Date: 20/10/2021

Q1. Define intensity of magnetisation of a magnetic material. How does it vary with temperature of a paramagnetic material?

Q2. What is a magnet?

Q3. What is the dimensional formula of magnetic flux.

Q4. What do you mean by directive property of a magnetic dipole?

Q5. Which physical quantity, units is tesla, and define tesla.

Q6. Why two magnetic lines of force do not cross each other?

Q7. Name the physical quantity which is measured in weber ampere^{-1}.

Q8. A bar magnet always stand up *NS*-direction, when suspended freely. Why?

Q9. What happens to dipole moment, if a bar magnet is cut into two equal pieces parallel to its length?

Q10. What is the term magnetic flux.

Q11. What is the basis difference between magnetic lines of force and electric lines of force?

Q12. What is the unit of magnetic flux.

Q13. Compare the magnetic fields due to a straight solenoid and a bar magnet.

Q14. What is the SI units of magnetic flux and magnetic induction.

Q15. A bar magnet is cut into four equal pieces transverse to its length. What happens to its dipole moment?

Q16. In which case a magnetic dipole possess minimum potential energy inside a magnetic field?

Q17. The ordinary a piece of iron does not behave as a magnet. Why?

Q18. In which case a magnetic dipole possess maximum potential energy inside a magnetic field.

Q19. What is the source of magnetic field?

Q20. A bar magnet is stationary in magnetic meridian. Another similar magnet is kept parallel to it, such that the centers lie on their perpendicular bisectors. If the second magnet is free to move, then what type of motion it will have: translatory, rotatory or both?

Q21. A short bar magnet placed with its axis making an angle θ with a uniform external field B experiences a torque. What is the magnetic moment of the magnet?

Q22. Does an isolate magnetic pole exist or not?

Q23. Does one element of a current-carrying wire exert a force on another element of the same wire?

Q24. Find out the value of 1 Bohr magneton.

Q25. Which physical quantity has the unit Wb m^{-2}? Is it a scalar or a vector quantity?

Q26. What is the torque experienced by a magnetic dipole of magnetic moment placed with its axis at an angle θ with a uniform external magnetic field?

Q27. Does a bar magnet exert a torque on itself due to its own field?

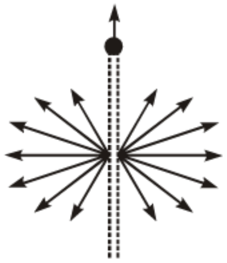
Q28. A circular coil of 300 turns and diameter 14 cm carries a current of 15 A. What is the magnitude of magnetic moment associated with the coil?

Q29. A magnetic needle, free to rotate in a vertical plane, orients itself vertically at a certain place on the earth. What are the values of

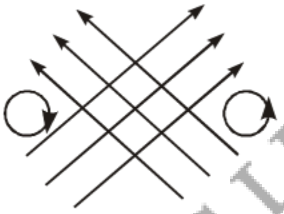
(a) Horizontal component of earth's magnetic field and

(b) Angle of dip at this place?

Q30. What is wrong given magnetic field lines explain it as shown figure.

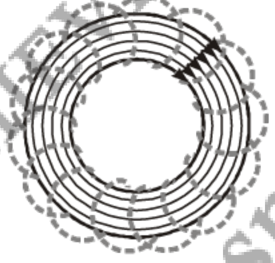


Q31. What is wrong given magnetic field lines explain it as shown figure.

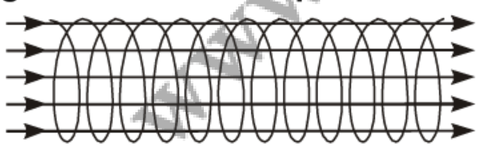


Empty space

Q32. Draw the magnetic field lines for toroid.



Q33. What is wrong given magnetic field lines explain it as shown figure.



Q34. Magnetic field arises due to charges in motion. Can a system have magnetic moments even though its net charge is zero?

Q35. Does a bar magnet exert a torque on itself due to its own field? Does one element of a current-carrying wire exert a force on another element of the same wire?

Q36. **Magnetic field lines can be entirely confined within the core of a toroid, but not within a straight solenoid. Why?**

Q37. **Magnetic field lines show the direction (at every point) along which a small magnetised needle aligns (at the point). Do the magnetic field lines also represent the lines of force on a moving charged particle at every point?**

Q38. **If magnetic monopoles existed, how would the Gauss's law of magnetism be modified?**

Q39. **Write four basic properties of magnets.**

Q40. **What are magnetic lines of force? Sketch the magnetic field lines of a bar magnet.**

Q41. **What are magnetic lines of force? Write any four important properties of these lines.**

Q42. **Define magnetic dipole moment of a magnet in term of torque acting on it in a magnetic field. Is it a vector or a scalar? What is its unit?**

Q43. **Magnetic field arises due to charges in motion. Can a system have magnetic moments even though its net charge is zero?**

Q44. **A magnetised needle of magnetic moment $4.8 \times 10^{-2}\, JT^{-1}$ is placed at 30° with the direction of uniform magnetic field of magnitude $3 \times 10^{-2}\, T$. Calculate (a) the magnitude of the torque experienced and (b) the direction on which it acts.**

Q45. **A bar magnet of magnetic moment M is aligned parallel to the direction of a uniform magnetic field B. What is the work done, to turn the magnets, so as to align its magnetic moment: (a) Opposite to the field direction and (b) normal to the field direction?**

Q46. **Two equal magnetic poles placed 10 cm in air attract each other with a force of $15.5 \times 10^{-4}\, N$. How far from each other should they be placed so that the force of attraction will be $1.5 \times 10^{-4}\, N$?**

Q47. **A short bar magnet placed with its axis at 30° to a uniform magnetic field of 0.2 T experiences a torque of 0.06 Nm. (a) Calculate the magnetic moment of the magnet and (b) find out what orientation of the magnet corresponds to the stable equilibrium in the magnetic field.**

Q48. **A magnet having magnetic dipole moment of $1.0 \times 10^{4}\, JT^{-1}$ is free to rotate in a horizontal plane having a magnetic field of strength $4 \times 10^{-5}\, T$. Calculate the work done in rotating the magnet from a direction parallel to the field to a direction making an angle of 60° with the field.**

Q49. **Two identical thin bar magnets, each of length L and pole-strength m are placed at right angles to each other, with the N-pole of one touching the south pole of the other. Find the magnetic moment of the system.**

Q50. **A circular coil of N turns and radius R carries a current I. It is unwound and rewound to make another coil of radius $R/2$, current I remaining the same. Calculate the ratio of the magnetic moments of the new coil and the original coil.**

Q51. **A magnetised needle in a uniform magnetic field experiences a torque but no net force. An iron nail near a bar magnet, however, experiences a force of attraction in addition to a torque. Why?**

Q52. **Two identical looking iron bars, *A* and *B* are given, one of which is definitely known to be magnetised. How would one ascertain, whether or not both are magnetised? If only one is magnetised, how does one ascertain which one? (Using nothing else, but the two bars *A* and *B*).**

Q53. **A short bar magnet of magnetic moment $M = 0.16\ JT^{-1}$ is placed in a uniform external magnetic field of 1.5 *T*. If the bar is free to rotate in the plane of the field, which orientations would correspond to its (a) stable and (b) unstable equilibrium? What is the potential energy of the magnet in each case?**

Q54. **The relative magnetic permeability of a magnetic material is 800. Identify the nature of magnetic material and state its two properties.**

Q55. **Draw, magnetic field lines when a (a) diamagnetic, (b) paramagnetic substance is placed in an external magnetic field. Which magnetic has property distinguishes this behaviour of the field lines due to the two substances?**

Q56. **What is a magnet? Write the important properties of a magnet.**

Q57. **Each atom of an iron bar (having dimensions 5 cm × 1 cm × 1 cm) has a magnetic dipole moment of $1.8 \times 10^{-23}\ Am^2$. (a) What will be the magnetic moment of the bar in the state of magnetic saturation? (b) What will be the torque required to place this magnetised bar perpendicular to magnetic field of 15,000 *G*? Given, density of iron = $7.8 \times 10^3\ kg\ m^{-3}$, atomic weight of iron = 56 and Avogadro number, $N = 6.02 \times 10^{26}\ kg\ mol^{-1}$.**

Q58. **Derive an expression for the potential energy of a magnetic dipole placed in a uniform magnetic field at an angle θ with it.**

Q59. **A short bar magnet placed with its axis inclined at 30° to the external magnetic field of 800 G acting horizontally experiences a torque of 0.016 Nm. Calculate (a) the magnetic moment of the magnet, (b) the work done by an external force in moving it from most stable to most unstable position, (c) what is the work done by the force due to the external magnetic field in the process mentioned in (b)?**

Q60. **(a)** **Deduce the expression for the magnetic dipole moment of an electron orbiting around the central nucleus.**

(b) **Two identical bar magnets, each of length *L* and pole-strength *m* are placed at right angles to each other, with the north pole of one touching the south pole of the other. Find the magnetic moment of the system.**

Q61. **(a)** **A small compass needle of magnetic moment *m* is free to turn about an axis perpendicular to the direction of uniform magnetic field *B*. The moment of inertia of the needle about the axis is *I*. The needle is slightly disturbed from its stable position and then released. Prove that it executes simple harmonic motion. Hence deduce the expression for its time period.**

(b) **A compass needle, free to turn in a vertical plane orients itself with its axis vertical at a certain place on the earth. Find out the values of (i) horizontal component of earth's magnetic field and (ii) angle of dip at the place.**

Q62. **(a)** **Derive the expression for the torque on a rectangular current carrying loop suspended in a uniform magnetic field.**

(b) **A proton and a deuteron having equal momenta enter in a region of a uniform magnetic at right angle to the direction of the field. Depict their trajectories in the field.**

Q63. **Derive an expression for the torque experienced by a magnetic dipole in a uniform magnetic field. Hence derive the expression for the potential energy of the dipole.**

Q64. **A short bar magnet placed with its axis at 30° with an external field of 500 *G* experiences a torque of 0.032 Nm (a) What is the magnetic moment of magnet? (b) What is the work done in moving it from its most stable to most unstable position? (c) The bar magnet is replaced by a solenoid of cross-sectional area 4×10^{-4} m^2 and 800 turns, but the same magnetic moment. Determine the current flowing through the solenoid.**

Date: 20/10/2021

S1. The intensity of magnetisation of a substance is defined as the magnetic moment developed per unit volume, when it is subjected to a magnetising field.

The magnetic intensity is inversely proportional to its absolute temperature of paramagnetic material.

S2. A magnet is an arrangement of two equal and opposite magnetic poles separated by certain distance. The attractive and repulsive are two main properties of a magnet.

S3. The dimensional formula of magnetic flux is $[M L^2 T^{-2} A^{-1}]$.

S4. If we freely suspended magnet always aligns itself along the North-pole and South-pole.

S5. It is magnetic induction.

The magnetic induction is called one tesla, if a magnetic flux of one weber metre^{-2} *passes normally through the surface, when placed inside it*.

S6. The two magnetic field lines can't intersect each other, because if they are intersect each other at point of intersection the point show two direction of magnetic field *i.e.*, not possible.

S7. Magnetic flux per unit electric current is measured in weber ampere^{-1}.

S8. Because, it is assumed that a huge magnet is lying deep inside the earth with its *S*-pole towards the geographical north and *N*-pole towards the geographical south.

S9. Let magnetic strength m and length of the bar magnet $2l$

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

If cut two equal pieces along the length is

Strength is $m' = m/2$

Length will be same $l' = 2l$

Now,

Magnetic dipole moment $M' = (m/2)(2\vec{l})$

$$M' = m\vec{l}$$

$$= \frac{(m\,2l)}{2}$$

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

Hence, magnetic dipole moment reduce to one half of the original magnet.

S10. Magnetic flux through a surface is defined as the number of magnetic field lines passing normally through a surface.

S11.

Electric line of force	Magnetic line of force
(a) The electric line of force originate from the + ve charge and end at – ve charge	(a) Magnetic line of force originate *N*-pole end at *S*-pole
(b) The electric line make the open loop curve	(b) Magnetic line make close loop curve.

S12. The SI units of magnetic flux is **weber**.

S13. The magnetic field of a bar magnet and a straight solenoid are identical. The two ends of the straight solenoid behave as the north and south poles as in case of a bar magnet.

S14. The SI units of magnetic flux and magnetic induction are **Wb** and **Wb m^{-2}** (or **tesla**) respectively.

S15. The magnetic strength *m* and length of the bar magnet $2l$

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

If cut the bar magnet into four equal bar along transverse it length

Strength is $m' = m$ and length is $l' = \frac{2l}{4}$

Now,

$$M' = \frac{(m\,2l)}{4} = \frac{M}{4}$$

$$M' = \frac{M}{4}$$

Hence, dipole moment reduce to one fourth of the original magnet.

S16. We know $U = -MB\cos\theta$.

Potential energy is minimum when its magnetic moment $\vec{M}$ and magnetic field $\vec{B}$ both are parallel ($\theta = 0°$).

S17. Because, the molecular magnets are randomly oriented and form closed chains. Since the molecular magnets cancel the effect of each other the ordinary iron piece does not behave as a magnet.

S18. We know $U = -MB\cos\theta$.

Potential energy is maximum when its magnetic moment $\vec{M}$ and magnetic field $\vec{B}$ both are antiparallel ($\theta = 180°$).

S19. Magnetism is of electrical origin. The electrons revolving in orbit an atom behave like current loop and these current loops give rise to magnetism.

S20. There will be only tranaslatory motion. It can be shown by finding the net force on the two poles of the second magnet due to the poles of the first by drawing a vector diagram.

S21. Torque on a dipole, $\tau = MB \sin\theta$

$$\therefore \qquad M = \frac{\tau}{B \sin\theta}.$$

S22. No, an isolate magnetic pole does not exist.

S23. Yes, an element of a current carrying conductor experiences force due to another element of the conductor.

S24. Bohr magneton $= \dfrac{eh}{4\pi m_e}$

$$= \frac{1.6 \times 10^{-19} \times 6.62 \times 10^{-34}}{4\pi \times 9.1 \times 10^{-31}}$$

$$= \mathbf{9.27 \times 10^{-24}\ Am^2}$$

S25. It is magnetic field induction and is a vector quantity.

S26. Torque on the dipole, $\tau = M \times B$.

$$\tau = MB \sin\theta$$

S27. No, a bar magnet does not exert a force or torque on itself due to its own field.

S28. Given: $n = 300$; $d = 14\,\text{cm}$; $I = 15\,\text{A}$.

We know, $M = nIA$

$$= 300 \times 15 \times \pi(7 \times 10^{-2})^2$$

$$= \mathbf{69.77\ Am^2}.$$

S29. (a) The coil is free to move in vertical plane it means that there is no component of earth's magnetic field in horizontal direction, so the horizontal component of earth's magnetic field is 0.

(b) The angle of dip is 0°.

S30. **Wrong.** Magnetic field lines can never emanate from a point, as shown in figure. Over any closed surface, the net flux of ***B*** must always be zero, *i.e.*, pictorially as many field lines should seem to enter the surface as the number of lines leaving it. The field lines shown, in fact, represent electric field of a long positively charged wire. The correct magnetic field lines are circling the straight conductor, as described in Chapter 4.

S31. **Wrong.** Magnetic field lines (like electric field lines) can never cross each other, because otherwise the direction of field at the point of intersection is ambiguous. There is further error in the figure. Magnetostatic field lines can never form closed loops around empty space. A closed loop of static magnetic field line must enclose a region across which a current is passing. By contrast, electrostatic field lines can never form closed loops, neither in empty space, nor when the loop encloses charges.

S32. **Right.** Magnetic lines are completely confined within a toroid. Nothing wrong here in field lines forming closed loops, since each loop encloses a region across which a current passes. Note, for clarity of figure, only a few field lines within the toroid have been shown. Actually, the entire region enclosed by the windings contains magnetic field.

S33. **Wrong.** Field lines due to a solenoid at its ends and outside cannot be so completely straight and confined; such a thing violates Ampere's law. The lines should curve out at both ends, and meet eventually to form closed loops.

S34. Yes. The average of the charge in the system may be zero. Yet, the mean of the magnetic moments due to various current loops may not be zero. We will come across such examples in connection with paramagnetic material where atoms have net dipole moment through their net charge is zero.

S35. No. There is no force or torque on an element due to the field produced by that element itself. But there is a force (or torque) on an element of the same wire. (For the special case of a straight wire, this force is zero.)

S36. If field lines were entirely confined between two ends of a straight solenoid, the flux through the cross-section at each end would be non-zero. But the flux of field $\boldsymbol{B}$ through any closed surface must always be zero. For a toroid, this difficulty is absent because it has no 'ends'.

S37. No. The magnetic force is always normal to $\boldsymbol{B}$ (remember magnetic force = $q\boldsymbol{v}\times\boldsymbol{B}$). It is misleading to call *magnetic field lines as lines of force*.

S38. Gauss's law of magnetism states that the flux of B through any closed surface is always zero $\oint_s \boldsymbol{B}\cdot d\boldsymbol{s} = 0$.

If monopoles existed, the right hand side would be equal to the monopole (magnetic charge) q_m enclosed by S. [Analogous to Gauss's law of electrostatics, $\oint_s \boldsymbol{B}\cdot d\boldsymbol{s} = \mu_0 q_m$ where q_m is the (monopole) magnetic charge enclosed by S.]

S39. Four properties of magnets:

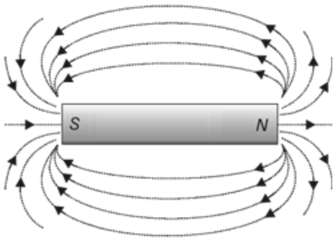
(a) A magnet attracts magnetic substances like iron, steel, nickel, etc. towards it. When a magnet is put in a heap of iron filings, they cling to the magnet. It is observed that maximum amount of iron filings cling to the magnet ends. the force of attraction decreases towards the middle and this force is almost zero at the venture. The regions of strongest magnetism near the ends are called the *poles* of the magnet.

(b) The magnetic poles always exist in pairs of equal strength. Magnetic monopole does not exist.

(c) When suspended freely a magnet aligns itself along geographic north-south direction. The pole which points towards geographic north is called *north pole* (*N*) and the pole which points towards geographic south is called *south pole* (S).

(d) Unlike poles (North-South) attract and like poles (North- North or South-South) repel.

S40. A magnetic line of force is a hypothetical line in a magnetic field along which magnetic force acts and the tangent drawn on the curve at any point of it gives the direction of the field at that point.



S41. A magnetic line of force is a hypothetical line in a magnetic field along which magnetic force acts and the tangent drawn on the curve at any point of it gives the direction of the field at that point.

Four important properties of magnetic lines of force:

(a) They do not intersect one another at any point.

(b) They are closed and continuous curve.

(c) Outside magnet, they start from *N*-pole and enter the magnet at *S*-pole.

(d) The tangent to magnetic line of force at any point gives the direction of magnetic field at that point.

S42. The torque (τ) acting on a magnet of dipole moment M in a uniform magnetic field $\vec{B}$ is given by

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

or $\tau = MB \sin\theta$

If $\theta = 90°$ and $B = 1$ Tesla

then $\tau = M \times 1 \times \sin 90° = M$

or $M = \tau$

Thus, magnetic dipole moment can be defined as the torque acting on the a magnetic dipole held perpendicular to a uniform magnetic field of unit strength.

It is a vector quantity.

Its SI unit is Joule per Tesla (J/T).

S43. Yes. The average of the charges in the system may be zero. Yet, the mean of the magnetic moments due to various current loops may not be zero. A neutron, for example, has zero charge but non-zero magnetic moment.

S44. Given: Magnetic moment $M = 4.8 \times 10^{-2}$ JT^{-1}

Magnetic field $B = 3 \times 10^{-2}$ T

Torque acting on the needle is,

$$\tau = MB \sin\theta$$

$$\tau = 4.8 \times 10^{-2} \times 3 \times 10^{-2} \times \frac{1}{2} \qquad [\because \sin 30° = 1/2]$$

$$= 7.2 \times 10^{-4}\,\text{Nm}.$$

S45. We know that work done is:

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

Along the field direction $\theta_1 = 0°$ is given

(a) to align magnetic moment opposite to the field direction, *i.e.*, $\theta_2 = 180°$

$$W = -MB(\cos 180° - \cos 0°)$$

$$W = 2MB\,(J).$$

(b) to align magnetic moment normal to the field direction, *i.e.*, $\theta_2 = 90°$.

$$W = -MB(\cos 90° - \cos 0°)$$

$$W = MB\,(J).$$

S46. Suppose m be the pole strength of each pole.

