5 Magnetism and Matter.

Magnet and Magnetism:- A magnet is a piece of material that has both attractive and directive properties. It attracts small pieces of iron nickel cobalt etc. This property of attraction is called magnetism.

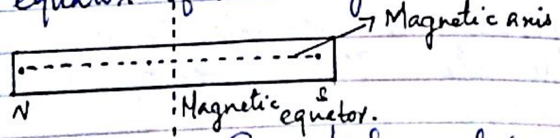
Basic Properties of magnets.

1. **Attractive property:-** A magnet attracts small pieces of iron, nickel, cobalt etc.
2. **Directive property:-** A freely suspended magnet aligns itself in the geometric north - South direction.
3. Like poles repel and unlike pole attract.
4. Magnetic poles exist in pairs. Isolated magnetic poles do not exist. If we break a magnet into two pieces, we get two smaller dipole magnets.

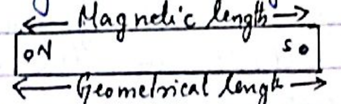
Magnetic poles:- These are the regions of apparently concentrated magnetic strength in a magnet where the magnetic attraction is maximum.
The poles of a magnet lie somewhat inside the magnet and not at its geometrical ends.

Magnetic axis:- The line passing through the poles of a magnet is called the magnetic axis of the magnet.

Magnetic equator:- The line passing through the centre of the magnet and at right angles to the magnetic axis is called the magnetic equator of the magnet.



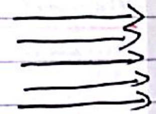
Magnetic length:- The distance between the two poles of a magnet is called the magnetic length of the magnet. It is slightly less than the geometric length of the magnet.



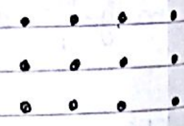
Uniform magnetic field.

A magnetic field in a region is said to be uniform if it has same magnitude and direction at all points of that region.

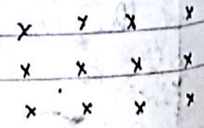
A uniform magnetic field acting in the plane of paper is represented by equidistant parallel lines.



A uniform magnetic field acting perpendicular to the paper and directed outwards is represented by dots.

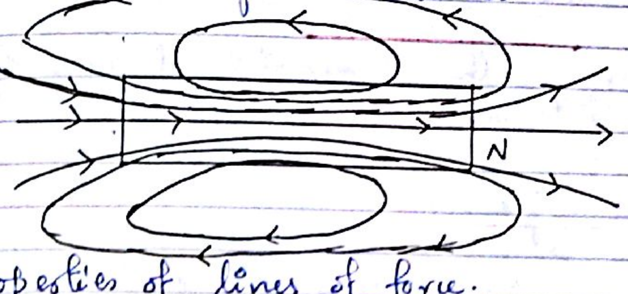


A uniform magnetic field acting perpendicular to the paper and directed inwards is represented by crosses.



Magnetic lines of force.

It is defined as the path along which a unit north pole would tend to move, if free to do so.



Properties of lines of force.

1. Magnetic lines of force are closed curves which start in air from N-pole and end at the S-pole and then return to the N-pole through the interior of the magnet.
2. The lines of force never cross each other.
3. The tangent at any point gives the direction of the magnetic field at that point.
4. The relative closeness of the lines of force is a measure of the strength of the magnetic field which is maximum at the poles.

Coulomb's law of magnetic force

:- Inverse square law.

The law states that the force of attraction or repulsion between two magnetic poles is directly proportional to the product of their pole strength and inversly proportional to the square of the distance between them.

If P_1 and P_2 are the pole strengths of the two magnetic poles which are distance 'r' apart then force between them is given by

$$F = \frac{\mu_0}{4\pi} \cdot \frac{P_1 P_2}{r^2}$$

where μ_0 is the permeability of free space $= 4\pi \times 10^{-7}\ TmA^{-1}$

Magnetic dipole :-

Any arrangement of two equal and opposite magnetic poles separated by a small distance is called a magnetic dipole.
eg. A bar magnet.

Magnetic dipolemoment:-

It is equal to the product of the pole strength (P) and the magnetic length (2l) of the magnet.

ie $\quad m = P \times 2l$

The S.I unit of magnetic dipolemoment is Am^2
It is a vector quantity

Intensity of magnetic field or Flux density (B)

It is measured as the force experienced by a unit magnetic north pole placed at the point

ie $\quad \vec{B} = \frac{\vec{F}}{P}$

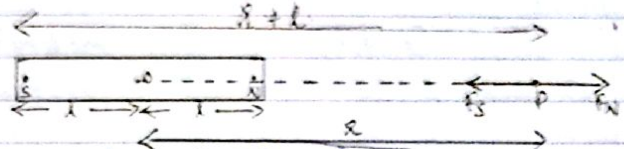
$\therefore$ Force $\vec{F} = p\vec{B}$

The S.I unit of $\vec{B}$ is Tesla ($Wb\,m^{-2}$) and its CGS unit is Gauss (G)

$1\ G = 10^{-4}\ T$

Magnetic field of a bar magnet at an axial point:

Let NS be a bar magnet of length 2l and of pole strength p. Suppose the magnetic field is to be determined at a point P which lies on the axis of the magnet at a distance 'r' from its centre.



