5. Magnetism & Matter

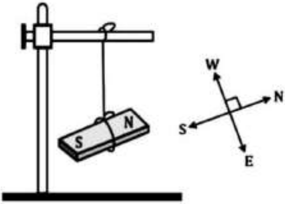
A Greek philosopher Thales had observed that a naturally occuring ore of iron attracted small pieces of iron towards it. This ore was found in an island in Greece called Magnesia. Hence that ore was named Magnetite.

Magnetism -

The phenomena of attraction of small bits of iron, steel, Cobalt, nickel etc. towards the ore is called magnetism. The structural formula of this natural ore was Fe_3O_4.

The Chinese discovered that a piece of magnetite when suspended freely, it always points out roughly in the north south direction.

- Thus a natural magnet has attractive and directive properties.



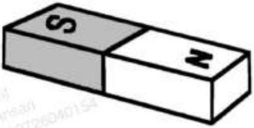
Artificial Magnets -

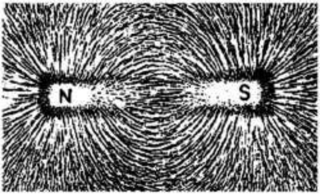
The natural magnets have often irregular shape and they are weak. It is found that a piece of iron or steel can acquire magnetic properties on rubbing with a magnet. Such magnets made out of iron and steel are called artificial magnets.

A bar magnet, a horse shoe magnet, magnetic needle etc. all are artificial magnets.

Bar Magnet

It is the most commonly used form of an artificial magnet which have north pole and south pole of same strength at some distance.





When we hold a sheet of glass over a short bar magnet and sprinkle some iron filings on the sheet then the iron filings rearrange themselves as shown in figure. The pattern suggests that attraction is maximum at the two ends of the bar magnet. These ends are called poles of the magnet.

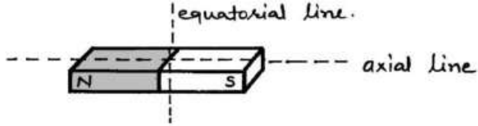
Basic properties of Bar Magnet

(1.) Every magnet attracts small piece of magnetic substances like iron, cobalt, nickel and steel towards it.

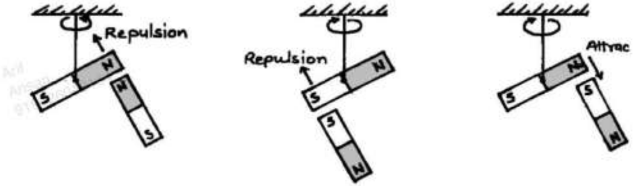
(2) When a magnet is suspended freely with the help of a thread, then it comes to rest along the north south direction.

The pole of the magnet which points towards geographic north is called north pole and the pole which points towards geographic south is called south pole.

(3) The straight line passing through north and south pole of magnet is called axial line. and the line passing through centre of the magnet in a direction perpendicular to the length of the magnet is called equatorial line of the magnet.



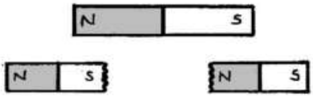
(4) Like poles repel and unlike poles attract each other.



(5) Inductive property

When a piece of a magnetic material like soft iron, cobalt, nickel etc. is placed near a bar magnet, it acquires magnetism. The magnetism so acquired is called induced magnetism and this property of magnetism is called inductive property.

(6) The magnetic poles always exist in pairs. The poles of a magnet can never be separated i.e. magnetic monopole do not exists.



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Magnetic Field

It is the space around a magnet or a current carrying conductor in which its magnetic effect can be felt.

In order to visualise a magnetic field graphically, Faraday introduced the concept of the magnetic field lines.

Magnetic Field Lines-

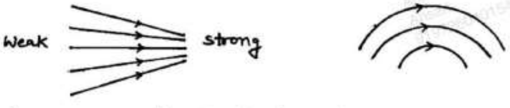
It is an imaginary curve, the tangent to which at any point gives us the direction of magnetic field $\vec{B}$ at that point.

There are basically two types of magnetic field-

(i) Uniform Magnetic Field-

Examples- Earth's magnetic Field, Magnetic field inside a solenoid carrying current etc.

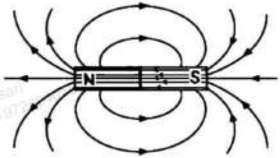
(ii) Non-Uniform Magnetic Field-

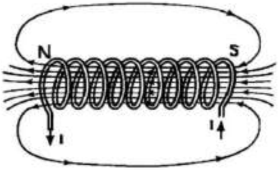


Example- Magnetic Field due to a bar Magnet.

Properties of Magnetic Field Lines

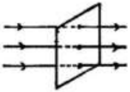
(1.) The magnetic field lines of a magnet (or of a solenoid) form closed continuous loops.
The magnetic field lines extending through the body of the magnet/solenoid from south pole to north pole.



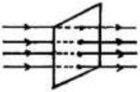


(2) Outside the body of the magnet the direction of magnetic field lines is from north pole to south pole.

(3) The magnitude of magnetic field at any point is represented by the number of magnetic field lines passing normally through unit area around that point.

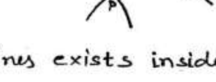


Weak Magnetic Field



Strong Magnetic field

(4) Two magnetic field lines can not intersect each other. Because at the point of intersection we get two directions of magnetic field which is not possible.



(5) Magnetic field lines exists inside every magnetised material.

Note - The electric field lines continuous curves which are not closed, whereas magnetic field lines are closed continuous curves

Magnetic Dipole -

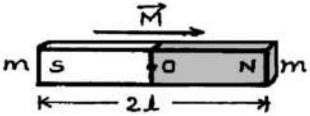
A magnetic dipole consist of two unlike poles of equal strength and separated by a small distance.

The distance between the two poles of a magnetic dipole is called the magnetic length of the magnet. It is a vector directed from south pole to north pole of the magnetic dipole. It is represented by $2\vec{l}$.

Magnetic Dipole Moment ($\vec{M}$)

It is the product of strength of either pole (m) and the magnetic length ($2\vec{l}$) of the magnet. It is represented by $\vec{M}$.

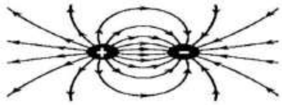
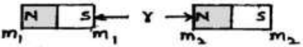
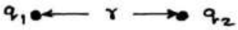
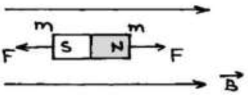
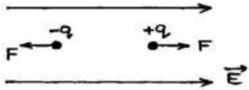
$$\vec{M} = m(2\vec{l})$$



* Magnetic dipole moment is a vector quantity and its direction is from south to north pole of the magnet.

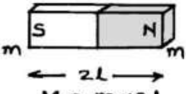
    * SI unit of $\vec{M}$ is **Jule/Tesla**
    * SI unit of pole strength m is **A-m.**

Note - Magnetic pole strength depend on nature and cross section area of the material

Magnetic Dipole	Electric Dipole
 $\vec{M} = m \times 2\vec{l}$	 $\vec{P} = q \times 2\vec{a}$
 $F = \frac{\mu_0}{4\pi} \frac{m_1 m_2}{r^2}$ $\frac{\mu_0}{4\pi} = 10^{-7}$ wb/A.m	 $F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$ $\frac{1}{4\pi\epsilon_0} = 9 \times 10^9$ Nm^2/c^2
 $F = mB$	 $\vec{F} = q\vec{E}$

Note -

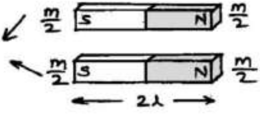
(i) When we cut a bar magnet along the length in two equal parts then its pole strength becomes half.