Case I: Magnetic force $F = 15.5 \times 10^{-4}\,\text{N}$; $r = 10\,\text{cm} = 0.1\,\text{m}$

We know, $$F = \frac{\mu_0}{4\pi} \cdot \frac{m \times m}{r^2} \quad \text{or} \quad m^2 = \frac{4\pi}{\mu_0}(F \cdot r^2)$$

or $$m = \left\{10^7 \times 15.5 \times 10^{-4} \times (0.1)^2\right\}^{1/2}$$

or $$m = 12.45\,\text{Am}.$$

Case II: Suppose r' be the distance between the poles, when force of attraction becomes $F' = 1.5 \times 10^{-4}\,\text{N}$.

We know, $$F' = \frac{\mu_0}{4\pi} \cdot \frac{m \times m}{r'^2} \quad \text{or} \quad r'^2 = \frac{\mu_0}{4\pi}\frac{m^2}{F'}$$

or $$r'^2 = 10^{-7} \times \frac{(12.45)^2}{1.5 \times 10^{-4}}$$

or $$r' = \mathbf{3.21\,m}.$$

S47. Given: Magnetic field $B = 0.2\,T$; $\theta = 30°$ and torque $\tau = 0.06\,\text{Nm}$

(a) We know, $$\tau = MB\sin\theta$$

or $$M = \frac{\tau}{B\sin\theta} = \frac{0.06}{0.2 \times \sin 30°} = \mathbf{0.6\,Am^2}$$

(b) The magnet will be in stable equilibrium in the magnetic field, if it experiences no torque due to magnetic field *i.e.*,

$$MB\sin\theta = 0 \qquad (\because \tau = 0)$$

or $\sin\theta = 0$ ($\because$ M and B can not be zero)

or $\theta = \sin^{-1}(0)$ or $\theta = 0°$

i.e., when the magnet aligns itself parallel to the magnetic field.

S48. Given, Magnetic dipole moment $M = 1.0 \times 10^4\ JT^{-1}$;

Magnetic field $B = 4 \times 10^{-5}\ T$ and $\theta = 60°$

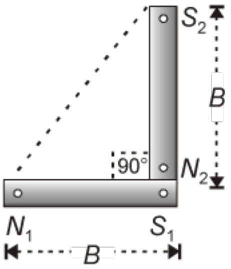
Work done to turn the magnet through at angle θ,

$$W = MB(1 - \cos\theta)$$

$$\therefore \quad W = 1.0 \times 10^4 \times 4 \times 10^{-5} \times (1 - \cos 60°)$$

$$= 0.4 \times (1 - 0.5) = \mathbf{0.2\ J}.$$

S49. When the magnets N_1S_1 and N_2S_2 each of pole strength m and length L, are placed at right angles to each other (figure shown below), the system behaves as a magnet, whose pole strength is m and length is N_1S_2.



Now, $N_1S_2 = \sqrt{N_1S_1^2 + N_2S_2^2} = \sqrt{L^2 + L^2} = \sqrt{2}\,L$ (Applying right angle property)

Hence, magnetic moment of the system,

$$M = \text{pole strength } N_1S_2 = m\ \sqrt{2}\,\text{L} = \sqrt{\mathbf{2}}\ \mathbf{mL}.$$

S50. The magnetic moment of the original coil,

$$M = NIA = NI \times \pi R^2 \qquad \text{... (i)}$$

If this coil is rewound into a coil of radius $R/2$, the number of turns will become double *i.e.*,

$$N' = 2\text{N and current } I' = I; \quad R' = \text{R}/2$$

Hence, magnetic moment of the new coil, is given by

$$M' = N'I'A' = 2NI \times \pi\left(\frac{R}{2}\right)^2 = \frac{1}{2}NI \times \pi R^2 \qquad \text{... (ii)}$$

Now from Eq. (ii) ÷ Eq. (i), we get

Therefore, $\dfrac{M'}{M} = \mathbf{\dfrac{1}{2}}.$

S51. The force and torque act on the nail due to the induced magnetic moment acquired by it. The iron needle will also not experience any force, if magnetic field is uniform. The magnetic field due to a bar magnet is not uniform. Therefore, an iron nail experiences both a force and torque, when placed near a bar magnet.

It may be point that the nail experiences a net attractive force. It is because the attractive force on the nearer end (unlike induced pole) of the nail is greater than the repulsive force on its farther end (like induced pole).

S52. If on bringing different ends of the two bars close to each other, they produce repulsion in some case, then both the iron bars are magnetised. Otherwise, one bar is magnetised and the other is simply iron bar. To find out which one is magnetised, call one bar as *A* and the other as *B*. Place bar *B* on table. Bring one end of bar *A* close to the one end of bar *B*. The bar *A* will experience attraction. Now, move the bar *A* to the middle of bar *B*. If *A* experiences no force, then *A* is iron bar and *B* is magnetised. On the other hand, if bar *A* experiences force, then *A* is magnetised and *B* is iron bar.

S53. Given: $M = 0.16\ \text{JT}^{-1}$; $B = 1.5\ T$; $\theta = 180°$

In stable equilibrium, magnetic moment is parallel to $\vec{B}$. *i.e.*, $\theta = 0°$

(a) $U = -MB\cos\theta$ $\qquad U = -MB = -0.16 \times 1.5\ \text{J}$

$U = -0.24\ \text{J}.$

(b) In unstable equilibrium, magnetic moment is antiparallel to $\vec{B}$. *i.e.*, $\theta = 180°$

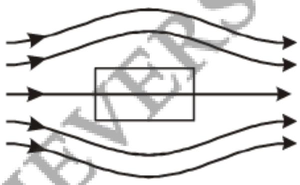
$U = +MB = 0.24\ \text{J}.$

S54. Ferromagnetic substance as these substances have very high magnetic permeability.

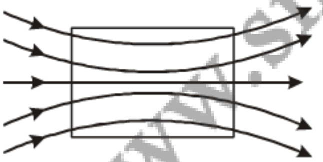
Properties: (i) High retentivity

(ii) High susceptibility

S55. (a) Behaviour of magnetic field lines when diamagnetic substance is placed in an external field.



(b) Behaviour of magnetic field lines when paramagnetic substance is placed in a external field.



Magnetic susceptibility: Distinguishes the behaviour of the field lines due to diamagnetic and paramagnetic substance.

S56. A magnet is a substance which attracts iron, nickel, cobalt, etc., when freely suspended it always aligns itself along geographic north-south direction.

Properties of magnets:

(a) A magnet attracts magnetic substances like iron, steel, nickel, etc. towards it. When a magnet is put in a heap of iron filings, they cling to the magnet. It is observed that maximum amount of iron filings cling to the magnet ends. the force of attraction decreases towards the middle and this force is almost zero at the venture. The regions of strongest magnetism near the ends are called the *poles* of the magnet.

(b) The magnetic poles always exist in pairs of equal strength. Magnetic monopole does not exist.

(c) When suspended freely a magnet aligns itself along geographic north-south direction. The pole which points towards geographic north is called *north pole* (N) and the pole which points towards geographic south is called *south pole* (S).

(d) Unlike poles (North-South) attract and like poles (North- North or South-South) repel.

(e) The force between two magnetic poles obey inverse square law.

(f) At very high temperature the magnetic properties of a magnet are lost.

S57. (a) Given, volume of the iron bar,

$$V = 5 \times 1 \times 1 = 5\,\text{cm}^3 = 5 \times 10^{-6}\,\text{m}^3$$

Mass of the iron bar, $m = V\rho = 5 \times 10^{-6} \times 7.8 \times 10^3$

$$= 3.9 \times 10^{-2}\,\text{kg}$$

Hence, number of atoms in the iron bar,

$$n = \frac{N}{A} \times m = \frac{6.02 \times 10^{26}}{56} \times 3.9 \times 10^{-2}$$

$$= 4.19 \times 10^{23}.$$

The magnetic moment of one atom of iron,

$$M' = 1.8 \times 10^{-23}\,\text{A m}^2.$$

In the state of magnetic saturation, all the atomic magnets will align themselves in the same direction and then, the magnetic moment of iron bar will become

$$M' = M \times n = 1.8 \times 10^{-23} \times 4.19 \times 10^{23}$$

$$= \mathbf{7.54\,Am^2}.$$

(b) Given, $B = 15{,}000\,G = 1.5\,T$ and $\theta = 90°$

The required torque,

$$\tau = MB \sin\theta = 7.54 \times 1.5 \sin 90°$$

$$= \mathbf{11.31\ Nm}.$$

S58. The torque acting on a magnetic dipole of moment $\vec{M}$ held at an angle θ with the direction of a uniform magnetic field $\vec{B}$ is given by

$$\tau = MB \sin \theta$$

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

The small amount of work done in rotating the dipole through angle $d\theta$ is given by

$$\begin{aligned} dW &= \tau \, d\theta \\ &= MB \sin \theta \, d\theta \end{aligned}$$

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

$$W = \int_{\theta_1}^{\theta_2} MB \sin \theta \, d\theta$$

$$= MB \left[-\cos \theta \right]_{\theta_1}^{\theta_2}$$

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

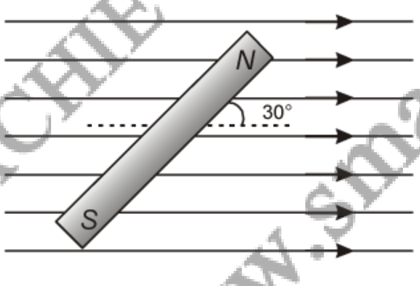
When dipole is rotated from $\theta_1 = 90°$ to $\theta_2 = \theta$, then

$$\begin{aligned} W &= -MB[\cos \theta - \cos 90°] \\ &= -MB \cos \theta \end{aligned}$$

$\therefore$ Potential energy of dipole $U (= W) = -MB \cos \theta$

In vector notation $\quad U = \vec{M} \cdot \vec{B}$.

S59. Given: $B = 800\,G = 800 \times 10^{-4}\,T; \quad \tau = 0.016\,\text{Nm}$



(a) $\tau = MB \sin \theta$

$$M = \frac{\tau}{B \sin \theta} = \frac{0.016}{8 \times 10^{-2} \times \sin 30°}$$

$$M = 0.4\,JT^{-1}$$

(b) $U = -MB(\cos \theta_2 - \cos \theta_1)$

$U = -MB[\cos 180° - \cos 0°]$

Most stable to most unstable means from $\theta = 0°$ to $\theta = 180°$

$$U = -MB[\cos 180° - \cos 0°]$$

$$= +2MB$$

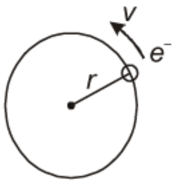
Setting the values $U = 2 \times 0.4 \times 8 \times 10^{-2}$

$$= 0.64 \text{ J.}$$

(c) Work done by external magnetic force = – 0.064 J.

S60. (a) As we know that a moving charge always produces an electric current, so there will be electric current due to revolving electron this is the current which produces field.

Let an electron revolve around the nucleus on a circular path of radius r with uniform linear speed v.



Time period of electron is given by

$$T = \frac{2\pi r}{v}$$

∴ Electric current produced due to the orbital motion of electron.

$$I = \frac{-e}{T} = \frac{-e}{\left(\frac{2\pi r}{v}\right)} = -\frac{ev}{2\pi r} \qquad \text{... (i)}$$

Magnetic dipole moment is given by

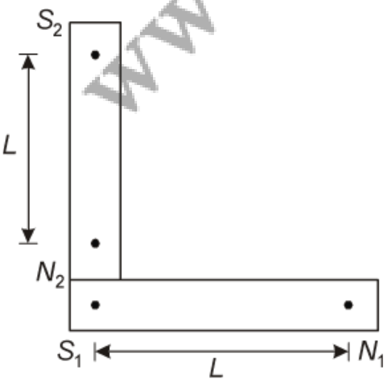
$$M = IA = \left(\frac{-eV}{2\pi r}\right)\cdot \pi r^2 = -\frac{evr}{2}$$

$\Rightarrow$ $M = -\frac{e}{2m}(mvr)$ where, m = mass of electron.

$\Rightarrow$ $M = -\frac{e}{2m}L$ where, $L = mvr$ and known as angular momentum.

The direction of magnetic dipole moment is perpendicular to the plane of paper and directed inward.

(b) $L_{N_1S_2} = \sqrt{L^2 + L^2} = \sqrt{2}L$



So, magnetic moment of the system is

$$M = m \times \sqrt{2}L = \sqrt{2}mL$$

S61. (a) The torque on the needle is $\tau = m \times B$

In magnitude $\tau = mB \sin \theta$

Here τ is restoring torque and θ is the angle between m and B.

Therefore, in equilibrium,

Restoring force = Deflecting torque

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

Negative sign with $mB \sin \theta$ implies that restoring torque is in opposition to deflecting torque. For small values of θ in radians, we approximate $\sin \theta = \theta$ and get

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

or $$\frac{d^2\theta}{dt^2} = -\frac{mB}{I}\theta \quad \text{or} \quad \frac{d^2\theta}{dt^2} = -\omega^2\theta$$

This equation represents a simple harmonic motion

where, $$\omega = \sqrt{\frac{mB}{I}}$$

$$\text{Time period } T = \frac{2\pi}{\omega} = 2\pi\sqrt{\frac{I}{mB}}$$

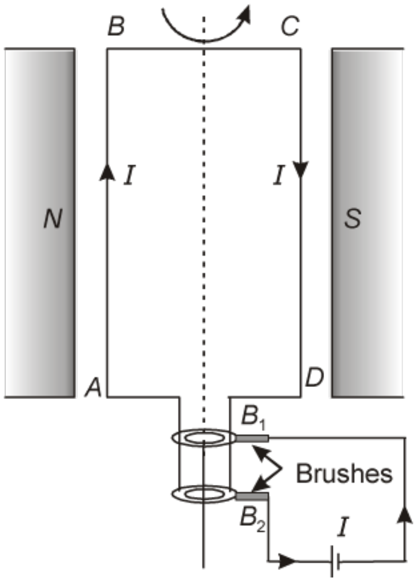
(b) (i) As, Horizontal component of earth's magnetic field, $B_H = B \cos \delta$

Putting $\delta = 90°$ (as compass needle orients itself vertically)

$\therefore \qquad B_H = 0$

(ii) For a compass needle align vertical at a certain place, angle of dip, $\delta = 90°$,

S62. (a) Consider a rectangular loop $ABCD$ carrying current I.



The rectangular loop is placed such that the uniform magnetic field B is in the plane of loop.

No force is exerted by the magnetic field on the arms AD and BC.

Magnetic field exerts a force F_1 and arm AB.

$\therefore \quad F_1 = IbB$

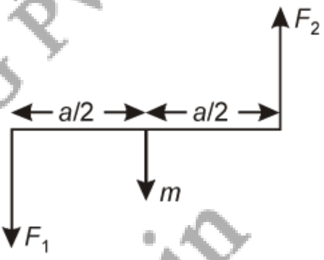
Magnetic field exerts a force F_2 on arm CD.

$\therefore \quad F_2 = IbB = F_1$

Net force on the loop is zero.

A F_1 and F_2 are equal in magnitude and opposite in direction. The two force equal in magnitude and having parallel line of action form a couple which times to rotate the body. The torque on the loop rotates the loop in anti-clockwise direction.

Torque, $\tau = F \times r$ where, F = Magnitude of force, r = Perpendicular distance



$$= F_1\frac{a}{2} + F_2\frac{a}{2} = IbB\frac{a}{2} + IbB\frac{a}{2} = I(ab)B$$

$$\tau = BIA$$

If there are 'n' such turns the torque will be $nIAB$

where, b = Breadth of the rectangular coil and
a = Length of the rectangular coil
$A = ab$ = Area of the coil

(b) We know, Lorentz force, $F = Bqv \sin\theta$

where, θ = angle between velocity of particle and magnetic field = 90°

So, Lorentz force, $F = Bqv \quad (\because \sin 90 = 1)$

When a charged particle enters in a magnetic field in a direction normal to the field then

In this condition, Lorentz force = centripetal force

$$Bqv = \frac{mv^2}{r} \quad \Rightarrow \quad r = \frac{mv}{Bq}$$

Let m_p = mass of proton, m_d = mass of deuteron, v_p = velocity of proton and v_d = velocity of deuteron.

The charge of proton and deuteron are equal, *i.e.*, $q_p = q_d = q$ (say)

Given that momentum of both particle is same, *i.e.*,

$$m_p v_p = m_d v_d$$

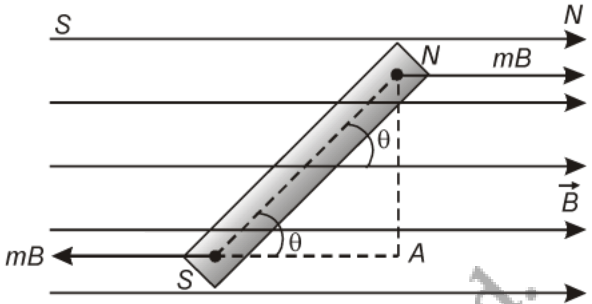
$$r_p = \frac{m_p v_p}{Bq} \quad \ldots \text{(i)}$$

$$r_d = \frac{m_d v_d}{Bq} \qquad \text{... (ii)}$$

As Eq (i) and (ii) are equal, so $r_p = r_d = r$

Thus, the trajectory of both the particles will be same

S63. Consider a bar magnet of magnetic length $2l$ is placed in a uniform magnetic field $\vec{B}$ making an angle θ, as shown in the figure. Let the strength of each pole be m.



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

Force on S-pole = mB, opposite to $\vec{B}$.

These two forces are equal and opposite but of collinear; hence they form a couple which tends to rotate the magnet anticlockwise.

$\therefore$ Torque acting on the magnet,

$$\tau = \text{Force} \times \perp \text{distance} = mB \times NA = mB \times 2l \sin\theta \quad (\because\ NA = 2l \sin\theta)$$

or $$\tau = MB \sin\theta \qquad (\because\ m \times 2l = M) \quad \text{... (i)}$$

In vector form, $\vec{\tau} = \vec{M} \times \vec{B}$

If $B = 1$ and $\theta = 90°$, then

$$\tau = M \times 1 \sin 90° = M \quad \text{or} \quad M = \tau$$

Thus, we can define magnetic dipole moment as the torque acting on a magnetic dipole held perpendicular to a uniform magnetic field of unit strength.

The small amount of work done in rotating the dipole through angle $d\theta$ is given by

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

Form Eq. (i), we get

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

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

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

$$W = -MB\,[\cos\theta_2 - \cos\theta_1]$$

When dipole is rotated from $\theta_1 = 90°$ to $\theta_2 = \theta$, then

$$W = -MB\,[\cos\theta - \cos 90°] = -MB\cos\theta$$

$\therefore$ Potential energy of dipole $U (= W) = -MB\cos\theta$

In vector notation $\quad U = \vec{M} \cdot \vec{B}$.

S64. (a) Given, $\theta = 30°$ $\qquad \tau = MB\sin\theta$

or $$M = \frac{\tau}{B\sin\theta}$$

$$= \frac{0.032}{500 \times 10^{-4} \times \sin 30°}$$

$$= \frac{0.032 \times 2}{500 \times 10^{-4}} = \mathbf{1.28\ Am^2}.$$

(b) $\theta = 0°$ corresponds to stable position and

$\theta = 180°$ corresponds to unstable position.

