Important Questions for Class 12

Physics

Chapter 5 - Magnetism and Matter

Very Short Answer Questions **1 Mark**

1. How does the intensity of magnetization of a paramagnetic material vary with increasing applied magnetic field?

Ans: The intensity of magnetization increases with the increase in applied magnetic field.

2. An iron bar magnet is heated to 1000^0C and then cooled in a magnetic field free space. Will it retain magnetism?

Ans: Curie temperature of iron is 770^0C. When it is heated to a very high temperature magnetism of iron is lost and does not retain its magnetism further.

3. How will the magnetic field intensity at the centre of a circular wire carrying current change, if the current through the wire is doubled and the radius of the coil is halved?

Ans: As $B = \frac{\mu_0}{4\pi}\frac{2\pi I}{r}$

$$\Rightarrow B' = \frac{\mu_0}{4\pi}\frac{2\pi(2I)}{r/2}$$

$$\Rightarrow B' = 4\left(\frac{\mu_0}{4\pi}\frac{2\pi I}{r}\right)$$

$$\Rightarrow B' = 4B$$

4. Can neutrons be accelerated in a cyclotron? Why?

Ans: No, neutrons cannot be accelerated in a cyclotron. This is because neutrons are neutral and cyclotrons can accelerate only charged particles.

5. What type of magnetic material is used in making permanent magnets?

Ans: Materials having high coercivity are used in making permanent magnets.

6. Which physical quantity has the unit Wb/m^2 ? Is it a scalar or a vector quantity?

Ans: Magnetic field has the unit Wb/m^2. It is a vector quantity.

Short Answer Questions **2 Marks**

1. 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 magnet, so as to align its magnetic moment:
(i) Opposite to the field direction?
Ans: We know that work done, $W = MB(\cos\theta_1 - \cos\theta_2)$
Here, $\theta_1 = 0^0$ and $\theta_2 = 180^0$
$\Rightarrow W = MB(\cos 0^0 - \cos 180^0)$
$\Rightarrow W = MB(1-(-1))$
$\Rightarrow W = 2MB$

(ii) Normal to the field direction?
Ans: Here, $\theta_1 = 0^0$ and $\theta_2 = 90^0$
$\Rightarrow W = MB(\cos 0^0 - \cos 90^0)$
$\Rightarrow W = MB$

2. An electron in the ground state of a hydrogen atom is revolving in an anti - clockwise direction in a circular orbit. The atom is placed normal to the electron orbit makes an angle of 30^0 in the magnetic field. Find the torque experienced by the orbiting electron?
Ans: In the above question it is given that:
Magnetic moment associated with electron $M = \frac{eh}{4\pi m_e}$
$\theta = 30^0$ and
$\tau = MB\sin\theta$
$\tau = \frac{eh}{4\pi m_e} B \times \sin 30^0 = \frac{eh}{8\pi m_e}$, which is the torque.

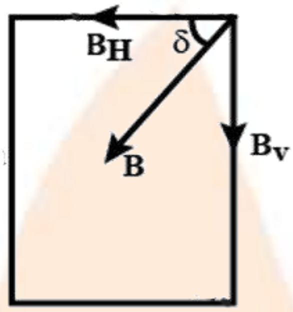
3. Define angle of dip. Deduce the relation connecting angle of dip and horizontal component of earth's total magnetic field with the horizontal direction.
Ans: We know that:

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

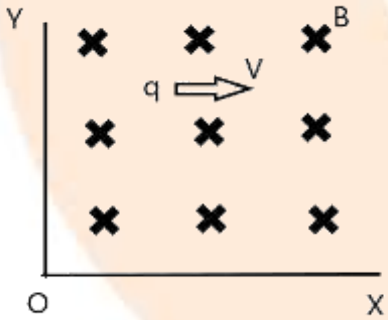
$$\frac{B_V}{B} = \sin\delta$$

$$\Rightarrow \frac{\sin\delta}{\cos\delta} = \frac{B_V}{B} \times \frac{B}{B_H}$$

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



4. A point charge +q is moving with speed perpendicular to the magnetic field B as shown in the figure. What should be the magnitude and direction of the applied electric field so that the net force acting on the charge is zero?



Ans: We know that:

Force on the charge due to magnetic field $= qVB\sin\theta$

Since $\vec{B} \perp$ to the plane of paper,

$F = qVB\sin 90^0$

$F = qVB$ (along OY)

Force on the charge due to electric field is:

$F = qE$

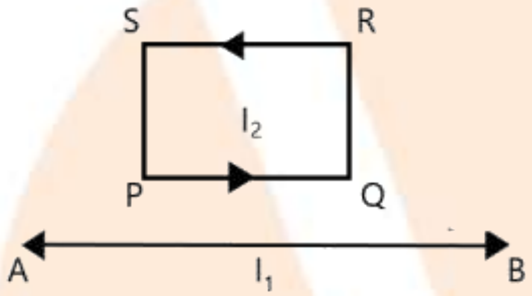
Net force on charge is zero if $qE = qVB$

$E = VB$ (along YO)

5. The energy of a charged particle moving in a uniform magnetic field does not change. Why?

Ans: The force on a charged particle in a uniform magnetic field always acts in a direction perpendicular to the motion of the charge. As the work done by the magnetic field on the charge is zero, hence energy of the charged particle will not change.

6. In the figure, straight wire AB is fixed; white the loop is free to move under the influence of the electric currents flowing in them. In which direction does the loop begin to move? Justify.



Ans: As the current in AB and arm PQ are in same direction therefore wire will attract the arm PQ with a force (say F_1). But repels the arm RS with a force (say F_2). Since arm PQ is closer to the wire AB, $F_1 > F_2$ i.e., the loop will move towards the wire.

7. State two factors by which voltage sensitivity of a moving coil galvanometer can be increased.

Ans: We know that:

$$\text{Voltage sensitivity } = \frac{nBA}{kr}$$

It can be increased by

(1) increasing B using powerful magnets.

(2) decreasing k by using a phosphor borne strip.

8. What is the magnetic moment associated with a coil of 1 turn, area of cross- section $10^{-4}m^2$ carrying a current of 2A?

Ans: We know that:

$$m = NIA$$

$$\Rightarrow m = 1 \times 10^{4} \times 2$$

$$\Rightarrow m = 2 \times 10^{4} Am^2$$

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

Ans: In the above question it is given that:

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, $I = 1.2\text{ A}$

The magnetic field is given by the relation:

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

Where,

$\mu_0 =$ Permeability of free space $= 4\pi \times 10^{-7}\,\text{TmA}^{-1}$

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

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

10. 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 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.

