Chapter - 4

4.1. Given, $N = 100$, $r = 8$ cm $= 0.08$ m, $I = 0.40$ A.

$$\therefore B = \frac{\mu_0 N I}{2r} = \frac{4\pi \times 10^{-7} \times 100 \times 0.40}{2 \times 0.08}$$

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

$$= 3.1 \times 10^{-4} \text{ T}$$

4.2. Here, $I = 35$ A, $r = 20$ cm $= 0.20$ m.

$\mu_0 = 4\pi \times 10^{-7}$ T m A^{-1}.

$$\therefore B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7} \times 35}{2\pi \times 0.20} = 3.5 \times 10^{-5} \text{ T}$$

4.6. Given, $l = 3$ cm $= 0.03$ m, $I = 10$ A

$\theta = 90^\circ$, $B = 0.02$ T

$$\therefore F = IlB \sin\theta$$

$$= 10 \times 0.03 \times 0.27 \times \sin 90^\circ$$

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

4.7. Force per unit length of each wire is $f = \dfrac{\mu_0 I_1 I_2}{2\pi r}$

$$\Rightarrow f = \frac{4\pi \times 10^{-7} \times 8 \times 5}{2\pi \times 4 \times 10^{-2}}$$

$$\Rightarrow f = 2 \times 10^{-4} \text{ N m}^{-1}$$

Force on 10 cm section of wire A is

$$F = fl = 2 \times 10^{-4} \times 10 \times 10^{-2} = 2 \times 10^{-5} \text{ N}.$$

4.8. Number of turns per unit length of the solenoid $(n) = \dfrac{\text{No. of turns per layer} \times \text{Number of layers}}{\text{Length of solenoid}}$.

$$= \frac{400 \times 5}{0.80} \ m^{-1}$$

$$= 2500 \ m^{-1}$$

Mangnetic field inside the solenoid is

$$B = \mu_0 n I = 4\pi \times 10^{-7} \times 2500 \times 8$$

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

$$= 2.5 \times 10^{-2} T.$$

4.11. The perpendicular magnetic field ~~ex~~ exerts a force on the electron perpendicular to its path. This force continuously deflects the electron from its path and makes it ~~m~~ move along a circular path.

$\therefore$ Magnetic force on the electron = Centripetal force.

$$\Rightarrow e v B \sin 90^\circ = \frac{m_e v^2}{r}.$$

$$\Rightarrow r = \frac{m_e v}{eB}$$

Now, $B = 6.5 G = 6.5 \times 10^{-4} T$, $v = 4.8 \times 10^{6}$ m/s

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

4.12. Frequency of ~~electron~~ revolution of the electron in its circular orbit,

$$f = \frac{eB}{2\pi m} = \frac{1.6 \times 10^{-19} \times 6.5 \times 10^{-4}}{2 \times 3.14 \times 9.1 \times 10^{-31}}$$

$$= 18.18 \times 10^{6} \ Hz$$

$$= 18 \ MHz.$$

No, the frequency f does not depend on the speed v of the electron.

4.13. a) $N = 30$, $r = 8.0$ cm $= 0.08$ m, $I = 6.0$ A

$B = 1$ T, $\theta = 60^\circ$

Magnitude of counter torque = Magnitude of deflecting torque

$= NIBA \sin\theta$

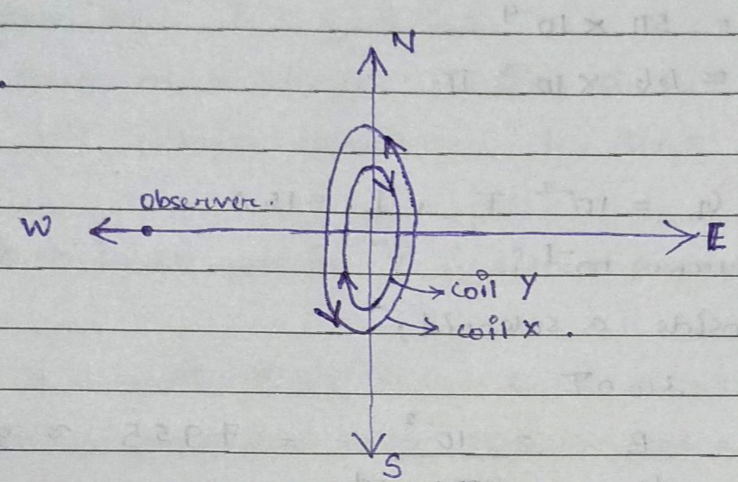
$= 30 \times 6 \times 1 \times (3.14 \times 0.08 \times 0.08) \sin 60^\circ$

$= 30 \times 6 \times 3.14 \times 64 \times 10^{-4} \times 0.866$

$= 3.1$ Nm.

b) No, the answer would not change because the above formula for the torque is true for a planar loop of any shape.

