Chapter 20

Magnetism and Matter

NATURAL MAGNET

A natural magnet is an ore of iron (Fe_3O_4) which

(i) attracts small pieces of iron, cobalt and nickel towards it.

(ii) when suspendeded freely, comes to rest along north-south direction.

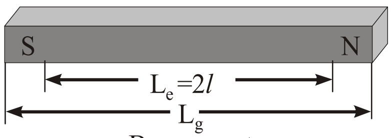
The magnets which are obtained artificially are called artificial magnets, e.g. a bar magnet, a magnetic needle, horse shoe magnet etc.

BAR MAGNET

A bar magnet consists of two equal and opposite magnetic poles 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 $L_e = 2l$ and $L_e = (5/6)\, L_g$.

For semicircular magnet $L_g = \pi R$ and $L_e = 2R$.



Bar magnet

Properties of Magnets

(i) **Attractive property :** A magnet attracts small pieces of iron, cobalt, nickel, etc. and other magnetic subsances.

(ii) **Directive property :** A freely suspended magnet aligns itself nearly in the geographical north-south direction.

(iii) **Law of magnetic poles :** Like magnetic poles repel, and unlike magnetic poles attract each other.

According to **Gauss's theorem in magnetism**, surface integral of magnetic field intensity over a surface (closed or open) is always zero i.e. $\oint \vec{B}.d\vec{s}$ (or $\int \vec{B}.d\vec{s}$) = 0.

This theorem establishes that the poles always exist in equal and unlike pairs.

(iv) **Magnetic poles exist in pairs :** Isolated magnetic poles do not exist. If we break a magnet into two pieces, we get two smaller dipole magnets.

(v) Repulsion is a sure test of magnetism.

MAGNETIC FIELD

The space around a magnet within which its influence can be experienced is called its magnetic field.

Uniform magnetic field : A uniform magnetic field is one where the strength of the magnetic field is the same at all points of the field. In a uniform field, all the magnetic lines of force are parallel to one another. But in **non-uniform magnetic field** the strength of magnetic field is not same at all points of the field and also the magnetic lines of force are not parallel.

Atom as a Magnetic Dipole

Every atom of a magnetic material behaves as a magnetic dipole, because electrons in the atom revolve round the nucleus. The magnetic moment M associated with an atomic dipole as

$$M = \frac{neh}{4\pi m} = n\mu_B$$

where n = 1, 2, 3 ..... denotes the no. of orbits and $\mu_B = \frac{eh}{4\pi m}$.

Least value of dipole moment of atom = 9.27×10^{-24} Am^2.

μ_B is called **Bohr magneton.**

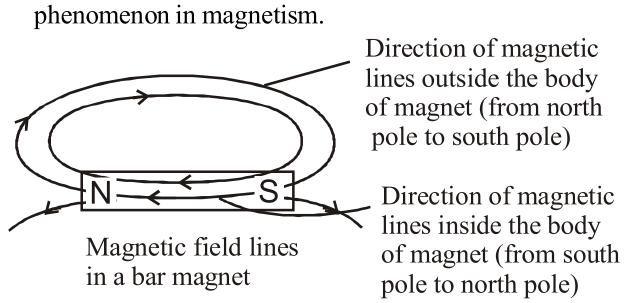
Most of the magnetic moment is produced due to electron spin, the contribution of the orbital revolution is very small.

MAGNETIC LINES OF FORCE

Magnetic line of force is an imaginary curve the tangent to which at a point gives the direction of magnetic field at that point or the magnetic field line is the imaginary path along which an isolated north pole will tend to move if it is free to do so.

Properties of Magnetic Lines of Force

(i) Magnetic lines of force are hypothetical lines use to depict magnetic field in a region and understand certain phenomenon in magnetism.



Magnetic field lines in a bar magnet

(ii) Tangent to field line at a point gives us the direction of magnetic field intensity $\vec{B}$ at that point. *No two magnetic lines of force can intersect each other* because magnetic field will have two directions at the point of intersection.

(iii) Magnetic lines of force are continuous curve from north to south, outside the body of the magnet and from south to north inside the body of the magnet.

(iv) The number of lines originating or terminating on a pole is proportional to its pole strength.

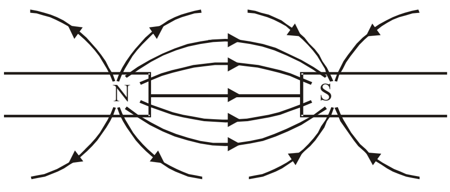
Magnetic flux = number of magnetic lines of force

$= \mu_0 \times m$

Where μ_0 is number of lines associated with unit pole.

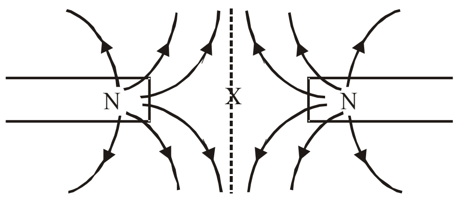
(v) The number of lines of force per unit area at a point gives magnitude of field at that point. The crowded lines show a strong field while distant lines represent a weak field.

(vi) The magnetic lines of force have a tendency to contract longitudinally like a stretched elastic string producing attraction between opposite pole.



Longitudnal contraction (attraction)

(vii) The magnetic lines of force have a tendency to repel each other laterally resulting in repulsion between similar poles.



Lateral expansion (repulsion)

(viii) The region of space with no magnetic field has no lines of force. At neutral point where resultant field is zero there cannot be any line of force.

SOME TERMS RELATED TO MAGNETISM

Magnetic poles : These are the regions of apparently concentrated magnetic strength where the magnetic attraction is maximum.

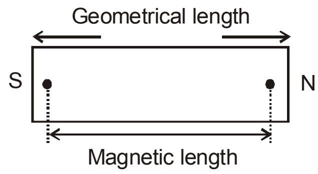
It means that pole of a magnet is located not at a point but over a region. Magnetic poles exist in pairs. An isolated magnetic pole (north or south) does not exist. If a magnet is cut into two pieces, then instead of obtaining separate N-pole and S-pole, each of the two parts are found to behave as complete magnets.

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

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

Magnetic length : The shortest distance between the two poles of a magnet is called its magnetic length. It is less than the geometrical length of the magnet. This magnetic length is also called an effective length.

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



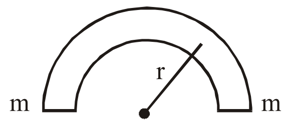
MAGNETIC MOMENT

The magnetic moment of a magnet in magnitude is equal to the product of pole strength with effective length (i.e. magnetic length). Its direction is along the axis of magnet from south pole to north pole.

$$\vec{M} = m \times 2\ell \times (\vec{n}) \Rightarrow |\vec{M}| = 2m\ell$$

If the same bar magnet is bent in a semicircle then

$$\pi r = 2l \Rightarrow r = \frac{2l}{\pi}$$



Net magnetic moment

$$M' = m \times 2r = m \times 2 \times \frac{2l}{\pi} = m \times \frac{4l}{\pi} = \frac{2M}{\pi}$$

Where m is pole strength, 2ℓ is effective length and $\vec{n}$ is unit vector having a direction from S-pole to N-pole.

The **SI unit** of $\vec{M}$ is A m^2, which is equivalent to J/T.

Circular current loop as a magnet : A small plane loop of current behaves as a magnet with a definite dipole moment given by

$$\vec{M} = I\, A\hat{n}$$

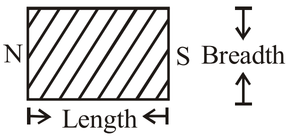
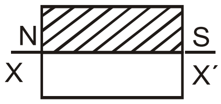
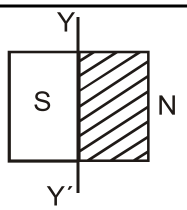
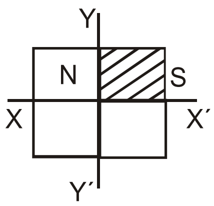
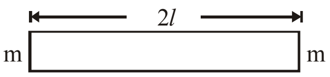
where A is the area of the loop, I the current in the loop and $\hat{n}$ is a unit vector perpendicular to the plane of the loop, and its direction is decided by the sense of flow of current I using the Fleming's right hand rule.

Relation between magnetic moment and angular momentum

$$\vec{M} = \frac{q}{2m}\vec{L}$$

Where q is the total charge on a body of mass m rotaing about a fixed axis.

Magnetic moment, pole strength and effective length when a magnet is cut

Magnet placed after cutting	**Pole strength**	**Effective length**	**Magnetic moment after cutting**
	m	2ℓ	$M = 2m\ell$
	m/2	2ℓ	$M_1 = \frac{m}{2}.2\ell = \frac{M}{2}$
	m	ℓ	$M_2 = m\ell = \frac{M}{2}$
	m/2	ℓ	$M_3 = \frac{m\ell}{2} = \frac{M}{4}$
	m	2ℓ	$M = m \times 2l$

COULOMB'S LAW OF MAGNETIC FORCE

It states that :

(i) *The force of attraction or repulsion between two magnetic poles is directly proportional to the product of their pole strengths.*

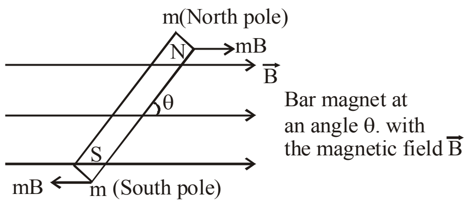
(ii) *The force of attraction or repulsion between two magnetic poles is inversely proportional to the square of the distance between them.* This law is also known as **inverse square law**.

i.e., $F \propto m_1 m_2$ and $F \propto \frac{1}{r}$ or, $F = \frac{\mu_0}{4\pi}.\frac{m_1\ m_2}{r^2}$

where m_1 and m_2 are the pole strengths of the two magnetic poles, r is the distance between them and μ_0 is the permeability of free space.

Unit magnetic pole : A unit magnetic pole may be defined as the pole which when placed in vacuum at a distance of one metre from an identical pole, repels it with a force of 10^{-7} newton.

TORQUE ON A MAGNET IN A MAGNETIC FIELD



A magnet of dipole moment M suspended freely in a magnetic field B experiences a torque $\vec{\tau}$ given by

$\vec{\tau} = \vec{M} \times \vec{B}$; $\tau = MB \sin\theta$

where θ is the angle between $\vec{M}$ and $\vec{B}$

It is clear from the expression that $|\tau_{max}| = MB$

i.e., *when dipole is perpendicular to field the torque is maximum and when they are parallel, the torque is minimum*

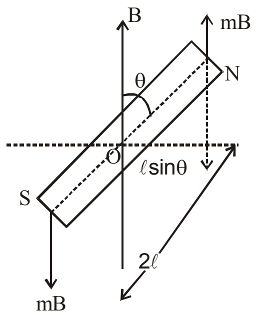
(for $\theta = 0$ or $180° \rightarrow |\vec{\tau}| = 0$).

The net force acting on a bar magnet placed

→ in a uniform magnetic field is zero

→ in a non-uniform magnetic field is non-zero

Let the length of a bar magnet be 2ℓ and pole strength be m, the magnetic field is B, and the angle between B and bar magnet is θ. Force on north pole is mB along the field and that on south pole is mB opposite to the field.



The torque of these two forces about O is

$\tau = 2mB\ell\sin\theta = MB\sin\theta$

$\tau = \overrightarrow{M} \times \overrightarrow{B}$

where M is the magnetic moment of the magnet. ($\because M = 2m\ell$)

This torque tries to align the magnet with the field.

Work Done by External Agent in Rotating the Magnet

If an external agent rotates the magnet slowly, the agent has to exert a torque MBsinθ opposite to that exerted by the field.

Work done by the agent in changing the angle from θ to θ + dθ is dW = (MBsinθ) dθ

$$W_{ext} = \int_{\theta_0}^{\theta} (MB\sin\theta)d\theta$$

$$W_{ext} = MB(\cos\theta_0 - \cos\theta)$$

W_{ext} is stored as potential energy of the field-magnet system. Thus

$U(\theta) - U(\theta_0) = MB(\cos\theta_0 - \cos\theta)$

If we take $U(\theta_0) = 0$ for $\theta_0 = 90^\circ$, then

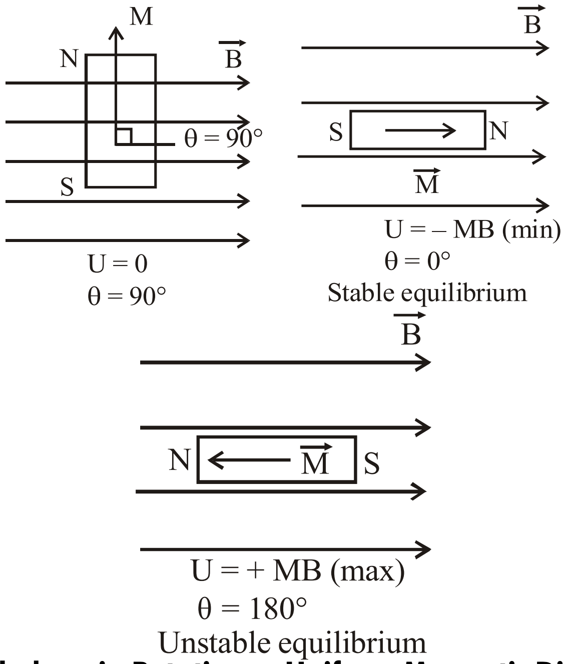
Potential energy

$U(\theta) = U(\theta) - U(90^\circ) = -MB\cos\theta = -\overrightarrow{M} \cdot \overrightarrow{B}$

(i) When θ = 0, U = – MB (minimum PE)

(ii) When $\theta = 90^\circ$, U = 0

(iii) When $\theta = 180^\circ$, U = MB (maximum PE)



Work done in Rotating a Uniform Magnetic Dipole in a Magnetic Field

Work done in deflecting the dipole through an angle θ is,

W = MB (1 – cos θ)

If θ = 0, cos θ = 1 then W = MB (1 – 1) = 0

If θ = 90°, cos θ = 0 then W = MB

If θ = 180°, cos θ = –1, then W = 2MB

GAUSS'S LAW IN MAGNETISM

The surface integral of magnetic field $\vec{B}$ over a closed surface S is always zero.