Ans: In the above question it is given that:

Angle of declination, $\theta = 12°$

Angle of dip, $\delta = 60^0$

Horizontal component of earth's magnetic field, $B_H = 0.16\text{ G}$

Earth's magnetic field at the given location $= B$

We can relate B and B_H as:

$$B_H = B\cos\delta$$

$$\Rightarrow B = \frac{B_H}{\cos\delta} = \frac{0.16}{\cos 60^0} = 0.32\text{G}$$

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 0.32G.

11. 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.

Ans: It is provided that,

The horizontal component of earth's magnetic field, $B_H = 0.35G$

The angle made by the needle with the horizontal plane (angle of dip) $= \delta = 22°$.

Earth's magnetic field strength is B.

We can relate B and B_H as: $B_H = B\cos\delta$

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

$$\Rightarrow B = \frac{0.35}{\cos 22°} = 0.377\text{G}$$

Clearly, the strength of earth's magnetic field at the given location is 0.377G.

12. If the solenoid in Exercise 5.5 is free to turn about the vertical direction and a uniform horizontal magnetic field of 0.25T is applied, what is the magnitude of torque on the solenoid when its axis makes an angle of $30°$ with the direction of the applied field?

Ans: Given is the magnetic field strength, $B = 0.25T$

Magnetic moment, $M = 0.6/T$

The angle, θ between the axis of the turns of the solenoid and the direction of the external applied field is $30°$.

Hence, the torque acting on the solenoid is given as:

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

$$\Rightarrow \tau = 0.6 \times 0.25\sin(30°)$$

$$\Rightarrow \tau = 7.5 \times 10^{-2}\text{J}$$

Hence the magnitude of torque is $= 7.5 \times 10^{-2}\text{J}$.

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

Ans: It is provided that the 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, $I = 3.0A$

A current-carrying solenoid is analogous to a bar magnet because a magnetic field develops along its axis, i.e., along its length joining the north and south poles.

The magnetic moment due to the given current-carrying solenoid is calculated as:

$$M = nIA = 800 \times 3 \times 2.5 \times 10^{-4} = 0.6\text{J/T}$$

Thus, the associated magnetic moment $=0.6\text{J}/\text{T}$

14. A short bar magnet placed with its axis at 30^0 with a uniform external magnetic field of 0.25 T experiences a torque of magnitude equal to $4.5\times10^{-2}\text{J}$. What is the magnitude of the magnetic moment of the magnet?

Ans: In the above question it is given that:

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

Torque on bar magnet, $\text{T}=4.5\times10^{-2}\text{J}$

Angle between the bar magnet external magnetic field, $\theta=30^0$

We know that:

$$\text{T}=\text{MB}\sin\theta$$

$$\Rightarrow \text{M}=\frac{\text{T}}{\text{B}\sin\theta}$$

$$\Rightarrow \text{M}=\frac{4.5\times10^{-2}}{0.25\sin30^0}=0.35\text{J}/\text{T}$$

Hence, the magnetic moment is $0.35\text{J}/\text{T}$.

Short Answer Questions **3 Marks**

1. A short bar magnet of magnetic moment 0.9 J/T is placed with its axis at 60^{o} to a uniform magnetic field. It experiences a torque of 0.063 Nm.

(i) calculate the strength of the magnetic field

Ans: As $\tau=\text{MB}\sin\theta$,

$\theta=60^0$

$\tau=0.063\text{ Nm}$

$\text{M}=0.9\text{ J}/\text{T}$

$$\text{B}=\frac{\tau}{\text{M}\sin\theta}=\frac{0.063}{0.9\sin60^0}=0.081\text{T}$$

(ii) What orientation of the bar magnet corresponds to the equilibrium position in the magnetic field?

Ans: The magnet will be in stable equilibrium in the magnetic field if $\tau=0$

$\Rightarrow \text{MB}\sin0^0=0$ i.e., When the magnet aligns itself parallel to the field.

2. A beam of electrons is moving with a velocity of $3\times10^6\text{m}/\text{s}$ and carries a current of $1\ \mu\text{A}$.

(a) How many electrons per second pass a given point?

Ans: We have $\text{I}=1\ \mu\text{A}=10^{-6}\text{A}$

And $n = \frac{I}{q} = \frac{10^{-6}}{1.6 \times 10^{-19}} = 6.25 \times 10^{12}$

(b) How many electrons are in 1m of the beam?

Ans: We know that electrons traverse a distance of $3 \times 10^{6}\,\text{m}$ per second.
Thus, number of electrons in one meter of the beam

$$= \frac{6.25 \times 10^{12}}{3 \times 10^{6}} = 2.08 \times 10^{6}\,\text{m}^{-1}$$

(c) What is the total force on all the electrons in 1m of the beam if it passes through the field of $0.1\text{NA}^{-1}\text{m}^{-1}$?

Ans: Force on one meter of the beam of electrons will be:

$$F = \frac{0.1}{10^{-6}} = 10^{5}\,\text{N}$$

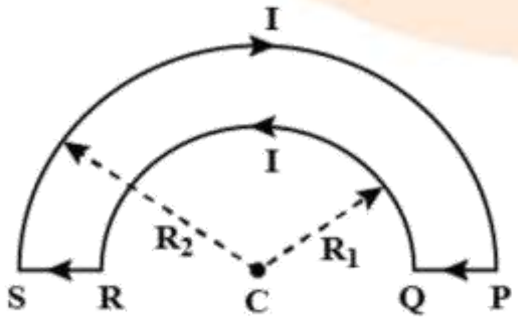
3. What is the main function of soft iron core used in a moving coil galvanometer? A galvanometer gives full deflection for Ig. Can it be converted into an ammeter of range $I < Ig$?

Ans: Soft iron core is used in the moving coil galvanometer because it increases the strength of the magnetic field and thus increases the sensitivity of the galvanometer.

We know that, $S = \frac{GI_g}{I - I_g}$

For $I < Ig$, S becomes negative. Clearly, it cannot be converted into an ammeter of range I < Ig.

4. Two wires loops PQRSP formed by joining two semicircular wires of different radii carry a current I as shown in the figure. What is the direction of the magnetic induction at the centre C.?



Ans: Magnetic field due to semicircle QR at C is

$$B_1 = \frac{1}{2}\frac{\mu_0}{4\pi}\frac{2\pi I}{R_1}$$

Magnetic field due to semicircle at C is

$$B_2 = \frac{1}{2}\frac{\mu_0}{4\pi}\frac{2\pi I}{R_2}$$

Net field,

$$B = B_1 - B_2$$

$$\Rightarrow B = \frac{2\pi I}{2}\frac{\mu_0}{4\pi}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\Rightarrow B = \frac{\mu_0 I}{4}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

5. A circular coil is placed in uniform magnetic field of strength 0.10T normal to the plane of coil. If current in the coil is 5.0A. Find.