Imagine a unit north pole placed at point P. Then from Coulomb's law of magnetic forces, the force exerted by the N-pole of strength p on unit north pole will be

$$F_N = \frac{\mu_0}{4\pi} \frac{p}{(r-l)^2} \quad \text{along } \vec{NP}$$

||ly the force exerted by S-pole on unit north pole is

$$F_S = \frac{\mu_0}{4\pi} \frac{p}{(r+l)^2} \quad \text{along } \vec{PS}$$

$\therefore$ the strength of the magnetic field $\vec{B}$ at point P is

$$\vec{B}_{axial} = F_N - F_S$$

$$= \frac{\mu_0 p}{4\pi}\left[\frac{1}{(r-l)^2} - \frac{1}{(r+l)^2}\right]$$

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

For a short magnet

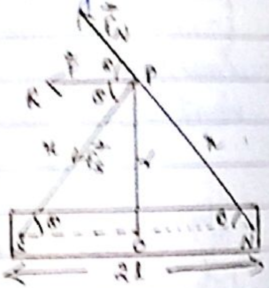
$$\vec{B}_{axial} = \frac{\mu_0}{4\pi}\frac{2\cdot 2Prl}{r^4} \quad (r>>l.)$$

$$= \frac{\mu_0}{4\pi}\frac{2\cdot 2Pl}{r^3}$$

$$\boxed{\vec{B}_{axial} = \frac{\mu_0}{4\pi}\frac{2m}{r^3}.}$$

Magnetic field of a bar magnet at an equatorial point

Consider a bar magnet NS of length 2l and of pole strength P. Suppose the magnetic field is to be determined at a point P lying on the equatorial line of the magnet NS at a distance r from its centre.



Imagine a unit north pole placed at point P. Then from Coulomb's law of magnetic forces the force exerted by the N-pole of the magnet on unit north pole is

$$F_N = \frac{\mu_0}{4\pi}\frac{P}{x^2} \text{ along } \vec{NP}$$

Similarly,
The force exerted by the S-pole of the magnet on unit north pole is

$$F_S = \frac{\mu_0}{4\pi}\frac{P}{x^2} \text{ along } \vec{PS}$$

As the magnitudes of F_N and F_S are equal so their vertical components get cancelled while the horizontal components add up along PR

Hence the magnetic field at the equatorial point P is

$$B_{equ} = F_N\cos\theta + F_S\cos\theta$$

$$= 2F_N\cos\theta \quad (F_N = F_S)$$

$$= 2\cdot\frac{\mu_0}{4\pi}\frac{P}{x^2}\cdot\frac{l}{x}$$

$$= \frac{\mu_0}{4\pi}\frac{2l\cdot P}{x^3} \quad (2l\cdot P = m)$$

But $x^2 = r^2+l^2$

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

$\therefore$ the above eqn becomes

$$B_{equ} = \frac{\mu_0}{4\pi}\frac{m}{(r^2+l^2)^{3/2}}$$

For a short magnet $r>>l$

$$= \frac{\mu_0}{4\pi}\frac{m}{(r^2)^{3/2}}$$

$$\boxed{\vec{B}_{equ} = \frac{\mu_0}{4\pi}\frac{m}{r^3}}$$

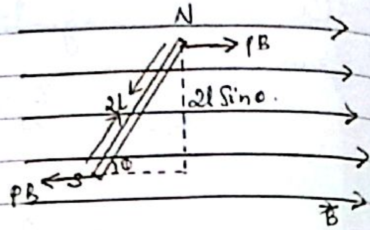
Torque on a magnetic dipole in a uniform magnetic field

Consider a bar magnet NS of length 2l placed in a uniform magnetic field $\vec{B}$. Let P be the pole strength of its each pole. Let the magnetic axis of the bar magnet make an angle θ with the field $\vec{B}$

Force on N-pole = pB along $\vec{B}$

Force on S-pole = pB opposite to $\vec{B}$

The forces on the two poles are equal and opposite. They form a couple.



Moment of couple or Torque is given by.

τ = force × $\perp^r$ distance

$= pB \times 2l\sin\theta.$

$= p2l\, B\sin\theta$

$= mB\sin\theta$ where $m = p.2l.$

$$\boxed{\vec{\tau} = \vec{m} \times \vec{B}.}$$

Special Cases.

1. When the magnet lies along the direction of the magnetic field

$\theta = 0°, \sin\theta = 0 \quad \therefore \tau = 0$

2. When the magnet lies $\perp^r$ to the direction of the field

$\theta = 90°, \sin 90 = 1, \quad \tau = mB$

Thus the torque is maximum $\tau_{max} = mB.$

Potential Energy of a magnetic dipole.

When a magnetic dipole is placed in a uniform magnetic field $\vec{B}$ at angle θ

$\tau = mB\sin\theta.$

This torque tend to align the dipole in the direction of $\vec{B}$.

If the dipole is rotated against the action of this torque work has to be done. This work done is stored as P.E of the dipole.

The work done in turning the dipole through a small angle $d\theta$ is

$dW = \tau d\theta$

$= mB\sin\theta\, d\theta.$

If the dipole is rotated from an initial position $\theta = \theta_1$ to the final position $\theta = \theta_2$, then the total work done will be

$W = \int dW$

$= \int_{\theta_1}^{\theta_2} \tau\, d\theta.$

$= \int_{\theta_1}^{\theta_2} mB\sin\theta\, d\theta. = mB\int_{\theta_1}^{\theta_2}\sin\theta\, d\theta.$

$= mB\left(-\cos\theta\right)_{\theta_1}^{\theta_2}.$

$= -mB\left[\cos\theta_2 - \cos\theta_1\right]$

This work done is stored as the P.E U of the dipole

$$\boxed{U = -mB\left[\cos\theta_2 - \cos\theta_1\right]}$$

The P.E of the dipole is zero when $\vec{m} \perp \vec{B}$. So P.E of the dipole in any orientation by putting $\theta_1 = 90°$ and $\theta_2 = \theta$ ∴ the above equation

$U = -mB\left[\cos\theta - \cos 90\right)$

$U = -mB\cos\theta$

$$\boxed{U = -\vec{m}\cdot\vec{B}}$$

Special Cases.