Mathematically $\oint_S \vec{B} \cdot \vec{da} = 0$

(1) Isolated magnetic poles do not exist is a direct consequence of gauss's law in magnetism.

(2) The total magnetic flux linked with a closed surface is always zero.

(3) If a number of magnetic field lines are leaving a closed surface, an equal number of field lines must also be entering the surface.

Magnetic Flux

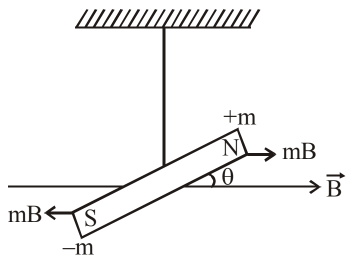
The magnetic flux through a given area may be defined as the total number of magnetic lines of force passing through this area. It is equal to the product of the normal components of the magnetic field B and the area over which it is uniform. In general, *Magnetic flux*, $\phi = \int_A \vec{B} . \vec{dA} = \int_A BdA\cos\theta$, where θ is angle between normal to the area dA with magnetic field B.

Magnetic flux linked with a closed surface is zero i.e., $\oint_s \vec{B} . \vec{dA} = 0$

The **S.I. Unit** of magnetic flux is weber (Wb) : If a magnetic field of 1 tesla passes normally through a surface of area 1 square metre, then the magnetic flux linked with this surface is said to be 1 weber.

Oscillations of a Bar Magnet in a Magnetic Field

A freely suspended magnet of magnetic moment M and of moment of inertia I oscillates simple harmonically in a magnetic field B with frequency

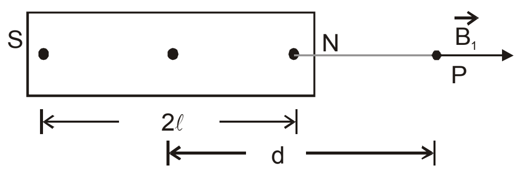


Freely suspended bar magnet, at an angle θ with the magnetic field $\vec{B}$

$$\nu = \frac{1}{2\pi}\sqrt{\frac{MB}{I}}, \therefore \textit{ Time period}, T = 2\pi\sqrt{\frac{I}{MB}}$$

MAGNETIC FIELD DUE TO A BAR MAGNET

(i) **Magnetic field intensity B_1 due to a bar magnet at any point on the axial line of the magnet is** $B_1 = \frac{\mu_0}{4\pi}\frac{2Md}{(d^2 - \ell^2)^2}$



where d = distance of the point from the centre of the magnet.
The direction of B_1 is along SN.

$$B_N = \frac{\mu_0}{4\pi}\frac{m}{(d-\ell)^2}$$ where, m is pole strength.

B_N is magnetic field due to north pole, it is directed away from the magnet.

$$B_S = \frac{\mu_0}{4\pi}\frac{m}{(d+\ell)^2}$$ it is directed towards the magnet.

$$\therefore B = B_N - B_S \Rightarrow B = \frac{\mu_0 m}{4\pi}\left[\frac{1}{(d-\ell)^2} - \frac{1}{(d+\ell)^2}\right]$$

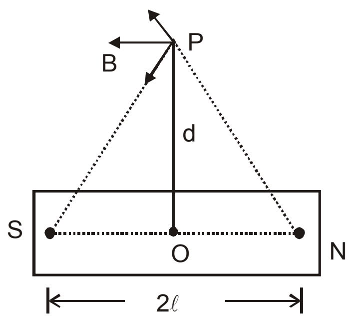
$$= \frac{\mu_0 m(4\ell d)}{4\pi\,(d^2-\ell^2)^2} = \frac{\mu_0}{4\pi}\frac{2Md}{(d^2-\ell^2)^2} \qquad [\because M = m(2L)]$$

If $d >> \ell$, $B = \frac{\mu_0}{4\pi}\frac{2M}{d^3}$

(ii) Magnetic field intensity (B_2) due to A bar magnet at any point on the equatorial line of the bar magnet is

$$B_2 = \frac{\mu_0}{4\pi}\frac{M}{(d^2+\ell^2)^{3/2}}$$

The direction of B_2 is along a line parallel to NS.



$$B_N = \frac{\mu_0}{4\pi}\frac{m\overrightarrow{NP}}{NP^3}, \quad B_S = \frac{\mu_0}{4\pi}\frac{m\overrightarrow{PS}}{PS^3}$$

Now, $NP = PS = (d^2+\ell^2)^{3/2}$

Resultant field at P is, $\vec{B} = \overrightarrow{B_N} + \overrightarrow{B_S}$

$$\Rightarrow \vec{B} = \frac{\mu_0}{4\pi}.\frac{m}{(d^2+\ell^2)^{3/2}}(\overrightarrow{NP}+\overrightarrow{PS}) = \frac{\mu_0}{4\pi}.\frac{m}{(d^2+\ell^2)^{3/2}}(\overrightarrow{NS})$$

$$|\vec{B}| = \frac{\mu_0}{4\pi}\frac{2ml}{(d^2+\ell^2)^{3/2}} = \frac{\mu_0}{4\pi}\frac{M}{(d^2+\ell^2)^{3/2}}$$

If $d >> \ell$, $|\vec{B}| = \frac{\mu_0}{4\pi}\frac{M}{d^3}$

The magnetic field at any point having polar coordinates (r, θ) relative to centre of magnet or loop

$$B = \frac{\mu_0}{4\pi}\frac{M}{r^3}\sqrt{(1+3\cos^2\theta)}$$ and direction is given by

$$\tan\alpha = \frac{1}{2}\tan\theta$$

MAGNETIC POTENTIAL

The magnetic potential at a point is defined as the work done in carrying a unit N-pole from infinity to that point against the field. It may also be defined as the quantity whose space rate of variation in any direction gives the intensity of the magnetic field

i.e., $$B = -\frac{dV_B}{dx}$$

(i) **Magnetic potential due to a point dipole, at a distance r from the pole of strength m** is given by

$$V_B = \frac{\mu_0}{4\pi}.\frac{m}{r} \text{ (joule/Wb)}$$

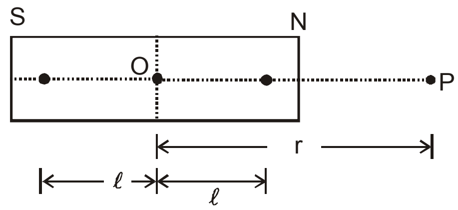
B due to a pole of Pole strength m at a distance r is given by

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

Now V_0 at A is the work done is bringing a unit pole from infinity to A.

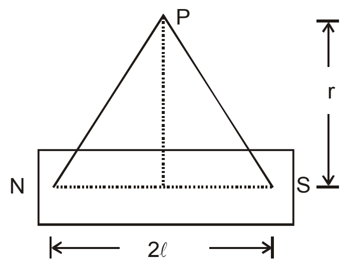
$$\therefore V_A - V_\infty = \int_\infty^r a\frac{\mu_0 m}{4\pi r^2}dr \Rightarrow V_A = \frac{\mu_0 m}{4\pi r}$$

(ii) **Potential due to a magnetic dipole at a point in end-side on position** is $V_B = \frac{\mu_0}{4\pi}.\left(\frac{m}{r^2-\ell^2}\right)$, where M = 2m*l*.



If $\ell^2 << r^2$ then $V_B = \frac{\mu_0}{4\pi}\frac{m}{r^2}$

(iii) **Potential due to a magnetic pole at a point in the broad side-on position**. Net potential at P = 0. The potential at any point lying on the magnetic equator of a magnet is zero in CGS and MKS system.



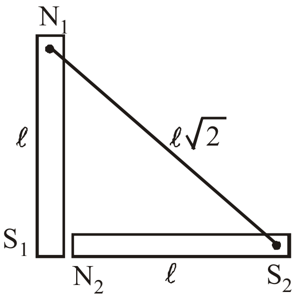
(iv) **The magnetic potential at a point lying on a line passing through the centre and making angle θ with the axis**

$$V_B = \frac{\mu_0}{4\pi}\frac{M\cos\theta}{(r^2-\ell^2)}$$ and for small dipole, $r >> \ell$

$$V_B = \frac{\mu_0}{4\pi}\frac{M\cos\theta}{r^2}$$

Example 1.

Two identical thin bar magnets each of length ℓ and pole strength m are placed at right angles to each other, with north pole of one touching south pole of the other, then find the magnetic moment of the system.



Solution :

Initial magnetic moment of each magnet = m × ℓ.

As is clear from fig., S_1 and N_2 neutralize each other.

Effective distance between

N_1 and $S_2 = \sqrt{\ell^2 + \ell^2} = \ell\sqrt{2}$ $\quad \therefore \; M' = m\ell\sqrt{2}$.

Example 2.

A steel wire of length ℓ has a magnetic moment M. It is then bent into a semi-circular arc. Find the new magnetic moment.

Solution :

Let d be the diameter of semi-circle.

$\therefore \; \ell = (\pi d/2)$ or $d = (2\ell/\pi)$

New magnetic moment = $m \times d = m \times (2\ell/\pi)$

$= 2m\ell/\pi = (2M/\pi)$

Example 3.

Work done in turning a magnet of magnetic moment M by an angle 90º from the magnetic meridian is n times the corresponding work done to turn through an angle of 60º, where n is

(a) 1/2 (b) 2

(c) 1/4 (d) 1

***Solution :* (b)**

$W_1 = -MB(\cos 90° - \cos 0°) = MB$

$W_2 = -MB(\cos 60° - \cos 0°)$

$$= -MB\left(\frac{1}{2} - 1\right) = \frac{1}{2}MB = \frac{1}{2}W_1$$

As $W_1 = n\,W_2$; $\quad \therefore \; n = 2$

Example 4.

In a hydrogen atom, an electron revolves with a frequency of 6.8 × 10^9 megahertz in an orbit of diameter 1.06 Å. What will be the equivalent magnetic moment?

Solution :

$\nu = 6.8 \times 10^9$ MHz $= 6.8 \times 10^{15}$ Hz,

$$r = \frac{1.06}{2} = 0.53 \text{ Å} = 0.53 \times 10^{-10} \text{ m}$$

$$M = IA = \left(\frac{e}{1/\nu}\right)\pi r^2 = e\nu\pi r^2$$

$$= (1.6 \times 10^{-19})\,(6.80 \times 10^{15}) \times \frac{22}{7}(0.53 \times 10^{-10})^2$$

$$= 9.7 \times 10^{-24} \text{ A m}^2$$

Example 5.

The time period of oscillation of a magnet in a vibration magnetometer is 1.5 sec. What will be the time period of oscillation of another magnet similar in size, shape and mass but having 1/4 magnetic moment than that of the 1st magnet oscillating at the same place?

Solution :

$$\frac{T_2}{T_1} = \sqrt{\frac{M_1}{M_2}} = \sqrt{\frac{M_1}{\frac{1}{4}M_1}} = 2 ; \quad \therefore \quad T_2 = 2T_1 = 3s .$$

Example 6.

The time period of oscillation of a magnet is 2 sec. When it is remagnetised so that its pole strength is 4 times, what will be its period?

Solution :

$$\frac{T_2}{T_1} = \sqrt{\frac{M_1}{M_2}} = \sqrt{\frac{m_1 \times 2\ell}{m_2 \times 2\ell}} ; \quad \frac{T_2}{T_1} = \sqrt{\frac{m_1}{4m_1}} = \frac{1}{2} ; T_2 = 1 \text{ sec.}$$

Example 7.

A thin rectangular magnet suspended freely has a period of oscillation of 4s. If it is broken into two equal halves, what will be the period of oscillation of each half ?

Solution :

For each half, mass is half and length is half;

As $\text{M.I.} = \dfrac{m\ell^2}{12}$ $\qquad \therefore$ M.I. becomes 1/8th.

Also M becomes 1/2

As $T = 2\pi\sqrt{\text{M.I.}/MB}$

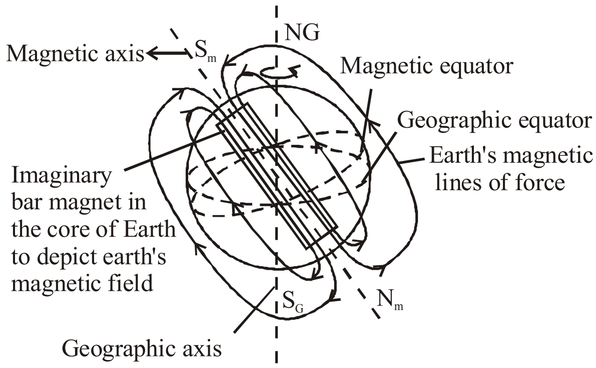
$\therefore$ T becomes $\sqrt{\dfrac{1/8}{1/2}}$ times $= \dfrac{1}{2}$ times

New time period $= \dfrac{1}{2} \times 4s = 2s$

EARTH'S MAGNETISM

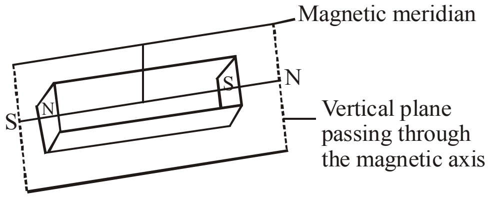
Magnetic field of earth extends nearly upto five times the radius of earth i.e., 3.2 × 10^4 km.

