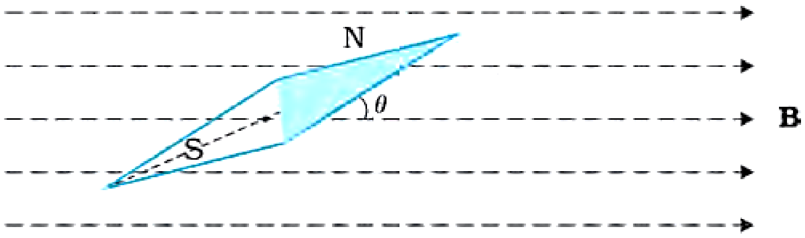
EXAMPLES

5.1. In the given figure, the magnetic needle has magnetic moment $B_A = \mu_0 2m / 4\pi r^3 = 6.4 \times 10^{-7} T$ $6.7 \times 10^{-2}\ Am^2$ **and moment of inertia 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?**



ANS: The time period of oscillation is,

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

From Eq. (5.5)

$$B = \frac{4\pi^2}{mT^2}$$

$= 4 \times (3.14)^2 \times 7.5 \times 10^{-6} / 6.7 \times 10^{-2} \times (0.67)^2$

$= 0.01T$

5.2 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** $2 \times 10^{-4}\ m^2$ **and** 1000 **turns but of the same magnetic moment. Determine the current flowing through the solenoid.**

ANS: a: Since, $\tau = mB\sin\theta, \theta = 30^\circ$

$$\text{hence}, \sin 30^\circ = \frac{1}{2}$$

Thus,

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

$$m = 160 \times 2 / 00 = 0.40 Am^2$$

(b) The most stable position is $\theta = 0°$ and the most unstable position is $\theta = 180°$. Work done is given by

$$W = U_m(\theta = 180^\circ) - U_m(\theta = 0^\circ)$$
$$= 2mB = 2 \times 0.40 \times 10^{-4} = 0.064J$$

(c) Since, ms = NIA.

From part (a),

$$m_s = 0.40 Am^2$$
$$0.40 = 1000 \times I \times / 2 \times 10^{-4}$$
$$I = 0.40 \times 10^4 (1000 \times 2) = 2A$$

5.3(a) What happens if a bar magnet is cut into two pieces: (i) transverse to its length, (ii) along its length? (b) A magnetized 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? (c) Must every magnetic configuration have a north pole and a south pole? What about the field due to a toroid? (d) Two identical looking iron bars A and B are given, one of which is definitely known to be magnetised. (We do not know which one.) How would one ascertain whether or not both are magnetised? If only one is magnetised, how does one ascertain which one? [Use nothing else but the bars A and B.]

ANS: (a) In any instance, two magnets with north and south poles are provided.

(b) If the field is uniform, there is no need for force. The bar magnet creates a no uniform field around the iron nail. Because the nail has an induced magnetic moment, it is subjected to both force and torque. Because the induced south pole (say) in the nail is closer to the north pole of the magnet than the induced north pole, the net force is attracting.

(c) Certainly not. True if the field's source has a net nonzero magnetic moment. For a toroid or even a straight infinite conductor, this is not the case.

(d) Try to bring the bars' ends closer together. In some situations, a repulsive force proves that both are magnetized. If it's constantly appealing, one of them isn't magnetized. The magnetic field intensity of a bar magnet is strongest at the two ends (poles) and weakest in the middle. This fact can be utilized to identify whether the magnet is A or B. Pick up one of the two bars (say, A) and lower one of its ends on one of the ends of the other (say, B), and then on the centre of B to see which one is a magnet. If you see that there is no force in the middle of B, then B is magnetized. If there hasn't been any change from the beginning to the finish,

5.4: 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 $0.40\ A\ m^2$, the same as in Example 5.2.

ANS: $B_E = \mu_0 m / 4\pi r^3 = 10^{-7} \times 0.4(0.5)^3 = 3.2 \times 10^{-7} T$

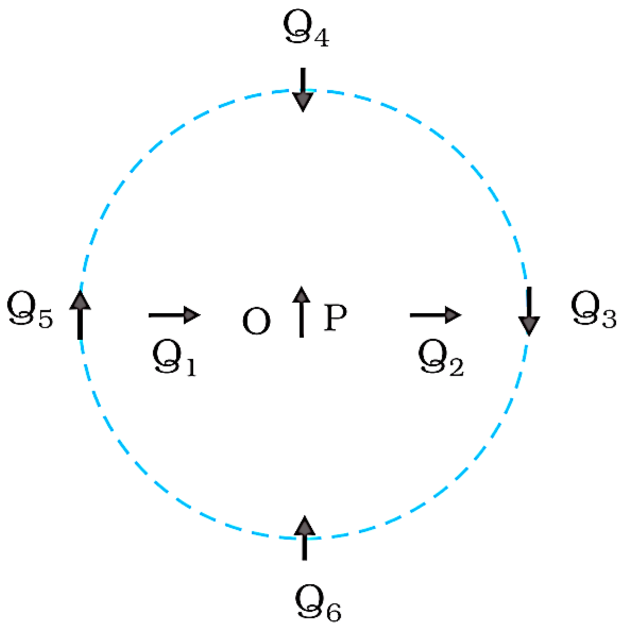
From Eq. (5.8), $B_A = \mu_0 2m / 4\pi r^3 = 6.4 \times 10^{-7} T$

5.5: Figure shows a small magnetized 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 magnetized needle Q.

(a) In which configuration the system is 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?



ANS: Potential energy of the configuration arises due to the potential energy of one dipole (say, Q) in the magnetic field due to other (P). Use the result that the field due to P is given by the expression:

$B_p = -\mu_0 m_p / 4\pi r^3$ (on the normal bisector)

$B_p = \mu_0 2m_p / 4\pi r^3$

(on the axis)

where m_P is the magnetic moment of the dipole P. Equilibrium is stable when m_P is parallel to

$\cos 60^{\circ} = H_E / B_E$

$B_E = H_E / \cos 60^{\circ} = 0.52G$

B_P, and unstable when it is anti-parallel to B_P.

For instance for the configuration Q3 for which Q is along the perpendicular bisector of the dipole P, the magnetic moment of Q is parallel to the magnetic field at the position 3. Hence Q3 is stable.

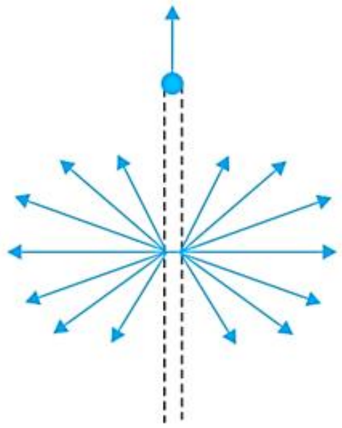
Thus,

(a) PQ1 and PQ2

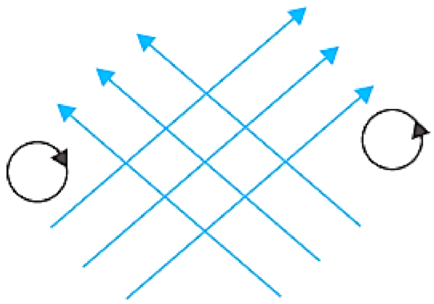
(b) (i) PQ3, PQ6 (stable); (ii) PQ5, PQ4 (unstable)

(c) PQ6

5.6: Many of the diagrams given in figure. Show magnetic field lines (thick lines in the figure) wrongly. Point out what is wrong with them. Some of them may describe electrostatic field lines correctly. Point out which ones:

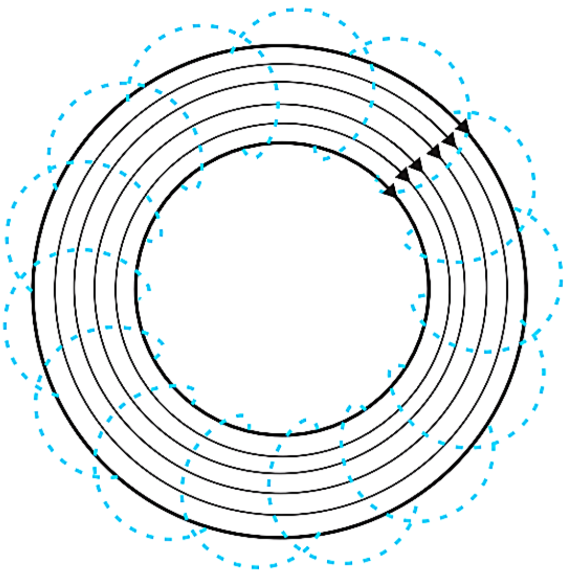


(a)

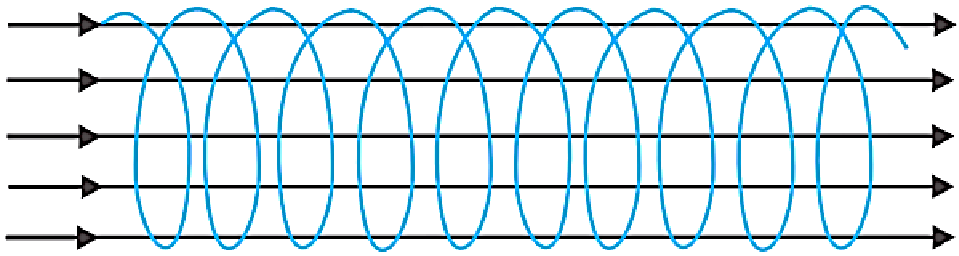


Empty space

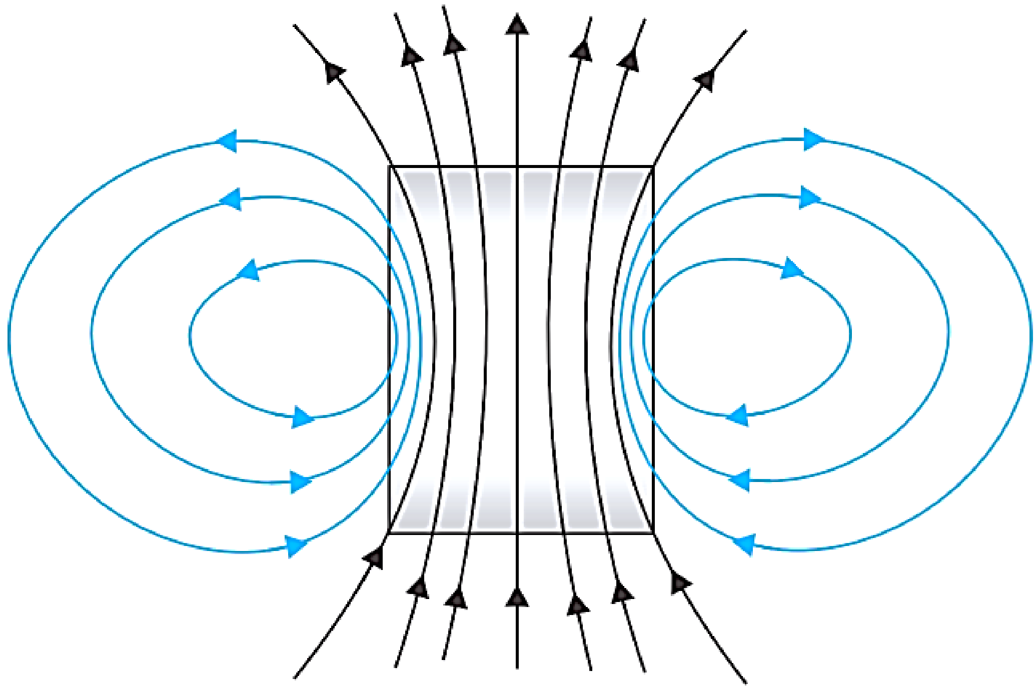
(b)



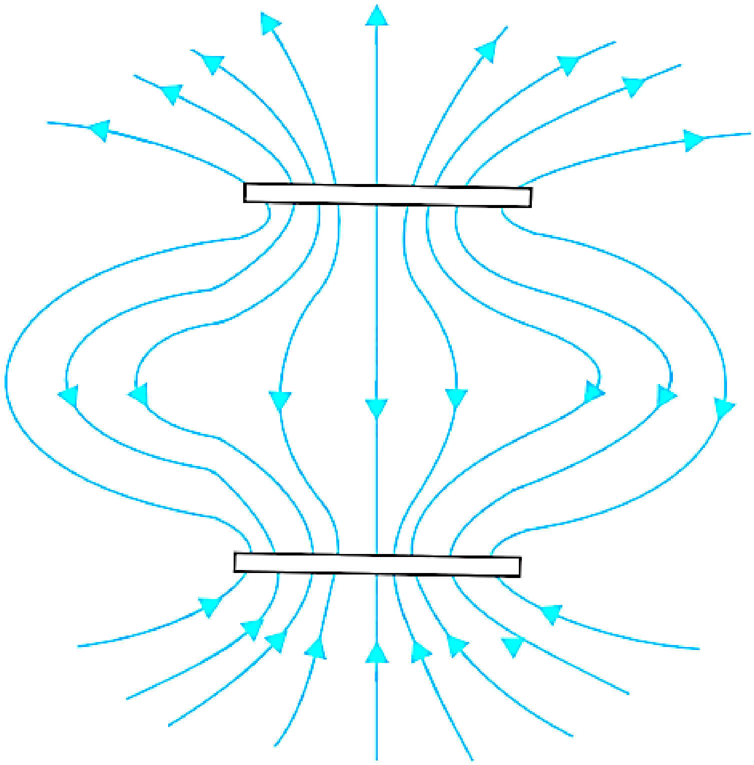
(c)



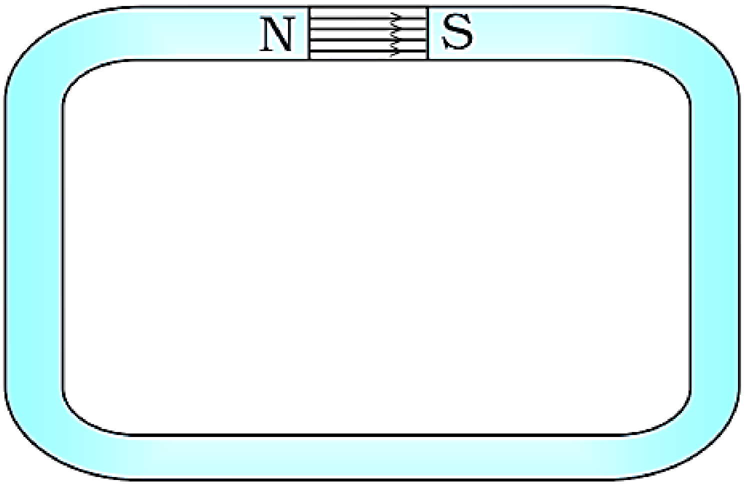
(d)



(e)



(f)



(g)

ANS:(a)Wrong. As seen in the diagram, magnetic field lines can never emanate from a point. The net flux of B over any closed surface must always be zero, i.e., as many field lines should appear pictorially as possible. As the number of lines leaving the surface increases, so does the number of lines entering it. The lines in the field In actuality, the image depicts the electric field of a long positively charged wire. The straight magnetic field lines are circling the correct magnetic field lines. Chapter 4 describes the conductor.

(b)Wrong. Magnetic field lines (like electric field lines) must never cross since the direction of the field at the place of intersection would be uncertain otherwise. In addition, there is an inaccuracy in the figure. Closed loops of magneto static field lines can never form around empty space. A current-carrying zone must be enclosed by a closed loop of static magnetic field line. In empty space or when the loop encloses charges, electrostatic field lines, on the other hand, can never form complete loops.