1. When $\theta = 0°$ $\quad U = -mB\cos 0 = -mB.$

Thus the P.E of the dipole is minimum when

$\vec{m}$ is parallel to $\vec{B}$. In this state the magnetic dipole is in stable equilibrium.

2. When $\theta = 90^\circ$ $U = -mB\cos 90 = 0$.
3. When $\theta = 180^\circ$, $U = -mB\cos 180 = mB$.

Thus P.E of a dipole is maximum when $\vec{m}$ is antiparallel to $\vec{B}$. In this state the magnetic dipole is in unstable equilibrium.

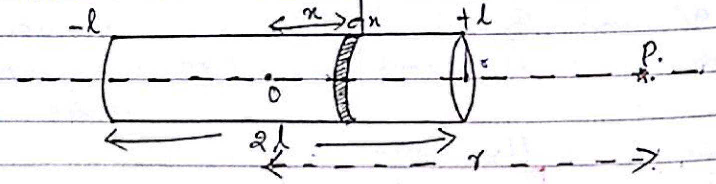
Bar Magnet as an Equivalent Solenoid.

A solenoid can be regarded as a combination of circular loops placed side by side. Each turn of the solenoid can be regarded as a small magnetic dipole. of dipole moment IA: for N turns $m = NIA$.

Consider a solenoid of length $2l$ and radius 'a'. Let 'n' be the number of turns per unit length.

To evaluate the magnetic field at a point P at a large distance 'r' along the axis of the solenoid. We consider a circular element of thickness dx of the solenoid at a distance 'x' from its centre.

$n = \frac{N}{2l}$



Number of turns of the element $= n\,dx$

If I is the current flowing through the solenoid the field at P due to the element distant x from its centre

$$dB = \frac{\mu_0 I a^2 N}{2(x^2+a^2)^{3/2}} = \frac{\mu_0}{4\pi}\,\frac{2\pi a^2 n\,dx\,I}{(a^2+(r-x)^2)^{3/2}}$$

$$= \frac{\mu_0}{4\pi}\cdot\frac{2\pi a^2 n\,dx\,I}{r^3}$$ Since $r >> a$ & x.

The magnetic field at P due to the whole solenoid

$$B = \int_{-l}^{+l} \frac{\mu_0}{4\pi}\cdot\frac{2\pi a^2 n\,dx\,I}{r^3}$$

$$= 2\cdot\frac{\mu_0}{4\pi}\cdot\frac{2\pi a^2 n I}{r^3}\int_0^l dx$$

$$= 2\cdot\frac{\mu_0}{4\pi}\cdot\frac{2\pi a^2 n I}{r^3}\,(x)_0^l$$

$$= 2\,\frac{\mu_0}{4\pi}\cdot\frac{2\pi a^2 n I}{r^3}\cdot l$$

But $\pi a^2 = A$ and $2ln = N$, the total no: of turns.

$$B = \frac{\mu_0}{4\pi}\,\frac{2AIN}{r^3}$$

$$B = \frac{\mu_0}{4\pi}\,\frac{2m}{r^2}$$ where $m = NIA$, is the moment of the solenoid.

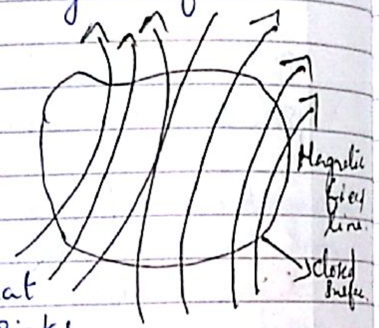
This is also the magnetic field at the far axial point of a bar magnet. Thus the bar magnet as an equivalent solenoid.

Gauss's theorem in Magnetism.

This law states that the net magnetic flux through any closed surface is zero.

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

ie $\phi_B = \oint_S \vec{B} \cdot \vec{ds} = 0$



Consequences of Gauss's law.

1. Gauss's Law indicates that there are no sources or sinks of magnetic field inside a closed surface. This implies that isolated magnetic poles ie monopoles do not exist.
2. The magnetic poles always exist as unlike pairs of equal strengths.
3. If a number of magnetic lines of force enter a closed surface, then an equal number of lines of force must leave that surface.

Earth's Magnetism:-

Earth is a powerful natural magnet. Its field can be approximated to that of a magnetic dipole of dipole moment $8 \times 10^{22}\ Am^2$ located at the centre of the earth. The axis of the dipole makes an angle of about $11.3°$ with the axis of rotation of the earth. The magnetic north pole N_m of the earth lies somewhere near the geographic south S_g while the magnetic south pole S_m lies somewhere near the geographic north pole N_g. The magnitude of the magnetic field on the earth's surface is typically about $10^{-4}T$

The Branch of Physics that deals with the study of earth's magnetism is called Terrestrial Magnetism or Geomagnetism.

Origin of earth's magnetism.

Some of the theories proposed about the cause of earth's magnetism are as follows.