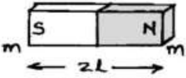
$M = m \times 2l$

$\Rightarrow M' = \frac{m}{2} \times 2l$

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

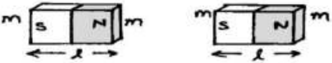


(ii) When we cut a bar magnet perpendicular to its length in two equal parts, then its pole strength remains the same.



$M = m \times 2l$

$\Rightarrow$



$M' = m \times l \Rightarrow M' = \frac{M}{2}$

Magnetic Field Strength due to Bar Magnet

The strength of magnetic field at any point is defined as the force experienced by a hypothetical unit north pole placed at that point.

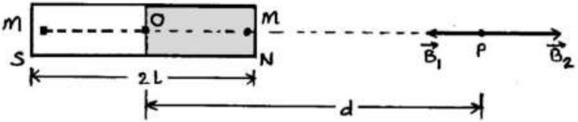
It is a vector quantity. The direction of magnetic field is along which hypothetical unit north pole would tend to move

(A) When a point lies on axial Line

Let $2l$ be the magnetic length of a bar magnet with centre O. M is the magnetic dipole moment of the magnet.

where $$\boxed{M = m \times 2l}$$

Here $OP = d$ is the distance of the point P on the axial line from the centre of the magnet.



If m is the strength of each pole, then magnetic field strength at point P due to S pole of magnet is -

$$B_1 = \frac{\mu_0}{4\pi} \frac{m}{(d+l)^2}$$

Magnetic field strength at P due to N pole of magnet -

$$B_2 = \frac{\mu_0}{4\pi} \frac{m}{(d-l)^2}$$

So the Magnetic field strength at P due to the bar magnet is -

$$B = B_2 - B_1$$

$$B = \frac{\mu_0}{4\pi}\frac{m}{(d-l)^2} - \frac{\mu_0}{4\pi} \times \frac{m}{(d+l)^2}$$

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

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

$$B = \frac{\mu_0}{4\pi} \frac{m \cdot 4ld}{(d^2-l^2)^2} = \frac{\mu_0}{4\pi} \frac{2Md}{(d^2-l^2)^2}$$

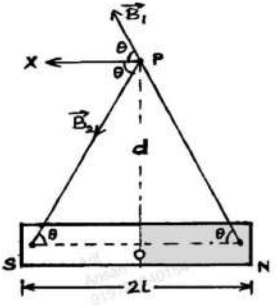
When the magnet is short ($l^2 << d^2$) so -

$$B = \frac{\mu_0}{4\pi}\frac{2Md}{d^4} \quad \text{or} \quad \boxed{\vec{B} = \frac{\mu_0}{4\pi}\frac{2\vec{M}}{d^3}} \quad (\text{Along NP})$$

* At any point on axial line of a dipole, magnetic field strength $\vec{B_1}$ is along $\vec{M}$

(B) When point Lies on equatorial line

Let here $OP = d$ and point P lies on equatorial line of the bar magnet.



Magnetic field strength at P due to North pole of magnet-

$$B_1 = \frac{\mu_0}{4\pi}\frac{m}{(d^2+l^2)}$$

Magnetic field strength at P due to south pole of magnet-

$$B_2 = \frac{\mu_0}{4\pi}\frac{m}{(d^2+l^2)}$$

As $B_1 = B_2$ in magnitude, so their vertical components $B_1 \sin\theta$ and $B_2 \sin\theta$ cance each other. However, components along PX add up.

Therefore Magnetic field strength at P due to the bar magnet is -

$$B = B_1 \cos\theta + B_2 \cos\theta$$

$$= 2 B_1 \cos\theta \quad (\text{along } PX)$$

so $$B = \frac{2\mu_0}{4\pi} \frac{m}{(d^2+l^2)} \times \frac{L}{\sqrt{(d^2+L^2)}} \quad \left[\cos\theta = \frac{L}{\sqrt{d^2+l^2}}\right.$$

$$\boxed{B = \frac{\mu_0}{4\pi} \frac{M}{(d^2+l^2)^{3/2}}}$$

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If the magnet is short ($l^2 << d^2$) then

$$B = \frac{\mu_0}{4\pi} \frac{M}{d^3} \quad \text{or} \quad \boxed{\vec{B} = -\frac{\mu_0}{4\pi} \frac{\vec{M}}{d^3}}$$

* An any point on equatorial line, magnetic field strength is in the direction opposite to $\vec{M}$.

Note- Magnetic field due to a short Magnet at any point on axial line of magnet is twice the magnetic field at a point at the same distance on the equatorial line of the magnet.

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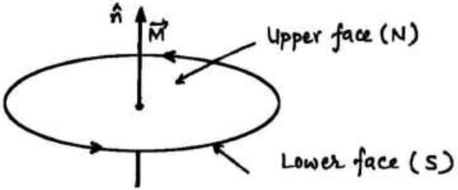
Current Loop as a Magnetic Dipole

Consider a plane loop of wire carrying current in anticlockwise direction. Therefore, it has a north polarity.

Looking at the lower face of the loop current is clockwise, therefore it has a south polarity.



Thus the current carrying loop behaves as a magnetic dipole.

The magnetic dipole moment of the current loop (M) is directly proportional to

$$M \propto I$$

& $$M \propto A$$

So $$M = KIA \quad \text{(Here } K = 1\text{)}$$

$$M = IA$$

for N turns $$\boxed{\vec{M} = NI\vec{A}}$$

SI Unit - ampere meter^2 (Am^2)

1 ampere meter^2 -

It is the magnetic moment of one turn loop of area one square meter carrying a current of one ampere.

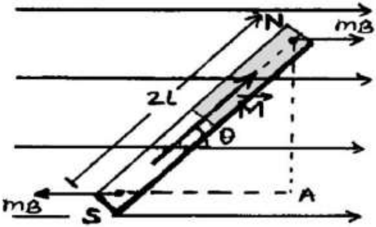
Torque on a Bar Magnet in a Magnetic field

The magnet is held at angle θ with the direction of $\vec{B}$.

Force on north pole = mB (along $\vec{B}$)

Force on South pole = mB (opposite to $\vec{B}$)

These forces are equal and tends to rotate the magnet clockwise.



Torque acting on the bar magnet is –

$$\text{Torque } (\tau) = \text{Force} \times \text{perpendicular distance}$$
$$= mB \times NA$$

In ΔNAS $\quad \sin\theta = \frac{NA}{2l}$

$\therefore \quad NA = 2l\sin\theta$

So $\quad \tau = mB \times 2l\sin\theta$

$$\boxed{\tau = MB\sin\theta} \quad (M = m \times 2l)$$

$$\boxed{\vec{\tau} = \vec{M} \times \vec{B}}$$

The direction of $\vec{\tau}$ is perpendicular to the plane containing $\vec{M}$ and $\vec{B}$ and is given by the right hand rule.

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When $B = 1$ and $\theta = 90^\circ$ then

$$\tau = M \times 1 \times \sin 90^\circ \Rightarrow \boxed{\tau = M}$$

Magnetic dipole moment is the torque acting on a dipole held perpendicular to a uniform magnetic field of unit strength.

SI Unit of $\vec{M}$ = Joule per Tesla (JT^{-1})

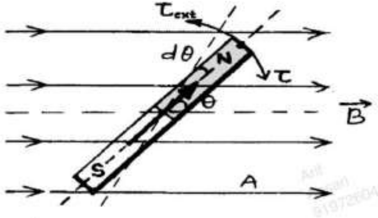
Potential Energy of a Magnetic Dipole in a Magnetic Field

The energy possessed by the dipole due to its particular position in the field is the potential energy of a magnetic dipole.