The magnetic field of earth is fairly uniform and can be represented by equidistant parallel lines.



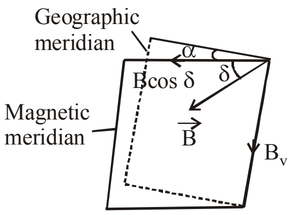
Geographic meridian : The geographic meridian at a place is the vertical plane passing through the geographic north & south at that place.

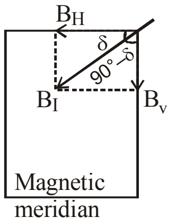
Magnetic meridian : The magnetic meridian at a place is the vertical plane passing through the magnetic axis of a freely suspended small magnet. The earth's magnetic field acts in the plane of magnetic meridian.

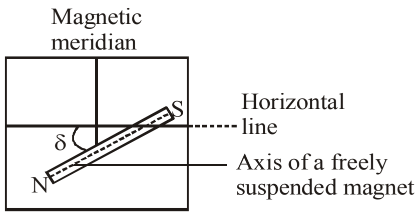


Elements of Earth's Magnetic Field

The earth's magnetic field at a place can be completely described by three independent parameters called elements of earth's magnetic field. These are :







(i) Magnetic declination (θ) : *The angle between the geographic meridian and the magnetic meridian at a place is called the magnetic declination at that place.*

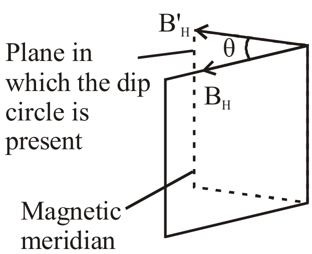
(ii) Angle of dip (δ) : *The angle made by the earth's total magnetic field $\vec{B}$ with the horizontal is called angle of dip at any place.*

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

True and apparent dip

When the plane of the dip circle is in the magnetic meridian, then the needle stops in the actual direction of the Earth's magnetic field. The angle made by the needle with the horizontal in this condition is called **true dip**.

In case, the plane of the dip circle is not in the magnetic meridian then the angle made by the needle with the horizontal is called **apparent dip**. In this case the vertical component of earth's magnetic field remains the same but the effective horizontal component $B'_H = B_H \cos\theta$



$$\tan\delta' = \frac{B'_V}{B'_H} = \frac{B_V}{B_H\cos\theta}$$

where δ′ = apparent dip

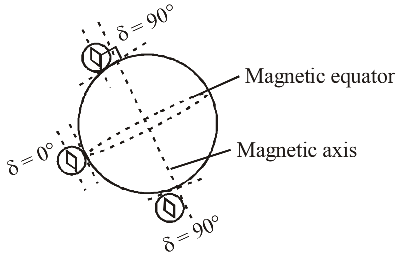
δ = true dip

If the dip circle is rotated by 90°, the new apparent dip δ″ and δ′ and δ are related as $\cot^2\delta = \cot^2\delta' + \cot^2\delta''$

(iii) Horizontal component of earth's magnetic field (B_H) : It is the *component of the earth's total magnetic field $\vec{B}$ in the horizontal diection and is given by, $B_H = B\cos\delta$*

Keep in Memory

1. Dip circle is an instrument used to measure angle of dip at a place.
2. At poles total magnetic intensity is 0.66 oersted and at equator it is 0.33 oersted
   The total magnetic intensity at a particular latitude is
   $I = I_0\sqrt{1+3\sin^2\lambda}$
   where λ is the angle of latitude



   The angle of dip δ = 0° at magnetic equator
   and δ = 90° at magnetic poles.
3. A spectacular effect due to earth's magnetism is observed near the magnetic poles of earth. This effect is called **aurora-borealis in the north** and **aurora - austorlis in south**. It is shown by patterns of coloured lights.

Magnetic Maps

Magnetic surveys all over the earth have been carried out and magnetic maps have been prepared which show the values of magnetic element throughout the world. Lines can be drawn to join places having the same value of a particular magnetic element.

(i) **Isogonic lines :** These join places of equal declination. A line joining places of zero declination is called **agonic line**.

(ii) **Isoclinic lines :** These join places of equal dip.
A line joining the places of zero-dip is called **aclinic line**.

(iii) **Isodynamic lines :** These join places of equal horizontal component.

Shielding from magnetic fields : For shielding a certain region of space from magnetic field, we surround the region by soft iron rings. Magnetic field lines will be drawn into the rings and the space enclosed will be free of magnetic field.

Neutral Points

Neutral points are the points where the net field intensity due to the field of the bar magnet and field of earth is zero. When magnet is placed with its north pole towards geographic north, neutral points lie **on equatorial line of the magnet**. At each neutral point,

$$B_2 = \frac{\mu_0}{4\pi}\frac{M}{(d^2+\ell^2)^{3/2}} = H$$

where H = horizontal component of earth's magnetic field.

When the bar magnet is placed with its north pole towards geographic south, the neutral points lie **on the axial line of the magnet**. At each neutral point,

$$B_1 = \frac{\mu_0}{4\pi}\frac{M}{(d^2-\ell^2)^2} = H$$

Relation between the units of quantities associated with magnetic field :

$1A = 1JT^{-1}\,m^{-2} = 1J\,Wb^{-1}$

$1T = 1JA^{-1}\,m^{-2} = 1Wb\,m^{-2}$

$1Wb = 1JA^{-1} = 1Tm^2$

$[B] = NA^{-1}\,m^{-1} = T = Wb\,m^{-2}$

$[M] = A\,m^2 = JT^{-1} = J\,m^2\,Wb^{-1}$

$[\mu_0] = NA^{-2} = T^2\,m^2\,N^{-1} = Wb^2\,J^{-1}\,m^{-1}$

Example 8.

A circular coil of radius 0.157 m has 50 turns. It is placed such that its axis is in magnetic meridian. A dip needle is supported at the centre of the coil with its axis of rotation horizontal and in the plane of the coil. The angle of dip is 30º, when a current flows through the coil. The angle of dip becomes 60º on reversing the current. Find the current in the coil assuming that magnetic field due to the coil is smaller than the horizontal component of earth's field. Take $H = 3 \times 10^{-5}$ T.

Solution :

If H is horizontal component and V is vertical component at the place, then true value of dip (δ) at the place is given by,

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

If B is magnetic field intensity at the centre of coil due to current I in circular coil and B is along H, then $\tan 30^\circ = \frac{V}{H+B}$.

On reversing the direction of current, the direction of B is reversed.

$$\therefore \tan 60^\circ = \frac{V}{H-B}$$

Dividing, we get $\frac{\tan 60^\circ}{\tan 30^\circ} = \frac{H+B}{H-B} = \frac{\sqrt{3}}{1/\sqrt{3}} = 3$

$$\therefore B = H/2 \Rightarrow B = \frac{3\times10^{-5}}{2} = 1.5\times10^{-5}\ T$$

For a circular coil, $B = \frac{\mu_o nI}{2r}$

$$\therefore 1.5\times10^{-5} = \frac{(4\pi\times10^{-7})\times50\times I}{2\times0.157}$$

$$\therefore I = \frac{1.5\times10^{-5}\times2\times0.157}{4\pi\times10^{-7}\times50} = 0.75\ A\cdot$$

Example 9.

If θ_1 and θ_2 are angles of dip in two vertical planes at right angle to each other and θ is true dip then prove $\cot^2\theta = \cot^2\theta_1 + \cot^2\theta_2$.

Solution :

If the vertical plane in which dip is θ_1 subtends an angle α with meridian than other vertical plane in which dip is θ_2 and is perpendicular to first will make an angle of $90^\circ - \alpha$ with magnetic meridian. If θ_1 and θ_2 are apparent dips then

$$\tan\theta_1 = \frac{B_V}{B_H\cos\alpha}\ ;\ \tan\theta_2 = \frac{B_V}{B_H\cos(90-\alpha)} = \frac{B_V}{B_H\sin\alpha}$$

$$\cot^2\theta_1 + \cot^2\theta_2 = \frac{1}{(\tan\theta_1)^2} + \frac{1}{(\tan\theta_2)^2}$$

$$= \frac{B_H^2\cos^2\alpha + B_H^2\sin^2\alpha}{B_V^2} = \frac{B_H^2}{B_V^2} = \left(\frac{B\cos\theta}{B\sin\theta}\right)^2 = \cot^2\theta$$

so $\cot^2\theta_1 + \cot^2\theta_2 = \cot^2\theta$

TERMS RELATED TO MAGNETISM

Magnetic intensity $(\vec{H})$: When a magnetic material is placed in a magnetic field, it becomes magnetised. *The capability of the magnetic field to magnetise a material is expressed by means of a magnetic vector $\vec{H}$, called the `magnetic intensity' of the field.*

The relation between magnetic induction B and magnetising field $\vec{H}$ $H = \frac{B}{\mu}$, μ being permeability of medium.

Intensity of magnetisation (I) : When a material is placed in a magnetising field, it acquires magnetic moment M. *The intensity of magnetisation is defined as the magnetic moment per unit volume* i.e., $I_m = \frac{M}{V}$

V being volume of mateiral. If the material is in the form of a bar of cross-sectional area A, length 2ℓ and pole strength m, then

$$M = m\times2\ell;\ V = A\times2\ell \qquad \therefore\ I_m = \frac{M}{V} = \frac{m.2\ell}{A.2\ell} = \frac{m}{A}$$

Magnetic susceptibility (χ) : *The magnetic susceptibility is defined as the intensity of magnetisation per unit magentising field.*

i.e., $\chi = \frac{I_m}{H}$

Magnetic permeability (μ) : The magnetic permeability of a material is the measure of degree to which the material can be permited by a magnetic field and is defined as *the ratio of magnetic induction (B) in the material to the magnetising field* i.e. $\mu = \frac{B}{H}$

Relation between Magnetic Susceptibility and Permeability

We have magnetic induction in mateiral, $B = \mu H$

Also $B = B_0 + B_m$

where B_0 = magnetic induction in vacuum produced by magnetising field

B_m = magnetic induction due to magnetisation of material.

But $B_0 = \mu_0 H$ and $B_m = \mu_0 I_m \Rightarrow B = \mu_0[H + I_m]$

$\therefore \quad B = \mu_0 H\,[1 + \frac{I_m}{H}] = B_0\,[1+\chi]; \quad \therefore \quad B/B_0 = [1+\chi]$

$\therefore\ B/B_0 = \frac{\mu H}{\mu_0 H} = \mu/\mu_0 = \mu_r$, the relative magnetic permeability

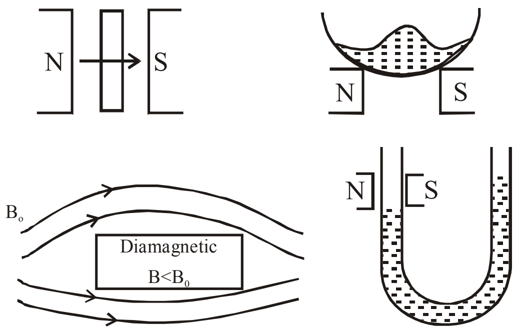
$\boxed{\therefore\ \mu_r = 1+\chi}$

This is required relation.

CLASSIFICATION OF MATERIALS

According to the behaviour of substances in magnetic field, they are classified into three categories:

1. Diamagnetic Substances : *These are the substances which when placed in a strong magnetic field acquire a feeble magnetism opposite to the direction of magnetising field.* The **examples** are copper, gold, antimony, bismuth, alcohol, water, quartz, hydrogen, etc.



Behaviour of diamagnetic substance in an external magnetic field $\vec{Bo}$

The characteristics of diamagnetic substances are

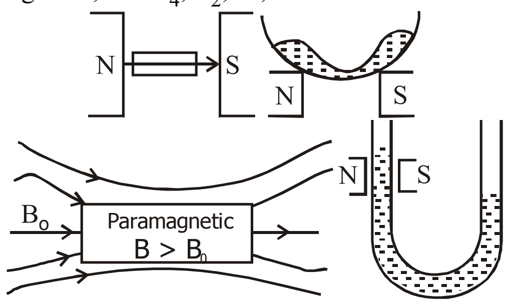
(a) They are feebly repelled by a strong magnet

(b) Their susceptibility is negative (i.e. $\chi < 0$)

(c) Their relative permeability is less than 1. (i.e. $\mu_r < 1$)

(d) Their susceptibility is independent of magnetising field and temperature (except for Bismuth at low temperature)

2. Paramagnetic Substances : *These are the materials which when placed in a strong magnetic field acquire a feeble magnetism in the same sense as the applied magnetic field.* The **examples** are platinum, aluminium, chromium, manganese, $CuSO_4$, O_2, air, etc.



Behaviour of paramagnetic substance in an external field $\vec{Bo}$

The characteristics of paramagnetic substances are

(a) They are attracted by a strong magnet

(b) Their susceptibility is positive but very small ($\chi > 0$)

(c) Their relative permeability is slightly greater than unity. ($\mu > 1$)

(d) Their susceptibility and permeability do not change with the variation of magnetising field.

(e) Their susceptibility is inversely proportional to temperature, $\left(\text{i.e. } \chi \alpha \frac{1}{T}\right)$.

(f) They are found in those material which have atoms containing odd number of electrons

3. Ferromagnetic Substances : *These are the substances which are strongly magnetised by relatively weak magnetising field in the same sense as the magnetising field.* The **examples** are Ni, Co, iron and their alloys.

The characteristics of ferromagnetic substances are

(a) They are attracted even by a weak magnet.

