Ch-4 : Moving Charges and Magnetism :-

NCERT :

Q1. 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, $r = 8.0\text{ cm} = 0.08\text{ m}$
Current flowing in the coil, $I = 0.4\text{ A}$.
Magnitude of the magnetic field at the centre of the coil is given by the relation,

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

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

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

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

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

Q2. A long straight wire carries a current of 35A. What is the magnitude of the field B at a point 20 cm from the wire?

Ans: Current in the wire, $I = 35\text{ A}$
Distance of a point from the wire, $r = 20\text{ cm} = 0.2\text{ m}$
Magnitude of the magnetic field at this point is given as

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

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

$$B = \frac{4\pi \times 10^{-7} \times 2 \times 35}{4\pi \times 0.2}$$
$$= 3.5 \times 10^{-5}\ T.$$

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

Q6. A 30 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?

Ans: Length of the wire, $l = 3\text{ cm} = 0.03$ m

Current flowing in the wire, $I = 10$ A.

Magnetic field, $B = 0.27$ T.

Angle betn the current and magnetic field, $\theta = 90^\circ$

(Because magnetic field produced by a solenoid is along its axis and current carrying wire is kept perpendicular to the axis).

Magnetic force exerted on the wire is given as:

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

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.

Q7. 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.

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

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

Distance bet^n the two wires, $r = 4.0\ cm = 0.04\ m$
Length of a section of wire A, $l = 10\ cm = 0.1\ m$
Force ~~ent~~ exerted on length l due to the magnetic field is given as:

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

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

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

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

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

Q8. 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.

Ans: 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, $N = 5 \times 400 = 2000$
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 $4\pi \times 10^{-7}\ Tm A^{-1}$

$$B = \frac{4\pi \, 10^{-7} \times 20008}{0.8}$$

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

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

Q11. In a chamber, a uniform magnetic field of 6.5 G ($1G = 10^{-4}\ T$) is maintained. An electron is shot into the field with a speed of 4.8×10^{6} m/s normal to the field. Explain why the path of the electron is a circle. Determine the radius of the circular orbit. ($e = 1.5 \times 10^{-19}$ C, $m_e = 9.1 \times 10^{-31}$ kg)

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

Speed of the electron, $V = 4.8 \times 0^{6}$ m/s

Charged on the electron, $e = 1.6 \times 10^{-19}$ C

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

Angle betn the shot electron & magnetic field, $\theta = 90^{\circ}$

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

$$F_c = F$$

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

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

$$= 4.2\times10^{-2}\ m = 4.2$$

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

Q12. 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: 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, $r = 4.2$ cm $= 0.042$ m

Frequency of revolution of the electron $= \nu$.

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, we can write:

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

$$eB = \frac{m}{r}(r\omega) = \frac{m}{r}(r\,2\pi\nu)$$

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

The frequency expression for frequency is independent of the speed of the electron.
On substituting the known values in this expression, we get the frequency as:

$$v = \frac{6.5 \times 10^{-4} \times 1.6 \times 10^{-19}}{2 \times 3.14 \times 9.1 \times 10^{-31}}$$
$$= 18.2 \times 10^{6}\ Hz$$
$$= 18 MHz.$$

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

Q13. (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 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, $r = 8.0 cm = 0.08 m$
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, $B = 1T$
Angle betn the field lines and normal with the coil surface, $\theta = 60°$.
The coil experience a torque in the magnetic field. Hence, it turns. The counter torque applied to prevent the coil from turning is given by the reln.
$T = nIBA \sin\theta$ ——— (1)
$= 30 \times 6 \times 1 \times 0.0201 \times \sin 60° = 3.133 Nm.$

(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: It can be inferred from relⁿ (1) that the ~~magnetic~~ 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.

Q14. Two concentric circular coils X and Y 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.

Ans: Radius of coil X, r_1 = 16 cm = 0.16 m

Radius of coil Y, r_2 = 10 cm = 0.1 m

Number of turns of on coil X, n_1 = 20

Number of turns of on coil Y, n_2 = 25

Current in coil X, I_1 = 16 A

Current in coil Y, I_2 = 18 A

Magnetic field due to coil X at their centre is given by the relⁿ.

