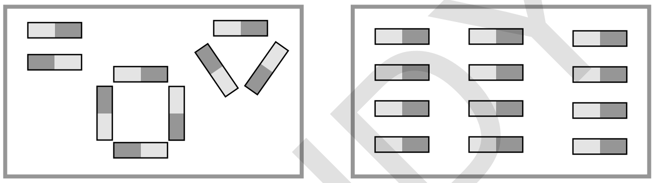
Chapter
22
Magnetism

The molecular theory of magnetism was given by Weber and modified later by Ewing. According to this theory.

Every molecule of a substance is a complete magnet in itself. However, in an **magnetic** substance the molecular magnets are randomly oriented to give net zero magnetic moment. On magnetising, the molecular magnets are realigned in a specific direction leading to a net magnetic moment.

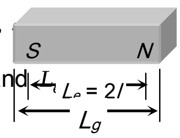


(A) Unmagnetised **(B)** Magnetised

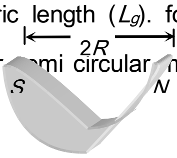
Fig. 22.1

Bar Magnet

A bar magnet consist of two equal and opposite magnetic pole separated by a small distance. Poles are not exactly at the ends. The shortest distance between two poles is called effective length (L_e) and is less than its geometric length (L_g). for bar magnet L_e = (5/6) L_g. for semi circular magnet $L_g = \pi R$ and L_e



(A) Bar magnet



(B) Semicircular magnet

Fig. 22.2

(1) **Directive properties** : When a magnet suspended freely it stays in the earth's N-S direction (in magnetic meridian).

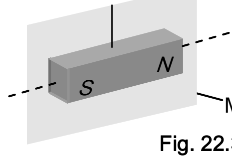


Fig. 22.3

(2) **Monopole concept** : If a magnet is Broken into number of pieces, each piece becomes a magnet. This in turn implies that monopoles do not exist. (*i.e.*, ultimate individual unit of magnetism in any magnet is called dipole).

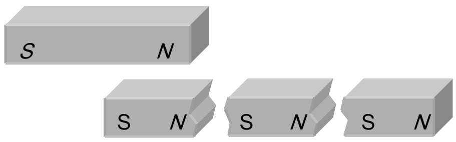


Fig. 22.4

(3) For two rods as shown, if both the rods attract in figure (A) and doesn't attract in figure (B) then, Q is a magnetic and P is simple iron rod. Repulsion is sure test of magnetism.

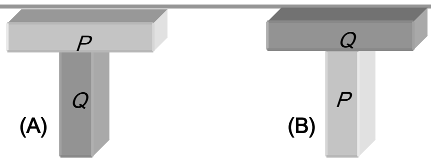


Fig. 22.5

(4) **Pole strength (m) :** The strength of a magnetic pole to attract magnetic materials towards itself is known as pole strength.

(i) It is a scalar quantity.

(ii) Pole strength of N and S pole of a magnet is conventionally represented by $+m$ and $-m$ respectively.

(iii) It's SI unit is *amp* × *m* or *N/Tesla* and dimensions are [LA].

(iv) Pole strength of the magnet depends on the nature of material of magnet and area of cross section. It doesn't depends upon

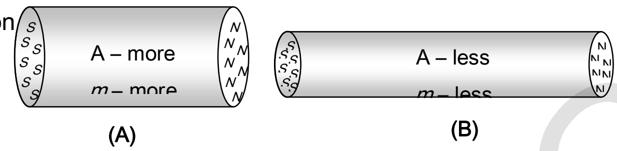


Fig. 22.6

(5) **Magnetic moment or magnetic dipole moment ($\vec{M}$) :** It represents the strength of magnet. Mathematically it is defined as the product of the strength of either pole and effective length. *i.e.* $\vec{M} = m(2\vec{l})$

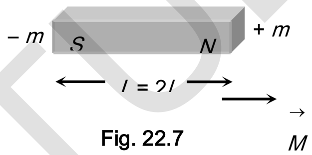


Fig. 22.7

(i) It is a vector quantity directed from south to north.

(ii) It's S.I. unit *amp*×*m*^{2} or *N-m / Tesla* and dimensions [AL^2]

(6) **Cutting of a rectangular bar magnet :** Suppose we have a rectangular bar magnet having length, breadth and mass are L, b and w respectively if it is cut in n equal parts along the length as well as perpendicular to the length simultaneously as shown in the figure then