(b) The susceptibility is very large and positive. ($\chi >> 0$)

(c) The relative permeability is very high (of the order of hundreds and thousands). ($\mu >> 1$)

(d) The intensity of magnetisation is proportional to the magnetising field H for smaller values, varies rapidly for moderate values and attains a constant value for larger values of H.

(e) The susceptibility of a ferromagnetic substance is inversely proportional to temperature i.e., $\chi \propto 1/T$

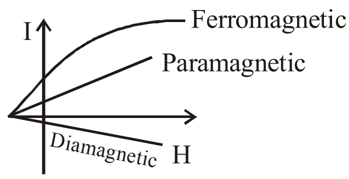
$\Rightarrow \chi = \frac{C}{T}$; C = curie constant .

This is called **Curie law**. *At a temperature called* **curie temperature**, *ferromagnetic substance becomes paramagnetic*. The curie temperatures for Ni, Fe and Co are 360ºC, 740ºC and 1100ºC respectively.

(f) They are found in those material which have domains and can be converted into strong magnets

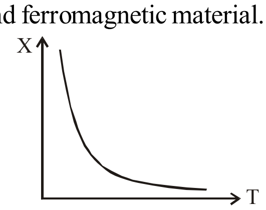
Keep in Memory

1. Diamagnetism is universal. It is present in all materials. But it is weak and hard to detect if substance is para or feromagnetic.
2. I – H curve for different materials



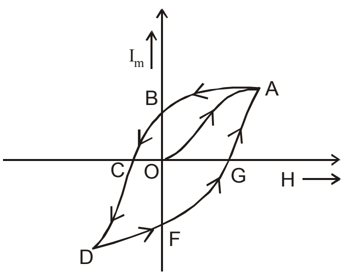
3. Curve for magnetic susceptibility and temperature for a paramagnetic and ferromagnetic material.

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



HYSTERESIS

When a bar of ferromagnetic material is magnetised by a varying magnetic field and the intensity of magnetisation I_m induced is measured for different values of magnetising field H, the graph of I versus H is as shown in fig



The graph shows :

(i) When magnetising field is increased from O the intensity of magnetisation I_m increases and becomes maximum (i.e. point A). This maximum value is called the **saturation value**.

(ii) When H is reduced, I_m reduces but is not zero when H = 0. The remainder value OB of magnetisation when H = 0 is called the residual magnetism or **retentivity**. OB is retentivity.

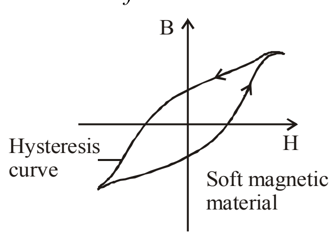
(iii) When magnetic field H is reversed, the magnetisaiton decreases and for a particular value of H, it becomes zero i.e., for H = OC, I = 0. This value of H is called the **coercivity**.

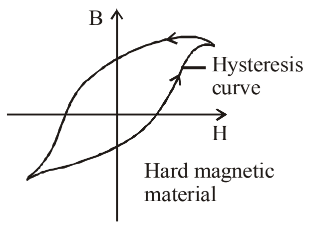
(iv) When field H is further increased in reverse direction, the intensity of magnetisation attains saturation value in reverse direction (i.e., point D).

(v) When H is decreased to zero and changed direction in steps, we get the part DFGA.

Properties of Soft Iron and Steel

For soft iron, the susceptibility, permeability and retentivity are greater while coercivity and hysteresis loss per cycle are smaller than those of steel.





PERMANENT MAGNETS AND ELECTROMAGNETS

Permanent magnets are made of steel and cobalt while electromagnets are made of soft iron.

An electromagnet is made by inserting a soft iron core into the interior of a solenoid. Soft iron does not retain a significant permanent magnetization when the solenoid's field is turned off– soft iron does not make a good permanent magnet. When current flows in the solenoid, magnetic dipoles in the iron tend to line up with the field due to the solenoid. The net effect is that the field inside the iron is intensified by a factor known as the relative permeability. The relative permeability is analogous in magnetism to the dielectric constant in electricity. However, the dielectric constant is the factor by which the electric field is weakened, while the relative permeability is the factor by which the magnetic field is strengthened. The reactive permeability of a ferromagnet can be in the hundreds or even thousands–the intensification of the magnetic field is significant. Not only that, but in an electromagnet the strength and even direction of the magnetic field can be changed by changing the current in the solenoid.

Keep in Memory

1. By alloying soft-iron with 4% silicon 'transformer steel' is produced. It has a higher relative permeability and is an ideal material for cores of transformers. Alloys of iron and nickel called 'permalloys', also have very large permeabilities.
2. Energy spent per unit volume of specimen is complete cycle of magnetisation is numerically equal to area of I – H loop

	Perme-ability	Suscep-tibility	Intensity of magnetisation	Reten-tivity	Coerc-ivity	Hysteresis loss
Soft iron	high	high	high	high	low	low
Steel	low	low	low	low	high	high

⇒ Steel is most suitable for making parmanent magnet

⇒ Soft iron is most suitable for making core of an electromagnet.

Example 10.

A magnetising 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.

Solution :

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

$A = 0.2\ cm^2 = 0.2 \times 10^{-4}\ m^2$, $\mu = ?$ $\chi_m = ?$

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

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

$$[\because \text{As } \mu = \mu_0(1+\chi_m)]$$

$$\therefore\ \chi_m = \frac{\mu}{\mu_0} - 1 = \frac{7.5 \times 10^{-4}}{4\pi \times 10^{-7}} - 1\ ;$$

$$\chi_m = \frac{7.5 \times 10^3}{4\pi} - 1 = 597.1 - 1 = 596.1$$

Example 11.

A solenoid of 500 turns/m is carrying a current of 3A. Its core is made of iron which has a relative permeability of 5000. Determine the magnitude of magnetic intensity, magnetisation and magnetic field inside the core.

Solution :

Magnetic intensity

$H = ni = 500 \times 3 = 1500$ A/m

$\mu_r = 1 + \chi_m$ so $\chi_m = \mu_r - 1 = 4999 \approx 5000$

Intensity of magnetisation

$I = \chi H = 5000 \times 1500 = 7.5 \times 10^6$ A/m

Magnetic field $B = \mu_r \mu_0 H = 5000 \times 4\pi \times 10^{-7} \times 1500$

$= 9.4$ tesla.

TANGENT GALVANOMETER

It is an instrument used for measuring small current. It is based on tangent law. It is a moving magnet and fixed coil type galvanometer.

Tangent Law : *If a small magnetic needle is under the influence of two crossed magnetic fields (B) and (H) and suffers a deflection θ from field H, then by tangent law, $B = H \tan \theta$.*

Formula for current : If a current passing through the coil of n turns and mean radius r of a tangent galvanometer placed in magnetic meridian causes a deflection θ in the magnetic needle kept at the centre of the coil, then

$I = \left(\frac{2rH}{\mu_0 n}\right)\tan\theta$; $I = K\tan\theta$ where $K = \frac{2rH}{\mu_0 n}$ and is called the **reduction factor**.

DEFLECTION MAGNETOMETER

It's working is based on the principle of tangent law.

(a) **Tan A Position :** In this position the magneto- meter is set perpendicular to magnetic meridian so that, magnetic field due to magnet is in axial position and perpendicular to earth's field and hence

$$\frac{\mu_0}{4\pi}\frac{2Md}{(d^2-\ell^2)^2} = H\tan\theta$$

where d = distance of needle from centre of magnet and

2ℓ = length of magnet.

(b) **TanB position :** The arms of magnetometer are set in magnetic meridian, so that the field is at equatorial position

and hence, $H\tan\theta = \frac{\mu_0}{4\pi}\frac{M}{(d^2-\ell^2)^{3/2}}$

Magnetic field of earth extends nearly upto five times the radius of earth i.e., 3.2×10^4 km.

The magnetic field of earth is fairly uniform and can be represented by equidistant parallel lines.

VIBRATION MAGNETOMETER

It is an instrument for comparing the magnetic moments of two magnets and for comparing their magnetic fields.

The time period of a bar magnet vibrating in the vibration magnetometer kept in magnetic meridian is given by

$$T = 2\pi\sqrt{\frac{I}{MH}} \qquad \therefore \quad M = \frac{4\pi^2 I}{T^2 H}$$

where $I = \left(\frac{m(\ell^2+b^2)}{12}\right)$ is the moment of inertia of the vibrating magnet, m = mass of magnet, ℓ = length of magnet, b = breadth of magnet.

Example 12.

A vibration magnetometer consists of two identical bar magnets, placed one over the other, such that they are mutually perpendicular and bisect each other. The time period of oscillation in a horizontal magnetic field is 4 second. If one of the magnets is taken away, find the period of oscillation of the other in the same field.

Sol. For a vibration magnetometer, we know that $T = 2\pi\sqrt{I/MH}$

Let M be the magnetic moment and M.I, moment of inertia of each magnet,

$$\therefore\ M' = \sqrt{M^2+M^2} = M\sqrt{2}$$

and net $\quad M.I' = M.I + M.I = 2M.I$

$$\therefore\ T' = 2\pi\sqrt{\frac{2\,M.I.}{M\sqrt{2}H}} = 2\times\sqrt{\frac{\sqrt{2}M.I.}{MH}} \qquad ....(1)$$

When one of the magnets is taken away,

$M'' = M,\ MI'' = MI,$

$$\therefore\ T'' = 2\pi\sqrt{\frac{M.I}{MH}} \qquad ...(2)$$

Divide eqn. (2) by (1),

$$\frac{T''}{T'} = \frac{1}{(2)^{1/4}} \text{ or } T'' = \frac{T'}{(2)^{1/4}} = \frac{4}{2^{1/4}} = 3.34\ \text{s}$$

Examples 13.

The magnetic needle of an oscillation magnetometer makes 10 oscillations per minute under the action of earth's magnetic field alone. When a bar magnet is placed at some distance along the axis of the needle, it makes 14 oscillations per minute. If the bar magnet is turned so that its poles interchange their positions, then what will be the new frequency of oscillation of the needle?

Sol. $$10 = \frac{1}{2\pi}\sqrt{\frac{MH}{I}} \qquad ...(i)$$

$$14 = \frac{1}{2\pi}\sqrt{\frac{M(H+F)}{I}} \qquad ...(ii)$$

$$n = \frac{1}{2\pi}\sqrt{\frac{M(H-F)}{I}} \qquad ...(iii)$$

Divide eqs. (ii) by (i), $\frac{14}{10} = \sqrt{\frac{H+F}{H}} = \sqrt{1+\frac{F}{H}} = \frac{7}{5}$

$$\therefore\ \frac{F}{H} = \frac{24}{25}$$

Divide eqs. (iii) by (i), $\frac{n}{10} = \sqrt{\frac{H-F}{H}} = \sqrt{1-\frac{F}{H}} = \frac{1}{5}$

or, $\quad n = \frac{10}{5} = 2$ vibs /minute.

Example 14.

The period of oscillation of a magnet in a vibration magnetometer is 2 sec. What will be the period of oscillation of a magnet whose magnetic moment is four times that of the first magnet?

Sol. $$T = 2\pi\sqrt{\left(\frac{I}{MB_H}\right)}$$

$$T' = 2\pi\sqrt{\left(\frac{I}{4MB_H}\right)} = \frac{1}{2}\left[2\pi\sqrt{\frac{I}{(MB_H)}}\right]$$

$$= \frac{1}{2}\times 2 = 1 \text{ second.}$$

Example 15.

A magnet is suspended in such a way that it oscillates in the horizontal plane. It makes 20 oscillations per minute at a place where dip angle is 30º and 15 oscillations per minute at a place where dip angle is 60º. What will be the ratio of the total earth's magnetic field at the two places?

Sol. Let the total magnetic fields due to earth at the two places be B_1 and B_2. If horizontal components be $(B_H)_1$ and $(B_H)_2$ respectively, then

$(B_H)_1 = B_1 \cos 30^o$ and $(B_H)_2 = B_2 \cos 60^o$

Here $T_1 = 3$ sec. and $T_2 = 4$ sec.

