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Moving Charges And Magnetism

Exercise

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

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

where,

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

$$|B| = \frac{4\pi \times 10^{-7}}{4\pi} \times \frac{2\pi \times 100 \times 0.4}{0.08}$$

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

∴ the magnitude of the magnetic field ~~at~~ is 3.14×10^{-4}T.

4.2 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 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

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

where, μ_0 = Permeability of free space $= 4\pi \times 10^{-7}\ TmA^{-1}$

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

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

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

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

ans Length of the wire, $l = 3cm = 0.03m$
Current flowing in the wire, $I = 10A$
Magnetic field, $B = 0.27T$

Angle between the current and magnetic field, $\theta = 90°$
Magnetic force exerted on the wire is given as:

$$F = BIl\sin\theta$$
$$= 0.27 \times 10 \times 0.03 \times \sin 90°$$
$$= 8.1 \times 10^{-2}\ N$$

∴ 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.

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4.7 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 Current flowing in the wire A, $I_A = 8.0A$
Current flowing in the wire B, $I_B = 5.0A$
Distance between the two wires, $r = 4.0cm = 0.04m$
Length of a section of the wire A, $l = 10cm = 0.1m$

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

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

where, μ_0 = Permability of free space = $4\pi \times 10^{-7} TmA^{-1}$

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

$$= 2 \times 10^{-5} N$$

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

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

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

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

∴ Total number of turns on the solenoid, $N = 5 \times 400 = 200$
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 = $4\pi \times 10^{-7}\,TmA^{-1}$

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

$$= 8\pi \times 10^{-3} = 2.512 \times 10^{-2}\,T$$

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

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

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ans Magnetic field strength, $B = 6.5G = 6.5 \times 10^{-4}$ 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,
$\theta = 90°$

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,
$$F_c = \frac{mv^2}{r}$$

In equilibrium, the centripetal force exerts on the electron is equal to the magnetic force i.e.,
$$F_c = F$$
$$\frac{mv^2}{r} = evB\sin\theta$$
$$\Rightarrow r = \frac{mv}{Be\sin\theta}$$

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

$$= 4.2 \times 10^{-2} \text{ m} = 4.2 \text{ cm}$$
$\therefore$ the radius of the circular orbit of the electron is 4.2 cm.

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

ans Magnetic field strength, $B = 6.5 \times 10^{-4}$ T
Charge of the electron, $e = 1.6 \times 10^{-19}$ C
Mass of the electron, $m_e = 9.1 \times 10^{-31}$ kg
Velocity 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 $= \nu$
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:

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

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

$$\nu = \frac{Be}{2\pi m}$$

This expression for frequency is independent of the speed of the electron.
On substituting the known values in this expression,

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get the frequency as:

$$V = \frac{6.5 \times 10^{-4} \times 1.6 \times 10^{-19}}{2 \times 3.14 \times 9.1 \times 10^{-31}}$$

$$= 18.2 \times 10^{6} Hz$$

$$\approx 18 MHz$$

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

4.13 (a) A circular coil of 30 turns 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.

(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 (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, $I = 6.0 A$

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Magnetic field strength, $B = 1T$
Angle betn the field lines and normal with the coil surface, $\theta = 60°$

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,

$$T = nIBA \sin\theta \quad \text{--- (1)}$$
$$= 30 \times 6 \times 1 \times 0.0201 \times \sin 60°$$
$$= 3.133 \, Nm$$

(b) It can be inferred from relation (i) that the magnitude of the applied torque isn't dependent on the shape of the coil. It depends on the area of the coil. Hence, the answer wouldn't change if the circular coil is above case is replaced by a planar coil of some irregular shape that encloses the same area.

