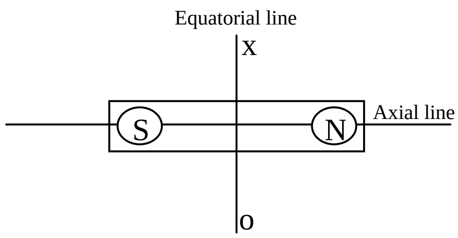
MAGNETISM

Synopsis :

1. A substance which attracts substances like iron, nickel, cobalt, etc. is called **magnet.**
2. **Properties of a magnet:**
   a) When a magnet is freely suspended or pivoted, it comes to rest showing north and south directions.
   b) Like poles repel and unlike poles attract each other (Dufay's law).
   c) A magnet attracts substances like iron, nickel, cobalt, steel etc.
   d) A magnet imparts its properties to other magnetic substances.
3. Magnets are of two types. They are
   i) Natural magnets and ii) Artificial magnets
   i) **Natural magnets :**
      (a) Magnets which are available in nature are called *Natural Magnets*.
      (b) Magnetite is a natural magnet.
      (c) It is also called *lode stone*.
      (d) It is the magnetic oxide of iron.
      (e) Its formula is Fe_3O_4.

   Natural magnets have no regular shape. They have less magnetic power.

   ii) **Artificial magnets :** Magnets which are made by artificial methods are called *Artificial magnets*.
   Ex: Bar magnets, cylindrical magnets, Horse shoe magnets, Robinson magnets, Pot shaped magnets etc.
   Artificial magnets have regular shape. Their magnetic power is more.
   Horse shoe magnets are used in cycle dynamos.
   Pot shaped magnets are used in loud speakers.
   Magnets are also used in magneto-therapy to cure some diseases.
4. **Bar magnet :**



   i) The two poles of the magnet generally are of equal strength and lie just below the ends.
   ii) The straight line joining the two poles of a magnet is called *axial line*.
   iii) The line passing through the midpoint and normal to the axial line is called *equatorial line*.
   iv) The straight line joining the poles of the magnet is known as '*magnetic length*'.
   It is denoted by 2l. It is a vector and its direction is $\overrightarrow{SN}$.
   v) Magnetic length is about 5/6 times or 83.3 % of the geometric length.

5. **Pole strength (m) :**
   i) Pole strength is a scalar.
   ii) S.I unit is ampere-metre.
   iii) Dimensional formula of m = [IL]
   iv) It (a) depends on nature of the material of the magnet (b) depends on level of magnetisation (c) is directly proportional to area of cross-section.
   v) Pole strength is independent of the shape of the magnet.
   vi) Isolated magnetic poles do not exist. They are imaginary.

6. **Magnetic moment :**
   i) It is measured as the product of magnetic length and pole strength $M = 2l \times m$.
   ii) Its S.I unit is ampere-metre^2 or Joule / Tesla or N–m^3/weber.
   iii) Dimensional formula is $[I^1L^2]$.
   iv) It is a vector with its direction from south pole to north pole along its axial line (SN).
   v) $M = I \times V$ and $M = \frac{C}{B \sin\theta}$

   $I \Rightarrow$ intensity of magnetisation
   $V \Rightarrow$ magnetised volume,
   $C \Rightarrow$ Moment of the couple.

7. **Bar Magnet cut into pieces :**
   i) When a boar magnet is cut into 'n' equal parts parallel to its axis
      a) Pole strength of each part = $m^1 = \frac{m}{n}$
      b) Magnetic moment of each part $M^1 = M/n$
      c) Length of each part = $2l^1 = 2l$
   ii) When a bar magnet is cut into 'n' equal parts normal to its axis
      a) Pole strength of each part $m^1 = m$
      b) Magnetic moment of each part $M^1 = M/n$
      c) Length of each part $2l^1 = 2l/n$
   iii) When a bar magnet is cut into 'xy' equal parts x parts parallel to its axis and y parts normal to the axis.
      a) Pole strength of each part $m^1 = \frac{m}{x}$
      b) Magnetic moment of each part $M^1 = M/xy$
      c) Length of each part $2l^1 = 2l/y$

8. **Bending of a magnet :**
   vi) When a thin bar magnet of magnetic moment 'M' and length '2l' is *bent at its mid point* with an angle 'θ' between the two parts its new magnetic moment = $M^1 = M\sin(\theta/2)$.
   vii) When a Magnetised wire of length '2l' and magnetic moment 'M' is *bent in to an arc* of a circle that makes an angle 'θ' at the centre of the circle.

a) Its length decreases and becomes $4\left[\dfrac{\ell \sin\frac{\theta}{2}}{\theta}\right]$

b) Its pole strength remains same as 'm'.

c) Its magnetic moment decreases and becomes $M^1 = \left[\dfrac{2M\ \text{Sin}\frac{\theta}{2}}{\theta}\right]$ where θ is in radian.

9. **Combination of magnets :**

i) When two magnets are placed at an angle θ with each other and with like pole together, the resultant magnetic moment is

$$\sqrt{M_1^2 + M_2^2 + 2M_1M_2\text{Cos}\theta}$$

ii) When two magnets are placed at an angle θ with each other and with unlike pole together, the resultant magnetic moment is

$$\sqrt{M_1^2 + M_2^2 - 2M_1M_2\text{Cos}\theta}$$

iii)

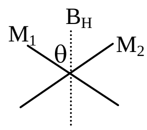
Angle between the axes of two bar magnets	Resultant moment when	
	like poles are together	unlike poles are together
60^0	$\sqrt{3}$ M	M
90^0	$\sqrt{2}$ M	$\sqrt{2}$ M
120^0	M	$\sqrt{3}$ M

iv) When 'n' identical bar magnets form a closed polygon with unlike poles nearer the resultant magnetic moment is zero.

v) If one magnet is removed from the polygon the resultant magnetic moment becomes equal to the magnetic moment of one magnet (M).

vi) If one magnet in the polygon is reversed and kept at the same position, the resultant magnetic moment becomes '2M'.

vii) Two magnets of magnetic moments M_1 and M_2 of equal mass are joined in the form of a cross and this arrangement is pivoted so that it is free to rotate in a horizontal plane under the influence of earth's magnetic field. If θ is the angle made by the magnetic meridian with M_1 then $\text{Tan}\theta = \dfrac{M_2}{M_1}$



10. If small holes are made in the body of the magnet, its magnetic moment decreases because its magnetised volume decreases.

