Moving charges and Magnetism

4 Chapter

1. A circular coil of wire consisting of 100 turns, each of radius 8.0cm carries a current of 0.40A. What is the magnitude of the magnetic field B at the centre of the coil?

Ans: We are given:

Number of turns on the circular coil, $n = 100$

Radius of each turn, $r = 8.0cm = 0.08m$

Current flowing in the coil is given to be, $I = 0.4A$

We know the expression for magnetic field at the centre of the coil as,

$$|B| = \frac{\mu_0}{4\pi}\frac{2\pi nI}{r}$$

Where, $\mu_0 = 4\pi\times10^{-4}TmA^{-1}$ is the permeability of free space.

On substituting the given values we get,

$$|B| = \frac{4\pi\times10^{-7}\times2\pi\times100\times0.4}{4\pi\times0.08}$$

$$\Rightarrow |B| = 3.14\times10^{-4}T$$

Clearly, the magnitude of the magnetic field is found to be $3.14\times10^{-4}T$.

2. A long straight wire carries a current of 35A. What is the magnitude of the field B at a point 20cm from the wire?

Ans: We are given the following:

Current in the wire, $I = 35A$

Distance of the given point from the wire, $r = 20cm = 0.2m$

We know the expression for magnetic field as,

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

Where, $\mu_0 = 4\pi\times10^{-4}TmA^{-1}$ is the permeability of free space.

On substituting the given values, we get,

$$B = \frac{4\pi\times10^{-7}\times2\times35}{4\pi\times0.2}$$

$$\Rightarrow B = 3.5\times10^{-5}T$$

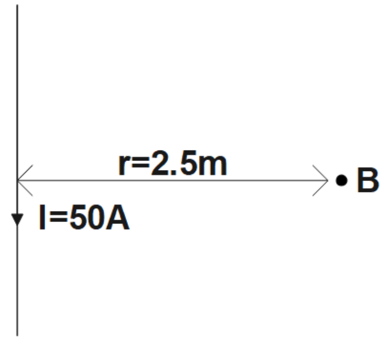
Thus, we found the magnitude of the magnetic field at the given point to be $3.5\times10^{-5}\text{T}$.

3. A long straight wire in the horizontal plane carries a current of 50A in north to south direction. Give the magnitude and direction of B at a point 2.5m east of the wire.

Ans: We are given the following:

The current in the wire, $I = 50\text{A}$

The distance of the given point from the wire, $r = 2.5\text{m}$



We have the expression for magnetic field as,

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

Where, $\mu_0 = 4\pi\times10^{-4}\text{TmA}^{-1}$ is the permeability of free space.

Substituting the given values, we get,

$$B = \frac{4\pi\times10^{-7}\times2\times50}{4\pi\times2.5}$$

$$\Rightarrow B = 4\times10^{-6}\text{T}$$

Now from Maxwell's right hand thumb rule we have the direction of the magnetic field at the given point B to be vertically upward.

4. A horizontal overhead power line carries a current of 90A in east to west direction. What is the magnitude and direction of the magnetic field due to the current 1.5m below the line?

Ans: We are given the following:

Current in the power line, $I = 90\text{A}$

Distance of the mentioned point below the power line, $r = 1.5\text{m}$

Now, we have the expression for magnetic field as,

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

Where, $\mu_0 = 4\pi \times 10^{-4} \text{TmA}^{-1}$ is the permeability of free space.
On substituting the given values, we get,

$$B = \frac{4\pi \times 10^{-7} \times 2 \times 90}{4\pi \times 1.5}$$

$$\Rightarrow B = 1.2 \times 10^{-5} \text{T}$$

We found the magnitude of the magnetic field to be $1.2 \times 10^{-5} \text{T}$ and it will be directed towards south as per Maxwell's right hand thumb rule.

5. What is the magnitude of magnetic force per unit length on a wire carrying a current of 8And making an angle of $30°$ with the direction of a uniform magnetic field of 0.15T?