Work done is

$$W = -MB(\cos\theta_2 - \cos\theta_1)$$
$$= -MB(\cos 180° - \cos 0°)$$
$$= 2\,MB = 2 \times 1.28 \times 500 \times 10^{-4} = \mathbf{0.128}.$$

(c) $$M_s = NIA$$

$$I = \frac{M_s}{NA} = \frac{1.28}{800 \times 4 \times 10^{-4}}$$

$$I = \mathbf{4A}.$$

Date: 20/10/2021

Q1. **The charged currents in the outer conducting regions of the Earth's core are thought to be responsible for Earth's magnetism. What migh might be the 'battery' (*i.e.*, the source of energy) to sustain these currents?**

Q2. **The Earth's magnetic field varies from point to point in space. Does it also change with time? If so, on what time scale does it change appreciably?**

Q3. **The Earth may have even reversed the direction of its field several times during its history of 4 to 5 billion years. How can geologists know about the Earth's field in such distant past?**

Q4. **The Earth's field departs from its dipole shape substantially at large distances (greater than about 30,000 km). What agencies may be responsible for this distortion?**

Q5. **Interstellar space has an extremely weak magnetic field of the order of 10^{-12} T. Can such a weak field be of any significant consequence? Explain.**

Q6. **The Earth's magnetic field at the equator is approximately 0.4 G. Estimate the Earth's magnetic moment.**

Q7. **In the magnetic meridian of a certain place, the horizontal component of the Earth's magnetic field is 0.26 G and the dip angle is 60°. What is the magnetic field of the Earth at this location?**

Q8. **Define magnetic meridian? What is geomagnetic equator?**

Q9. **A small magnet is pivoted to move freely in the magnetic meridian. At what place on the surface of the Earth will the magnet be vertical?**

Q10. **Define geographic meridian.**

Q11. **The horizontal component of the earth's magnetic field at a place is *B* and angle of dip is 60°. What is the value of vertical component of earth's magnetic field at equator?**

Q12. **The earth's core is known to contain iron, but geologists do not regard this as a source of magnetic field. Why?**

Q13. **The earth's field, it is claimed, roughly approximates the field due to a dipole of magnetic moment $8 \times 10^{22}\ JT^{-1}$ located at its centre. Find out the magnitude of magnetic field on magnetic equator of earth.**

Q14. **A magnetic needle, free to rotate in a vertical plane, orients itself vertically at a certain place on the Earth. What are the values of (a) horizontal component of Earth's magnetic field and (b) angle of dip at this placed.**

Q15. **If you made a map of magnetic field lines at Melbourne in Australia, would the lines seem to go into the ground or come out of the ground?**

Q16. **Name the parameters needed to completely specify the earth's magnetic field at a point on the earth's surface.**

Q17. In which direction would a compass free to move in the vertical plane point to, if located right on the geomagnetic north or south pole?

Q18. Name the elements of earth's magnetic field.

Q19. A vector needs two quantities for its specification. Name the two independent quantities conventionally used to specify the earth's magnetic field.

Q20. What is the value of the horizontal component of the earth's magnetic field at magnetic poles?

Q21. What is the angle of magnetic declination at a place.

Q22. The angle of dip at a location in southern India is about 18°. Would you except a greater or smaller dip angle in Britain?

Q23. Define the terms with diagram: (a) magnetic declination and (b) angle of dip at a given place.

Q24. Angle of declination at a place is 18°. How can a magnetic compass be used to find the exact direction of geographical North at that place?

Q25. At a certain location in Africa, a compass needle points 15° west of the geographic north. What is the angle of declination at that point?

Q26. It is found that the neutral points lie along the axis of a magnet placed on a on a table. What is the orientation of the magnet w.r.t. the earth's magnetic field?

Q27. If a toroid uses bismuth for its core, will the field in the core be (slightly) greater or (slightly) less than when the core is empty?

Q28. How does the knowledge of declination at a place help in navigation?

Q29. The vertical component of Earth's magnetic field at a place is $\sqrt{3}$ times the horizontal component. What is the value of angle of dip at this place?

Q30. A small magnet is pivoted to move freely in the magnetic meridian. At what place on the earth's surface, will the magnet be vertical?

Q31. What would be the direction of a compass needle, when placed exactly at the geo-magnetic *N*-pole.

Q32. A magnet is placed with its north pole towards south of the earth. Predict the position of the neutral points.

Q33. Which direction would a compass point to, if located right on the geomagnetic north or south pole.

Q34. A magnet is placed with its north pole towards north of the earth. Predict the position of the neutral points.

Q35. Define angle of dip at a given place?

Q36. What is the value of angle of dip at any place situated on the magnetic equator of the earth?

Q37. What is the maximum value of angle of dip? At what places, does it occur?

Q38. The horizontal component of the earth's magnetic field at a place is *B* and angle of dip is 60. What is the value of vertical component of earth's magnetic field at equator?

Q39. What do you mean by neutral point in a magnetic field?

Q40. The horizontal component of earth's magnetic field at a place *B* and angle of dip is 60°. What is the value of vertical component of earth's magnetic field at equator?

Q41. Where on the surface of earth is the angle of dip 90°?

Q42. Define the term 'magnetic declination'.

Q43. If the horizontal and vertical components of the earth's magnetic field are equal at a certain place, what would be the angle of dip at that place?

Q44. Where on the surface of earth is the vertical component of earth's magnetic field zero?

Q45. A magnetic needle free to rotate in a vertical plane parallel to the magnetic meridian has its North tip pointing down at 22° with the horizontal. The horizontal component of the Earth's magnetic field at the place is known to be 0.35 G. Determine the magnitude of the Earth's magnetic field at the place.

Q46. At a certain location in Africa, a compass points 12° west of the geographic North. The North tip of the magnetic needle of a dip circle placed in the plane of magnetic meridian points 60° above the horizontal. The horizontal component of the Earth's field is measured to be 0.16 G. Specify the direction and magnitude of the Earth's field at the location.

Q47. A magnetic dipole is under the influence of two magnetic fields. The angle between the field directions is 60°, and one of the fields has a magnitude of 1.2×10^{-2} T. If the dipole comes to stable equilibrium at an angle of 15° with this field, what is the magnitude of the other field?

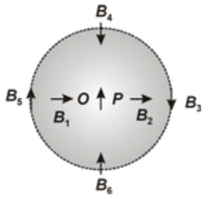
Q48. A long straight horizontal cable carries a current of 2.5 A in the direction 10° South of West to 10° North of East. The magnetic meridian of the place happens to be 10° West of the geographic meridian. The earth's magnetic field at the location is 0.33 G, and the angle of dip is zero. Locate the line of neutral points (ignore the thickness of the cable). (At *neutral points*, magnetic field due to a current-carrying cable is equal and opposite to the horizontal component of earth's magnetic field.)

Q49. Define the terms magnetic inclination and horizontal component of earth's magnetic field at a place. Establish the relationship between the two help of a diagram.

Q50. Define the terms 'Magnetic Dip' and 'Magnetic Declination' with the help of relevant diagrams.

Q51. The ratio of the horizontal component to the resultant magnetic field of earth at a given place is $1/\sqrt{2}$. What is the angle of dip at that place?

Q52. Adjoining figure shows a small magnetised needle *P* placed at a point *O*. The arrow shows the direction of its magnetic moment. The other arrows show different positions (and orientations of the magnetic moment) of another identical magnetised needle *B*.



(a) In which configurations is the system not in equilibrium?

(b) In which configuration is the system in (i) stable, and (ii) unstable equilibrium?

(c) Which configuration corresponds to the lowest potential energy among all the configurations shown?

Q53. Horizontal component of earth's magnetic field at a place is $\sqrt{3}$ times the vertical component. What is the value of angle of dip at this place?

Q54. A magnetic needle free to rotate in a vertical plane parallel to the magnitude meridian has its north tip down at 60° with the horizontal. The horizontal component of the earth's magnetic field at the place is known to be 0.4 G. Determine the magnitude of the earth's magnetic field at the place.

Q55. Derive a relation between permeability and susceptibility.

Q56. The horizontal component of the earth's magnetic field at a place is $\sqrt{3}$ times its vertical component there. Find the value of the angle of dip at that place. What is the ratio of the horizontal component to the total magnetic field of the earth at that place?

Q57. A telephone cable at a place has four long straight horizontal wires carrying a current of 1.0 A in the same direction east to west. The earth's magnetic field at the place is 0.39 G, and the angle of dip is 35°. The magnetic declination is nearly zero. What are the resultant magnetic fields at points 4.0 cm below the cable?

Q58. A compass needle free to turn in a horizontal plane is placed at the centre of circular coil of 30 turns and radius 12 cm. The coil is in a vertical plane making an angle of 45° with the magnetic meridian. When the current in the coil is 0.35 A, the needle points West to East.

(a) Determine the horizontal component of the Earth's magnetic field at the location.

(b) The current in the coil is reversed, and the coil is rotated about its vertical axis by an angle of 90° in the anticlockwise sense looking from above. Predict the direction of the needle. Take the magnetic declination at the places to be zero.

Q59. A wheel with 8 metallic spokes each 50 cm long is rotated with a speed of 120 rev/min in a plane normal to the horizontal component of the Earth's magnetic field. The Earth's magnetic field at the place is 0.4 G and the angle of dip is 60°. Calculate the emf induced between the axle and the rim of wheel. How will the value of emf be affected if the number of spokes were increased?

Q60. Using a labeled diagram show the elements of earth's magnetic field. Obtain relation between them.

Q61. A compass needle free to turn in a horizontal plane is placed at the centre of circular coil of 30 turns and radius 12 cm. The coil is in a vertical plane making an angle of 45° with the magnetic meridian, then the current in the coil is 0.35 A, the needle points west to east

(a) Determine the horizontal component of the earth's magnetic field at the location.

(b) The current in the coil is reversed, and the coil is rotated about its vertical axis by an angle of 90° in the anticlockwise sense looking from above. Predict the direction of the needle. Take the magnetic declination at the place to be zero.

Q62. Where on the earth's surface is the value of the vertical component of earth's magnetic field zero? A bar magnet of magnetic moment 1.5 JT^{-1} lies aligned with the direction of a uniform magnetic field of 0.22 T. Calculate the amount of work done to turn the magnet so as to align its magnetic moment (a) normal to the field direction (b) opposite to the field direction.

Q63. Earth's magnetic field may be supposed to be due to a small bar magnet located at the centre of the earth. If the magnetic field at a point on the magnetic equator is 0.3 G, what is the magnetic moment of such a bar magnet? What is the magnetic field at the north pole? Given, radius of earth = 6.4×10^6 m.

Q64. A short magnet of magnetic moment 2 Am^2 is in a horizontal plane with its north pole pointing 60° east of north. Find the net horizontal magnetic field at a point north of the magnet 0.2 m away from it. Horizontal component of earth's magnetic field = 0.3×10^{-4} *T*.

Q65. Where on the earth's surface is the value of vertical component of the earth's magnetic field zero? The horizontal component of the earth's magnetic field at a given place is 0.2×10^{-4} Wb/m^2 and angle of dip is 45°. Calculate the value of (a) vertical component, (b) the total intensity of the earth's magnetic field.

Q66. Name three elements required to specify the earth's magnetic field at a given place. Draw a labelled diagram to define these elements. Explain briefly how these elements are determining to find out the magnetic field at a given place on the surface of earth.

Date: 20/10/2021

S1. The radioactivity in Earth's interior is the source of energy that sustains the currents in the outer conducting regions of earth's core. These charged currents are considered to be responsible for Earth's magnetism.

S2. Earth's magnetic field changes with time. It takes a few hundred years to change by an appreciable amount. The variation in Earth's magnetic field with the time cannot be neglected.

S3. Earth reversed the direction of its field several times during its history of 4 to 5 billion years. These magnetic fields got weakly recorded in rocks during their solidification. One can get clues about the geomagnetic history from the analysis of this rock magnetism.

S4. Earth's field departs from its dipole shape substantially at large distances (greater than about 30,000 km) because of the presence of the ionosphere. In this region, Earth's field gets modified because of the field of single ions. While in motion, these ions produce the magnetic field associated with them.

S5. An extremely weak magnetic field can bend charged particles moving in a circle. This may not be noticeable for a large radius path. With reference to the gigantic interstellar space, the deflection can affect the passage of charged particles.

S6. The equatorial magnetic field is,

$$B_E = \frac{\mu_0 m}{4\pi r^3}$$

We are given that $B_E \sim 0.4$ G $= 4 \times 10^{-5}$ T. For r, we take the radius of the Earth 6.4×10^6 m. Hence,

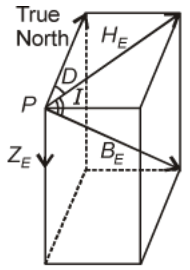
$$m = \frac{4 \times 10^{-5} \times (6.4 \times 10^6)^3}{\mu_0 / 4\pi}$$

$$= 4 \times 10^2 \times (6.4 \times 10^6)^3 \qquad (\mu_0/4\pi = 10^{-7})$$

$$= 1.05 \times 10^{23} \text{ A m}^2$$

This is close to the value 8×10^{22} A m^2 quoted in geomagnetic texts.

S7. It is given that $H_E = 0.26$ G. (see figure), we have



$$\cos 60° = \frac{H_E}{B_E}$$

$$B_E = \frac{H_E}{\cos 60°} = \frac{0.26}{(1/2)} = 0.52 \text{ G.}$$

S8. The vertical plane passing through the magnetic axis of the earth that is known as magnetic meridian.

The great circle on the earth is surface, whose plane is perpendicular to the magnetic axis that is known as magnetic equator.

S9. At poles.

S10. The vertical plane passing through the geographical *N-S* line *i.e.*, known as geographical meridian.

S11. The vertical component of earth's magnetic field at 0° of equator.

S12. The temperature inside the earth is so high that it is impossible for the iron core to remain as a source of magnetic field. The magnetic field due to the earth is considered to be due to the circulating electric currents induced in the iron in molten state and other conducting materials inside the earth.

S13. Magnetic moment, $M = 8 \times 10^{22}\, J T^{-1}$

Radius of earth, $r = 6.4 \times 10^{6}$ m

Magnetic field strength, $B = \dfrac{\mu_0 M}{4\pi r^3}$

Where,

μ_0 = Permeability of free space = $4\pi \times 10^{-7}$ TmA^{-1}

$$\therefore \quad B = \frac{4\pi \times 10^{-7} \times 8 \times 10^{22}}{4\pi \times (6.4 \times 10^{6})^3} = 0.3\, G$$

This quantity is of the order of magnitude of the observed field on earth.

S14. (a) The horizontal component of Earth's magnetic at 0°.

(b) The angle of dip is this place 90°.

S15. It is hypothetically considered that a huge bar magnet is dipped inside earth with its north pole near the geographic South Pole and its south pole near the geographic North Pole.

Magnetic field lines emanate from a magnetic north pole and terminate at a magnetic south pole. Hence, in a map depicting earth's magnetic field lines, the field lines at Melbourne, Australia would seem to come out of the ground.

S16. The parameters needed to completely specify the earth's magnetic field are declination, dip and the horizontal component of the earth's magnetic field.

S17. If a compass is located on the geomagnetic North Pole or South Pole, then the compass will be free to move in the horizontal plane while earth's field is exactly vertical to the magnetic poles. In such a case, the compass can point in any direction.

S18. Magnetic elements: declination, dip and the horizontal component of the earth's magnetic field.

S19. The two quantities are:

(a) The horizontal component of the earth's magnetic field.

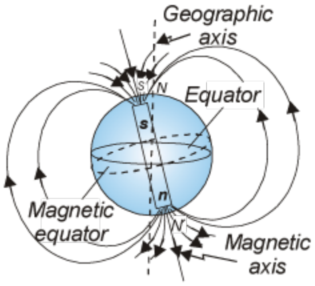
(b) Magnetic declination.

S20. The horizontal component of the earth's magnetic field at magnetic poles is 0.

S21. Declination at a place is the angle between the geographic and magnetic meridian.

S22. The angle of dip at a point depends on how far the point is located with respect to the North Pole or the South Pole. The angle of dip would be greater in Britain (it is about 70°) than in southern India because the location of Britain on the globe is closer to the magnetic North Pole.

S23. Dip at a place is the angle made by the direction of the Earth's total magnetic field with the horizontal direction.



At any place the acute angle between the magnetic meridian and the geographical meridian is called the *Magnetic Declination*.

S24. If we subtended a magnet freely. It will be directed in magnetic meridian. Then 18° to the left of it would indicate exact geographical north.

S25. The declination, $\theta = 15°$ west of the geographic north.

S26. The neutral points lie along the axis of the magnet; when the magnet is placed along the magnetic *N*-*S* line, with its north pole towards the south of the earth.

S27. Bismuth is a diamagnetic material. It will slightly less.

S28. Declination at a place is the angle between the geographic and magnetic meridians. By knowing the declination, the ship can be steered in the required direction, so as to reach the destination.

S29. Given:

$$B_V = \sqrt{3}\, B_H$$

Angle of dip is $$\tan\delta = \frac{B_V}{B_H}$$

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

$$\tan\delta = \sqrt{3}$$

$$\delta = \tan^{-1}(\sqrt{3}) = 60°$$

$$\delta = 60°$$

S30. At the magnetic poles of the earth.

S31. It will stand vertical with its *N*-pole downwards and *S*-pole upwards.

S32. On the axial line of the magnet.

S33. The magnetic compass needle can point in any direction on the geomagnetic north or south pole. It is because, the horizontal component of the earth's field is zero at these points.

S34. On the equatorial line of the magnet.

S35. Dip at a place is the angle made by the direction of the earth's total magnetic field with the horizontal direction.

S36. 0°.

S37. It is 90°. The magnet becomes critical ($\delta = 90°$) at both the magnetic north and south poles.

S38. At equator, the earth's magnetic field is 0° to horizontal. *i.e.*, the vertical component of earth's magnetic field at equator is zero.

S39. A neutral point in the magnetic field of a bar magnet is that point, where the field due to the magnet is completely neutralised by the horizontal component of earth's magnetic field.

S40. The horizontal and vertical components of earth's magnetic field are perpendicular to each other.

Horizontal component

$$H = B_e \cos 60° = B \text{ (given)}$$

$$\Rightarrow \quad B_e \times \frac{1}{2} = B \quad \text{or} \quad B_e = 2B$$

Vertical component

$$V = B_e \sin 60°$$

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

$$= \sqrt{3}B$$

S41. At poles, the angle of dip is 90°.

S42. The angle between geographical meridian and magnetic meridian at any place of earth is known as magnetic declination (α) at that place of earth.

S43.

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

where δ = angle of dip,

H and V = horizontal and vertical components of magnetic field.

For $\quad V = H$

$$\therefore \quad \tan \delta = 1$$

$$\Rightarrow \quad \delta = \frac{\pi}{4}$$

S44. At equator.

S45. Horizontal component of earth's magnetic field, $B_H = 0.35$ G

Angle made by the needle with the horizontal plane = Angle of dip = $\delta = 22^\circ$

Earth's magnetic field strength = B

We can relate B and B_H as:

$$B_H = B \cos \delta$$

$$\therefore \qquad B = \frac{B_H}{\cos \delta} = \frac{0.35}{\cos 22^\circ} = \mathbf{0.377\ G}$$

Hence, the strength of Earth's magnetic field at the given location is 0.377 G.

S46. Angle of declination, $\theta = 12^\circ$

Angle of dip, $\delta = 60^\circ$

Horizontal component of earth's magnetic field, $B_H = 0.16$ G

Earth's magnetic field at the given location = B

We can relate B and B_H as:

$$B_H = B \cos \delta$$

$$\therefore \qquad B = \frac{B_H}{\cos \delta} = \frac{0.16}{\cos 60^\circ} = \mathbf{0.32\ G}$$

Earth's magnetic field lies in the vertical plane, 12° West of the geographic meridian, making an angle of 60° (upward) with the horizontal direction. Its magnitude is 0.32 G.

S47. Magnitude of one of the magnetic fields, $B_1 = 1.2 \times 10^{-2}$ T

Magnitude of the other magnetic field = B_2

Angle between the two fields, $\theta = 60^\circ$

At stable equilibrium, the angle between the dipole and field B_1, $\theta_1 = 15^\circ$

Angle between the dipole and field B_2, $\theta_2 = \theta - \theta_1 = 60^\circ - 15^\circ = 45^\circ$

At rotational equilibrium, the torques between both the fields must balance each other.

$$\therefore \qquad \text{Torque due to field } B_1 = \text{Torque due to field } B_2$$

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

Where, M = Magnetic moment of the dipole

$$\therefore \qquad B_2 = \frac{B_1 \sin \theta_1}{\sin \theta_2}$$

$$= \frac{1.2 \times 10^{-2} \times \sin 15^\circ}{\sin 45^\circ} = \mathbf{4.39 \times 10^{-3}\ T}$$

Hence, the magnitude of the other magnetic field is 4.39×10^{-3} T.