When a magnetic dipole of moment $\vec{M}$ is held at an angle θ with the direction of a uniform magnetic field $\vec{B}$, so the magnitude of the torque acting on the dipole is -

$$\boxed{\tau = MB\sin\theta}$$

This torque tend to align the dipole in the direction of the field. Work has to be done in rotating the dipole against the action of the torque.
This work done is stored in the magnetic dipole as potential energy of dipole.



Now, small amount of work done in rotating the dipole through a small angle $d\theta$ against the rotating torque is -

$$dW = \tau\, d\theta = MB\sin\theta\, d\theta$$

Total work done in rotating the dipole from θ_1 to θ_2 is

$$W = \int_{\theta_1}^{\theta_2} MB\sin\theta \, d\theta = MB\left[-\cos\theta\right]_{\theta_1}^{\theta_2}$$

$$W = -MB\left[\cos\theta_2 - \cos\theta_1\right]$$

So the potential energy of the dipole is -

$$\boxed{\Delta U = W = -MB\left(\cos\theta_2 - \cos\theta_1\right)}$$

When $\theta_1 = 90^\circ$ and $\theta_2 = \theta$ then.

$$\boxed{\begin{aligned} U &= W = -MB\cos\theta \\ U &= -\vec{M}\cdot\vec{B} \end{aligned}}$$

Special Cases -

(i) When $\theta = 90^\circ$ then

$$U = -MB\cos 90^\circ = 0$$

when the dipole is perpendicular to magnetic field its potential energy is zero.

(ii) When $\theta = 0^\circ$ then

$$U = -MB\cos 0^\circ = -MB$$

It is minimum. This is the position of stable equilibrium.

So when the magnetic dipole is aligned along the magnetic field, it is in stable equilibrium having minimum P.E.

(iii) When $\theta = 180^\circ$ then

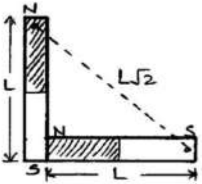
$$U = -MB\cos 180^\circ = MB$$

It is maximum. This is the position of unstable equilibrium.

Q.1 Two identical thin bar magnets, each of length L and pole strength m are placed at right angles to each other, with the N-pole of one touching the S-pole of the other. Find the magnetic moment of the system.

Sol.

Here the system behaves as a magnet whose pole stength is m and length is $L\sqrt{2}$



So the magnetic moment of the system is

$$M = \text{Pole strength} \times L\sqrt{2}$$

$$M = \sqrt{2}\, mL$$

Q. What is the magnitude of the equatorial and axial fields due to a bar magnet of length 5 cm at a distance of 50 cm. from its mid point? . The magnetic moment of the bar magnet is $0.4\ Am^2$.

Sol. on axial line the magnetic field is

$$B_1 = \frac{\mu_0}{4\pi}\frac{2Md}{(d^2-l^2)^2} = \frac{\mu_0}{4\pi}\frac{2M}{d^3} \qquad (l \ll d)$$

$$B_1 = \frac{10^{-7}\times 2\times 0.4}{(0.5)^3} = 6.4\times 10^{-7}\ T$$

on equatorial line the magnetic field is.

$$B_2 = \frac{\mu_0}{4\pi}\times\frac{M}{(d^2+l^2)^{3/2}} = \frac{\mu_0}{4\pi}\frac{M}{d^3} \qquad (l \ll d)$$

$$B_2 = 10^{-7}\times\frac{0.4}{(0.5)^3} = 3.2\times 10^{-7}\ T$$

Q. A bar magnet of magnetic moment $1.5\ JT^{-1}$ lies aligned with the direction of a uniform magnetic field of 0.22 T.

(a) What is the amount of work done to turn the magnet so as to align its magnetic moment

(i) Normal to the field direction

(ii) Opposite to the field direction ?

(b) What is the torque on the magnet in cases (i) and (ii) ?

Sol. Here $M = 1.5\ JT^{-1}$, $B = 0.22\ T$

(a) (i) Here $\theta_1 = 0°$ (along the fied)

$\theta_2 = 90°$ ($\perp$ to the field)

As $W = -MB(\cos\theta_2 - \cos\theta_1)$

$\therefore$ $W = -1.5 \times 0.22 (\cos 90° - \cos 0°)$

$= -0.33(0-1) = 0.33\ J$

(ii) Here $\theta_1 = 0°$, $\theta_2 = 180°$

$W = -1.5 \times 0.22 (\cos 180° - \cos 0°)$

$= -0.33(-1-1) = 0.66\ J$

(b) Torque $\tau = MB\sin\theta$

(i) Here $\theta = 90°$

so $\tau = 1.5 \times 0.22 \sin 90° = 0.33\ Nm$

(ii) Here $\theta = 180°$

so $\tau = 1.5 \times 0.22 \sin 180° = 0$

Q. A circular coil of 16 turns and radius 10 cm. carrying a current of 0.75 A rests with its plane normal to an external field of magnitude 5×10^{-2} T. The coil is free to turn about an axis in its plane perpendicular to the field direction. when the coil is turned slightly and released, it oscillates about its stable equilibrium with a frequency of $2\ s^{-1}$. What is the moment of inertia of the coil about its axis of rotation?

Sol. Here $N = 16$, $r = 10$ cm $= 0.1$ m.

$I = 0.75$ A, $B = 5 \times 10^{-2}$ T, $\nu = 2\ s^{-1}$

So that $M = NIA = NI\pi r^2$

$$M = 16 \times 0.75 \times 3.14 \times (0.1)^2$$

$$M = 0.377\ J T^{-1}$$

As $\nu = \frac{1}{2\pi}\sqrt{\frac{MB}{I}}$ where I is the moment of inertia of the coil.

$$\therefore\ I = \frac{MB}{4\pi^2 \nu^2} = \frac{0.377 \times 5 \times 10^{-2}}{4 \times (3.14)^2 \times 2^2}$$

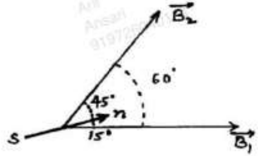
$$I = 1.2 \times 10^{-4}\ Kg m^2.$$

Q. A magnetic dipole is under the influence of two magnetic fields. The angle between the field directions is 60° and one of the fields has a magnitude of 1.2×10^{-2} T. If the dipole comes to stable equilibrium at an angle of 15° with this field, what is the magnitude of the other field?

Sol. Here $\theta = 60°$

$B_1 = 1.2 \times 10^{-2}$ T

$\theta_1 = 15°$, $\theta_2 = 60° - 15° = 45°$



In equilibrium, torques due to two fields must balance.

$$\tau_1 = \tau_2$$

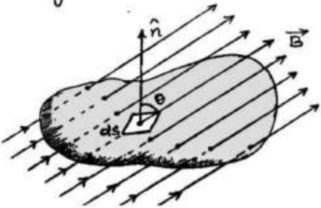
$$MB_1 \sin\theta_1 = MB_2 \sin\theta_2$$

$$B_2 = \frac{B_1 \sin\theta_1}{\sin\theta_2} = \frac{1.2 \times 10^{-2} \times \sin 15^\circ}{\sin 45^\circ}$$

$$B_2 = \frac{1.2 \times 10^{-2} \times 0.2588}{0.7071} = 4.4 \times 10^{-3}\ T$$

Gauss's Law for Magnetism

According to Gauss's Law for magnetism, the net magnetic flux (ϕ_B) through any closed surface is always zero.



