Q 5.1) Answer the following:

(a) A vector needs three quantities for its specification. Name the three independent quantities conventionally used to specify the earth's magnetic field.

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

(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?

(d) In which direction would a compass free to move in the vertical plane point to, is located right on the geomagnetic north or south pole?

(e) The earth's field, it is claimed, roughly approximates the field due to a dipole of the magnetic moment 8 x 10^{22} J T^{-1} located at its centre. Check the order of magnitude of this number in some way.

(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?

Solution:

(a) The three independent conventional quantities used for determining the earth's magnetic field are:

(i) Magnetic declination,

(ii) Angle of dip

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

(b) 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. Hence, as the location of Britain on the globe is closer to the magnetic North pole, the angle of dip would be greater in Britain (About 70°) than in southern India.

(c) It is assumed that a huge bar magnet is submerged inside the earth with its north pole near the geographic South Pole and its south pole near the geographic North Pole.

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

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

(e) Magnetic moment, M = $8 \times 10^{22}\ J\,T^{-1}$

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

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

Where,

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

Therefore, B = $\frac{4\pi\times10^{-7}\times8\times10^{22}}{4\pi\times(6.4\times10^{6})^{3}} = 0.3\ G$

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

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

Q 5.2) Answer the following:

(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?

(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?

(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?

(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 a distant past?

(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?

(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.

Solution:

(a) Earth's magnetic field varies with time and it takes a couple of hundred years to change by an obvious sum. The variation in the Earth's magnetic field with respect to time can't be ignored.

(b) The Iron core at the Earth's centre cannot be considered as a source of Earth's magnetism because it is in its molten form and is non-ferromagnetic.

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

(d) The Earth's magnetic field reversal has been recorded several times in the past about 4 to 5 billion years ago. These changing magnetic fields were weakly recorded in rocks during their solidification. One can obtain clues about the geomagnetic history from the analysis of this rock magnetism.

(e) Due to the presence of ionosphere, the Earth's field deviates from its dipole shape substantially at large distances. The Earth's field is slightly modified in this region because of the field of single ions. The magnetic field associated with them is produced while in motion.

(f) A remarkably weak magnetic field can deflect charged particles moving in a circle. This may not be detectable for a large radius path. With reference to the gigantic interstellar space, the deflection can alter the passage of charged particles.

Q 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 $4.5 \times 10^{-2}\ J$. What is the magnitude of the magnetic moment of the magnet?

Solution:

Magnetic field strength, B = 0.25 T

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

The angle between the bar magnet and the external magnetic field, $\theta = 30^\circ$

Torque is related to magnetic moment (M) as:

$T = MBsin\theta$

$\therefore\ M = \frac{T}{Bsin\theta}$

= $\frac{4.5 \times 10^{-2}}{0.25 \times sin30^\circ} = 0.36\ J\ T^{-1}$

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

Q 5.4) A short bar magnet of magnetic moment m = 0.32 JT^{-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?

Solution:

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

External magnetic field, B = 0.15 T

(a) The bar magnet is aligned along the magnetic field. This system is considered as being in stable equilibrium.

Hence, the angle θ, between the bar magnet and the magnetic field is 0°.

Potential energy of the system = $-MBcos\theta$

= $-0.32 \times 0.15\ cos 0^{\circ}$

= $-4.8 \times 10^{-2}\ J$

(b) The bar magnet is oriented 180^0 to the magnetic field. Hence, it is in unstable equilibrium. θ =180°

Potential energy = $-MBcos\theta$

= $-0.32 \times 0.15\ cos 180^{\circ}$

= $4.8 \times 10^{-2}\ J$

Q 5.5) A closely wound solenoid of 800 turns and area of cross-section 2.5 × 10^{-4} m^2 carries a current of 3.0 A. Explain the sense in which the solenoid acts like a bar magnet. What is its associated magnetic moment?

Solution:

Number of turns in the solenoid, n = 800

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

Current in the solenoid, I = 3.0 A

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

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

M = n I A

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

= $0.6\ J\ T^{-1}$

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

Solution:

Magnetic field strength, B = 0.25 T

Magnetic moment, M = 0.6 T^{-1}

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

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

$\tau = MBsin\theta$

= $0.6 \times 0.25\ sin30^\circ$

= 7.5×10^{-2} J

Q 5.7) A bar magnet of magnetic moment 1.5 J T^{-1} lies aligned with the direction of a uniform magnetic field of 0.22 T.

