MAGNETISM AND MATTER

5 Chapter

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

Ans: Provided in the question,
Magnetic field strength $B=0.25T$
Torque on the bar magnet, $T=4.5\times10^{-2}J$
Angle between the given bar magnet and the external magnetic field, $\theta=30°$
Torque is related to magnetic moment (M) as:
$T=MB\sin(\theta)$

$$\Rightarrow M=\frac{4.5\times10^{-2}}{0.25\times\sin30°}=0.36J/T$$

Clearly, the magnetic moment of the magnet is $0.36J/T$.

2. A short bar magnet of magnetic moment $M=0.32J/T$ is placed in a uniform magnetic field of $0.15T$. If the bar is free to rotate in the plane of the field, which orientation and would correspond to its

a) Stable?

Ans: It is provided that moment of the bar magnet, $M=0.32J/T$.
External magnetic field, $B=0.15T$
It is considered as being in stable equilibrium, when the bar magnet is aligned along the magnetic field. Therefore, the angle θ, between the bar magnet and the magnetic field is $0°$.
Potential energy of the system $=-MB\cos(\theta)$

$$\Rightarrow -MB\cos(\theta)=-0.32\times0.15\times\cos(0)=-4.8\times10^{-2}J$$

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

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

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

External magnetic field, $B = 0.15T$

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

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

$\Rightarrow -MB\cos(\theta) = -0.32 \times 0.15 \times \cos(180°) = 4.8 \times 10^{-2} J$

Hence the potential energy is $= 4.8 \times 10^{-2} J$.

3. A closely wound solenoid of 800 turns and area of cross section $2.5 \times 10^{-4} m^2$ 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: It is provided that number of turns in the solenoid, $n = 800$.

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

Current in the solenoid, $I = 3.0A$

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

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

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

Thus, the associated magnetic moment $= 0.6 J/T$

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

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

Magnetic moment, $M = 0.6/T$

The angle, θ between the axis of the turns of the solenoid and the direction of the external applied field is $30°$.
Hence, the torque acting on the solenoid is given as:

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

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

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

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

5. A bar magnet of magnetic moment $1.5 J/T$ 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 filed direction?**

Ans: Provided that,
Magnetic moment, $M = 1.5 J/T$
Magnetic field strength, $B = 0.22 T$

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

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

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

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

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

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

$\Rightarrow W = 0.33 J$

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

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

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

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

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

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

$\Rightarrow W = 0.66 J$

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

Ans: For the first (i) case,

$\theta = \theta_1 = 90°$

Hence the Torque, $\vec{\tau} = \vec{M} \times \vec{B}$
And its magnitude is: $\tau = MB\sin(\theta)$
$\Rightarrow \tau = 1.5 \times 0.22\sin(90°)$
$\Rightarrow \tau = 0.33 Nm$
Hence the torque involved is $= 0.33 Nm$
For the second-(ii) case:
$\theta = \theta_1 = 180°$
And its magnitude of the torque is: $\tau = MB\sin(\theta)$
$\Rightarrow \tau = 1.5 \times 0.22\sin(180°)$
$\Rightarrow \tau = 0 Nm$
Hence the torque is zero.

6. 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 center allowing it to turn in a horizontal plane.

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

Ans: Given is the number of turns on the solenoid, $n = 2000$
Area of cross-section of the solenoid, $A = 1.6 \times 10^{-4} m^2$
Current in the solenoid, $I = 4A$
The magnetic moment inside the solenoid at the axis is calculated as:
$M = nAI = 2000 \times 1.6 \times 10^{-4} \times 4 = 1.28 Am^2$

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: Provided that,
Magnetic field, $B = 7.5 \times 10^{-2} T$
Angle between the axis and the magnetic field of the solenoid, $\theta = 30°$
Torque, $\tau = MB\sin(\theta)$
$\Rightarrow \tau = 1.28 \times 7.5 \times 10^{-2} \sin(30°)$
$\Rightarrow \tau = 4.8 \times 10^{-2} Nm$

Given the magnetic field is uniform, and the force on the solenoid is zero.
The torque on the solenoid is $4.8 \times 10^{-2} Nm$.

7. A short bar magnet has a magnetic moment of $0.48 J/T$. Give the direction and magnitude of the magnetic field produced by the magnet at a distance of $10 cm$ from the center of the magnet on

a) **the axis,**

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

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

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

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

here,

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

Substituting these values, B becomes as follows:

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

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

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

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

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

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

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

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

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

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 $14cm$ from the centre of the magnet. The earth's magnetic field at the place is $0.36\,G$ and the angle of dip is zero. What is the total magnetic field on the normal bisector of the magnet at the same distance as the null–point (i.e., $14\,cm$) from the centre of the magnet? (At null points, field due to a magnet is equal and opposite to the horizontal component of earth's magnetic field).

Ans: Provided that,

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

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

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

Here,

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

$M =$ The magnetic moment

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

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

$\Rightarrow B_2 = H/2$ (comparing with B_1)

Therefore, the total magnetic field,

$$B = B_1 + B_2$$

$$\Rightarrow B = H + H/2$$

$$\Rightarrow B = 0.36 + 0.18 = 0.54$$

Clearly, the magnetic field is 0.54 G along the direction of earth's magnetic field.

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

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

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

here,

M is the magnetic moment

μ_0 is the permeability of free space

H is the horizontal component of the given magnetic field at d_1

When the bar magnet is turned through $180°$, then the neutral point will lie on the equatorial line.

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

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

Equating B_1 and B_2 we get:

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

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

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

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