11. **Coulomb's inverse square law :**

(i) The force of attraction between two point magnetic poles is directly proportional to the product of their pole strengths and inversely proportional to the square of the distance them.

$$F \propto \frac{m_1m_2}{d^2}$$

Where m_1, m_2 are pole strength 'd' is the distance between the magnetic poles.

(ii) $F = \frac{\mu}{4\pi} \cdot \frac{m_1 m_2}{d^2}$ (In S.I system)

But $\mu = \mu_0 \mu_r$

where $\mu_0 = 4\pi \times 10^{-7}$ Hm^{-1} (henry/meter) and for air or vacuum $\mu_r = 1$.

(iii) $\therefore\ F = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{d^2} = 10^{-7} \times \frac{m_1 m_2}{d^2}$

iv) The force F acts along the straight line joining the two magnetic fields. The force F is conservative, internal and mutual force.

v) If F_1 is the force between two magnetic poles when they are separated by a distance d_1 and F_2 is the force between the same poles when they are separated by a distance d_2 them, $F_1 d_1^2 = F_2 d_2^2$

vi) If F is the force between two magnetic poles in the medium and F_0 is the force between the same poles when they are in air or vacuum, then the relative permeability is given by

$$\mu_r = \frac{F}{F_0}$$

12. Unit Pole : Unit pole is one which when placed at a distance of one metre apart from a similar pole in air or vacuum repels it with a force of 10^{-7} newton.

i) The S.I. unit of pole strength = amp – metre.

ii) Retionalised M.K.S. unit of pole strength is weber.

iii) 1 weber = μ_0 Am

iv) C.G.S. unit of pole strength is ab.amp-cm.

1ab. Amp-cm = 10^{-1} amp-metre.

13. Magnetic lines of force : A line of force in a magnetic field is the path or the curve along which a free unit north pole travels.

14. Characteristics of magnetic lines of force :

i. Magnetic lines of force starts from North – Pole and ends on the South – Pole outside the magnet.

ii. Inside the magnet magnetic lines of force run from South pole to North pole.

iii. They are closed loops.

iv. No two magnetic lines of force intersect each other.

v. They have a tendency to repel each other laterally (They have lateral elongation).

vi. They contract longitudinally.

vii. The tangent drawn to the magnetic line of force at any point gives the direction of magnetic field at that point.

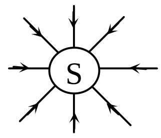
viii. In uniform magnetic field lines of force will be straight and parallel lines.

ix. The number of lines of force at a region represents the intensity of magnetic field at that region.

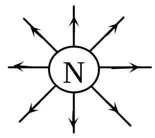
i.e., if field is strong, the lines of force are crowded, where as in weak fields they are spaced apart.

15. Lines of force in case of isolated poles :

i) For an isolated North–pole, the lines of force are radial, pointing away.



ii) For an isolated South–pole, the lines of force are radial, pointing inwards.



16. **Magnetic flux :**

a) The number of magnetic lines of induction passing normal to the cross-section is called magnetic flux.

b) S.I. unit of magnetic flux is *weber* (*wb*).

c) C.G.S unit of magnetic flux is gauss-cm^2.

d) Magnetic flux is a scalar quantity.

e) Dimensional formula of magnetic flux is $[M L^2 T^{-2} A^{-1}]$.

f) Magnetic flux, $\phi = \vec{B}.\vec{A}$ or $\phi = \oint \vec{B}.d\vec{A}$.

i) Magnetic flux linked with a small surface element dA = $d\phi = \vec{B}.d\vec{A} = BdA\cos\theta$

where $d\vec{A}$ =area of small element

ii) The flux linked with total area of the surface A

$$\phi = \int_A d\phi = \int_A B.dA = \int_A \vec{B}.d\vec{A}\cos\theta$$

iii) **Positive magnetic flux**: When the magnetic induction $\vec{B}$ and the unit normal vector $\hat{n}$ are in the same direction them ϕ is called the positive magnetic flux.

$\rightarrow \vec{B}$; $\rightarrow \vec{A}$

$\phi = BA$

iv) **Negative magnetic flux :** When the magnetic induction $\vec{B}$ and unit normal vector are mutually in opposite directions then ϕ is called negative magnetic flux.

$\phi = -BA$

v) Magnetic flux emerging out of a magnetic pole, $\phi = \mu_0\mu_r m$

17. **Magnetic field induction :**

i) It is defined as the force experienced by a unit north pole placed at a point in a magnetic field.

ii) $B = \frac{F}{m}$

iii) Unit of B is $\frac{\text{newton}}{\text{ampere}-\text{metre}}$ (or) weber /m^2 or tesla (T).

iv) B is a vector quantity.

v) The direction of B is along the direction in which the unit north pole travels.