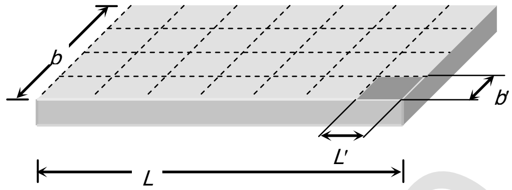


Fig. 22.8

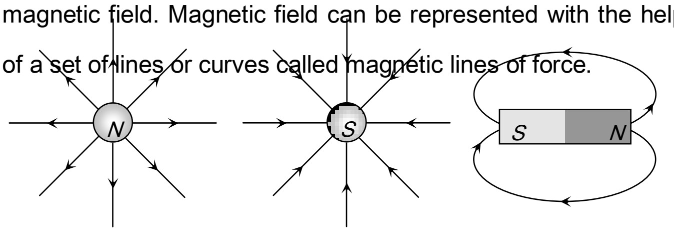
Length of each part $L' = \frac{L}{\sqrt{n}}$, breadth of each part $b' = \frac{b}{\sqrt{n}}$, Mass of each part $w' = \frac{w}{n}$, pole strength of each part $m' = \frac{m}{\sqrt{n}}$, Magnetic moment of each part $M' = m'L' = \frac{m}{\sqrt{n}} \times \frac{L}{\sqrt{n}} = \frac{M}{n}$

If initially moment of inertia of bar magnet about the axes passing from centre and perpendicular to it's length is $I = w\left(\frac{L^2 + b^2}{12}\right)$ then moment of inertia of each part $I' = \frac{I}{n^2}$

(7) **Cutting of a thin bar magnet :** For thin magnet b = 0 so $L' = \frac{L}{n}$, $w' = \frac{w}{n}$, $m' = \frac{m}{n}$, $I' = \frac{I}{n^3}$

Various Terms Related to Magnetism

(1) **Magnetic field and magnetic lines of force :** Space around a magnetic pole or magnet or current carrying wire within which it's effect can be experienced is defined as magnetic field. Magnetic field can be represented with the help of a set of lines or curves called magnetic lines of force.



(A) Isolated north pole **(B)** Isolated south pole **(C)** Magnetic dipole

Fig. 22.9

(2) **Magnetic flux (ϕ) and flux density (B)**

(i) The number of magnetic lines of force passing normally through a surface is defined as magnetic flux (ϕ). It's S.I. unit is *weber* (*wb*) and CGS unit is *Maxwell*.

Remeber 1 *wb* = 10^8 *Maxwell*.

(ii) When a piece of a magnetic substance is placed in an external magnetic field the substance becomes magnetised. The number of magnetic lines of induction inside a magnetised substance crossing unit area normal to their direction is called magnetic induction or magnetic flux density ($\vec{B}$). It is a vector quantity.

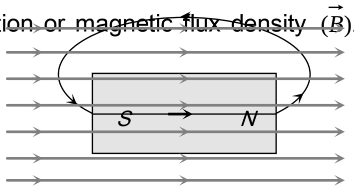
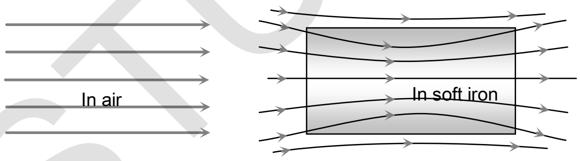


Fig. 22.10

It's SI unit is *Tesla* which is equal to $\frac{wb}{m^2} = \frac{N}{amp \times m} = \frac{J}{amp \times m^2} = \frac{volt \times \sec}{m^2}$

and CGS unit is *Gauss*. Remember 1 *Tesla* = 10^4 *Gauss*.

(3) **Magnetic permeability :** It is the degree or extent to which magnetic lines of force can enter a substance and is denoted by μ. Or characteristic of a medium which allows magnetic flux to pass through it is called it's permeability. *e.g.* permeability of soft iron is 1000 times greater than that of air.



(A) (B)

Fig. 22.11

Also $\mu = \mu_0 \, \mu_r$; where μ_0 = absolute permeability of air or free space = $4\pi \times 10^{-7} \, tesla \times m / amp$.

and μ_r = Relative permeability of the medium = $\frac{B}{B_0} = \frac{\text{flux density in material}}{\text{flux density in vacuum}}$.

(4) **Intensity of magnetising field $(\vec{H})$ (magnetising field) :** It is the degree or extent to which a magnetic field can magnetise a substance. Also $H = \frac{B}{\mu}$.

It's SI unit is

$A/m. = \frac{N}{m^2 \times Tesla} = \frac{N}{wb} = \frac{J}{m^3 \times Tesla} = \frac{J}{m \times wb}$ It's CGS unit is *Oersted*. Also 1 *Oersted* = 80 *A*/*m*

(5) **Intensity of magnetisation (*I*) :** It is the degree to which a substance is magnetised when placed in a magnetic field.

It can also be defined as the pole strength per unit cross sectional area of the substance or the induced dipole moment per unit volume.

Hence *I* = $\frac{m}{A} = \frac{M}{V}$. It is a vector quantity, it's S.I. unit is *Amp*/*m*.

(6) **Magnetic susceptibility (χ_m) :** It is the property of the substance which shows how easily a substance can be magnetised. It can also be defined as the ratio of intensity of magnetisation (*I*) in a substance to the magnetic intensity (*H*) applied to the substance, *i.e.* $\chi_m = \frac{I}{H}$. It is a scalar quantity with no units and dimensions.