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

where,

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

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

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

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

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

$$B_1 = \frac{4\pi \times 10^{-7} \times 25 \times 18}{2 \times 0.10}$$

$$= 9\pi \times 10^{-4}\ T \text{ (toward East)}$$

Hence, net magnetic field can be obtained as:

$$B = B_2 - B_1$$

$$= 9\pi \times 10^{-4} - 4\pi \times 10^{-4}$$

$$= 5\pi \times 10^{-4}\ T$$

$$1.57 \times 10^{-3}\ T \text{ (towards west)}.$$

Q15. 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 & 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.

Ans: Magnetic field strength, $B = 100\ G = 100 \times 10^{-4}\ T$

Number of turns per unit length, $n = 1000$ turns m^{-1}

Current flowing in the coil, $I = 15\ A$.

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Permeability of free space, $\mu_0 = 4\pi \times 10^{-7}\ Tm A^{-1}$
Magnetic field is given the relⁿ,

$B = \mu_0 n I$

$\therefore nI = \frac{B}{\mu_0}$

$= \frac{100 \times 10^{-4}}{4\pi \times 10^{-7}} = 7657.74$

$\approx 8000\ A/m$

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

Q17. A toroid has a core (non-ferromagnetic of inner radius 25 cm and outer radius 26 cm, around which 3500 turns of a wire are wound. If the current in the wire is 11 A, 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, $r_1 = 25\ cm = 0.25\ m$
Outer radius of the toroid, $r_2 = 26\ cm = 0.26\ m$
Number of turns on the coil, $N = 3500$
Current in the coil, $I = 11\ A$.

(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 relaⁿ, $B = \frac{\mu_0 N I}{l}$

$l = 2\pi \left[\frac{r_1 + r_2}{2}\right]$

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$\pi \times 10^{-7}\ Tm A^{-1}$

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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 zero.

Q18. (a) A magnetic field that varies in magnitude from point to 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 the const. speed. What can you say about the initial velocity of the particle?.

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

Ans: Yes, the final speed of the charged particle will be equal to its initial speed. This is becoz magnetic force can change direction of velocity, but not its magnitude.

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

Ans: An electron travelling from west to East enters a chamber having a uniform electrostatic field in the North - South direction. This moving electron can remain undeflected if 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 a vertically downward direction.

Q19. An electron emitted by a heated cathode & accelerated through a potential difference of 2.0 kV, enters a region with uniform magnitude field 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 the 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 $= eV$

$\Rightarrow eV = \frac{1}{2} m v^2$

$$v = \sqrt{\frac{2eV}{m}} \qquad \text{---(1)}$$

Where,

v = Velocity of the electron.

(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 relⁿ, BeV.

Centripetal force $= \frac{mv^2}{r}$

$\therefore BeV = \frac{mr^2}{r}$

$r = \frac{mv}{Be}$ ——— (2)

From eqⁿ (1) & (2), we get

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

$$= \frac{9.1 \times 10^{-31}}{0.15 \times 1.6 \times 10^{-19}} \times \left(\frac{2 \times 1.6 \times 10^{-19} \times 2 \times 10^{3}}{9.1 \times 10^{-31}}\right)^{1/2}$$

$= 100.55 \times 10^{-5}$
$= 1.01 \times 10^{-3}$ m
$= 1$mm

Hence, the electron has a circular trajectory of radius 1.0 mm normal to the magnetic field.