18. **Flux density (or) Magnetic field induction (B):**

i) The number of magnetic lines of induction passing through unit area normal to the surface is called *magnetic flux density* or magnetic field induction (B).

ii) Magnetic induction (or) flux density

$B = \frac{\text{Magnetic flux}}{\text{Area}} \Rightarrow B = \frac{\phi}{A}$

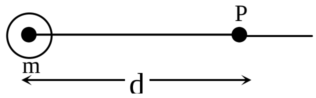
iii) B is a vector quantity

iv) Unit is gauss (In C.G.S system) ; weber/m^2 (or) tesla (in. S.I system)

v) 1 tesla = 10^4 gauss

19. **Magnetic induction due to an isolated pole :**

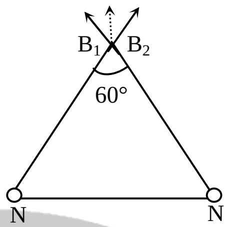
The magnetic induction (B) at any point at a distance 'd' from a magnetic pole of strength 'm' is given by $B = \frac{\mu_0}{4\pi}\frac{m}{d^2}$



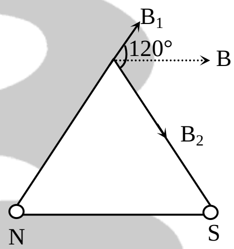
20. **Magnetic induction due to isolated poles:**

a) The magnetic induction at appoint due to a single pole is given by $B = \frac{\mu_0}{4\pi}\frac{m}{d^2}$

b) Two identical magnetic poles each of strength 'm' are placed at the two vertices of an equilateral triangle of side 'd' then resultant magnetic induction at the third vertex is B = $\sqrt{3}\left[\frac{\mu_0}{4\pi}\frac{m}{d^2}\right]$



c) Two equal and unlike poles each of strength 'm' are placed at the two vertices of an equilateral triangle of side 'd' then the resultant magnetic induction at the third vertex is B = $\left[\frac{\mu_0}{4\pi}\frac{m}{d^2}\right]$.



d) Three identical magnetic poles each of strength 'm' are placed at the three vertices of an equilateral triangle then the resultant magnetic induction at the centre of the triangle is zero.

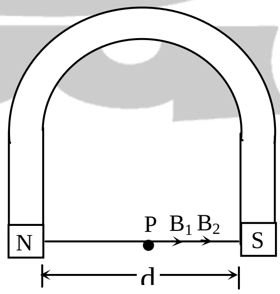
e) Four identical magnetic poles each of strength 'm' are placed at the four corners of a square, then the resultant magnetic induction at the centre of the square is zero.

21. **Magnetic induction at the mid point of the line joining the pole of an horse-shore magnet :**

If 'm' is the pole strength and 'd' is the distance between the poles of a horse-shoe magnet, the magnetic induction at the mid point of N, S is given by $B = B_1 + B_2 \Rightarrow$

$$B = \frac{\mu_0}{4\pi}.\frac{m}{\left(\frac{d}{2}\right)^2} + \frac{\mu_0}{4\pi}\frac{m}{\left(\frac{d}{2}\right)^2}$$

$$\therefore B = 8 \times \frac{\mu_0}{4\pi}.\frac{m}{d^2} \text{ along } \xrightarrow[NS]{}$$



22. **Intensity of the magnetic field or magnetising field strength (H) :**

a) 'H' is an auxillary field which is measured as the ratio of magnetic induction to the permeability of the medium at the given point.

b) H=$\frac{B}{\mu}$(in medium) and H=$\frac{B}{\mu_0}$ in air or Vacuum

c) H is a vector in the direction of the magnetic field B.

d) Dimensional formula of H is $[IL^{-1}]$

e) S.I unit of H is Am^{-1}

f) 1 $Am^{-1} = 4\pi \times 10^{-3}$ orested

g) H is independent of the medium.

h) Intensity of the magnetic field due to an isolated pole of strength m is given by

$H = \frac{B}{\mu_0} = \frac{1}{4\pi}\frac{m}{d^2}$ (in air or medium)

23. **Relation between B and H:**

i) If B is the magnetic induction field and H is the intensity of magnetic field at the same point then they are related as follows.

$B = \mu H$

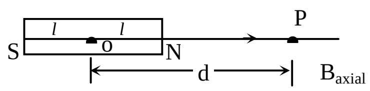
where μ = permeability of the medium and is equal to $\mu_0\mu_r$.

ii) $\therefore$ $B = \mu_0\mu_r H$(for any other media)

For air or vacuum $\mu_r = 1$

iii) $\therefore$ $B = \mu_0 H$ (for air or vacuum)

24. **Magnetic induction at a point on the axial line of a bar magnet :**



Let 'P' is a point which is at a distance 'd' from the centre of a bar magnet on its axial line.
The magnetic induction field at point 'P' is given by

$$B_{axial} = \frac{\mu_0}{4\pi}\frac{2Md}{\left(d^2 - \ell^2\right)^2}$$

i) For a short bar magnet $\ell^2 << d^2$. Hence ℓ^2 can be neglected.

$\therefore$ $B_{axial} = \frac{\mu_0}{4\pi}\frac{2M}{d^3}$

ii) The direction of B is from south to north along the axial line.

iii) Direction of $\vec{B}$ is parallel to magnetic moment $\vec{M}$.

iv) In C.G.S system the magnetic induction due to a bar magnet at a point on the axial line is given by $B_{axial} = \frac{2Md}{\left(d^2 - \ell^2\right)^2}$