(7) **Relation between permeability and susceptibility :** Total magnetic flux density *B* in a material is the sum of magnetic flux density in vacuum B_0 produced by magnetising force and magnetic flux density due to magnetisation of material B_m. *i.e.* $B = B_0 + B_m \Rightarrow B = \mu_0 H + \mu_0 I = \mu_0 (H + I) = \mu_0 H(1 + \chi_m)$. Also $\mu_r = (1 + \chi_m)$

Force and Field

(1) **Coulombs law in magnetism** : The force between two magnetic poles of strength m_1 and m_2 lying at a distance r is

given by $F = k.\frac{m_1 m_2}{r^2}$. In S.I. units $k = \frac{\mu_0}{4\pi} = 10^{-7} wb / Amp \times m$,

In CGS units $k = 1$

(2) **Magnetic field**

(i) Magnetic field due to an imaginary magnetic pole (Pole strength *m*) : Is given by $B = \frac{F}{m_0}$ also $B = \frac{\mu_0}{4\pi}.\frac{m}{d^2}$

(ii) Magnetic field due to a bar magnet : At a distance *r* from the centre of magnet

(a) On axial position

$B_a = \frac{\mu_0}{4\pi}\frac{2Mr}{(r^2 - l^2)^2}$; If *l*<<*r* then $B_a = \frac{\mu_0}{4\pi}\frac{2M}{r^3}$

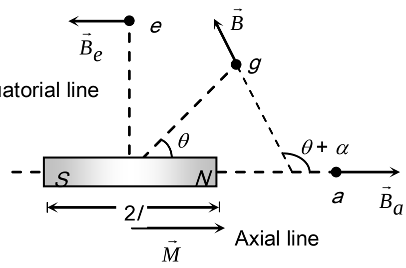


Fig. 22.12

(b) On equatorial position : $B_e = \frac{\mu_0}{4\pi}\frac{M}{(r^2 + l^2)^{3/2}}$; If *l* <<*r*; then $B_e = \frac{\mu_0}{4\pi}\frac{M}{r^3}$

(c) General position : In general position for a short bar magnet $B_g = \frac{\mu_0}{4\pi}\frac{M}{r^3}\sqrt{(3\cos^2\theta + 1)}$

(3) **Bar magnet in magnetic field** : When a bar magnet is left free in an uniform magnetic field, if align it self in the directional field.

(i) Torque : $\tau = MB\sin\theta \Rightarrow \vec{\tau} = \vec{M} \times \vec{B}$

(ii) Work : $W = MB(1 - \cos\theta)$

(iii) Potential energy : $U = -MB\cos\theta = -\vec{M}.\vec{B}$; ($\theta$ = Angle made by the dipole with the field)

(4) **Gauss's law in magnetism** : Net magnetic flux through any closed surface is always zero *i.e.* $\oint \vec{B}.\vec{ds} = 0$

Earth's Magnetic Field (Terrestrial Magnetism)

As per the most established theory it is due to the rotation of the earth where by the various charged ions present in the molten state in the core of the earth rotate and constitute a current.

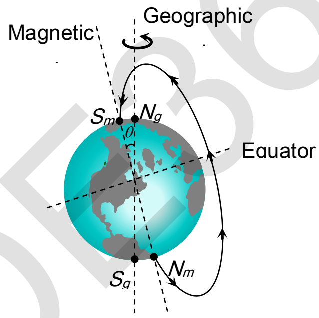


Fig. 22.13

(1) The magnetic field of earth is similar to one which would be obtained if a huge magnet is assumed to be buried deep inside the earth at it's centre.

(2) The axis of rotation of earth is called geographic axis and the points where it cuts the surface of earth are called geographical poles (N_g, S_g). The circle on the earth's surface perpendicular to the geographical axis is called equator.

(3) A vertical plane passing through the geographical axis is called geographical meridian.

(4) The axis of the huge magnet assumed to be lying inside the earth is called magnetic axis of the earth. The points where the magnetic axis cuts the surface of earth are called magnetic poles. The circle on the earth's surface perpendicular to the magnetic axis is called magnetic equator.

(5) Magnetic axis and Geographical axis don't coincide but they make an angle of 17.5° with each other.

(6) Magnetic equator divides the earth into two hemispheres. The hemisphere containing south polarity of

earth's magnetism is called northern hemisphere while the other, the southern hemisphere.

(7) The magnetic field of earth is not constant but changes irregularly from place to place on the surface of the earth and even at a given place it varies with time too.

(8) Direction of earth's magnetic field is from *S* (geographical south) to *N* (geographical north).

Elements of Earth's Magnetic Field

The magnitude and direction of the magnetic field of the earth at a place are completely given by certain. quantities known as magnetic elements.

(1) **Magnetic Declination (*θ*) :** It is the angle between geographic and the magnetic meridian planes.