(a) Total torque on the coil

Ans: We have:

$B = 0.10T$

$\theta = 0^0$ (Normal to plane of the coil)

$I = 5.0\text{ A}$, Area $= 10^{-5}\text{m}^2$, $n = 10^{29}/\text{m}^3$

$\tau = MB\sin\theta = MB\sin 0^0 = 0$, which is the required torque.

(b) Total force on the coil

Ans: Total force on the coil $= 0\text{N}$

(c) Average force on each electron due to magnetic field (The coil is made of copper wire of cross- sectional area and free electron density in copper is $10^{29}/m^3$)

Ans: We know that:

$$F_{av} = q\left(\vec{v}_d \times \vec{B}\right)$$

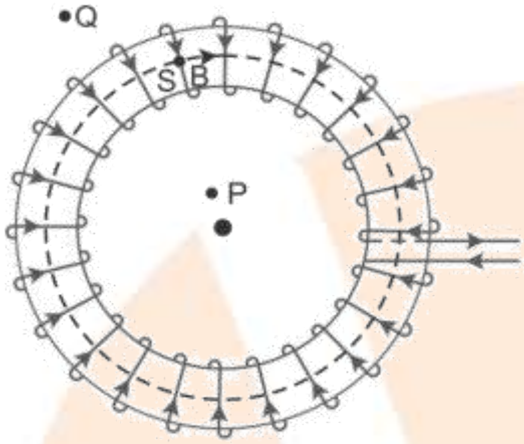
$$\left(I = neAv_d\right)$$

$$\Rightarrow F_{av} = q\left(\frac{qI}{neA} \times B\right)$$

$$\Rightarrow F_{av} = \frac{IB}{nA} = \frac{5 \times 0.10}{10^{29} \times 10^{-5}} = 5 \times 10^{-25}\text{N}$$

6. Using Ampere's circuital law, derive an expression for magnetic field along the axis of a Toroidal solenoid.

Ans: If n is the number of turns per unit length; I be the current flowing through the Toroid;



Then from Ampere's circuital law

$\oint \vec{B}.d\vec{l} = \mu_0 \times$ total current flowing through toroid

$\Rightarrow \oint \vec{B}.d\vec{l} = \mu_0 (2\pi rnI)$

$\Rightarrow \int_0^{2\pi r} Bdl\cos 0^0 = \mu_0 (2\pi rnI)$

$\Rightarrow B\int_0^{2\pi r} dl = \mu_0 (2\pi rnI)$

$\Rightarrow B.2\pi r = \mu_0 (2\pi rnI)$

$\Rightarrow B = \mu_0 nI$, which is the required magnetic field here.

7. A short bar magnet of magnetic moment $M = 0.32\,J/T$ 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 and would correspond to its

a) Stable equilibrium? What is the potential energy of the magnet in this case?

Ans: It is provided that moment of the bar magnet, $M = 0.32J/T$.

External magnetic field, $B = 0.15T$

It is considered as being in stable equilibrium, when the bar magnet is aligned along the magnetic field. Therefore, the angle θ, between the bar magnet and the magnetic field is $0°$.

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

$\Rightarrow -MB\cos(\theta) = -0.32 \times 0.15 \times \cos(0) = -4.8 \times 10^{-2} J$

Hence the potential energy is $=-4.8\times10^{-2}\,\text{J}$.

b) Unstable equilibrium? What is the potential energy of the magnet in this case?

Ans: It is provided that moment of the bar magnet, $M = 0.32\,\text{J/T}$

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

When the bar magnet is aligned opposite to the magnetic field, it is considered as being in unstable equilibrium, $\theta = 180°$

Potential energy of the system is hence $= -MB\cos(\theta)$

$\Rightarrow -MB\cos(\theta) = -0.32\times0.15\times\cos(180°) = 4.8\times10^{-2}\,\text{J}$

Hence the potential energy is $=4.8\times10^{-2}\,\text{J}$.

8. A closely wound solenoid of 2000 turns and area of cross-section $1.6\times10^{-4}\text{m}^2$, carrying a current of $4.0\,\text{A}$, is suspended through its centre allowing it to turn in a horizontal plane.

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

Ans: Given is the number of turns on the solenoid, $n = 2000$

Area of cross-section of the solenoid, $A = 1.6\times10^{-4}\text{m}^2$

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

The magnetic moment inside the solenoid at the axis is calculated as:

$M = nAI = 2000\times1.6\times10^{-4}\times4 = 1.28\text{Am}^2$

b) What is the force and torque on the solenoid if a uniform horizontal magnetic field of $7.5\times10^{-2}\text{T}$ is set up at an angle of $30°$ with the axis of the solenoid?

Ans: Provided that,

Magnetic field, $B = 7.5\times10^{-2}\text{T}$

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

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

$\Rightarrow \tau = 1.28\times7.5\times10^{-2}\sin(30°)$

$\Rightarrow \tau = 4.8\times10^{-2}\,\text{Nm}$

Given the magnetic field is uniform, and the force on the solenoid is zero. The torque on the solenoid is $4.8\times10^{-2}\,\text{Nm}$.

9. A circular coil of 16 turns and radius $10\,\text{cm}$ carrying a current of $0.75\,\text{A}$ rests with its plane normal to an external field of magnitude $5.0\times10^{-2}\,\text{T}$. 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 $2.0/s$. What is the moment of inertia of the coil about its axis of rotation?

Ans: It is provided that,

The number of turns in the given circular coil solenoid, $N = 16$

Radius of the coil, $r = 10cm = 0.1m$

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

Current in the coil, $I = 0.75A$

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

Frequency of oscillations of the coil, $\upsilon = 2.0/s$

Therefore, magnetic moment, $M = NAI = NI\pi r^2$

$\Rightarrow M = 16 \times 7.5 \times \pi \times 0.1^2$

$\Rightarrow M = 0.3777 J/T$

Frequency is given by the relation:

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

where,

$I =$ Moment of inertia of the coil

$$\Rightarrow I = \frac{MB}{4\pi^2 \nu^2}$$

$$\Rightarrow I = \frac{0.377 \times 5 \times 10^{-2}}{4\pi^2 \times 2^2}$$

$\Rightarrow I = 1.19 \times 10^{-4} kg\,m^2$

Clearly, the moment of inertia of the coil about its axis of rotation $1.19 \times 10^{-4} kg\,m^2$.

