Moving Charges and Magnetism

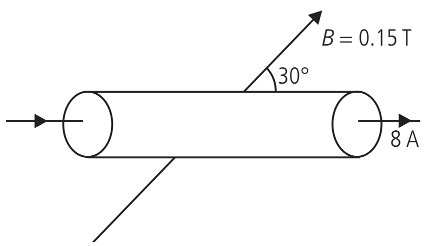
CHAPTER 4

NCERT FOCUS

ANSWERS

Topic 1

1.



Let l be length of wire, carrying a current of 8 A at an angle 30° with the magnetic field.

Force on the wire, $F = iBl \sin\theta$

Force per unit length $F/l = iB \sin\theta$

$F/l = 8 \times 0.15 \times \sin 30° = 0.6 \text{ N m}^{-1}$.

2. The magnetic force $f = qvB$ act normal to the direction of motion, thus provide the necessary centripetal force to follow the circular path.

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

$$r = \frac{mv}{qB} = \frac{9.1\times10^{-31}\times4.8\times10^{6}}{1.6\times10^{-19}\times6.5\times10^{-4}}$$

or $r = 4.2 \times 10^{-2} = 42$ mm

3. Time period can be calculated.

$$T = \frac{2\pi r}{v} = \frac{2\pi m}{Bq}$$

So, frequency

$$f = \frac{1}{T} = \frac{Bq}{2\pi m} \text{ or } f = \frac{6.5\times10^{-4}\times1.6\times10^{-19}}{2\pi\times9.1\times10^{-31}}$$

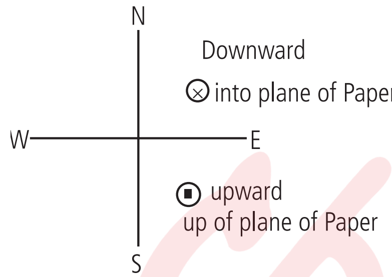
$f = 18.2 \times 10^{6}$ Hz = 18.2 MHz.

The frequency of revolution of electron is independent of speed of electron.

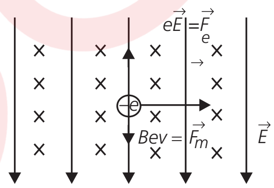
4. (a) If a charged particle move parallel or antiparallel to the magnetic field, no magnetic force will act on it and it move undeflected. So, in the given condition either the charged particle enters east to west or west to east.

(b) A magnetic force can only change the direction of charged particle but never changes magnitude of speed as force act normal to direction of speed. So, charged particle may follow a complicated trajectory, but its speed remains the same.

(c)



If we want the electron to move undeflected in the presence of electric and magnetic fields, then the electric force should be balanced by magnetic force.



So, the magnetic field should act in downward direction.

5. A electron which is accelerated by a potential difference of 2.0 kV will have a kinetic energy gained 2000 eV.

$E = 1/2 m_e v^2 = 2000 \times 1.6 \times 10^{-19}$

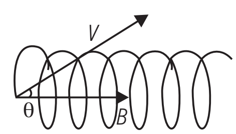
$$v = \sqrt{\frac{4\times1.6\times10^{-16}}{9\times10^{-31}}} = 2.66 \times 10^{7} \text{ m s}^{-1}$$

(a) When the electron enters in the uniform magnetic field which is normal to the velocity of electron the electron follows a circular path of radius.

$$r = \frac{mv}{Bq} = \frac{9.1\times10^{-31}\times2.66\times10^{7}}{0.15\times1.6\times10^{-19}} = 99.75 \times 10^{-5} \approx 1 \text{ mm}$$

(b) When the magnetic field makes an angle 30° with the initial velocity, the trajectory of the electron becomes helical.

radius of the helical path is



$$r = \frac{mv\sin\theta}{Bq}$$

$r = 99.75 \times 10^{-5} \times \frac{1}{2}$

$r = 49.875 \times 10^{-5}$ m ≈ 0.5 mm

$v = v\cos\theta = 2.66 \times 10^{7} \cos 30° = 2.3 \times 10^{7} \text{ m s}^{-1}$

Pitch of the helical path is

$$\text{Pitch} = T \times v\cos\theta = \frac{2\pi m}{Bq} \times v\cos\theta$$

$$= \frac{2\pi \times 9 \times 10^{-31} \times 2.66 \times 10^{7}}{0.15 \times 1.6 \times 10^{-19}} \times \frac{\sqrt{3}}{2} = 542.5 \times 10^{-5} \text{ m}$$

so, pitch = 5.42 mm.