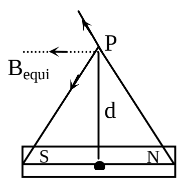
For short bar magnet $B = \frac{2M}{d^3}$

v) Intensity of magnetic field at the same point is given by, $H_{axial} = \frac{B_{axial}}{\mu_0}$

$$H_{axial} = \frac{1}{4\pi} \times \frac{2M}{d^3}$$

25. **Magnetic induction at a point of the equatorial line of a bar magnet :**

Let 'P' is a point on the equatorial line of a bar magnet which is at a distance 'd' from the centre of the bar magnet.
The magnetic induction field at point 'P' is given by



$$B_{eqi} = \frac{\mu_0}{4\pi}\frac{M}{\left(d^2 + \ell^2\right)^{3/2}}$$

i) For a short bar magnet, $B_{eqi} = \frac{\mu_0}{4\pi}\frac{M}{d^3}$

ii) In C.G.S system, $B_{eqi} = \frac{M}{d^3}$

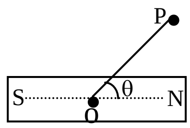
iii) The direction of B is from North to South parallel to its axis.

iv) Direction of $\vec{B}$ is antiparallel to $\vec{M}$.

v) Intensity of magnetic field at point 'P' is given by, $H = \frac{1}{4\pi}\frac{M}{d^3}$

26. **Magnetic induction at a point due to a dipole :**

Let 'P' is a point which is at a distance 'd' from the centre of a short bar magnet and the line joining the point (P) to the centre of the magnet makes an angle 'θ' with the axis of the bar magnet, then magnetic induction at point P is given by, $B = \frac{\mu_0}{4\pi}\frac{M}{d^3}\sqrt{1+3\cos^2\theta}$



27. **Force acting on a magnetic pole placed in a magnetic field**

i) If a magnetic pole of strength 'm' is placed in a magnetic induction field of strength 'B', then force acting on it is given by F =mB.

ii) For a North pole $\vec{F}$ is parallel to $\vec{B}$.

iii) For a South pole $\vec{F}$ is antiparallel to $\vec{B}$.

28. **Neutral points (or) Null point s :**

A null or neutral point is that point where the resultant magnetic induction is zero.

a) Due to two isolated poles :

i) If two poles of strengths m_1 and m_2 are separated by a distance 'd' then the distance of the neutral point (the point where resultant magnetic induction is zero) from the first pole m_1 is $x = \frac{d}{\sqrt{\frac{m_2}{m_1}} \pm 1}$ where m_1 is pole strength of weak pole.

ii) '+' sign is used for like poles and '–' sign is used for unlike poles.

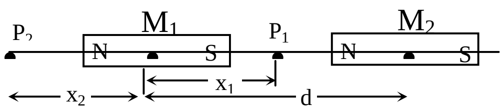
iii) Null point is always located nearer to weak pole.

iv) For like poles the neutral point is situated in between the poles on the line joining the poles.

v) For unlike poles, the neutral point is situated outside on the line joining the poles.

b) Due to two short bar magnets :

i) If two short bar magnets of moments M_1 and M_2 are place along the same straight line with their like poles towards each other such that the distance between the centres of the magnet is 'd' then



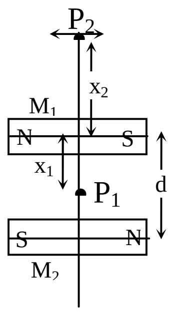
a) Null point is located on the line joining the magnets.

b) Two null points are formed one within the magnets and the other outside the magnets.

c) Both the null points are located nearer to weak magnet.

d) From weak magnet null point is located at a distance x_1 within the magnets and $x_1 = \dfrac{d}{\left[\dfrac{M_2}{M_1}\right]^{1/3} + 1}$

ii) If two short bar magnets have same equatorial line and their axes are parallel then



a) If opposite poles are facing each other and axes are perpendicular to each other, two null points are formed one within the magnets and other outside the magnets on the common equatorial line.

b) Both the null points are located nearer to weak magnet.

c) From weak magnet null point is located at a distance x_2 within the magnets and $x_2 = \dfrac{d}{\left[\dfrac{M_2}{M_1}\right]^{1/3} - 1}$

c) Null points – when N –pole of the magnet pointing geographic North :

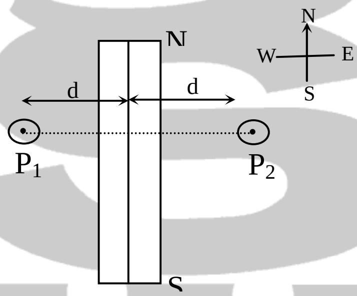
When a short magnet is placed with its axis is the meridian with its north pole pointing north of the earth, two null points are obtained on the equatorial.

In this case,

$$\frac{\mu_0}{4\pi} \times \frac{M}{d^3} = B_H$$

Note: In C.G.S

units $\dfrac{M}{d^3} = B_H$



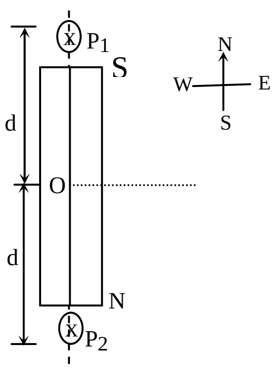
d) Null points -when N-pole of the magnet pointing geographic south :

When a short magnet is placed in the magnet meridian with the south pole of the magnet pointing north of the earth, two null points are obtained on the axial line of the magnet.

In this case, $\dfrac{\mu_0}{4\pi} \times \dfrac{2M}{d^3} = B_H$

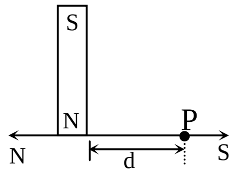
Note : In C.G.S,

units $\dfrac{2M}{d^3} = B_H$



e) Null points- when a long magnet placed vertically on a horizontal table :

i) When a long magnet of pole strength ‘m’ is placed vertically in a horizontal table such that its N –pole is on the table. Only one null point is formed.



ii) $d = \frac{\mu_0}{4\pi} \times \frac{m}{d^2} = B_H$

iii) If N – pole is on the table null point lies towards geographic South.

iv) It S – pole is on the table then null point lies towards geographic North.