(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?

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

Solution:

(a) Magnetic moment, M = $1.5\ J\ T^{-1}$

Magnetic field strength, B = 0.22 T

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

Final angle between the axis and the magnetic field, $\theta_2 = 90^\circ$

The work required to make the magnetic moment normal to the direction of the magnetic field is given as:

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

= $-1.5 \times 0.22(cos90^\circ - cos0^\circ)$

= – 0.33 (0 – 1)

= 0.33 J

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

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

The work required to make the magnetic moment opposite to the direction of the magnetic field is given as:

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

= $-1.5 \times 0.22(cos180^\circ - cos0^\circ)$

= – 0.33 (– 1 – 1)

= 0.66 J

(b)
For case (i):

$\theta = \theta_2 = 90^\circ$

∴ Torque, $\tau = MBsin\theta$

= $MBsin90^\circ$

= 1.5 × 0.22 sin 90^0

= 0.33 J

The torque tends to align the magnitude moment vector along B.

For case (ii):

$\theta = \theta_2 = 180^\circ$

∴ Torque, $\tau = MBsin\theta$

= $MBsin180^\circ$

= 0 J

Q 5.8) A closely wound solenoid of 2000 turns and area of cross-section 1.6 x 10^{-4} m^2, carrying 4.0 A current, is suspended through its centre, thereby allowing it to turn in a horizontal plane.

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

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

Solution:

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 = 4.0 A

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

M = nAI

= $2000 \times 4 \times 1.6 \times 10^{-4}$

= 1.28 Am^2

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

The angle between the magnetic field and the axis of the solenoid, $\theta = 30^\circ$

Torque, $\tau = MBsin\theta$

= $1.28 \times 7.5 \times 10^{-2}\ sin30^\circ$

= $0.048J$

Since the magnetic field is uniform, the force on the solenoid is zero. The torque on the solenoid is $0.048J$.

Q 5.9) A circular coil of 16 turns and radius 10 cm carrying a current of 0.75 A rests with its plane normal to an external field of magnitude 5.0 × 10^{-2} T. The coil is free to turn about an axis in its plane perpendicular to the field direction. When the coil is turned slightly and released, it oscillates about its stable equilibrium with a frequency of 2.0 s^{-1}. What is the moment of inertia of the coil about its axis of rotation?

Solution:

Number of turns in the circular coil, N = 16

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

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

Current in the coil, I = 0.75 A

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

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

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

$16 \times 0.75 \times n \times (0.1)^2$

= $0.377 \ J \ T^{-1}$

Frequency is given by the relation:

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

Where,

I = Moment of inertia of the coil

Rearranging the above formula, we get:

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

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

= $1.2 \times 10^{-4} \ kg \ m^2$

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

Q 5.10) 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.

Solution:

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

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

Earth's magnetic field strength = B

We can relate B and B_H as:

$B_H = B cos\delta$

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

= $\frac{0.35}{cos\ 22^\circ}$ = 0.38 G

Hence, the strength of the earth's magnetic field at the given location is 0.38 G.

Q 5.11) At a certain location in Africa, a compass points 12° west of the geographic north. The north tip of the magnetic needle of a dip circle placed in the plane of magnetic meridian points 60° above the horizontal. The horizontal component of the earth's field is measured to be 0.16 G. Specify the direction and magnitude of the earth's field at the location.

Solution:

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

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

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

Earth's magnetic field at the given location = B

We can relate B and B_H as:

$B_H = B cos\delta$

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

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

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

Q 5.12) A short bar magnet has a magnetic moment of 0.48 J T^{-1}. Give the direction and magnitude of the magnetic field produced by the magnet at a distance of 10 cm from the centre of the magnet on (a) the axis, (b) the equatorial lines (normal bisector) of the magnet.

Solution:

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

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

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

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

Where,

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

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

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

The magnetic field is along the S-N direction.

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

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

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

= 0.48 G

The magnetic field is along with the N – S direction.

Q 5.13) A short bar magnet placed in a horizontal plane has its axis aligned along the magnetic north-south direction. Null points are found on the axis of the magnet at 14 cm from the centre of the magnet. The earth's magnetic field at the place is 0.36 G and the angle of dip is zero. What is the total magnetic field on the normal bisector of the magnet at the same distance as the null–point (i.e., 14 cm) from the centre of the magnet? (At null points, field due to a magnet is equal and opposite to the horizontal component of earth's magnetic field.)