4.14 Two concentric circular coils X and Y of radii 16cm and 10cm, respectively, lie in the same vertical plane containing the north to south direction. Coil X has 20 turns and carries a current of 16A; coil Y has 25 turns and carries a current of 18A. 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 magnitude field due to the coils at their centre

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ans Radius of coil X, $r_1 = 16\,cm = 0.16\,m$
Radius of coil Y, $r_2 = 10\,cm = 0.10\,m$

No. of turns ~~of~~ on coil X, $n_1 = 20$
No. of turns of on coil Y, $n_2 = 25$

Current in coil X, $I_1 = 16A$
Current in coil Y, $I_2 = 18A$

Magnetic field due to coil X at their centre is given by the relation,

$$B_1 = \frac{\mu_0 n_1 I_1}{2r_1}$$

where,
μ_0 = Permeability of free space $= 4\pi \times 10^{-7}\ TmA^{-1}$

$$\therefore B_1 = \frac{4\pi \times 10^{-7} \times 20 \times 16}{2 \times 0.16}$$

$$= 4\pi \times 10^{-4}\,T \text{ (towards East)}$$

Magnetic field due to coil Y at their centre is given by the relation,

$$B_2 = \frac{\mu_0 n_2 I_2}{2r_2}$$

$$\therefore B_2 = \frac{4\pi \times 10^{-7} \times 25 \times 18}{2 \times 0.1}$$

$$= 9\pi \times 10^{-4}\,T \text{ (towards West)}$$

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Hence, net magnetic field can be obtained as:-

$$B = B_2 - B_1$$
$$= 9\pi \times 10^{-4} - 4\pi \times 10^{-4}$$
$$= 5\pi \times 10^{-4}\ T$$
$$= 1.57 \times 10^{-3}\ T \text{ (Toward west)}$$

4.15 A magnetic field of 100G ($1G = 10^{-4}T$) 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 15A and the number of turns per unit length that can be wound round a core is at most 1000 turn's m^{-1}. Suggest some appropriate design particulars of a solenoid for the required purpose. Assume the core is n't ferromagnetic.

ans Magnetic field strength, $B = 100G = 100 \times 10^{-4}\ T$
No. of turns per unit length, $n = 1000$ turns m^{-1}
Current flowing in the coil, $I = 15A$

Permability of free space, $\mu_0 = 4\pi \times 10^{-7}\ TmA^{-1}$
Magnetic field is given by the relation,

$$B = \mu_0 n I$$
$$\therefore nI = B/\mu_0$$

$$= \frac{100 \times 10^{-4}}{4\pi \times 10^{-7}} = 7957.74$$
$$\approx 8000\ A/m$$

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If the length of the coil is taken as 50cm, radius 4cm, number of turns 400, and current 10A, then these values aren't unique for the given purpose. There is always a possibility of some adjustments with limits.

4.17 A toroid has a core (non-ferromagnetic) of inner radius 25cm and outer radius 26cm, around which 3500 turns of a wire are wound. If the current in the wire is 11A, what is the magnetic field (a) outside the toroid (b) inside the core of the toroid and (c) in the empty space surrounded by the toroid.

ans Inner radius of the toroid, $r_1 = 25cm = 0.25m$
Outer radius of the toroid, $r_2 = 26cm = 0.26m$
Number of turns on the coil, $N = 3500$
Current in the coil, $I = 11A$

(a) Magnetic field outside a toroid is zero. It is non-zero only inside the core of a toroid.

(b) Magnetic field inside the core of a toroid is given by the relation,

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

where,

μ_0 = Permeability of free space, $= 4\pi \times 10^{-7}\ TmA^{-1}$
l = length of toroid
$= 2\pi \left[\frac{r_1 + r_2}{2}\right]$

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$= \pi(0.25 + 0.26)$
$= 0.51\pi$

$$\therefore B = \frac{4\pi \times 10^{-7} \times 3500 \times 11}{0.51\pi}$$
$$\approx 3.0 \times 10^{-2}\,T$$

(c) Magnetic field in the empty space surrounded by the toroid is 0.

4.18. (a) A magnetic field that varies in magnitude from point but has a constant direction (east to west) is set up in a chamber. A charged particle enters the chamber and travels undeflected along a straight path with constant speed. What can u say about the intial velocity of the particle?

(b) A charged particle enters an environment of a strong and non-uniform magnetic field varying from point to point both in magnetic and direction, and comes out of it following a complicated trajectory. Would its final speed equal the initial speed of if it suffered no collisions with the environment?