10. A short bar magnet has a magnetic moment of $0.48 J/T$. 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,

Ans: Provided that the magnetic moment of the given bar magnet, M is $0.48J/T$

Given distance, $d = 10cm = 0.1m$

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

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

here,

$\mu_0 =$ Permeability of free space $= 4\pi \times 10^{-7} Tm/A$

Substituting these values, B becomes as follows:

$$\Rightarrow B = \frac{4\pi \times 10^{-7}}{4\pi} \frac{2 \times 0.48}{0.1^3}$$

$$\Rightarrow B = 0.96 \times 10^{-4} T = 0.96 G$$

The magnetic field is $0.96G$ along the South-North direction.

b) the equatorial lines (normal bisector) of the magnet.

Ans: The magnetic field at a point which is $d = 10cm = 0.1m$ away on the equatorial part of the magnet is given as:

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

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

$$\Rightarrow B = 0.48 \times 10^{-4} T = 0.48G$$

The magnetic field is $0.48G$ along the North-South direction.

11. 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 $14cm$ 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, the field due to a magnet is equal and opposite to the horizontal component of earth's magnetic field).

Ans: Provided that,

The magnetic field of Earth at the given place, $H = 0.36G$

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

$$B_1 = \frac{\mu_0}{4\pi} \frac{2M}{d^3} = H$$

Here,

$\mu_0 =$ Permeability of free space $= 4\pi \times 10^{-7} Tm/A$

$M =$ The magnetic moment

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

$$B_2 = \frac{\mu_0}{4\pi} \frac{M}{d^3}$$

$\Rightarrow B_2 = H/2$ (comparing with B_1)
Therefore, the total magnetic field,
$B = B_1 + B_2$
$\Rightarrow B = H + H/2$
$\Rightarrow B = 0.36 + 0.18 = 0.54$
Clearly, the magnetic field is 0.54 G along the direction of earth's magnetic field.

12. 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 $0.33G$, and the angle of dip is zero. Locate the line of neutral points (ignore the thickness of the cable). (At neutral points, the magnetic field due to a current-carrying cable is equal and opposite to the horizontal component of earth's magnetic field.)

Ans: Provided that,
Current in the wire, $I = 2.5A$
The angle of dip at the location, $\delta = 0°$
The Earth's magnetic field, $H = 0.33G = 0.33 \times 10^{-4}T$
The horizontal component of earth's magnetic field is given as:
$H_H = H\cos\delta = 0.33 \times 10^{-4} \times \cos 0° = 0.33 \times 10^{-4}T$
The magnetic field at the neutral point at a distance R from the cable is given by the relation:

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

here, μ_0 = Permeability of free space $= 4\pi \times 10^{-7} Tm/A$

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

$$\Rightarrow R = \frac{4\pi \times 10^{-7}}{2\pi}\frac{2.5}{0.33 \times 10^{-4}} = 15.15 \times 10^{-3} m = 1.51cm$$

Clearly, a set of neutral points lie on a straight line parallel to the cable at a perpendicular distance of $1.51cm$ above the plane of the paper.

13. 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.

Ans: Provided that,
The number of turns in the given circular coil, $N = 30$
The radius of the given circular coil, $r = 12cm = 0.12m$
Current in the coil, $I = 0.35A$
Angle of dip, $\delta = 45°$
The magnetic field due to the current I, at a distance r, is given as:

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

here,
μ_0 = Permeability of free space $= 4\pi \times 10^{-7} Tm/A$

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

$$\Rightarrow B = 54.9 \times 10^{-4} T = 0.549G$$

The compass needle points West to East. Hence, the horizontal component of earth's magnetic field is given as:

$$B_H = B.\sin\delta$$

$$\Rightarrow B_H = 0.549 \sin 45° = 0.388G$$

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.

Ans: If the direction of the current flowing in the coil is reversed and if the coil is also rotated about its vertical axis by an angle of $90°$, the needle will rearrange and reverse its original direction. In the given case, the needle would point from East to West.

14. 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 $1.2 \times 10^{-2} T$. If the dipole comes to stable equilibrium at an angle of $15°$ with this field, what is the magnitude of the other field?

Ans: Provided that,
Magnitude of one of the magnetic fields, $B_1 = 1.2 \times 10^{-2} T$
Magnitude of the other magnetic field is B_2.
Angle between the above-mentioned two fields, $\theta = 60°$
At the state of stable equilibrium, the angle between the dipole and field B_1 is $\theta_1 = 15°$
Angle between the dipole and field B_2 is $\theta_2 = \theta - \theta_1 = 60° - 15° = 45°$

At a rotational equilibrium, the torques experienced by the dipole, due to both fields, must balance each other.
Therefore, torque due to field B_1 = Torque due to field B_2

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

Where,

M = Magnetic moment of the dipole

$$\Rightarrow B_2 = \frac{B_1 \sin\theta_1}{\sin\theta_2}$$

$$\Rightarrow B_2 = 4.39 \times 10^{-3} T$$

Clearly, the magnitude of the other magnetic field is $4.39 \times 10^{-3} T$.

15. The magnetic moment vectors μ_s and μ_l associated with the intrinsic spin angular momentum $\vec{S}$ and orbital angular momentum $\vec{l}$, 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.

Ans: According to the definition of magnetic moment-μ_l and orbital angular momentum-l.

Magnetic moment associated with the motion of the electron is:

$$\mu_l = iA = -(e/T).\pi r^2$$

And the corresponding angular momentum is:

$$l = mvr = m(2\pi r/T)r$$

Where r is the radius of the orbit, which the mass of electron is m and its charge $(-e)$ completes in time T.

Dividing μ_l by l, one would get:

$$\frac{\mu_l}{l} = \frac{-e}{T}.\pi r^2 \times \frac{T}{m^2 \pi r^2} = -\frac{e}{2m}$$

$$\Rightarrow \vec{\mu}_l = -\left(\frac{e}{2m}\right)\vec{l}$$

Evidently, it can be seen that $\vec{\mu}_l$ and $\vec{l}$ will be antiparallel (both being normal to the plane of the orbit).

In contrast, $\frac{\mu_s}{s}=\left(\frac{e}{m}\right)$ and it is derived on the basis of quantum mechanics and is verified experimentally.