(c)Right. Within a toroid, magnetic lines are totally contained. There's nothing wrong with field lines creating closed loops because each loop encloses a current-passing zone. Only a few field lines within the toroid have been shown for clarity in the illustration. In fact, a magnetic field exists across the region contained by the windings.

(d)Wrong. A solenoid's field lines at its ends and on the outside cannot be absolutely straight and confined; otherwise, Ampere's law would be broken. To make closed loops, both ends of the lines should curve out and eventually meet.

(e)Right. Outside and within a bar magnet, they are field lines. Inside, pay attention to the direction of the field lines. A north pole does not produce all field lines (or converge into a south pole). The net flux of the field is zero around both the N-pole and the S-pole.

(f)Wrong. There is no way these field lines can represent a magnetic field. Take a look at the upper part of the picture. The darkened plate appears to be the source of all field lines. The net flux across the shaded plate's surrounding surface is not zero. For a magnetic field, this is impossible. The electrostatic field lines around a positively charged top plate and a negatively charged bottom plate are depicted by the given field lines. It's important to understand the difference between Fig. (e) and (f)].

(g)Wrong. At their ends, magnetic field lines linking two pole pieces cannot be precisely straight. It's impossible to avoid some line fringing. If this isn't done, Ampere's law will be broken. Electric field lines aren't any different.

5.7: (a) Magnetic field lines show the direction (at every point) along which a small magnetized needle aligns (at the point). Do the magnetic field lines also represent the lines of force on a moving charged particle at every point? (b) Magnetic field lines can be entirely confined within the core of a toroid, but not within a straight solenoid. Why? (c) If magnetic monopoles existed, how would the Gauss's law of magnetism be modified? (d) 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? (e) Magnetic field arises due to charges in motion. Can a system have magnetic moments even though its net charge is zero?

ANS:(a) No. The magnetic force is always normal to **B** (remember magnetic force = **qv** × **B**). It is erroneous to refer to magnetic field lines as force lines.

(b) The flux through the cross-section at each end of a straight solenoid would be non-zero if field lines were totally contained between two ends. The flow of field **B**, on the other hand, must always be zero across any closed surface. Because a toroid has no 'ends,' this challenge isn't present.

(c) Gauss's law of magnetism states that the flux of B through any closed surface is always zero

$$\int_s B.\Delta s = 0$$

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, $\int_s B.\Delta s = \mu_0 q_m$ where q_m = (monopole) magnetic charge enclosed by S.]

(d)No. There is no force or torque acting on an element as a result of the field created by that element. However, there is a force (or torque) on a wire element. (This force is zero in the particular situation of a straight wire.)

(e)Yes. It's possible that the system's average charge is zero. The average magnetic moment due to numerous current loops, however, may not be zero. Such examples can be found in paramagnetic materials, where atoms exhibit a net dipole moment despite their net charge being zero.

5.8: The earth's magnetic field at the equator is approximately $0.4\ G$. Estimate the earth's dipole moment.

ANS: The equatorial magnetic field is, $B_E = \mu_0 m / 4\pi r^3$

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,

$$m = 4\times10^{-5}\times\left(6.4\times10^6\right)^3 / \mu_0 / 4\pi$$

$$=1.05\times10^{23}\,Am^2$$

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

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

ANS: It is given that H_E = 0.26 G.

We have

$$\cos 60^\circ = H_E / B_E$$

$$B_E = H_E / \cos 60^\circ = 0.52G$$

5.10: A $M_{\max} = m_{\max}$ / domain volume $= 8.0\times10^{-13}$ 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 2 A. If the number of turns is 1000 per metre, calculate (a) H, (b) M, (c) B and (d) the magnetising current I_m.

ANS: (a) The field H is dependent of the material of the core, and is

$$H = nI = 1000\times2.0 = 2\times10^3 A/m$$

(b) The magnetic field B is given by

$B = \mu_r \mu_0 H$

$= 400 \times 4\pi \times 10^{-7} \left(N / A^2 \right) \times 2 \times 10^3 \left(A / m \right) = 1.0T$

(c) Magnetisation is given by

$M = \left(B - \mu_0 H \right) / \mu_0$

$= \left(\mu_r \mu_0 H - \mu_0 H \right) / \mu_0 = \left(\mu_r - 1 \right) H = 399 \times H = 8 \times 10^5 A / m$

(d) In the absence of the core, the magnetising current I_M is the additional current that must be supplied through the solenoid's windings to produce the same B value as in the presence of the core. As a result, $B = \mu_r n \left(I + I_m \right)$ I_m = 794 A is obtained by multiplying I = 2A and B = 1 T.

5.11: A domain in ferromagnetic iron is in the form of a cube of side length 1µm. Estimate the number of iron atoms in the domain and the maximum possible dipole moment and magnetisation of the domain. The atomic 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 9.27×10^{-24} A m^2.

ANS: The volume of the cubic domain is $V = (10^{-6} m)^3 = 10^{-18} m^3 = 10^{-12} cm^3$

Its mass is volume × density = $7.9 gcm^{-3} \times 10^{-12} cm^3 = 7.9 \times 10^{-12} g$

$N = 7.9 \times 10^{-12} \times 6.023 \times 10^{23} / 55$

$= 8.65 \times 10^{10} atoms$

The maximum possible dipole moment $m_{\max}$ is achieved for the (unrealistic) case when all the atomic moments are perfectly aligned. Thus,

$m_{\max} = (8.65 \times 10^{10}) \times \left(9.27 \times 10^{-24} \right)$

$= 8.0 \times 10^{13} Am^2 / 10^{-18} m^3$

$= 8.0 \times 10^5 Am^{-1}$

The consequent magnetisation is

$M_{\max} = m_{\max} / domainvolume$

$= 8.0 \times 10^{-13} Am^2 / 10^{-18} m^3$

$= 8.0 \times 10^5 Am^{-1}$

Exercises

5.1:Answer the following questions regarding earth’s magnetism:

a) **A vector needs three quantities for its specification. Name the three independentquantities conventionally used to specify the earth’s magnetic field.**

Ans. The three separate quantities used to describe the earth's magnetic field are:

i. Angle of Dip
ii. Magnetic Declination
iii. Horizontal component of earth's magnetic field

b) The angle of dip at a location in southern India is about 18°. Would you expect agreater or smaller dip angle in Britain?

Ans. The distance between the North Pole and the South Pole determines the angle of dip at a given place. Because Britain is closer to the planet's magnetic North Pole, the angle of dip in Britain (approximately) would be greater than in southern India.

c) If you made a map of magnetic field lines at Melbourne in Australia, would the linesseem to go into the ground or come out of the ground?

Ans. A massive bar magnet is plunged inside the earth with its north pole near the geographicSouth Pole and its south pole near the geographic North Pole, as an example.Magnetic field lines run from the magnetic north pole to the magnetic south pole. As a result, the field lines near Melbourne, Australia appear to emerge from the ground on a map depicting the earth's magnetic field lines.

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. When a compass is placed on the geomagnetic North Pole or South Pole, it is free to travel in the horizontal plane since the earth's magnetic field is exactly vertical to the magnetic poles. The compass in this scenario 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. Magnetic moment, $M=8\times10^{22}\,JT^{-1}$

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

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

Where, μ_0 = Permeability of free space = $4\pi\times10^{-7}\,TmA^{-1}$

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

The magnitude of this amount is comparable to the measured 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. On the earth's surface, there are several local poles oriented in various directions. A magnetized mineral deposit is an example of a local N-S pole.

5.2 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. The magnetic field of the Earth changes over time. It takes a few hundred years for a significant amount of change to occur. The change in the earth's magnetic field throughout time cannot be overlooked.

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

Ans. Molten iron can be found in the Earth's core. The iron in this form is not ferromagnetic. As a result, this isn't thought to be a source of earth's magnetic.

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 the earth's interior is the source of energy that keeps the currents flowing in the core's outer conducting areas. The earth's magnetism is thought to be caused by these charged currents.

