Exercises

Question 4.1:

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

Answer 4.1:

Number of turns on the circular coil, n = 100

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

Current flowing in the coil, I = 0.4 A

Magnitude of the magnetic field at the centre of the coil is given by the relation,

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

Where,

$\mu_0 =$ Permeability of free space

$= 4\pi \times 10^{-7}$ T m A^{-1}

So,

$$|\vec{B}| = \frac{4\pi \times 10^{-7}}{4\pi} \times \frac{2\pi \times 100 \times 0.4}{r}$$

$$= 3.14 \times 10^{-4}\ T$$

Hence, the magnitude of the magnetic field is 3.14×10^{-4} T.

Question 4.2:

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

Answer 4.2:

Current in the wire, I = 35 A

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

Magnitude of the magnetic field at this point is given as:

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

Where,

$\mu_0 =$ Permeability of free space

$= 4\pi \times 10^{-7}$ T m A^{-1}

$$|\vec{B}| = \frac{4\pi \times 10^{-7}}{4\pi} \times \frac{2 \times 35}{0.2}$$

$$= 3.5 \times 10^{-5}\, T$$

Hence, the magnitude of the magnetic field at a point 20 cm from the wire is 3.5×10^{-5} T.

Question 4.3:

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

Answer 4.3:

Current in the wire, I = 50 A

A point is 2.5 m away from the East of the wire.

∴ Magnitude of the distance of the point from the wire, r = 2.5 m.

Magnitude of the magnetic field at that point is given by the relation,

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

Where,

$\mu_0 =$ Permeability of free space

$= 4\pi \times 10^{-7}$ T m A^{-1}

$$|\vec{B}| = \frac{4\pi \times 10^{-7}}{4\pi} \times \frac{2 \times 50}{2.5} = 4 \times 10^{-6}\, T$$

The point is located normal to the wire length at a distance of 2.5 m. The direction of the current in the wire is vertically downward. Hence, according to the Maxwell's right hand thumb rule, the direction of the magnetic field at the given point is vertically upward.

Question 4.4:

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

Answer 4.4

Current in the power line, I = 90 A

Point is located below the power line at distance, r = 1.5 m

Hence, magnetic field at that point is given by the relation,

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

Where,

$\mu_0 =$ Permeability of free space

$= 4\pi \times 10^{-7}$ T m A^{-1}

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

$$= 1.2 \times 10^{-5}\, T$$

The current is flowing from East to West. The point is below the power line. Hence, according to Maxwell's right hand thumb rule, the direction of the magnetic field is towards the South.

Question 4.5:

What is the magnitude of magnetic force per unit length on a wire carrying a current of 8 A and making an angle of 30º with the direction of a uniform magnetic field of 0.15 T?

Answer 4.5:

Current in the wire, I = 8 A

Magnitude of the uniform magnetic field, B = 0.15 T

Angle between the wire and magnetic field, θ = 30°.

Magnetic force per unit length on the wire is given as: $F = BI\ sin\theta$

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

$= 0.6\ N\ m^{-1}$

Hence, the magnetic force per unit length on the wire is $0.6\ N\ m^{-1}$.

Question 4.6:

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

Answer 4.6:

Length of the wire, l = 3 cm = 0.03 m

Current flowing in the wire, I = 10 A

Magnetic field, B = 0.27 T

Angle between the current and magnetic field, θ = 90°

Magnetic force exerted on the wire is given as:

$F = BIl\sin\theta$

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

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

Hence, the magnetic force on the wire is 8.1×10^{-2} N. The direction of the force can be obtained from Fleming's left hand rule.

Question 4.7:

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

Answer 4.7:

Current flowing in wire A, I_A = 8.0 A

Current flowing in wire B, I_B = 5.0 A

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

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

Force exerted on length L due to the magnetic field is given as:

$$F = \frac{\mu_0 I_A I_B L}{2\pi r}$$

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

$$F = \frac{4\pi \times 10^{-7} \times 8 \times 5 \times 0.1}{2\pi \times 0.04} = 2 \times 10^{-5}\ N$$

The magnitude of force is 2×10^{-5} N. This is an attractive force normal to A towards B because the direction of the currents in the wires is the same.

Question 4.8:

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

Answer 4.8:

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

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

∴ Total number of turns on the solenoid, N = 5 × 400 = 2000

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

Current carried by the solenoid, I = 8.0 A

Magnitude of the magnetic field inside the solenoid near its centre is given by the relation, $B = \frac{\mu_0 N I}{l}$

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

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

$$= 2.5 \times 10^{-2}\, T$$

Hence, the magnitude of the magnetic field inside the solenoid near its centre is 2.512×10^{-2} T.