29. **Couple acting an a bar magnet in a uniform magnetic field.**

i) When a magnet with magnetic moment M is suspended in a uniform field of induction B at an angle θ with the field direction then the couple acting on the magnet, C = MB sinθ and vectorially $\vec{C} = \vec{M} \times \vec{B}$

ii) When θ = 90° C is maximum.

If $|\vec{C}_{max}| = MB$. If θ = 90° and B = 1 C_{max} = M

iii) When θ = 0° $\vec{C} = \vec{O}$

iv) In an uniform magnetic field a bar magnet experiences only a couple but no net force. Therefore it has only rotatory motion.

v) In a non-uniform magnetic field a bar magnet experiences a couple and also a net force. So it undergoes both rotational and translational motion.

vi) A bar magnet of moment M is initially parallel to the magnetic field of induction B. The angle through which it must be rotated so that it experiences half of the maximum couple is 30°

$C = \frac{C_{max}}{2} = MB\sin\theta = \frac{MB}{2} \Rightarrow \theta = 30°$

vii) A bar magnet of moment M is initially perpendicular to the magnetic field of induction B. The angle through which it must be rotated so that it experiences half of the maximum couple is 60°.

viii) The work done in rotating a magnet from angular position θ_1 to θ_2 with respect to field in given by $W = \int_{\theta_1}^{\theta_1} MB\sin\theta \, d\theta = MB(\cos\theta_1 - \cos\theta_2)$

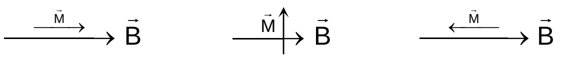
ix) If the magnet is rotated fro field direction to position θ then W = MB (1 – cos θ).

x) a)The work done in rotating a magnet from direction perpendicular to the field to the given direction is equal to the *potential energy* of the magnet.

b) $\therefore$ P.E = $W_\theta - W_{90}$ = MB (1 – cos θ) – MB
= – MB Cos θ = $-\vec{M}.\vec{B}$

c) The potential energy of the magnet will be minimum (=–MB) when θ=0° (stable equilibrium)

d) Maximum (=MB) when θ = 180° (unstable equilibrium)



θ = 0°	θ = 90°	θ = 0
C = min = 0	C = max = MB	C = min = 0
W = min = 0	W = MB	W=max = 2MB
P.E = min = – MB	P.E = 0	P.E= max= MB

30. **Deflection Magnetometer :**

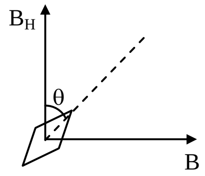
a) i) Deflection magnetometer works on the principle of tangent law.

ii) According to tangent law when two uniform magnetic fields act at right angles to each other on a magnetic needle, it comes to rest in the direction of resultant field. $B = B_H \tan\theta$

where B is the magnetic induction due to bar magnet

B_H is the horizontal component of earth's magnetic field

θ is the angle through which the needle is deflected.



iii) The magnetic needle in the compass is small, so that it is in the uniform field.

iv) The pointer is of aluminium because it is a paramagnetic substance.

v) The mirror under the pointer helps to take readings without parallax error.

vi) The container of the compass is non magnetic like Brass. If it is made of magnetic material the needle does not deflect by the external magnetic field due to magnetic shielding.

vii) The zero of the horizontal scale coincides with the centre of the circular scale.

viii) Deflection magnetometer does not work at the magnetic poles of the earth, because at poles $B_H = 0$.

ix) The deflection magnetometer has minimum relative error when the deflection is 45°.

x) The deflection is independent of the strength of the magnetic needle.

b) Sources of errors and their elimination in deflection magnetometer :

Source of error	**Method of elimination**
1) Magnetic needle may not be pivoted exactly at the centre of the circular scale.	1) Deflections are noted on either side of the aluminium pointer.
2) The two magnetic poles may not be equidistant from the centre of the magnet.	2) Deflections are noted by reversing the magnet.
3) The zeros of the linear scales fixed on the wooden arms may not coincide with the centre of the magnetometer	3) Reading are to be noted by repeating the experiment by transforming the magnet on the other arm.

c) Tan – A position or Gauss – A position or End on position :

i) Arms of the magnetometer are perpendicular to the magnetic meridian i.e. arms lie in East – West direction.

ii) Aluminium pointer is parallel to the arm

iii) The bar magnet is placed in such a way that its axial line passes through the centre of the needle. Bar magnet is parallel to the arms

iv) $\frac{\mu_0}{4\pi}\frac{2M}{d^3} = B_H \tan\theta$ (For short bar magnet)

$\frac{\mu_0}{4\pi}\frac{2Md}{\left(d^2 - \ell^2\right)^2} = B_H \tan\theta$ (For long bar magnet)

d) Tan – B position or Gauss B position or broad side on position :

i) arms are in the magnetic meridian i.e, in the north south direction.
ii) Aluminium pointer is perpendicular to the arms.
iii) The bar magnet is placed in such a way that its equatorial line passes through the centre of the needle. The bar magnet is perpendicular to the arms.
iv) $\frac{\mu_0}{4\pi}\frac{M}{d^3} = B_H \tan\theta$ (For short bar magnet)

$\frac{\mu_0}{4\pi}\frac{M}{\left(d^2+\ell^2\right)^{\frac{3}{2}}}$ (For long bar magnet)

e) i) Both in Tan A as well as in Tan B position the bar magnet is in east west direction.
ii) Tan A position is preferred to Tan – B position because for the same distance between the centre of the needle and deflection magnetometer deflection is more in tan – A position ($\because$ the field is more on axial line then equatorial line)

f) Deflection magnetometer is used to
i) compare magnetic moments
ii) compare earth's magnetic inductions
iii) verify inverse square law and
iv) determine the horizontal component of the earth's magnetic induction.