6. Narrow beam of charged particles remains undeflected and is perpendicular to both electric field and magnetic fields which are mutually perpendicular. So, the electric force is balanced by magnetic force.

$qE = qvB$

Speed of charged particles

$$v = E/B = \frac{9 \times 10^{-5}}{0.75} = 12 \times 10^{-5} \text{ m s}^{-1}$$

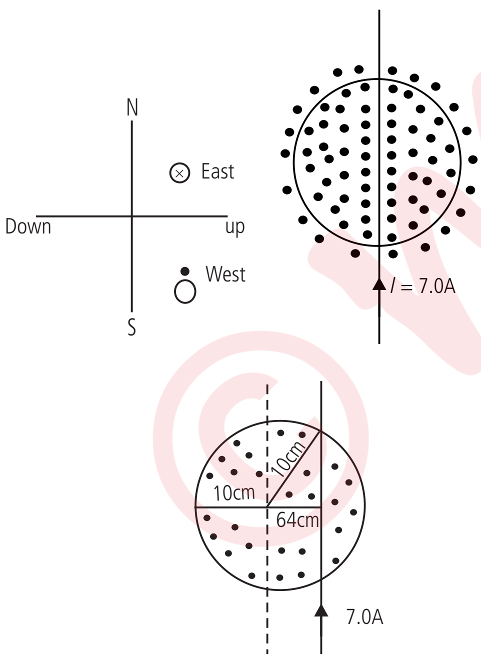
Because the beam is accelerated through 15 kV, if charge is q, then kinetic energy gained by charged particles

$$\frac{1}{2}mv^2 = qV$$

$$\frac{m}{q} = \frac{2V}{v^2} = \frac{2 \times 15 \times 10^3}{(12 \times 10^{-5})^2} = 20.8 \times 10^{11} \text{ kg C}^{-1}$$

Here, we can only obtain charge to mass ratio and same ratio can be in Deuterium ions, He^{++}, Li^{+++}, so the beam can contain any of these charged particles.

7.



The magnetic field is in the direction east to west and in the cylindrical region of radius 10 cm.

(a) A current carrying wire, intersects the axis.

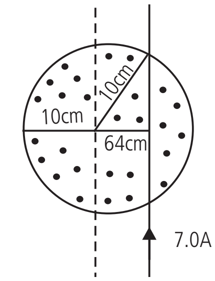
Force on wire,

$F = iBl = iB(2r) = 7 \times 1.5 \times 2 \times 1 \times 10^{-2}$

$F = 2.1$ N Downwards

(b) By turning the wire by an angle 45° in NE and NW direction the force remain the same, $F = 2.1$ N Downwards

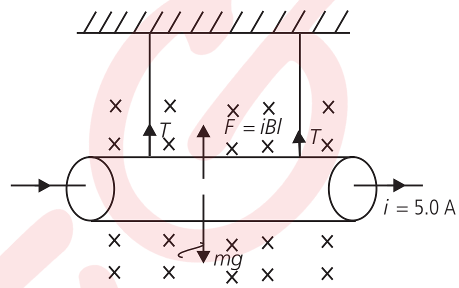
(c) Now the wire is lowered from the axis by a distance of 6.0 cm.



Length of wire inside cylindrical region is 16 cm now.

So, the force is $F = iBl = 7 \times 1.5 \times 16 \times 10^{-2} = 1.68$ N, vertically downwards

8.



Tension in the strings and magnetic force iBl balance the weight of wire.

$2T + iBl = mg$

(a) For tension in the wire to be zero.

$iBl = mg$

$$B = \frac{mg}{il} = \frac{60 \times 10^{-3} \times 9.8}{5 \times 0.45} = 0.26 \text{ T}$$

(b) If the direction of current is now reversed, keeping the current and magnetic field same, then

$2T = iBl + mg$

$2T = 2\text{ mg} = 2 \times 60 \times 10^{-3} \times 9.8$

Total tension = 1.176 N.