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. Several times over Earth's 4 to 5 billion-year history, the direction of its field was reversed. During the solidification of rocks, these magnetic fields were poorly recorded. The investigation of this rock magnetism can provide information about the geomagnetic history.

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. Because of the ionosphere, the Earth's field deviates significantly from its dipole structure at considerable distances (more than around $30,000$ km). Because of the field of single ions in this region, the earth's field is altered. These ions produce the magnetic field associated with them while in motion.

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.

Ans. Charged particles travelling in a circle can be bent by an extremely weak magnetic field. For a big radius path, this may not be evident. The deflection can have an impact on the flow of charged particles in the vast interstellar vacuum.

5.3 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 $4.5\times10^{-2}\,J$. What is the magnitude of magnetic moment of the magnet?

Ans. Magnetic field strength: $0.25T$

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

Angle between the bar magnet and the external magnetic field: $\theta = 30^{\circ}$

Torque is related to magnetic moment (M) as:

$$T = MB\sin\theta$$

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

$$= \frac{4.5\times10^{-2}}{0.25\times\sin 30^{\circ}} = 0.36\text{JT}^{-1}$$

As a result, the magnet's magnetic moment is $0.36JT^{-1}$

5.4 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?

Ans. Moment of the bar magnet, $M = 0.32JT^{-1}$

External magnetic field, $B = 0.15T$

The magnetic field is aligned with the bar magnet. This system is said to be in a state of stable equilibrium. As a result, the angle formed by the bar magnet and the magnetic field is 0° .

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

$$= -0.32\times0.15\cos 0^{\circ}$$
$$= -4.8\times10^{-2} J$$

(b)The bar magnet is facing the magnetic field at an angle of 180°. As a result, it's in an unstable balance.

$$\theta = 180°$$

Potential energy $= -MB\cos\theta$

$$= -0.32\times0.15\cos180°$$
$$= 4.8\times10^{-2} J$$

5.5 A closely wound solenoid of 800 turns and area of cross section $2.5\times10^{-4}m^2$ 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. Number of turns is the solenoid: $n = 800$

Area of cross-section: $A = 2.5\times10^{-4} m^2$

Current in the solenoid: $I = 3.0A$

A current-carrying solenoid works like a bar magnet because its magnetic field builds along its axis, or length. A current-carrying solenoid's magnetic moment is calculated as follows:

$M = nIA$

$= 800 \times 3 \times 2.5 \times 10^{-4}$
$= 0.6JT^{-1}$

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

Ans. Magnetic field strength: $B = 0.25T$

Magnetic moment: $M = 0.6T^{-1}$

The angle formed by the solenoid's axis and the applied field's direction is 30 degrees.As a result, the torque operating on the solenoid is:

$\tau = MB\sin\theta$

$0.6 \times 0.25 \sin 30^\circ$
$= 7.5 \times 10^{-2} J$

5.7 A bar magnet of magnetic moment $1.5JT^{-1}$ 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 asto align its magnetic moment: (i) normal to the field direction, (ii) opposite to the field direction?

Ans. Magnetic moment: $M = 1.5JT^{-1}$

Magnetic field strength: $B = 0.22T$

$\theta_1 = 0°$ is the initial angle between the axis and the magnetic field.

$\theta_2 = 90^\circ$ is the final angle between the axis and the magnetic field.

The work required to align the magnetic moment with the magnetic field's direction is given as:

$$W = -MB(\cos\theta_2 - \cos\theta_1)$$
$$= -1.5 \times 0.22(\cos 90^\circ - \cos 0^\circ)$$
$$= -0.33(0-1)$$
$$= 0.33\text{J}$$

ii) $\theta_1 = 0°$ is the initial angle between the axis and the magnetic field.

$\theta_2 = 180°$ final angle between the axis and the magnetic field
The work necessary to turn the magnetic moment in the opposite direction of the magneticfield is calculated as follows:

$$W = -MB(\cos\theta_2 - \cos\theta_1)$$
$$= -1.5 \times 0.22(\cos 180 - \cos 0^\circ)$$
$$= -0.33(-1-1)$$
$$= 0.66\text{J}$$

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

Ans. For case (i): $\theta = \theta_1 = 90^\circ$

$\therefore$ Torque $\tau = MB\sin\theta$

$= 1.5 \times 0.22 \sin 90^\circ$

$= 0.33J$

For case (ii): $\theta = \theta_2 = 180°$

$\therefore$ Torque $\tau = MB\sin\theta$

$= MB\sin 180^\circ = 0\text{J}$.

5.8 A closely wound solenoid of 2000 turns and area of cross-section $1.6 \times 10^{-4} m^2$, 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?

Ans. Number of turns on the solenoid: $n = 2000$

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

Current in the solenoid, I = 4 A

The magnetic moment along the solenoid's axis is computed as follows:

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

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

Ans. Magnetic field: $B = 7.5 \times 10^{-2} T$

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

Torque $\tau = MB \sin\theta$

$= 1.28 \times 7.5 \times 10^{-2} \sin 30^\circ$
$= 4.8 \times 10^{-2}$ Nm

5.9: **A circular coil of 16 turns and radius 10 cm carrying a current of $0.75A$ rests with its plane normal to an external field of magnitude $5.0 \times 10^{-2} T$. The coil is free to turn aboutan axis in its plane perpendicular to the field direction. When the coil is turned slightlyand 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?**

Ans. Number of turns in the circular coil: $N = 16$

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: $v = 2.0 s^{-1}$

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

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

Frequency is given by the relation:

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

Where, $I =$ moment of inertia of the coil

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

$$= \frac{0.377 \times 5 \times 10^{-2}}{4\pi^2 \times (2)^2}$$

$$= 1.19 \times 10^{-4} \text{kgm}^2$$

As a result, the coil's moment of inertia about its axis of rotation is $1.19 \times 10^{-4} kg\, m^2$

5.10: A magnetic needle free to rotate in a vertical plane parallel to the magnetic meridian hasits north tip pointing down at 22º with the horizontal. The horizontal component of theearth's magnetic field at the place is known to be 0.35 G. Determine the magnitude ofthe earth's magnetic field at the place.

Ans. Horizontal component of earth's magnetic field: $B_H = 0.35G$

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

Earth's magnetic field strength = B

We can relate B and B_H as:

$$B_H = B\cos\theta$$

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

$$= \frac{0.35}{\cos 22^\circ} = 0.377\text{G}$$

Hence, the strength of earth'smagnetic field at the given location is $0.377G$

5.11 At a certain location in Africa, a compass points $12°$ west of the geographic north. Thenorth 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 $0.16G$. Specify the direction and magnitude of the earth's field at the location.

Ans. Angle of declination: $\theta = 12°$

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

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

Earth's magnetic field at the given location = B

We can relate B and B_H as:

$$B_H = B\cos\delta$$

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

$$= \frac{0.16}{\cos 60^\circ} = 0.32\text{G}$$

The magnetic field of the Earth is located in the vertical plane, 12° west of the geographic meridian, and forms a 60° (upward) angle with the horizontal direction. It is $0.32G$ in magnitude.

5.12 A short bar magnet has a magnetic moment of $0.48JT^{-1}$. Give the direction andmagnitude 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 themagnet.

Ans. Magnetic moment of the bar magnet: $M = 0.48JT^{-1}$

(a) Distance $d = 10cm = 0.1m$

The magnetic field at d meters from the magnet's centre on the axis is given by the equation:

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

Where,

μ_0 = Permeability of free space = $4\pi\times10^{-7}TmA^{-1}$

$$\therefore B = \frac{4\pi\times10^{-7}\times2\times0.48}{4\pi\times(0.1)^3}$$

$$= 0.96\times10^{-4}\text{T} = 0.96\text{G}$$

$$= 0.48G$$

The magnetic field is along the N – S direction.

