Q 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:

Given:

The number of turns on the coil (n) is 100

The radius of each turn (r) is 8 cm or 0.08 m

The magnitude of the current flowing in the coil (I) is 0.4 A

The magnitude of the magnetic field at the centre of the coil can be obtained by the following relation:

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

where μ_0 is the permeability of free space = $4\pi \times 10^{-7}\ T\ m\ A^{-1}$

hence,

$$|\bar{B}| = \frac{4\pi\times10^{-7}}{4\pi} \times \frac{2\pi\times100\times0.4}{r}$$

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

The magnitude of the magnetic field is $3.14 \times 10^{-4}\ T$.

Q 4.2) A long 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:

The magnitude of the current flowing in the wire (I) is 35 A

The distance of the point from the wire (r) is 20 cm or 0.2 m

At this point, the magnitude of the magnetic field is given by the relation:

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

where,

μ_0 = Permeability of free space

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

Sunstituting the values in the equation, we get

$$|\bar{B}| = \frac{4\pi\times10^{-7}}{4\pi} \times \frac{2\times35}{0.2}$$

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

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

Q 4.3) A long straight wire in the horizontal plane carries a current of 50 A in the north to south direction. Give the magnitude and direction

of B at a point 2.5 m east of the wire.

Answer 4.3:

The magnitude of the current flowing in the wire is (I) = 50 A.

The point B is 2.5 m away from the East of the wire.

Therefore, the magnitude of the distance of the point from the wire (r) is 2.5 m

The magnitude of the magnetic field at that point is given by the relation:

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

where,

μ_0 = Permeability of free space

= $4\pi \times 10^{-7}\ T\ m\ A^{-1}$ $|\bar{B}| = \frac{4\pi\times10^{-7}}{4\pi} \times \frac{2\times50}{2.5}$

= $4 \times 10^{-6}\ T$

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 Maxwell's right-hand thumb rule, the direction of the magnetic field at the given point is vertically upward.

Q 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:

The magnitude of the current in the power line is (I) = 90 A

The point is located below the electrical cable at distance (r) = 1.5 m

Hence, magnetic field at that point can be calculated as follows,

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

where,

μ_0 = Permeability of free space

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

Substituting values in the above equation, we get

$$|\bar{B}| = \frac{4\pi\times10^{-7}}{4\pi} \times \frac{2\times90}{1.5}$$

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

The current flows from East to West. The point is below the electrical cable.

Hence, according to Maxwell's right-hand thumb rule, the direction of the magnetic field is towards the South.

Q 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 30° with the direction of a uniform magnetic field of 0.15 T?

Answer 4.5:

In the problem,

The current flowing in the wire is (I) = 8 A

The magnitude of the uniform magnetic field (B) is 0.15 T

The angle between the wire and the magnetic field, $\theta = 30^{\circ}$

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

= $0.15 \times 8 \times 1 \times sin30^{\circ}$

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

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

Q 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:

In the problem,

the length of the wire (l) is 3 cm or 0.03 m

the magnitude of the current flowing in the wire (I) is 10 A

the strength of the magnetic field (B) is 0.27 T

the angle between the current and the magnetic field is $\theta = 90^{\circ}$.

the magnetic force exerted on the wire is calculated as follows:

$$F = BIl sin\theta$$

Substituting the values in the above equation, we get

= $0.27 \times 10 \times 0.03 \; sin90^{\circ}$

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

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

Q 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:

The magnitude of the current flowing in the wire A (I_A) is 8 A

The magnitude of the current flowing in wire B (I_B) is 5 A

The distance between the two wires (r) is 4 cm or 0.04 m

The length of the section of wire A (L) = 10 cm = 0.1 m

The force exerted on the length L due to the magnetic field is calculated as follows:

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

where,

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

Substituting the values, we get

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

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

Q 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:

Solenoid length (l) = 80 cm = 0.8 m

Five layers of windings of 400 turn each on the solenoid.

