop touches the south of the next. Hence their effects cancel each other. That is there will be poles only at the ends of the solenoid. One end of the solenoid act as north pole(the end with anti – clockwise current) and the other end act as south pole (the end with clockwise current). The length of the solenoid is the distance between the poles. Thus the solenoid is equivalent to a bar magnet.

Note : Inside the solenoid the direction of magnetic field is from South to North.

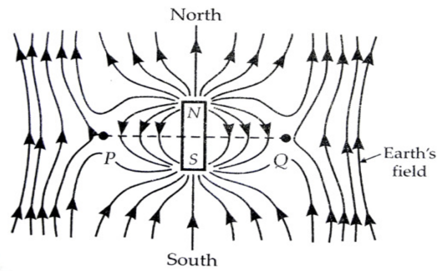
5.20 Finding the direction of the magnetic dipole moment of a current carrying solenoid

The magnetic dipole moment of a current carrying solenoid can be found using **right hand moment rule**. If the curly fingers of right hand represent the direction of current in the solenoid, then the stretched thumb gives the direction of magnetic moment.

5.21 Mapping of magnetic field lines of a bar magnet

- **Magnet placed with its north pole pointing geographic north:**

Figure shows the magnetic lines of force of a bar magnet placed in the magnetic meridian with its north pole pointing the geographical north of the earth.



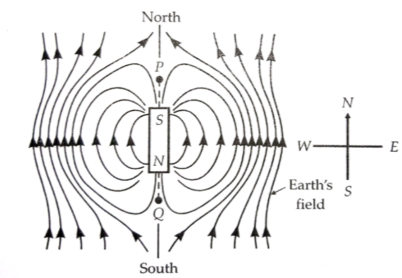
<u>Null point (Neutral point)</u>

Null points are the points where the magnetic field due to the magnet is equal and opposite to the horizontal component of earth's magnetic field. The net magnetic field at the null point is zero.

A compass needle kept at null point can stay in any direction. In this case (N→N), the magnetic field due to the magnet on the equatorial line and the horizontal component of earth's magnetic field are equal.

$\frac{\mu_0}{4\pi} \frac{m}{(r^2+l^2)^{3/2}} = B_H$ where B_H is the horizontal component of earth's magnetic field.

- **Magnet placed with its north pole pointing geographical south.**



In this case (N→S) the magnetic field due to the magnet on the axial line and the horizontal component of earth's magnetic field are equal.

$\frac{\mu_0}{4\pi} \frac{2mr}{(r^2-l^2)^2} = B_H$

1T = 10^4 G (gauss)
Gauss is the CGS unit of magnetic field intensity.

5.22 Magnetizing field

When a magnetic material is kept in a magnetic field , it gets magnetic power. The magnetic field which exists in vacuum and can induce magnetism is called magnetizing field.
eg: The magnetic field developed inside a current carrying solenoid.

5.23 Magnetic induction

Magnetic induction indicates the total magnetic field inside the material. It is the sum of external magnetizing field and the magnetic field due to magnetization of material.

The unit of magnetic induction is tesla or weber/m^2 Or $Nm^{-1}A^{-1}$ or J A^{-1} m^{-2}.

5.24 Magnetizing field intensity (magnetic intensity)

The ability of a magnetizing field to magnetize a material medium is expressed as a vector called magnetizing field intensity(represented as $\vec{H}$).

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

Unit: ampere/ metre OR $Nm^{-2}T^{-1}$ Or J m^{-1} wb^{-1}. Its dimension is AL^{-1}.
The CGS unit is oersted.
1 oersted = 80 A/m

5.25 Dynamo Effect

The core of the earth is in molten state. It contains elements like iron, nickel etc. With the axis rotation of the earth, these also rotate. This produces current which is responsible for the magnetic field of the earth. This effect is called dynamo effect.