5.13 A short bar magnet placed in a horizontal plane has its axis aligned along the magneticnorth-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 $0.36G$ and the angle ofdip is zero. What is the total magnetic field on the normal bisector of the magnet at thesame distance as the null–point (i.e.,$14cm$) from the centre of the magnet? (At nullpoints, field due to a magnet is equal and opposite to the horizontal component of earth'smagnetic field.)

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

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

$$B_1 = \frac{\mu_0}{4\pi}\frac{2M}{d^3} = H \qquad \ldots(1)$$

Where,

μ_0 = Permeability of free space

M = magnetic moment

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

$$B_2 = \frac{\mu_0 M}{4\pi d^3} = \frac{H}{2}. \qquad \{\text{from } 1$$

Total magnetic field, $B = B_1 + B_2$

$$= H + \frac{H}{2}$$
$$= 0.36 + 0.18 = 0.54G$$

As a result, the magnetic field in the direction of the earth's magnetic field is $0.54G$.

5.14 If the bar magnet in exercise 5.13 is turned around by $180°$, where will the new nullpoints be located?

Ans. At a distance of $d_1 = 14cm$, the magnetic field on the axis of the magnet may be represented as:

$$B_1 = \frac{\mu_0 2M}{4\pi (d_1)^3} = H \qquad \ldots(1)$$

Where,

M = magnetic moment

μ_0 = permeability of free space

H = Horizontal component of the magnetic field at d_1

When the bar magnet is rotated $180°$, the neutral point is on the equatorial line.

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

written as:

$$B_2 = \frac{\mu_0 M}{4\pi (d_2)^3} = H \qquad \ldots(2)$$

Equating equations (1) and (2), we get:

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

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

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

$$= 14 \times 0.794 = 11.1cm$$

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

5.15 A short bar magnet of magnetic moment $5.25\times10^{-2}\,JT^{-1}$ is placed with its axisperpendicular 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(a) its normal bisector and (b) its axis.Magnitude of the earth's field at the place is givento be 0.42 G. Ignore the length of the magnet in comparison to the distances involved.

Ans. Magnetic moment of the bar magnet, $M = 5.25\times10^{-2}\,JT^{-1}$

Magnitude of earth's magnetic field at a place, $H = 0.42G = 0.42\times10^{-4}T$

(a) On the normal bisector, the magnetic field at a distance R from the magnet's centre is given by the relation:

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

Where,

μ_0 = permeability of free space = $4\pi\times10^{-7}\,TmA^{-1}$

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

$$\therefore \frac{\mu_0 M}{4\pi R^3} = H = 0.42\times10^{-4}$$

$$R^3 = \frac{\mu_0 M}{0.42\times10^{-4}\times4\pi}$$

$$= \frac{4\pi\times10^{-7}\times5.25\times10^{-2}}{4\pi\times0.42\times10^{-4}} = 12.5\times10^{-5}$$

$$\therefore R = 0.05m = 5cm$$

(b) The magnetic field at a distance R' from the centre of the magnet on its axis is given as:

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

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

$$\therefore B' = H$$

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

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

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

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

5.16: Answer the following questions:

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

Ans. Because of the random thermal motion of molecules at high temperatures, dipole alignments are broken. When the temperature drops, this disruption is reduced. As a result, cooling a paramagnetic sample makes it more magnetised.

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

Ans. In a diamagnetic substance, the induced dipole moment is always in the opposite direction of the magnetizing field. As a result, the internal mobility of atoms (which is connected to temperature) has no effect on a material's diamagnetism.

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. Bismuth has a diamagnetic property. As a result, a toroid with a bismuth core has asomewhat higher magnetic field than one with an empty core.

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 applied magnetic field has no effect on the permeability of ferromagnetic materials. For a lower field, it is greater, and vice versa.

e) Magnetic field lines are always nearly normal to the surface of a ferro magnet 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. A ferromagnetic substance has a permeability of at least one. It's always a multiple of one. As a result, magnetic field lines in such materials are almost parallel to the surface at all times.

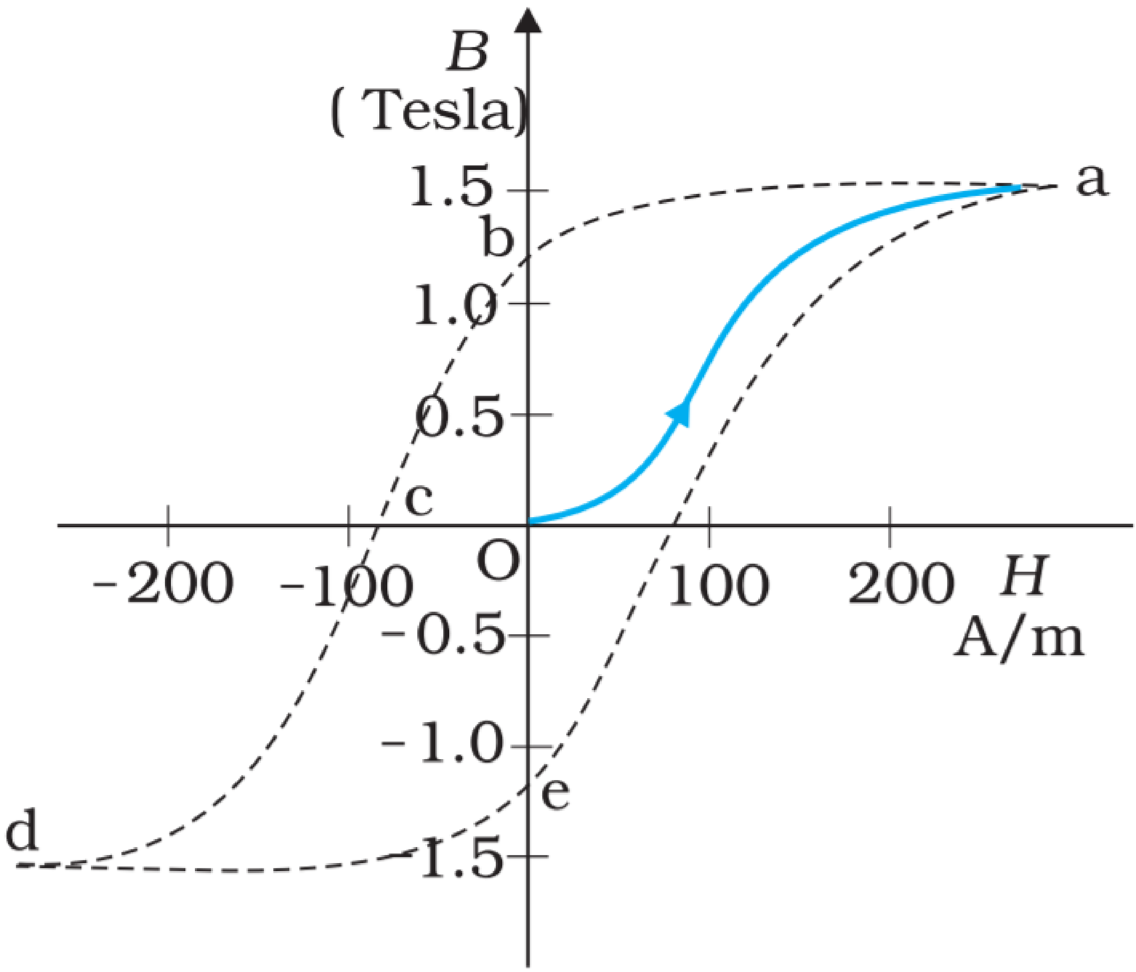
f) Would the maximum possible magnetisation of a paramagnetic sample be of the same order of magnitude as the magnetization of a ferromagnet?

Ans. A paramagnetic sample's greatest possible magnetisation can be on the same order of magnitude as that of a ferromagnet. For saturation, large magnetising fields are required.

5.17 **Answer the following questions:**

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

Ans.