4.14.



For coil X : $r_x = 16$ cm $= 0.16$ m, $N_x = 20$, $I_x = 16$ A

$\therefore$ Magnetic field at the centre of coil X (B_x)

$$= \frac{\mu_0 I_x N_x}{2 r_x}$$

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

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

For coil Y : $r_y = 10$ cm $= 0.10$ m, $N_x = 25$, $I = 18$ A

$\therefore$ Magnetic field at the centre of coil Y (B_y)

$$= \frac{\mu_0 I_y N_y}{2 r_y}$$

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

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

As the current in the coil Y is clockwise, the field B_y is directed towards west. Since $B_y > B_x$, so, the net field is directed towards west and its magnitude is

$$B = B_y - B_x$$
$$= 5\pi \times 10^{-4}$$
$$\approx 1.6 \times 10^{-3} \text{ T}$$

4.15. Here, $B = 100 \text{ G} = 10^{-2} \text{ T}$, $I = 15 \text{ A}$,
$n = 1000$ turns m^{-1}.

Magnetic field inside a solenoid,

$$B = \mu_0 n I$$

$$\Rightarrow nI = \frac{B}{\mu_0} = \frac{10^{-2}}{4\pi \times 10^{-7}} = 7955 \approx 8000$$

And let $I = 10 \text{ A}$ then $n = 800$

The solenoid may have length 50 cm and area of cross-section $5 \times 10^{-2} \text{ m}^2$ (five times the given value) so as to avoid edge effects etc.

4.17. Here, $I =$ [illegible] 11 A, total no. of turns $= 3500$.

Mean radius of toroid,

$$r = \frac{25 + 26}{2} = 25.5 \text{ cm} = 25.5 \times 10^{-2} \text{ m}$$

Total length of the toroid $= 2\pi r$

$$= 2\pi \times 25.5 \times 10^{-2} = 51.0 \times 10^{-2} \pi \text{ m}$$

$\therefore$ No. of turns per unit length, $n = \dfrac{3500}{51.0 \times 10^{-2}\pi}$

a) The field outside the toroid is zero.

b) The field inside the core of the toroid,

$$B = \mu_0 n I = 4\pi \times 10^{-7} \times \frac{3500}{51 \times 10^{-2}\pi} \times 11$$

$$= 3.02 \times 10^{-2}\ T$$

c) The field in the empty space surrounded by the toroid is also zero

4.18. a) The force on a charged particle moving in a magnetic field is given by $F = qvB\sin\theta$.

The force on a charged particle will be zero or the particle will remain undeflected if $\sin\theta = 0$ i.e $\theta = 0°, 180°$.

$\Rightarrow$ initial velocity $\vec{v}$ is either parallel or antiparallel to $\vec{B}$.

b) Yes, a magnetic field exerts force on a charged particle in a direction perpendicular to its direction of motion and hence does no work on it. So, the charged particle will have its final speed equal to its initial speed.

4.19. $V = 2.0\ kV = 2 \times 10^3\ V$, $B = 0.15\ T$, $e = 1.6 \times 10^{-19}\ C$, $m = 9.1 \times 10^{-31}\ kg$

Potential difference V imparts kinetic energy to the electron given by

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

$\Rightarrow$ velocity gained by electron, $v = \sqrt{\dfrac{2eV}{m}} = \sqrt{\dfrac{2 \times 1.6 \times 10^{-19} \times 2 \times 10^3}{9.1 \times 10^{-31}}}\ ms^{-1}$

$$= 2.65 \times 10^7\ m/s.$$

i) when the field $\vec{B}$ is transverse to the initial velocity $\vec{v}$,

$$evB\sin 90° = \frac{mv^2}{r}.$$

$\Rightarrow r = \dfrac{mv}{eB} = \dfrac{9.1 \times 10^{-31} \times 2.65 \times 10^{7}}{1.6 \times 10^{-19} \times 0.15}$ m

$\simeq 10^{-3}$ m $= 1$ mm.