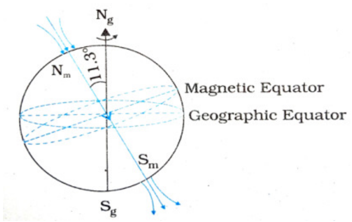
5.26 Some important terms

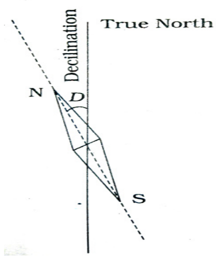
Magnetic Meridian
It is the vertical plane containing the given place and magnetic north and south poles.

Geographic Meridian
It is the vertical plane containing the given place and geographic north and south poles.

5.27 Elements of earth's magnetic field

- **Declination:** It is the angle between magnetic meridian and geographic meridian.
- **Dip (inclination):** It is the angle between the net magnetic field of earth with horizontal.
  Dip at pole is 90^0 .Dip is maximum at poles. Dip at equator is zero.
- **Horizontal Intensity(B_H):** It is the resolved component of earth's magnetic field in the horizontal direction.
  The value of (B_H) is zero at poles.





Note: Magnetic latitude λ and dip angle δ are related as $\frac{\tan\delta}{\tan\lambda}$ = 2

5.28 Dip needle

It is a compass needle pivoted freely to move in a vertical plane containing the magnetic field of the earth.

At the poles the dip needle will point straight down.

5.29 What is the dip angle at a place where the vertical and horizontal components of earth's field are equal?

$\tan\delta = \frac{V}{H} = 1$ i.e. $\delta = 45^0$

5.30 A magnetic needle orients with its axis vertical at a certain place on the earth. What are the values of (a) horizontal component of earth's field (b) angle of dip?

Ans:(a) Zero (b) 90^0

5.31 The angle of dip and total magnetic field of earth at a place are θ and B respectively. What are the horizontal and vertical components of earth's magnetic field at the place?

$B_H = B\cos\theta$ and $B_V = B\sin\theta$

5.32 Magnetization

A circulating electron in an atom has a magnetic moment. For a bulk material these moments add up vectorially to give a non-zero magnetic moment.

Magnetization (M) of a sample is the ratio of net magnetic moment to volume of the sample.

M = $\frac{m_{net}}{V}$ It is a vector quantity. Unit: ampere/metre. Dimension = AL^{-1}

Some important relations

Magnetic field in the interior of a current carrying solenoid $B_0 = \mu_0 n I$

If the solenoid has a core, magnetization increases to $B = B_0 + B_m$ where $B_m = \mu_0 M$

5.33 Expression for magnetic intensity (H)

We have $B = \mu_0 (H + M)$

$B = \mu_0 H + \mu_0 M$

Or $\mu_0 H = B - \mu_0 M$

ie$H = \frac{B}{\mu o} - M$

Unit: ampere/metre . Dimension: AL^{-1}

5.34 Magnetic susceptibility (χ)

Susceptibility $\chi = \frac{M}{H}$. It is the ratio of magnetization to magnetic intensity. It has no unit and no dimension.

The extent to which magnetic field lines can enter a substance is called **magnetic susceptibility .**

Some important relations

$B = \mu_0 (H + M)$

But $B = \mu H$

$\therefore \mu H = \mu_0 (H + M)$

$\mu = \mu_0 (1 + \frac{M}{H})$

$\mu = \mu_0 (1 + \chi)$ But $\mu = \mu_0 \mu_r$

$\therefore \mu_0 \mu_r = \mu_0 (1 + \chi)$ or $\mu_r = 1 + \chi$

A substance which can be easily magnetized has large value of permeability.

5.34 Cutting magnet

If a magnet is cut into two along its length, into two equal parts, the pole strength reduces to half. Dipole moment reduces to half.

If it is cut into two equal parts perpendicular to length, pole strength remains same, dipole moment reduces to half.

Very important terms

Lines joining places of same declination are **isogonal lines.**

Lines joining places of zero declination are **agonal lines.**

Lines joining places of same dip are **isoclinic lines.**

Line joining places of zero dip are **aclinic lines** (magnetic equator).