Question 4.9:

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

Answer 4.9:

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

Current flowing in the coil, I = 12 A

Number of turns on the coil, n = 20

Angle made by the plane of the coil with magnetic field, θ = 30°

Strength of magnetic field, B = 0.80 T

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

$$\tau = n\,BIA\,sin\theta$$

Where,

A = Area of the square coil

$= l \times l = 0.1 \times 0.1 = 0.01\ m^2$

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

$= 0.96$ N m

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

Question 4.10:

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

$R_1 = 10\ \Omega$, $N_1 = 30$,

$A_1 = 3.6 \times 10^{-3}\ m^2$, $B_1 = 0.25\ T$

$R_2 = 14\ \Omega$, $N_2 = 42$,

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

(The spring constants are identical for the two meters).

Determine the ratio of **(a)** current sensitivity and **(b)** voltage sensitivity of M_2 and M_1.

Answer 4.10:

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, $B_1 = 0.25\ T$

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, $B_2 = 0.50\ T$

Spring constant, $K_2 = K$

(a) 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:

$$I_{s2} = \frac{N_2 B_2 A_2}{K_2}$$

$$\therefore Ratio \quad \frac{I_{s2}}{I_{s1}} = \frac{N_2 B_2 A_2}{N_1 B_1 A_1} = \frac{42 \times 0.5 \times 1.8 \times 10^{-3} \times K}{K \times 30 \times 0.25 \times 3.6 \times 10^{-3}} = 1.4$$

Hence, the ratio of current sensitivity of M_2 to M_1 is 1.4.

(b) Voltage sensitivity for M_2 is given as:

$$V_{s2} = \frac{N_2 B_2 A_2}{K_2 R_2}$$

And, voltage sensitivity for M_1 is given as:

$$V_{s1} = \frac{N_1 B_1 A_1}{K_1 R_1}$$

$$\therefore Ratio \quad \frac{I_{s2}}{V_{s1}} = \frac{N_2 B_2 A_2 K_1 R_1}{N_1 B_1 A_1 K_2 R_2} = \frac{42 \times 0.5 \times 1.8 \times 10^{-3} \times 10 \times K}{K \times 14 \times 30 \times 0.25 \times 3.6 \times 10^{-3}} = 1$$

Hence, the ratio of voltage sensitivity of M_2 to M_1 is 1.

Question 4.11:

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

Answer 4.11:

Magnetic field strength, B = 6.5 G = 6.5×10^{-4} T

Speed of the electron, v = 4.8×10^6 m/s

Charge on the electron, e = 1.6×10^{-19} C

Mass of the electron, m_e = 9.1×10^{-31} kg

Angle between the shot electron and magnetic field, θ = 90°

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

$$F = evB\ sin\theta$$

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

Hence, centripetal force exerted on the electron,

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

In equilibrium, the centripetal force exerted on the electron is equal to the magnetic force i.e.,

$$F_e = F$$

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

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

So,

$$r = \frac{9.1 \times 10^{-31} \times 4.8 \times 10^{6}}{6.5 \times 10^{-4} \times 1.6 \times 10^{-19} \times \sin 90°} = 4.2 \times 10^{-2}\ m = 4.2\ cm$$

Hence, the radius of the circular orbit of the electron is 4.2 cm.

Question 4.12:

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.

Answer 4.12:

Magnetic field strength, B = 6.5×10^{-4} T

Charge of the electron, e = 1.6×10^{-19} C

Mass of the electron, $m_e = 9.1 \times 10^{-31}$ kg

Velocity of the electron, v = 4.8×10^{6} m/s

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

Frequency of revolution of the electron = ν

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

Velocity of the electron is related to the angular

frequency as: $v = r\omega$

In the circular orbit, the magnetic force on the electron is balanced by the centripetal force.

Hence, we can write:

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

$$\Rightarrow eB = \frac{mv}{r} = \frac{m(r\omega)}{r} = \frac{m(r.2\pi\nu)}{r}$$
$$\Rightarrow \nu = \frac{Be}{2\pi m}$$

This expression for frequency is independent of the speed of the electron.

On substituting the known values in this expression, we get the frequency as:

$$\nu = \frac{6.5 \times 10^{-4} \times 1.6 \times 10^{-19}}{2 \times 3.14 \times 9.1 \times 10^{-31}} = 1.82 \times 10^{6}\ Hz \approx 18\ MHz$$

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

Question 4.13:

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

(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.)

Answer 4.13:

(a) Number of turns on the circular coil, $n = 30$

Radius of the coil, r = 8.0 cm = 0.08 m
Area of the coil $\pi r^2 = \pi(0.08)^2 = 0.0201\ m^2$

Current flowing in the coil, I = 6.0 A

Magnetic field strength, B = 1 T

Angle between the field lines and normal with the coil surface, θ = 60°

The coil experiences a torque in the magnetic field. Hence, it turns. The counter torque applied to prevent the coil from turning is given by the relation,

$\tau\ =\ n\, IBA\, sin\theta$

= 30 × 6 × 1 × 0.0201 × sin60°

= 3.133 N m

(b) It can be inferred from relation $\tau\ =\ n\, IBA\, sin\theta$ that the magnitude of the applied torque is not dependent on the shape of the coil. It depends on the area of the coil. Hence, 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.