(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 as:

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$$r_1 = \frac{mv_1}{Be}$$

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

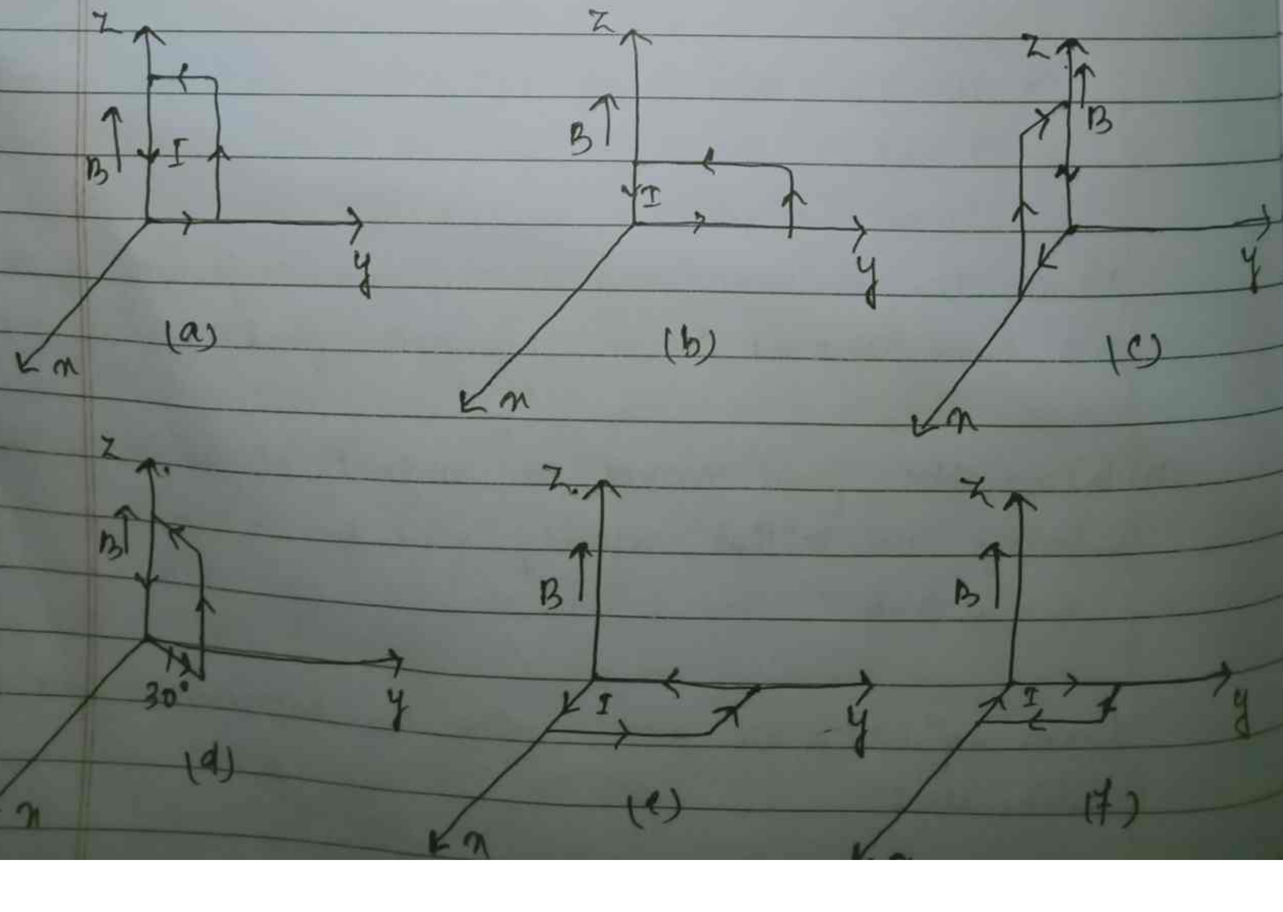
$$= \frac{9.1 \times 10^{-31}}{0.15 \times 1.6 \times 10^{-19}} \times \left[\frac{2 \times 1.6 \times 10^{-19} \times 2 \times 10^{3}}{9 \times 10^{-31}}\right] \times \sin 30^\circ$$

$$= 0.5 \times 10^{-3}\, m$$

$$= 0.5\, mm$$

Hence, the electron has a helical trajectory of radius 0.5 mm, with axis of the solenoid along the magnetic field direction.