Line joining places of same horizontal intensity is called **isodynamic lines**.

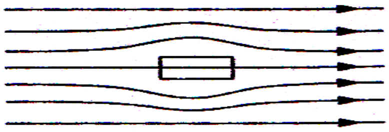
5.35 Properties of diamagnetic substances

- Diamagnetic substances are substances which experience weak repulsive force from a magnet
- When a diamagnetic material is kept is a non-uniform magnetic field, it moves from stronger region to the weaker region of the field.
- Diamagnetism is independent of temperature.
- Their relative permeability is less than one.
- Their susceptibility is small and negative

Reason for repulsion from external field

Orbiting electron in an atom possesses orbital angular momentum. It possesses orbital magnetic moment also. The resultant magnetic moment in an atom is zero. When external magnetic field is applied, electrons having angular momentum in the same direction of field slow down and opposite direction speed up.

Therefore the substances develop a net magnetic moment opposite to external field and are repelled from the field. Eg: Bi, Cu, Ag, Au, Pb, Zn, quartz, glass, diamond, water, alcohol, NaCl, hydrogen, helium, argon, nitrogen (at S.T.P), Hg, marble etc. Figure shows the behaviour of a diamagnetic material in an external field. The field lines are repelled or expelled.



Diamagnetic

The perfect diamagnetism exhibited by super conductor is known as **Meissner Effect**

5.36 Properties of paramagnetic substances

- Paramagnetic substances are the substances which are weakly magnetized when placed in an external field.
- When a para magnetic substance is kept in a non-uniform field, it moves from weaker region to stronger region of the field.
- The relative permeability of a para magnetic material is greater than one.
- The susceptibility of a para magnetic material is small and positive.

Behaviour of paramagnetic material in an external field

For a para magnetic material, individual atoms or molecules possess a permanent dipole moment. Due to random arrangement no net magnetization is found. When kept in a strong external field, the dipoles are aligned and point in the same direction of field.

The field lines get concentrated inside the material.

The field inside is strengthened.

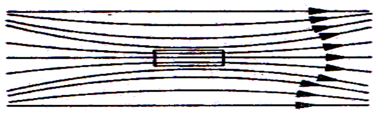
Magnetization is inversely proportional to temperature .

$M \propto \frac{1}{T}$ Or $M = \frac{CB_o}{T}$ or $M = \frac{C\mu_o H}{T}$

where C is curie constant. Here B_o is the magnetizing field. $\frac{M}{H} = \frac{C\mu_o}{T}$ or $\chi = \frac{C\mu_o}{T}$

$\chi \propto \frac{1}{T}$ This law is called Curie's law.

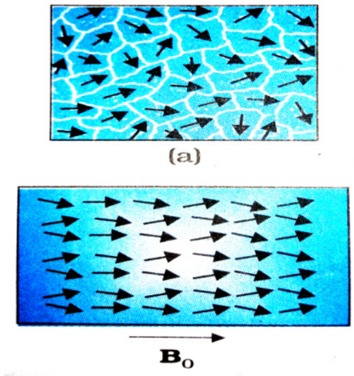
Example for para magnetic substances: aluminum, sodium, manganese, magnesium, chromium, platinum, tungsten, lithium, niobium, calcium, oxygen (at STP), copper chloride etc.



Paramagnetic

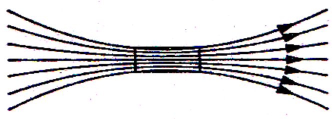
5.37 Properties of ferro magnetic substances

- Ferromagnetic substances are substances which are strongly magnetized when kept in an external field
- In a non-uniform field, it moves from weaker to stronger region of the field
- Relative permeability of a ferro magnetic material is very high.
- Susceptibility of a ferro magnetic material is high and positive.



Individual atoms or molecules possess a permanent dipole moment. They inter act with each other and align in a common direction over a macroscopic volume called domain. Each domain is of 1mm and contains nearly 10^{11} atoms. Magnetism varies from domain to domain and bulk magnetism is zero. When external field is applied the domains arrange in the same direction of field.
eg: Iron, cobalt, nickel, alnico etc.
Boundaries of domains of ferromagnetic material are called block walls.