Magnetisation occurs even when the external field is removed, as seen by the provided graph. This represents a ferromagnet's irreversibility.

b) **The hysteresis loop of a soft iron piece has a much smaller area than that of a carbonsteel piece. If the material is to go through repeated cycles of magnetisation, which piece will dissipate greater heat energy?**

Ans. The size of a hysteresis loop is exactly proportional to the dissipated heat energy. The hysteresis curve area of a carbon steel component is larger. As a result, it dissipates more heat energy.

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

Ans. The memory or record of hysteresis loop magnetisation cycles is the value of magnetisation. These bits of data relate to the magnetisation cycle. Information may be stored viahysteresis loops.

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 is used to cover magnetic tapes in cassette players and to manufacture currentcomputer memory storage.

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

Ans. If an area of space is enclosed by soft iron rings, it can be insulated from magnetic fields. Magnetic lines are drawn out of the area in such setups.

5.18 A long straight horizontal cable carries a current of 2.5 A in the direction 10o south ofwest to 10° north of east. The magnetic meridian of the place happens to be 10º west of the geographic meridian. The earth's magnetic field at the location is 0.33 G, and theangle 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.)

Ans. Current in the wire: $I = 2.5A$

Angle of dip at the given location on earth, $\delta = 0^{\circ}$

Earth's magnetic field: $\mathrm{H} = 0.33\mathrm{G} = 0.33\times10^{-4}\mathrm{T}$

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

$$H_H = H\cos\delta$$

$$= 0.33\times10^{-4}\times\cos 0^{\circ} = 0.33\times10^{-4}T$$

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

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

Where,

$\mu_0 =$ permeability of free space = $4\pi\times10^{-7}\,TmA^{-1}$

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

$$= \frac{4\pi\times10^{-7}\times2.5}{2\pi\times0.33\times10^{-4}} = 15.15\times10^{-3}\mathrm{m} = 1.51\mathrm{cm}$$

As a result, at a standard distance of$1.51cm$, a series of neutral spots parallel to and above the wire are identified.

5.19 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 theangle of dip is 35º. The magnetic declination is nearly zero. What are theresultant magnetic fields at points 4.0 cm below the cable?

Ans. Number of horizontal wires in the telephone cable: $n = 4$

Current in each wire: $I = 1.0A$

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

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

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

For a point $4\,cm$ below the cable:

Distance, $r = 4\,cm = 0.04\,m$

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

$$H_{\text{h}} = H\cos\delta - B$$

Where,

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

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

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

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

$$\therefore B = 4 \times \frac{4\pi \times 10^{-7} \times 1}{2\pi \times 0.04}$$
$$= 0.2 \times 10^{-4}\text{T} = 0.2\text{G}$$
$$\therefore \text{H}_{\text{h}} = 0.39\cos 35^{\circ} - 0.2$$
$$= 0.39 \times 0.819 - 0.2 \approx 0.12\text{G}$$

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

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

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

$$\theta = \tan^{-1}\frac{H_v}{H_h}$$

$$= \tan^{-1}\frac{0.22}{0.12} = 61.39^{\circ}$$

The resultant field at the point is given as:

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

5.20 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 $0.35A$, 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 theneedle. Take the magnetic declination at the places to be zero.

Ans. Number of turns in the circular coils: $N = 30$

Radius of the circular coil: $r = 12\,cm = 0.12\,m$

Current in the coil: $I = 0.35A$

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 = $4\pi \times 10^{-7}\,TmA^{-1}$

$$\therefore B = \frac{4\pi \times 10^{-7} \times 2\pi \times 30 \times 0.35}{4\pi \times 0.12}$$
$$= 5.49 \times 10^{-5}\text{T}$$

The compass needle points from West to East. Hence, the horizontal component ofearth'smagnetic field is given as:

$$\text{B}_\text{H} = \text{B}\sin\delta$$
$$= 5.49 \times 10^{-5} \sin 45^\circ = 3.88 \times 10^{-5}\text{T} = 0.388\text{G}$$

(b) The needle will reverse its original orientation when the current in the coil is reversed and the coil is turned by 90° around its vertical axis. The needle will point from East to West in this situation.

5.21 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 dipolecomes to stable equilibrium at an angle of 15o with this field, what is the magnitude ofthe other field?

Ans: Magnitude of one of the magnetic fields: $B_1 = 1.2\times10^{-2}T$

Magnitude of the other magnetic field $= B_2$

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

The angle between the dipole and the field in stable equilibrium is: $\theta_1 = 15^\circ$

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

$\therefore$ 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

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

$$= \frac{1.2\times10^{-2}\times\sin 15^\circ}{\sin 45^\circ} = 4.39\times10^{-3}\text{T}$$

As a result, the other magnetic field has a magnitude of $4.39\times10^{-3}T$.

5.22 A mono energetic ($18keV$) electron beam initially in the horizontal direction is subjectedto a horizontal magnetic field of $0.04G$ normal to the initial direction. Estimate the up ordown deflection of the beam over a distance of $30\,cm$ ($m_e = 9.11\times10^{-19}C$). [Note: Datain this exercise are so chosen that the answer will give you an idea of the effect of earth'smagnetic field on the motion of the electron beam from the electron gun to the screen ina TV set.]

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

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

$E = 18\times10^3 \times 1.6\times10^{-19}\text{J}$

Magnetic field: $B = 0.04\text{G}$

Mass of an electron: $m_e = 9.11\times10^{-19}\text{kg}$

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:

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

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

$$=\sqrt{\frac{2\times18\times10^3\times1.6\times10^{-19}\times10^{-15}}{9.11\times10^{-31}}}=0.795\times10^8\,\mathrm{m/s}$$

The electron beam deflects along a circular path of radius, r.

The magnetic field's force cancels out the path's centripetal force:

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

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

$$=\frac{9.11\times10^{-31}\times0.795\times10^8}{0.4\times10^{-4}\times1.6\times10^{-19}}=11.3\mathrm{m}$$

Let the electron beams up and down deflection be $x=r(1-\cos\theta)$,

Where $\theta=$ Angle of Declination.

$$\sin\theta=\frac{d}{r}$$

$$=\frac{0.3}{11.3}$$

$$\theta=\sin^{-1}\frac{0.3}{11.3}=1.521^\circ$$

$$\text{And } x=11.3\left(1-\cos1.521^\circ\right)$$

$$=0.0039\mathrm{m}=3.9\mathrm{mm}$$

As a result, the beam's up and down deflection is $3.9\,mm$

5.23 A sample of paramagnetic salt contains 2.0×10^{24} atomic dipoles each of dipole moment $1.5\times10^{-23}\,JT^{-1}$. The sample is placed under a homogeneous magnetic field of 0.64 T, 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. Number of atomic dipoles: $n=2.0\times10^{24}$

Dipole moment of each atomic dipole: $M=1.5\times10^{-23}\,\mathrm{JT}^{-1}$

When the magnetic field: $\mathrm{B}_1=0.64\mathrm{T}$

The sample is cooled to a temperature: $T_1 = 4.2^\circ K$

Total dipole moment of the atomic dipole: $M_{tot} = n \times M$.

$$= 2\times10^{24}\times1.5\times10^{-23}$$
$$= 30JT^{-1}$$

Magnetic saturation is achieved at 15% .

Hence, effective dipole moment: $M_1 = \frac{15}{100}\times 30 = 4.5JT^{-1}$

When the magnetic field: $B_2 = 0.98T$

Temperature: $T_2 = 2.8^\circ K$

Its total dipole moment = M_2

Curie's law states that the ratio of two magnetic dipoles is:

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

$$= \frac{0.98\times4.2\times4.5}{2.8\times0.64} = 10.336JT^{-1}$$

Therefore, $10.336JT^{-1}$ is the total dipole moment of the sample for a magnetic field of $0.98T$ and a temperature of $2.8K$

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

Ans. Mean radius of a Rowland ring: $r = 15cm = 0.15m$

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

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

Magnetising current: $I = 1.2A$

The magnetic field is given by the relation:

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

Where,

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

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

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

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

$$\mu_s = -(e/m)S,$$
$$\mu_1 = -(e/2m)l$$

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

Ans. The intrinsic spin angular momentum and the orbital angular momentum are linked via the magnetic moment.

