4. Moving charges and Magnetism

Question1. 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?

Solution : Given:

Number of turns, n = 100

Radius of coil, r = 8 cm

Current through the coil, I = 0.40 A

Magnitude of magnetic field at centre of coil, B = ?

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

∴ Magnitude of magnetic field at the centre of the coil is $3.14 \times 10^{4} T$.

Question2. 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?

Solution : Given:

Current through the wire, I = 35 A

Distance of point P from the wire, d = 20 cm

Question3. 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.

Solution : Given:

Current through the wire, I = 50 A (North to South)

Distance of point P East of the wire, d = 2.5 m

Direction of magnetic field,

The point is in a plane normal to the wire and the wire carries current in north to south. Using Right hand thumb rule we can conclude that the direction of magnetic field is vertically upwards, or out of the paper.

The magnitude of the magnetic field is 4×10^{-6}T and its direction is upwards or out of paper.

Question4. 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?

Solution : Given:

Current through the wire, I = 90 A (East to West)

Distance of point P below the wire, d = 1.5 m

Direction of magnetic field,

We know that wire carries current in east to west direction. Using Right hand thumb rule, we can conclude that the direction of magnetic field is from north to south as indicated in the figure.

The magnitude of the magnetic field is 1.2×10^{-5}T and its direction is from north to south.

Question5. 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?

Solution :
Current in the wire, I = 8 A

Magnitude of the uniform magnetic field, B = 0.15 T

Angle between the wire and magnetic field, $\theta = 30°$.

Magnetic force per unit length on the wire is given as:

f = BI sinθ

= 0.15 × 8 ×1 × sin30°

= 0.6 N m^{-1}

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

Question6. 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?

Solution :
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 = BIlsinθ

= 0.27 × 10 × 0.03 sin90°

= 8.1 × 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.

Question7. 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.

Solution : Given:

Current in wire A, I_A = 8.0 A

Current in wire B, I_B = 5.0 A

Distance between the conductors A and B, d = 4 cm

Length of conductor on which we have to calculate force, L = 10cm

So, the force on the 10 cm section on wire A is 2×10^{-5}N. Since the current is flowing in the same direction the force will be attractive in nature.

Note: The force will be same on both the wires, we can use Newton's third law of motion to such conclusion.

Question8. 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.

Solution : Given:

Length of solenoid, L = 80cm

Number of turns = number of layers × number of turns per layer

Number of turns, n = 5 × 400 = 2000

Radius of solenoid, r = Diameter/2 = 0.9 cm

Current through the solenoid = 8.0A

Hence the magnetic field strength at the centre of the solenoid is 2.512×10^{-2}T.

Question9. 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?

Solution : Given:

Length of side of square, L = 10 cm

Number of turns, n = 20

Current through the square coil, I = 12 A

Angle between the normal to the coil and uniform magnetic field, θ = 30°

Magnitude of magnetic field, B = 0.80 T

Question10. Two moving coil meters, M_1 and M_2 have the following particulars:

R_1 = 10 Ω, N_1 = 30,

$A_1 = 3.6 \times 10^{-3}$ m², B_1 = 0.25 T

R_2 = 14 Ω, N_2 = 42,

$A_2 = 1.8 \times 10^{-3}$ m², 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.

Solution : Given:

For moving coil meter M_1

Resistance of wire, $R_1 = 10\Omega$

Number of turns, $N_1 = 30$

Area of cross-section, $A_1 = 3.6 \times 10^{-3}$ m²

Magnetic field strength, $B_1 = 0.25$ T

For moving coil meter M_2

Resistance of wire, $R_2 = 14\Omega$

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, $K_1 = K_2 = K$

Current sensitivity is given by,

Hence, the ratio of current sensitivities is 1.4.

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

Question11. 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)

Solution : Given:

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

Initial velocity of electron = $4.8 \times 10^6\ ms^{-1}$

Angle between the initial velocity of electron and magnetic field, $\theta = 90^0$

$\Rightarrow F_e = 1.6 \times 10^{-19}\ C \times 4.8 \times 10^6\ ms^{-1} \times 6.5 \times 10^{-4} T \times \sin 90$

$\Rightarrow F_e = 4.99 \times 10^{-16} N$

This force serves as the centripetal force, which explains the circular trajectory of the electron.

Centripetal force $F_c = mv^2/r$ …(2)

By equating equation (1) and equation (2) we get,

Question12. 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.

Solution : Given:

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

Initial velocity of electron $= 4.8 \times 10^{6}\ ms^{-1}$

Angle between the initial velocity of electron and magnetic field, $\theta = 90^{0}$

We can relate the velocity of the electron to its angular frequency by the relation,

$V = r\omega$ …(1)

Where,

V = velocity of electron

r = radius of path

ω = angular frequency

Question13. (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.)

Solution : Given:

Number of turns in the coil, n = 30

Radius of coil, r = 8 cm

Current through the coil, I = 6.0 A

Strength of magnetic field = 1.0 T

Angle between the direction of field and normal to coil, $\theta = 60°$

We can understand that the counter torque required to prevent the coil from rotating is equal to the torque being applied by the magnetic field.

Torque on the coil due to magnetic field is given by,

$T = n \times B \times I \times A \times \sin\theta$ …(1)

Where,

n = number of turns

B = Strength of magnetic field

I = Current through the coil

A = Area of cross-section of coil

$A = \pi r^2 = 3.14 \times (0.08 \times 0.08) = 0.0201 m^2$ …(2)

θ = Angle between normal to cross-section of coil and magnetic field

Now, by putting the values in equation (1) we get,

$\Rightarrow T = 30 \times 6.0T \times 1A \times 0.0201 m^2 \times \sin 60°$

T = 3.133 Nm

Hence, the counter torque required to prevent the coil from rotating is 3.133 Nm.

b) From equation (1) we can understand that, torques depends on the total area of cross-section and has no relation with the geometry of cross-section. Hence, the answer will remain unaltered if the circular coil in (a) were replaced by a planar coil of some irregular shape that encloses the same area.

ADDITIONAL EXERCISES

Question14. Two concentric circular coils X and Y of radii 16 cm and 10 cm, respectively, lie in the same vertical plane containing the north to south direction. Coil X has 20 turns and carries a current of 16 A; coil Y has 25 turns and carries a current of 18 A. The sense of the current in X is anticlockwise, and clockwise in Y, for an observer looking at the coils facing west. Give the magnitude and direction of the net magnetic field due to the coils at their centre.

Solution : Here we have to find total magnetic field produced by the system so we will first find magnetic field due to each coil with direction and then add them in accordance with vector addition. Using the Right-hand thumb rule we can predict the direction of induced magnetic field in both the coils.

The orientation of both the coils is shown below in the figure.

Question15. A magnetic field of 100 G (1 G = 10^{-4} T) is required which is uniform in a region of linear dimension about 10 cm and area of cross-section about 10^{-3} m^2. The maximum current-carrying capacity of a given coil of wire is 15 A and the number of turns per unit length that can be wound round a core is at most 1000 turns m^{-1}. Suggest some appropriate design particulars of a solenoid for the required purpose. Assume the core is not ferromagnetic.

Solution : Here, we have a particular value of No. of turns per unit Length and Current in the coil in order to obtain the given magnetic field.

The Required Magnetic field B = 100 G = $100 \times 10^{-4} = 10^{-2}$ T

Maximum Number of turns per unit length, n = 1000/m

Maximum Current flowing in the coil, I = 15 A

Permeability of free space, $\mu_0 = 4\pi \times 10^{-4}$ TmA^{-1}

We know magnetic field for a solenoid is given by B =