Ans: Given that,
Current in the wire, $I = 8\text{A}$
Magnitude of the uniform magnetic field, $B = 0.15\text{T}$
Angle between the wire and magnetic field, $\theta = 30°$
We have the expression for magnetic force per unit length on the wire as,

$$F = BI\sin\theta$$

Substituting the given values, we get,

$$F = 0.15 \times 8 \times 1 \times \sin 30°$$

$$\Rightarrow F = 0.6\text{Nm}^{-1}$$

Thus, the magnetic force per unit length on the wire is found to be 0.6Nm^{-1}

6. A 3.0cm wire carrying a current of 10A is placed inside a solenoid perpendicular to its axis. The magnetic field inside the solenoid is given to be 0.27T. What is the magnetic force on the wire?

Ans: We are given the following,
Length of the wire, $l = 3\text{cm} = 0.03\text{m}$
Current flowing in the wire, $I = 10\text{A}$
Magnetic field, $B = 0.27\text{T}$
Angle between the current and magnetic field, $\theta = 90°$
(Since the magnetic field produced by a solenoid is along its axis and current carrying wire is kept perpendicular to the axis)
The magnetic force exerted on the wire is given as,

$$F = BIl\sin\theta$$

Substituting the given values,

$$F = 0.27 \times 10 \times 0.03 \sin 90°$$

$$\Rightarrow F = 8.1 \times 10^{-2} \text{N}$$

Clearly, the magnetic force on the wire is found to be $8.1\times10^{-2}N$. The direction of the force can be obtained from Fleming's left-hand rule.

7. Two long and parallel straight wires A and B carrying currents of $8.0A$ and $5.0A$ in the same direction are separated by a distance of $4.0cm$. Estimate the force on a $10cm$ section of wire A.

Ans: We are given:

Current flowing in wire A, $I_A = 8.0A$

Current flowing in wire B, $I_B = 5.0A$

Distance between the two wires, $r = 4.0cm = 0.04m$

Length of a section of wire A, $l = 10cm = 0.1m$

Force exerted on length l due to the magnetic field is given as,

$$B = \frac{2\mu_0 I_A I_B l}{4\pi r}$$

Where, $\mu_0 = 4\pi\times10^{-4}TmA^{-1}$ is the permeability of free space.

On substituting the given values, we get,

$$B = \frac{4\pi\times10^{-7}\times2\times8\times5\times0.1}{4\pi\times0.04}$$

$$\Rightarrow B = 2\times10^{-5}N$$

The magnitude of force is $2\times10^{-5}N$. This is an attractive force that is normal to A towards B because the direction of the currents in the wires is the same.

8. A closely wound solenoid $80cm$ long has 5 layers of windings of 400 turns each. The diameter of the solenoid is $1.8cm$. If the current carried is $8.0A$, estimate the magnitude of B inside the solenoid near its centre.

Ans: We are given the following:

Length of the solenoid, $l = 80cm = 0.8m$

Since there are five layers of windings of 400 turns each on the solenoid.

Total number of turns on the solenoid would be, $N = 5\times400 = 2000$

Diameter of the solenoid, $D = 1.8cm = 0.018m$

Current carried by the solenoid, $I = 8.0A$

We have the magnitude of the magnetic field inside the solenoid near its centre given by the relation,

$$B = \frac{\mu_0 NI}{l}$$

Where, $\mu_0 = 4\pi\times10^{-4}TmA^{-1}$ is the permeability of free space.

On substituting the given values we get,

$$B = \frac{4\pi \times 10^{-7} \times 2000 \times 8}{0.8}$$

$\Rightarrow B = 2.512 \times 10^{-2} T$

Clearly, the magnitude of the magnetic field inside the solenoid near its centre is found to be $2.512 \times 10^{-2} T$.

9. A square coil of side $10cm$ consists of 20 turns and carries a current of $12A$. The coil is suspended vertically and the normal to the plane of the coil makes an angle of $30°$ with the direction of a uniform horizontal magnetic field of magnitude $0.80T$. What is the magnitude of torque experienced by the coil?