Long Answer Questions **5 Marks**

1. A particle of mass m and charge q moving with a uniform speed normal to a uniform magnetic field B describes a circular path of radius & Derive expressions for
(1) Radius of the circular path (2) time period of revolution (3) Kinetic energy of the particle?
Ans: A particle of mass (m) and change (q) moving with velocity normal to describes a circular path if

$$\frac{mv^2}{r}=qBv\sin\theta$$

$$\Rightarrow \frac{mv^2}{r}=qBv\left(\because \theta=90^\circ\right)$$

$$\Rightarrow r=\frac{mv}{Bq} \quad \ldots\ldots (1)$$

This is the required radius of the circular path.
Now, since

$$\text{Time period of Revolution during circular path}=\frac{\text{Circumference of circle}}{\text{velocity}};$$

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

$$\Rightarrow T=\frac{2\pi r.m}{Bqr} \quad \ldots\ldots. \text{(from 1)}$$

$$\Rightarrow T=\frac{2\pi m}{Bq} \quad \ldots\ldots (2)$$

This is the required time period.
Now,

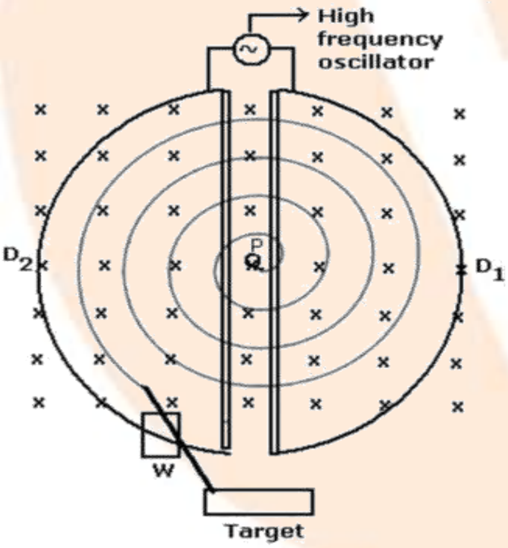
$$\text{Kinetic energy K.E}=\frac{1}{2}mv^2$$

$$\Rightarrow \text{K.E}=\frac{1}{2}m\left(\frac{Bqr}{m}\right)^2$$

$\Rightarrow K.E = \dfrac{B^2q^2r^2}{2m}$, which is the required kinetic energy.

2. Write an expression for the force experienced by the charged particle moving in a uniform magnetic field B with the help of labeled diagram explain the working of cyclotron. Show that cyclotron frequency does not depend upon the speed of the particle.

Ans: Force experienced by the charged particle moving at right angles to uniform magnetic field $\vec{B}$ with velocity $\vec{v}$ is given by $F = q\left(\vec{v}\times\vec{B}\right)$ Initially Dee D_1 is negatively charged and Dee D_2 is positively charged so, the positive ion will get accelerated towards Dee D_1. Since the magnetic field is uniform and acting at right angles to the plane of the Dees so the ion completes a circular path in D_1 when ions come out into the gap, polarity of the Dee's gets reversed and the ion is further accelerated towards Dee D_2 with greater speed and cover a bigger semi-circular path. This process is separated time and again and the speed of the ion becomes faster until it reaches the periphery of the dees where it is brought out by means of a deflecting plate and is made to bombard the target.



Since $F = qVB\sin 90^0$ provides the necessary centripetal force to the ion to cover a circular path so we can say $\dfrac{mv^2}{r} = qvB$

$$r = \frac{mv}{Bq} \qquad \ldots\ldots (1)$$

$$\text{Time period} = \frac{2\pi r}{v} = \frac{2\pi rm}{Bqr} = \frac{2\pi m}{Bq}$$

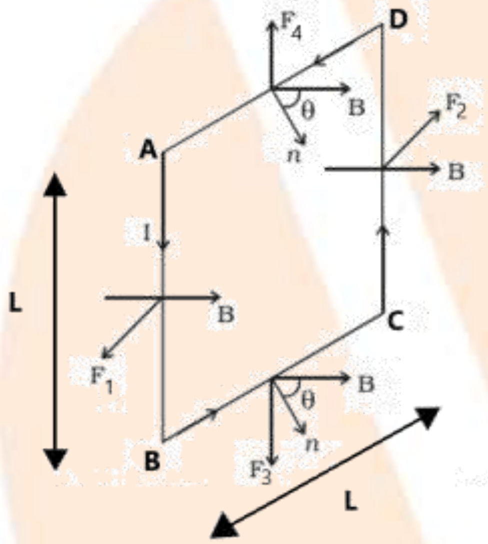
$$V=\frac{1}{T}=\frac{Bq}{2\pi m}$$

Thus, frequency is independent of velocity.

3.

(a) Obtain an expression for the torque acting on a current-carrying circular loop.

Ans: ABCD is a square loop of length (L) and area (A). Let I be the current flowing in the anticlockwise direction. Let θ be the angle between the normal to the loop and magnetic field $\vec{B}$.



Force acting on arm AB of the loop

$\vec{F}_1=I(\vec{L}\times\vec{B})(\text{outwards})$

Force on arm CD

$\vec{F}_2=I(\vec{L}\times\vec{B})(\text{inwards})$

Force on arm BC

$\vec{F}_3=I(\vec{L}\times\vec{B})(\text{downwards})$

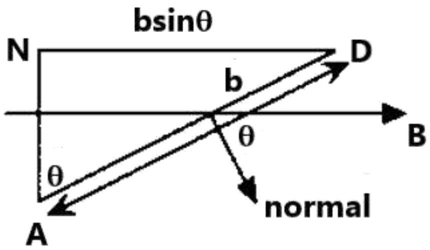
Force on arm DA

$\vec{F}_4=I(\vec{L}\times\vec{B})(\text{upwards})$

Since $\vec{F}_3$ and $\vec{F}_4$ are equal and opposite and also act along the same line, hence they cancel each other out.

$\vec{F}_1$ and $\vec{F}_2$ are also equal and opposite but their line of action is different, so they form a couple and make the rectangular loop rotate anti-clockwise.

Thus $\tau=$ either force $\times\ \perp$ distance



$\tau = I\left(\vec{L}\times\vec{B}\right)\times DN$

$\tau = I\left(\vec{L}\times\vec{B}\right)\times b\sin\theta$

$\tau = ILB\sin 90^0 \times b\sin\theta$

$\tau = IAB\sin\theta$

For loop of N turns

$\tau = NIAB\sin\theta$

$\tau = MB\sin\theta\left(\because M = NIA\right)$

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

Where M is magnetic moment of the loop.

(b) What is the maximum torque on a galvanometer coil 5 cm × 12 cm of 600 turns when carrying a current of 10^{-5} A in a field where flux density is $0.10\,Wb/m^2$?

Ans: It is known that

$\tau = NIAB\sin\theta$

Torque will be maximum when $\theta = 90^o$

$\tau_{max} = NIAB\left(\because \sin 90^0 = 1\right)$

$\tau_{max} = 600\times10^{-5}\times(0.10)\left(60\times10^{-4}\right) = 3.6\times10^{-6}\,Nm.$

4. The current sensitivity of a moving coil galvanometer increases by 20% when its resistance is increased by a factor of two. Calculate by what factor the voltage sensitivity changes?