Additional Exercises

5.16 Answer the following questions:

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

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

(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?

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

(e) Magnetic field lines are always nearly normal to the surface of a ferro magnet 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?

(f) Would the maximum possible magnetization of a paramagnetic sample be of the same order of magnitude as the magnetization of a ferro magnet?

Solution:

(a) At high temperatures, the alignments of dipoles are broken due to the random thermal motion of molecules. This disruption is lessened when the temperature drops. As a result, when a paramagnetic sample is cooled, it becomes more magnetized.

(b) In a diamagnetic substance, the induced dipole moment is always in opposition to the magnetizing field. As a result, the internal mobility of atoms (which is connected to temperature) has no effect on a material's diamagnetism.

(c) Bismuth has a diamagnetic property. As a result, a toroid with a bismuth core has a somewhat higher magnetic field than one with an empty core.
(d) The applied magnetic field has no effect on the permeability of ferromagnetic materials. For a lower field, it is greater, and vice versa.
(e) A ferromagnetic substance has a permeability of at least one. It's always a multiple of one. As a result, magnetic field lines are virtually parallel to the surface of such materials at all times.
(f) A paramagnetic sample's greatest possible magnetization can be on the same order of magnitude as a ferromagnetic sample's magnetization. For saturation, large magnetizing fields are required.

5.17 Answer the following questions:

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

(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 magnetisation, which piece will dissipate greater heat energy?

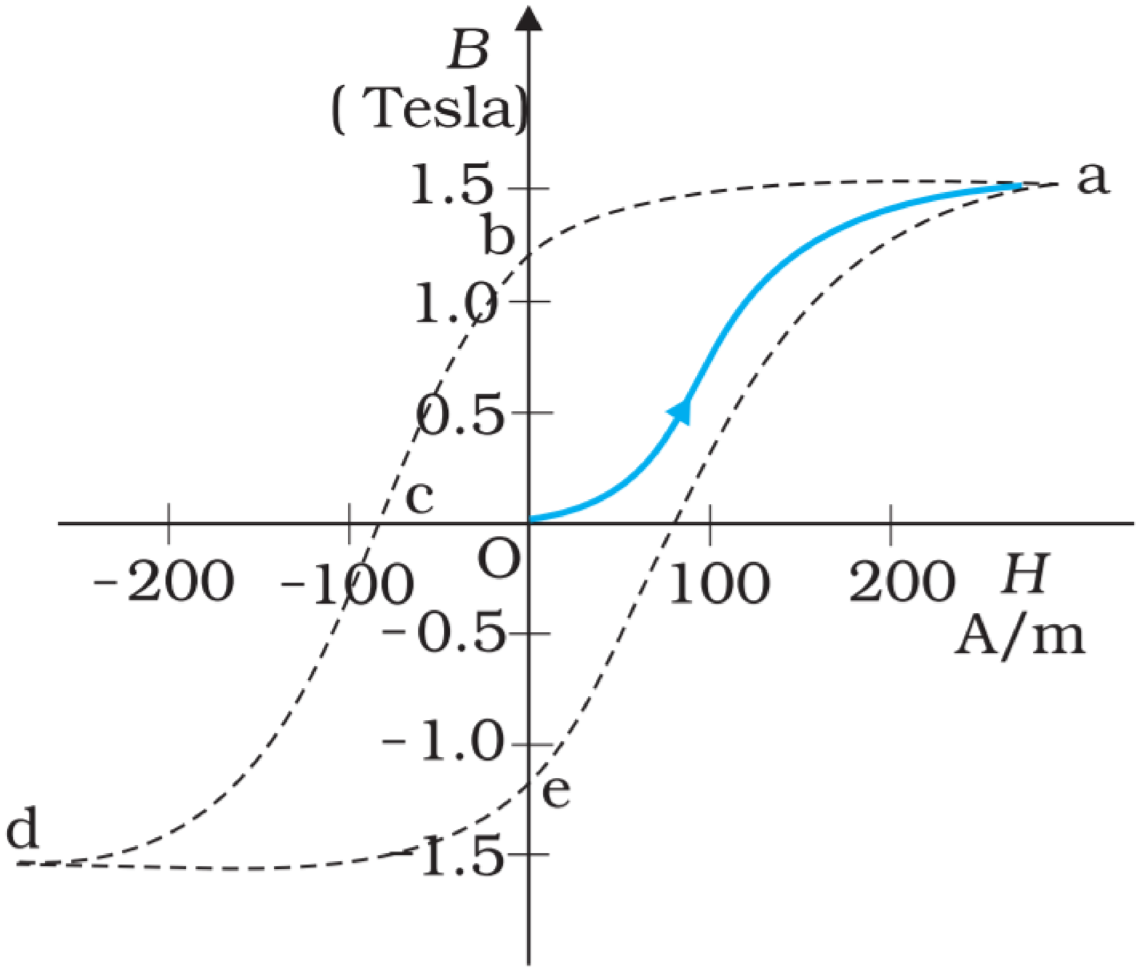
(c) 'A system displaying a hysteresis loop such as a ferro magnet, is a device for storing memory?' Explain the meaning of this statement.

(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?

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

Solution:

The following diagram depicts the hysteresis curve (B-H curve) of a ferromagnetic material.



(a) Magnetization occurs even when the external field is removed, as shown by the given curve. This reflects a ferromagnet's irreversibility.

(b) The area of a hysteresis loop is directly proportional to the dissipated heat energy. The hysteresis curve area of a carbon steel component is larger. As a result, it dissipates more heat energy.

(c) The memory or record of magnetization hysteresis loop cycles is the value of magnetism. These bits of data relate to the magnetization cycle. Information can be stored via hysteresis loops.

(d) Ceramic is used to cover magnetic tapes in cassette players and to manufacture current computer memory stores.

(e) If a region of space is enclosed by soft iron rings, it can be insulated from magnetic fields. Magnetic lines are drawn out of the region in such setups.

5.18 A long straight horizontal cable carries a current of 2.5 A in the direction 10^o south of west to 10^o north of east. The magnetic meridian of the place happens to be 10^o 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, magnetic field due to a current-carrying cable is equal and opposite to the horizontal component of earth's magnetic field.)

Solution:

The current flowing through the wire, $I = 2.5\,A$

Angle of dip at a specific point on the earth, $\delta = 0^o$

The magnetic field of the Earth, $H = 0.33, g = 0.33\times10^{-4}T$

The horizontal component of the earth's magnetic field is calculated as follows:

$$H_H = H\,\text{Cos}\,\delta$$

$$= 0.33\times10^{-4}\times\cos 0^o = 0.33\times10^{-4}T$$

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

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

Where,

$\mu_o =$ Permeability of free space

$$\mu_o = 4\pi\times10^{-7}TmA^{-1}$$

$$\therefore R = \frac{\mu_o I}{2\pi H_H}$$

$$R = \frac{4\pi\times10^{-7}\times2.5}{2\pi\times0.33\times10^{-4}}$$

$$R = 15.15\times10^{-3}m$$

$$R = 1.51cm$$

As a result, a series of neutral sites parallel to and above the wire are spaced at a standard distance of $1.51\,cm$.

5.19 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^o. The magnetic declination is nearly zero. What are the resultant magnetic fields at points 4.0 cm below the cable?

Solution:

The number of horizontal wires in a telephone cable is the number of wires that run horizontally, $n = 4$

Each wire's current , $I = 1.0\,A$

The magnetic field of the Earth at a specific location,

$$H = 0.39\ G$$

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

At the site, the angle of dip, $\delta = 35°$

Declination angle, $\theta \sim 0°$

For a point $4\ cm$ below the cable, use the following formula:

Distance,

$$r = 4\ cm$$

$$r = 0.04\ m$$

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

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

Where,

B = Due to current I in the four wires, there is a magnetic field at $4\ cm$.