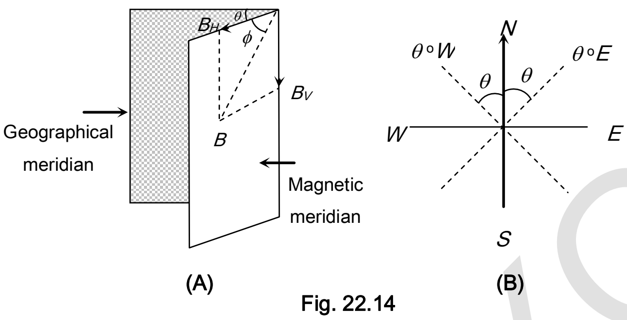


Fig. 22.14

Declination at a place is expressed at $\theta^o E$ or $\theta^o W$ depending upon whether the north pole of the compass needle lies to the east or to the west of the geographical axis.

(2) **Angle of inclination or Dip (*ϕ*) :** It is the angle between the direction of intensity of total magnetic field of earth and a horizontal line in the magnetic meridian.

(3) **Horizontal component of earth's magnetic field (B_H) :** Earth's magnetic field is horizontal only at the magnetic equator. At any other place, the total intensity can be resolved into horizontal component (B_H) and vertical component (B_V).

Also $B_H = B\cos\phi$ ...... (i) and $B_V = B\sin\phi$ ...... (ii)

By squaring and adding equation (i) and (ii)

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

Dividing equation (ii) by equation (i) $\tan\phi = \dfrac{B_V}{B_H}$

Magnetic Maps and Neutral Points

(1) **Magnetic maps :** Magnetic maps (*i.e.* Declination, dip and horizontal component) over the earth vary in magnitude from place to place. It is found that many places have the same value of magnetic elements. The lines are drawn joining all place on the earth having same value of a magnetic element. These lines form magnetic map.

(i) Isogonic lines: These are the lines on the magnetic map joining the places of equal declination.

(ii) Agonic line: The line which passes through places having zero declination is called agonic line.

(iii) Isoclinic lines : These are the lines joining the points of equal dip or inclination.

(iv) Aclinic line : The line joining places of zero dip is called aclinic line (or magnetic equator)

(v) Isodynamic lines : The lines joining the points or places having the same value of horizontal component of earth's magnetic field are called isodynamic lines.

(2) **Neutral points :** A neutral point is a point at which the resultant magnetic field is zero. In general the neutral point is obtained when horizontal component of earth's field is balanced by the field produced by the magnet.

Tangent Law

When a small magnet is suspended in two uniform magnetic fields B and B_H which are at right angles to each other, the magnet comes to rest at an angle θ with respect to B_H.

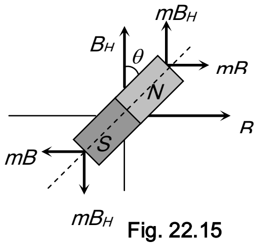


Fig. 22.15

In equilibrium

$$MB_H \sin\theta = MB\sin(90^o - \theta)$$

$\Rightarrow B = B_H \tan\theta$. This is called tangent law.

Tangent Galvanometer

It consists of three circular coils of insulated copper wire wound on a vertical circular frame made of nonmagnetic material as ebonite or wood. A small magnetic compass needle is pivoted at the centre of the vertical circular frame. When the coil of the tangent galvanometer is kept in magnetic meridian and current passes through any of the coil then the needle at the centre gets deflected and comes to an equilibrium position under the action of two perpendicular field : one due to horizontal component of earth and the other due to field (B) set up by the coil due to current.

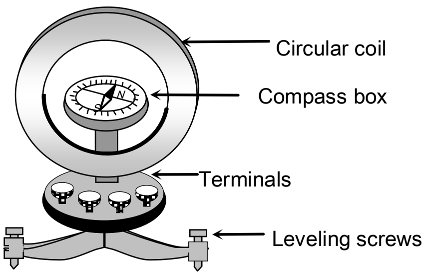


Fig. 22.16

In equilibrium $\boldsymbol{B} = \boldsymbol{B_H} \tan\theta$ where $B = \frac{\mu_0 ni}{2r}$; n = number of turns, r = radius of coil, i = the current to be measured, θ = angle made by needle from the direction of B_H in equilibrium.

Hence $\frac{\mu_0 Ni}{2r} = B_H \tan\theta \;\Rightarrow i = k\tan\theta$ where $k = \frac{2rB_H}{\mu_0 N}$ is called reduction factor.

Deflection Magnetometer

It's working is based on the principle of tangent law. It consists of a small compass needle, pivoted at the centre of a circular box. The box is kept in a wooden frame having two meter scale fitted on it's two arms. Reading of a scale at any point directly gives the distance of that point from the centre of compass needle.