Ans: We know that:

Current sensitivity, $\frac{\alpha}{I} = \frac{nBA}{k}$ …… (i)

Voltage sensitivity, $\frac{\alpha}{V} = \frac{nBA}{kr}$ …… (ii)

Resistance of a galvanometer increases when n and A are changed

Given $R' = 2R$

Then $n = n'$ and $A = A'$

New current sensitivity

$$\frac{\alpha'}{I'}=\frac{n'BA'}{k} \quad \ldots\ldots \text{(iii)}$$

New voltage sensitivity

$$\frac{\alpha'}{V}=\frac{\alpha'}{I'R'}=\frac{n'BA'}{2kr} \quad \ldots\ldots \text{(iv)}$$

Since, $\frac{\alpha'}{I'}=\frac{120\alpha}{100I}$ …… (v)

From (i) and (iii)

$$\frac{n'A'B}{R}=\frac{\alpha 120}{I100}$$

$$\frac{n'A'B}{R}=\frac{nAB120}{k100}$$

$$n'A'=\frac{6}{5}nA$$

Using equation (iv)

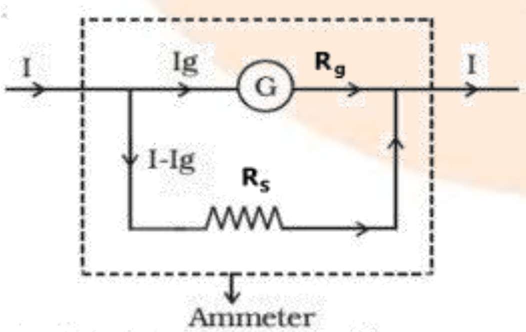
$$\frac{\alpha'}{V}=\frac{6}{5}\frac{nBA}{2kr}=\frac{3}{5}\frac{\alpha}{V}$$

Thus, voltage sensitivity decreases by a factor of $\frac{3}{5}$.

5.

(a) Show how a moving coil galvanometer can be converted into an ammeter.

Ans: A galvanometer can be converted into an ammeter by connecting a low resistance called shunt parallel to the galvanometer. Since G and R_S are in parallel voltage across then is same $I_gR_G=\left(I-I_g\right)R_s$.



$$R_s=\left(\frac{I_g}{I-I_g}\right)R_G$$

(b) **A galvanometer has a resistance of 30 and gives a full-scale deflection for a current of 2mA. How much resistance must be connected to convert into?**

i. An ammeter of range 0.3A

Ans: We have:

$I = 0.3A$, $G = 30\Omega$, $Ig = 2mA = 2\times10^{-3}A$

$$\text{Shunt}(S) = \frac{I_g G}{I - I_g}$$

$$S = \frac{2\times10^{-3}\times30}{\left(0.3 - 2\times10^{-3}\right)} = 0.2\Omega$$

ii. A voltmeter of range 0.2V.

Ans: We have:

$G = 30\Omega$, $Ig = 2mA = 2\times10^{-3}A$, $V = 0.2V$

$$\text{Shunt Resistance}(R) = \left(\frac{V}{I_g} - G\right)$$

$$\Rightarrow (R) = \left(\frac{0.2}{2\times10^{-3}} - 30\right) = 70\Omega$$

6. A monoenergetic (18keV) electron beam initially in the horizontal direction is subjected to a horizontal magnetic field of $0.04G$ normal to the initial direction. Estimate the up or down deflection of the beam over a distance of $30cm$ $(m_e = 9.11\times10^{-31}kg)$. [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.]

Ans: Provided that,

Energy of an electron beam, $E = 18keV = 18\times10^{3}eV$

Charge on an electron, $e = 1.6\times10^{-19}C$

$\therefore E = 18\times10^{3}\times1.6\times10^{-19}V = 2.88\times10^{-15}V$

The magnetic field, $B = 0.04G$

The mass of an electron, $m_e = 9.11\times10^{-31}kg$

Distance till where the electron beam travels, $d = 30cm = 0.3m$

We can write the kinetic energy carried by the electron beam as:

$E = \frac{1}{2}mv^2$

$\Rightarrow v = \sqrt{\frac{2E}{m}}$

$\Rightarrow v = \sqrt{2 \times \frac{2.88 \times 10^{-15}}{9.11 \times 10^{-31}}} = 0.795 \times 10^8 m/s$

The electron beam deflects and gets in a circular path of radius, r .
The force experienced due to the magnetic field balances the centripetal force of the path.

$BeV = \frac{mv^2}{r}$

$\Rightarrow r = \frac{mv}{Be}$

$\Rightarrow r = \frac{9.11 \times 10^{-31} \times 0.795 \times 10^8}{0.4 \times 10^{-4} \times 1.6 \times 10^{-19}} = 11.3m$

Let the up-down deflection of the beam be $x = r(1 - \cos\theta)$.
Where,
θ is the angle of declination given by,
$\theta = \sin^{-1}(d/r) = 1.521°$
And
$x = 11.3(1 - \cos 1.521°) = 0.0039m$
Clearly, the up and down deflection of the bean $= 3.9mm$.

7. A sample of paramagnetic salt contains 2.0×10^{24} atomic dipoles each of dipole moment $1.5 \times 10^{-23} J/T$. The sample is placed under a homogeneous magnetic field of $0.64T$, and cooled to a temperature of $4.2K$ The degree of magnetic saturation achieved is equal to 15%. What is the total dipole moment of the sample for a magnetic field of $0.98T$ and a temperature of $2.8K$? (Assume Curie's law)

Ans: Provided that,
The number of atomic dipoles, $n = 2.0 \times 10^{24}$
Dipole moment for each atomic dipole, $M = 1.5 \times 10^{-23} J/T$
The given magnetic field, $B_1 = 0.64T$
The sample is then cooled to a temperature, $T_1 = 4.2K$
Total dipole moment of the atomic dipole,
$M_{tot} = n \times M = 2 \times 10^{24} \times 1.5 \times 10^{-23} = 30J/T$

Magnetic saturation is achieved at 15%.

Hence, effective dipole moment, $M_1 = \frac{15}{100}30 = 4.5J/T$

Now when the magnetic field is $B_2 = 0.98T$

Temperature, $T_2 = 2.8K$

Its total dipole moment $= M_2$

According to Curie's law, the ratio of the two magnetic dipoles at different temperatures is:

$$\frac{M_2}{M_1} = \frac{B_2}{B_1}\frac{T_1}{T_2}$$

$$\Rightarrow M_2 = \frac{B_2 T_1 M_1}{B_1 T_2}$$

$$\Rightarrow M_2 = 10.336J/T$$

Clearly, it can be seen that, $10.336J/T$ is the total dipole moment of the sample for a magnetic field of $0.98T$ when its temperature is $2.8K$.

8. 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 $0.39G$, 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 and above the cable?