g) To compare magnetic moments :
i) **Equal distance method :** For Tan A or TanB position $\frac{M_1}{M_2} = \frac{\tan\theta_1}{\tan\theta_2}$

ii) Null deflection method : For Tan A or TanB position $\frac{M_1}{M_2} = \frac{d_1^3}{d_2^3}$

iii) Null deflection method is preferred to equal distance method.

h) To compare B_H values :
Earth's horizontal component of magnetic field B_H at two places can be compared using a single magnet at same distance from the centre of the needle in the two places. $\frac{B_{H_1}}{B_{H_2}} = \frac{\tan\theta_2}{\tan\theta_1}$.

i) To verify inverse square law :
i) **Gauss method :** When a short magnet is placed at a distance 'd' in tanA and then tanB positions and θ_A and θ_B are the average deflection then $\frac{\tan\theta_A}{\tan\theta_B}$ =2(verification of inverse square law)
ii) Only one bar magnet is used while verifying inverse square law.
iii) In **single pole method** or **Robinson's method**, the inverse square law is verified if $\frac{\mu_0}{4\pi}\frac{m}{d^2} = B_H \tan\theta$ or $d^2 \tan\theta$ = const.

j) Deflection magnometer is more accurate when the deflection is 45°. Therefore the reading should lie between 30° to 60° for accurate results.

k) The relative error $\frac{d\theta}{\theta}$ is minimum when θ = 45°

31. **Vibration magnetometer :**

a) When a magnet of moment M is suspended freely in a horizontal plane, where the horizontal component of the earth's magnetic field is B_H, the magnet sets itself in the direction of B. If the magnet is given a slight angular displacement about the axis of suspension, the magnet undergoes S.H.M. The restoring torque is due to B_H.

b) Its time period T is given by $T = 2\pi\sqrt{\frac{I}{MB_H}}$

where I = moment of inertia of the magnet about the axis of suspension = $\frac{m(\ell^2 + b^2)}{12}$

c) Its frequency is given by n = $\frac{1}{2\pi}\sqrt{\frac{MB_H}{I}}$

d) Its time period (or) frequency is independent of length of the suspension.

e) To compare the magnetic moments of two bar magnets.

i) when the bar magnets are equal sizes

$\frac{M_1}{M_2} = \frac{T_2^2}{T_1^2}$ where

T_1 = time period of the first magnet

T_2 = time period of the second magnet

ii) when the bar magnets are of unequal size

$\frac{M_1}{M_2} = \frac{T_2^2 + T_1^2}{T_2^2 - T_1^2}$ (or) $\frac{M_1}{M_2} = \frac{n_1^2 + n_2^2}{n_1^2 - n_2^2}$ where

T_1 = time period of the combination when their like poles touches each other

T_2 = time period of the combination when their unlike poles touches each other.

f) To compare horizontal components of earth's magnetic field at two different places.

$\frac{B_{H_1}}{B_{H_2}} = \frac{T_2^2}{T_1^2}$

g) To calculate M and B_H (together with reflection magneto meter)

$M = \frac{2\pi(d^2 - \ell^2)}{T}\sqrt{\frac{4\pi I \tan\theta}{\mu_0 2d}}$

$B_H = \frac{2\pi}{T(d^2 - \ell^2)}\sqrt{\frac{\mu_0}{4\pi}\frac{2Id}{\tan\theta}}$

h) **Magnet cut into pieces :**

The time period of vibrating bar magnet is T, then

i) If it is cut into 'n' equal parts perpendicular to its length then time period of each part is given by $T' = T/n$

ii) If it is cut into 'n' equal parts parallel to its length then time period of each part is equal to initial value ($\therefore$ $T' = T$)

iii) If it is cut into 'n' equal parts perpendicular to its length and the parallel to its length then time period of each part is given by T = T/n.

i) A bar magnet vibrating horizontally in B_H has a time period T_1. An external magnetic field B is applied on magnet then its time period is T_2.

$\therefore \frac{T_1}{T_2} = \sqrt{\frac{B_r}{B_H}}$

i) If B_H and B are in same direction then $B_r = B_H + B$

ii) If B_H and B are in opposites direction then $B_h = B_H - B$

iii) If B_H and B are perpendicular to each other then $B_r = \sqrt{B_H^2 + B^2}$

j) For small changes in B(< 8%)

% change in T = $\frac{1}{2} \times \%$ change in B.

k) **Uses of vibration magnetometer :**

i) to compare the magnetic moments of two bar magnets.

ii) to compare the horizontal components of earth's magnetic field at two different places.

iii) Together with deflection magnetometer vibration magnetometer can be used to

a) Find the magnetic moment of a magnet and

b) The horizontal component of earth's field at a given place.

32. **Properties of magnetic materials :**

a) **Magnetising force (or)**

Intensity of magnetising field ($\vec{H}$) :

i) The ratio of magnetic induction produced in vacuum($\vec{B}_0$) to the magnetic permeability of vacuum is defined as magnetising field $\vec{H}$ i.e $\vec{H} = \vec{B}_0 / \mu$ and $\vec{B}_0 = \mu_0 \vec{H}$.

ii) The part of magnetic induction in free space or vacuum which is produced only by actual external current is known as magnetising field.

iii) H is a vector and its direction is same as that of $\vec{B}$.

iv) SI unit $\vec{H}$ is Am^{-1} and its dimensional formulas is IL^{-1}

v) $\vec{H}$ depends only on external free currents and not on the nature of medium.

vi) Magnetic properties are inducted in a given material due to H only.