9. The magnetic field inside the solenoid is along its axis. Here the current in the wire flows perpendicular to the axis.

$F = iBl \sin 90°$

or $F = 10 \times 0.27 \times 3 \times 10^{-2} \times 1 = 0.081$ N

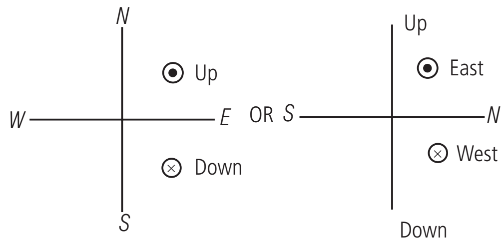
Topic 2

1. The magnetic field at the centre of a circular coil having 100 turns.

$$B = \left(\frac{\mu_0 I}{2r}\right)N \text{ or } B = \left[\frac{4\pi \times 10^{-7} \times 0.4}{2 \times 8 \times 10^{-2}}\right] \times 100$$

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

2. The concentric coils are in the plane north to south. Let us decide the directions with conveniences in the plane of paper.



Magnetic field at centre due to coil Y.

$$B_1 = \left(\frac{\mu_0 I}{2r}\right) \times 25$$

$$B_1 = \left[\frac{4\pi\times10^{-7}\times18}{2\times10\times10^{-2}}\right]\times25 \otimes \text{Towards west}$$

$B_1 = 2826 \times 10^{-6}$ T $\otimes$ west

Magnetic field at centre due to coil X

$$B_2 = \left[\frac{\mu_0 I}{2r}\right]20 \quad \text{or}$$

$$B_2 = \left[\frac{4\pi\times10^{-7}\times16}{2\times\left(16\times10^{-2}\right)}\right]20 \odot \text{East}$$

$B_2 = 1256 \times 10^{-6}$ T $\odot$ East

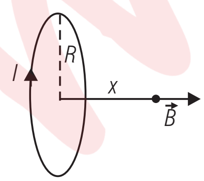
At centre of coils

$B_{net} = B_1 - B_2 = 1570 \times 10^{-6}$ T $\otimes$ West

So, a magnetic field nearly 1.6×10^{-3} T will appear at centre of the circular coil directed towards west.

3. On the axis of the circular coil of radius R and N turns carrying a current I at a distance x from centre the magnetic field is

$$B = \frac{\mu_0 I R^2 N}{2\left(x^2+R^2\right)^{3/2}}$$



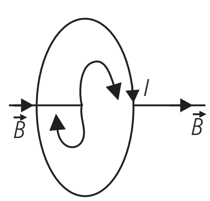
(a) At centre of the coil $x = 0$

So, the magnetic field

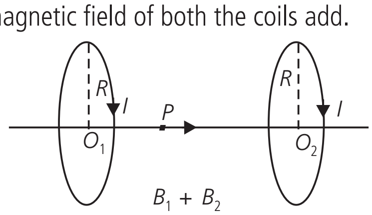
$$B = \frac{\mu_0 I R^2 N}{2R^3} = \frac{\mu_0 N I}{2R}$$

Which is the same result as is obtained by integration at centre of the coil.

(b) The side of the loop where current flows clockwise becomes south pole and where the current appear anticlockwise becomes north pole. Direction of magnetic field is from south pole to north pole.



Now, two parallel coils each of radius R with N turns. The magnetic field of both the coils add.



Net magnetic field,

$$B_{net} = B_2 + B_2 = \frac{\mu_0 I R^2 N}{2}\left[\frac{2}{\left[(R/2)^2+R^2\right]^{3/2}}\right]$$

$$B_{net} = \frac{\mu_0 I R^2 N}{2}\left[\frac{8\times2}{5\sqrt{5}R^3}\right]; B_{net} = \frac{8\mu_0 N I}{5\sqrt{5}R} = 0.72\frac{\mu_0 N I}{R}$$

4. The magnetic field required is 100 G in a length of 10 cm. So, the solenoid should have a length larger than 10 cm. The maximum current capacity of wire is 15 A, so less than 15 A should flow in wire.