S48. Current in the wire, $I = 2.5$ A

Angle of dip at the given location on Earth, $\delta = 0°$

Earth's magnetic field, $H = 0.33$ G $= 0.33 \times 10^{-4}$ T

The horizontal component of Earth's magnetic field is given as:

$$H_H = H \cos \delta$$
$$= 0.33 \times 10^{-4} \times \cos 0° = 0.33 \times 10^{-4}\ \text{T}$$

The magnetic field at the neutral point at a distance R from the cable is given by the relation:

$$H_H = \frac{\mu_0 I}{2\pi R}$$

Where, μ_0 = Permeability of free space

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

$$\therefore \quad R = \frac{\mu_0 I}{2\pi H_H}$$
$$= \frac{4\pi \times 10^{-7} \times 2.5}{2\pi \times 0.33 \times 10^{-4}}$$
$$= 15.15 \times 10^{-3}\ \text{m} = \mathbf{1.51\ cm}$$

Hence, a set of neutral points parallel to and above the cable are located at a normal distance of 1.51 cm.

S49. **Magnetic Inclination** or **Magnetic Dip (δ):** The angle of dip at a place is the angle between the direction of earth's magnetic field and the horizontal in the magnetic meridian at that place is called *Magnetic Dip*.

Horizontal Component: Is the component of total intensity of earth's magnetic field in the horizontal direction in magnetic meridian. It is given by

$$B_H = B \cos \delta$$

where B_H is horizontal component, B is the total intensity of earth's magnetic field and δ the dip angle.

The magnetic field B_E may be resolved into a horizontal component of earth's magnetic field, B_H, and a vertical component of earth's magnetic field, B_V.

$$B_H = B_E \cos \theta$$

and

$$B_V = B_E \sin \theta,$$

where θ is the angle of dip. These equations give

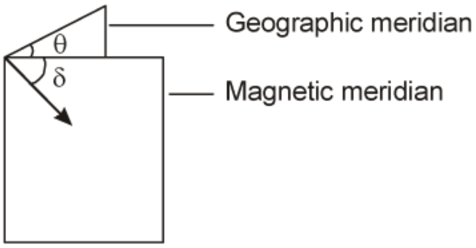
$$\mathbf{B_E = \sqrt{B_H^2 + B_V^2}}$$

and $$\frac{B_V}{B_H} = \tan\theta$$

or $$\boldsymbol{\theta = \tan^{-1}\left(\frac{B_V}{B_H}\right)}.$$

S50. **Magnetic Dip (δ):** The angle of dip at a place is the angle between the direction of earth's magnetic field and the horizontal in the magnetic meridian at that place is called *Magnetic Dip*.

Magnetic Declination (θ): At any place the acute angle between the magnetic meridian and the geographical meridian is called the *Magnetic Declination*.



S51. Given, $$\frac{B_H}{B} = \frac{1}{\sqrt{2}}$$

We know, $$\cos\delta = \frac{B_H}{B} = \frac{1}{\sqrt{2}} \quad \text{or} \quad \delta = \cos^{-1}\left(\frac{1}{\sqrt{2}}\right)$$

or $$\delta = \mathbf{45°}.$$

S52. Potential energy of the configuration arises due to potential energy of one dipole (say *B*), in the magnetic field due to the other (*A*). Use the result that

$$B_A = \frac{\mu_0 M_A}{4\pi r^3} \quad \text{(on the normal bisector)}$$

$$B_A = \frac{\mu_0 2M_A}{4\pi r^3} \quad \text{(on the axis)}$$

Equilibrium is stable when M_B is parallel to B_A and unstable when M_B is anti-parallel to B_A.

(a) AB_1 and AB_6

(b) (i) AB_3, AB_6 (stable)

(ii) AB_5, AB_4 (unstable)

(c) AB_6 Maximum negative)

S53. Given, $$B_H = \sqrt{3}\,B_V$$

Now, $$\tan\delta = \frac{B_V}{B_H} = \frac{B_V}{\sqrt{3}\,B_H} = \frac{1}{\sqrt{3}} \quad \text{or} \quad \delta = \tan^{-1}\left(\frac{1}{\sqrt{3}}\right)$$

or $$\delta = \mathbf{30°}.$$

S54. Angle of dip, $\delta = 60° = \frac{\pi}{3}$

Horizontal component of earth's magnetic field, $H = 0.4$ G

Earth magnetic field (B_e) = ?

Horizontal component of earth's magnetic field, $H = B_e \cos\delta$

$$\Rightarrow \quad B_e = \frac{H}{\cos\delta} = \frac{0.4G}{\cos 60°}$$

$$= \frac{0.4G}{\left(\frac{1}{2}\right)} = 0.8 \text{ G}$$

$$\therefore \quad B_e = 0.8 \text{ G}$$

S55. When a magnetic material is placed in a magnetising field of strength $\vec{H}$ the materials gets magnetised. The total magnetic flux density $\vec{B}$ in a material is the sum of the magnetic flux density B_0 in vacuum and magnetic flux density $\vec{B}_m$ due to magnetisation of the material. That is,

$$\vec{B} = \vec{B}_0 + \vec{B}_m \qquad \text{... (i)}$$

But, $\vec{B}_0 = \mu_0 \vec{H}$ and $\vec{B}_m = \mu_0 \vec{I}$,

where $\vec{I}$ is the intensity of magnetisation induced in the magnetic material and μ_0 is permeability of free space or vacuum. Thus,

$$\vec{B} = \mu_0 \vec{H} + \mu_0 \vec{I}$$

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

As, magnetisation $I = \chi_m H$ (χ_m = magnetic susceptibility)

and $B = \mu H$ (μ = permeability of medium)

$$\therefore \quad \mu H = \mu_0 (H + \chi_m H) = \mu_0 H (1 + \chi_m)$$

$$\text{or} \quad \frac{\mu}{\mu_0} = 1 + \chi_m$$

$$\text{or} \quad \mu_r = 1 + \chi_m \qquad \left(\because \ \mu_r \frac{\mu}{\mu_0} = \text{relative permeability}\right)$$

S56. According to the question, $H = \sqrt{3}V$, where H and V are the horizontal and vertical components of earth's magnetic field.

If angle of dip at that place is δ, then

$$\tan\delta = \frac{V}{H} = \frac{V}{\sqrt{3}V} \qquad [\because H = \sqrt{3}V]$$

$$\tan\delta = \frac{1}{\sqrt{3}} \quad \Rightarrow \quad \delta = \frac{\pi}{6}$$

$\because$ Horizontal component of earth's magnetic field,

$$H = B_e \cos\delta$$

where, B_e = earth's magnetic field

$$\frac{H}{B_e} = \cos\delta = \cos\frac{\pi}{6} = \frac{\sqrt{3}}{2}$$

$$H : B_e = \sqrt{3} : 2$$

S57. Number of horizontal wires in the telephone cable, $n = 4$

Current in each wire, $I = 1.0$ A

Earth's magnetic field at a location, $H = 0.39\text{ G} = 0.39 \times 10^{-4}\text{ T}$

Angle of dip at the location, $\delta = 35°$

Angle of declination, $\theta \sim 0°$

For a point 4 cm below the cable:

Distance, $r = 4\text{ cm} = 0.04\text{ m}$

The horizontal component of Earth's magnetic field can be written as:

$$H_h = H\cos\delta - B$$

Where, B = Magnetic field at 4 cm due to current I in the four wires

$$= 4 \times \frac{\mu_0 I}{2\pi r}$$

μ_0 = Permeability of free space

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

$$\therefore \quad B = 4 \times \frac{4\pi \times 10^{-7} \times 1}{2\pi \times 0.04} = 0.2 \times 10^{-4}\text{ T} = 0.2\text{ G}$$

$$\therefore \quad H_h = 0.39\cos 35° - 0.2$$

$$= 0.39 \times 0.819 - 0.2 \approx 0.12\text{ G}$$

The vertical component of Earth's magnetic field is given as:

$$H_v = H\sin\delta = 0.39\sin 35° = 0.22\text{ G}$$

The angle made by the field with its horizontal component is given as:

$$\theta = \tan^{-1}\frac{H_v}{H_h} = \tan^{-1}\frac{0.22}{0.12} = 61.39°$$

The resultant field at the point is given as:

$$H_1 = \sqrt{(H_v)^2 + (H_h)^2} = \sqrt{(0.22)^2 + (0.12)^2} = 0.25\,\text{G}$$

For a point 4 cm above the cable:

Horizontal component of Earth's magnetic field:

$$H_h = H\cos\delta + B$$
$$= 0.39\cos 35° + 0.2 = 0.52\ \text{G}$$

Vertical component of earth's magnetic field:

$$H_v = H\sin\delta$$
$$= 0.39\sin 35° = 0.22\,\text{G}$$

Angle, $\theta = \tan^{-1}\frac{H_v}{H_h} = \tan^{-1}\frac{0.22}{0.52} = 22.9°$

And resultant field: $H_2 = \sqrt{(H_v)^2 + (H_h)^2} = \sqrt{(0.22)^2 + (0.52)^2} = 0.56\,\text{T}.$

S58. Number of turns in the circular coil, $N = 30$

Radius of the circular coil, $r = 12\ \text{cm} = 0.12\ \text{m}$

Current in the coil, $I = 0.35\,\text{A}$

Angle of dip, $\delta = 45°$

(a) The magnetic field due to current I, at a distance r, is given as:

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

Where, μ_0 = Permeability of free space

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

$$\therefore \quad B = \frac{4\pi\times10^{-7}\times2\pi\times30\times0.35}{4\pi\times0.12} = 5.49\times10^{-5}\,\text{T}$$

(b) The compass needle points from West to East. Hence, the horizontal component of Earth's magnetic field is given as:

$$B_H = B\sin\delta$$
$$= 5.49\times10^{-5}\sin 45° = 3.88\times10^{-5}\,\text{T} = 0.388\ \text{G}$$

When the current in the coil is reversed and the coil is rotated about its vertical axis by an angle of 90º, the needle will reverse its original direction. In this case, the needle will point from East to West.

S59. $\because$ Horizontal component

$$H = B\cos\theta = 0.4\cos 60°$$

$$= 0.4 \times \frac{1}{2} = 0.2\ \text{G} = 0.2 \times 10^{-4}\ \text{T} \qquad [\because \cos 60° = 1/2]$$

The wheel is rotating in a plane normal to horizontal component, so it will cut the horizontal component only, vertical component of earth will contribute nothing in emf

Thus, the emf induced is given as

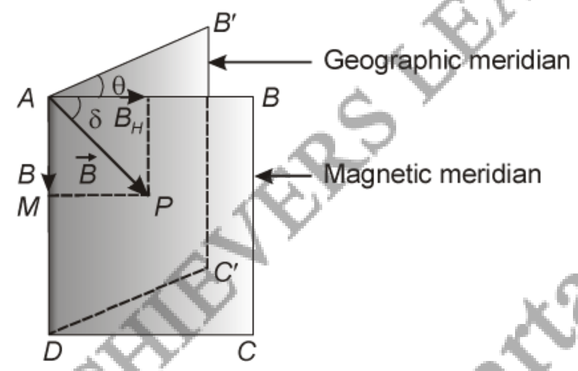
$$E = \frac{1}{2}Hl^2\omega, \quad \text{where } \omega = \frac{2\pi N}{t} \text{ and}$$

$$l = \text{length of the spoke}$$
$$= 50\ \text{cm} = 0.5\ \text{m}$$

$$\therefore \qquad E = \frac{1}{2} \times 0.2 \times 10^{-4} \times (0.5)^2 \times \frac{2 \times 3.14 \times 120}{60}$$
$$= 3.14 \times 10^{-5}\ \text{V}$$

The value of emf induced is independent of the number of spokes as the emf's across the spokes are in parallel. So, the emf will be unaffected with the increase in spokes.

S60. Figure shows the three elements of the earth's magnetic field. Here, (a) δ is the angle of dip; (b) θ is the magnetic declination and (c) B_H represents the horizontal component of earth's magnetic field.



If at any place δ is the angle of dip, then the horizontal component of earth's magnetic field $\vec{B}$ is given by

$$B_H = B\cos\delta \qquad \text{... (i)}$$

and the vertical component is given by

$$B_V = B\sin\delta \qquad \text{... (ii)}$$

Dividing Eqn. (ii) by Eqn. (i), we get

$$\frac{B_V}{B_H} = \frac{B\sin\delta}{B\cos\delta} = \tan\delta \qquad \text{... (iii)}$$

Also, $$B_H^2 + B_V^2 = B_2(\cos^2\delta + \sin^2\delta) = B^2$$

or $$B = \sqrt{B_H^2 + B_V^2}\,. \qquad \text{... (iv)}$$

Equations (iii) and (iv) give the required relations.

S61. (a) $N = 30$, $r = 12 \times 10^{-2}\,\text{m}$, $I = 0.35\,\text{A}$.

Magnetic field at the centre of the coil is normal to its plane and its magnitude is given as

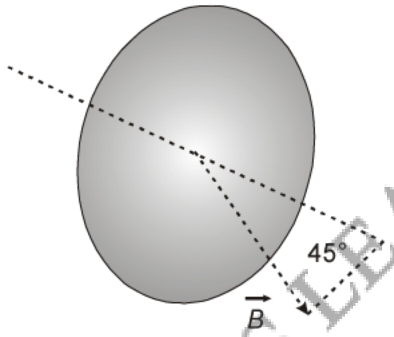
$$B = N\left(\frac{\mu_0 I}{2r}\right)$$

As coil is making an angle of 45° with the magnetic meridian.

Component of the field in the magnetic meridian

$$B' = B\cos 45^\circ$$

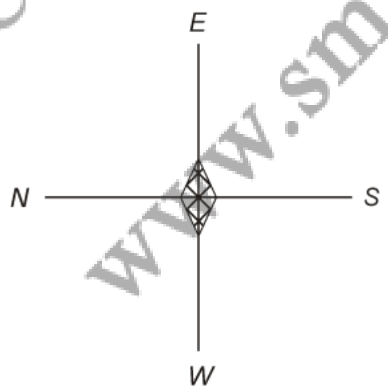
Component perpendicular to the magnetic meridian is



$$B' = B\sin 45^\circ$$

Since needle points in the west-east direction

$$B_H = \frac{\mu_0 N I}{2r}\cos 45^\circ$$



$$B_H = \frac{4\pi \times 10^{-7} \times 30 \times 0.35}{2 \times 0.12 \times \sqrt{2}}$$

$$= 0.39 \times 10^{-4}\,T$$

$$B_H = 0.39\,G.$$

(b) Needle will set in east to west direction.

S62. At the equator vertical component of earth's magnetic field is zero.

Given: $M = 1.5\ \text{JT}^{-1}$, $B = 0.22\ \text{T}$

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

Here, $$\theta_1 = 0°$$
$$\theta_2 = 90°$$

$$W = -MB(0-1)$$
$$= MB\ \text{J}$$
$$W = 1.5 \times 0.22 = 0.33\ \text{J}$$

(b) $\theta_1 = 0°$, $\theta_2 = 180°$
$$W = -MB[-1-1] = 2\,MB$$
$$W = 0.66\ \text{J}$$

S63. Given, $B_{\text{equi}} = 0.3\,\text{G} = 0.3 \times 10^{-4}\,\text{T}$; $r = 6.4 \times 10^6\,\text{m}$

For a short bar magnet,

$$B_{\text{equi}} = \frac{\mu_0}{4\pi}\cdot\frac{M}{r^3}$$

or $$M = \frac{4\pi}{\mu_0} B_{\text{equi}}.r^3$$

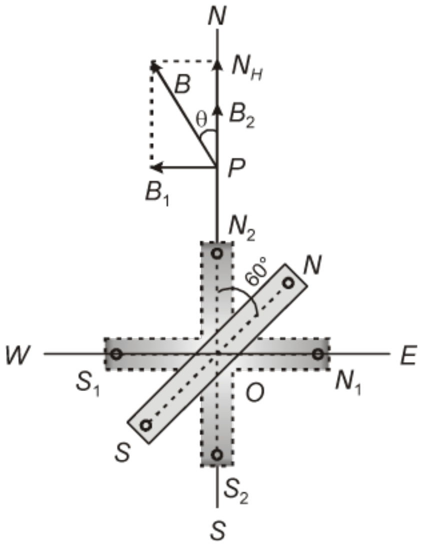
or $$= \frac{0.3 \times 10^{-4}(6.4 \times 10^6)^3}{10^{-7}}$$

or $$M = \mathbf{7.864 \times 10^{22}\ Am^2}.$$

The point at the north pole of the earth lies on its axial line at a distance equal to radius of the earth.

For a short bar magnet,
$$B = B_{\text{axial}} + B_H$$
$$= \mathbf{2 \times 0.3 = 0.6\,G}.$$

S64. The magnet *NS* of magnetic moment *M* is placed with its north pole pointing 60° east of north as shown in the figure below:



The point P lies at a distance $OP = 0.2$ m north of the magnet.

Given, $M = 2\,\text{Am}^2$, $B_H = 0.3 \times 10^{-4}\,T$.

The magnetic moment M of the magnet NS can be resolved into two components:

(a) $M \sin 60°$ along EW-line and

(b) $M \cos 60°$ along NS-line.

In other words, the magnet NS of magnetic moment M placed 60° east of north can be replaced by two magnets $N_1 S_1$ (of magnetic moment M sin 60° placed along EW-line) and $N_2 S_2$ (of magnetic moment M cos 60° placed along NS-line). Let B_1 and B_2 be the magnetic fields at the point P due to the magnets $N_1 S_1$ and $N_2 S_2$ respectively. Then,

$$B_1 = \frac{\mu_0}{4\pi} \cdot \frac{M \sin 60°}{(OP)^3} = \frac{10^{-7} \times 2 \times \sin 60°}{(0.2)^3} = 0.2165 \times 10^{-4}\,T$$

and
$$B_2 = \frac{\mu_0}{4\pi} \cdot \frac{2M \cos 60°}{(OP)^3} = \frac{10^{-7} \times 2 \times 2 \times \cos 60°}{(0.2)^3} = 0.25 \times 10^{-4}\,T.$$

Resultant magnetic field at the point P,

$$B = \sqrt{(B_1)^2 + (B_2 + B_H)^2}$$

$$= \sqrt{(0.2165 \times 10^{-4})^2 + (0.25 \times 10^{-4} + 0.3 \times 10^{-4})^2} = 0.59 \times 10^{-4}\,T.$$

Suppose that the resultant magnetic field B is in a direction θ west of north as shown in the figure. Then,

$$\tan\theta = \frac{B_1}{B_2 + B_H} = \frac{0.2165 \times 10^{-4}}{0.25 \times 10^{-4} + 0.3 \times 10^{-4}} = 0.3936$$

⇒ $\theta = \tan^{-1}(0.3936)$

or $\theta =$ **21.48° (west of north)**.

S65. Vertical component of earth's magnetic field is zero at the equator.

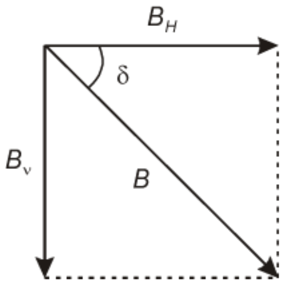
$$B_H = 0.2 \times 10^{-4}\,\text{Wb}\,\text{m}^{-2}$$

$$\delta = 45°$$

(a)
$$B_v = B \sin \delta$$

$$B_H = B \cos \delta$$

$$B = \frac{B_H}{\cos \delta}$$



$$B_v = \frac{B_H \sin \delta}{\cos \delta} = B_H \tan \delta$$

$$B_v = 0.2 \times 10^{-4} \times \tan 45° = 0.2 \times 10^{-4}$$

(b)
$$B = \frac{B_H}{\cos \delta} = \frac{0.2 \times 10^{-4}}{\cos 45°}$$

$$B = \sqrt{2} \times 0.2 \times 10^{-4} = 0.28 \times 10^{-4}$$

$$B = 0.28 \times 10^{-4}\,\text{Wb}\,\text{m}^{-2}.$$

S66. There are three elements determining earth's magnetic field at any point of the earth

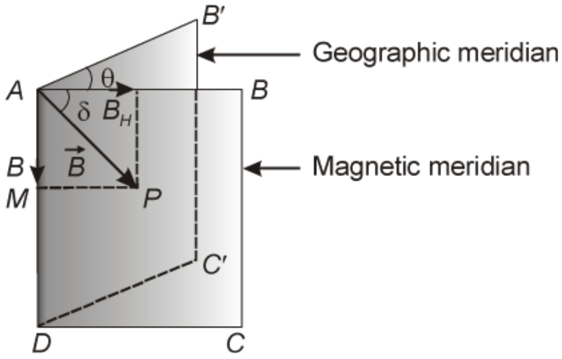
(a) magnetic declination

(b) magnetic dip

(c) and horizontal component of earth's magnetic field.