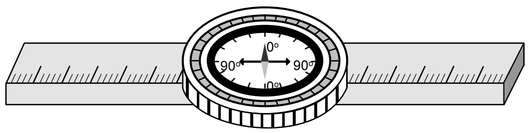


Fig. 22.17

(1) **Tan A position :** In this position the magnetometer is set perpendicular to magnetic meridian. So that, magnetic field due to magnet, is in axial position and perpendicular to earth's field. Hence $B_H \tan\theta = \frac{\mu_0}{4\pi}\cdot\frac{2Mr}{(r^2 - l^2)^2}$ or $B_H \tan\theta = \frac{\mu_0}{4\pi}\cdot\frac{2M}{r^3}$

(2) **Tan B position :** The arms of magnetometer are set in magnetic meridian, so that the magnetic field due to magnet is at it's equatorial position. Hence $B_H \tan\theta = \frac{\mu_0}{4\pi}\cdot\frac{M}{(r^2 + l^2)^{3/2}}$ or $B_H \tan\theta = \frac{\mu_0}{4\pi}\cdot\frac{M}{r^3}$

(3) **Comparison of magnetic moments :** According to deflection method $\frac{M_1}{M_2} = \frac{\tan\theta_1}{\tan\theta_2}$

According to null deflection method $\frac{M_1}{M_2} = \left(\frac{d_1}{d_2}\right)^3$

Vibration Magnetometer

Vibration magnetometer is used for comparison of magnetic moments and magnetic fields. This device works on the principle, that whenever a freely suspended magnet in a uniform magnetic field, is disturbed from it's equilibrium position, it starts vibrating about the mean position.

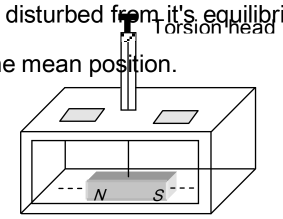


Fig. 22.18

Time period of oscillation of experimental bar magnet (magnetic moment M) in earth's magnetic field (B_H) is given by the formula. $T = 2\pi\sqrt{\frac{I}{MB_H}}$; where, $I =$ moment of inertia of short bar magnet $= \frac{wL^2}{12}$ (w = mass of bar magnet)

(1) **Determination of magnetic moment of a magnet :** The experimental (given) magnet is put into vibration magnetometer and it's time period T is determined. Now $T = 2\pi\sqrt{\frac{I}{MB_H}} \Rightarrow M = \frac{4\pi^2 I}{B_H . T^2}$

(2) **Comparison of horizontal components of earth's magnetic field at two places**

$T = 2\pi\sqrt{\frac{I}{MB_H}}$; since I and M of the magnet are constant,

So $T^2 \propto \frac{1}{B_H} \Rightarrow \frac{(B_H)_1}{(B_H)_2} = \frac{T_2^2}{T_1^2}$

(3) **Comparison of magnetic moment of two magnets of same size and mass**

$T = 2\pi\sqrt{\frac{I}{M.B_H}}$; Here I and B_H are constants.

So $M \propto \frac{1}{T^2} \;\Rightarrow \frac{M_1}{M_2} = \frac{T_2^2}{T_1^2}$

(4) **Comparison of magnetic moments by sum and difference method**

Sum position

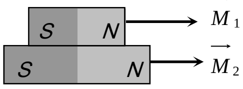


Fig. 22.19

Net magnetic moment $M_s = M_1 + M_2$

Net moment of inertia $I_s = I_1 + I_2$

Time period of oscillation of this pair in earth's magnetic field (B_H)

$$T_s = 2\pi\sqrt{\frac{I_s}{M_s\,B_H}} = 2\pi\sqrt{\frac{I_1 + I_2}{(M_1 + M_2)B_H}} \quad ....(i)$$

Frequency $\nu_s = \frac{1}{2\pi}\sqrt{\frac{(M_1 + M_2)B_H}{I_s}}$

Difference position

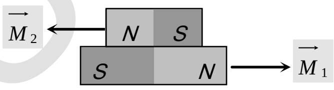


Fig. 22.20

Net magnetic moment

$M_d = M_1 + M_2$

Net moment of inertia $I_d = I_1 + I_2$

and $T_d = 2\pi\sqrt{\frac{I_d}{M_d\,B_H}} = 2\pi\sqrt{\frac{I_1 + I_2}{(M_1 - M_2)B_H}}$ ....(ii)

and $\nu_d = \frac{1}{2\pi}\sqrt{\frac{(M_1 + M_2)B_H}{(I_1 + I_2)}}$. From equation (i) and (ii) we get

$$\frac{T_s}{T_d} = \sqrt{\frac{M_1 - M_2}{M_1 + M_2}} \Rightarrow \frac{M_1}{M_2} = \frac{T_d^2 + T_s^2}{T_d^2 - T_s^2} = \frac{\nu_s^2 + \nu_d^2}{\nu_s^2 - \nu_d^2}$$

(5) **To find the ratio of magnetic field :** Suppose it is required to find the ratio $\frac{B}{B_H}$ where B is the field created by magnet and B_H is the horizontal component of earth's magnetic field.

To determine $\frac{B}{B_H}$ a primary (main) magnet is made to first oscillate in earth's magnetic field (B_H) alone and it's time period of oscillation (T) is noted.

$T = 2\pi\sqrt{\frac{I}{M\,B_H}}$

and frequency $\nu = \frac{1}{2\pi}\sqrt{\frac{M\,B_H}{I}}$

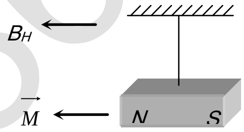


Fig. 22.21

Now a secondary magnet placed near the primary magnet so primary magnet oscillate in a new field with is the resultant of B and B_H and now time period, is noted again.