1. In 1600 William Gilbert in his book De Magnete first suggested that the earth behaves as a bar magnet and its magnetism is due to the presence of magnetic material at its centre, which could be a permanent magnet. However, the core of the earth is so hot that a permanent magnet cannot exist there.
2. Cosmic rays cause the ionisation of gases in the earth's atmosphere. As the earth rotates, strong electric currents are set up due to the movement of the charged ions. These currents may be the source of earth's magnetism.
3. According to Sir E. Bullard and W. M. Elsasser the magnetic field of the earth arises due to electric currents produced by convection motion of metallic fluids consisting mostly of iron and nickel, in the outer core of the earth. This is known as the dynamo effect. This hypothesis seems most probable.

Some Definitions in connection with earth's magnetism

1. Geographic axis :- The straight line passing through the geographical north and south poles of the earth is called its geographic axis. It is the axis of rotation of the earth.
2. Magnetic axis :- The straight line passing through the magnetic north and south poles of the earth's is called the magnetic axis. At present it makes a small angle of about 11.3° with the geographic axis.
3. Magnetic Equator :- It is the great circle on the earth ⊥r to the magnetic axis.
4. Magnetic Meridian :- The vertical plane passing through the magnetic axis of a freely suspended small magnet is called magnetic meridian. The earth's magnetic field acts in the direction of the magnetic meridian.
5. Geographic Meridian :- The vertical plane passing through the geographic north and south poles is called geographic meridian.

Element's of Earth's Magnetic field.

The earth's magnetic field at a place can be completely described by three parameters which are called element's of earth's magnetic field. They are declination dip and horizontal component of earth's magnetic field.

1. Magnetic declination (D) : or (α)
   The angle between the geographical meridian and magnetic meridian at a place is called the declination at that place.

The declination is greater at higher altitudes and smaller at the equator.

2. Angle of dip / Magnetic Inclination (I) (δ)
   The angle made by the earth's total magnetic field $\vec{B}$ with the horizontal direction in the magnetic meridian is called angle of dip (I) at any place.
   At the magnetic equator the angle of dip is zero and the angle of dip is 90° at the magnetic poles. At all other places, the dip angle lies between 0° and 90°.

3. Horizontal component of earth's magnetic field.
   δ
   It is the component of the earth's total magnetic field $\vec{B}$ in the horizontal direction in the magnetic meridian.
   The total magnetic field $= \vec{B}_E$ / $\vec{B}_T$
   It can be resolved into a horizontal component $\vec{H}_E$ and a vertical component $\vec{Z}_E$
   The angle that $\vec{B}_E$ makes with $\vec{H}_E$ is the angle of dip I

Thus B_V $Z_E = B_E \sin I$ or

B_H $H_E = B_E \cos I$

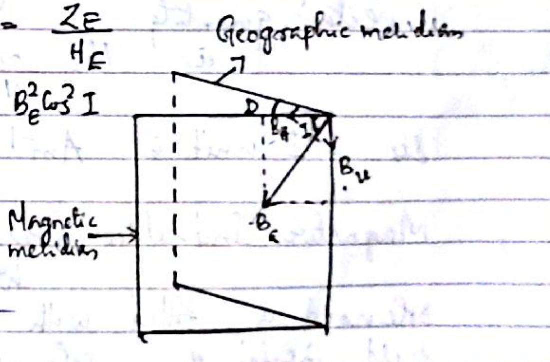
which gives $\tan I = \dfrac{Z_E}{H_E}$

Also $Z_E^2 + H_E^2 = B_E^2 \sin^2 I + B_E^2 \cos^2 I$ ($B_V^2 + B_H^2$)

$= B_E^2$

or $B_E = \sqrt{Z_E^2 + H_E^2}$

$B_E = \sqrt{B_V^2 + B_H^2}$



Magnetising field:- The magnetic field that exists in vacuum and induces magnetism is called magnetising field.

The magnetising field set up in a solenoid carrying current I and placed in vacuum is $B_0 = \mu_0 n I$

S.I unit of B_0 = Tesla (T)

Magnetic intensity : (H) It is the number of ampere-turns flowing round the unit length of the solenoid required to produce a given magnetising field.

Thus $H = nI$.

Also $B_0 = \mu_0 n I$
$= \mu_0 H$.

$$\therefore \quad H = \frac{B_0}{\mu_0}$$

S.I unit of $H = Am^{-1}$ or $N Wb^{-1}$ or $N m^{-1} T^{-1}$.

Dimension $L^{-1} A$

Magnetisation (M): It is the magnetic moment developed per unit volume of a material when placed in a magnetising field. It is a vector quantity

ie $M = \frac{m}{V}$.

Its S.I unit is Am^{-1} or NWb^{-1} or $Nm^{-1}T^{-1}$

Magnetic Induction : (B)

When the interior of a solenoid is filled with a magnetic material the field inside the solenoid becomes greater than B_0.

The net field inside the solenoid will be
$\vec{B} = \vec{B_0} + \vec{B_m}$.

where $\vec{B_m}$ is the field contributed by the core material due to its magnetisation in the external field.

The total magnetic field inside a magnetic material is the sum of the external magnetising field and the additional magnetic field produced due to magnetisation of the material and is called magnetic induction $\vec{B}$.

The additional field B_M is proportional to the magnetisation M of the material

$\therefore \quad B_M = \mu_0 M$.

Hence $B = B_0 + B_M$
$= \mu_0 H + \mu_0 M$
$= \mu_0 (H + M)$

Magnetic Permeability:- Permeability is the measure of the extent to which a material can be penetrated or permeated by a magnetic field.

The magnetic permeability of a material may be defined as the ratio of its magnetic induction B to the magnetic intensity H.