Angle between geographical meridian and the magnetic meridian at any point is known as the magnetic declination at that point. Magnetic dip is the angle between the direction of earth's magnetic field and the horizontal direction along the magnetic meridian.

Given below figure shows the three elements of the earth's magnetic field. Here, (a) δ is the angle of dip; (b) θ is the magnetic declination and (c) B_H represents the horizontal component of earth's magnetic field.



If at any place δ is the angle of dip, then the horizontal component of earth's magnetic field $\vec{B}$ is given by

$$B_H = B\cos\delta \qquad \text{... (i)}$$

and the vertical component is given by

$$B_V = B\sin\delta \qquad \text{... (ii)}$$

Dividing Eqn. (ii) by Eqn. (i), we get

$$\frac{B_V}{B_H} = \frac{B\sin\delta}{B\cos\delta} = \tan\delta \qquad \text{... (iii)}$$

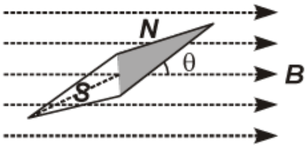
Also, $B_H^2 + B_V^2 = B^2(\cos^2\delta + \sin^2\delta) = B^2$

or $B = \sqrt{B_H^2 + B_V^2}$ . ... (iv)

Date: 20/10/2021

Q1. **What is the magnitude of the equatorial and axial fields due to a bar magnet of length 5.0 cm at a distance of 50 cm from its mid-point? The magnetic moment of the bar magnet is 0.40 A m^2.**

Q2. **In figure, the magnetic needle has magnetic moment 6.7×10^{-2} Am^2 and moment of inertia $\mathcal{I} = 7.5 \times 10^{-6}$ kg m^2. It performs 10 complete oscillations in 6.70 s. What is the magnitude of the magnetic field?**



Q3. **The susceptibility of a magnetic material is 1.9×10^{-5}. Name the type of magnetic materials it represents.**

Q4. **What is magnetic susceptibility.**

Q5. **How does the (a) pole strength and (b) magnetic moment of each part of a bar magnet change if it is cut into two equal pieces transverse to its length?**

Q6. **What is magnetic permeability.**

Q7. **An iron rod of 0.1 m^2 area of cross-section is subjected to magnetising field of 1,000 Am^{-1}. Calculate its magnetic permeability. Given susceptibility of iron is 599.**

Q8. **Name the source of magnetic properties of materials.**

Q9. **The permeability of a magnetic material is 0.9983. Name the type of magnetic material it represents.**

Q10. **The susceptibility of a magnetic material is 2.0×10^{-5}. Name the type of magnetic material it represents.**

Q11. **The susceptibility of a magnetic material is -4.2×10^{-6}. Name type of magnetic material it represents.**

Q12. **A short bar magnet placed with its axis at 30° with a uniform external magnetic field of 0.25 T experiences a torque of magnitude equal to 4.5×10^{-2} J. What is the magnitude of magnetic moment of the magnet?**

Q13. **A short bar magnet of magnetic moment $m = 0.32$ J T^{-1} is placed in a uniform magnetic field of 0.15 T. If the bar is free to rotate in the plane of the field, which orientation would correspond to its (a) stable, and (b) unstable equilibrium? What is the potential energy of the magnet in each case?**

Q14. **A closely wound solenoid of 800 turns and area of cross-section 2.5×10^{-4} m^2 carries a current of 3.0 A. Explain the sense in which the solenoid acts like a bar magnet. What is its associated magnetic moment?**

Q15. **A closely wound solenoid of 2000 turns and area of cross-section 1.6×10^{-4} m^2, carrying a current of 4.0 A, is suspended through its centre allowing it to turn in a horizontal plane.**

(a) **What is the magnetic moment associated with the solenoid?**

(b) **What is the force and torque on the solenoid if a uniform horizontal magnetic field of 7.5×10^{-2} T is set up at an angle of 30° with the axis of the solenoid?**

Q16. A short bar magnet has a magnetic moment of 0.48 J T^{-1}. Give the direction and magnitude of the magnetic field produced by the magnet at a distance of 10 cm from the centre of the magnet on (a) the axis, (b) the equatorial lines (normal bisector) of the magnet.

Q17. A circular coil of 16 turns and radius 10 cm carrying a current of 0.75 A rests with its plane normal to an external field of magnitude 5.0×10^{-2} T. The coil is free to turn about an axis in its plane perpendicular to the field direction. When the coil is turned slightly and released, it oscillates about its stable equilibrium with a frequency of 2.0 s^{-1}. What is the moment of inertia of the coil about its axis of rotation?

Q18. A short bar magnet placed in a horizontal plane has its axis aligned along the magnetic North-South direction. Null points are found on the axis of the magnet at 14 cm from the centre of the magnet. The earth's magnetic field at the place is 0.36 G and the angle of dip is zero. What is the total magnetic field on the normal bisector of the magnet at the same distance as the null-point (*i.e.*, 14 cm) from the centre of the magnet? (At *null points*, field due to a magnet is equal and opposite to the horizontal component of Earth's magnetic field.)

Q19. A Rowland ring of mean radius 15 cm has 3500 turns of wire wound on a ferromagnetic core of relative permeability 800. What is the magnetic field *B* in the core for a magnetising current of 1.2 A?

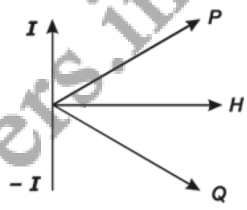
Q20. Differentiate between uniform and non-uniform magnetic fields. Sketch lines of force for a uniform field.

Q21. A solenoid has a core of a material with relative permeability 400. The windings of the solenoid are insulated from the core and carry a current of 2A. If the number of turns is 1000 per metre, calculate (a) *H*, (b) *M*, (c) *B* and (d) the magnetising current I_m.

Q22. The following figure shows the variation of intensity of magnetisation versus the applied magnetic field intensity *H*, for two magnetic materials *P* and *Q*:

(a) Identify the materials *P* and *Q*.

(b) Draw the variation of susceptibility with temperature for *Q*.



Q23. Draw a plot showing the variation of intensity of magnetisation with the applied magnetic field intensity for Bismuth. Under what condition does diamagnetic material exhibit perfect conductivity and perfect diamagnetism?

Q24. The susceptibility of magnesium at 300 K is 0.6×10^{-5}. At what temperature will the susceptibility equal to 1.12×10^{-5}?

Q25. The susceptibility of a magnetic material is -2.6×10^{-5}. Identify the type of magnetic material and state its two properties.

Q26. If the bar magnet is turned around by 180°, where will the new null points be located?

Q27. The magnetic moment vectors μ_s and μ_l associated with the intrinsic spin angular momentum *S* and orbital angular momentum *l*, respectively, of an electron are predicted by quantum theory (and verified experimentally to a high accuracy) to be given by:

$$\mu_s = -(e/m)\,S,$$

$$\mu_l = -(e/2m)\,l$$

Which of these relations is in accordance with the result expected *classically*? Outline the derivation of the classical result.

Q28. A short bar magnet of magnetic moment 5.25×10^{-2} J T^{-1} is placed with its axis perpendicular to the Earth's field direction. At what distance from the centre of the magnet, the resultant field is inclined at 45° with Earth's field on its normal bisector and its axis. Magnitude of the Earth's field at the place is given to be 0.42 G. Ignore the length of the magnet in comparison to the distances involved.

Q29. How will you judge as to which of the two given similar magnets is stronger without using a third magnet?

Q30. Three identical specimens of a magnetic material, nickel, antimony, aluminium are kept in a non-uniform magnetic field. Draw the modification in the field lined in each case. Justify your answer.

Q31. A short bar magnet placed with its axis at 30° with an external field of 800 G experiences a torque of 0.016 Nm (a) What is the magnetic moment of the magnet? (b) What is the work done in moving it from its most stable to most unstable position? (c) The bar magnet is replaced by a solenoid of cross-sectional area 2×10^{-4} m^2 and 1000 turns, but the same magnetic moment. Determine the current flowing through the solenoid.

Q32. Define the term magnetic permeability of a magnetic material. Write any two characteristics of a magnetic substance if it is to be used to make a permanent magnet. Give an example of such a material.

Q33. A short bar magnet of magnetic moment 5.25×10^{-2} JT^{-1} is placed with its axis perpendicular to the earth's field direction. At what distance from the centre of the magnet, the resultant field is inclined at 45° with the earth's field on (a) its normal bisector and (b) its axis. Magnitude of the earth's field at the place is given to be 0.42 G. Ignore the length of the magnet in comparison to the distances involved.

Q34. A short bar magnet is placed in a horizontal plane with its axis in the magnetic meridian. Null points are found on its equatorial line (*i.e.*, its normal bisector) at 12.5 cm from the centre of the magnet. The earth's magnetic field at the place is 0.38 G and the angle of dip is zero. (a) What is the total magnetic field at points on the axis of the magnet located at the same distance (12.5 cm) as the null-points from the centre? (b) Locate the null-points, when the bar is turned around by 180°. Assume that the length of the magnet is negligible as compared to the distance of the null-points from the centre of the magnet.

Q35. What is the magnetic susceptibility and write its unit.
If χ_m stands for the magnetic susceptibility of a given material, identify the class of materials for which

(a) $-\infty \le \chi_m < 0$

(b) $0 < \chi_m < \varepsilon$ (ε stands for a small positive number)

  (i) Write the range of relative magnetic permeability of these materials.

  (ii) Draw the pattern of the magnetic field lines when these materials are placed in an external magnetic field.

Q36. Verify the Ampere's law for magnetic field of a point dipole of dipole moment $m = m\hat{k}$ Take C as the closed curve running clockwise along (a) the z-axis from $z = a > 0$ to $z = R$; (b) along the quarter circle of radius R and centre at the origin, in the first quadrant of $x - z$ plane; (c) along the x-axis from $x = R$ to $x = a$, and (d) along the quarter circle of radius a and centre at the origin in the first quadrant of $x - z$ plane.

Q37. A short bar magnet of magnetic moment $2.25 \times 10^{-2}\ JT^{-1}$ is placed with its axis perpendicular to the earth's field direction. At what distance from the centre of the magnet, the resultant field is inclined at 45° with the earth's field on (a) is normal bisector and (b) its axis. Magnetic of the earth's field at the place is given to be 0.21 *G*. Ignore the length of the magnet in comparison to the distances involved.

Q38. A small coil of radius 0.002 m is placed on the axis of a magnet of magnetic moment $10^5\ JT^{-1}$ and length 0.1 m at a distance of 0.15 m from the centre of the magnet. The plane of the coil is perpendicular to the axis of the magnet. Find the force on the coil, when the current of 2.0 *A* is passed through it.

Date: 20/10/2021

S1.

$$B_E = \frac{\mu_0 m}{4\pi r^2} = \frac{10^{-7} \times 0.4}{(0.5)^2} = \frac{10^{-7} \times 0.4}{0.125} = 3.2 \times 10^{-7}\,\text{T}$$

B_E = Magnetic field on equatorial line

$$B_A = \frac{\mu_0 2m}{4\pi r^2} = 6.4 \times 10^{-7}\,\text{T}$$

B_E = Magnetic field on axial line

S2. The time period of oscillation is,

$$T = \frac{6.70}{10} = 0.67\,\text{s}$$

$$B = \frac{4\pi^2 \mathcal{I}}{mT^2} = \frac{4 \times (3.14)^2 \times 7.5 \times 10^{-6}}{6.7 \times 10^{-2} \times (0.67)^2} = 0.01\,\text{T}$$

S3. Paramagnetic.

S4. It is nothing but the ratio of the intensity (I) of magnetisation of a substance to the intensity of magnetising field (B).

Therefore, $\chi_m = \dfrac{I}{H}$.

S5. (a) Pole strength does not affected.

(b) Magnetic moment half the original value.

S6. It is nothing but the ratio of the magnetic induction (B) to the magnetic intensity (H)

Therefore, $\mu = \dfrac{B}{H}$.

S7. Given, $A = 0.1\,\text{m}^2$; $H = 1{,}000\,\text{Am}^{-1}$ and $\chi_m = 599$

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

Since, $\mu = \mu_0 (1 + \chi_m) = 4\pi \times 10^{-7} (1 + 599)$

$= \mathbf{7.54 \times 10^{-4}\,TA^{-1}\,m}$

S8. Magnetism is an effect of electric charges in motion. The magnetic properties of the materials due to the atomic magnets, which are the tiny circulating currents in the form of electrons revolving in atomic orbits.

S9. The magnetic material is diamagnetic substance for which $\mu_r < 1$.

S10. The small and positive susceptibility of like 2.0×10^{-5} represents paramagnetic substance.

S11. Negative susceptibility represents diamagnetic substance.

S12. Magnetic field strength, $B = 0.25\,\text{T}$

Torque on the bar magnet, $\tau = 4.5 \times 10^{-2}\,\text{J}$

Angle between the bar magnet and the external magnetic field,

$\theta = 30°$

Torque is related to magnetic moment (M) as:

$$\tau = MB \sin\theta$$

$$\therefore \qquad M = \frac{\tau}{B \sin\theta}$$

$$= \frac{4.5 \times 10^{-2}}{0.25 \times \sin 30°} = \mathbf{0.36\ J\,T^{-1}}$$

Hence, the magnetic moment of the magnet is $0.36\ \text{J}\,\text{T}^{-1}$.

S13. Moment of the bar magnet, $M = 0.32\ \text{J}\,\text{T}^{-1}$

External magnetic field, $B = 0.15\,\text{T}$

(a) The bar magnet is aligned along the magnetic field. This system is considered as being in stable equilibrium. Hence, the angle θ, between the bar magnet and the magnetic field is 0°.

Potential energy of the system $= -MB\cos\theta$

$$= -0.32 \times 0.15 \cos 0° = \mathbf{-4.8 \times 10^{-2}\ J}.$$

(b) The bar magnet is oriented 180° to the magnetic field. Hence, it is in unstable equilibrium.

$$\theta = 180°$$

Potential energy $= -MB\cos$

$$= -0.32 \times 0.15 \cos 180° = \mathbf{4.8 \times 10^{-2}\ J}.$$

S14. Number of turns in the solenoid, $n = 800$

Area of cross-section, $A = 2.5 \times 10^{-4}\ \text{m}^2$

Current in the solenoid, $I = 3.0\,\text{A}$

A current-carrying solenoid behaves as a bar magnet because a magnetic field develops along its axis, *i.e.*, along its length.

The magnetic moment associated with the given current-carrying solenoid is calculated as:

$$M = nIA$$

$$= 800 \times 3 \times 2.5 \times 10^{-4} = \mathbf{0.6\ J\,T^{-1}}.$$

S15. Number of turns on the solenoid, $n = 2000$

Area of cross-section of the solenoid, $A = 1.6 \times 10^{-4}\ \text{m}^2$

Current in the solenoid, $I = 4\,\text{A}$

(a) The magnetic moment along the axis of the solenoid is calculated as:

$$M = nAI$$
$$= 2000 \times 1.6 \times 10^{-4} \times 4 = 1.28\ \text{Am}^2$$

(b) Magnetic field, $B = 7.5 \times 10^{-2}\ \text{T}$

Angle between the magnetic field and the axis of the solenoid, $\theta = 30°$

Torque, $\tau = \text{MB} \sin \theta$

$$= 1.28 \times 7.5 \times 10^{-2} \sin 30°$$

$$= 4.8 \times 10^{-2}\ \text{Nm}$$

Since the magnetic field is uniform, the force on the solenoid is zero. The torque on the solenoid is 4.8×10^{-2} Nm.

S16. Magnetic moment of the bar magnet, $M = 0.48\ \text{J T}^{-1}$

Distance, $d = 10\ \text{cm} = 0.1\ \text{m}$

(a) The magnetic field at distance d, from the centre of the magnet on the axis is given by the relation:

$$B = \frac{\mu_0}{4\pi} \frac{2M}{d^3}$$

Where, μ_0 = Permeability of free space

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

$$\therefore \quad B = \frac{4\pi \times 10^{-7} \times 2 \times 0.48}{4\pi \times (0.1)^3}$$

$$= 0.96 \times 10^{-4}\ \text{T} = \mathbf{0.96\ G}$$

The magnetic field is along the S – N direction.

(b) The magnetic field at a distance of 10 cm (*i.e.*, $d = 0.1$ m) on the equatorial line of the magnet is given as:

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

$$= \frac{4\pi \times 10^{-7} \times 0.48}{4\pi \times (0.1)^3}$$

$$= 0.96 \times 10^{-4}\ \text{T} = \mathbf{0.96\ G}$$

The magnetic field is along the N – S direction.

S17. Number of turns in the circular coil, $N = 16$

Radius of the coil, $r = 10\ \text{cm} = 0.1\ \text{m}$

Cross-section of the coil, $A = \pi r^2 = \pi \times (0.1)^2\ \text{m}^2$

Current in the coil, $I = 0.75\ \text{A}$

Magnetic field strength, $B = 5.0 \times 10^{-2}\ \text{T}$

Frequency of oscillations of the coil, $v = 2.0\ \text{s}^{-1}$

$\therefore$ Magnetic moment, $M = NIA = NI\pi r^2$

$$= 16 \times 0.75 \times \pi \times (0.1)^2 = 0.377\ \text{J T}^{-1}$$

Frequency is given by the relation:

$$v = \frac{1}{2\pi}\sqrt{\frac{MB}{I}}$$

Where, I = Moment of inertia of the coil

$$\therefore \quad I = \frac{MB}{4\pi^2 v^2}$$

$$= \frac{0.477 \times 5 \times 10^{-2}}{4\pi^2 \times (2)^2} = \mathbf{1.18 \times 10^{-4}\ kg\ m^2}$$

Hence, the moment of inertia of the coil about its axis of rotation is 1.18×10^{-4} kg m^2.

S18. Earth's magnetic field at the given place, $H = 0.36$ G

The magnetic field at a distance d, on the axis of the magnet is given as:

$$B_1 = \frac{\mu_0}{4\pi}\frac{2M}{d^3} = H \qquad \text{... (i)}$$

Where, μ_0 = Permeability of free space

M = Magnetic moment

The magnetic field at the same distance d, on the equatorial line of the magnet is given as:

$$B_2 = \frac{\mu_0 M}{4\pi d^3} = \frac{H}{2} \qquad \text{[Using Eqn. (i)]}$$

Total magnetic field, $B = B_1 + B_2$

$$= H + \frac{H}{2}$$

Hence, the magnetic field is 0.54 G in the direction of Earth's magnetic field.

S19. Mean radius of a Rowland ring, $r = 15\ \text{cm} = 0.15\ \text{m}$

Number of turns on a ferromagnetic core, $N = 3500$

Relative permeability of the core material, $\mu_r = 800$

Magnetising current, $I = 1.2$ A

The magnetic field is given by the relation:

$$B = \frac{\mu_r \mu_0 IN}{2\pi r}$$

Where, μ_0 = Permeability of free space

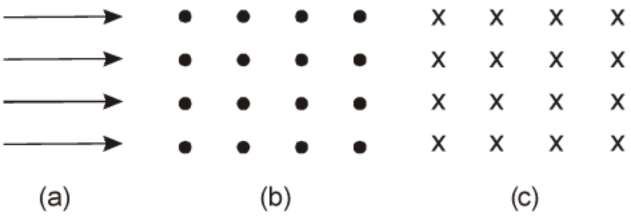
$$= 4\pi \times 10^{-7}\ \text{T m A}^{-1}$$

$$B = \frac{800 \times 4\pi \times 10^{-7} \times 1.2 \times 3500}{2\pi \times 0.15} = \mathbf{4.48\ T}$$

Therefore, the magnetic field in the core is 4.48 T.

S20. **Uniform Magnetic field:** Magnetic field in a region is said to be uniform, if the magnetic vector $\vec{B}$ has the same magnitude and the same direction at all the points in the region.