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

Solenoid Diameter (D) = 1.8 cm = 0.018 m

Current carried by the solenoid (I) = 8.0 A

The relation that gives the magnitude of magnetic field inside the solenoid near its centre is given below:

$$B = \frac{\mu_0 N I}{l}$$

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 B inside the solenoid near its centre is $2.5 \times \ 10^{-2}\ T$.

Q 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 30° with the direction of a uniform
the horizontal magnetic field of magnitude 0.80 T. What is the magnitude of torque experienced by the coil?

Answer 4.9:

In the given problem,

the length of a side of the square coil (l) is 10 cm or 0.1 m

The magnitude of the current flowing in the coil (I) is 12 A

The number of turns on the coil (n) is 20

The angle made by the plane of the coil with B (Magnetic field), $\theta = \ 30^\circ$

The strength of the magnetic field (B) is 0.8 T

The following relation gives the magnitude of the magnetic torque experienced by the coil in the magnetic field:

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

Where,

A = Area of the square coil

= 1 x 1 = 0.1 x 0.1 = 0.01 m^2

So, $\tau = 20 \times 0.8 \times 12 \times 0.01 \times sin30^\circ$

= 0.96 N m

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

Q 4.10) Two moving coil meters, M^1 and M^2 have the following particulars:

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

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

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

$$A_2 = 1.8 \times 10^{-3}\,m^2,\ B_2 = 0.5\,T$$

(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:

Given data:

Moving coil meter M_1

Resistance, $R_1 = 10\,\Omega$

Number of turns, $N_1 = 30$

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

Magnetic field strength, B_1 = 0.25 T

Spring constant K_1 = K

Moving coil meter M_2

Resistance, $R_1 = 10\,\Omega$

Number of turns, $N_2 = 42$

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

Magnetic field strength, B_2 = 0.5 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:

$$I_{s2} = \frac{N_2 B_2 A_2}{K_2}\ \therefore\ Ratio\frac{I_{s2}}{I_{s1}} = \frac{N_2 B_2 A_2}{N_1 B_1 A_1} = \frac{42 \times 0.5 \times 1.8 \times 10^{-3} \times K}{K \times 30 \times 0.25 \times 3.6 \times 10^{-3}} = 1.4$$

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:

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

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

Q 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 x 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. ($e = 1.6 \times 10^{-19}\ C,\ m_e = 9.1 \times 10^{-31}\ kg$)

Answer 4.11:

Magnetic field strength (B) = 6.5 G = $6.5 \times 10^{-4}\ T$

Speed of the electron (v) = $4.8 \times 10^{6}\ m/s$

Charge on the electron (e) = $1.6 \times 10^{-19}\ C$

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

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

The relation for 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

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

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

So,

$$r = \frac{9.1 \times 10^{-31} \times 4.8 \times 10^{6}}{6.5 \times 10^{-4} \times 1.6 \times 10^{-19} \times sin90^\circ} = 4.2 \times 10^{-2}\ m = 4.2cm$$

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

Q 4.12) In Exercise 4.11 find 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) = $6.5 \times 10^{-4}\ T$

Charge on the electron (e) = $1.6 \times 10^{-19}\ C$

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

Speed of the electron (v) = $4.8 \times 10^6\ m/s$

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

Frequency of revolution of the electron = v

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

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:

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

=> $eB = \frac{mv}{r} = \frac{m(r\omega)}{r} = \frac{m(r.2\pi v)}{r}$

=> $v = \frac{Be}{2\pi m}$

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:

$$v = \frac{6.5\times10^{-4}\times1.6\times10^{-19}}{2\times3.14\times9.1\times10^{-31}} = 1.82 \times 10^6\ Hz \approx 18\ MHz$$

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

Q 4.13) (a) A circular coil having radius as 8.0 cm, number of turn as 30 and 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 60^0 with the normal of the coil. To prevent the coil from turning, determine the magnitude of the counter-torque that must be applied.

(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

The angle between the field lines and normal with the coil surface, $\theta = 60^\circ$

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,

$$\tau = nIBA\ sin\theta$$

= $30 \times 6 \times 1 \times 0.0201 \times sin60^\circ$

= 3.133 N m

(b) It can be inferred from the relation $\tau = nIBA\ sin\theta$ 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.