Now using

$$B = \mu_0\frac{Ni}{l} \text{ or } 10 \times 10^{-4} = 4\pi\times10^{-7}\frac{Ni}{l}$$

$$\frac{Ni}{l} = 7{,}961.8$$

Now we can think of a possible combination with $i = 10$ A and total length of solenoid $l = 50$ cm

$$\frac{N}{50\times10^{-2}}\times10 = 7961.8 \quad \text{or} \quad N = 398.09 \text{ turns}$$

So, one combination for the desired 100 G magnetic field in a length 10 cm can be a total length of solenoid of 50 cm and current in the solenoid of 10 A and total turns nearly 400.

5. Magnetic in the solenoid $B = \mu_0 n i$

where $n = \dfrac{300\times3}{60\times10^{-2}} = 1500$ turns/m

$B = 4\pi \times 10^{-7} \times 1500 \times i = 18.84\, i \times 10^{-4}$ T

A current carrying wire is suspended inside solenoid and a current $i = 6.0$ A is flowing in it.

To balance the weight of the wire by the magnetic force

$iBl = mg$

$6 \times [18.84\, i \times 10^{-4}] \times 2 \times 10^{-2} = 2.5 \times 10^{-3} \times 9.8$

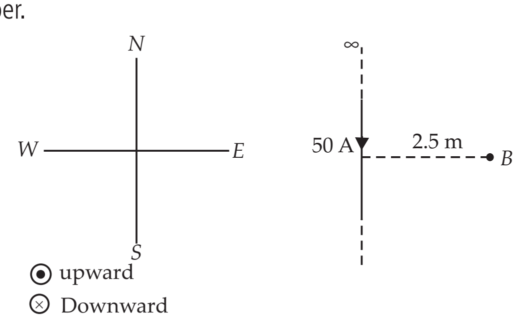
$i = 108.4$ A.

6. Magnetic field due to a long straight wire

$$B = \frac{\mu_0}{4\pi}\frac{2I}{r} \quad \text{or} \quad B = 10^{-7}\times\frac{2\times35}{20\times10^{-2}}$$

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

7. Let us first decide the standard directions on the plane of paper.



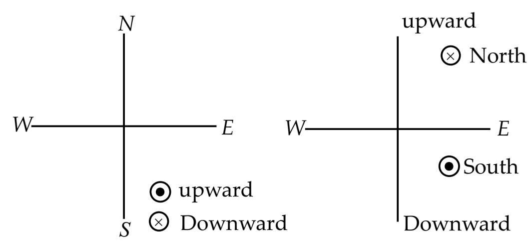
Magnitude of magnetic field

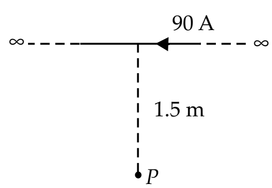
$$|\vec{B}| = \frac{\mu_0}{4\pi}\frac{2I}{r} = 10^{-7} \times \frac{2\times 50}{2.5} = 40 \times 10^{-7}\,\text{T}$$

By right hand palm rule, the direction of magnetic field can be seen as upward.

$$\vec{B} = 40 \times 10^{-7}\,\hat{k}\ \text{T}$$

8. The standard directions on the plane of paper can be different according to requirements.





The magnitude of magnetic field,

$$B = \frac{\mu_0}{4\pi}\frac{2I}{r} = 10^{-7} \times \frac{2\times 90}{1.5} = 120 \times 10^{-7}\,\text{T}$$

Direction of magnetic field can be observed by right hand palm rule and it is southward.

Topic 3

1. Total number of turns in 80 cm length of solenoid can be calculated

$N = 5 \times 400 = 2000$ turns.

$$n = \frac{\text{number of turns}}{\text{length}}$$

$$\frac{2000}{80\times 10^{-2}} = 2500\ \text{turns/m}$$

Magnetic field near centre of long solenoid, $B = \mu_0 nI$

$B = 4\pi \times 10–7 \times 2500 \times 8$ or $B = 8\pi \times 10–3$ T

2. Two wires connecting battery of an automobile to the starting motor carry 300 A current in opposite direction. So, the force is repulsive between them.