Non-uniform magnetic field: If the magnetic field vector $\vec{B}$ varies in magnitude and/or direction over different points in a region, the field as said to be non-uniform.



A uniform magnetic field acting in the plane of paper is represented by equidistant parallel lines, as shown in figure (b).(a). A uniform field acting perpendicular to the plane of paper and directed inwards is represented by equidistant dots, as shown in figure (b).(b). A uniform magnetic field acting perpendicular to the plane of the paper and directed outward is represented by equidistant crosses, as shown in figure (b).(c).

S21. (a) The field H is dependent of the material of the core, and is

$$H = nI = 1000 \times 2.0 = 2 \times 10^3\ \text{A/m}.$$

(b) The magnetic field B is given by

$$\begin{aligned} B &= \mu_r \mu_0 H \\ &= 400 \times 4\pi \times 10\ (\text{N/A}^2) \times 2 \times 10^3\ (\text{A/m}) \\ &= 1.0\ \text{T} \end{aligned}$$

(c) Magnetisation is given by

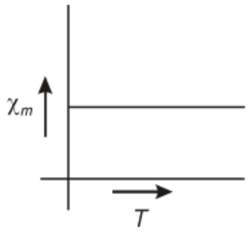
$$\begin{aligned} M &= (B - \mu_0 H)/\mu_0 \\ &= (\mu_r \mu_0 \text{H} - \mu_0 \text{H})/\mu_0 \\ &= (\mu_r - 1) H = 399 \times H \\ &\cong 8 \times 10^5\ \text{A/m} \end{aligned}$$

(d) The magnetising current I_M is the additional current that needs to be passed through the windings of the solenoid in the absence of the core which would give a B value as in the presence of the core. Thus $B = \mu_r n_0 (I + I_M)$. Using I = 2A, B = 1 T, we get I_M = 794 A.

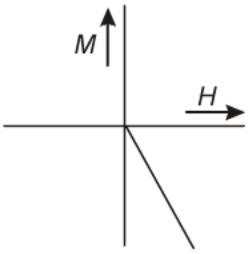
S22. (a) Slope of the line gives susceptibility χ_m of the material.

Slope is +ve for material A, *i.e.*, susceptibility is +ve. So, material 'A' is paramagnetic. Slope for material B is –ve *i.e.*, susceptibility is –ve. So, material 'B' is diamagnetic.

(b)



S23. (a) Intensity of magnetisation (*M*) vs magnetic field intensity (*H*) for Bismuth.



At very very low temperature the material exhibits perfect conductivity.

(b) On super cooling, the material exhibits perfect diamagnetism.

S24. Given: $\chi_m = 0.6 \times 10^{-5}$ at 300 K

From Currie's law

$$\chi_m = \frac{C}{T} \qquad \dots (i)$$

$$\chi'_m = 1.12 \text{ x } 10^{-5} \text{ at T'K}$$

$$\chi'_m = \frac{C}{T'} \qquad \dots (ii)$$

Now Eq. (i) ÷ Eq. (ii), we get

$$\therefore \qquad \frac{\chi_m}{\chi'_m} = \frac{T'}{T}$$

$$\text{or} \qquad T' = T \times \frac{\chi_m}{\chi'_m} = \frac{300 \times 0.6 \times 10^{-5}}{1.12 \times 10^{-5}} = \mathbf{160\,K}.$$

S25. Diamagnetic materials have negative susceptibility. So, the given magnetic material is diamagnetic.

Two properties are

(a) They do not obey Curie's law.

(b) They are feebly repelled by a magnet.

S26. The magnetic field on the axis of the magnet at a distance d_1 = 14 cm, can be written as:

$$B_1 = \frac{\mu_0 2M}{4\pi (d_1)^3} = H \quad \dots \text{(i)}$$

Where, M = Magnetic moment

μ_0 = Permeability of free space

H = Horizontal component of the magnetic field at d_1

If the bar magnet is turned through 180°, then the neutral point will lie on the equatorial line.

Hence, the magnetic field at a distance d_2, on the equatorial line of the magnet can be written as:

$$B_2 = \frac{\mu_0 M}{4\pi (d_2)^3} = H \quad \dots \text{(ii)}$$

Equating Eqns. (i) and (2), we get:

$$\frac{2}{(d_1)^3} = \frac{1}{(d_2)^3}$$

$$\left(\frac{d_2}{d_1}\right)^3 = \frac{1}{2}$$

$$\therefore \quad d_2 = d_1 \times \left(\frac{1}{2}\right)^{\frac{1}{3}} = 14 \times 0.794 = \mathbf{11.1\ cm}$$

The new null points will be located 11.1 cm on the normal bisector.

S27. The magnetic moment associated with the intrinsic spin angular momentum (s) is given as

The magnetic moment associated with the orbital angular momentum (l) is given as

For current i and area of cross-section A, we have the relation:

Where, e = Charge of the electron

r = Radius of the circular orbit

T = Time taken to complete one rotation around the circular orbit of radius r

Angular momentum, $l = mvr$

Where, m = Mass of the electron

v = Velocity of the electron

Dividing equation (i) by equation (ii), we get:

Therefore, of the two relations, is in accordance with classical physics.

S28. Magnetic moment of the bar magnet,

$$M = 5.25 \times 10^{-2}\ \text{J}\,\text{T}^{-1}$$

Magnitude of earth's magnetic field at a place,

$$H = 0.42\ \text{G} = 0.42 \times 10^{-4}\ \text{T}$$

The magnetic field at a distance R from the centre of the magnet on the normal bisector is given by the relation:

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

Where, μ_0 = Permeability of free space

$= 4\pi \times 10^{-7}\,\mathrm{T\,m\,A^{-1}}$

When the resultant field is inclined at 45° with earth's field, $B = H$

$$\therefore \quad \frac{\mu_0 M}{4\pi R^3} = \mathrm{H} = 0.42 \times 10^{-4}$$

$$R^3 = \frac{\mu_0 M}{0.42 \times 10^{-4} \times 4\pi}$$

$$= \frac{4\pi \times 10^{-7} \times 5.25 \times 10^{-2}}{4\pi \times 0.42 \times 10^{-4}} = 12.5 \times 10^{-5}$$

$$\therefore \quad R = 0.05\text{ m} = 5\text{ cm}$$

The magnetic field at a distanced R' from the centre of the magnet on its axis is given as:

$$B' = \frac{\mu_0 2M}{4\pi R^3}$$

$$\therefore \quad B' = H$$

$$\frac{\mu_0 2M}{4\pi (R')^3} = H$$

$$(R')^2 = \frac{\mu_0 2M}{4\pi \times H}$$

$$= \frac{4\pi \times 10^{-7} \times 2 \times 5.25 \times 10^{-2}}{4\pi \times 0.42 \times 10^{-4}} = 25 \times 10^{-5}$$

$$\therefore \quad R' = 0.063\text{ m} = \mathbf{6.3\text{ cm}}$$

The resultant field is inclined at 45° with earth's field.

S29. Time period of vibration is given by

$$T = 2\pi\sqrt{\frac{1}{MB_H}}$$

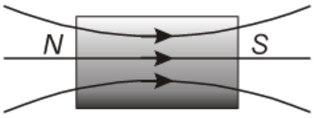
As the magnets are similar

$$T \propto \sqrt{\frac{1}{M}} \quad \text{or} \quad T \approx \frac{1}{\sqrt{m}}$$

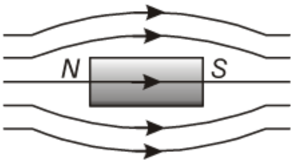
where m is the pole strength.

Higher is the pole strength, lesser will be the time period. Thus, the magnet vibrating faster is stronger.

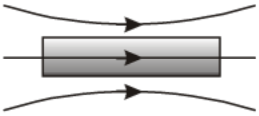
S30.



Nickel



Antimony



Aluminium

The modifications are shown in figure. It happens because

(a) nickel is a ferromagnetic substance

(b) antimony is diamagnetic substance

(c) aluminium is a paramagnetic substance.

S31. (a)

$$\tau = mB \sin\theta$$

Here, $\theta = 30°$

Thus,

$$0.016 = m \times (800 \times 10^{-4}) \times \frac{1}{2}$$

$$m = 0.40\ \text{Am}^2$$

(b) $\theta = 0°$ corresponds to stable position and

$\theta = 180°$ corresponds to unstable position

Work done is

$$W = U_m\ (\theta = 180°) - U_m(\theta = 0°)$$

$$= 2\ MB = 0.064\ \text{J}$$

(c)

$$M_s = NIA$$

$$I = \frac{M_s}{NA} = \frac{0.40}{1000 \times 2 \times 10^{-4}}$$

$$I = 2\ \text{A}$$

S32. Magnetic permeability. The ratio of magnetic induction (B) and magnetising field (H) for a given specimen is known as magnetic permeability

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

For diamagnetic substance, $0 < \mu < 1$

For paramagnetic substance, $1 < \mu <$ a small.

No greater than 1

For ferromagnetic substance, $\mu >> 1$

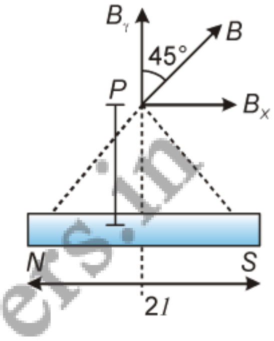
Two characteristics of material used for making permanent magnets are

- High coercitivity
- High retentivity and high hysteresis loss.

S33. (a) For resultant field $\vec{B}$ to be inclined at 45° to the Earth's magnetic field

$$B_X = B_Y \text{ (Earth's field)}$$

Here B_X is the magnetic field due to magnet



i.e., $B_X = \dfrac{\mu_0 2M}{4\pi r^3}$

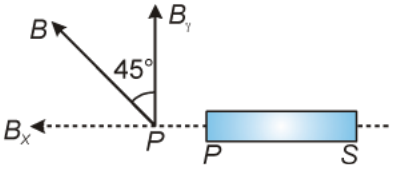
or $B_Y = \dfrac{\mu_0 M}{4\pi r^3}$

($\because$ $r >> l$)

$$r^3 = \frac{4\pi \times 10^{-7} \times 5.25 \times 10^{-2}}{4\pi \times 0.42 \times 10^{-4}}$$

$$r = 0.05 \text{ cm}$$

(b) *i.e.*, $B_X = \dfrac{\mu_0 2M}{4\pi r^3}$



or $B_X = B_Y$ (Earth's field)

$$r^3 = \frac{\mu_0 2M}{4\pi B_Y}$$

$$= \frac{4\pi \times 10^{-7} \times 2 \times 5.25 \times 10^{-2}}{4\pi \times 0.42 \times 10^{-4}}$$

$$r = 6.3 \text{ cm}$$

S34. At the neutral point on equatorial line of a short magnet,

$$B_H = \frac{\mu_0}{4\pi} \cdot \frac{M}{r^3}$$

or $$M = \frac{4\pi}{\mu_0}(B_H . r^3)$$

$$= \frac{0.38 \times 10^{-4} \times (12.5 \times 10^{-2})^3}{10^{-7}} = \mathbf{0.74\ Am^2}.$$

(a) Now, $$B_{axial} = \frac{\mu_0}{4\pi} \cdot \frac{2M}{r^3}$$

$$= \frac{10^{-7} \times 2 \times 0.74}{(12.5 \times 10^{-2})^3} = 0.76 \times 10^{-4}\ T = \mathbf{0.76\ G}.$$

Since at point on the axial line, B_H and B_{axial} are in the same direction, total magnetic field,

$$B = B_{\text{axial}} + B_H$$
$$= 0.76 + 0.38 = \mathbf{1.14\ G}.$$

(b) When the magnet is turned throught180°, neutral points will be obtained on axial line.

Now, at the neutral point on axial line of a short magnet,

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

or $$r^3 = \frac{\mu_0}{4\pi} \cdot \frac{2M}{B_H}$$

or $$r^3 = \frac{10^{-7} \times 2 \times 0.74}{0.38 \times 10^{-4}}$$

or $$r^3 = 3.895 \times 10^{-3}$$

or $$r = 0.157\text{ m} = \mathbf{15.7\ cm}.$$

S35. The magnetic susceptibility of a magnetic substance is defined as the ratio of the intensity of magnetisation to the magnetic intensity. It is denoted by χ_m.

Therefore, $$\chi_m = \frac{I}{H}$$

It has no units.

(a) $-\infty < \chi_m < 0 \Rightarrow$ diamagnetic material

(b) $0 < \chi_m < \varepsilon$ (ε stands for a small positive number)

⇒ Paramagnetic substance

(i) Relative permeability of diamagnetic material

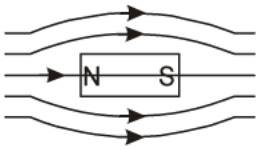
$$\mu = \frac{B}{H'} \qquad \text{where, } 0 < \mu < 1$$

For paramagnetic substance

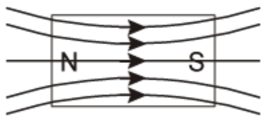
$$\mu = 1$$

But, m is not very large.

(ii)



Diamagnetic substance

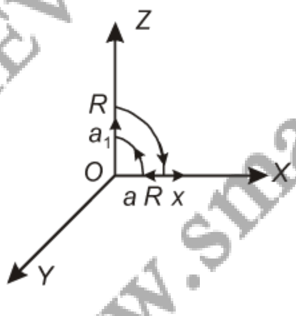


Paramagnet substance

S36. (a) Along z-axis

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

$$\int_a^R B.dl = \frac{\mu_0}{4\pi}2m\int_a^R \frac{dZ}{z^3} = \frac{\mu_0 m}{2\pi}\left(-\frac{1}{2}\right)\left(\frac{1}{R^2}-\frac{1}{a^2}\right)$$



(b) Along the quarter circle of radius R

$$B_\phi = \frac{\mu_0}{4\pi}\frac{-m.\hat{\theta}}{R^3} = \frac{-\mu_0}{4\pi}\frac{m}{R^3}(-\sin\theta)$$

$$B.dl = \frac{\mu_0 m}{4\pi R^2}\sin\theta d\theta$$

$$\int_0^{\frac{\pi}{2}} \vec{B}.\vec{dl} = \frac{\mu_0 m}{4\pi R^2}\int_0^{\frac{\pi}{2}}\sin\theta d\theta = \frac{\mu_0 m}{4\pi R^2}.$$

(c) Along x-axis

$$B = \frac{\mu_0}{4\pi}\left(\frac{-m}{x^3}\right)$$

$$\int B.dl = 0.$$

(d) Along the quarter circle of radius a

$$B.dl = \frac{-\mu_0 m}{4\pi a^2}\sin\theta\, d\theta$$

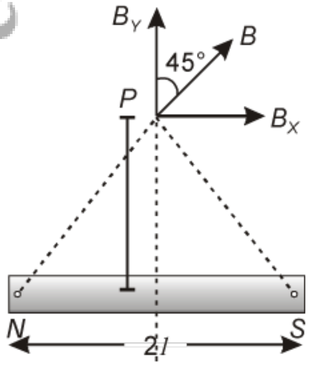
$$\int B.dl = -\frac{-\mu_0 m}{4\pi a^2}\int_0^{\frac{\pi}{2}}\sin\theta\, d\theta = \frac{-\mu_0 m}{4\pi a^2}$$

Add $\oint_C B.dl = 0.$

S37. Given: $M = 2.25 \times 10^{-2}\,\text{JT}^{-1}$.

(a) For resultant field $\vec{B}$ to be inclined at 45° to the earth's magnetic field

$$B_X = B_Y \quad \text{(earth's field)}$$



Here B_X is the magnetic field due to magnet

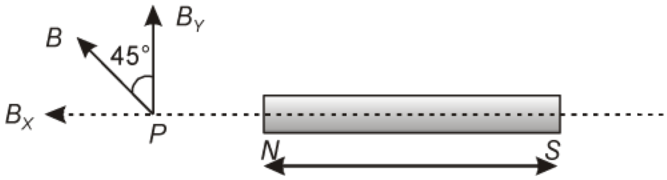
i.e., $B_X = \frac{\mu_0 2M}{4\pi r^3}$

or $B_Y = \frac{\mu_0 M}{4\pi r^3}$ $(\because\ r >> l)$

$$r^3 = \frac{4\pi \times 10^{-7} \times 2.25 \times 10^{-2}}{4\pi \times 0.21 \times 10^{-4}} = 33134.52$$

$r =$ **32.12 m**.

(b) *i.e.*, $B_X = \frac{\mu_0 2M}{4\pi r^3}$

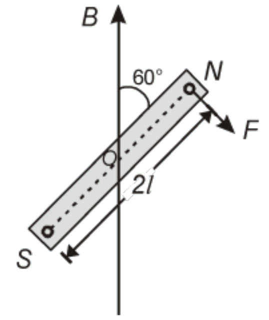


or $$B_X = B_Y \quad \text{(earth's field)}$$

$$r^3 = \frac{\mu_0 2M}{4\pi B_Y} = \frac{4\pi \times 10^{-7} \times 2 \times 2.25 \times 10^{-2}}{4\pi \times 0.21 \times 10^{-4}} = 1.07 \times 10^{-4}$$

$$r = \mathbf{0.0475\ m}.$$

S38. The circular coil carrying current is placed on the axis of the magnet as shown in the figure below:



Here, $a = 0.002\,\text{m}$, $I = 2\,\text{A}$; $2l = 0.1\,\text{m}$; $r = 0.15\,\text{m}$ and $M = 10^5\,JT^{-1}$.

Therefore, pole strength of the magnet,

$$m = \frac{M}{2l} = \frac{10^5}{0.1} = 10^6\,\text{Am}$$

Magnetic field at a distance x from the centre of a current carrying coil of radius a,

$$B = \frac{\mu_0}{4\pi} \cdot \frac{2\pi I a^2}{x^3} \qquad (a \ll x)$$

If B_1 and B_2 are magnetic fields due to the coil at the north and south poles of the magnet, then force on the magnet due to the coil,

$$F = mB_2 - mB_1$$

According to Newton's third law, magnet will exert an equal and opposite force on the coil. Therefore, force on the coil due to the magnet,

$$F = mB_1 - mB_2 = m(B_1 - B_2)$$

$$= m\left[\frac{\mu_0}{4\pi} \cdot \frac{2\pi I a^2}{(r-l)^3} - \frac{\mu_0}{4\pi} \cdot \frac{2\pi I a^2}{(r+l)^3}\right]$$

$$= \frac{\mu_0}{4\pi} \cdot 2\pi I a^2 m \left[\frac{1}{(r-l)^3} - \frac{1}{(r+l)^3}\right]$$

$$= 10^{-7} \times 2\pi \times 2 \times (0.002)^2 \times 10^6$$

$$\times \left[\frac{1}{(0.15-0.05)^3} - \frac{1}{(0.15+0.05)^3}\right]$$

$$= 5.027 \times 10^{-6}(1{,}000 - 125) = \mathbf{4.4 \times 10^{-3}\ N}.$$

Date: 20/10/2021

Q1. Is the permeability of a ferromagnetic material independent of the magnetic field? If not, is it more for lower or higher fields?

Q2. Magnetic field lines are always nearly normal to the surface of a ferromagnet at every point. (This fact is analogous to the static electric field lines being normal to the surface of a conductor at every point.) Why?

Q3. Would the maximum possible magnetisation of a paramagnetic sample be of the same order of magnitude as the magnetisation of a ferromagnet?

Q4. Explain qualitatively on the basis of domain picture the irreversibility in the magnetisation curve of a ferromagnet.

Q5. 'A system displaying a hysteresis loop such as a ferromagnet, is a device for storing memory?' Explain the meaning of this statement.

Q6. What kind of ferromagnetic material is used for coating magnetic tapes in a cassette player, or for building 'memory stores' in a modern computer?

Q7. A certain region of space is to be shielded from magnetic fields. How it can be done?

Q8. What is the characteristic property of a diamagnetic material?

Q9. What is meant by the non-magnetic material?

Q10. What is a diamagnetic substance? Give one example.

Q11. The permeability of a magnetic material is 0.9983. Name the type of magnetic materials it represents.

Q12. Give any two diamagnetic substances.

Q13. Write two properties of diamagnetic substances.

Q14. Steel is preferred for making permanent magnets where as soft iron is preferred for making electromagnets. Give one reason.

Q15. What happens, when a diamagnetic substances.