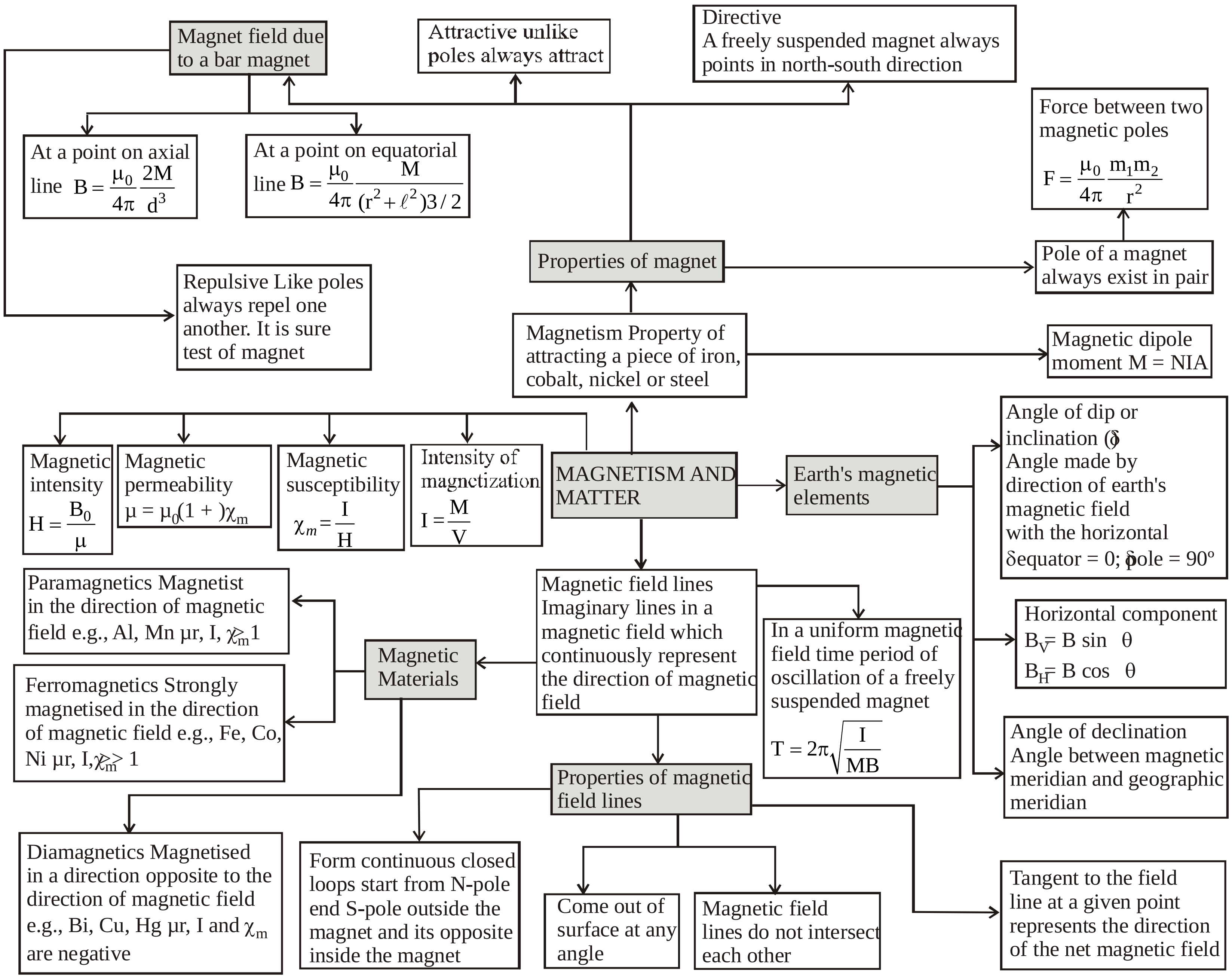
$$T_1 = 3 = 2\pi\sqrt{\left(\frac{I}{MB_1 \cos 30}\right)}$$

and $$T_2 = 4 = 2\pi\sqrt{\left(\frac{I}{MB_2 \cos 60^o}\right)}$$

$$\therefore \frac{3}{4} = \left(\frac{B_2 \cos 60}{B_1 \cos 30}\right)^{1/2} \quad \text{or} \quad \frac{B_1}{B_2} = \frac{16}{9} \times \frac{\cos 60}{\cos 30}$$

or $$\frac{B_1}{B_2} = \frac{16}{9} \times \frac{1}{2} \times \frac{2}{\sqrt{3}} = \frac{16}{9\sqrt{3}} \quad \text{or} \quad B_1 : B_2 = 16 : 9\sqrt{3}$$

CONCEPT MAP


MAGNETISM AND MATTER
Magnetism Property of attracting a piece of iron, cobalt, nickel or steel
Properties of magnet
Magnet field due to a bar magnet
At a point on axial line $B = \frac{\mu_0}{4\pi}\frac{2M}{d^3}$
At a point on equatorial line $B = \frac{\mu_0}{4\pi}\frac{M}{(r^2+\ell^2)3/2}$
Attractive unlike poles always attract
Directive A freely suspended magnet always points in north-south direction
Repulsive Like poles always repel one another. It is sure test of magnet
Pole of a magnet always exist in pair
Force between two magnetic poles $F = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{r^2}$
Magnetic dipole moment M = NIA
Magnetic intensity $H = \frac{B_0}{\mu}$
Magnetic permeability $\mu = \mu_0(1 +)\chi_m$
Magnetic susceptibility $\chi_m = \frac{I}{H}$
Intensity of magnetization $I = \frac{M}{V}$
Earth's magnetic elements
Angle of dip or inclination (δ Angle made by direction of earth's magnetic field with the horizontal δequator = 0; δpole = 90°
Horizontal component
$B_V = B \sin \theta$
$B_H = B \cos \theta$
Angle of declination Angle between magnetic meridian and geographic meridian
Magnetic field lines Imaginary lines in a magnetic field which continuously represent the direction of magnetic field
In a uniform magnetic field time period of oscillation of a freely suspended magnet $T = 2\pi\sqrt{\frac{I}{MB}}$
Magnetic Materials
Paramagnetics Magnetist in the direction of magnetic field e.g., Al, Mn μr, I, χ_m > 1
Ferromagnetics Strongly magnetised in the direction of magnetic field e.g., Fe, Co, Ni μr, I, χ_m > 1
Diamagnetics Magnetised in a direction opposite to the direction of magnetic field e.g., Bi, Cu, Hg μr, I and χ_m are negative
Properties of magnetic field lines
Form continuous closed loops start from N-pole end S-pole outside the magnet and its opposite inside the magnet
Come out of surface at any angle
Magnetic field lines do not intersect each other
Tangent to the field line at a given point represents the direction of the net magnetic field

EXERCISE - 1
Conceptual Questions

1. The main difference between electric lines of force and magnetic lines of force is
(a) electric lines of force are closed curves whereas magnetic lines of force are open curves
(b) electric lines of force are open curves whereas magnetic lines of force are closed curves
(c) magnetic lines of force cut each other whereas electric lines of force do not cut
(d) electric lines of force cut each other whereas magnetic lines of force do not cut

2. Current i is flowing in a coil of area A and number of turns N, then magnetic moment of the coil, M is
(a) NiA (b) $\frac{Ni}{A}$ (c) $\frac{Ni}{\sqrt{A}}$ (d) N^2Ai

3. Nickel shows ferromagnetic property at room temperature. If the temperature is increased beyond Curie temperature, then it will show
(a) anti ferromagnetism (b) no magnetic property
(c) diamagnetism (d) paramagnetism

4. The line on the earth surface joining the point where the field is horizontal, is called
(a) magnetic equator (b) magnetic line
(c) magnetic axis (d) magnetic inertia

5. When a ferromagnetic material is heated to temperature above its Curie temperature, the material
(a) is permanently magnetized
(b) remains ferromagnetic
(c) behaves like a diamagnetic material
(d) behaves like a paramagnetic material

6. The force between two short bar magnets with magnetic moments M_1 and M_2 whose centres are r metres apart is 8 N when their axes are in same line. if the separation is increased to 2 r, the force between them in reduced to
(a) 4 N (b) 2 N (c) 1 N (d) 0.5 N

7. The magnet of pole strength m and magnetic moment M is cut into two pieces along its axis. Its pole strength and magnetic moment now becomes
(a) $\frac{m}{2}, \frac{M}{2}$ (b) $m, \frac{M}{2}$ (c) $\frac{m}{2}, M$ (d) m, M

8. A bar magnet of magnetic moment M and length L is cut into two equal parts each of length L/2. The magnetic moment of each part will be
(a) M (b) M/4 (c) $\sqrt{2}M$ (d) M/2

9. A superconductor exhibits perfect :
(a) ferrimagnetism (b) ferromagnetism
(c) paramagnetism (d) diamagnetism

10. In end on and broadside on position of a deflection magnetometer, if θ_1 and θ_2 are the deflections produced by short magnets at equal distances, then $\tan\theta_1 / \tan\theta_2$ is
(a) 2 : 1 (b) 1 : 2
(c) 1 : 1 (d) None of these

11. A watch glass containing some powdered substance is placed between the pole pieces of a magnet. Deep concavity is observed at the centre. The substance in the watch glass is
(a) iron (b) chromium
(c) carbon (d) wood

12. Needles N_1, N_2 and N_3 are made of a ferromagnetic, a paramagnetic and a diamagnetic substance respectively. A magnet when brought close to them will
(a) attract N_1 and N_2 strongly but repel N_3
(b) attract N_1 strongly, N_2 weakly and repel N_3 weakly
(c) attract N_1 strongly, but repel N_2 and N_3 weakly
(d) attract all three of them

13. A bar magnet is oscillating in the Earth's magnetic field with a period T. What happens to its period and motion if its mass is quadrupled?
(a) Motion remains S.H. and period remains nearly constant
(b) Motion remains S.H. with time period $= \frac{T}{2}$
(c) Motion remains S.H. with time period $= 2T$
(d) Motion remains S.H. with time period $= 4T$

14. Two magnets of magnetic moments M and 2M are placed in a vibration magnetometer, with the identical poles in the same direction. The time period of vibration is T_1. If the magnets are placed with opposite poles together and vibrate with time period T_2, then
(a) T_2 is infinite (b) $T_2 = T_1$
(c) $T_2 > T_1$ (d) $T_2 < T_1$

15. If horizontal and vertical components of earths magnetic field are equal, then angle of dip is
(a) 60° (b) 45° (c) 30° (d) 90°

16. The magnetic materials having negative magnetic susceptibility are
(a) non-magnetic (b) para magnetic
(c) dia magnetic (d) ferro magnetic

17. For protecting a sensitive equipment from the external electric arc, it should be
(a) wrapped with insulation around it when passing current through it
(b) placed inside an iron can
(c) surrounded with fine copper sheet
(d) placed inside an aluminium can

18. If a diamagnetic substance is brought near north or south pole of a bar magnet, it is
(a) attracted by the poles
(b) repelled by the poles
(c) repelled by north pole and attracted by the south pole
(d) attracted by the north pole and repelled by the south pole

19. A bar magnet, of magnetic moment $\vec{M}$, is placed in a magnetic field of induction $\vec{B}$. The torque exerted on it is

(a) $\vec{M} \cdot \vec{B}$ (b) $-\vec{M} \cdot \vec{B}$ (c) $\vec{M} \times \vec{B}$ (d) $\vec{B} \times \vec{M}$

20. Current i is flowing in a coil of area A and number of turns N, then magnetic moment of the coil M is

(a) NiA (b) $\frac{Ni}{A}$ (c) $\frac{Ni}{\sqrt{A}}$ (d) N^2Ai

21. A diamagnetic material in a magnetic field moves
(a) perpendicular to the field
(b) from stronger to the weaker parts of the field
(c) from weaker to the stronger parts of the field
(d) None of these

22. According to Curie's law, the magnetic susceptibility of a substance at an absolute temperature T is proportional to

(a) T^2 (b) $\frac{1}{T}$ (c) T (d) $\frac{1}{T^2}$

23. The magnetic moment of a diamagnetic atom is
(a) equal to zero
(b) much greater than one
(c) unity
(d) between zero and one

24. There are four light-weight-rod samples A,B,C,D separately suspended by threads. A bar magnet is slowly brought near each sample and the following observations are noted
(i) A is feebly repelled
(ii) B is feebly attracted
(iii) C is strongly attracted
(iv) D remains unaffected
Which one of the following is true ?
(a) B is of a paramagnetic material
(b) C is of a diamagnetic material
(c) D is of a ferromagnetic material
(d) A is of a non-magnetic material

25. If the magnetic dipole moment of an atom of diamagnetic material, paramagnetic material and ferromagnetic material are denoted by μ_d, μ_p and μ_f respectively, then
(a) $\mu_d = 0$ and $\mu_p \neq 0$ (b) $\mu_d \neq 0$ and $\mu_p = 0$
(c) $\mu_p = 0$ and $\mu_f \neq 0$ (d) $\mu_d \neq 0$ and $\mu_f \neq 0$

EXERCISE - 2
Applied Questions

1. A bar magnet 8 cms long is placed in the magnetic merdian with the N-pole pointing towards geographical north. Two netural points separated by a distance of 6 cms are obtained on the equatorial axis of the magnet. If horizontal component of earth's field = 3.2×10^{-5} T, then pole strength of magnet is
(a) 5 ab-amp × c (b) 10 ab-amp × cm
(c) 2.5 ab-amp × cm (d) 20 ab-amp × cm

2. Two tangent galvanometers having coils of the same radius are connected in series. A current flowing in them produces deflections of 60° and 45° respectively. The ratio of the number of turns in the coils is

(a) 4/3 (b) $\frac{\sqrt{3}+1}{1}$ (c) $\frac{\sqrt{3}+1}{\sqrt{3}-1}$ (d) $\frac{\sqrt{3}}{1}$

3. Two identical magnetic dipoles of magnetic moments 1.0 A-m^2 each, placed at a separation of 2 m with their axis perpendicular to each other. The resultant magnetic field at point midway between the dipole is
(a) 5×10^{-7} T (b) $\sqrt{5} \times 10^{-7}$ T
(c) 10^{-7} T (d) 2×10^{-7} T

4. Two isolated point poles of strength 30 A-m and 60 A-m are placed at a distance of 0.3m. The force of repulsion is
(a) 2×10^{-3} N (b) 2×10^{-4} N
(c) 2×10^{5} N (d) 2×10^{-5} N

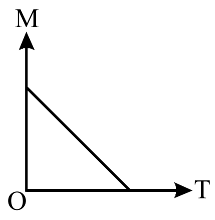
5. The magnetic moment of a magnet is 0.1 amp × m^2. It is suspended in a magnetic field of intensity 3×10^{-4} weber/m^2. The couple acting upon it when deflected by 30° from the magnetic field is
(a) 1×10^{-5} N m (b) 1.5×10^{-5} N m
(c) 2×10^{-5} N m (d) 2.5×10^{-5} N m

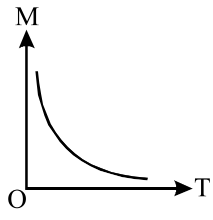
6. When 2 ampere current is passed through a tangent galvanometer, it gives a deflection of 30°. For 60° deflection, the current must be

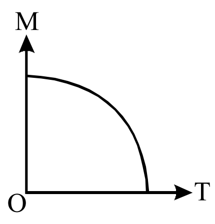
(a) 1 amp. (b) $2\sqrt{3}$ amp.