Force per unit length

$$F/l = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r} = 10^{-7} \times \frac{2\times 300\times 300}{1.5\times 10^{-2}}$$

$$= 1.2\ \text{N m}^{-1}$$

3. Force of attraction per unit length on two parallel wires carrying current in same direction.

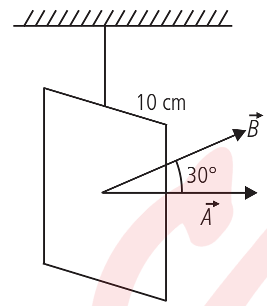
$$F/l = \frac{\mu_0}{4\pi}\frac{2I_1I_2}{r} = 10^{-7} \times \frac{2\times 8\times 5}{4\times 10^{-2}} = 20 \times 10^{-5}\ \text{N m}^{-1}$$

Attractive force on 10 cm section of wire A

$F = [20 \times 10^{-5}][10 \times 10^{-2}] = 2 \times 10^{-5}$ N

Topic 4

1.



Torque experienced by the coil carrying current in the given magnetic field.

$\tau = NIAB \sin\theta$

$\tau = 20 \times 12 \times [100 \times 10^{-4}] \times 0.8 \sin 30°$ or $\tau = 0.96$ N m.

2. Current sensitivity of a moving coil galvanometer is defined as

$$C.S. = \frac{\phi}{I} = \frac{NAB}{k} \text{ and voltage sensitivity, } V.S. = \frac{NAB}{k}$$

(i) Ratio of current sensitivity

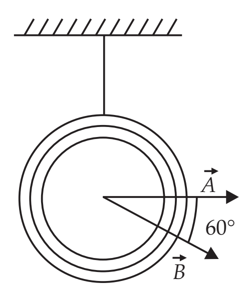
$$\frac{C\cdot S_2}{C\cdot S_1} = \frac{N_2B_2A_2k}{N_1B_1A_1k}$$

$$= \frac{42\times 1.8\times 0.5\times 10^{-3}\times k}{30\times 0.25\times 03.6\times 10^{-3}\times k} = 1.4$$

(ii) Ratio of voltage sensitivity

$$\frac{V\cdot S_2}{V\cdot S_1} = \frac{C\cdot S_2 \times R_1}{C\cdot S_1 \times R_2} = \frac{7}{5}\times\frac{10}{14} = 1$$

3. (a) The given coil is circular and is suspended such that field lines makes angle 60° with normal of the coil.



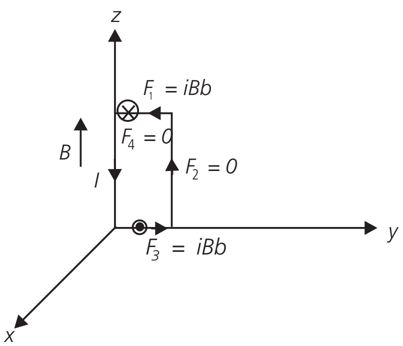
Torque on the coil, $\tau = NIBA \sin\theta$

$\tau = 30 \times 6 \times 1 \times \pi \times (8 \times 10^{-2})^2 \times \sin 60° = 3.13$ N m

A similar torque is required to prevent the coil from turning.

(b) As long as the area of the planar coil remains same, the torque on the coil is also same, irrespective of the shape.

4. (a) Let us detail each case separately,



Dipole moment is along +x direction

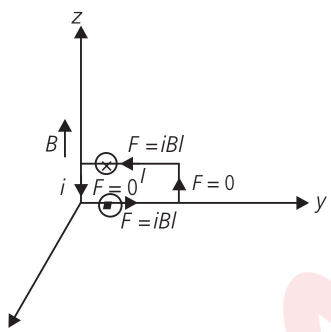
$\vec{M} = 10 \times 5 \times 10^{-4} \times 12\,\hat{i} = 0.06\,\hat{i}$; $\vec{B} = 3000 \times 10^{-4}\,\hat{k}$

Torque, $\vec{\tau} = \vec{M} \times \vec{B} = -1.8 \times 10^{-2}\,\hat{j}$ N m

So, torque is 1.8×10^{-2} N–m along $-y$ direction net force on the coil is zero coil not in equilibrium.

(b) Dipole moment is along $+x$ direction

$\vec{M} = 0.06\,\hat{i}, \vec{B} = 0.3\,\hat{k}$

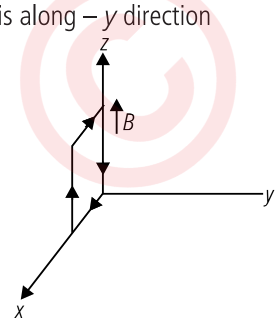


Torque, $\vec{\tau} = \vec{M} \times \vec{B} = -1.8 \times 10^{-2}\,\hat{j}$ N m

So, torque is 1.8×10^{-2} N m along $-y$ direction.