(c) An electron travelling west to east enters a chamber having a uniform electrostatic field in north to south dir^n, Specify the dir^n in which a uniform magnetic field should be set up to prevent the electron from deflecting from its straight line.

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ans a) The initial velocity of the particle is either parallel or anti-parallel to the magnetic field. Hence, it travels along a straight path without suffering any deflection in the field.

b) Yes, the final speed of the charged particle will be equal to its initial speed. This is because magnetic force can change the dirⁿ of velocity, but not its magnitude.

c) ~~An~~ electron travelling from West to East enters a chamber having a uniform electrostatic field in the North-South dirⁿ. This moving electron can remain undeflected if the electric force acting on it is equal and opposite of magnetic field. Magnetic force is directed towards the south. According to Fleming's left hand rule, magnetic field should be applied in vertically downward dirⁿ.

4.19 An electron emitted by a heated cathode and accelerated through a potential difference of 2.0 kV, enters a region with uniform magnetic ~~force~~ of 0.15 T. Determine the trajectory of the electron if the field (a) is transverse to its initial velocity, (b) makes an angle of 30° with initial velocity.

ans Magnetic field strength, $B = 0.15\,T$
Charge on the electron, $e = 1.6 \times 10^{-19}\,C$
Mass of the electron, $m = 9.1 \times 10^{-31}\,kg$
Potential difference, $V = 2.0\,kV = 2 \times 10^{3}\,V$
Thus, kinetic energy of the electron $= eV$

$$\Rightarrow eV = \frac{1}{2} mv^2$$

$$v = \sqrt{\frac{2eV}{m}} \quad \text{—— (1)}$$

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(a) Magnetic force on the electron provides the required centripetal force of the electron. Hence, the electron traces a circular path of radius r.

Magnetic force on the electron is given by the relation

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

$$\therefore Bev = \frac{mv^2}{r}$$

$$r = \frac{mv}{Be} \quad \text{—— (2)}$$

From (1) and (2),

$$r = \frac{m}{Be}\left[\frac{2eV}{m}\right]^{1/2}$$

$$= \frac{9.1\times10^{-31}}{0.15\times1.6\times10^{-19}} \times \left(\frac{2\times1.6\times10^{-19}\times2\times10^{3}}{9.1\times10^{-31}}\right)^{1/2}$$

$$= 100.55\times10^{-5} \Rightarrow 1.01\times10^{-3}\,m$$

$$= \underline{1mm}$$

(b) When the field makes an angle θ of 30° with initial velocity, the initial velocity will be,

$$V_1 = V\sin\theta$$

From Eqn (2), we can write the expression for new radius,

$$r_1 = \frac{mV_1}{Be}$$

$$= \frac{mV\sin\theta}{Be} = \frac{9.1\times10^{-31}}{0.15\times1.6\times10^{-19}} \times \left[\frac{2\times1.6\times10^{-19}\times2\times10^{3}}{9\times10^{-31}}\right]^{1/2} \times \sin30^\circ$$

$$= 0.5\times10^{-3}\,m \Rightarrow \underline{0.5mm}$$

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4.20 Magnetic field, $B = 0.75T$
Accelerating voltage, $V = 15KV = 15 \times 10^3 V$
Electrostatics field, $E = 9 \times 10^5 Vm^{-1}$
Mass of the electron $= m$
charge of the electron $= e$
Velocity of the electron $= v$
kinetic energy of the electron $= eV$

$$\Rightarrow \frac{1}{2}mv^2 = eV$$

$$\therefore e/m = v^2/2V \quad \text{--- (1)}$$

Since the particle remains undeflected by electric and magnetic fields, we can infer that the electric field is balancing the magnetic field.

$$\therefore eE = evB$$

$$v = E/B \quad \text{--- (2)}$$

Putting Eq^{n}s (2) in (1).,

$$e/m = \frac{1}{2}\frac{\left(\frac{E}{B}\right)^2}{V} = \frac{E^2}{2VB^2}$$

$$= \frac{(9.0 \times 10^5)^2}{2 \times 15000 \times (0.75)^2} = 4.8 \times 10^7 \, C/kg$$

The value of specify charge e/m is equal to the value of deuteron or deuterium ions. This is not a unique answer. Other possible answer are He^{++}, Li^{++} etc.