The behaviour of ferro magnetic substance in an external field is shown below. The field lines are highly concentrated.



5.38 Curie point

When a ferro magnetic substance is heated, its magnetic properties decreases. At a particular temperature the ferromagnetic substance becomes para magnetic. This temperature is called Curie point(Curie temperature). The curie temperature of iron is about 1043 K.

5.39 Modified Curie's law for ferro magnetic substances

Above Curie point(ie, in para magnetic condition), $\chi = \frac{C'}{T - T_c}$ where C' is a constant. Here $T > T_c$ .This is known as Curie- Weiss law.

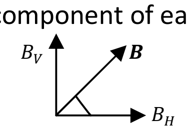
ie, The susceptibility of a ferro magnetic substance above its Curie temperature is inversely proportional to the excess temperature above Curie temperature.

5.40 The earth's core is known to contain iron, but geologists do not regard this as a source of magnetic field. Why?

The temperature of core is more than the curie temperature of iron. At this temperature, iron loses its magnetic properties.

Note
At the equator, the vertical component of earth's magnetic field is zero.

5.41 The vertical component of earth's magnetic field at a place is $\sqrt{3}$ times the horizontal component. What is the dip angle?



δ

$\tan\delta = \frac{B_V}{B_H}$, $\tan\delta = \frac{\sqrt{3}B_H}{B_H}$, $\tan\delta = \sqrt{3}$ OR $\delta = \tan^{-1}\sqrt{3}$

5.42 The angle of dip of a location in southern India is about 18^0. Would you expect a greater or lesser dip at Britain?

More. It is located close to North Pole of earth. Dip angle is about 4 times than in southern India.

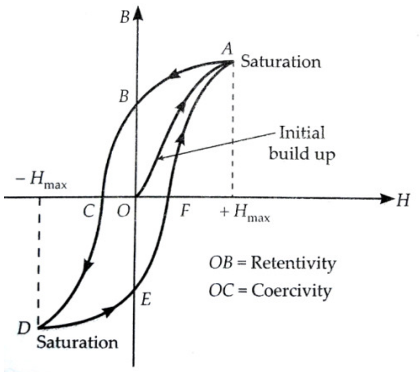
5.42 Difference between hard ferromagnetic substances and soft ferromagnetic substances

Consider a ferromagnetic substance which is kept in an external magnetic field. When external field is removed some ferromagnetic substances retain the magnetic power they got. They are called hard ferromagnetic substances. Hard Ferro magnetic material can not be demagnetized easily. Eg: alnico (alloy of aluminum, nickel, cobalt, iron and copper), lode stone

Some ferromagnetic substances cannot retain the magnetic power when external field is removed. They are called soft ferromagnetic substances. Soft ferromagnetic material can be demagnetized easily.

Eg: soft iron, cobalt, nickel, gadolinium etc.

5.43 Variation of 'B' with 'H' field



Consider a ferromagnetic substance which is kept inside a solenoid. Suppose initially there is no magnetization to the substance. When external field is increased by increasing the current in the solenoid, the magnetic field 'B' in the material increases. It reaches saturation at 'A'. Now the H field is decreased to zero. But the substance retains some magnetism. The point 'B' represents retentivity or remanence or residual magnetism.

Now the external field is reduced to –ve value by reversing the current in the solenoid. At 'C' the magnetic field in the substance becomes zero. This –ve value of H is called coercivity.

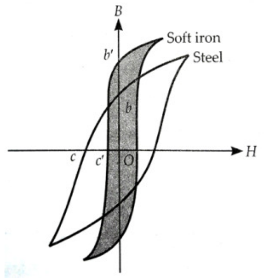
Current in the reverse direction is increased.The negative H value increases. Magnetic saturation is again attained (at D).