Ans: We are given the following:

Length of a side of the square coil, $l = 10cm = 0.1m$

Area of the square, $A = l^2 = (0.1)^2 = 0.01m^2$

Current flowing in the coil, $I = 12A$

Number of turns on the coil, $n = 20$

Angle made by the plane of the coil with magnetic field, $\theta = 30°$

Strength of magnetic field, $B = 0.80T$

Magnitude of the magnetic torque experienced by the coil in the magnetic field is given by the relation,

$\tau = nIAB\sin\theta$

Substituting the given values, we get,

$\tau = 20 \times 0.8 \times 12 \times 0.01 \times \sin 30°$

$\Rightarrow \tau = 0.96Nm$

Thus, the magnitude of the torque experienced by the coil is 0.96 N m.

10. Two moving coil meters, M_1 and M_2 have the following particulars:

$R_1 = 10\Omega$, $N_1 = 30$, $A_1 = 3.6 \times 10^{-3} m^2$, $B_1 = 0.25T$, $R_2 = 14\Omega$, $N_2 = 42$

$A_2 = 1.8 \times 10^{-3} m^2$, $B_2 = 0.50T$

(The spring constants are identical for the meters).

Determine the ratio of:

a) current sensitivity of M_2 and M_1

Ans: We are given:

For moving coil meter M_1,

Resistance, $R_1 = 10\Omega$

Number of turns, $N_1 = 30$

Area of cross-section, $A_1 = 3.6 \times 10^{-3} m^2$

Magnetic field strength, $B_1 = 0.25T$

Spring constant, $K_1 = K$

For moving coil meter M_2:

Resistance, $R_2 = 14\Omega$

Number of turns, $N_2 = 42$

Area of cross-section, $A_2 = 1.8 \times 10^{-3} m^2$

Magnetic field strength, $B_2 = 0.50T$

Spring constant, $K_2 = K$

Current sensitivity of M_1 is given as:

$$I_{S1} = \frac{N_1 B_1 A_1}{K_1}$$

And, current sensitivity of M_2 is given as:

$$I_{S2} = \frac{N_2 B_2 A_2}{K_2}$$

On taking the ratio, we get,

$$\Rightarrow \frac{I_{S2}}{I_{S1}} = \frac{\frac{N_2 B_2 A_2}{K_2}}{\frac{N_1 B_1 A_1}{K_1}}$$

Substituting the values we get,

$$\Rightarrow \frac{I_{S2}}{I_{S1}} = \frac{42 \times 0.5 \times 1.8 \times 10^{-3} \times 10 \times K}{14 \times 30 \times 0.25 \times 3.6 \times 10^{-3} \times K}$$

$$\Rightarrow \frac{I_{S2}}{I_{S1}} = 1.4$$

Therefore, the ratio of current sensitivity of M_2 and M_1 is 1.4.

b) voltage sensitivity of M_2 and M_1

Ans: Voltage sensitivity for M_2 is given is:

$$V_{S2}=\frac{N_2B_2A_2}{K_2R_2}$$

And, voltage sensitivity for M_1 is given as:

$$V_{S1}=\frac{N_1B_1A_1}{K_1R_1}$$

On taking the ratio we get,

$$\Rightarrow\frac{V_{S2}}{V_{S1}}=\frac{N_2B_2A_2K_1R_1}{K_2R_2N_1B_1A_1}$$

Substituting the given values, we get,

$$\Rightarrow\frac{V_{S2}}{V_{S1}}=\frac{42\times0.5\times1.8\times10^{-3}\times10\times K}{K\times14\times30\times0.25\times3.6\times10^{-3}}=1$$

Thus, the ratio of voltage sensitivity of M_2 and M_1 is 1.