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Consider a small vector area element $\vec{ds}$ of this surface. Magnetic flux through this area element is defined as

$$d\phi_B = \vec{B} \cdot \vec{ds}$$

Summing over all small area elements of the surface we obtain according to Gauss's Law for magnetism.

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

* The law implies that the number of magnetic field lines leaving any closed surface is always equal to the number of magnetic field lines entering it.
* The fact that $\phi_B = 0$ indicates that the simplest magnetic element is a dipole or current loop. The isolated magnetic poles (called magnetic monopoles) are not known to exist.

Magnetic Field of Earth

Sir william Gilbert was the first to suggest in the year 1600, that earth itself is a huge magnet.

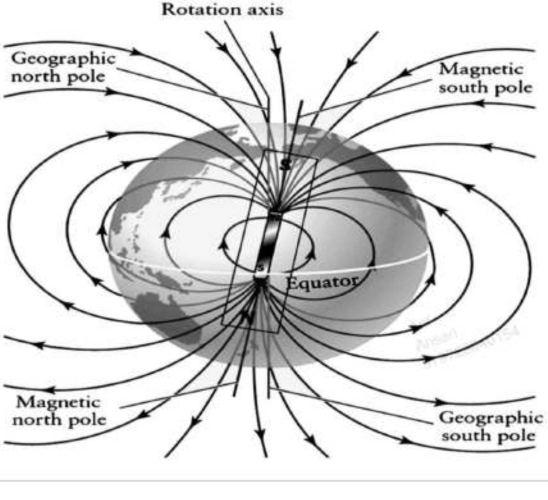
A magnet suspended from a thread and free to rotate in the horizontal plane comes to rest along the north-south direction.

This is like a huge bar magnet is placed approximately along the axis of rotation of earth and deep in its interior.

The north pole of this imaginary magnet must be towards geographic south so as to attract south pole of the suspended magnet and vice-versa.

The imaginary magnetic axis of earth makes an angle of 12' with the geographic rotational axis.

Magnetic poles are approximately 2000 km. away from the geographic poles.



Cause of Earth's Magnetism

The exact causes of earth's magnetism is not yet known fully. However, some important postulates in this respect are as follows -

(i) Earth's magnetism may be due to rotation of earth about its axis. This is because every substance is made up of charged particles (protons & electrons). Therefore a substance rotating about an axis is equivalent to circulating currents, which are responsible for magnetism.

(ii) In the outer layers of earth's atmosphere, gases are in the ionised state, primarily on account of cosmic rays. As earth rotates, strong electric currents are set up due to movement of (charged) ions. These currents might be magnetising the earth.

(iii) The earth's core is extremely hot and molten. circulating ions of iron and nickel in the highly conducting liquid region of the earth's core might be forming current loops and producing earth's magnetic field.

Magnetic Elements of Earth

Magnetic elements of earth at a place are the quantities which describe completely in magnitude as well as direction the magnetic field of earth at that place.

Magnetic axis :-

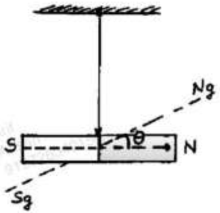
The line joining the north and south poles of a freely suspended magnet is called magnetic axis.

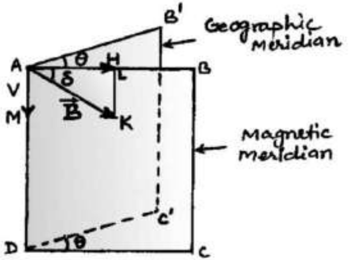
Geographic axis :-

The axis about which earth rotates is the geographic axis.

(i) Magnetic declination (θ)

The small angle between magnetic axis and geographic axis at a place is defined as the magnetic declination at the place.





Magnetic Meridian

A verticle plane passing through N-S line of a freely suspended magnet is called magnetic meridian.

Geographic Meridian

The verticle plane passing through the geographic north south direction is called geographic meridian.

Here in figure CD represents the magnetic axis and C'D represents the geographic axis.

The verticle plane CDAB is the magnetic meridian and verticle plane C'DAB' is the **geographic meridian.**

(ii) Magnetic Dip or Magnetic Inclination (δ)

It is defined as the angle, which the direction of total strength of earths magnetic field makes with a horizontal line in magnetic meridian.

At different places on the surface of earth, δ is different. The angle of dip at two poles is 90°. On the magnetic equator, the angle of dip is zero. At other places, the value of δ lies between 0° and 90°.

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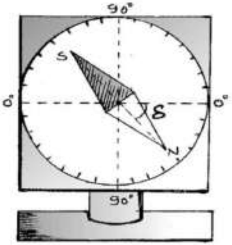
Note -

* The magnetic declination θ is determined by a compass needle, free to rotate in the horizontal plane about the verticle axis.

* The magnetic dip angle δ is measured by allowing the compass needle to rotate freely in the verticle plane of magnetic meridian about the horizontal axis.

The value of magnetic dip at a place can be measured using an instrument called **'dip circle'**.



(iii) Horizontal Component (H) -

It is the Component of the total intensity of earth's magnetic field in the horizontal direction in magnetic meridian.

The resultant intensity B along AK is resolved into two rectangular components-

Horizontal Component along AB $\quad H = B\cos\delta$

Verticle Component along AD $\quad V = B\sin\delta$

So $$\boxed{B = \sqrt{H^2 + V^2}}$$

and $$\boxed{\tan \delta = \frac{V}{H}}$$

The value of horizontal Component (H) is different at different places.

(i) At the Magnetic poles ($\delta = 90^\circ$) $\boxed{H = \text{zero}}$

(ii) At the Magnetic equator ($\delta = 0^\circ$) $\boxed{H = R}$

- ✱ The value of H at a place on the surface of earth is of the order of 3.2×10^{-5} T.
- ✱ The direction of the Horizontal Component H of the earth's magnetic field is from geographic south to geographic north above the surface of earth.

Q. The vertical component of earth's magnetic field at a place is $0.16\sqrt{3} \times 10^{-4}$ T. Calculate the value of horizontal component of earth's magnetic field, if angle of dip at that place is 30°.

Sol. Here $V = 0.16\sqrt{3} \times 10^{-4}$ T , $\delta = 30^\circ$

From $\tan \delta = \frac{V}{H}$

$$H = \frac{V}{\tan \delta} = \frac{0.16\sqrt{3} \times 10^{-4}}{\tan 30^\circ}$$

$$H = \frac{0.16\sqrt{3} \times 10^{-4}}{1/\sqrt{3}} = 0.48 \times 10^{-4} \text{ T}$$

Q. The horizontal component of the earth's magnetic field at a place is $\sqrt{3}$ times its vertical component there. Find the value of the angle of dip at that place. What is the ratio of the horizontal component to the total magnetic field of the earth at that place?

CBSE 2010

Sol. Here $H = \sqrt{3}V$, where H and V are the horizontal and vertical components of earth's magnetic field.

If angle of dip at that place is δ, then

$$\tan\delta = \frac{V}{H} = \frac{V}{\sqrt{3}V} = \frac{1}{\sqrt{3}}$$

So that $$\delta = \tan^{-1}\left(\frac{1}{\sqrt{3}}\right) = \frac{\pi}{6}$$

Horizontal component of earth's magnetic field

$$H = R\cos\delta \qquad (R \rightarrow \text{earth's magnetic field})$$

$$\frac{H}{R} = \cos\delta = \cos\frac{\pi}{6}$$

So $$\frac{H}{R} = \frac{\sqrt{3}}{2}$$

Q. The horizontal component of earth's magnetic field at a place is B and angle of dip is 60°. What is the value of vertical component of earth's magnetic field at equator?