vii) When a medium is exposed to a magnetic field of intensity H, it causes an induction B in the medium such that $B = \mu H = \mu_0 \mu_r H$

b) **Intensity of magnetisation ($\vec{I}$):**

i) When a magnetic material is magnetised by keeping it in a magnetising field, the induced magnetic moment per unit volume or induced pole strength per unit area of cross section of that material is known as *intensity of magnetisation* $\vec{I}$.

e $\vec{I} = \frac{\vec{M}}{V} = \frac{m2\ell\hat{n}}{V}$ (or) $I = \frac{M}{V}$

$\vec{I} = \frac{m}{A}\hat{n}$ (A is area of cross section) or $I = \frac{m}{A}$

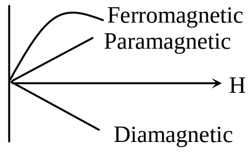
ii) I is a vector quantity having same direction as that of magnetising field (ferro, paramagnetics) or oppositve to it (dia magnetics).

iii) S I unit of I is same as that of H ie. $A.m^{-1}$

iv) Dimensional formula of I is IL^{-1}

v) I is produced in materials due to spin motion of electrons.

vi) The value of I and its direction in a material depend on the nature of the material as shown in the graph.



c) **Magnetic susceptibility [χ] :**

i) The ratio of magnitude of intensity of magnetisation (I) in a material to that of magnetising field (H) is called *magnetic susceptibility* of that material.

$\chi = I / H$

ii) The intensity of magnetisation inducted in a material by unit magnetising field is known as magnetic susceptibility.

iii) χ has no units and no dimensions.

iv) χ physically represents the ease with which a magnetic material can be magnetised.

v) Large value of χ implies that the material can be easily magnetised.

vi) For diamagnetic materials χ is low and negative.

vii) For paramagnetic materials χ is low but positive.

viii) For ferro magnetic materials χ is high and positive.

d) **Absolute magnetic permeability (μ) :**

i) The ratio of magnitudes of magnetic induction to magnetising field is defined as magnetic permeability.

$\Rightarrow \mu = B/H$

ii) Magnetic permeability of a medium is the extent to which magnetic lines of force can enter a medium. It is the characteristic property of the magnetic material.

iii) Magnetic permeability represents the amplification of magnetising field in that material.

iv) μ value is always positive and is different for different materials.

v) μ value depends on magnetising field and temperature (T).

vi) For ferromagnetic material μ is high, for paramagnetic materials μ is low and for diamagnetic materials μ is very low.

vii) Value of μ for a material can be greater or less than μ_0.

viii) μ is a scalar. Its S.I unit is H m^{-1} (Henry per meter) Its dimensional formula is $MLT^{-1}I^{-2}$.

e) **Relative permeability (μ_ρ)** :

i) It is the ratio of absolute magnetic permeability of a medium (μ) to the magnetic permeability of free space (μ_0) $\Rightarrow \mu_r = \mu / \mu_0$

ii) μ_γ has no units and no dimensions.

iii) For diamagnetic substances $\mu_r < 1$ (but +ve)

iv) μ_r can be expressed as the ratio of number of lines of force passing through unit area in medium to the number of lines of force passing through unit area in vacuum.

v) μ_r can be expressed as the ratio of magnetic flux density in medium to the magnetic flux density in vacuum.

$$\mu_r = \frac{B}{B_0}$$

f) Relation between μ and χ : When a magnetic material is placed in a magnetising field, the field inside that material is the resultant of the magnetic induction field $\vec{B}_0$ and the induced field $\vec{B}_i \Rightarrow \vec{B} = \vec{B}_0 + \vec{B}_i$

But by definition, $\vec{B}_0 = \mu_0 \vec{H}$ and $\vec{B}_i = \mu_0 \vec{I}$

So, $\vec{B} = \mu_0 (\vec{H} + \vec{I})$

$\Rightarrow B = \mu_0(H + I)$

$\Rightarrow \frac{B}{H} = \mu_0 \left(1 + \frac{I}{H}\right)$

But $B/H = \mu$ and $I / H = \chi$

So, $\mu = \mu_0 (1 + \chi)$

$\mu_r = 1 + \chi \quad (\because \mu_r = \mu/\mu_0)$

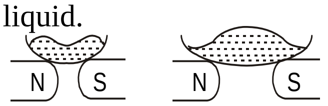
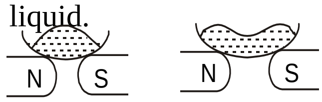
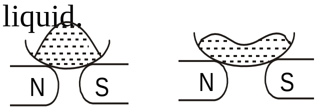
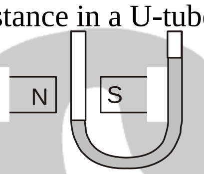
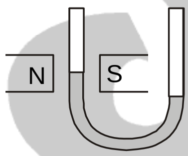
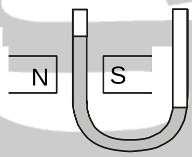
33. Weber-Ewing theory

a) All ferromagnetic substances are built up of *molecular magnets* (also known as weber elements).

b) In an unmagnetised piece of ferromagnetic material, molecular magnets are randomly oriented and the resultant is zero.

c) When magnetic substance is magnetised molecular magnets are oriented in a particular direction due to which it acts as a magnet.

