5. Magnetism and Matter

3) Magnetic field strength, $B = 0.25\,T$
Torque on the bar magnet, $T = 4.5 \times 10^{-2}\,J$
Angle between the bar magnet and the external magnetic field, $\theta = 30^\circ$
Torque is related to magnetic field (M) as:
$T = MB \sin\theta$

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

$$= \frac{4.5 \times 10^{-2}}{0.25 \times \sin 30^\circ} = 0.36\,JT^{-1}$$

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

4) a) The bar magnet is aligned along the magnetic field. This system is considered as being in stable equilibrium. Hence, the angle θ, between the bar magnet and the magnetic field is 0°.
potential energy of the system $= -MB\cos\theta$
$= -0.32 \times 0.15 \cos 0^\circ$.
$= -4.8 \times 10^{-2}\,J$

b) The bar magnet is oriented 180° to the magnetic field. Hence, it is in unstable equilibrium.
$\theta = 180^\circ$
potential energy $= -MB\cos\theta$
$= -0.32 \times 0.15 \cos 180^\circ = 4.8 \times 10^{-2}\,J$.

5) 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 as a bar magnet because a magnetic field develops along its axis, i.e., along its length.

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

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

7) a) Magnetic moment, $M = 1.5 \ JT^{-1}$
Magnetic field strength, $B = 0.22 T$

i) Initial angle between the axis and the magnetic field, $\theta_1 = 0°$
Final angle between the axis and the magnetic field, $\theta_2 = 90°$
The work required to make the magnetic moment normal to the direction of magnetic field is given as:

$$W = -MB(\cos\theta_2 - \cos\theta_1)$$
$$= -1.5 \times 0.22 (\cos 90° - \cos 0°)$$
$$= -0.33 (0 - 1)$$
$$= 0.33 J$$

ii) Initial angle between the axis and the magnetic field, $\theta_1 = 0°$
Final angle between the axis and the magnetic field, $\theta_2 = 180°$
The work required to make the magnetic moment opposite to the direction of magnetic field is given as:

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

b) For case (i): $\theta = \theta_2 = 90°$

$\therefore$ Torque, $\tau = MB \sin\theta$
$= 1.5 \times 0.22 \sin 90°$
$= 0.33 \text{ J}$

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

$\therefore$ Torque, $\tau = MB \sin\theta$
$= MB \sin 180° = 0 \text{ J}$

9) Number of turns on the solenoid, $n = 2000$
Area of cross-section of the solenoid,
$A = 1.6 \times 10^{-4} \text{ m}^2$

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

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

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

b) Magnetic Field, $B = 7.5 \times 10^{-2}\ T$
Angle between the magnetic field and the axis of the solenoid, $\theta = 30^\circ$
Torque, $\tau = MB \sin\theta$
$= 1.28 \times 7.5 \times 10^{-2} \sin 30^\circ$
$= 4.8 \times 10^{-2}\ NM$

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

9) 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, $I = 0.75A$
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 x~~ $= 0.377\ JT^{-1}$

Frequency is given by the relation:

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

Where,

I = Moment of ~~mass~~ inertia of the coil

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

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

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

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

11) ~~Ag~~ 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.

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

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

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

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:

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

Total magnetic field, $B = B_1 + B_2$

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

$$= 0.36 + 0.18 = 0.54 \text{ G}$$

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

18) Current in the wire, $I = 2.5A$
Angle of dip at the given location on earth, $\delta = 0°$
Earth's magnetic field, $H = 0.33 G$
$= 0.33 \times 10^{-4} T$

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

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

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

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

Where,

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

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

$$= \frac{4\pi \times 10^{-7} \times 2.5}{2\pi \times 0.33 \times 10^{-4}}$$

$$= 15.15 \times 10^{-3} m = 1.51 cm$$

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

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