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Sol. Horizontal Component

$$H = R\cos 60^\circ = B \quad (\text{given})$$

$$R = \frac{B}{\cos 60^\circ} = \frac{B}{1/2} = 2B$$

Vertical Component

$$V = R\sin 60^\circ$$

$$= 2B \times \frac{\sqrt{3}}{2} = \sqrt{3}\,B$$

Some Important Terms used in Magnetism

(i) Magnetic Permeability (μ)

It is the ability of a material to permit the passes of magnetic lines of force through it.

The degree or extent to which magnetic field can penetrate or permeate a material is called relative magnetic permeability of the material. It is represented by μ_r.

Relative Magnetic permeability of a material

The relative magnetic permeability of a material may also be defined as the ratio of magnetic permeability of the material (μ) and magnetic permeability of free space (μ_0).

$$\mu_r = \frac{\mu}{\mu_0} \quad \text{or} \quad \mu_r = \frac{B}{B_0}$$

μ_r has no dimensions. Its value is 1 for vacuum.

$$\mu_0 = 4\pi \times 10^{-7} \text{ Wb A}^{-1} \text{m}^{-1}$$

(ii) Magnetising Force or Magnetic Intensity (H)

The degree to which a magnetic field can magnetise a material is represented in terms of magnetising force or magnetic intensity (H).

Lets consider a toroidal solenoid with n turns per unit length carrying a current I wound round a ring of a magnetic material.

The magnetic field produced in the material is

$$B = \mu n I$$

The product nI is called the magnetising force or magnetic intensity H.

$$\text{So} \quad B = \mu H \quad \text{or} \quad H = \frac{B}{\mu}$$

If inside the toroidal solenoid, there is free space, then magnetic field.

$$\boxed{B_0 = \mu_0 H} \quad \text{or} \quad \boxed{H = \frac{B_0}{\mu_0}}$$

The SI unit of H is Ampere turn/m (Am^{-1})

(iii) Magnetisation Intensity (I)

The Magnetisation intensity of a magnetic material is defined as the magnetic moment per unit volume of the material.

$$\boxed{I = \frac{\text{Magnetic moment}}{\text{Volume}} = \frac{M}{V}}$$

$$\boxed{I = \frac{m \times 2L}{A \times 2L} = \frac{m}{A}} \qquad \boxed{I = \frac{B_m}{\mu_0}}$$

Hence the Magnetisation intensity of a material is also defined as the pole strength per unit area of cross-section of the material.

$$I = \frac{\text{Magnetic moment}}{\text{Volume}} = \frac{\text{Amp} \cdot \text{metre}^2}{\text{metre}^3} = Am^{-1}$$

So the SI unit of I is Am^{-1}

(iv) Magnetic Susceptibility (χ_m)

It is a property which determine how easily a material can be magnetised.

Susceptibility of a magnetic material is defined as the ratio of the intensity of magnetisation (I) induced in the material to the magnetising force (H) applied on it.

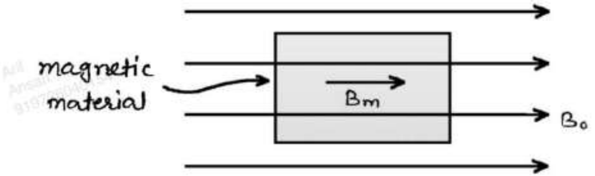
Magnetic susceptibility is represented by χ_m.

$$\boxed{\chi_m = \frac{I}{H}}$$

As unit of I and H are same (Am^{-1}), therefore (χ_m) has no units and no dimensions.

Relation between Magnetic Permeability and Magnetic Susceptibility -

When a magnetic material is placed in a magnetic field of Magnetic Intensity H, the material get magnetised.



The total magnetic field B in the material is the sum of the magnetic field B_0 in vacuum produced by the magnetic intensity and magnetic field B_m, due to magnetisation of the material.

$$\boxed{B = B_0 + B_m}$$

But $B_0 = \mu_0 H$ $\quad B_m = \mu_0 I$ and $B = \mu H$

So $\mu H = \mu_0 H + \mu_0 I$

dividing by $\mu_0 H$ we get

$$\frac{\mu}{\mu_0} = 1 + \frac{I}{H}$$

so $\boxed{\mu_r = 1 + \chi_m}$ as $\chi_m = I/H$

This is the relation between the relative magnetic permeability and magnetic susceptibility of the material.

Some Important terms used in Magnetism

	Physical Quantity	Symbol	Nature	Units	Remarks
1.	Magnetic field, magnetic flux density, Magnetic Induction,	$\vec{B}$	Vector	T	$1T = 10^4 G$ G → Gauss
2.	Magnetic Intensity Magnetising force	$\vec{H}$	Vector	Am^{-1}	
3.	Magnetisation Intensity	$\vec{I}$	Vector	Am^{-1}	$\vec{I} = \frac{\vec{M}}{V}$
4.	Magnetic Moment	$\vec{M}$	Vector	Am^2	
5.	Magnetic Permeability	μ	Scalar	TmA^{-1}	
6.	Magnetic Permeability of free space	μ_0	Scalar	TmA^{-1}	$\frac{\mu_0}{4\pi} = 10^{-7}$
7.	Relative Magnetic Permeability	μ_r	Scalar	No	$\mu_r = \frac{\mu}{\mu_0}$
8.	Magnetic Susceptibility	χ_m	Scalar	No	$\mu_r = 1 + \chi_m$

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Q. A 1m long iron bar of cross section area $1 mm^2$ is placed inside a solenoid. If the magnetising force inside the Solenoid is 4×10^3 A/m then find the magnetic dipole moment of the iron bar.
(Magnetic permeability of iron = $16\pi \times 10^{-5}$ H/m)

Answer: 1.596 Am^2

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Classification of Magnetic Materials

Diamagnetic | Paramagnetic | Ferromagnetic

(i) Diamagnetic Substances -

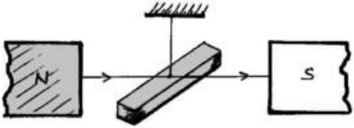
The diamagnetic substances are those in which the individual atoms / molecules / ions do not possess any net magnetic moment on their own.

When such substances are placed in an external magnetic field they get weekly magnetised in a direction opposite to the magnetising field.

Examples- Antimony, Bismuth, Copper, Lead, Quartz, Water, Mercury, Hydrogen, inert gases etc.

Properties -

(i) When diamagnetic substances are suspended in a uniform magnetic field, they set their longest axis at right angle to the direction of the field.

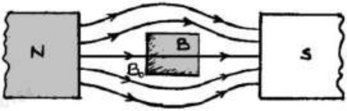


(ii) When diamagnetic substances are placed in a non-uniform magnetic field, these substances have a tendency to more from stonger parts of the field to the weaker parts.

(a) (b)

(iii) When a piece of diamagnetic material is placed in a magnetising field, the magnetic field lines prefer not to pass through the material.

It implies that the magnetic field lines are repelled and the field inside the material is reduced slightly.



$B < B_0$

(iv) Relative magnetic permeability of diamagnetic substances is always less than unity.

$$\mu_r = \frac{B}{B_0} \qquad \text{as} \quad B < B_0$$

So $\boxed{\mu_r < 1}$

(v) As $\mu_r = 1 + \chi_m$

and $\mu_r < 1$ so **χ_m is negative**

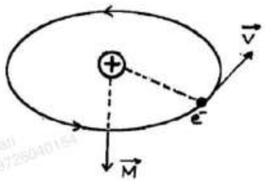
Hence susceptibility of diamagnetic material has a small negative value.