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

S.I unit of $\mu = \frac{T}{Am^{-1}} = Tm A^{-1}$

Dimension $MLT^{-2}A^{-2}$

Relative permeability :-

It is defined as the ratio of the permeability of the medium to the permeability of free space.

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

Magnetic susceptibility :-

Magnetic susceptability measures the ability of a substance to take up magnetisation when placed in a magnetic field.

It is defined as the ratio of the intensity of magnetisation M to the magnetising field intensity H. It is denoted by χ

It has no unit.

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

Relation between μ_r and χ.

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

But $B = \mu H$

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

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

$$\mu = \mu_0 \left[1+\chi\right]$$

$B = \mu H$, $\frac{M}{H} = \mu_0 [$

But $\mu = \mu_0 \mu_r$

$$\cancel{\mu_0}\mu_r = \cancel{\mu_0}\left[1+\chi\right]$$

$$\mu_r = 1+\chi$$

Classification of magnetic materials.

On the basis of their behaviour in external magnetic fields Faraday classified the various substances into three categories.

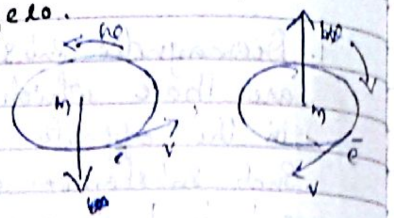
1. Diamagnetic substances:- Diamagnetic substances are those which develop feeble magnetisation in the opposite direction of the magnetising field. Such substances are feebly repelled by magnets and tend to move from stronger to weaker parts of a magnetic field.
eg's:- Bismuth, Cu, Pb, tin, gold, silicon, N_2 (at STP) H_2O, NaCl etc

2. Paramagnetic substances:- Paramagnetic substances are those which develop feeble magnetisation in the direction of the magnetising field. Such substances are feebly attracted by magnets and tend to move from weaker to stronger parts of a magnetic field.
eg's – Manganese, Al, Cr, platinum, Na, $CuCl_2$, O_2 at STP. etc.

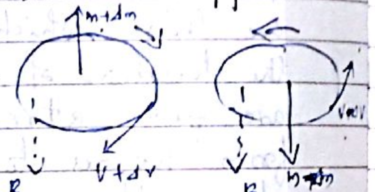
3. Ferromagnetic substances:- Ferromagnetic substances are those which develop strong magnetisation in the direction of the magnetising field. They are strongly attracted by magnets and tend to move from weaker to stronger parts of a magnetic field.
eg's: Fe, Co, Ni, gadolinium and alloys like alnico.

Origin of diamagnetism

In atoms of some material like Bi, Cu, Pb, the electrons occur in pairs with one of them revolving clockwise and other anticlockwise around the nucleus. Net magnetic moment of an atom is zero.

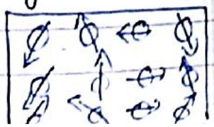


When such an atom is placed in a magnetic field $\vec{B}$, the speed of revolution of one $\bar{e}$ increases and that of other decreases. The magnetic moment of the former $\bar{e}$ increases to $\vec{m}+\Delta\vec{m}$ and that of latter $\bar{e}$ decreases to $\vec{m}-\Delta\vec{m}$. So each $\bar{e}$ pair gains a net magnetic moment $2\Delta\vec{m}$ which is proportional to the field $\vec{B}$ but in opposite direction. A sufficient magnetic moment is induced in the diamagnetic sample in the opposite direction of $\vec{B}$. This sample moves from stronger to the weaker parts of the field. i.e a diamagnetic substance is repelled by a magnet. The behaviour of diamagnetic materials is independent of temperature.



Origin of Paramagnetism:

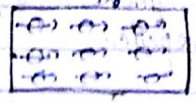
The atoms or molecules of a paramagnetic material possess a permanent magnetic moment. In the absence of an external magnetic field, the atomic dipoles are randomly oriented. There is no net magnetisation.



$B_0 = 0$

When a strong enough field $\vec{B_0}$ is applied and the temperature is low enough, the field $\vec{B_0}$ tends to align the atomic dipoles in its own direction, producing a weak magnetic moment in the direction of $\vec{B_0}$. The material tends to move from a weak field region to a stronger field region. This is paramagnetism.

B_0



Origin of Ferromagnetism.

Weiss explained ferromagnetism on the basis of domain theory. In materials like Fe, Ni, Co, the individual atoms are associated with large magnetic moments. The magnetic moments of neighbouring atoms interact with each other and align themselves spontaneously in a common direction over macroscopic regions called domains. Each domain has a typical size of about 1mm and contains about 10^{11} atoms. So each domain possesses a strong magnetic moment. In the absence of any external magnetic field, these domains are randomly distributed so that the net magnetic moment is zero.

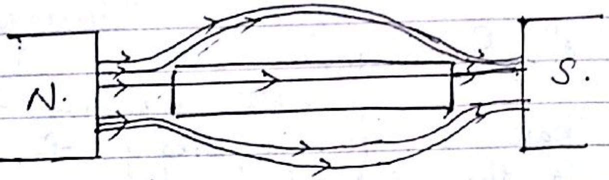
When a ferromagnetic material is placed in a magnetic field all the domains align themselves along the direction of the field leading to the strong magnetisation of the material along the direction of the field. That is why the ferromagnetic substances are strongly attracted by magnets.

Domain

Properties of Diamagnetic Substances

1. When placed in an external magnetic field a diamagnetic substance develops feeble magnetisation in the opposite direction of the applied field.