Solution:

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

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

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

Where,

μ_0 = Permeability of free space

M = Magnetic moment

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

$$B_2 = \frac{\mu_0 M}{4\pi d^3} = \frac{H}{2} \quad [Using\ equation\ (i)]$$

Total magnetic field, B = $B_1 + B_2$

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

= 0.36 + 0.18 = 0.54 G

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

Q 5.14) If the bar magnet in exercise 5.13 is turned around by 180°, where will the new null points be located?

Solution:

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

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

Where,

M = Magnetic moment

μ_0 = Permeability of free space

H = Horizontal component of the magnetic field at d_1

If the bar magnet is turned through 180^0, then the neutral point will lie on the equatorial line.

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

$$B_1 = \frac{\mu_0 2M}{4\pi (d_2)^3} = H \quad \ldots (2)$$

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 11.1 cm on the normal bisector.

Q 5.15) A short bar magnet of magnetic moment 5.25 × 10^{-2} J T^{-1} is placed with its axis perpendicular to the earth's field direction. At what distance from the centre of the magnet, the resultant field is inclined at 45° with earth's field on (a) its normal bisector and (b) its axis. The magnitude of the earth's field at the place is given to be 0.42 G. Ignore the length of the magnet in comparison to the distances involved.

Solution:

Magnetic moment of the bar magnet, M = $5.25 \times 10^{-2}\ J\ T^{-1}$

Magnitude of earth's magnetic field at a place, H = 0.42 G = $0.42 \times 10^{-4}\ T$

(a) The magnetic field at a distance R from the centre of the magnet on the ordinary bisector is given by:

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

Where,

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

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

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

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

= $R^3 = \frac{4\pi \times 10^{-7} \times 5.25 \times 10^{-2}}{4\pi \times 0.42 \times 10^{-4}}$

= 12.5×10^{-5}

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

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

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

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

$$\therefore\ B' = H$$

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

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

$$= \frac{4\pi\times10^{-7}\times2\times5.25\times10^{-2}}{4\pi\times0.42\times10^{-4}} = 25 \times 10^{-5}$$

$$\therefore\ R = 0.063\ m = 6.3\ cm$$

Q 5.16) Answer the following questions:
(a) Why does a paramagnetic sample display greater magnetisation (for the same magnetising 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 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?
(f) Would the maximum possible magnetisation of a paramagnetic sample be of the same order of magnitude as the magnetization of a ferromagnet?

Solution:

(a) The thermal motion reduces at a lower temperature and the tendency to disrupt the alignment of the dipoles decreases.

(b) The dipole moment induced is always opposite to the magnetising field. Therefore, the internal motion of the atoms due to the temperature will not affect the magnetism of the material.
(c) Bismuth is diamagnetic substance. Therefore, a toroid with bismith core will have a field slightly less than when the core is empty.
(d) Permeability of the ferromagnetic material depends on the magnetic field. Permeability is greater for lower fields.

(e) Proof of this important fact (of much practical use) is based on boundary conditions of magnetic fields (B and H) at the interface of two media. (When one of the media has $\mu >> 1$, the field lines meet this medium nearly normally.)
(f) Yes. Apart from minor differences in strength of the individual atomic dipoles of two different materials, a paramagnetic sample with saturated magnetisation will have the same order of magnetisation. But of course, saturation requires impractically high magnetising fields.

Q 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 ferromagnet, 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:

(a) The domain aligns in the direction of the magnetic field when the substance is placed in an external magnetic field. Some energy is spent in the process of alignment. When the external field is removed, the substance retains some magnetisation. The energy spent in the process of magnetisation is not fully recovered. It is lost in the form of heat. This is the basic cause for the irreversibility of the magnetisation curve of a ferromagnet substance.
(b) Carbon steel piece, because heat lost per cycle is proportional to the area of the hysteresis loop.
(c) Magnetisation of a ferromagnet is not a single-valued function of the magnetising field. Its value for a particular field depends both on the field and also on the history of magnetisation (i.e., how many cycles of magnetisation it has gone through, etc.). In other words, the value of magnetisation is a record or memory of its cycles of magnetisation. If information bits can be made to correspond to these cycles, the system displaying such a hysteresis loop can act as a device for storing information.
(d) Ceramics (specially treated barium iron oxides) also called ferrites.
(e) Surrounding the region with soft iron rings. Magnetic field lines will be drawn into the rings, and the enclosed space will be free of a magnetic field. But this shielding is only approximate, unlike the perfect electric shielding of a cavity in a conductor placed in an external electric field.