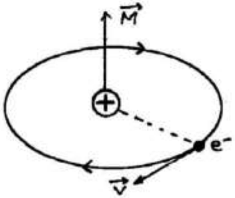
(vi) Susceptibility of diamagnetics does not change with temperature.

Explanation of Diamagnetism -

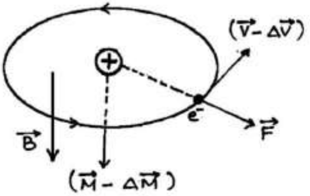
In a diamagnetic substance the motion of all the electrons in an atom is assumed as the motion of two electrons revolving with same angular velocity in a circular orbit of same radius, but in opposite sense.

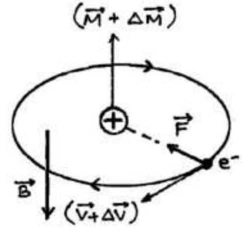
In the absence of any external magnetic field the magnetic moment of two electrons being equal and opposite and cancel each other for every atom, so that net magnetic moment of each atom is zero.





When a uniform magnetic field $\vec{B}$ be applied then each electron experiences a magnetic Lorentz force $F = evB$. According to Fleming's Left hand rule, the Lorentz force F acts radially outwards on the electron revolving anti-clockwise. It tends to decrease the centripetal force and hence decrease the velocity of electron to $(\vec{V} - \Delta\vec{V})$. As a result, the magnetic moment of electron decreases to $(\vec{M} - \Delta\vec{M})$.



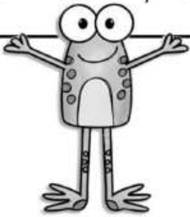


On the electron revolving clockwise, the Lorentz force acts radially inwards, tending to increase the centripetal force and hence the velocity of electron to $(\vec{V} + \Delta\vec{V})$. Therefore, the magnetic moment of electron increases to $(\vec{M} + \Delta\vec{M})$.

The vector addition of these two magnetic moments gives rise to a net dipole magnetic moment $2\Delta\vec{M}$, directed upward i.e. opposite to external field $\vec{B}$.

The net magnetic moment $2\Delta\vec{M}$ so developed is called induced magnetic moment. The magnetic moment induced in different atoms add vertically to give a net magnetization of the material in a direction opposite to $\vec{B}$. This accounts for the diamagnetic behaviour of material.

* The appearence of induced magnetic moment in atoms is not affected by the thermal motion of atoms, therefore, magnetic susceptibility of such materials does not depends on temperature of the materials.



(ii) Paramagnetic Substances

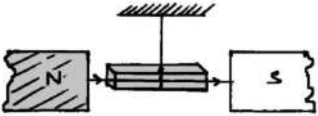
Paramagnetic substances are those in which each individual atom/molecule/ion has a net non-zero magnetic moment of its own.

When such substances are placed in an external magnetic field they get weakly magnetised in the direction of the magnetising field.

Examples - Aluminium, chromium, manganese, Lithium, Platinum, Tungsten, Sodium, Oxygen etc.

Properties -

(i) When a paramagnetic substance is suspended in a uniform magnetic field, they rotate so as to bring their longest axis along the direction of the field.

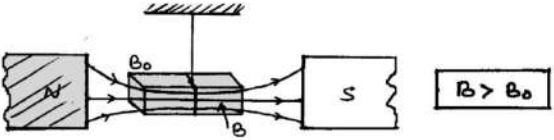


(ii) When the paramagnetic materials are placed in a non-uniform magnetic field they tend to move from weaker parts of the field to the stronger parts.

It implies that paramagnetic substances get weakly attracted to the magnet.

(iii) When a piece of a paramagnetic substance is placed in a magnetising field, the magnetic field lines prefer to pass through the piece rather than through air.

Thus magnetic field B inside the piece is more than the magnetic field B_0 outside the piece. $B > B_0$



(iv) Relative magnetic permeability of paramagnetic substance is always more than unity.

As $\mu_r = \frac{B}{B_0}$ and $B > B_0$

so $\boxed{\mu_r > 1}$

It means paramagnetic substances have a tendency to pull in magnetic field lines when placed in a magnetising field.

(v) As $\mu_r = 1 + \chi_m$ and $\mu_r > 1$

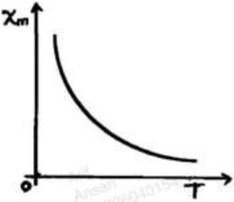
therefore χ_m must be positive.

Hence susceptibility of paramagnetic substance is positive with small value.

(vi) Susceptibility of paramagnetic substances varies inversely as the temperature of the substance.

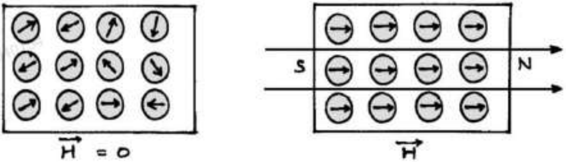
$$\boxed{\chi_m \propto \frac{1}{T}}$$

It means they loose their magnetic character with rise in temperature.



Explanation of paramagnetism -

In paramagnetic materials, every atom has some permanent magnetic dipole moment. In the absence of external magnetic field, the atomic dipoles are randomly oriented so that average magnetic moment per unit volume of the material is zero. Therefore a paramagnetic material does not behave as a magnet in the absence of an external magnetic field.



When an external magnetic field is applied, it tries to align the atomic magnetic dipole in the direction of the field. That is why the material gets magnetised weakly in the direction of the field. This is paramagnetism.

> * When we raise the temperature of the material, the atomic magnetic dipoles acquires some Kinetic energy. This tend to disorient the dipoles. That is why magnetic susceptibility of the paramagnetic materials decreases with rise in temperature.

(iii) Ferromagnetic Substances

Ferromagnetic substances are those in which each individual atom / molecule / ion has a non zero magnetic moment, as in a paramagnetic substances.

When such substances are placed in an external magnetising field, they get strongly magnetised in the direction of the field.

Examples - Iron, Cobalt, Nickel and a number of their alloys.

Properties -

(i) They are strongly magnetised in the direction of external field in which they are placed.

(ii) They have a strong tendency to move from a region of weak magnetic field to the region of strong magnetic field. Hence they get strongly attracted to a magnet.

(iii) Relative magnetic permeability of feromagnetic materials is very large. ($\approx 10^3$ to 10^5)

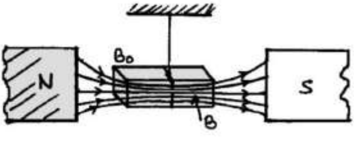
$$\mu_r \gg 1$$

(iv) The susceptibility of ferromagnetic materials is very large. That is why they can be magnetised easily and strongly.

$$\chi_m = \mu_r - 1 \qquad \chi_m = \text{large positive value}$$

(v) With rise in temperature, susceptibility of ferromagnetic materials decreases. At a certain temperature ferromagnetics change over to paramagnetics. This transition temperature is called curie temperature. For example, curie temperature of iron is about 1000 K.

(vi) When a piece of a ferromagnetic substance is placed in a magnetising field, the magnetic field lines prefer to pass through the piece rather than through air.



$$B \gg B_0$$

Explanation :-

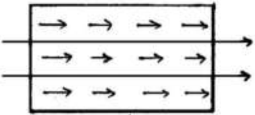
Each atom of feromagnetic substance is a tiny magnetic dipole having permanent dipole moment.