2. When a rod of diamagnetic material is placed in a magnetic field, the lines of force get expelled or repelled.



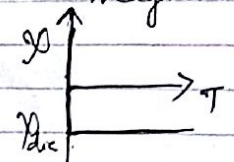
3. When placed in a non-uniform magnetic field, a diamagnetic substance moves from stronger to the weaker part of the field.

4. When a rod of diamagnetic material is suspended freely in a uniform magnetic field, it aligns itself $\perp^r$ to the magnetising field.

5. The susceptability of a diamagnetic material is small and ~~the~~ negative.

6. The relative permeability μ_r is +ve but less than 1 for a diamagnetic material.

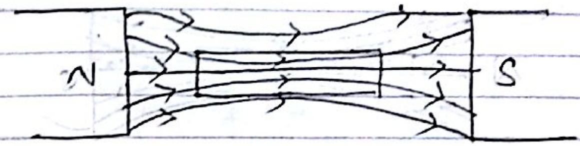
7. The susceptability of diamagnetic substances is independent of the magnetising field and the temperature.



Properties of Paramagnetic Substances.

1. When placed in an external magnetic field a paramagnetic substance develops a feeble magnetisation in the direction of the applied field.

2. When a rod of paramagnetic material is placed in a magnetic field, the lines of force get slightly concentrated inside the material.



3. When placed in a non-uniform magnetic field, a paramagnetic substance moves from weaker to the stronger parts of the field.

4. When a rod of paramagnetic material is suspended freely in a uniform magnetic field, it aligns itself parallel to the magnetising field.

5. The susceptability of a paramagnetic material is small and positive.

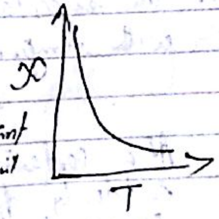
6. The relative permeability μ_r is slightly greater than 1

7. The magnetic susceptability of a paramagnetic material varies inversely as the temperature

ie $\chi \propto \frac{1}{T}$

$\chi = \frac{C}{T}$ where C is a constant called Curie constant

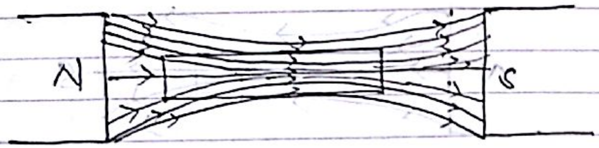
and this is called Curie law.



Properties of Ferromagnetic Substances

1. When placed in an external magnetic field a ferro magnetic material develops strong magnetisation in the direction of the applied field.

2. When a rod of ferromagnetic material is placed in a magnetic field, the lines of force concentrate greatly into the material



3. When a ferromagnetic substance is placed in non-uniform magnetic field it moves from weaker to the stronger parts of the field.

4. When a rod of a ferromagnetic material is suspended freely in a uniform magnetic field of quickly aligns itself parallel to the magnetic field.

5. The susceptability of a ferromagnetic material has a large positive value.

6. The relative permeability μ_r of a ferro magnetic material has a large positive value.

7. The susceptability of ferromagnetic material has decreases with temperature in accordance with Curie - Weiss law.

$$\chi = \frac{C}{T - T_c} \quad (T > T_c)$$

- At a certain temperature called Curie point the susceptability suddenly falls and the ferro magnetic substance becomes paramagnetic

Magnetic Hysteresis. (B - H curve)

When a ferromagnetic sample is placed in a magnetic field, the sample gets magnetised by induction. As the magnetising field intensity H varies the magnetic induction B does not vary linearly with H i.e the permeability $\mu = B/H$ is not a constant but varies with H. This is hysteresis.

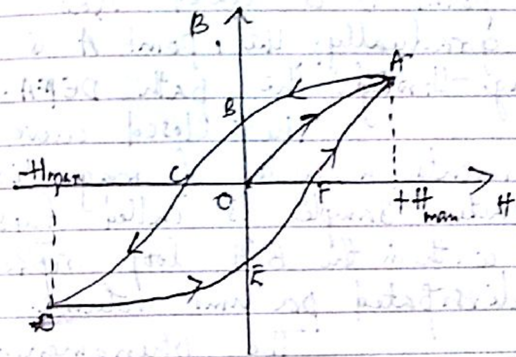


Figure shows the hysteresis loop of a ferromagnetic sample. Point O represent the initial unmagnetised state of a ferromagnetic sample. As H increases, the magnetic induction B first gradually increases and then attains a constant value $+H_{max}$.

If H is gradually decreased to zero that B decreases but along a new path AB. It is found that B does not become zero even the magnetising field H is zero. i.e the sample is not demagnetised even when the magnetising field has been removed.

The magnetic induction OB left behind the sample after the magnetising field has been removed is called residual magnetism or remanence or retentivity.

To reduce the magnetism to zero, the field

H is gradually increased in the reverse direction the induction B decreases and become zero at a value of H = OC. The value of reverse magnetising field intensity H required for the residual magnetism of a sample to become zero is called coercivity of the sample.

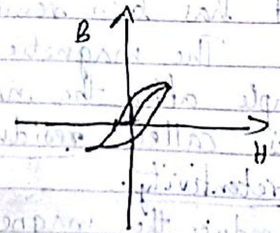
On further increasing H in the reverse direction to a value $-H_{max}$, the saturation point D is located. Now H is decreased gradually, the point A is reached after going through the path DEFA.

The closed curve ABCDEFA which represents a cycle of magnetisation of a ferromagnetic sample is called hysteresis loop. The area with in the B-H loop represents the energy dissipated per unit volume.