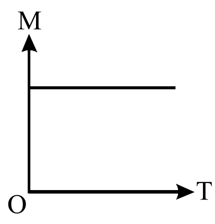
(c) 4 amp. (d) 6 amp.

7. A curve between magnetic moment and temperature of magnet is

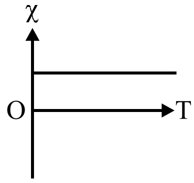
(a)


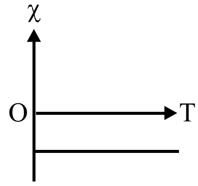
(b)


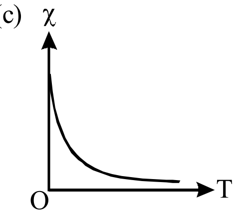
(c)


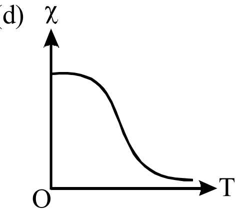
(d)


8. The variation of magnetic susceptibility (x) with temperature for a diamagnetic substance is best represented by

(a)


(b)


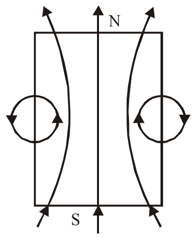
(c)


(d)


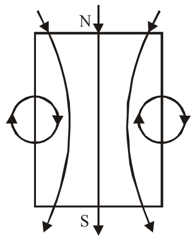
9. At a temperatur of 30°C, the susceptibility of a ferromagnetic material is found to be χ. Its susceptibility at 333°C is

(a) χ (b) 0.5χ (c) 2χ (d) 11.1χ

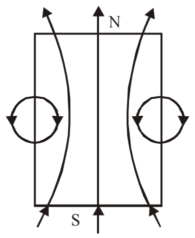
10. Of the following fig., the lines of magnetic induction due to a magnet SN, are given by



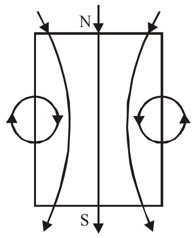
(1)



(2)



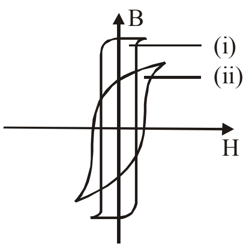
(3)



(4)

(a) 1 (b) 2 (c) 3 (d) 4

11. The B – H curve (i) and (ii) shown in fig. associated with



(a) (i) diamagnetic and (ii) paramagnetic substance
(b) (i) paramagnetic and (ii) ferromagnetic substance
(c) (i) soft iron and (ii) steel respectively
(d) (i) steel and (ii) soft iron respectively

12. A thin bar magnet of length 2 ℓ and breadth 2 b pole strength m and magnetic moment M is divided into four equal parts with length and breadth of each part being half of original magnet. Then the pole strength of each part is

(a) m (b) m/2 (c) 2m (d) m/4

13. In the above question, magnetic moment of each part is

(a) M/4 (b) M (c) M/2 (d) 2 M

14. Two points A and B are situated at a distance x and 2x respectively from the nearer pole of a magnet 2 cm long. The ratio of magnetic field at A and B is

(a) 4 : 1 exactly (b) 4 : 1 approximately
(c) 8 : 1 approximately (d) 1 : 1 approximately

15. If a magnet is suspended at angle 30° to the magnetic meridian, the dip needle makes an angle of 45° with the horizontal. The real dip is

(a) $\tan^{-1}(\sqrt{3/2})$ (b) $\tan^{-1}(\sqrt{3})$

(c) $\tan^{-1}(\sqrt{3}/2)$ (d) $\tan^{-1}(2/\sqrt{3})$

16. Two bar magnets of the same mass, same length and breadth but having magnetic moments M and 2M are joined together pole for pole and suspended by a string. The time period of assembly in a magnetic field of strength H is 3 seconds. If now the polarity of one of the magnets is reversed and combination is again made to oscillate in the same field, the time of oscillation is

(a) $\sqrt{3}$ sec (b) $3\sqrt{3}$ sec
(c) 3 sec (d) 6 sec

17. A compass needle placed at a distance r from a short magnet in Tan A position shows a deflection of 60°. If the distance is increased to r $(3)^{1/3}$, then deflection of compass needle is

(a) 30° (b) $60\times 3^{\frac{1}{3}}$

(c) $60\times 3^{\frac{2}{3}}$ (d) $60\times 3^{\frac{3}{3}}$

18. Two short magnets have equal pole strengths but one is twice as long as the other. The shorter magnet is placed 20 cms in tan A position from the compass needle. The longer magnet must be placed on the other side of the magnetometer for no deflection at a distance equal to

(a) 20 cms (b) $20\,(2)^{1/3}$ cms
(c) $20\,(2)^{2/3}$ cms (d) $20\,(2)^{3/3}$ cms

19. A dip needle lies initially in the magnetic meridian when it shows an angle of dip θ at a place. The dip circle is rotated through an angle x in the horizontal plane and then it shows an angle of dip θ′.

Then $\frac{\tan\theta'}{\tan\theta}$ is

(a) $\frac{1}{\cos x}$ (b) $\frac{1}{\sin x}$ (c) $\frac{1}{\tan x}$ (d) $\cos x$

20. A dip circle is so set that its needle moves freely in the magnetic meridian. In this position, the angle of dip is 40º. Now the dip circle is rotated so that the plane in which the needle moves makes an angle of 30º with the magnetic meridian. In this position, the needle will dip by an angle

(a) 40º (b) 30º
(c) more than 40º (d) less than 40º

21. Work done in turning a magnet of magnetic moment M by an angle of 90º from the mgnetic meridian is n times the corresponding work done to turn through an angle of 60º, where n is

(a) 1/2 (b) 2 (c) 1/4 (d) 1

22. Two magnets are held together in a vibration magnetometer and are allowed to oscillate in the earth's magnetic field with like poles together. 12 oscillations per minute are made but for unlike poles together only 4 oscillations per minute are executed. The ratio of their magnetic moments is

(a) 3 : 1 (b) 1 : 3 (c) 3 : 5 (d) 5 : 4

23. At a certain place, horizontal component is $\sqrt{3}$ times the vertical component. The angle of dip at this place is

(a) 0 (b) $\pi/3$
(c) $\pi/6$ (d) None of these

24. A freely suspended magnet oscillates with period T in earth's horizontal magnetic field. When a bar magnet is brought near it, such that the magnetic field created by bar magnet is in same direction as earth's horizontal magnetic field, the period decreases to $\frac{T}{2}$. The ratio of the field of the magnet F to the earth's magnetic field (H) is

(a) 1 : 3 (b) 1 : 1 (c) 3 : 1 (d) 9 : 1

25. If relative permeability of iron is 2000. Its absolute permeability in S.I. units is

(a) $8\pi \times 10^{-4}$ (b) $8\pi \times 10^{-3}$
(c) $800/\pi$ (d) $8\pi \times 10^{9}/\pi$

26. A steel wire of length ℓ has a magnetic moment M. It is then bent into a semicircular arc. The new magnetic moment is

(a) $\frac{M}{\pi}$ (b) $\frac{2M}{\pi}$ (c) $\frac{3M}{\pi}$ (d) $\frac{4M}{\pi}$

27. The magnetic moment of atomic neon is equal to

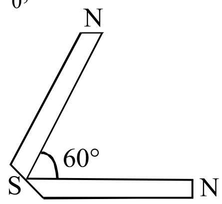
(a) zero (b) $\frac{1}{2}\mu_B$ (c) μ_B (d) $\frac{3}{2}\mu_B$

28. Torques τ_1 and τ_2 are required for a magnetic needle to remain perpendicular to the magnetic fields at two different places. The magnetic fields at those places are B_1 and B_2 respectively; then ratio $\frac{B_1}{B_2}$ is

(a) $\frac{\tau_2}{\tau_1}$ (b) $\frac{\tau_1}{\tau_2}$

(c) $\frac{\tau_1+\tau_2}{\tau_1-\tau_2}$ (d) $\frac{\tau_1-\tau_2}{\tau_1+\tau_2}$

29. The net magnetic moment of two identical magnets each of magnetic moment M_0, inclined at 60° with each other is



(a) M_0
(b) $\sqrt{2}\,M_0$
(c) $\sqrt{3}\,M_0$
(d) $2M_0$

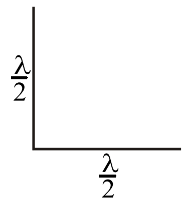
30. A magnetic needle vibrates in a vertical plane parallel to the magnetic meridian about a horizontal axis passing through its centre. Its frequency is n. If the plane of oscillation is turned about a vertical axis by 90°C, the frequency of its oscillation in vertical plane will be

(a) n (b) zero
(c) less than n (d) more than n

31. A thin rectangular magnet suspended freely has a period of oscillation of 4 s. If it is broken into two halves (each having half the original length) and one of the pieces is suspended similarly. The period of its oscillation will be

(a) 4 s (b) 2 s
(c) 0.5 s (d) 0.25 s

32. A steel wire of length ℓ has a magnetic moment M. It is bent in L-shape (Figure). The new magnetic moment is



(a) M
(b) $\frac{M}{\sqrt{2}}$
(c) $\frac{M}{2}$
(d) 2M

33. The time period of oscillation of a magnet in a vibration magnetometer is 1.5 sec. The time period of oscillation of another magnet similar in size, shape and mass but having 1/4 magnetic moment than that of the 1st magnet oscillating at the same place will be

(a) 0.75 sec (b) 1.5 sec
(c) 3.0 sec (d) 6.0 sec

34. Time periods of vibation of two bar magnets in sum and difference positions are 4 sec and 6 sec respectively. The ratio of their magnetic moments M_1 / M_2 is

(a) 6 : 4 (b) 30 : 16
(c) 2 . 6 : 1 (d) 1 . 5 : 1

35. Horizontal component of earth's field at a height of 1 m from the surface of earth is H. Its value at a height of 10 m from surface of earth is

(a) H/10 (b) H/9
(c) H/100 (d) H

36. If a toroid uses bismuth for its core, the field in the core compared to that in empty core will be slightly

(a) greater (b) smaller
(c) equal (d) None of these

37. The relative permeability of a medium is 0.075. What is its magnetic susceptibility?

(a) 0.925 (b) –0.925 (c) 1.075 (d) –1.075

38. Relative permittivity and permeability of a material ε_r and μ_r, respectively. Which of the following values of these quantities are allowed for a diamagnetic material?

(a) $\varepsilon_r = 0.5, \mu_r = 1.5$ (b) $\varepsilon_r = 1.5, \mu_r = 0.5$

(c) $\varepsilon_r = 0.5, \mu_r = 0.5$ (d) $\varepsilon_r = 1.5, \mu_r = 1.5$

39. The moment of a magnet (15 cm × 2 cm × 1 cm) is 1.2 A-m^2. What is its intensity of magnetisation?

(a) 4×10^4 A m^{-1} (b) 2×10^4 A m^{-1}

(c) 10^4 A m^{-1} (d) None of these

40. The work done in turning a magnet of magnetic moment M by an angle of 90° from the meridian, is n times the corresponding work done to turn it through an angle of 60°. The value of n is given by

(a) 2 (b) 1 (c) 0.5 (d) 0.25

41. At a certain place, the angle of dip is 30º and the horizontal component of earth's magnetic field is 0.50 oerested. The earth's total magnetic field (in oerested) is

(a) $\sqrt{3}$ (b) 1 (c) $\frac{1}{\sqrt{3}}$ (d) $\frac{1}{2}$

42. A coil in the shape of an equilateral triangle of side l is suspended between the pole pieces of a permanent magnet such that $\vec{B}$ is in plane of the coil. If due to a current i in the triangle a torque τ acts on it, the side l of the triangle is

(a) $\frac{2}{\sqrt{3}}\left(\frac{\tau}{B.i}\right)^{\frac{1}{2}}$ (b) $2\left(\frac{\tau}{\sqrt{3}B.i}\right)^{\frac{1}{2}}$

(c) $\frac{2}{\sqrt{3}}\left(\frac{\tau}{B.i}\right)$ (d) $\frac{1}{\sqrt{3}}\frac{\tau}{B.i}$

43. Iron is ferromagnetic

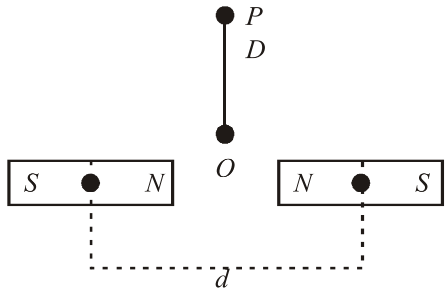
(a) above 770°C (b) below 770°C

(c) at all temperature (d) above 1100°C

44. A vibration magnetometer placed in magnetic meridian has a small bar magnet. The magnet executes oscillations with a time period of 2 sec in earth's horizontal magnetic field of 24 microtesla. When a horizontal field of 18 microtesla is produced opposite to the earth's field by placing a current carrying wire, the new time period of magnet will be

(a) 1 s (b) 2 s (c) 3 s (d) 4 s

45. Two identical bar magnets are fixed with their centres at a distance d apart. A stationary charge Q is placed at P in between the gap of the two magnets at a distance D from the centre O as shown in the figure.