In ferromagnetic substances, atoms form a very large number of small effective regions called domains. Each domain is a strong magnet without any external magnetic field.

Inspite of this, a ferromagnetic substance does not behave as a magnet, because in the absence of external magnetic field the magnetic moments of different domains are randomly oriented so that their resultant magnetic moment in any direction is zero.

When an external magnetic field is applied on the ferromagnetic substance it gets strongly magnetised.

$\vec{B} = 0$



$\vec{B}$

The domains starts to rotate till their magnetic moments are aligned in the direction of the applied magnetic field. and arranged to form a single giant domain. This is how ferromagnetic materials gets strongly magnetised in the direction of the applied field.

Soft Ferromagnets :-

When external magnetic field is removed, magnetisation disappears in some of the materials like soft iron. These materials are called soft ferromagnets.

Hard Ferromagnets :-

In materials like Alnico (an alloy of iron, aluminium, nickel, cobalt and copper) the magnetisation persists even after removal of external magnetic field. Such materials are called hard ferromagnets.

* When ferromagnetic materials is heated, its magnetisation decreases gradually. This is because the domain structure disturbs with rise in temperature

χ_m, μ_r and μ of Magnetic Substances

	substance	χ_m	μ_r	μ
1.	Diamagnetic	$-1 \le \chi_m < 0$	$0 \le \mu_r < 1$	$\mu < \mu_0$
2.	paramagnetic	$0 < \chi_m < 1$	$1 < \mu_r < (1+\delta)$	$\mu > \mu_0$
3.	Ferromagnetic	$\chi_m >> 1$	$\mu_r >> 1$	$\mu >> \mu_0$

* Here δ is a small positive number.

Q. A magnetic field of 1600 Am^{-1} produces a magnetic flux of 2.4×10^{-5} weber in a bar of iron of cross section 0.2 cm^2. Calculate permeability and susceptibility of the bar.

Sol. Here $H = 1600\ Am^{-1}$, $\phi = 2.4 \times 10^{-5}$ wb

$a = 0.2\ cm^2 = 0.2 \times 10^{-4}\ m^2$

So $B = \frac{\phi}{a} = \frac{2.4 \times 10^{-5}}{0.2 \times 10^{-4}} = 1.2$ weber/m^2

$\mu = \frac{B}{H} = \frac{1.2}{1600} = 7.5 \times 10^{-4}\ TA^{-1}m.$

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

$\therefore \chi_m = \frac{\mu}{\mu_0} - 1$

$\chi_m = \frac{7.5 \times 10^{-4}}{4\pi \times 10^{-7}} - 1$

$\chi_m = 596.1$

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Curie Law in Magnetism :-

Intensity of magnetisation (I) of a magnetic material is -

(i) directly proportional to magnetic field (B), and

(ii) inversely proportional to the temperature (T) of a material.

$$I \propto B \quad \text{and} \quad I \propto \frac{1}{T}$$

Combining these factors we get -

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

Also $\quad B \propto H$

So magnetisation Intensity $\quad I \propto \frac{H}{T}$

or $\quad \frac{I}{H} \propto \frac{1}{T}$

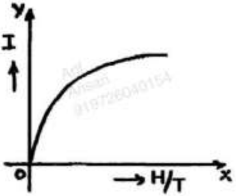
But $\quad \frac{I}{H} = \chi_m$

$\therefore \quad \chi_m \propto \frac{1}{T} \quad$ or $\quad \boxed{\chi_m = \frac{C}{T}}$

Here C is a constant called **curie constant.**

★ Thus for a paramagnetic material both χ_m and μ_r depends not only on the material, but also on the sample temperature.

★ At very low temperatures, the magnetisation approaches its maximum value, when all atomic dipole moments are aligned. This is called the saturation magnetisation



Q. The given figure shows the variation of intensity of magnetisation versus the applied magnetic field intensity H for two magnetic materials A and B.

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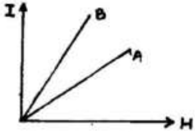

(a) Identify the materials A and B.

(b) Why does the material B have a larger susceptibility than A, for a given field at constant temperature?

Sol.- (a) The slope of I-H curve gives magnetic susceptibility $\chi_m = \frac{I}{H}$

Material A is paramagnetic substance because χ_m is small but positive.

Material B is Ferromagnetic substance because χ_m is large and positive.

(b) The susceptibility of material B is Larger than A at given magnetic field because ferromagnetic material gets strongly magnetised and hence produces larger intensity of magnetisation in comparison to paramagnetic substance, therefore it is strongly magnetized.

Q. Why does a paramagnetic substance display greater magnetization for the same magnetizing field when cooled? How does diamagnetic substance respond to similar temperature change?

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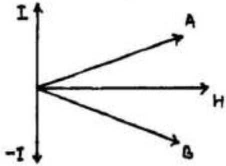
Sol. Since intensity of magnetization of paramagnetic substance varies as -

$$I \propto \frac{H}{T} \quad (\text{Curie Law})$$

Smaller the temperature at a given magnetizing field H, Higher the intensity of magnetization.

The susceptibility of diamagnetic substance is independent of temperature and magnetizing field.

Q. The given figure shows the variation of intensity of magnetization versus the applied magnetic field intensity H for two magnetic materials A and B.
CBSE 2008

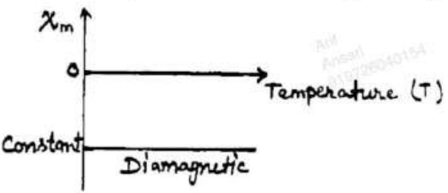


(a) Identify the material A and B.
(b) Draw the variation of susceptibility (χ_m) with temperature for B.

Sol:
(a) Material A is paramagnetic substance because χ_m is small and positive.

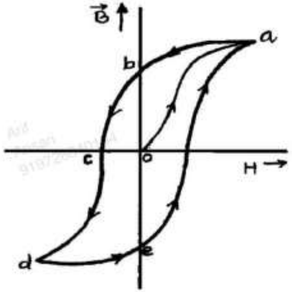
Material B is Diamagnetic substance because χ_m is small but negative.

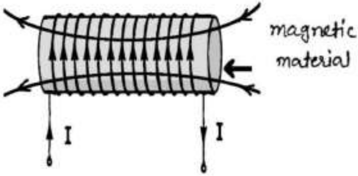
(b) The susceptibility of Diamagnetic substance is independent of temperature and magnetizing field.



Hysteresis Curve

The hysteresis curve represents the relation between magnetic field ($\vec{B}$) of a ferromagnetic material with magnetising force ($\vec{H}$).





Suppose the material is unmagnetised initially i.e. $B = 0$ and $H = 0$. This state is represented by the origin o.

Now we place the material in a solenoid and increase the current through the solenoid gradually. The magnetising force $\vec{H}$ increases.

The magnetic field increases and saturates as shown in the curve oa. This behaviour represents alignment of the domain of ferromagnetic material until no further increase in $\vec{B}$ is possible. Therefore there is no use of increase in current of solenoid and hence magnetic intensity beyond this.

Now we decrease the solenoid current and hence magnetic intensity $\vec{H}$ till it reduce to zero. The curve follow the path ab, which is showing that $H = 0$ but $B \neq 0$. Thus some magnetism is left in the material.

The value of magnetic field left in the material when the magnetic intensity ($\vec{H}$) is reduced to zero is called Retentity or Residual magnetism of the material.

Next, the current in the solenoid is reversed and increased slowly. Certain domains are flipped until the net magnetic field inside is reduced to zero. This is represented by the curve bc.