DIAMAGNETIC SUBSTANCES	PARAMAGNETIC SUBSTANCES	FERROMAGNETIC SUBSTANCES
1. This is a universal property of all materials.	1. Properties are specifically possessed by some materials only.	1. Properties are specifically possessed by some materials only. (In general ferromagnetic substances show all the properties of paramagnetic substances with greater intensity).
2. When placed in a magnetic field, they get magnetised in a direction opposite to the applied field.	2. They get magnetised in the direction of the applied field.	2. They get magnetised in the direction of the applied field.
3. When placed in a magnetic field, they move from	3. They move from weaker to stronger parts of the field.	3. They move from weaker to stronger parts of the field.

stronger to weaker parts of the field.		
4. When a rod of a diamagnetic substance is freely suspended in a magnetic field, it orients itself perpendicular to the field.	4. When a rod of paramagnetic substance is freely suspended in a magnetic field, it orients itself in the direction of the field.	4. When a rod of paramagnetic substance is freely suspended in a magnetic field, it orients itself in the direction of the field.
5. Behaviour of a diamagnetic liquid.  when poles are very close	5. Behaviour of a paramagnetic liquid.  when poles are very close	5. Behaviour of a ferromagnetic liquid.  when poles are very close
6. When a diamagnetic substance is placed in a magnetic field, the concentration of magnetic lines of force is more outside than inside the substance.	6. When a paramagnetic substance is placed in a magnetic field, the concentration of lines of force is slightly more inside than outside the substance.	6. When a ferromagnetic substance is placed in a mag-netic field, the concentration of lines of force inside is much more than outside the substance.
7. Behaviour of corresponding substance in a U-tube. 		
8. Permeability (μ) :less than 1 and positive.	8. Slightly greater than 1.	8. Much greater than 1.
9. Susceptibility(χ):low &negative.	9. Small and positive.	9. Large and positive.
10. Do not obey Curie's law.	10. Obey Curie's law. $\chi = \frac{C}{T}$	10. Obey Curie's law. At Curie temperature ferromagnetic substances changes to paramagnetic substances. $\chi = \frac{C}{T - T_C}$
11. e.g : inert gases : He, Ar etc. Metals : Au, Zn, Cu, Hg, Bi, Sb, Pb, Sn, Others Like : P, H_2O, Glass, Marble, Alkyl halides and many organic compounds.	11.e.g. : gases : O_2, N_2 Metals : Al, Pt, Mn, Cr, Pd Alkali & alkaline earth metals and rare earths.	11. e.g. : Fe, Co, Ni, Gadolinium (Gd), Dysprosium (Dy) alloys like Alnico.

34. **Ferromagnetism (Domain theory) :**

a) Every ferromagnetic material is made of a very large number of very small regions which are known as *domains*.

b) Domains are the effective regions in which the atoms will have mutual interaction or exchange interaction.

c) Each domain will have a volume of 10^{-6} to 10^{-2} cm^3 and contains 10^{17} to 10^{21} atoms with their axes or moments aligned in the same direction.

d) All spin magnetic moments are in the same direction in a particular domain but it is different than that in any other domain.

e) At ordinary temperatures these domains align randomly and give zero resultant magnetic moment.

f) when an external magnetic field is applied these domains rotate and align in the direction of magnetic field.

g) When the external magnetic field is weak, the substance is magnetised mostly by the displacement of the domains but in strong fields the magnetisation takes place mostly by the rotation of the domains. When the external field is removed, the substance is not demagnetised completely but some residual magnetism remains in it.

h) When the ferromagnetic material is heated, above curie temperature, the thermal agitation of the atoms becomes so vigorous that the domains are totally disturbed and the resultant magnetic moment becomes zero.

35. **Electron theory of magnetism :**

a) Molecular theory of magnetism was first given by *Weber* and was later developed by Ewing.

b) Electron theory of magnetism was proposed by *Langevin*.

c) Due to orbital motion as well as spin motion of the electron atom gets magnetic moment. The magnetic moment of the atom is equal to the vector sum of the magnetic moments of constituent electrons. Most of the magnetic moment is produced due to spin of electron. The contribution of orbital revolution is very small.

d) Based on this theory paramagnetism and diamagnetism can be explained.

36. **Explanation of diamagnetism :**

a) This property is generally found in those substances whose atoms or molecules have even number of electrons which form pairs.

b) In the electron pairs, the direction of spin of one electron is opposite to that of the other so, the magnetic moment of one electron is cancelled by that of the other. As such that net magnetic moment of the atom of a diamagnetic substance is zero.

c) When a diamagnetic substance is placed in an external magnetic field, one electron of each pair is slowed down, where as the other is accelerated. In the case electrons of the pair do not neutralize the magnetic moments of each other. As a result a magnetic moment is induced in the atom whose direction is opposite to that of ht external field. It means the substance is magnetised opposite to the external field.

d) *Diamagnetism* is present in all materials. So, it can be considered as a *universal property*.

37. **Paramagnetism :**

a) Paramagnetic materials will have a permanent magnetic moment in them.

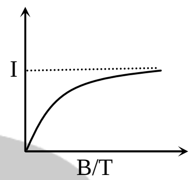
b) Paramagnetism is found in those substance whose atoms or molecules have an excess of electrons spinning in the same direction.

c) Due to the permanent magnetic moment of the atom it behaves like a tiny magnet called atomic magnet.

d) In the absence of external magnetic field, atomic magnets are randomly oriented and neutralize the magnetic moment of earth other. So the magnetic moment of the bulk of the substance remains zero.

e) When a paramagnetic substance is placed in an external magnetic field, each atomic magnet experiences a couple which tends to turn the magnetic in the direction of the field and thermal agitation opposes them to do so. It means the alignment of atomic magnets is continuously disturbed due to thermal agitation. So, magnetism in paramagnetic substances is very weak. The magnetism increases on reducing the temperature or by increasing the external magnetic field.

f) At low fields, the total magnetic moment would be directly proportional to the magnetic induction B and inversely proportional to absolute temperature. At higher fields and low temperature the total moment reaches the saturation when all the atomic magnets align in the direction of the field.



$M \propto \frac{B}{T} \Rightarrow M = \frac{CB}{T}$ where C is a constant

$\Rightarrow I \propto \frac{B}{T}$ (I is intensity of magnetisation)