The force on the charge Q is

(a) directed perpendicular to the plane of paper

(b) zero

(c) directed along OP

(d) directed along PO

46. A short bar magnet of magnetic moment 0.4J T^{-1} is placed in a uniform magnetic field of 0.16 T. The magnet is in stable equilibrium when the potential energy is

(a) – 0.064 J (b) zero

(c) – 0.082 J (d) 0.064 J

DIRECTIONS (Qs. 47 to 50) : Each question contains STATEMENT-1 and STATEMENT-2. Choose the correct answer (ONLY ONE option is correct) from the following-

(a) Statement -1 is false, Statement-2 is true

(b) Statement -1 is true, Statement-2 is true; Statement -2 is a correct explanation for Statement-1

(c) Statement -1 is true, Statement-2 is true; Statement -2 is not a correct explanation for Statement-1

(d) Statement -1 is true, Statement-2 is false

47. **Statement-1** : The ferromagnetic substance do not obey Curie's law.

Statement-2 : At Curie point a ferromagnetic substance start behaving as a paramagnetic substance.

48. **Statement-1** : Magnetism is relativistic.

Statement-2 : When we move along with the charge so that there is no motion relative to us, we find no magnetic field associated with the charge.

49. **Statement-1** : A paramagnetic sample display greater magnetisation (for the same magnetic field) when cooled.

Statement-2 : The magnetisation does not depend on temperature.

50. **Statement-1** : Electromagnetic are made of soft iron.

Statement-2 : Coercivity of soft iron is small.

EXERCISE - 3

Exemplar & Past Years NEET/AIPMT Questions

Exemplar Questions

1. A toroid of n turns, mean radius R and cross-sectional radius a carries current I. It is placed on a horizontal table taken as xy-plane. Its magnetic moment m

(a) is non-zero and points in the z-direction by symmetry

(b) points along the axis of the toroid ($m = m\phi$)

(c) is zero, otherwise there would be a field falling as $\frac{1}{r^3}$ at large distances outside the toroid

(d) is pointing radially outwards

2. The magnetic field of the earth can be modelled by that of a point dipole placed at the centre of the earth. The dipole axis makes an angle of 11.3° with the axis of the earth. At Mumbai, declination is nearly zero. Then,

(a) the declination varies between 11.3° W to 11.3° E

(b) the least declination is 0°

(c) the plane defined by dipole axis and the earth axis passes through Greenwich

(d) declination averaged over the earth must be always negative

3. In a permanent magnet at room temperature.

(a) magnetic moment of each molecule is zero

(b) the individual molecules have non-zero magnetic moment which are all perfectly aligned

(c) domains are partially aligned

(d) domains are all perfectly aligned

4. Consider the two idealised systems (i) a parallel plate capacitor with large plates and small separation and (ii) a long solenoid of length L >> R, radius of cross-section. In (i) E is ideally treated as a constant between plates and zero outside. In (ii) magnetic field is constant inside the solenoid and zero outside. These idealised assumptions, however, contradict fundamental laws as below

(a) case (i) contradicts Gauss' law for electrostatic fields

(b) case (ii) contradicts Gauss' law for magnetic fields

(c) case (i) agrees with $\oint E.dl = 0$.

(d) case (ii) contradicts $\oint H.dl = I_{en}$

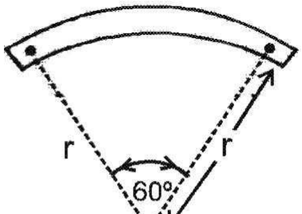
5. A paramagnetic sample shows a net magnetisation of 8 Am^{-1} when placed in an external magnetic field of 0.6 T at a temperature of 4 K. When the same sample is placed in an external magnetic field of 0.2 T at a temperature of 16 K, the magnetisation will be

(a) $\frac{32}{3}Am^{-1}$ (b) $\frac{2}{3}Am^{-1}$

(c) $6Am^{-1}$ (d) $2.4Am^{-1}$

NEET/AIPMT (2013-2017) Questions

6. A bar magnet of length 'ℓ' and magnetic dipole moment 'M' is bent in the form of an arc as shown in figure. The new magnetic dipole moment will be ***[2013]***



(a) $\frac{3}{\pi}M$ (b) $\frac{2}{\pi}M$

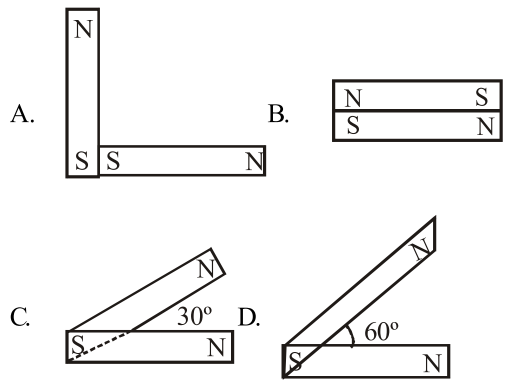
(c) $\frac{M}{2}$ (d) M

7. A bar magnet of magnetic moment M is placed at right angles to a magnetic induction B. If a force F is experienced by each pole of the magnet, the length of the magnet will be ***[NEET Kar. 2013]***

(a) F/MB (b) MB/F

(c) BF/M (d) MF/B

8. Following figures show the arrangement of bar magnets in different configurations. Each magnet has magnet ic dipole moment $\vec{m}$. Which configuration has highest net magnetic dipole moment ? ***[2014]***



(a) A (b) B

(c) C (d) D

9. The magnetic susceptibility is negative for : **[2016]**

(a) diamagnetic material only

(b) paramagnetic material only

(c) ferromagnetic material only

(d) paramagnetic and ferromagnetic materials

10. If θ_1 and θ_2 be the apparent angles of dip observed in two vertical planes at right angles to each other, then the true angle of dip θ is given by :- ***[2017]***

(a) $\tan^2\theta = \tan^2\theta_1 + \tan^2\theta_2$

(b) $\cot^2\theta = \cot^2\theta_1 - \cot^2\theta_2$

(c) $\tan^2\theta = \tan^2\theta_1 - \tan^2\theta_2$

(d) $\cot^2\theta = \cot^2\theta_1 + \cot^2\theta_2$

Hints & Solutions

EXERCISE - 1

1. (b) 2. (a) 3. (d) 4. (a)
5. (d)
6. (d) As $F \propto \frac{1}{r^4}$ and r becomes twice, therefore, F becomes

$\frac{1}{2^4} = \frac{1}{16}$ times

$\therefore \frac{1}{16} \times 8 = 0.5$ N.

7. (a) When cut along the axis, area of cross-section becomes half. Therefore, pole strength is halved and $M = m(2\ell)$, is also halved.
8. (d) As magnetic moment = pole strength x length and length is halved without affecting pole strength, therefore, magnetic moment becomes half.
9. (d) A superconductor exhibits perfect diamagnetism.
10. (a) $\frac{\tan\theta_1}{\tan\theta_2} = \frac{2}{1}$
11. (a) Iron is ferromagnetic.
12. (b) Ferromagnetic substance has magnetic domains whereas paramagnetic substances have magnetic dipoles which get attracted to a magnetic field.
Diamagnetic substances do not have magnetic dipole but in the presence of external magnetic field due to their orbital motion these substance are repelled.
13. (c) $T \propto \sqrt{I}$; $I \alpha M \Rightarrow T \alpha \sqrt{M}$

$$\frac{T_1}{T_2} = \sqrt{\frac{M_1}{M_2}} \Rightarrow T_2 = 2T_1 = 2T$$

14. (c) $T_1 = 2\pi\sqrt{\frac{K_1 + K_2}{(M + 2M)H}} = 2\pi\sqrt{\frac{K}{3MH}}$

$$T_2 = 2\pi\sqrt{\frac{K}{(2M - M)H}} = 2\pi\sqrt{\frac{K}{MH}}$$

Obviously $T_2 > T_1$

15. (b) $\tan\theta = \frac{B_V}{B_H} = 1, B_V = B_H$

$$\theta = \tan^{-1}(1) = 45°$$

16. (c) χ_m is negative for diamagnetic materials.
17. (b) The iron can produces a magnetic screening for the equipment as lines of magnetic force can not enter iron enclosure.
18. (b) Diamagnetic substances do not have any unpaired electron. and they magnetised in direction opposite to that of magnetic field. Hence when they are brought to North or South pole of Bar magnet, they are repelled by poles.
19. (c) We know that when a bar magnet is placed in the magnetic field at an angle θ, then torque acting on the bar magnet

$$(\tau) = MB\sin\theta = \vec{M} \times \vec{B}$$

Note : This torque τ has a tendency to make the axis of the magnet parallel to the direction of the magnetic field.
20. (a) Magnetic moment linked with one turn = iA
Magnetic moment linked with N turn
= iNA amp-m^2.
Here A = Area of current loop.
21. (b) A diamagnetic material in a magnetic field moves, from stronger to the weaker parts of the field.
22. (b) According to Curie's law, $\chi_m \propto \frac{1}{T}$
23. (a) The magnetic moment of a diamagnetic atom is equal to zero.
24. (a) $A \to$ diamagnetic $B \to$ paramagnetic
$C \to$ Ferromagnetic $D \to$ Non-magnetic
25. (a) The magnetic dipole moment of diamagnetic material is zero as each of its pair of electrons have opposite spins, i.e., $\mu_d = 0$.
Paramagnetic substances have dipole moment > 0, i.e. $\mu_p \neq 0$, because of excess of electrons in its molecules spinning in the same direction.
Ferro-magnetic substances are very strong magnets and they also have permanent magnetic moment, i.e. $\mu_f \neq 0$.

EXERCISE - 2

1. (a) Here, $2\ell = 8$ cm, $\ell = 4$ cm, $d = \frac{6}{2} = 3$ cm.
At neutral point,

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

$$= 10^{-7}\frac{M}{(5 \times 10^{-2})^3} = \frac{M}{1250}$$

$$\therefore M = 1250H = 1250 \times 3.2 \times 10^{-5} \text{ Am}^2$$

$$m = \frac{M}{2\ell} = \frac{1250 \times 3.2 \times 10^{-5}}{8 \times 10^{-2}} \text{A m.}$$

$$= 0.5 \text{ Am} = 0.5 \times \frac{1}{10} \text{ab amp} \times 100 \text{ cm}$$

$$= 5 \text{ ab-amp cm.}$$

2. (d) In series, same current flows through two tangent galvanometers.

3. (b) As the axes are perpendicular, mid point lies on axial line of one magnet and on equatorial line of other magnet.

$$\therefore \; B_1 = \frac{\mu_0}{4\pi}\frac{2M}{d^3} = \frac{10^{-7} \times 2 \times 1}{1^3} = 2 \times 10^{-7}$$

and $B_2 = \frac{\mu_0}{4\pi}\frac{M}{d^3} = 10^{-7}$

$\therefore$ Resultant field $= \sqrt{B_1^2 + B_2^2} = \sqrt{5} \times 10^{-7}\,T$

4. (a) $F = \frac{\mu_0}{4\pi}\frac{m_1 m_2}{r^2} = 10^{-7} \times \frac{30 \times 60}{(0.3)^2} = 2 \times 10^{-3}$ N.

5. (b) $\tau = MB \sin\theta = 0.1 \times 3 \times 10^{-4} \sin 30^\circ$
or $\tau = 1.5 \times 10^{-5}$ N–m.

6. (d) As $\frac{i_2}{i_1} = \frac{\tan\theta_2}{\tan\theta_1}$

7. (c) 8. (b)

9. (b) According to Curie's law, $\chi_m = \frac{\mu_0 C}{T}$
where C is Curie constant, T = temperature

$$\therefore \chi_m \alpha \frac{1}{T}$$

$$\frac{\chi_{m_1}}{\chi_{m_2}} = \frac{T_2}{T_1} = \frac{273+333}{273+30} = \frac{606}{303} = 2$$

$$\therefore \chi_{m_2} = \chi_{m_1}/2 = 0.5\chi_{m_1} = 0.5\chi.\left(\because \chi_{m_1} = \chi\right)$$

10. (a) As lines of magnetic induction B are continuous curves, they run continuously through the bar and outside, as shown in Fig. (1).

11. (c) The loop (i) is for soft iron and the loop (ii) is for steel in Fig.

12. (b) As breadth of each part is half the original breadth, therefore, pole strength becomes half (i.e. m/2).

13. (a) As length of each part also becomes half, therefore magnetic moment M = pole strength × length

$$\Rightarrow \frac{1}{2} \times \frac{1}{2} = \frac{1}{4}\text{th i.e. } M/4.$$

14. (c) Taking distances from the centre of the magnet,

$$\frac{B_1}{B_2} = \left(\frac{x_2}{x_1}\right)^3 = \left(\frac{2x+1}{x+1}\right)^3 = 8:1, \text{ approximately.}$$

15. (d) Angle of dip, $\delta = 45^\circ$

$$\therefore \; \tan\delta' = \frac{\tan\delta}{\cos\theta} = \frac{\tan 45}{\cos 30^\circ} = \frac{1}{\sqrt{3}/2} = \frac{2}{\sqrt{3}}$$

$\therefore$ Real dip $\delta' = \tan^{-1}(2/\sqrt{3})$

16. (b) $\frac{T_2^2}{T_1^2} = \frac{2M+M}{2M-M} = 3 \qquad \therefore \; T_2 = T_1\sqrt{3} = 3\sqrt{3}$ s.