Q 5.18) A long straight horizontal cable carries a current of 2.5 A in the direction 10° south of west to 10° north of east. The magnetic meridian of the place happens to be 10° west of the geographic meridian. The earth's magnetic field at the location is 0.33 G, and the angle of dip is zero. Locate the line of neutral points (ignore the thickness of the cable)? (At neutral points, magnetic field due to a current-carrying the cable is equal and opposite to the horizontal component of earth's magnetic field.)

Solution:

Current in the wire = 2.5 A
The earth's magnetic field at a location, R= 0.33 G = 0.33×10^{-4} T

Angle of dip is zero, $\delta = 0$
Horizontal component of earth's magnetic field, $B_H = R \cos\delta = 0.33 \times 10^{-4} \cos 0 = 0.33 \times 10^{-4}$ T
Magnetic field due to a current carrying conductor, $B_c = (\mu_0/2\pi) \times (I/r)$
$B_c = (4\pi \times 10^{-7}/2\pi) \times (2.5/r) = (5 \times 10^{-7}/r)$
$B_H = B_c$
$0.33 \times 10^{-4} = 5 \times 10^{-7}/r$
$r = 5 \times 10^{-7}/0.33 \times 10^{-4}$
= 0.015 m = 1.5 cm
Hence neutral points lie on a straight line parallel to the cable at a perpendicular distance of 1.5cm.

Q 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°. The magnetic declination is nearly zero. What are the resultant magnetic fields at points 4.0 cm below the cable?

Solution:

First let us decide the direction which would best represent the situation.
We know that
$B_H = B \cos \delta$
$= 0.39 \times \cos 35^o$ G
$B_H = 0.32$G
Here
$B_V = B \sin \delta$
$= 0.39 \times \sin 35^o$ G
$B_V = 0.22$G
It is given that the telephone cable carry a total current of 4.0 A in the direction east to west. So the resultant magnetic field 4.0 cm below.

$B_{wire} = \frac{\mu_0}{4\pi}\frac{2I}{r}$
$= 10^{-7} \times \frac{2\times4}{4\times10^{-2}}$
$= 2 \times 10^{-5}$ T
= 0.2G
Net magnetic field

$$B_{net} = \sqrt{(B_H - B_{wire})^2 + B_V^2}$$
$$= \sqrt{(0.12)^2 + (0.22)^2}$$
$$= \sqrt{0.0144 + 0.0484}$$
= 0.25G
The resultant magnetic field at points 4 cm below the cable 0.25 G.

Q 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 0.35 A, the needle points west to east.
(a) Determine the horizontal component of the earth's magnetic field at the location.
(b) The current in the coil is reversed, and the coil is rotated about its vertical axis by an angle

of 90° in the anticlockwise sense looking from above. Predict the direction of the needle. Take the magnetic declination at the places to be zero.

Solution:

Number of turns = 30
Radius of the coil = 12 cm
Current in the coil = 0.35 A
Angle of dip, $\delta = 45^0$
(a) Horizontal component of earth's magnetic field,
$B_H = B \sin\delta$
B is the magnetic field strength due to the current in the coil
$B = (\mu_0/4\pi)\ (2\pi nI/r)$
$= (4\pi \times 10^{-7}/4\pi)\ (2\pi \times 30 \times 0.35/0.12)$
$= 5.49 \times 10^{-5}$ T
Therefore, $B_H = B \sin\delta$
$= (5.49 \times 10^{-5}) \sin 45^0$
$= 3.88 \times 10^{-5}$ T = 0.388 G
(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 direction. The needle will point from east to west.

Q 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 1.2×10^{-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?