$T' = 2\pi\sqrt{\frac{I}{M(B + B_H)}}$

or $\nu' = \frac{1}{2\pi}\sqrt{\frac{M(B + B_H)}{I}}$

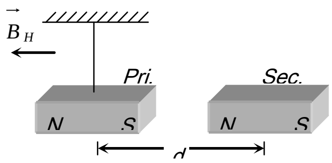


Fig. 22.22

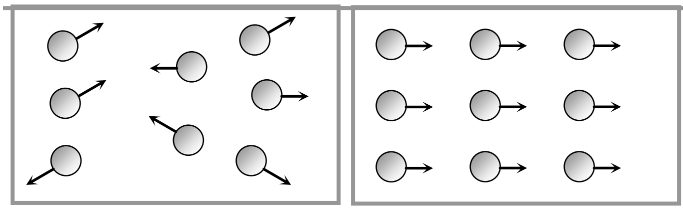
$\Rightarrow \frac{B}{B_H} = \left(\frac{\nu'}{\nu}\right)^2 - 1$

Magnetic Materials

On the basis of mutual interactions or behaviour of various materials in an external magnetic field, the materials are divided in three main categories.

(1) **Diamagnetic materials :** Diamagnetism is the intrinsic property of every material and it is generated due to mutual interaction between the applied magnetic field and orbital motion of electrons.

(2) **Paramagnetic materials :** In these substances the inner orbits of atoms are incomplete. The electron spins are uncoupled, consequently on applying a magnetic field the magnetic moment generated due to spin motion align in the direction of magnetic field and induces magnetic moment in its direction due to which the material gets feebly magnetised. In these materials the electron number is odd.



(A)
When no field is applied

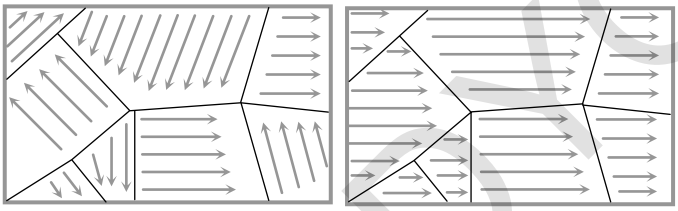
(B)
On application of field $(\vec{B})$

Fig. 22.23

(3) **Ferromagnetic materials :** In some materials, the permanent atomic magnetic moments have strong tendency to align themselves even without any external field.

These materials are called ferromagnetic materials.

In every unmagnetised ferromagnetic material, the atoms form domains inside the material. Different domains, however, have different directions of magnetic moment and hence the materials remain unmagnetised. On applying an external magnetic field, these domains rotate and align in the direction of magnetic field.



(A) Unmagnetised

(B) Magnetised

Fig. 22.24

(4) **Curie Law :** The magnetic susceptibility of paramagnetic substances is inversely proportional to its absolute temperature *i.e.* $\chi \propto \frac{1}{T} \Rightarrow \chi \propto \frac{C}{T}$; where C = Curie constant, T = absolute temperature.

On increasing temperature, the magnetic susceptibility of paramagnetic materials decreases and vice versa.

The magnetic susceptibility of ferromagnetic substances does not change according to Curie law.

(5) **Curie temperature (T_c) :** The temperature above which a ferromagnetic material behaves like a paramagnetic material is defined as Curie temperature (T_c).

or

The minimum temperature at which a ferromagnetic substance is converted into paramagnetic substance is defined as Curie temperature. For various ferromagnetic materials its values are different, *e.g.* for *Ni*, $T_{C_{Ni}} = 358^o C$ for *Fe*, $T_{C_{Fe}} = 770^o C$

for *CO*, $T_{C_{CO}} = 1120^o C$

At this temperature the ferromagnetism of the substances suddenly vanishes.

(6) **Curie-weiss law :** At temperatures above Curie temperature the magnetic susceptibility of ferromagnetic materials is inversely proportional to ($T - T_c$)

i.e. $\chi \propto \frac{1}{T - T_c}$

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

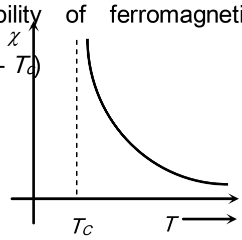


Fig. 22.25

Here T_c = Curie temperature

χ-T curve is shown (for Curie-Weiss Law)

Hysteresis Curve

For ferromagnetic materials, by removing external magnetic field *i.e.* H = 0. The magnetic moment of some domains remain aligned in the applied direction of previous magnetising field which results into a residual magnetism.

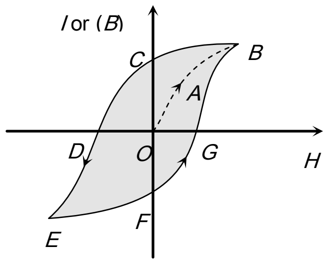


Fig. 22.26

The lack of retracibility as shown in figure is called hysteresis and the curve is known as hysteresis loop.