Q16. Which orientation of a magnetic dipole in a uniform magnetic field will correspond to its stable equilibrium?

Q17. A permanent magnet in the shape of a thin cylinder of length 10 cm has $M = 10^6$ A/m. Calculate the magnetisation current I_M.

Q18. The diamagnetism, in contrast, almost independent of temperature. Why?

Q19. Give two essential characteristics of a material used for preparing an electromagnet.

Q20. State two methods to destroy the magnetism of a magnet.

Q21. A ball of superconducting material is dipped in liquid nitrogen and placed near a bar magnet

(a) In which direction will it move?

(b) What will be the direction of it's magnetic moment?

Q22. What is reduction factor of galvanometer?

Q23. A proton has spin and magnetic moment just like an electron. Why then its effect is neglected in magnetism of materials?

Q24. The hysteresis loop of a soft iron piece has a much smaller area than that of a carbon steel piece. If the material is to go through repeated cycles on magnetisation, which piece will dissipate grater heat energy?

Q25. Why should the material used for making permanent magnets have high coercivity?

Q26. The soft iron is used in making the core of a transformer. Why?

Q27. In which material used in making the core of a transformer or a moving coil galvanometer .

Q28. The value of intensity of magnetisation is small positive for a specimen. Is it diamagnetic or paramagnetic or ferromagnetic?

Q29. From molecular view point, discuss the temperature dependence of susceptibility for diamagnetism, paramagnetism and ferromagnetism.

Q30. Why is the core of an electromagnet made of ferromagnetic materials?

Q31. Write two properties of a paramagnetic substance.

Q32. How does the intensity of magnetisation of a paramagnetic material vary with increasing applied magnetic field?

Q33. The material used for making permanent magnets have high coercivity. Why?

Q34. How does the magnetic induction of a paramagnetic material vary with temperature?

Q35. The coercivity be low for the material used for making electromagnets. Why?

Q36. Define the Curie point?

Q37. The steel is preferred to make permanent magnets. Why?

Q38. State Curie law in magnetism.

Q39. Name one metal each to make a permanent magnet and a temporary magnet.

Q40. Why does a paramagnetic sample display greater magnetisation (for the same magnetising field), when cooled?

Q41. Soft iron is used to make electromagnets. Why?

Q42. How can paramagnetic and diamagnetic materials be distinguished by studying their behavior in a magnetic field?

Q43. What type of magnetic material is used for making permanent magnets?

Q44. What is the coercivity ?

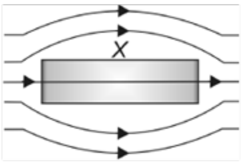
Q45. What are ferromagnetic materials? Give one example.

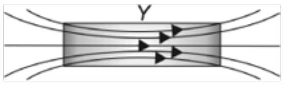
Q46. Give two properties of ferromagnetic substances.

Q47. Define the hysteresis.

Q48. What is retentivity?

Q49. When two materials are placed in an external uniform magnetic field, the behavior of magnetic field lines is as shown in figure.





Identify the magnetic nature of each of these two materials.

Q50. What are permanent magnets? Give one example.

Q51. Why do magnetic field lines prefer to pass through ferromagnetic substances (*i.e.*, iron) than through air?

Q52. What is the characteristic property of a diamagnetic material?

Q53. Steel is preferred for making permanent magnets whereas soft iron is preferred for making electromagnets. Give one reason.

Q54. A domain in ferromagnetic iron is in the form of a cube of side length 1 mm. Estimate the number of iron atoms in the domain and the maximum possible dipole moment and magnetisation of the domain. The molecular mass of iron is 55 g/mole and its density is 7.9 g/cm^3. Assume that each iron atom has a dipole moment of $9.27 \times 10\ \mathrm{A\,m^2}$.

Q55. Draw magnetic field lines when a

(a) diamagnetic,

(b) paramagnetic substance is placed in an external magnetic field, which magnetic property distinguishes this behaviour of the field lines due to the two substances?

Q56. (a) Write two characteristics of a material used for making permanent magnets.

(b) Why is core of an electromagnet made of ferromagnetic materials?

Q57. The susceptibility of a magnetic material is -2.6×10^{-5}. Identify the type of magnetic material and state its two properties.

Q58. Explain the following:

(a) Why do magnetic lines of force form continuous closed loops?

(b) Why are the field lines repelled (expelled) when a diamagnetic material is placed in an external uniform magnetic field?

Q59. The relative magnetic permeability of a magnetic material is 800. Identify the nature of magnetic material and state it's two properties

Q60. Define: (a) Hysteresis; (b) Retentivity and (c) Coercivity.

Q61. Distinguish between dia, para and ferro magnetic substances. Give one example of each.

Q62. The hysteresis loss for a specimen of iron weighing 10 kg is equivalent to 250 $\mathrm{J\,m^{-3}\,cycle^{-1}}$. Find the loss of energy per hour at 60 cycles $\mathrm{s^{-1}}$. Given, density of iron = 7,500 $\mathrm{kg\,m^{-3}}$.

Q63. Discuss Curie law in magnetism.

Q64. Define magnetic susceptibility of a material. Name two elements, one having positive susceptibility and the other having negative susceptibility. What does negative susceptibility signify?

Q65. Out of the following, identify the materials, which can be classified as (a) paramagnetic and (b) diamagnetic: Aluminium, bismuth, copper and sodium.
Write one property to distinguish between paramagnetic and diamagnetic materials.

Q66. Does the magnetisation of a paramagnetic salt depend on temperature? Give reason for your answer.

Q67. Give two points to compare the magnetic properties of steel and soft iron.

Q68. (a) How does a diamagnetic material behave when it is cooled to very low temperatures?
(b) Why does a paramagnetic sample display greater magnestisation when cooled? Explain.

Q69. (a) Write two characteristics of a material used for making permanent magnets?
(b) Why core made ferromagnetic material?

Q70. State, briefly, an afficient way of making a permanent magnet. Write two properties to select suitable materials for making permanent magnets.

Q71. Out of the following identify the materials which can be classified as (a) paramagnetic (b) diamagnetic
(i) Aluminium (ii) Bismuth (iii) Copper (iv) Sodium
Write one property to distinguish between paramagnetic and diamagnetic materials.

Q72. A monoenergetic (18 keV) electron beam initially in the horizontal direction is subjected to a horizontal magnetic field of 0.04 G normal to the initial direction. Estimate the up or down deflection of the beam over a distance of 30 cm ($m_e = 9.11 \times 10^{-31}$ kg)

[*Note: Data* in this exercise are so chosen that the answer will give you an idea of the effect of Earth's magnetic field on the motion of the electron beam from the electron gun to the screen in a TV set.]

Q73. (a) What happens when a diamagnetic substance is placed in a varying magnetic field?
(b) Name the properties of a magnetic material that make it suitable for making (i) a permanent magnet and (ii) a core of an electromagnet.

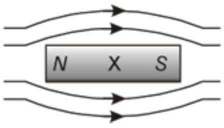
Q74. Distinguish between diamagnetic and ferromagnetic materials in respect of their: (a) intensity of magnetisation; (b) behavior in uniform magnetic field; (c) suscepbility

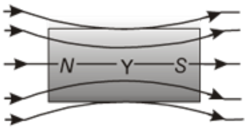
Q75. A sample of paramagnetic salt contains 2.0×10^{24} atomic dipoles each of dipole moment 1.5×10^{-23} J T^{-1}. The sample is placed under a homogeneous magnetic field of 0.64 T, and cooled to a temperature of 4.2 K. The degree of magnetic saturation achieved is equal to 15%. What is the total dipole moment of the sample for a magnetic field of 0.98 T and a temperature of 2.8 K? (Assume Curie's law)

Q76. (a) How does angle of dip change as one goes from magnetic pole to magnetic equator of the Earth?

(b) A uniform magnetic field gets modified as shown below when two specimens *X* and *Y* are placed in it. Identify whether specimens *X* and *Y* are diamagnetic, paramagnetic or ferromagnetic.

(c) How is the magnetic permeability of specimen *X* different from that of specimen *Y*?





Q77. Explain atomic theory of magnetism.

Q78. Three identical specimens of magnetic materials, Antimony, Aluminium, Nickel are kept in a non-uniform magnetic field. Draw the modification in the field lines in each case. Justify your answer.

Q79. Define the term magnetic permeability of a magnetic material. Write any two characteristics of a magnetic substance if it is to be used to make a permanent magnet. Give an example of such a material.

Q80. Classify materials on the basis of their behavior in a magnetic field. Under which category does iron come? How does the magnetic property of iron change with increase of temperature?

Q81. Explain the phenomenon of hysteresis in magnetic materials.

Q82. Distinguish between ferromagnetic, paramagnetic and diamagnetic materials. Give main properties of diamagnetic materials.

Q83. Classify materials on the basis of their behaviour in magnetic field. Explain the atomic origin of diamagnetism. Why diamagnetic substances are repelled by magnets?

Q84. (a) Distinguish the magnetic properties of diamagnetic, paramagnetic and ferromagnetic substances in terms of

(i) susceptibility, (ii) magnetic permeability and (iii) coercitivity

(b) Give one example of each of these materials. Draw the field lines due to an external magnetic field near a

(i) diamagnetic (ii) paramagnetic substance

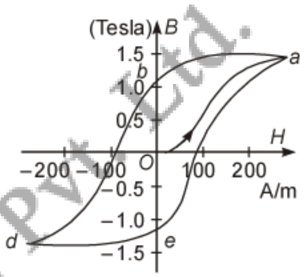
Date: 20/10/2021

S1. The permeability of ferromagnetic materials is not independent of the applied magnetic field. It is greater for a lower field and vice versa.

S2. The permeability of a ferromagnetic material is not less than one. It is always greater than one. Hence, magnetic field lines are always nearly normal to the surface of such materials at every point.

S3. The maximum possible magnetisation of a paramagnetic sample can be of the same order of magnitude as the magnetisation of a ferromagnet. This requires high magnetising fields for saturation.

S4. The hysteresis curve (*B*-*H* curve) of a ferromagnetic material is shown in the following figure.



It can be observed from the given curve that magnetisation persists even when the external field is removed. This reflects the irreversibility of a ferromagnet.

S5. The value of magnetisation is memory or record of hysteresis loop cycles of magnetisation. These bits of information correspond to the cycle of magnetisation. Hysteresis loops can be used for storing information.

S6. Ceramic is used for coating magnetic tapes in cassette players and for building memory stores in modern computers.

S7. A certain region of space can be shielded from magnetic fields if it is surrounded by soft iron rings. In such arrangements, the magnetic lines are drawn out of the region.

S8. When a diamagnetic material is placed inside magnetic field the magnetic field lines become slightly less dense in the diamagnetic material.

S9. Non-magnetic materials are those materials, which are not affected by the magnetic field.

S10. *Diamagnetic substance.* A substance, which when placed in a magnetic field gets feebly magnetised in a direction opposite to that of the magnetising field, is called diamagnetic substance.

Example: Zinc.

S11. Diamagnetic.

S12. (a) Marble; (b) Silver.

S13. When a rod of diamagnetic substance is suspended inside a magnetic field, it slowly sets itself at right angles to the direction of the field.

For a diamagnetic substance, the intensity of magnetisation (I) has a small negative value

S14. Because, the coercivity of steel is high and the soft iron is less.

S15. It moves from stronger part of the magnetic field to the weaker part.

S16. In stable equilibrium when dipole moment vector and magnetic field both are in same direction.

S17. Given, $H = 0$, $I = 0$, $M = 10^6$ and $l = 0.1$ m

$$Bl = \mu_0 Ml = \mu_0 (I + I_M)$$

$$Ml = I + I_M$$
$$I_M = Ml = 10^6 \times 0.1 = 10^5 \text{ A.}$$

S18. The atoms of a diamagnetic do not have intrinsic magnetic dipole moment. On placing a diamagnetic sample in a magnetic field, the magnetic moment of the sample is always opposite to the direction of the field. It is not affected by the thermal motion of the dipoles.

S19. (a) Less hysteresis losses of the material.

(b) High value of retentivity of the material.

S20. (a) By applying magnetic field in the reverse direction.

(b) By heating the magnet.

S21. (a) Away from the magnet.

(b) Magnetic moment is from left to right

S22. It is define as the amount of current required to produce at 45° deflection.

S23. We know,

$$\mu \approx \frac{e\hbar}{2m}$$

Where, e and $\hbar$ both are constant

Therefore, $\mu \propto \dfrac{1}{m}$

Hence,

$$\mu_e >> \mu_p \quad \text{because} \quad m_p >> m_e.$$

S24. A piece of carbon steel will dissipate a greater amount of heat energy as its hysteresis loop has greater area.

S25. Because, it is not get demagnetist easily.

S26. The area of the hysteresis loop for soft iron is very small. Since energy dissipated during a complete cycle of magnetisation and demagnetisation is proportional to the area of the hysteresis loop, a small amount of energy will be wasted, when the core of the transformer is made of soft iron.

S27. Soft iron is used in making the core of the galvanometer. It makes the magnetic field strong as magnetic field lines tend to cross through a ferromagnetic.

S28. Paramagnetic

S29. Diamagnetism is due to orbital motion of electrons developing magnetic moments opposite to applied field and hence is not much affected by temperature. Paramegnetism and ferromagnetism is due to alignments of atomic magnetic moments in the direction of the applied field. As temperature increases, this alignment is disturbed and hence susceptibilities of both decrease as temperature increases.

S30. It is because, the ferromagnetic materials possess a high value of relative permeability and a low value of retentivity.

S31. (a) For paramagnetic substances, the intensity of magnetisation (I) has a small positive value.

(b) The magnetic susceptibility (χ_m) of a paramagnetic substance has a small positive value.

S32. The intensity of magnetisation of a paramagnetic material increases directly with increase in the applied magnetic field.

S33. The magnetisation in the material having high coercivity is not easily destroyed, even if it gets exposed to stray reverse magnetic fields or when handled roughly.

S34. It decreases with the increase of temperature.

S35. The magnetisation in the material having low coercivity is easily destroyed, when the current passed through the windings of the electromagnet is switched off.

S36. It is the temperature for a ferromagnetic substance above which, it behaves as paramagnetic.

S37. It is because, steel (or alnico) has a large value of coercivity.

S38. The susceptibility of a ferromagnetic substance above its curie temperature is inversely proportional to the excess of temperature above the Curie temperature. It is called Curie-Weiss law.

S39. For permanent magnet : Steel

For temporary magnet : Soft iron.

S40. When cooled, the tendency of the thermal agitation to disrupt the alignment of magnetic dipoles decreases in case of paramagnetic materials. Hence, they display greater magnetisation.

S41. Soft iron is used to make electromagnets for the reason that the hysteresis loop for soft iron is narrow. Due to this, the loss of energy per unit volume is small, when soft iron is taken over complete cycle of magnetisation.

S42. In a non-uniform magnetic field, a paramagnetic substance will move from weaker part of the magnetic field to the stronger part, while a diamagnetic substance will move from stronger to weaker part of the field.

S43. For making permanent magnet, the material should possess a high value of both retentivity and coercivity.

S44. The value of reverses magnetising field required so as to reduce residual magnetism to zero, is called coercivity of the material.

S45. Ferromagnetic material. Those substances, which when placed in a magnetic field are strongly magnetised in the direction of the magnetising field, are called ferromagnetic substances.

Example: Iron.

S46. (a) The ferromagnetic materials move from weaker part of the magnetic field to the stronger part.

(b) When a ferromagnetic material is placed inside a magnetic field, the magnetic field lines becomes highly dense in the ferromagnetic substance.

S47. The lag of intensity of magnetisation behind the magnetising field during the process of magnetisation and demagnetisation of a ferromagnetic material is called hysteresis.

S48. The value of the intensity of magnetisation of a material, when the magnetising field is reduced to zero, is called retentivity of the material.

S49. The material shown in figure is diamagnetic, while that shown in figure is ferromagnetic in nature.

S50. Permanent magnets are those magnets which have high retentivity and coercivity. The magnetization of permanent magnet is not easily destroyed even if it is handled roughly or exposed in stray reverse magnetic field. For example steel.

S51. The ferromagnetic substances have relative permeability quite greater than 1. Therefore, the magnetic field lines prefer to pass through them.

S52. Diamagnetic material acquired feeble magnetisation in the opposite direction of the magnetic field when they are placed in an external magnetic field.

S53. Steel is preferred for making permanent magnets because steel have high coercitivity and soft iron is preferred for making electromagnets because it have high retentivity.

S54. The volume of the cubic domain is

$$V = (10\ \text{m}^{-3})^3\ \text{m}^3 = 10^{-9}\ \text{m}^3$$

Its mass is volume $\times$ density $= 7.9\ \text{g cm}^{-3} \times 10^{-9}\ \text{cm}^3 = 7.9 \times 10^{-9}\ \text{g}$

It is given that Avagadro number (6.023×10^{23}) of iron atoms have a mass of 55 g. Hence, the number of atoms in the domain is

$$N = \frac{7.9 \times 10^{-9} \times 6.023 \times 10^{23}}{55}$$

$$= 8.65 \times 10^{13}\ \text{atoms}$$

The maximum possible dipole moment m_{max} is achieved for the (unrealistic) case when all the atomic moments are perfectly aligned.

Thus, $$m_{\text{max}} = (8.65 \times 10^{13}) \times (9.27 \times 10^{-24})$$

$$= 8.0 \times 10^{-10}\ \text{A m}^2$$

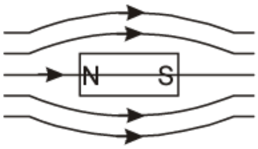
The consequent magnetisation is

$$M_{\text{max}} = m_{\text{max}} / \textit{Domain volume}$$

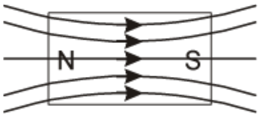
$$= 8.0 \times 10^{-10}\,\text{A m}^2/10^{-18}\,\text{m}^3$$

$$= 8.0 \times 10^{8}\,\text{A m}^{-1}.$$

S55. (a) Diamagnetic material



(b) Paramagnetic material



S56. (a) The making permanent magnet has **high coercivity** and **high retentivity**.

(b) Because it has **high permeability** and **low permeability**.

S57. As the susceptibility is –ve or very small, we conclude that material is diamagnetic.

Two properties:

(a) They have tendency to move from stronger to weaker part of the external magnetic field.

(b) Get feebly magnetised in a direction opposite to that of the applied magnetic field.

S58. (a) Net magnetic flux through any closed surface is zero.

(b) Diamagnetic material gets magnetised in a direction opposite to the direction of external magnetic field.

S59. Nature of magnetic material: Ferromagnetic.

Two properties:

(a) Get strongly magnetised when placed in an external magnetic field.

(b) Have strong tendency to move from a region of weak magnetic field to strong magnetic field *i.e.*, they get strongly attracted to a magnet.

S60. (a) **Hysteresis:** The phenomenon of lagging of the intensity of magnetisation (I) or magnetic induction (B) behind the magnetising field (H) when a specimen of a magnetic material is subjected to a cycle of magnetisation is called *hysteresis*.

(b) **Retentivity:** After the magnetisation of a specimen is maximum, the intensity of magnetisation does not reduce to zero even if the magnetising field is reduced to zero. The value of the intensity of magnetisation of material, when the magnetising field is reduced to zero is called *retentivity* or *residual magnetism* of the material.

(c) **Coercivity:** The reduce the residual magnetism or retentivity of a magnetised material to zero, we have to apply some magnetic field in opposite direction. This value of the demagnetising field is called *coercivity* of the material.

S61. A diamagnetic is feebly magnetised in a direction opposite to the direction of magnetising field, whereas a paramagnetic is magnetised feebly and ferromagnetic strongly in the same direction as that of the field.

Examples: Diamagnetic Substances are Bismuth, Copper, Lead.,

Paramagnetic Substances are Aluminium, Sodium copper-sulphate

Ferromagnetic Substances are Iron, Cobalt, nickel.

S62. Given, hysteresis loss per unit volume per cycle

$$= 250\ \text{Jm}^{-3}\ \text{cycle}^{-1}$$

Time, t = 1 hour = 3,600s, frequency, ν = 60 cycles s^{-1}.