4.24 Magnetic field strength, $B = 3000G = 3000 \times 10^{-4} T = 0.3$
Length of the rectangular loop, $l = 10cm$
Width of the rectangular loop, $b = 5cm$
Area of the loop,

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$$A = l \times b = 10 \times 5 = 50 cm^2 = 50 \times 10^{-4} m^2$$

Current in the loop, $I = 12A$

Now, taking the anti-clockwise dir^n of the current as positive and vice-versa:

(a) Torque, $\vec{\tau} = I\vec{A} \times \vec{B}$

From the given figure, it can be observed that A is normal to the y-z plane and B is directed along z-axis.

$$\therefore \tau = 12 \times (50 \times 10^{-4}) \hat{i} \times 0.3\hat{k}$$
$$= -1.8 \times 10^{-2} \hat{j} Nm$$

The torque is 1.8×10^{-2} Nm along the negative y-dir^n. The force on the loop is zero because the angle between A and B is zero.

(b) This case is similar to case (a). Hence, the answer is the same as (a).

(c) Torque, $\tau = I\vec{A} \times \vec{B}$

From the given figure, it can be observed that A is normal to the x-z plane and B is directed along the z-axis.

$$\therefore \tau = -12 \times (50 \times 10^{-4}) \hat{j} \times 0.3\hat{k}$$
$$= -1.8 \times 10^{-2} \hat{i} Nm$$

The torque is 1.8×10^{-2} Nm along the negative x-dir^n and the force is zero.

(d) Magnitude of torque is given as:-

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$|\tau| = IAB$
$= 12 \times 50 \times 10^{-4} \times 0.3$
$= 1.8 \times 10^{-2}$ Nm

Torque is 1.8×10^{-2} **Nm** at an angle of 240° with positive x-dirn. The ~~x~~ force is zero.

(e) Torque, $\tau = I\vec{A} \times \vec{B}$
$= (50 \times 10^{-4} \times 12)\hat{k} \times 0.3\hat{k}$
$= 0$

Hence, the torque is zero. The force also zero.

(f) Torque, $\tau = I\vec{A} \times \vec{B}$
$= (50 \times 10^{-4} \times 12)\hat{k} \times 0.3\hat{k}$
$= 0$

Hence, the torque is zero. The force is also zero.

In case (e), the direction of $I\vec{A}$ and $\vec{B}$ is the same and the angle between them is zero. If displaced, they come back to an equilibrium. Hence, its equilibrium is stable.

4.27 Resistance of the galvanometer coil, $G = 12\,\Omega$

Current for which there is full scale deflection, $I_g = 3$ mA
$= 3 \times 10^{-3}$ A

Range of the voltmeter is 0, which needs to be converted to 18V.
$\therefore V = 18$ V

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Let a resistor of resistance R be connected in series with the galvometer to convert it into a voltmeter. This resistor is given as:-

$$R = V/I_g - G$$

$$= \frac{18}{3 \times 10^{-3}} - 12 = 6000 - 12$$

$$= 5988\,\Omega$$

Hence, a resistor of resistance $5988\,\Omega$ is to be connected in series with the galvometer.

4.28 Resistance of the galvometer coil, $G = 15\,\Omega$
Current for which the galvometer show full scale deflection,

$$I_g = 4mA = 4 \times 10^{-3} A$$

Range of the ammeter is 0, which needs to be converted to 6A.

$\therefore$ Current, $I = 6A$

A shunt resistor of resistance S is to be connected in parallel with the galvometer to convert it into an ammeter. The value of S is given as:-

$$S = \frac{I_g G}{I - I_g}$$

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$$= \frac{4\times10^{-3}\times15}{6-4\times10^{-3}}$$

$$S = \frac{6\times10^{-2}}{6-0.004} = \frac{0.06}{5.996}$$

$$\approx 0.01\,\Omega = 10\,m\Omega$$

Hence, a $10\,m\Omega$ shunt resistor is to be connected in parallel with the galvometer.

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