(1) **Retentivity :** When H is reduced, I reduces but is not zero when H = 0. The remainder value OC of magnetisation when H = 0 is called the residual magnetism or retentivity.

The property by virtue of which the magnetism (I) remains in a material even on the removal of magnetising field is called Retentivity or Residual magnetism.

(2) **Corecivity or corecive force** : When magnetic field H is reversed, the magnetisation decreases and for a particular value of H, denoted by H_c, it becomes zero *i.e.*, $H_c = OD$ when $I = 0$. This value of H is called the corecivity.

Magnetic hard substance (steel) $\rightarrow$ High corecvity

Magnetic soft substance (soft iron) $\rightarrow$ Low corecivity

(3) When field H is further increased in reverse direction, the intensity of magnetisation attains saturation value in reverse direction (*i.e.* point E)

(4) When H is decreased to zero and changed direction in steps, we get the part $EFGB$.

Thus complete cycle of magnetisation and demagnetisation is represented by $BCDEFGB$. This curve is known as hysteresis curve

Table 22.1 : Comparison between soft iron and steel

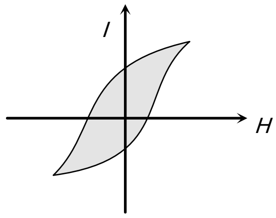
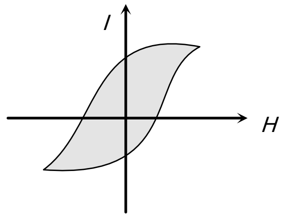
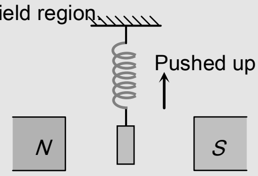
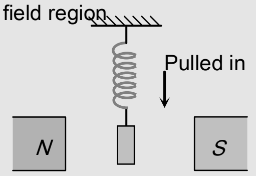
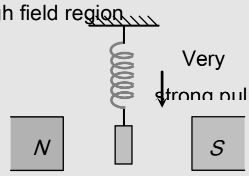
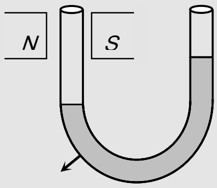
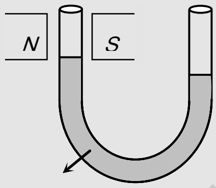
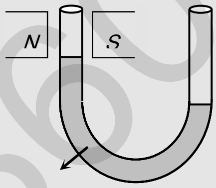
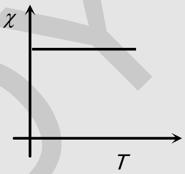
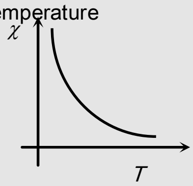
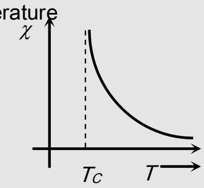
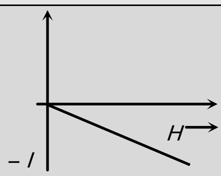
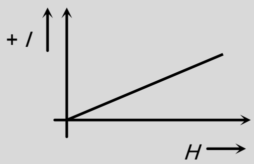
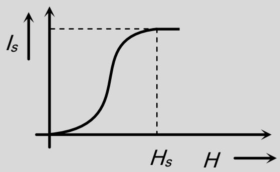
Soft iron	Steel
	
The area of hysteresis loop is less (low energy loss)	The area of hysteresis loop is large (high energy loss)
Less relativity and corecive force	More retentivity and corecive force
Magnetic permeability is high	Magnetic permeability is less
I and χ both are high	I and χ both are low
It magnetised and demagnetised easily	Magnetisation and demagnetisation is not easy
Used in dynamo, transformer, electromagnet tape recorder and tapes *etc.*	Used for making permanent magnet.

Table 22.2 : Comparative study of magnetic materials

Property	Diamagnetic substances	Paramagnetic substances	Ferromagnetic substances
Cause of magnetism	Orbital motion of electrons	Spin motion of electrons	Formation of domains
Explanation of magnetism	On the basis of orbital motion of electrons	On the basis of spin and orbital motion of electrons	On the basis of domains formed
Behaviour In a non-uniform magnetic field	These are repelled in an external magnetic field *i.e.* have a tendency to move from high to low field region 	These are feebly attracted in an external magnetic field *i.e.*, have a tendency to move from low to high field region 	These are strongly attracted in an external magnetic field *i.e.* they easily move from low to high field region 