Ans: It is provided that,

The number of horizontal wires in the telephone cable, $n = 4$

Current in each wire, $I = 1.0A$

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

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

and the angle of declination, $\theta \sim 0°$

For a point that is 4cm below the cable:

Distance, $r = 4cm = 0.04m$

The horizontal component (parallel to Earth's Surface) of Earth's magnetic field is:

$$H_H = H.\cos\delta - B$$

Here, B is the magnetic field at 4 cm due to current I in the four wires and

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

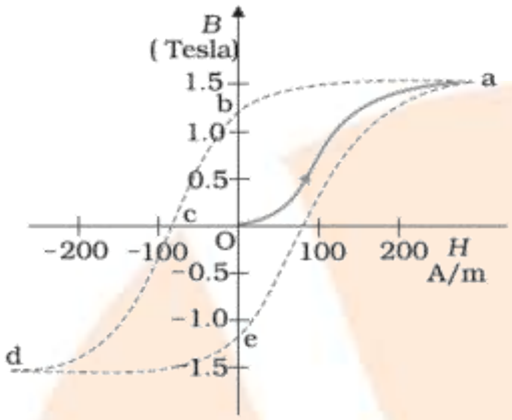
Here, μ_0 is the permeability of free space $= 4\pi \times 10^{-7}\,Tm/A$

$$\Rightarrow B = 4\frac{4\pi \times 10^{-7}}{2\pi}\frac{1}{0.01}$$
$$\Rightarrow B = 0.2 \times 10^{-4} T = 0.2G$$
$$\therefore H_H = 0.39 \times \cos 35° - 0.2 \approx 0.12G$$
The vertical component (perpendicular to Earth's surface) of earth’s magnetic field is given as:
$$H_v = H.\sin\delta$$
$$\Rightarrow H_v = 0.39 \times \sin 35° = 0.22G$$
The angle between the field with its horizontal component is given as:
$$\theta = \tan^{-1}\frac{H_v}{H_H}$$
$$\Rightarrow \theta = \tan^{-1}\frac{0.22}{0.12} = 61.39$$
The resultant field at the point is obtained as:
$$H_1 = \sqrt{H_H{}^2 + H_v{}^2}$$
$$\Rightarrow H_1 = \sqrt{0.22^2 + 0.12^2} = 0.25G$$
For a point that is 4 cm above the cable,
Horizontal component of earth’s magnetic field:
$$H_H = H.\cos\delta - B$$
$$\Rightarrow H_H = 0.39\cos 35° + 0.2 = 0.52$$
Vertical component of earth’s magnetic field:
$$H_v = H.\sin\delta$$
$$\Rightarrow H_v = 0.39\sin 35° = 0.22$$
The angle $\theta = \tan^{-1}\frac{H_v}{H_H}$
$$\Rightarrow \theta = \tan^{-1}\frac{0.22}{0.52} = 22.9°$$
And the resultant field is:
$$H_1 = \sqrt{H_H{}^2 + H_v{}^2}$$
$$\Rightarrow H_1 = \sqrt{0.22^2 + 0.52^2} = 0.56G$$
Clearly, the resultant magnetic field below the cable is $0.25G$ and above the cable is $0.56G$.

9. Answer the following questions:

a) Explain qualitatively on the basis of the domain picture the irreversibility in the magnetization curve of a ferromagnet.

Ans: The B-H curve i.e., the Hysteresis curve of a ferromagnetic material is as shown in the figure below:



It can be seen from the above-given curve that magnetization-B persists even when the external field-H is removed. This shows the irreversibility of a ferromagnet, i.e., the magnetization will not drop by reducing the magnetization field just the same way it was increased by increasing the magnetization field.

b) 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 of magnetization, which piece will dissipate greater heat energy?

Ans: The dissipated heat energy is in proportion to the area inside the hysteresis loop. For a carbon steel piece, the hysteresis curve area is large. Thus, it dissipates greater heat energy.

c) 'A system displaying a hysteresis loop such as a ferromagnet, is a device for storing memory?' Explain the meaning of this statement.

Ans: The information of magnetization corresponds to the cycle of magnetization. Also, it can be seen that Hysteresis loops can be used for storing such information.

The value of magnetization is memory or record of hysteresis loop cycles of magnetization.

d) What kind of ferromagnetic material is used for coating magnetic tapes in a cassette player, or for building 'memory stores' in a modern computer?

Ans: Ceramic.

Ceramic is usually used for coating magnetic tapes in memory storage devices like cassette players and also for building memory stores in today's computers.

e) A certain region of space is to be shielded from magnetic fields. Suggest a method.

Ans: A 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.

10. Answer the following questions:

a) Why does a paramagnetic sample display greater magnetization (for the same magnetizing field) when cooled?

Ans: The thermal motion of molecules is random, and the randomness increases with increasing temperature. Considering this fact, the alignments of dipoles get disrupted at high temperatures.

On cooling, this disruption is reduced. Hence, a paramagnetic sample displays greater magnetization when its temperature is lowered i.e., it is cooled.

b) Why is diamagnetism, in contrast, almost independent of temperature?

Ans: In the presence of a magnetizing field, the induced dipole moment in a diamagnetic substance is always opposite to the magnetizing field.

Hence, the change in temperature that leads to a change in the internal motion of the atoms does not affect the diamagnetism of a material.

c) 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?

Ans: It is known that Bismuth is a diamagnetic substance. This means, the magnetic field due to the toroid will be the magnetizing field for the bismuth core which will be opposite to the induced magnetic field of Bismuth.

Hence the total field generated by the toroid will be slightly less than the empty-core-toroid.

d) Is the permeability of a ferromagnetic material independent of the magnetic field? If not, is it more for lower or higher fields?

Ans: The permeability of ferromagnetic materials is dependent on the applied magnetic field. As observed from the hysteresis curve, it is greater for a lower field and vice versa.

e) 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?

Ans: The permeability of ferromagnetic material is greater than 1; not less than 1. Therefore, magnetic field lines are always nearly normal to the surface of such materials at every point.

f) Would the maximum possible magnetization of a paramagnetic sample be of the same order of magnitude as the magnetization of a ferromagnet?
Ans: The maximum possible magnetization of a paramagnetic sample can be of the same order of magnitude as the magnetization of a ferromagnet. This requires high magnetizing fields for saturation.