Thus the electron follows a circular trajectory of radius 1 mm normal to the field B.

ii) when field $\vec{B}$ makes an angle of 30° to the initial velocity $\vec{v}$,

$v_\perp = v \sin 30^\circ = 2.65 \times 10^7 \times \frac{1}{2} = 1.33 \times 10^7$ m/s.

$v_\parallel = v \cos 30^\circ = 2.65 \times 10^7 \times 0.866 = 2.3 \times 10^7$ m/s

The radius of the helical path is $r = \dfrac{mv_\perp}{eB}$

$= \dfrac{mv \sin 30^\circ}{eB}$

$= \dfrac{9.1 \times 10^{-31} \times 1.33 \times 10^{7}}{1.6 \times 10^{-19} \times 0.15}$

$= 50.4 \times 10^{-5}$ m

$= 0.50$ mm

4.20. $B = 0.75$ T, $E = 9 \times 10^5$ V/m, V (potential) $= 15$ kV $= 15 \times 10^3$ V

For the undeflected beam velocity of charged particles must be.

$v \text{ (velocity)} = \dfrac{E}{B} = \dfrac{9 \times 10^5}{0.75}$ m/s $= 12 \times 10^5$ m/s.

But the kinetic energy of the charged particles is

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

$\Rightarrow \dfrac{q}{m} = \dfrac{1}{2} \cdot \dfrac{v^2}{V} = \dfrac{1}{2} \dfrac{(12 \times 10^5)^2}{15 \times 10^3}$ C/kg

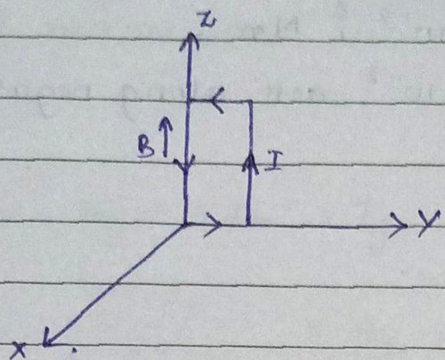
$= 4.8 \times 10^7$ C/kg

Now for deutrons, $\frac{q}{m} = \frac{1.6 \times 10^{-19}}{2 \times 1.67 \times 10^{-27}} = 4.8 \times 10^{7}$ C/kg

which means that the particles may be deutrons each of which contains one proton and one neutron.

The answer is not unique because we have determined only the ratio of charge to mass. Other possible answers are He^{2+} and Li^{3+} etc.

4.24. (a).



Here, $B = 3000\,G = 3000 \times 10^{-4}$
$= 0.3\,T$

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

$I = 12\,A$.

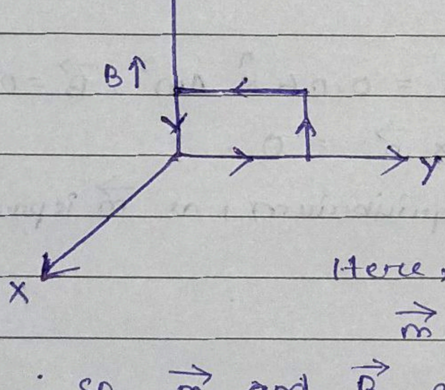
Magnetic current, $m = IA$
$= 12 \times 50 \times 10^{-4}$
$= 0.06\,Am^2$

a) Here, $\vec{m} = 0.06\,\hat{i}\,Am^2$, $B = 0.3\,\hat{k}\,T$

$\vec{\tau} = \vec{m} \times \vec{B}$
$= 0.06\,\hat{i} \times 0.3\,\hat{k}$
$= -1.8 \times 10^{-2}\,\hat{j}\,Nm$.

Hence, a torque of 1.8×10^{-2} Nm acts along negative Y-axis.

b)



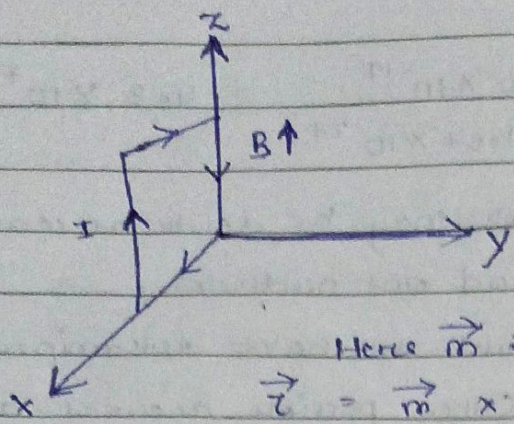
Here, ~~$\vec{m} = 0.06 \ldots Am^2, \vec{B} = 0.3$~~

$\vec{m} = 0.06\,\hat{i}\,Am^2$, $\vec{B} = 0.3\,\hat{k}\,T$

So, $\vec{m}$ and $\vec{B}$ are same as in case of (a).