Therefore, number of hysteresis cycle in 1 hour,

$$N = \nu \times t = 60 \times 3{,}600 = 2.16 \times 10^5$$

Volume of the iron specimen,

$$V = \frac{\text{mass}}{\text{density}} = \frac{10}{7{,}500} = 1.33 \times 10^{-4}\text{m}^3$$

Hence, loss of energy in one hour,

$$W = \text{energy loss per unit volume per cycle} \times V \times N$$

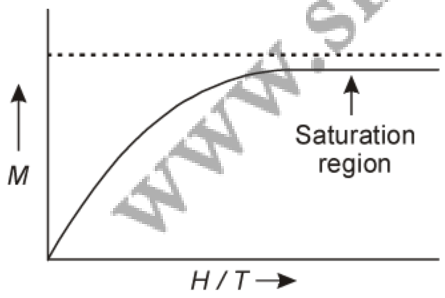
$$= 250 \times 1.3 \times 10^{-4} \times 2.16 \times 10^5 = \mathbf{7.182 \times 10^3\ J}.$$

S63. According to Curie law, the total magnetic moment $\vec{M}$ of a paramagnetic material is directly proportional to the strength ($\vec{H}$) of the externally applied magnetic field and inversely proportional to the temperature (T) of the material. That is,

$$M \propto \frac{H}{T} \quad \text{or} \quad M = C\frac{H}{T} \qquad \text{... (i)}$$

where C is a constant of proportionality. The variation of M with $\frac{H}{T}$ is shown in figure.

In the saturation region all the atomic dipoles of the material are completely aligned in the direction of the externally applied field



As, intensity of magnetisation $I \propto M$, therefore from Eq. (i)

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

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

or $$\chi_m \propto \frac{1}{T} \qquad \left(\because \ \chi_m = \frac{I}{H}\right)$$

This is another form of Curie law.

S64. (a) **Magnetic susceptibility (χ_m):**

It may be defined as the ratio of the intensity of magnetisation to the magnetic intensity of the magnetising field.

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

Positive susceptibility: paramagnetic material *e.g.*, Al, Ca.

Negative susceptibility: diamagnetic material e.g., Bi, Cu.

Negative susceptibility signifies that the material is diamagnetic in nature.

Alternatively:

Any one characteristics/property of diamagnetic materials.

S65. (a) **Paramagnetic materials:** Aluminium and sodium.

(b) **Diamagnetic materials:** Bismuth and copper.

A diamagnetic is feebly magnetised in a direction opposite to the direction of magnetising field, whereas a paramagnetic is magnetised feebly in the same direction as that of the field.

S66. Yes, the magnetisation of a paramagnetisation of a paramagnetic salt depends on temperature. The atoms of a paramagnetic material possess small magnetic dipole moments, but these atomic dipoles are randomly oriented. When an external magnetic field is applied, the magnetic dipoles try to align, but the thermal agitation hampers the alignment. Hence, the magnetisation of a paramagnetic salt depends on the temperature.

S67. (a) The area of the hysteresis loop for steel is larger than that for soft iron. On account of this, the loss of energy per unit volume in case of steel will be much larger as compared to that in case of soft iron, when they are taken over a complete cycle of magnetisation. For this reason, soft iron is used to make the core of a transformer.

(b) The coercivity for steel is very large as compared to that for soft iron. For this reason, steel is used to make the permanent magnets.

S68. (a) As the resistance (electrical of metal decreases with decrease in temperature).

But for diamagnetic substances the variation of susceptibility is very small *i.e.*, diamagnetic materials are unaffected by the change in temperature (except bismuth).

(b) Paramagnetic materials, when cooled, due to thermal agitation tendency alignment of magnetic dipoles decreases. Hence they shown greater magnetisation.

S69. (a) Two characteristics of material used for making permanent magnets are

- (i) High coercitivity.
- (ii) High retentivity and high hysteresis loss.

(b) Core of an electromagnet made of ferromagnetic material, because of its

- (i) low corecitivity
- (ii) low hysteresis loss

S70. Permanent magnet can be made by putting a steel rod inside the solenoid and a strong current is allowed to pass through solenoid. The strong magnetic field inside the solenoid magnetise the rod.

Two characteristics of material used for making permanent magnets are

- (a) High coercitivity.
- (b) High retentivity and high hysteresis loss.

S71. (a) **Paramagnetic substance:** Aluminium, sodium.

(b) **Diamagnetic substance:** Bismuth, copper.

The susceptibility of the diamagnetic materials is small and negative *i.e.*, $-1 < \chi_m < 0$, whereas for paramagnetic substance the susceptibility is small and positive *i.e.*, $0 < \chi_m < a$, where a is a small number.

S72. Energy of an electron beam, $E = 18\text{ keV} = 18 \times 10^3\text{ eV}$

Charge on an electron, $e = 1.6 \times 10^{-19}\text{ C}$

$$E = 18 \times 10^3 \times 1.6 \times 10^{-19}\text{ J}$$

Magnetic field, $B = 0.04\text{ G}$

Mass of an electron, $m_e = 9.11 \times 10^{-31}\text{ kg}$

Distance up to which the electron beam travels,

$$d = 30\text{ cm} = 0.3\text{ m}$$

We can write the kinetic energy of the electron beam as:

$$E = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{2E}{m}}$$

$$= \sqrt{\frac{2 \times 18 \times 10^{3} \times 1.6 \times 10^{-19} \times 10^{-15}}{9.11 \times 10^{-31}}}$$

$$= 0.795 \times 10^{8}\ \text{m/s}$$

The electron beam deflects along a circular path of radius, *r*.

The force due to the magnetic field balances the centripetal force of the path.

$$BeV = \frac{mv^2}{r}$$

$$\therefore \qquad r = \frac{mv}{Be}$$

$$= \frac{9.11 \times 10^{-31} \times 0.795 \times 10^{8}}{0.4 \times 10^{-4} \times 1.6 \times 10^{-19}} = 11.3\ \text{m}$$

Let the up and down deflection of the electron beam be $x = r(1 - \cos\theta)$.

Where, θ = Angle of declination

$$\sin\theta = \frac{d}{r} = \frac{0.3}{11.3}$$

$$\theta = \sin^{-1}\frac{0.3}{11.3} = 1.521°$$

and $x = 11.3\,(1 - \cos 1.521°)$

$= 0.0039$ m = **3.9 mm**

Therefore, the up and down deflection of the beam is 3.9 mm.

S73. (a) It tends to shift towards the weaker field.

(b) (i) **Permanent magnet:** Ferromagnetic materials with higher coercivity and higher retentivity.

(ii) **Core of an electromagnet:** Lesser retentivity and lesser coercivity in a ferro or paramagnetic materials.

S74.

Diamagnetic	*Ferromagnetic*
1. A diamagnetic substance, the intensity of magnetisation has small and negative value	1. A ferromagnetic material, the intensity of magnetisation has large positive value
2. When a diamagnetic material is placed inside the magnetic field line become slightly less in the diamagnetic material.	2. When ferromagnetic material is placed inside the magnetic field the line become highly dense in the ferromagnetic substance
3. The magnetic susceptibility χ_m of diamagnetic substance has small negative value.	3. The magnetic susceptibility χ_m of ferromagnetic material has large positive value.

S75. Number of atomic dipoles, $n = 2.0 \times 10^{24}$

Dipole moment of each atomic dipole, $M = 1.5 \times 10^{-23}\ \text{J T}^{-1}$

When the magnetic field, $B_1 = 0.64\ \text{T}$

The sample is cooled to a temperature, $T_1 = 4.2\ \text{K}$

Total dipole moment of the atomic dipole, $M_{\text{tot}} = n \times M$

$$= 2 \times 10^{24} \times 1.5 \times 10^{-23}$$

$$= 30\ \text{J T}^{-1}$$

Magnetic saturation is achieved at 15%.

Hence, effective dipole moment, $M = \frac{15}{100} \times 30 = 4.5\ \text{J T}^{-1}$

When the magnetic field, $B_2 = 0.98\ \text{T}$

Temperature, $T_2 = 2.8\ \text{K}$

Its total dipole moment = M_2

According to Curie's law, we have the ratio of two magnetic dipoles as:

$$\frac{M_2}{M_1} = \frac{B_2}{B_1} \times \frac{T_1}{T_2}$$

$$\therefore \quad M_2 = \frac{B_2 T_1 M_1}{B_1 T_2}$$

$$= \frac{0.98 \times 4.2 \times 4.5}{2.8 \times 0.64} = \mathbf{10.335\ JT^{-1}}$$

Therefore, 10.335 JT^{-1} is the total dipole moment of the sample for a magnetic field of 0.98 T and a temperature of 2.8 K.

S76. (a) Since B_V gets reduced as one moves from the poles to the equator, the value of the angle of dip decreases.

(b) $X \rightarrow$ Expulsion of field, so diamagnetic.

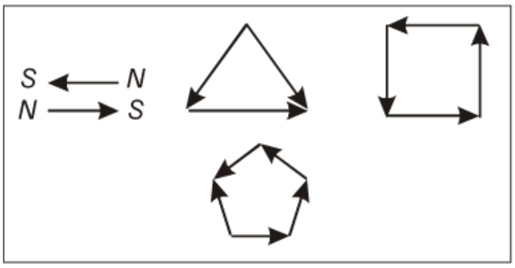
$Y \rightarrow$ Field is pulled in, so ferromagnetic.

(c) Magnetic permeability of X is less than 1 and that of Y is very much greater than 1.

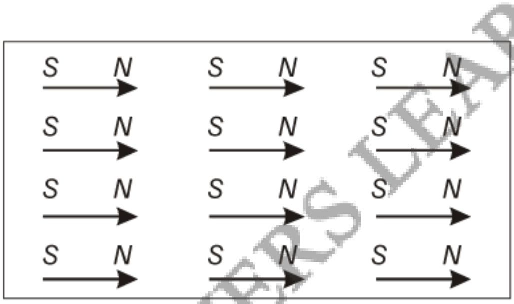
S77. **According to atomic theory of magnetism:**

(a) Each molecule of a magnetic substance is a complete magnet in itself, having a north pole and a south pole of equal strength.

(b) In an unmagnetised substance, the molecular magnets are randomly oriented such that they form closed chains, as shown in figure. In the chains, the north pole of one molecular magnet cancels the effect of south pole of the other so that the net magnetism is zero.



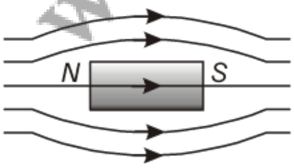
(c) On magnetising the substance, the molecular magnets align themselves in such a manner that north poles of all molecular magnets point in one direction and south poles of all molecular magnets point in the opposite direction, as shown in the figure.



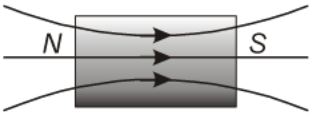
(d) When the alignment of molecular magnets is complete, the substance is fully magnetised *i.e.*, it is saturated.

(e) On heating the magnetised specimen, molecular magnets acquire kinetic energies and therefore their random thermal motion increase. This disturbs the alignment of molecular magnets resulting in a reduction of magnetisation *i.e.*, causes demagnetisation.

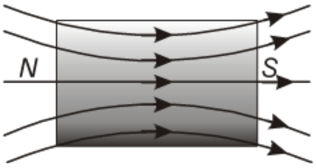
S78. Antimony is diamagnetic material permeability is less than unity, so it repels magnetic lines of force.



Alunimium is paramagnetic material permeability is greater than unity, so it attracts magnetic lines of force.



Nickel is ferromagnetic material permeability is very large in comparison to the paramagnetic material. Thus, it has greater tendency to attract magnetic lines of force.



S79. **Magnetic permeability:** It is a measure of extent of which magnetic field influence can pass through a material.

Two characteristics (any two):

1. Material should have high retentivity.
2. Material should have high coercivity.
3. Material should have high permeability.

A suitable material for permanent magnet is alnico.

S80. On the basis of their behavior in a magnetic field, the materials are classified into the following three categories:

(a) **Diamagnetic materials:** These materials are feebly repelled by a magnet and when placed in a magnetic field get weakly magnetised in a direction opposite to that of external magnetic field. Permeability of diamagnetic substances is always less than unity but never negative. Susceptibility of diamagnetic substance is negative.

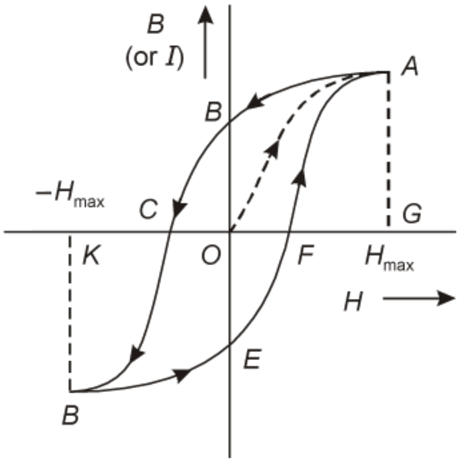
(b) **Paramagnetic materials:** These materials are weakly attracted by a magnet and when placed in a magnetic field they are feebly magnetised in the direction of the external field. Permeability of paramagnetic substances is slightly greater than unity. Susceptibility of these substances have a small positive value.

(c) **Ferromagnetic materials:** These materials are strongly attracted by magnets and when placed in a magnetic field get strongly magnetised in the direction of the field. These materials show strong magnetic properties. Permeability of ferromagnetic materials is very large (in thousands). Susceptibility has large positive value.

Iron is a ferromagnetic material.

The magnetic property of iron decreases with increase of temperature due to increased random thermal motion of atomic dipoles.

S81. When a ferromagnetic specimen (*e.g.*, piece of soft iron) is placed in a magnetic field, it gets magnetised due to induction (as shown in the figure below). The variation of the magnetic induction B with the magnetising field H. The magnetising field is increased from zero to H_{max}, then decreased to zero, reversed in direction and made H_{max} and finally brought to zero. This is called magnetisation cycle. The magnetic induction (B) follows the path $ABCDEFA$. This curve is called *hysteresis curve* or B-H curve of the ferromagnetic specimen.



Through the cycle, magnetic induction (or intensity of magnetisation) lags behind the magnetising field. This phenomenon of lagging of magnetic induction (or magnetisation) behind the magnetising field is called *hysteresis*.

The Magnetic induction (*OB* in figure) present in the specimen even if the magnetising field *H* is reduced to zero is known as *retentivity* or *residual magnetism* of the specimen.

As evident in figure, reduce the magnetisation of the sample to zero, we have to apply a magnetising field (*OC* in figure) in the opposite direction. This value of the magnetising field is called *coercivity* of the specimen.

S82.

Diamagnetic substances	*Paramagnetic substance*	*Ferromagnetic substances*
1. These materials are weakly repelled by a magnet.	1. These materials are weakly attracted by a magnet.	1. These materials are strongly attracted by a magnet.
2. When a rod of diamagnetic substance is suspended freely in a magnetic field, it aligns perpendicular to the field.	2. When a rod of paramagnetic substance is suspended freely in a magnetic field, it aligns itself along the direction of the field.	2. When a rod of ferromagnetic substance is suspended freely in a magnetic field, it aligns itself along the direction of the field.
3. Permeability is always less than unity but never negative.	3. Permeability is slightly greater than unity.	3. Permeability is very large (in thousands).
4. Susceptibility is negative.	4. Susceptibility has small positive value.	4. Susceptibility is very large (positive).

(a) A diamagnetic substance is feebly repelled by a magnet.

(b) When a rod of diamagnetic substance is suspended inside a magnetic field, it slowly sets itself at right angles to the direction of the field.

(c) If a diamagnetic liquid contained in a watch glass is placed on two closely spaced pole-pieces of a magnet, it suffers slight depression in the middle. However, the liquid shows a rise in the middle, when the pole-pieces are moved apart.

(d) For a diamagnetic substance, the intensity of magnetisation (I) has a small negative value.

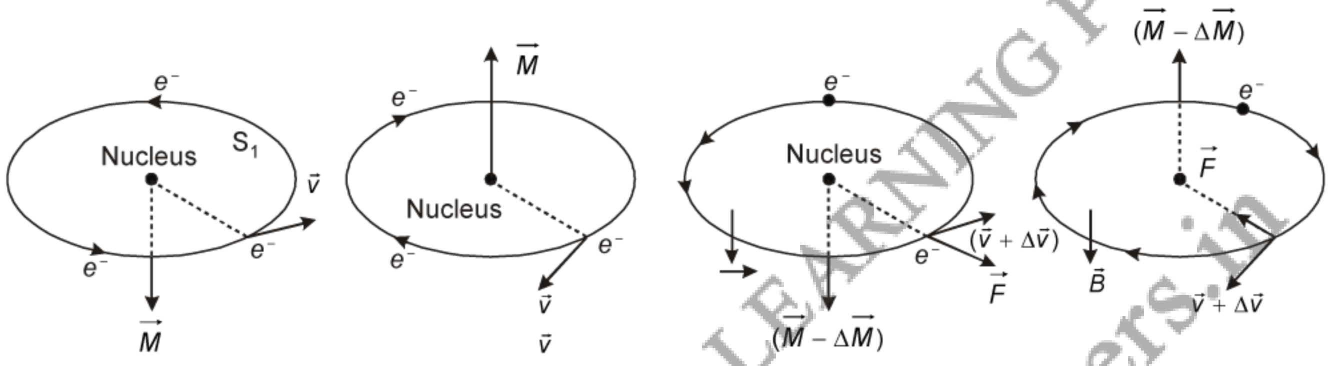
S83. On the basis of their behaviour in a magnetic field, the materials are classified into the following three categories:

(a) **Diamagnetic materials:** These materials are feebly repelled by a magnet and when placed in a magnetic field get weakly magnetised in a direction opposite to that of external magnetic field. Permeability of diamagnetic substances is always less than unity but never negative. Susceptibility of diamagnetic substance is negative.

(b) **Paramagnetic materials:** These materials are weakly attracted by a magnet and when placed in a magnetic field they are feebly magnetised in the direction of the external field. Permeability of paramagnetic substances is slightly greater than unity. Susceptibility of these substances have a small positive value.

(c) **Ferromagnetic materials:** These materials are strongly attracted by magnets and when placed in a magnetic field get strongly magnetised in the direction of the field. These materials show strong magnetic properties. Permeability of ferromagnetic materials is very large (in thousands). Susceptibility has large positive value.

In atoms of diamagnetic materials (*e.g.*, bismuth, lead, mercury, tin, etc.), the atomic magnetic moments due to orbital motion of electrons are randomly directed and they cancel out each other. Therefore, there is no net magnetism *i.e.* the net magnetic moment is zero (see the given figures (a) and (b))



(*a*) (*b*) (*c*) (*d*)

Suppose a diamagnetic material is placed in a magnetic field *B*, applied perpendicular to the plane of the paper directed inward. Each electron will experience a force = *Bev* (*v*-velocity of electron) directed always from the centre in the situation shown in the given figure (*c*) and towards the centre in the situation shown in the given figure (*d*). The velocity of electron in the former case reduces to v-Δv and in the later case increases to $v + \Delta v$. Correspondingly, the magnetic moment in the former case becomes $M - \Delta M$ directed downward and $M + \Delta M$ in the later case directed upward. Thus, in the presence of a magnetic field, these two magnetic moments do not cancel each other and there is net magnetic moment in a direction opposite to that of the field. The magnetic moments due to all the electrons add up to produce a net moment in a direction opposite to that of the field. As a result, in an externally applied magnetic field, a diamagnetic material is weakly magnetised in a direction opposite to that of the field.

Due to this oppositely directed magnetisation, diamagnetic material has a tendency to move from stronger to weaker region of magnetic field *i.e.*, a diamagnetic magnetic substance is repelled by a magnet.

S84. (a) (i) **Susceptibility:**

Ferromagnetic materials – Very high positive.

Paramagnetic materials — positive small

Diamagnetic materials — negative

(ii) **Relative permeability:**

Ferromagnetic materials — Very high (*i.e.*, $\mu >> \mu_0$)

Paramagnetic materials — Greater than 1 (*i.e.*, $\mu > \mu_0$)

Diamagnetic materials — Smaller than 1 (*i.e.*, $\mu < \mu_0$)

(iii) **Coercitivity:**

Ferromagnetic materials — May be low or high

Paramagnetic materials — Very low

Diamagnetic material — Very low and opposite to that of paramagnetic materials.

(b) (i) The examples of paramagnetic, diamagnetic and ferromagnetic materials are *Al*, *Bi* and Fe respectively.

(ii)