Net force on the coil is zero, coil is not in equilibrium

(c) Dipole moment is along $-y$ direction



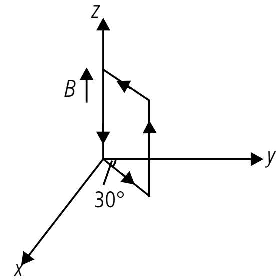
$\vec{M} = -0.06\,\hat{j}, B = 0.3\,\hat{k}$

Torque, $\vec{\tau} = \vec{M} \times \vec{B} = -1.8 \times 10^{-2}\,\hat{i}$ N m

So, the torque is 1.8×10^{-2} N m along –x direction.

Net force on the coil is zero, coil is not in equilibrium.

(d)



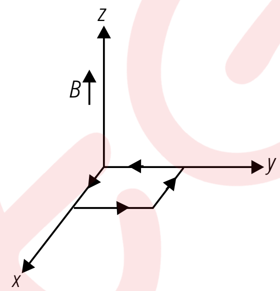
Dipole moment is at an angle 150° with the $+x$ direction.

Torque $\tau = MB \sin\theta$

$\tau = 1.8 \times 10^{-2} \sin\frac{\pi}{2} = 1.8 \times 10^{-2}$ N m

At an angle 240° with the $+x$ direction net force on the coil is zero, coil is not in equilibrium.

(e)



Dipole moment is along $+z$ direction.

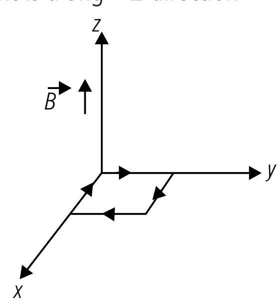
$\vec{\tau} = \vec{M} \times \vec{B} = 1.8 \times 10^{-2}\,\hat{k} \times \hat{k} = 0$

Potential energy $U = -\vec{M}.\vec{B}$

$U = -1.8 \times 10^{-2} (\hat{k}.\hat{k}) = -1.8 \times 10^{-2}$ J

Negative energy shows equilibrium is stable.

(f) Dipole moment is along $-z$ direction

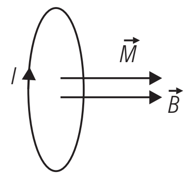


$\vec{\tau} = \vec{M} \times \vec{B} = 1.8 \times 10^{-2} (-\hat{k} \times \hat{k}) = 0$

P.E, $U = -MB = +1.8 \times 10^{-2}$ J

Positive energy shows equilibrium is unstable.

5. The magnetic field is normal to the plane of the coil, so condition of minimum torque.



(a) Torque on the coil

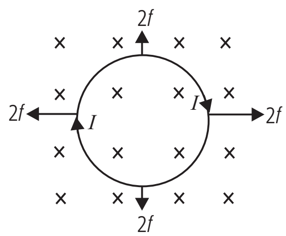
$\tau = NIBA \sin\theta$

here $\theta = 0°$

$\tau = 0$

(b) Force on every element of the coil is cancelled by force on corresponding element.

Net force on the unit is zero.



(c) To calculate force on each electron, let us find drift velocity.

$I = Anev_d$

$5 = 10^{-5} \times 10^{29} \times 1.6 \times 10^{-19} v_d$

or $v_d = 3.125 \times 10^{-5}$ m s^{-1}

Now force, $F = ev_d B$

$F = 1.6 \times 10^{-19} \times 3.125 \times 10^{-5} \times 0.1$

$= 5 \times 10^{-25}$ N

6. By using the formula

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

We can calculate required resistance to be connected in series.

$$R_V = \frac{18}{3\times10^{-3}} - 12 = 5{,}988\ \Omega$$

7. For converting galvanometer into ammeter of required range, required shunt can be calculated

$$S = \frac{I_g G}{I - I_g} = \frac{4\times10^{-3}\times15}{6-0.004} = 0.01\ \Omega = 10\ \text{m}\Omega.$$