11. A short bar magnet of magnetic moment $5.25\times10^{-2}\,J/T$ is placed with its axis perpendicular to the earth's field direction. Magnitude of the earth's field at the place is given to be $0.42G$. Ignore the length of the magnet in comparison to the distances involved. At what distance from the centre of the magnet, the resultant field is inclined at $45°$ with earth's field on
(a) its normal bisector and
Ans: Provided that,
The magnetic moment of the bar magnet, $M=5.25\times10^{-2}\,J/T$
The magnitude of the Earth's magnetic field at a place,
$G=0.42G=0.42\times10^{-4}T$
The magnetic field at the distance of R from the centre of the magnet on the normal bisector is given by the relation:
$$B=\frac{\mu_0}{4\pi}\frac{M}{R^3}$$
Here,
M is the above-mentioned magnetic moment
μ_0 is the permeability of free space
When the resultant field is inclined at $45°$ with earth's field, $B=H$
$$\frac{\mu_0}{4\pi}\frac{M}{R^3}=H=0.42\times10^{-4}$$
$$\Rightarrow R^3=\frac{4\pi\times10^{-7}}{4\pi}\frac{5.25\times10^{-2}}{0.42\times10^{-4}}=12.5\times10^{-5}$$
$$\Rightarrow R=5\times10^{-2}m=5cm$$
Clearly, at a distance of 5cm from the centre of the magnet, the resultant field is inclined at $45°$ with earth's field on its normal bisector.

(b) its axis
Ans: Provided that,

The magnetic moment of the bar magnet, $M = 5.25\times10^{-2}\,J/T$
The magnitude of the Earth's magnetic field at a place,
$G = 0.42G = 0.42\times10^{-4}T$
The given magnetic field at R distanced from the centre of the magnet on a point on its axis is given as:

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

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

$$B' = H$$

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

$$\Rightarrow (R')^3 = \frac{4\pi\times10^{-7}}{4\pi}\frac{2\times5.25\times10^{-2}}{0.42\times10^{-4}} = 2.5\times10^{-4}$$

$$\Rightarrow R = 6.3\times10^{-2}m = 6.3cm$$

Clearly, at a distance of 6.3cm from the centre of the magnet, the resultant field is inclined at $45°$ with earth's field on its axis.

12. If the bar magnet in exercise 5.13 is turned around by $180°$, where will the new null points be located?

Ans: According to what is given, the magnetic field on the axis of the magnet at a distance $d_1 = 14cm$, can be written as:

$$B_1 = \frac{\mu_0}{4\pi}\frac{2M}{d_1^3} = H$$

here,
M is the magnetic moment
μ_0 is the permeability of free space
H is the horizontal component of the given magnetic field at d_1
When the bar magnet is turned through $180°$, then the neutral point will lie on the equatorial line.
Also, the magnetic field at a distance d_2 on the equatorial line of the magnet can be written as:

$$B_2 = \frac{\mu_0}{4\pi}\frac{M}{d_2^3} = H$$

Equating B_1 and B_2 we get:

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

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

$\Rightarrow 14 \times 0.794 = 11.1\text{cm}$

Thus, the new null point will be located 11.1cm on the normal bisector.

13. A bar magnet of magnetic moment $1.5\,\text{J/T}$ lies aligned with the direction of a uniform magnetic field of 0.22T.

(a) What is the amount of work required by an external torque to turn the magnet so as to align its magnetic moment: (i) normal to the field direction, (ii) opposite to the field direction?

Ans: Provided that,

Magnetic moment, $M = 1.5\text{J/T}$

Magnetic field strength, $B = 0.22\text{T}$

(i) Initial angle between the magnetic field and the axis is, $\theta_1 = 0°$

Final angle between the magnetic field and the axis is, $\theta_2 = 90°$

The work that would be required to make the magnetic moment perpendicular to the direction of magnetic field would be:

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

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

$\Rightarrow W = -0.33(0-1)$

$\Rightarrow W = 0.33\text{J}$

(ii) Initial angle between the magnetic field and the axis, $\theta_1 = 0°$

Final angle between the magnetic field and the axis, $\theta_2 = 180°$

The work that would be required to make the magnetic moment opposite (180 degrees) to the direction of the magnetic field is given as:

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

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

$\Rightarrow W = -0.33(-1-1)$

$\Rightarrow W = 0.66\text{J}$

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

Ans: For the first (i) case,

$\theta = \theta_1 = 90°$

Hence the Torque, $\vec{\tau} = \vec{M} \times \vec{B}$

And its magnitude is: $\tau = MB\sin(\theta)$

$\Rightarrow \tau = 1.5 \times 0.22\sin(90°)$

$\Rightarrow \tau = 0.33\text{Nm}$

Hence the torque involved is $=0.33\text{Nm}$
For the second-(ii) case:
$\theta=\theta_1=180°$
And its magnitude of the torque is: $\tau=MB\sin(\theta)$
$\Rightarrow \tau=1.5\times 0.22\sin(180°)$
$\Rightarrow \tau=0\text{Nm}$
Hence the torque is zero.

14. Answer the following questions regarding earth's magnetism:
(a) A vector needs three quantities for its specification. Name the three independent quantities conventionally used to specify the earth's magnetic field.
Ans: The three independent quantities conventionally used for specifying earth's magnetic field are:
(i) Magnetic declination
(ii) Angle of dip
(iii) Horizontal component of earth's magnetic field

(b) The angle of dip at a location in southern India is about 18^0. Would you expect a greater or smaller dip angle in Britain?
Ans: 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.

(c) 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?
Ans: 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.

(d) 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?
Ans: 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.

(e) The earth's field, it is claimed, roughly approximates the field due to a dipole of magnetic moment $8\times10^{22}\,JT^{-1}$ located at its centre. Check the order of magnitude of this number in some way.

Ans: Given that,

Magnetic moment, $M=8\times10^{22}\,JT^{-1}$

Radius of earth, $r=6.4\times10^{6}m$

Magnetic field strength,

$$B=\frac{800\times4\pi\times10^{-7}\times1.2\times3500}{2\pi\times0.15}=4.48T$$

Where,

$\mu_0 =$ Permeability of free space $=4\pi\times10^{-7}TmA$.

$$\Rightarrow\frac{4\pi\times10^{-7}\times8\times10^{22}}{4\pi\times\left(6.4\times10^{6}\right)^{3}}=0.3G$$

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

(f) Geologists claim that besides the main magnetic N-S poles, there are several local poles on the earth's surface oriented in different directions. How is such a thing possible at all?

Ans: Yes, there are several local poles on earth's surface oriented in different directions. A magnetised mineral deposit is an example of a local N-S pole.

15. Answer the following questions:

(a) 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?

Ans: 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 time cannot be neglected.

(b) The earth's core is known to contain iron. Yet geologists do not regard this as a source of the earth's magnetism. Why?

Ans: Earth's core contains molten iron. This form of iron is not ferromagnetic. Hence, this is not considered as a source of earth's magnetism.

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

Ans: 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.

(d) 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?

Ans: 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.

(e) 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?

Ans: 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.

(f) 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. [Note: Exercise 5.2 is meant mainly to arouse your curiosity. Answers to some questions above are tentative or unknown. Brief answers wherever possible are given at the end. For details, you should consult a good text on geomagnetism.]

Ans: 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.