Q24. A uniform magnetic field of 3000 G is established along the positive z-direction. A rectangular loop of sides 10 cm & 5 cm carries a current of 12 A. What is the torque on the loop in the different cases shown in Fig. 4.28? What is the force on each case? Which case corresponds to stable equilibrium?



Sol: Magnetic field strength, $B = 2000\,G = 3000 \times 10^{-4}\,T = 0.3\,T$
length of the rectangular loop, $l = 10\,cm$
Width of the rectangular loop, $b = 5\,cm$
Area of the loop,
$A = l \times b = 10 \times 5\,cm^2 = 50 \times 10^{-4}\,m^2$
Current in the loop, $I = 12\,A$
Now, taking the anti-clockwise direction 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 & B is directed along the z-axis.
$\tau = 12 \times (50 \times 10^{-4})\,\hat{i} \times 0.3\hat{k}$
$= -1.8 \times 10^{-2}\,\hat{j}\,Nm$.
The torque is $1.8 \times 10^{-2}\,Nm$ along the negative y-direct^n
The force on the loop is zero, bcoz the external magnetic field is uniform.

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

(c) Torque $\vec{\tau} = I\vec{A} \times \vec{B}$
From the given figure, it can be observed that A is normal to the x-z plane & B is directed along the z-axis.
$\tau = 12 \times (50 \times 10^{-4})\,\hat{j} \times 0.3\hat{k}$
$= -1.8 \times 10^{-2}\,\hat{i}\,Nm$
The torque is $1.8 \times 10^{-2}\,Nm$ along the negative x direct^n & the force is zero.

(d) Magnitude of torque is given as:
$|\tau| = IAB$.

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$12 \times 50 \times 10^{-4} \times 0.3$

$= 1.8 \times 10^{-2}$ Nm

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

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

$= (50 \times 10^{-4} \times 12)\hat{k} \times 0.3\hat{k}$

$= 0.$

Hence, the torque is zero. The force is also zero.
In case (e), the directⁿ of $I\vec{A}$ & $\vec{B}$ is the same & the angle betⁿ them is zero. If is displaced, they come back ~~of~~ to an eqᵐ. Hence, the eqᵐ is stable.

Whereas in case (f), the direction of $I\vec{A}$ & $\vec{B}$ is opposite. The angle betⁿ them is $180°$. If disturbed, it does not come back to its original position. Hence, its eqᵐ is unstable.

Q27. A galvanometer coil has a resistance of $12\,\Omega$ and the meter shows full scale deflection for a current of 3mA. How will you convert the meter into a voltmeter of range 0 to 18 V?

Ans: Resistance of the galvanometer coil, $G = 12\,\Omega$
Current for which there is full scale deflection, $I_g = 3\text{mA} = 3 \times 10^{-3}$ A.
Range of the voltmeter, needs to be connected in series with the galvanometer to convert it into a voltmeter. This resistance is given as:

$$R = \frac{V}{I_g} - G$$

$$= \frac{18}{3 \times 10^{-3}} - 12 = 6000 - 12 = 5988\,\Omega$$

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Hence, a resistor of resistance 5988 Ω is to be connected in series with the galvanometer.

Q28. A galvanometer coil has a resistance of 15 Ω and the meter shows full scale deflection for a current of 4mA. How will you convert the metre into an ammeter of range 0 to 6 A?

Ans: Resistance of the galvanometer coil, $G = 15\,\Omega$.
Current for which the galvanometer shows full scale deflection, $I_g = 4\text{mA} = 4 \times 10^{-3}$ A
Range of the ammeter needs to be 6 A.
Current, $I = 6$ A
A shunt resistor of resistance S is to be connected in parallel with the galvanometer to convert it into an ammeter. The value of S is given as:

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

$$= \frac{4 \times 10^{-3} \times 15}{6 - 4 \times 10^{-3}}$$

$$S = \frac{6 \times 10^{-2}}{6 - 0.004} = \frac{0.06}{5.996}$$

$$= 0.01\,\Omega = 10\,\text{m}\Omega$$

Hence, a 10 mΩ shunt resistor is to be connected in || with the galvanometer.

—X—