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

$\mu_o =$ Permeability of free space

$$\mu_o = 4n \times 10^{-7} TmA^{-1}$$

$$\therefore B = 4 \times \frac{4\pi \times 10^{-7} \times 1}{2\pi \times 0.04}$$

$$B = 0.2 \times 10^{-4} T$$

$$B = 0.2G$$

$$\therefore H_h = 0.39 \cos 35^o - 0.2$$

$$H_h = 0.39 \times 0.819 - 0.2 \approx 0.12G$$

The earth's magnetic field's vertical component is given as:

$$H_h = H \sin \delta$$

$$H_h = 0.39 \sin 35^o$$

$$H_h = 0.22G$$

The field's horizontal component creates the following angle:

$$\theta = \tan^{-1}\frac{H}{H_h}$$

$$\theta = \tan^{-1}\frac{0.22}{0.12}$$

$$\theta = 61.39^o$$

The point's resultant field is as follows:

$$H_1 = \sqrt{(H_v)^2 + (H_h)^2}$$

$$H_1 = \sqrt{(0.22)^2 + (0.12)^2}$$

$$H_1 = 0.25G$$

For a point $4\ cm$ above the cable, use the following formula:

Component of the earth's magnetic field that is horizontal:

$$H_h \ = \ Hcos\delta \ + \ B$$

The earth's magnetic field has a vertical component:

$$H_v \ = \ Hsin\delta$$

= 0.39 sin 35° = 0.22 G

$$= \ 0.39\ cos\ 35° \ + \ 0.2$$

$$= \ 0.52\ G$$

Angle, $\theta = \tan^{-1}\frac{H_v}{H_h}$

$$\theta = \tan^{-1}\frac{0.22}{0.52}$$

$$\theta = \ 22.9°$$

And this is the resultant field:

$$H_1 = \sqrt{(H_v)^2 + (H_h)^2}$$

$$H_1 = \sqrt{(0.22)^2 + (0.52)^2}$$

$$H_1 = 0.56T$$

5.20 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^o 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^o in the anticlockwise sense looking from above. Predict the direction of the needle. Take the magnetic declination at the places to be zero.

Solution:

The circular coil's number of turns, $N = 30$

The circular coil's radius,

$r = 12\ cm$

$r = 0.12\ m$

The coil's current, $I = 0.35\ A$

The dip angle, $\delta = 45°$

(a) At a distance of r, the magnetic field due to current I is given as:

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

Where,

$\mu_o =$ Permeability of free space

$\mu_o = 4n \times 10$

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

$B = 5.49 \times 10^{-5} T$

From West to East, the compass needle points. As a result, the horizontal component of the earth's magnetic field is:

$B_H = Bsin\ \delta$

$= 5.49 \times 10^{-5}\ sin\ 45°$

$= 3.88 \times 10^{-5}\ T$

$= 0.388\ G$

(b) The needle will reverse its original direction when the current in the coil is reversed and the coil is turned by an angle of 90^o approximately its vertical axis. The needle will point from East to West in this situation.

5.21 A magnetic dipole is under the influence of two magnetic fields. The angle between the field directions is 60^o, 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^o with this field, what is the magnitude of the other field?

Solution:

One of the magnetic fields' magnitudes, $B_1 = 1.2 \times 10^{-2} T$

The other magnetic field's magnitude $= B_2$

The angle formed by the two fields, $\theta = 60^o$

The angle between the dipole and the field is stable at equilibrium B_1, $\theta_1 = 15^o$

The angle formed by the dipole and the field $B_2, \theta_2 = \theta - \theta_1 = 60^o - 15^o = 45^o$

The torques between both fields must balance each other at rotational equilibrium.

$\therefore$ Torque due to field $B_2 =$ Torque due to field B_2

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

Where,

M = The dipole's magnetic moment

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

$$B_2 = \frac{1.2 \times 10^{-2} \times \sin 15^o}{\sin 45^o}$$

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

As a result, the other magnetic field's magnitude is $4.39 \times 10^{-3} T$.

5.22 A mono energetic (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 ($m_e = 9.11 \times 10^{-19}$ C). [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.]

Solution:

An electron beam's energy,

$$E = 18\ keV$$

$$E = 18 \times 10^3\ eV$$

An electron's charge,

$$e = 1.6 \times 10^{-19}\ C$$

$$E = 18 \times 10^3 \times 1.6 \times 10^{-19}\ J$$

Magnetic field, $B = 0.04\ G$

An electron's mass, $m_e = 9.11 \times 10^{-19}\ kg$

The distance travelled by the electron beam,

$$d = 30\ cm$$

$$d = 0.3\ m$$

The electron beams kinetic energy can be written as:

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

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

$$v = \sqrt{\frac{2 \times 18 \times 10^3 \times 1.6 \times 10^{-19} \times 10^{-15}}{9.11 \times 10^{-31}}}$$

$$v = 0.795 \times 10^8 m/s$$

The electron beam deflects along an r-radius circular path.

The magnetic field's force counteracts the path's centripetal force.

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

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

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

$$r = 11.3m$$

Allow the electron beam to deflect up and down. $x = r(1 - \cos\theta)$

Where,

$\theta =$ Angle of declination

$$\sin\theta = \frac{d}{r}$$

$$\sin\theta = \frac{0.3}{11.3}$$

$$\theta = \sin^{-1}\frac{0.3}{11.3}$$

$$\theta = 1.521^o$$

And $x = 11.3(1 - \cos 1.521^o)$

$$x = 0.0039m$$

$$x = 3.9mm$$

As a result, the beam's up and down deflection is $3.9mm$.

5.23 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 0.98T and a temperature of 2.8 K? (Assume Curie's law).

Solution:

The number of atomic dipoles is the number of atomic dipoles that exist in a given

$$n = 2.0 \times 10^{24}$$

Each atomic dipole's dipole moment, $M = 1.5 \times 10^{-23}\ J\ T^{-1}$

When a magnetic field is present, $B_1 = 0.64\ T$

The sample is cooled to the following temperature: $T_1 = 4.2°K$

The atomic dipole's total dipole moment, $M_{tot} = n \times M$

$$M_{tot} = 2 \times 10^{24} \times 1.5 \times 10^{-23}$$

$$M_{tot} = 30\ J\ T^{-1}$$

At 15%, magnetic saturation is attained.

As a result, the effective dipole moment,

$$M_1 = \frac{15}{100} \times 30$$

$M_1 = 4.5\,J\,T^{-1}$

When a magnetic field is present, $B_2 \;=\; 0.98\;T$

Temperature, $T_2 \;=\; 2.8°K$

The magnitude of its whole dipole moment $=\; M_2$

Curie's law states that the ratio of two magnetic dipoles is:

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

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

$$M_2 = \frac{0.98}{2.8} \times \frac{4.2}{0.64} \times 4.5$$

$$M_2 = 10.336\,J\,T^{-4}$$

As a result, for a magnetic field of $0.98\;T$ and a temperature of $2.8\;K$, the total dipole moment of the sample is $10.336\,J\,T^{-4}$.

5.24 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?

Solution:

A Rowland ring's average radius,

$r \;=\; 15\;cm$

$r = \; 0.15\;m$

The number of turns on a ferromagnetic core is measured in turns. $N \;=\; 3500$

The core material's relative permeability, $\mu_r = 800$

Magnetizing current, $I \;=\; 1.2\;A$

The magnetic field can be calculated using the following formula:

$$A = \frac{\mu_r \mu_o IN}{2\pi r}$$

Where,

μ_0 = Free space permeability

$\mu_0 \;=\; 4n \;\times\; 10^{-7}\;Tm\,A^{-1}$

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

$$B=4.48T$$

As a result, the core's magnetic field is $4.48T$.

5.25 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.

Solution:

The magnetic moment associated with the intrinsic spin angular momentum and the orbital angular momentum.