Solution:

Magnitude of one of the magnetic field, $B_1 = 1.2 \times 10^{-2}$ T
Let the magnitude of the other field is B_2
Angle between the field, $\theta = 60°$
At stable equilibrium, the angle between the dipole and the field B_1, $\theta_1 = 15°$
Angle between the dipole and the field B_2, $\theta_2 = \theta - \theta_1 = 45°$
Torque due to the field B_1 = Torque due to the field B_2
$MB_1 \sin\theta_1 = MB_2 \sin\theta_2$
here, M is the magnetic moment of the dipole
$B_2 = MB_1 \sin\theta_1/M \sin\theta_2$
$= (1.2 \times 10^{-2}) \times \sin 15^0/\sin 45^0 = 4.39 \times 10^{-3}$ T
Magnetic field due to the other magnetic field is 4.39×10^{-3} T

Q 5. 22) A monoenergetic (18 keV) electron beam initially in the horizontal direction is subjected to a horizontal magnetic field of 0.04 G normal to the initial direction. Estimate the up or down deflection of the beam over a distance of 30 cm ($m_e = 9.11 \times 10^{-31}$ kg). [Note: Data in this exercise are so chosen that the answer will give you an idea of the effect of earth's magnetic field on the motion of the electron beam from the electron gun to the screen in a TV set.]

Solution:

Energy of the electron beam, E = 18 keV = 18 x 10^3 eV = 18 x 10^3 x 1.6 x 10^{-19} J
Magnetic field, B = 0.04 G
Mass of the electron, m_e = 9.11 × 10^{-31} kg
Distance to which the beam travels, d = 30 cm = 0.3 m
Kinetic energy of the electron beam is
E = (1/2) mv^2

$$v = \sqrt{\frac{2\times18\times10^3\times1.6\times10^{-19}}{9.11\times10^{-31}}} = 0.795 \times 10^8 m/s$$

The electron beam deflects along the circular path of radius r.
The centripetal force is balanced by the force due to the magnetic field
Bev = mv^2/r
r = mv/Be
= (9.11 x 10^{-31} x 0.795 x 10^8)/(0.04 x 10^{-4} x 1.6 x 10^{-19})
= (7.24 x 10^{-23})/(0.064 x 10^{-23})
= 113.125
Let the up and down deflection of the beam be x = r (1 – cosθ)
here, θ is the angle of deflection
sin θ = d/r
= 0.3/113.12 = 0.0026
θ = sin $^{-1}$ (0.0026)= 0.1489^0
x = r (1 – cosθ) = 113.12 (1 – cos 0.1489^0)
= 113.12 (1- 0.999)= 113.12 x 0.01 = 1.13 mm

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

Solution:

Number of diatomic dipoles = 2.0 × 10^{24}
Dipole moment of each dipole, M'= 1.5 × 10^{-23} J T^{-1}
Magnetic field strength, B_1= 0.64 T
Cooled to a temperature, T_1= 4.2 K
Total dipole moment of the sample = n x M' = 2.0 × 10^{24} x1.5 × 10^{-23} = 30
Degree of magnetic saturation = 15 **%**
Therefore, M_1 = (15/100) x 30 = 4.5 J/T
Magnetic field strength, B_2 = 0.98 T
Temperature, T_2 = 2.8 K
The ratio of magnetic dipole from Curie temperature,

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

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

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

= 18.52/1.79 = 10.34 J/T

Q 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:

Mean radius of the Rowland ring = 15 cm
Number of turns = 3500
Relative permeability of the core, μ_r = 800
Magnetising current, I = 1.2 A

Magnetic field at the core, $B = \frac{\mu_r \mu_0 I N}{2\pi r}$

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

The magnetic field in the core is 4.48 T

Q 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:
μ_s= –(e/m) S,
μ_l= –(e/2m)l
Which of these relations is in accordance with the result expected classically? Outline the derivation of the classical result.

Solution:

Of the two, the relation μ_l = – (e/2m)l is in accordance with classical physics. It follows easily from the definitions of μ_l and l:
μ_l = IA = (e/T) πr^2 ——(1)
l = mvr = m ($2\pi r^2$/T) ——(2)
where r is the radius of the circular orbit which the electron of mass m and charge (–e) completes in time T.
Dividing (1) by (2).
Clearly, μ_l/l = [(e/T) πr^2]/[m ($2\pi r^2$/T)] = –(e/2m)
Therefore, μ_l= (−e /2 m) l
Since the charge of the electron is negative (–e), it is easily seen that μ_l and l are antiparallel, both normal to the plane of the orbit.

Note μ_s/S in contrast to μ_l /l is e/m, i.e., twice the classically expected value. This latter result (verified experimentally) is an outstanding consequence of modern quantum theory and cannot be obtained classically