Physics

(Chapter 5) (Magnetism and Matter)
(Class 12)
Exercises

Question 5.1:
A short bar magnet placed with its axis at 30° with a uniform external magnetic field of 0.25 T experiences a torque of magnitude equal to 4.5×10^{-2} J. What is the magnitude of magnetic moment of the magnet?

Answer 5.1:
Magnetic field strength, B = 0.25 T
Torque on the bar magnet, T = 4.5×10^{-2} J
Angle between the bar magnet and the external magnetic field, θ = 30° Torque is related to magnetic moment (M) as: T = MB sin θ

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

$$= \frac{4.5\times10^{-2}}{0.25\times\sin30^{0}} = 0.36\ \mathrm{J\ T^{-1}}$$

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

Question 5.2:
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?

Answer 5.2:
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 = $-MB\cos\theta$
$= -0.32\times0.15\cos0°$
$= -4.8\times10^{-2}$ J

(b) The bar magnet is oriented 180° to the magnetic field. Hence, it is in unstable equilibrium. θ = 180°
Potential energy = − MB cos θ
$= -0.32\times0.15\cos180°$
$= -4.8\times10^{-2}$ J

Question 5.3:
A closely wound solenoid of 800 turns and area of cross section 2.5×10^{-4} m² 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?

Answer 5.3:
Number of turns in the solenoid, n = 800, Area of cross-section, A = 2.5×10^{-4} m²
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 = n I A = $800 \times 3 \times 2.5 \times 10^{-4} = 0.6$ J T^{-1}

Question 5.4:

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 torque on the solenoid when its axis makes an angle of 30° with the direction of applied field?

Answer 5.4:

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:

$\tau = MB \sin\theta$

$= 0.6 \times 0.25 \sin 30^{o}$

$= 7.5\times10^{-2}$ J

Question 5.5:

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*)?

Answer 5.5:

(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, $\theta_1 = 0°$

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:

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

$= -1.5\times0.22(\cos 90^{0}-\cos 0^{0})$

$= 0.33\ (0 - 1)$

$= 0.33$ 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:

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

$= -1.5 \times 0.22\ (\cos 180 - \cos 0^{o})$

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

$= 0.66$ J

(b) For case (i) : $\theta = \theta_2 = 90^{o}$

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

$= 1.5 \times 0.22 \sin 90^{o} = 0.33$ J

For case (ii) : $\theta = \theta_2 = 180^{o}$

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

$= MB \sin 180^{o} = 0$ J

Question 5.6:

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

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

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

Answer 5.6:

Number of turns on the solenoid, n = 2000

Area of cross-section of the solenoid, A = 1.6 × 10−4 m^2

Current in the solenoid, I = 4 A

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

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

(b) Magnetic field, B = 7.5 × 10−2 T

Angle between the magnetic field and the axis of the solenoid, θ = 30°

Torque, $\tau = MB \sin\theta = 1.28 \times 7.5 \times 10^{-2} \sin 30° = 4.8 \times 10^{-2}$ 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.

Question 5.7:

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.

Answer 5.7:

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:

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

Where, μ_0 = Permeability of free space = $4\pi \times 10^{-7}$ T m A^{-1} m

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

$= 0.96 \times 10^{-4}$ 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:

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

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

$= 0.48\ G$

The magnetic field is along the N – S direction.

Question 5.8:

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.)

Answer 5.8:

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:

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

$B_2 = \frac{\mu_0 M}{4\pi d^3} = \frac{H}{2}$ [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.

Question 5.9:

If the bar magnet in exercise 5.13 is turned around by 180^0, where will the new null points be located?

Answer 5.9:

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

$B_1 = \frac{\mu_0 2M}{4\pi (d_1)^3} = \frac{H}{2}$ ... (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°, then the neutral point will lie on the equatorial line.

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

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

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

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

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

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

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