State of magnetisation	These are weekly magnetised in a direction opposite to that of applied magnetic field	These get weekly magnetised in the direction of applied magnetic field	These get strongly magnetised in the direction of applied magnetic field
When the material in the form of liquid is filled in the *U*-tube and placed between pole pieces.	Liquid level in that limb gets depressed  Liquid	Liquid level in that limb rises up  Liquid	Liquid level in that limb rises up very much  Liquid
On placing the gaseous materials between pole pieces	The gas expands at right angles to the magnetic field.	The gas expands in the direction of magnetic field.	The gas rapidly expands in the direction of magnetic field
The value of magnetic induction B	$B < B_0$ (where B_0 is the magnetic induction in vacuum)	$B > B_0$	$B >> B_0$
Magnetic susceptibility χ	Low and negative $\|\chi\| \approx 1$	Low but positive $\chi \approx 1$	Positive and high $\chi \approx 10^2$
Dependence of χ on temperature	Does not depend on temperature (except *Bi* at low temperature) 	On cooling, these get converted to ferromagnetic materials at Curie temperature 	These get converted into paramagnetic materials at Curie temperature 
Relative permeability (μ_r)	$\mu_r < 1$	$\mu_r > 1$	$\mu_r >> 1$ $\mu_r = 10^2$
Intensity of magnetisation (I)	I is in a direction opposite to that of H and its value is very low	I is in the direction of H but value is low	I is in the direction of H and value is very high.
I-H curves			

Magnetic moment (*M*)	Very low (≈ 0)	Very low	Very high
Examples	*Cu, Ag, Au, Zn, Bi, Sb, NaCl,* H_2O air and diamond *etc.*	*Al, Mn, Pt, Na,* $CuCl_2$, O_2 and crown glass	*Fe, Co, Ni, Cd,* Fe_3O_4 *etc.*

Tips & Tricks

✍ Bohr magneton $\mu_B = \frac{eh}{4\pi m} = 9.27\times10^{-24}\ A/m^2$. It serves as natural unit of magnetic moment. Bohr magneton can be defined as the orbital magnetic moment of an electron circulating in inner most orbit.

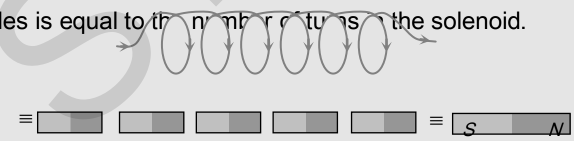
✍ Magnetic moment of straight current carrying wire is zero.

✍ Magnetic moment of toroid is zero

✍ Atoms which have paired electron have the magnetic moment zero.

✍ Magnetostriction : The length of an iron bar changes when it is magnetised, when an iron bar magnetised it's length increases due to alignment of spins parallel to the field. This increase is in the direction of magnetisation. This effect is known as magnetostriction.

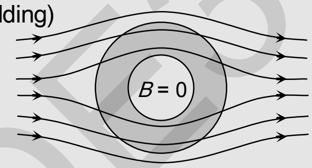
✍ A current carrying solenoid can be treated as the arrangement of small magnetic dipoles placed in line with each other as shown. The number of such small magnetic dipoles is equal to the number of turns in the solenoid.



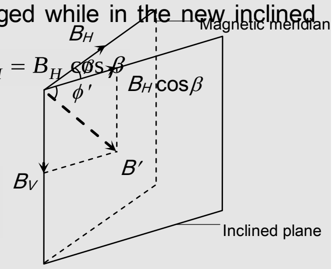
✍ When a magnetic dipole of moment *M* moves from unstable equilibrium to stable equilibrium position in a magnetic field B, the kinetic energy will decrease by 2 *MB*.

✍ Intensity of magnetisation (*I*) is produced in materials due to spin motion of electrons.

✍ For protecting a sensitive equipment from the external magnetic field it should be placed inside an iron cane. (magnetic shielding)



✍ **Apparent dip :** In a vertical plane inclined at an angle β to the magnetic meridian, vertical component of earth's magnetic field remains unchanged while in the new inclined plane horizontal component $B'_H = B_H \cos\beta$



$\phi' =$ apparent angle of dip

and $\tan\phi' = \frac{B_V}{B'_H} = \frac{B_V}{B_H \cos\beta}$

$\Rightarrow \tan\phi' = \frac{\tan\phi}{\cos\beta}$

✍ If at any place the angle of dip is θ and magnetic latitude is λ then $\tan\theta = 2\tan\lambda$

✍ At the poles and equator of earth the values of total intensity are 0.66 and 0.33 *Oersted respectively.*

✍ Remember time period of oscillation in difference position is greater than that in sum position $T_d > T_s$.

✍ If a rectangular bar magnet is cut in n equal parts then time period of each part will be $\frac{1}{\sqrt{n}}$ times that of complete magnet (i.e. $T' = \frac{T}{\sqrt{n}}$) while for short magnet $T' = \frac{T}{n}$. If nothing is said then bar magnet is treated as short magnet.

✍ Suppose a magnetic needle is vibrating in earth's magnetic field. With temperature rise M decreases hence time period (T) increases but at $770^{o}C$ (Curie temperature) it stops vibrating.

✍ An iron cored coil and a bulb are connected in series with an ac generator. If an iron rod is introduced inside a coil, then the intensity of bulb will decrease, because some energy lost in magnetising the rod.

✍ Hysteresis energy loss = Area bound by the hysteresis loop = $VAnt$ *Joule*; Where , V = Volume of ferromagnetic sample, A = Area of $B - H$ loop P, n = Frequency of alternating magnetic field and t = Time