The phenomenon of the lagging of magnetic induction behind the magnetising field is called hysteresis.

Types of ferromagnetic materials

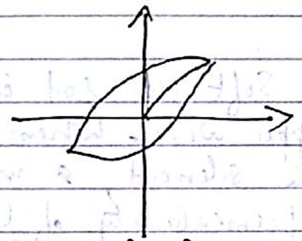
1. Soft ferromagnetic materials :- These are the ferromagnetic materials in which the magnetisation disappears on the removal of the external magnetising field. Such materials have narrow hysteresis loop.



They have (i) low retentivity
(ii) low coercivity
(iii) low hysteresis loop.
(iv) high magnetic permeability.

Eg's: Soft iron, mu metal etc.
They are used as cores of solenoids and transformers.

2. Hard ferromagnetic materials :- These are the ferromagnetic materials in which they retain magnetisation even after the removal of the external magnetising field. Such materials have wide hysteresis loop.



They have (i) high retentivity
(ii) high coercivity
(iii) large hysteresis loop.
(iv) ~~high~~ magnetic permeability.

egs: Steel, alnico etc
They are used for making permanent magnets.

Selection of magnetic materials

1. Permanent magnets :- The material used for making permanent magnets must have
(1) High retentivity
(2) High coercivity
(3) High permeability

Electromagnets :- The materials used for making cores of electromagnets must have the following characteristics

1. High initial permeability
2. Low retentivity

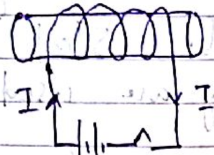
eg :- Soft iron

Transformer cores :- The materials used for making transformer cores must have

1. High initial permeability
2. Low hysteresis loss
3. Low retentivity eg :- soft iron.

Electromagnet.

A soft iron rod is wounded by means of copper wire. When we pass a current through the solenoid a magnetic field is set up. Thus the permeability of the soft iron increases and act as a magnet. When the current in the solenoid is switched off, the soft iron rod loses its magnetism almost completely due to low retentivity.



Uses :-

1. In electric bells, loud speakers and telephone diaphrams.
2. Large electromagnets are used in cranes to lift heavy machinery and bulk quantities of iron & steel.
3. In hospitals, electromagnets are used to remove iron or steel bullets from the human body.

Oscillations of a freely suspended magnet.

Consider a small bar magnet of magnetic moment $\vec{m}$ in a uniform magnetic field $\vec{B}$. Then, restoring torque $\tau = \vec{m} \times \vec{B}$

$= mB\sin\theta$. θ is the angle between $\vec{m}$ and $\vec{B}$. —①

I is the moment of inertia of the magnet about the axis of rotation, deflecting torque then $\tau = I\alpha$

$= I\dfrac{d^2\theta}{dt^2}$ —②

In equilibrium

$$I\frac{d^2\theta}{dt^2} = -mB\sin\theta$$

the negative sign shows that $mB\sin\theta$ (restoring torque is in opposition to deflecting torque.

For small angles of θ.

$$I\frac{d^2\theta}{dt^2} = -mB\theta \qquad (\sin\theta = \theta)$$

$$\frac{d^2\theta}{dt^2} = -\frac{mB}{I}\theta$$

$\dfrac{d^2\theta}{dt^2} + \dfrac{mB}{I}\theta = 0 \implies \dfrac{d^2\theta}{dt^2} + \omega^2\theta = 0$ represents a SHM. ie the oscillation of a freely suspended magnet is simple harmonic

$\therefore \omega^2 = \dfrac{mB}{I}$

$\omega = \sqrt{\dfrac{mB}{I}}$

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

$$\boxed{T = 2\pi\sqrt{\frac{I}{MB}}}$$

or $T^2 = \frac{4\pi^2 I}{MB}$

$$\boxed{B = \frac{4\pi^2 I}{MT^2}}$$

Isogonic lines: The lines joining the places of equal declination are called isogonic lines.

Isoclinical lines: - The lines joining the places of equal dip or inclination are called isoclinical lines

Isodynamic lines: The lines joining the places having the same value of the horizontal component of earth's magnetic field are called isodynamic line.

Previous years CBSE board questions

1. A coil of N turns and radius R carries a current I. It is unwound and rewound to make another coil of radius $\frac{R}{2}$, current I remaining the same. Calculate the ratio of the magnetic moments of the new coil and the original coil.

Ans: If L is the length of the wire
then $L = N \times 2\pi R = N' \times 2\pi \frac{R}{2}$

Number of turns in new coil

$N \times \cancel{2\pi} R = N' \times \cancel{2\pi} \frac{R}{2}$

$N = \frac{N'}{2}$

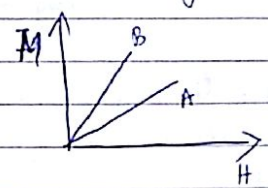
or $N' = 2N$.

Original magnetic moment $M = NIA$
$= NI\pi R^2$

New magnetic moment $M' = N'IA'$
$= 2NI\left(\pi \frac{R}{2}\right)^2$

$\frac{m'}{m} = \frac{1}{2} = 1:2$

2. Figure shows the variation of intensity of magnetisation versus the applied magnetic field intensity H, for two magnetic materials A and B.



(a) Identify the materials A and B.
(b) For the material A, plot the variation of intensity of magnetisation versus temperature.

Ans: (a) Slope of the graph $= \frac{M}{H} = \chi$.