Here also a torque of 1.8×10^{-2} Nm acts along negative Y-axis.

c)



Here $\vec{m} = -0.06\hat{j}\ Am^2$; $\vec{B} = 0.3\hat{k}\ T$

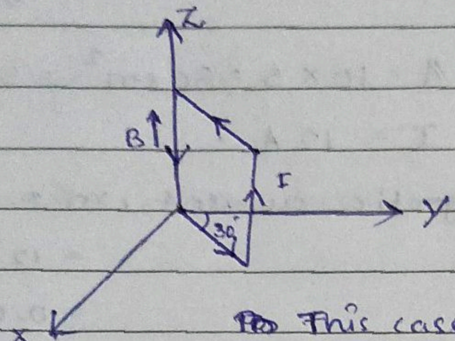
$\vec{\tau} = \vec{m} \times \vec{B}$

$= -0.06\hat{i} \times 0.3\hat{k}$

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

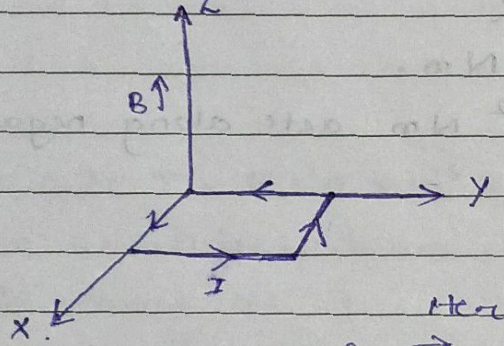
Hence, a torque of 1.8×10^{-2} act along negative x-axis.

d)



This case is similar to case (c). But here the direction of the torque is 60° anticlockwise with negative x-direction ie. 240° with positive x-direction.

e.

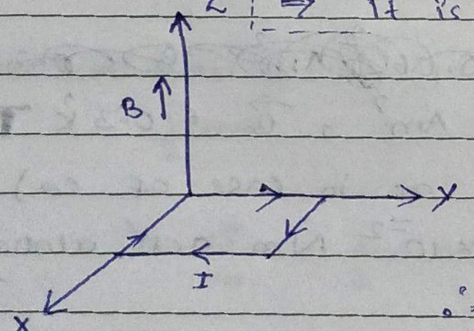


Here, $\vec{m} = 0.06\hat{k}\ Am^2$, $\vec{B} = 0.3\hat{k}\ T$

$\therefore \vec{\tau} = \vec{m} \times \vec{B} = 0$.

$\Rightarrow$ It is stable equilibrium, as $\vec{m}$ is parallel to $\vec{B}$

f.



Here, $\vec{m} = -0.06\hat{k}\ Am^2$, $\vec{B} = 0.3\hat{k}\ T$

$\therefore \vec{\tau} = -\vec{m} \times \vec{B} = 0$.

$\Rightarrow$ It is unstable equilibrium, as $\vec{m}$ is antiparallel to $\vec{B}$.

4.27. Here, $R_g = 12\,\Omega$, $I_g = 3\,mA = 3 \times 10^{-3}\,A$, $V = 18\,V$

$$R = \frac{V}{I} - R_g = \frac{18}{3 \times 10^{-3}} - 12$$

$$= 6000 - 12$$

$$= 5988\,\Omega.$$

By connecting a resistance of $5988\,\Omega$ in series with the given galvanometer, we get a voltmeter of range 0 to 18 V.

4.28. Here, $R_g = 15\,\Omega$, $I_g = 4\,mA = 0.004\,A$, $I = 6\,A$.

$$\therefore R_s = \frac{I_g}{I - I_g} \times R_g = \frac{0.004}{6 - 0.004} \times 15$$

$$= 0.010\,\Omega$$

$$= 10\,m\Omega.$$

By connecting a shunt of resistance $10\,m\Omega$ across the given galvanometer, we get an ammeter of range 0 to 6 A.