It means to reduce the residual magnetism or retentivity to zero, **we** have to apply a magnetising force or magnetic intensity which is equal to oc in opposite direction. This value of magnetising force is called **coercivity** of the material.

As the reverse current in solenoid is increased in magnitude, we once again obtain saturation in the reverse direction at d. The variation is represented by the curve cd.

Next the solenoid current is reduced curve (de), reversed and increased (curve ea) The cycle repeats itself.

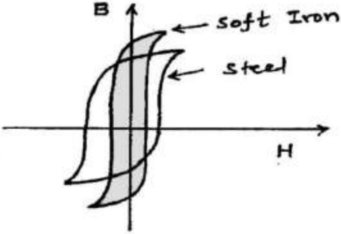
Thus it is clear that when a piece of a magnetic material is taken through a cycle of magnetisation, the intensity of magnetization (I) and magnetic field (B) lag behind the magnetising force (H). Thus

The phenomenon of lagging of I or B behind H when a specimen of a magnetic material is subjected to a cycle of magnetisation is called **hysteresis**.

★ We can plot I-H loop in the same way as we have plotted B-H loop of a ferromagnetic material. The shapes of I-H loop and B-H loop for a given material are identical.

Hysteresis Loop for soft iron and steel -

Hysteresis loop for soft iron is narrow and large whereas the loop for steel is wide and short.



The hysteresis loops of soft iron and steel reveal that -

(i) The retentivity of soft iron is greater than the retentivity of steel.

(ii) soft iron is more strongly magnetised than steel.

(iii) Coercivity of soft iron is less than the steel. It means soft iron looses its magnetism more rapidly then steel does.

(iv) As the area of B-H Loop for soft iron is smaller than the area of B-H loop for steel therefore hysteresis loss in case of soft iron is smaller than the steel.

Hysteresis Loss –

When a ferromagnetic material undergoes a complete cycle of hysteresis curve then there will be an energy Loss because to demagnetise the material we give energy to the material in the form of magnetic field in opposite direction. This type of energy loss is called hysteresis loss.

The area of the hysteresis curve is equal to the energy loss per unit volume of the material in a complete cycle of hysteresis loop.

Total Energy loss $Q = VAnt$

n : frequency of cycles
t = time
V = Volume of the material
A : Area of hysteresis loop

Q. The area of a hysteresis curve for a material is equivalent to 250 J. Find the energy loss in one hour to magnetise a 10 kg material with frequency 50 Hz. Density of the material is 7.5 g/cm³.

Answer: 6×10^4 J

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Use of Ferromagnetics

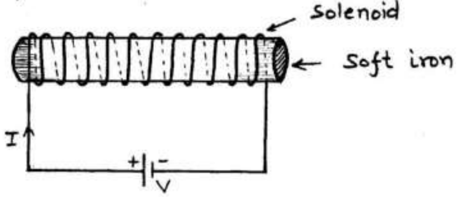
(i) Permanent Magnets-

Permanent magnets are the materials which retain their ferromagnetic properties for a long time. The material chosen should have-

(i) High retentivity so that the magnet is strong.
(ii) High coercivity so that the magnetisation is not erased by little magnetic fields, temperature changes or mechanical damage due to rough handling.
(iii) Heigh permeability so that it can be magnetised easily.

(ii) Elertromagnets -

The core of electromagnets are made of ferromagnetic materials, which have high permeability and low retentivity. Soft iron is suitable material for this purpose.



Use -

Electromagnets are used in electric bells, loudspeakers, telephone diaphragm and to lift machinery etc.

(iii) Transformer Core.

Soft iron is used for making transformer Cores Because hysteresis loss for this is minimum and it has high resistivity to decrease energy losses due to eddy currents.

Q.1. *When a bar magnet is placed at 90^o to a uniform magnetic field, it is acted upon by a couple which is maximum. For the couple to be half of the maximum value, at what angle should the magnet be inclined to the magnetic field (B) ?*

Sol: We know that, $\tau = MB\sin\theta$

If $\theta = 90°$ then $\tau_{max} = MB$ ..... (1)

$$\frac{\tau_{max}}{2} = MB\sin\theta \quad ..... (2)$$

From equations (1) and (2)

$$2 = \frac{1}{\sin\theta} \text{ or } \sin\theta = \frac{1}{2} \text{ or } \theta = 30°$$

Q.2. *A bar magnet of magnetic moment M_1 is suspended by a wire in a magnetic field. The upper end of the wire is rotated through 180^0, then the magnet rotated through 45^0. Under similar conditions another magnet of magnetic moment M_2 is rotated through 30^0. Then find the ratio of M_1 & M_2.*

Sol:

$$C(a - q) = MB\sin q$$

For first magnet, $C(180-45) = M_1 B\sin 45^0$ ----(1)

For second magnet, $C(180-30) = M_2 B\sin 30^0$ ----(2)

Diving equation (1) by equation (2)

$$\frac{135}{150} = \frac{M_1}{M_2} \times \sqrt{2} \Rightarrow \frac{M_1}{M_2} = \frac{9}{10\sqrt{2}}$$

Q.3. *A compass needle of magnetic moment $60 A\text{-}m^2$, pointing towards geographical north at a certain place where the horizontal component of earth's magnetic field is $40 \mu wb/m^2$ experiences a torque of 1.2×10^{-3} Nm. Find the declination at that place.*

Sol. If θ is the declination of the place, then the torque acting on the needle is $\tau = M B_H \sin\theta$

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$$\Rightarrow \sin\theta = \frac{\tau}{M B_H}$$

$$= \frac{1.2 \times 10^{-3}}{60 \times 40 \times 10^{-6}} = \frac{1}{2} \qquad \theta = 30^0$$

Q.4. A bar magnet has a magnetic moment 2.5 $J T^{-1}$ and is placed in a magnetic field of 0.2 T. Calculate the work done in turning the magnet from parallel to antiparallel position relative to field direction.

Sol. Work done in changing the orientation of a dipole of moment M in a field B from position $q_1 to q_2$ is

given by $W = MB(\cos q_1 - \cos q_2)$

Here, $q_1 = 0^0$ and $q_2 = 180^0$

So, $W = 2MB = 2 \times 2.5 \times 0.2 = 1 J$

Q.5. *The permeability of substance is 6.28×10^{-4} wb/A-m. Find its relative permeability and susceptibility ?*

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Sol. $$\mu_r = \frac{\mu}{\mu_0} = \frac{6.28 \times 10^{-4}}{4\pi \times 10^{-7}} = 500$$

$$\mu_r = 1 + \chi \quad \therefore \chi = \mu_r - 1 = 500 - 1 = 499$$

Q.6. The magnetic moment of a magnet of mass 75 gm is 9×10^{-7} A-m^2. If the density of the material of magnet is 7.5×10^3 kg m^{-3}, then find intensity of magnetisation is

Sol. $I=\dfrac{M}{V}$ Where volume, $V=\dfrac{mass(m)}{density(\rho)}$

$$=\frac{M\times\rho}{m}=\frac{9\times10^{-7}\times7.5\times10^{3}}{75\times10^{-3}}=0.09A/m$$

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Q.7. A magnetic field strength (H) 3×10^3 Am^{-1} produces a magnetic field of induction (B) of $12\pi T$ in an iron rod. Find the relative permeability of iron ?

Sol.

$$\mu=\frac{B}{H}=\frac{12\pi}{3\times10^{3}}=4\pi\times10^{-3}$$

$$\therefore \mu_r=\frac{\mu}{\mu_0}=\frac{4\pi\times10^{-3}}{4\pi\times10^{-7}}=10^{4}$$

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