17. (a) $\frac{\tan\theta_2}{\tan\theta_1} = \frac{d_1^3}{d_2^3} = \frac{r^3}{[r(3)^{1/3}]^3} = \frac{1}{3}$

$$\tan\theta_2 = \frac{1}{3}\tan\theta_1 = \frac{\tan 60}{3} = \frac{\sqrt{3}}{3} = \frac{1}{\sqrt{3}} \qquad \therefore \; \theta_2 = 30^\circ$$

18. (b) Here, $d_1 = 20$ cm, $M_2 = 2M_1$, $d_2 = ?$

$$\frac{M_2}{M_1} = \frac{d_2^3}{d_1^3} = 2 \Rightarrow d_2 = 2^{1/3} d_1 = 20(2)^{1/3} \text{ cm}$$

19. (a) $\tan\theta = \frac{V}{H}, \tan\theta' = \frac{V}{H\cos x}; \; \frac{\tan\theta'}{\tan\theta} = \frac{1}{\cos x}$

20. (d) $\delta_1 = 40^\circ, \delta_2 = 30^\circ, \delta = ?$

$$\cot\delta = \sqrt{\cot^2\delta_1 + \cot^2\delta_2}$$

$$= \sqrt{\cot^2 40^\circ + \cot^2 30^\circ}$$

$$\cot\delta = \sqrt{1.19^2 + 3} = 2.1$$

$\therefore \; \delta = 25^\circ$ i.e. $\delta < 40^\circ$.

21. (b) $W_1 = -MB(\cos 90^\circ - \cos 0^\circ) = MB$
$W_2 = -MB(\cos 60^\circ - \cos 0^\circ)$

$$= -MB\left(\frac{1}{2} - 1\right) = \frac{1}{2}MB = \frac{1}{2}W_1$$

As $W_1 = n\,W_2 \qquad \therefore \; n = 2$

22. (d) Here, $T_1 = \frac{60}{12} = 5\,s, \; T_2 = \frac{60}{4} = 15\,s$

$$\frac{M_1}{M_2} = \frac{T_2^2 + T_1^2}{T_2^2 - T_1^2} = \frac{15^2 + 5^2}{15^2 - 5^2} = \frac{250}{200} = \frac{5}{4}$$

23. (c) $\tan\delta = \frac{V}{H} = \frac{V}{\sqrt{3}V} = \frac{1}{\sqrt{3}}$

$\therefore\ \delta = 30^\circ = \pi/6$ radian

24. (c) $T_1 = 2\pi\sqrt{\frac{I}{HM}}$,

$T_2 = 2\pi\sqrt{\frac{I}{(H+F)M}}$

$\frac{T_1^2}{T_2^2} = \frac{H+F}{H} = \frac{T^2}{T^2/4} = \frac{4}{1} \Rightarrow H+F = 4H$

$\Rightarrow 3H = F$

25. (a) $\mu = \mu_0\,\mu_r = (4\pi\times10^{-7})\times2000 = 8\pi\times10^{-4}$ S.I. units

26. (b) Let pole strength = m
So, $M = m\ell$
When wire is in form of arc, then the distance between poles = $\frac{2\ell}{\pi}$

So, $M' = \frac{m2\ell}{\pi} = \frac{2M}{\pi}$

27. (a) Magnetic moment is cancelled and $\mu_{net} = 0$.

28. (c) $\tau = MB\sin\theta$ $(\theta = 90^\circ)$

$\tau = MB \Rightarrow \frac{B_1}{B_2} = \frac{\tau_1}{\tau_2}$ (since magnetic moment is same)

29. (c) $M_{net} = \sqrt{M_0^2 + M_0^2 + 2M_0^2\cos 60^\circ}$

$= \sqrt{3M_0^2} = \sqrt{3}M_0$

30. (c) $n = \frac{1}{2\pi}\sqrt{\frac{MB}{I}}$
When it is turned by an angle 90° the effective field is vertical = V and B > V
So, new frequency < n.

31. (b) $T = 2\pi\sqrt{\frac{I}{MB}}$

$I = \frac{m}{2}\left(\frac{\ell}{2}\right)^2 \Rightarrow I' = \frac{I}{8}$

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

So, $T' = 2\pi\sqrt{\frac{I}{4MB}} \Rightarrow T' = \frac{T}{2} = 2$ sec.

32. (b) Magnetic moment, $M = m\ell$

$\frac{M}{\ell} = m$, where m is the polestrength.

Therefore distance between poles

$= \sqrt{(\ell/2)^2 + (\ell/2)^2} = \frac{\ell}{\sqrt{2}}$

So, $M' = \frac{m\ell}{\sqrt{2}} = \frac{M}{\sqrt{2}}$

33. (c) $\frac{T_2}{T_1} = \sqrt{\frac{M_1}{M_2}} = \sqrt{\frac{M_1}{\frac{1}{4}M_1}} = 2$

$\therefore T_2 = 2T_1 = 3$ s

34. (c) $\frac{M_1}{M_2} = \frac{T_2^2 + T_1^2}{T_2^2 - T_1^2} = \frac{6^2+4^2}{6^2-4^2} = \frac{52}{20} = (2.6):1$

35. (d) The value of H is fairly uniform.

36. (b) Field in the core with Bismuth will be smaller because bismuth is diamagnetic.

37. (b) From $\mu_r = 1 + \chi_m$;

Magnetic suscaptibility, $\chi_m = \mu_r - 1$

$\chi_m = 0.075 - 1 = -0.925$.

38. (b) For a diamagnetic material, the value of μ_r is less than one. For any material, the value of ϵ_r is always greater than 1.

39. (a) Intensity of magnetisation

$I_m = \frac{M}{V} = \frac{1.2}{(15\times2\times1)10^{-6}} = 4\times10^4\ A\,m^{-1}$

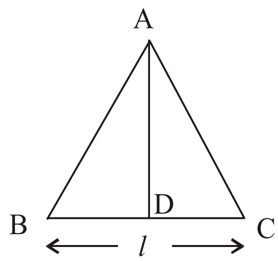
40. (a) Magnetic moment = M; Initial angle through which magnet is turned (θ_1) = 90° and final angle which magnet is turned (θ_2)= 60°. Work done in turning the magnet through
90°(W_1) = MB (cos 0° – cos 90°)= MB (1–0) = MB.
Similarly, W_2 = MB (cos 0° – cos 60°)

$= MB\left(1-\frac{1}{2}\right) = \frac{MB}{2}$.

$\therefore W_1 = 2W_2$ or n = 2.

41. (c) $B = \frac{H}{\cos\theta} = \frac{0.50}{\cos 30^\circ} = \frac{0.50\times2}{\sqrt{3}} = 1/\sqrt{3}$

42. (b) $\tau = MB\sin\theta$, $\tau = iAB\sin 90^\circ$



$$\therefore\ A = \frac{\tau}{iB} = 1/2\,(BC)\,(AD)$$

$$\text{But } \frac{1}{2}(BC)(AD) = \frac{1}{2}(l)\sqrt{l^2 - \left(\frac{l}{2}\right)^2} = \frac{\sqrt{3}}{4}l^2$$

$$\Rightarrow \frac{\sqrt{3}}{4}(l)^2 = \frac{\tau}{Bi}$$

$$\therefore\ l = 2\left(\frac{\tau}{\sqrt{3}\,B.i}\right)^{\frac{1}{2}}$$

43. (b)

44. (d) Time period of a vibration magnetometer,

$$T \propto \frac{1}{\sqrt{B}} \Rightarrow \frac{T_1}{T_2} = \sqrt{\frac{B_2}{B_1}}$$

$$\Rightarrow \quad T_2 = T_1\sqrt{\frac{B_1}{B_2}}$$

$$= 2\sqrt{\frac{24\times10^{-6}}{6\times10^{-6}}} = 4\,s$$

45. (b) Force on a charged particle is given by $F = qvB$. Here $v = 0$ and also resultant B is zero.

$\therefore$ Force = 0

46. (a) For stable equilibrium

$U = -MB = -(0.4)(0.16) = -0.064$ J

47. (c) The susceptibility of ferromagnetic substance decreases with the rise of temperature in a complicated manner. After Curies point in the susceptibility of ferromagnetic substance varies inversely with its absolute tempearture. Ferromagnetic substance obey's Curie's law only above its Curie point.

48. (b) A magnetic field is produced by the motion of electric charge. Since motion is relative, the magnetic field is also relative.

49. (d) A paramagnetic sample display greater magnetisation when cooled, this is because at lower temperature, the tendency to disrupt the alignment of dipoles (due to magnetising field) decreases on account of reduced random thermal motion.

50. (b) Electromagnets are magnets, which can be turnd on and off by switching the current on and off.

As the material in electromagnets is subjected to cyclic changes (magnification and demangetisation), the hysteresis loss of the material must be small. The material should attain high value of I and B with low value of magnetising field intensity H. As soft iron has small coercivity, so it is a best choice for this purpose.

EXERCISE - 3

Exemplar Questions

1. (c) Toroid is a hollow circular ring on which a large number of turns of a wire are closely wound. Thus, in this case magnetic field is only confined inside the body of toroid.

So no magnetic field outside the toroid and magnetic field only inside the toroid.

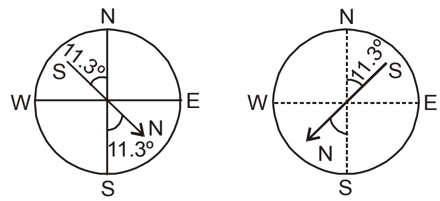
In case of toroid, the magnetic field is in the form of concentric magnetic lines of force and there is no magnetic field outside the body of toroid. This is because the loop encloses no current. Thus, the magnetic moment of toroid is zero.

In other case, if we take r as a large distance outside the toroid, then $m \propto \frac{1}{r^3}$. Which is not possible.

2. (a) Magnetic declination is an angle between angle of magnetic meridian and the geographic meridian.

As the earth's magnetism, the magnetic field lines of the earth resemble that of a hypothetical magnetic dipole located at the centre of the earth.

The axis of the dipole does not coincide with the axis of rotation of the earth but is presently tilted by 11.3° (approx) with respect to geographical of axis earth. This results into two situations as given in the figure.



So, the declination varies between 11.3° W to 11.3° E .

3. (d) We know that a permanent magnet is a substance which at room temperature retain ferromagnetic property for a long period of time. The individual atoms in a ferromagnetic material possess a dipole moment as in a paramagnetic material. However, they interact with one another in such a way that they spontaneously align themselves in a common direction over a macroscopic volume i.e., domain.

Hence, in a permanent magnet at room temperature, domains are all perfectly aligned.

4. (b) The electric field lines, do not form a continuous path while the magnetic field lines form the closed paths.

Gauss's law states that, $\oint_s E.ds = \frac{q}{\varepsilon_0}$ for electrostatic field. So, it does not contradict for electrostatic fields as the electric field lines do not form closed continuous path.

According to Gauss' law in magnetic field,

$$\oint_s E.ds = 0$$

It contradicts for magnetic field, because there is a magnetic field inside the solenoid and no field outside the solenoid carrying current but the magnetic field lines form the closed path.

5. (b) According to the Curie law, the intensity of magnetisation (I) is directly proportional to the magnetic field induction and inversely proportional to the temperature (t) in kelvin.

So, I magnetisation

$$\propto \frac{\text{B (magnetic field induction)}}{\text{t(temperature in kelvin)}}$$

$$\Rightarrow \quad \frac{I_2}{I_1} = \frac{B_2}{B_1} \times \frac{t_1}{t_2} \quad \text{... (i)}$$

As given that : $I_1 = 8\,Am^{-1}$, $I_2 = ?$

$B_1 = 0.6\,T$, $t_1 = 4K$

$B_2 = 0.2\,T$, $t_2 = 16K$

by putting the value of B_1, B_2, t_1, t_2 I_1 in equation (i)

So, $\frac{0.2}{0.6} \times \frac{4}{16} = \frac{I_2}{8}$

We get, $I_2 = 8 \times \frac{1}{12}$

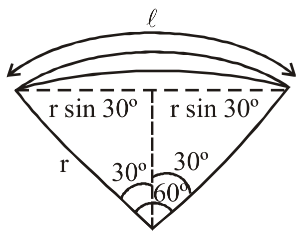
$I_2 = \frac{2}{3}$ A/m

NEET/AIPMT (2013-2017) Questions

6. (a) Magnetic dipole moment

$M = m \times \ell \qquad M' = m \times r$

From figure



$\ell = \frac{\pi r}{3}$ or $r = \frac{3\ell}{\pi}$

so, $M' = m \times r = \frac{m \times 3\ell}{\pi} = \frac{3}{\pi} M$

7. (b) $FL = MB$ (= Torque) $\Rightarrow L = \frac{MB}{F}$

8. (c) Net magnetic dipole moment $= 2\,M\cos\frac{\theta}{2}$

As value of $\cos\frac{\theta}{2}$ is maximum in case (c) hence net magnetic dipole moment is maximum for option (c).

9. (a) Magnetic susceptibility χ for dia-magnetic materials only is negative and low $|\chi| = -1$; for paramagnetic substances low but positive $|\chi| = 1$ and for ferromagnetic substances positive and high $|\chi| = 10^2$.

10. (d) If θ_1 and θ_2 are apparent angles of dip

Let α be the angle which one of the plane make with the magnetic meridian.

$$\tan\theta_1 = \frac{v}{H\cos\alpha}$$

$$\text{i.e., } \cos\alpha = \frac{v}{H\tan\theta_1} \quad \text{...(i)}$$

$$\tan\theta_2 = \frac{v}{H\sin\alpha},,$$

$$\text{i.e., } \sin\alpha = \frac{v}{H\tan\theta_2} \quad \text{...(ii)}$$

Squaring and adding (i) and (ii), we get

$$\cos^2\alpha + \sin^2\alpha = \left(\frac{V}{H}\right)^2 \left(\frac{1}{\tan^2\theta_1} + \frac{1}{\tan^2\theta_2}\right)$$

$$\text{i.e., } \quad 1 = \frac{V^2}{H^2}\left[\cot^2\theta_1 + \cot^2\theta_2\right]$$

$$\text{or} \quad \frac{H^2}{V^2} = \cot^2\theta_1 + \cot^2\theta_2$$

$$\text{i.e., } \quad \cot^2\theta = \cot^2\theta_1 + \cot^2\theta_2$$