Now H is reversed by reversing the current in the solenoid. B also increases and again the point 'A' is reached. For a given value of H, the value of B is not unique.

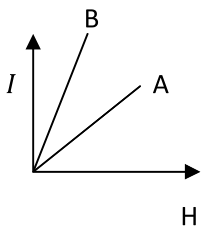
The phenomenon of the lagging of magnetization behind magnetizing field is known as hysteresis.
The area of hysteresis loop represents the energy dissipated as heat in the specimen when it undergoes a cycle of magnetization.

Area of hysteresis loop of hard ferromagnetic material is more.

5.44 Hysteresis loop for soft iron and steel



5.45 Graph showing the variation of intensity of magnetisation (I or M) versus H field for two materials A and B is given. Identify them? Why B has large χ for a given field at constant temperature?



$\chi = \frac{I}{H}$ is more for B. So B is ferromagnetic and A is paramagnetic. Ferromagnetic material is easily magnetized. So its χ value is more.

5.46 Properties of materials suitable for making permanent magnets

a)High permeability b)High retentivity c) High coercivity

5.47 Materials suitable for making permanent magnets

Steel, alnico, cobalt steel, ticonal etc.

5.48 Properties of materials used for making the core of electromagnets

a) High permeability b)Low retentively

Note
Soft iron is a suitable material for making electro magnets.

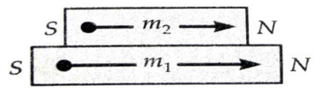
5.49 Vibration magnetometer

It is an instrument used to compare the magnetic moments of two magnets. It can also be used to determine the horizontal component of earth's magnetic field at a place. In it, a magnet is allowed to oscillate simple harmonically in a magnetic field. Time period of oscillations,

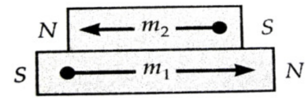
T = $2\pi\sqrt{\frac{I}{mB_H}}$ where I is the moment of inertia, m is the magnetic moment and is the horizontal component of earth's magnetic field. If two magnets are used, For the first magnet $T_1 = 2\pi\sqrt{\frac{I}{m_1 B_H}}$

For the second magnet $T_2 = 2\pi\sqrt{\frac{I}{m_2 B_H}}$ OR $\frac{T_1}{T_2} = \sqrt{\frac{m_2}{m_1}}$

5.50 If the magnets are placed as in the figures below,



(a)



(b)

Total moment of inertia $I = I_1 + I_2$

Total magnetic moment $m = m_1 + m_2$

Time period, T = $2\pi\sqrt{\frac{I_1+I_2}{(m_1+m_2)B_H}}$

Total moment of inertia $I = I_1 + I_2$

Total magnetic moment $m = m_1 - m_2$

Time period, T = $2\pi\sqrt{\frac{I_1+I_2}{(m_1-m_2)B_H}}$

5.50 Magnetic moment of two identical magnets each of moment m_0 inclined at 60^0 with each other

m= $\sqrt{m_0{}^2 + m_0{}^2 + 2m_0m_0\cos 60}$ = $\sqrt{m_0{}^2 + m_0{}^2 + 2m_0m_0\frac{1}{2}}$ = $\sqrt{3m_0{}^2}$ = $m_0\sqrt{3}$

5.51 What is a natural fundamental magnetic dipole?

Orbiting electron

5.52 A magnetic needle is made to float on the calm surface of a lake in northern hemi sphere. Will it move towards north?

It will come to rest along North – South direction

> ***Note***
>
> If a compass is taken to North Pole of the earth, it moves in horizontal plane. It may rest in any direction.
>
> A submarine is an iron shell which shields the compass from the magnetic field of the earth. So the compass is ineffective inside.

5.53 Magnetic shielding or magnetic screening

It is the protection of a region from the effect of external magnetic fields. When a soft iron ring is placed in a magnetic field, no magnetic field lines pass through the space inside the ring. Thus the the space inside is shielded. Super conductors also can create this effect as no magnetic field lines pass through them.