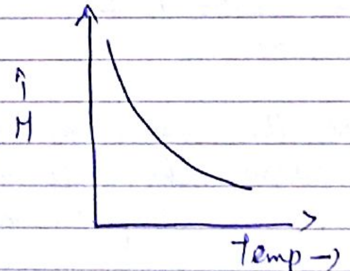
Slope of B > Slope of A

∴ χ of B > χ of A.

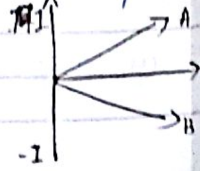
∴ for material A slope is +ve and smaller
it is likely to be paramagnetic
and for material B slope is +ve and large
it is likely to be ferromagnetic.

(b) For A material is paramagnetic
∴ its susceptibility is inversely
proportional to temperature
which means that magnetisation is
also inversely proportional to temperature

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

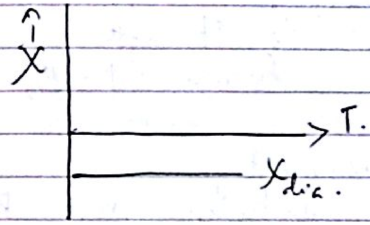


3. Figure shows the variation of intensity of magnetisation versus the applied magnetic field intensity H, for two magnetic materials A and B.
(a) Identify the materials A and B.
(b) Draw the variation of susceptibility with temperature for B.



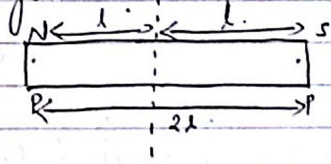
Ans: (a) For material A, the susceptibility χ = slope of the graph $\chi = \frac{M}{H}$ is small and positive so it is paramagnetic
For material B, the susceptibility χ is small and negative, so it is diamagnetic

(b) The susceptibility of the diamagnetic material B is independent of temperature



4. How does the (i) pole strength and (ii) magnetic moment of each part of a bar magnet change if it is cut into two equal pieces transverse to its length ?

Ans:



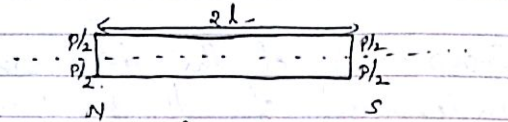
(i) Pole strength of each part remains same as that of the original magnet

(ii) Magnetic moment of each part is half of that of the original because length of each part is halved.

Initially $m = q \times 2l$
when it is cut in two equal pieces along its length
$m = q \times l$.

5. How does the (i) pole strength and (ii) magnetic moment of each part of a bar magnet change if it is cut into two equal pieces along its length?

Ans.



(i) Pole strength of each part becomes half of the original pole strength

because $p = P/_2$.

(ii) Magnetic moment

Initially $m = P \times 2l$.

when it cut along its length

$m = P/_2 \times 2l$

$= \frac{1}{2} \times p\,2l$.

= half of the original magnetic moment.

6. What will be the value of the horizontal component of earth's magnetic field at earth's geomagnetic pole?

Ans. At poles $\delta = 90°$

Horizontal component $B_H = B \cos \delta$

$= B \cos 90$

$= 0$

7. Horizontal component of earth's magnetic field at a place is $\sqrt{3}$ times the vertical component. What is the value of angle of dip at this place?

Ans: $\tan \delta = \frac{B_V}{B_H}$

$= \frac{B_V}{\sqrt{3} B_V}$

$= \frac{1}{3}$

$\therefore \delta = 30°$

8. If the horizontal component and vertical components of earth's magnetic field are equal at a place, find the angle of dip.

Ans: $B_V = B_H$

$\tan \delta = \frac{B_V}{B_H} = 1 \quad \therefore \delta = 45°$.

9. If magnetic monopoles existed, how would Gauss's law of magnetism be modified?

Ans. If the magnetic monopoles existed then the flux of $\vec{B}$ through any closed surface would be equal to μ_0 times the monopoles strength (p)

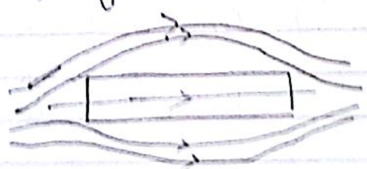
$\therefore$ The modified Gauss's law of magnetism would be

$$\oint_s \vec{B} \cdot \vec{ds} = \mu_0 p.$$

10. The susceptibility of a magnetic material is -0.085. Identify the magnetic type of

the substance. A specimen of this material is kept in a uniform magnetic field. Draw the modified field pattern.

Ans: As the Susceptability has a small negative value, so the given material is diamagnetic.
When a specimen of this material is placed in a uniform magnetic field, the lines of force get expelled from it as shown in



11. A magnetising field of 1500 A/m produces a flux of 2.4×10^{-5} Weber in a bar of cross-sectional area $0.5\,cm^2$. Calculate the permeability and susceptability of the iron bar used.

$H = 1500\ A/m$.
$\phi = 2.4 \times 10^{-5}\ Wb$.
$A = 0.5 \times 10^{-4}\ m^2$

$$B = \frac{\phi}{A} = \frac{2.4 \times 10^{-5}}{0.5 \times 10^{-4}} = 0.48\ T$$

· Permeability $\mu = \frac{B}{H} = \frac{0.48}{1500}$

$= 3.2 \times 10^{-4}\ TmA^{-1}$

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

$$\chi_m = \frac{\mu}{\mu_0} - 1 = \frac{3.2 \times 10^{-4}}{4 \times 3.14 \times 10^{-7}} - 1 = 254.77 - 1$$

$= 253.77$