11. In a chamber, a uniform magnetic field of $6.5G\left(1G=10^{-4}T\right)$ is maintained. An electron is shot into the field with a speed of $4.8\times10^{6}ms^{-1}$ normal to the field. Explain why the path of the electron is a circle. Determine the radius of the circular orbit. $\left(e=1.6\times10^{-19}C,m_e=9.1\times10^{-31}kg\right)$

Ans: Magnetic field strength, $B=6.5G=6.5\times10^{-4}T$

Speed of the electron, $V=4.8\times10^{6}m/s$

Charge on the electron, $e=1.6\times10^{-19}C$

Mass of the electron, $m_e=9.1\times10^{-31}kg$

Angle between the shot electron and magnetic field, $\theta=90°$

Magnetic force exerted on the electron in the magnetic field could be given as:

$$F=evB\sin\theta$$

This force provides centripetal force to the moving electron and hence, the electron starts moving in a circular path of radius r.

Hence, centripetal force exerted on the electron would be,

$$F_C=\frac{mv^2}{r}$$

However, we know that in equilibrium, the centripetal force exerted on the electron is equal to the magnetic force i.e.,

$F_C = F$

$$\Rightarrow \frac{mv^2}{r} = evB\sin\theta$$

$$\Rightarrow r = \frac{mv}{Be\sin\theta}$$

Substituting the given values we get,

$$\Rightarrow r = \frac{9.1\times10^{-31}\times4.8\times10^{6}}{6.5\times10^{-4}\times1.6\times10^{-19}\times\sin 90°}$$

$$\Rightarrow r = 4.2cm$$

Clearly, we found the radius of the circular orbit to be 4.2cm.

12. In Exercise 4.11 obtain the frequency of revolution of the electron in its circular orbit. Does the answer depend on the speed of the electron? Explain.

Ans: We are given the following:

Magnetic field strength, $B = 6.5\times10^{-4}T$

Charge of the electron, $e = 1.6\times10^{-19}C$

Mass of the electron, $m_e = 9.1\times10^{-31}kg$

Velocity of the electron, $v = 4.8\times10^{6}m/s$

Radius of the orbit, $r = 4.2cm = 0.042m$

Frequency of revolution of the electron ν

Angular frequency of the electron $\omega = 2\pi\theta$

Velocity of the electron is related to the angular frequency as:

$v = r\omega$

In the circular orbit, the magnetic force on the electron provides the centripetal force. Hence,

$$evB = \frac{mv^2}{r}$$

$$\Rightarrow eB = \frac{m}{r}(r\omega) = \frac{m}{r}(r2\pi\nu)$$

$$\Rightarrow \nu = \frac{6.5\times10^{-4}\times1.6\times10^{-19}}{2\times3.14\times9.1\times10^{-31}} \therefore \nu = 18.2\times10^{6}Hz \approx 18MHz$$

Thus, the frequency of the electron is around 18 MHz and is independent of the speed of the electron.

13.

a) A circular coil of 30turns and radius 8.0cm carrying a current of 6.0A is suspended vertically in a uniform horizontal magnetic field of magnitude 1.0T The field lines make an angle of 60° with the normal of the coil. Calculate the magnitude of the counter torque that must be applied to prevent the coil from turning.

Ans: Number of turns on the circular coil, $n = 30$
Radius of the coil, $r = 8.0cm = 0.08m$
Area of the coil, $A = \pi r^2 = \pi(0.08)^2 = 0.0201m^2$
Current flowing in the coil is given to be, $I = 6.0A$
Magnetic field strength, $B = 1T$
Angle between the field lines and normal with the coil surface, $\theta = 60°$
The coil will turn when it experiences a torque in the magnetic field. The counter torque applied to prevent the coil from turning is given by the relation, $\tau = nIAB\sin\theta$
$\Rightarrow \tau = 30 \times 6 \times 1 \times 0.0201 \times \sin 60°$
$\Rightarrow \tau = 3.133Nm$

b) Would your answer change, if the circular coil in (a) were replaced by a planar coil of some irregular shape that encloses the same area? (All other particulars are also unaltered).

Ans: From the part(a) we could infer that the magnitude of the applied torque is not dependent on the shape of the coil.
On the other hand, it is dependent on the area of the coil.
Thus, we could say that the answer would not change if the circular coil in the above case is replaced by a planar coil of some irregular shape that encloses the same area.