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CH-4 Moving Charges And magnetism
EXERCISE

4.1) No. 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 magnetic field at the sentre of the coil is given by the relation

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

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

So,
$$|\vec{B}| = \frac{4\pi \times 10^{-7}}{4\pi} \times \frac{2\pi \times 100 \times 0.4}{r}$$
$$= 3.14 \times 10^{-4}\, T$$

~~Hence~~ Ans

4.2) 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:

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

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

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

4.6) Length of the wire, $l = 3\,cm = 0.03\,m$
Current flowing in the wire, $I = 10\,A$

Magnetic field, $B = 0.27T$
Angle b/w the current and magnetic field, $\theta = 90°$

magnetic force exerted on the wire is given:
$\boxed{F = BIl\sin\theta}$
$= 0.27 \times 10 \times 0.03 \sin 90°$
$= 8.1 \times 10^{-2}\ N$
The direction of the force can be obtained from Fleming's left hand rule.

4.7) Current flowing in wire A, $I_A = 8.0\ A$
Current flowing in wire B, $I_B = 5.0\ A$
Distance b/w the two wires, $r = 4.0\ cm = 0.04\ m$
Length of a section of wire A, $l = 10\ cm = 0.1\ m$
Force exerted on length l due to the magnetic field is given as:

$$\boxed{F = \frac{\mu_0 I_A I_B l}{2\pi r}}$$

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

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

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.

4.8) Length of the solenoid, $l = 80\ cm = 0.8\ m$
There are 5 layers of windings of 400 turns each on the solenoid.

∴ Total no. 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, $I = 8.0A$

magnitude of the magnetic field inside the solenoid near its centre is given by the relation,

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

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

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

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

Hence, the magnitude of the magnetic field inside the solenoid near its centre is $2.5 \times 10^{-2}\ T$.

4.11) Magnetic field strength, $B = 6.5\ G = 6.5 \times 10^{-4}\ T$
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 b/w the shot electron and magnetic field, $\theta = 90°$
$\Rightarrow$ magnetic force exerted on the electron in the magnetic field is given:

$$\boxed{F = evB \sin\theta}$$

The force provides centripetal force to the moving e-. Hence, the e- starts moving in a circular path of radius r.

Hence, centripetal force exerted on the electron,

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

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

$$F_c = F$$

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

$$\Rightarrow r = \frac{mv}{eB\sin\theta}$$

So,

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

$$\Rightarrow 4.2\times10^{-2}\,m = 4.2\,cm$$

Hence, radius of the circular orbit of the electron is 4.2c

4.12) Magnetic field strength, $B = 6.5\times10^{-4}\,T$ $(1G = 10^{-4}T)$
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 $= \omega = 2\pi\nu$
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 :

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

$$\Rightarrow eB = \frac{mv}{r} = \frac{m(r\omega)}{r} = \frac{m(r.2\pi\nu)}{r}.$$

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

$\Rightarrow$ The expression for frequency is independent of the speed of the electron.

On substituting the known values of this expression, we get the frequency as:

$$\nu = \frac{6.5 \times 10^{-4} \times 1.6 \times 10^{-19}}{2 \times 3.14 \times 9.1 \times 10^{-31}}$$
$$= 1.82 \times 10^{6}\ Hz \approx 18\ MHz$$

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

13) (a) No. of turns on the circular coil, $n = 30$
Radius of the coil, $r = 8\ cm = 0.08\ m$
Area of the coil $\pi r^2 = \pi (0.08)^2 = 0.0201\ m^2$
Current flowing in the coil, $I = 6\ A$
Magnetic field strength, $B = 1\ T$
Angle b/w 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,

$$\tau = nIBA \sin\theta$$
$$= 30 \times 6 \times 1 \times 0.0201 \times \sin 60°$$
$$= 3.133\ Nm$$

(b) It can be inferred from relation $\tau = nIBA \sin\theta$ that the 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

4.14) Radius of coil X, $r_1 = 16\,cm = 0.16\,m$
Radius of coil Y, $r_2 = 10\,cm = 0.1\,m$
No. of turns of on coil X, $n_1 = 20$
No. of turns of on coil Y, $n_2 = 25$
Current in coil X, $I_1 = 16\,A$
Current in coil Y, $I_2 = 18\,A$

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

$$\boxed{B_1 = \frac{\mu_0 N_1 I_1}{2r_1}}$$

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

$$B_1 = \frac{4\pi \times 10^{-7} \times 20 \times 16}{2 \times 0.16} = 4\pi \times 10^{-4}\,T$$ (Towards East)

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

$$\boxed{B_2 = \frac{\mu_0 N_2 I_2}{2r_2}}$$

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

$$B_2 = \frac{4\pi \times 10^{-7} \times 25 \times 18}{2 \times 0.10} = 9\pi \times 10^{-4}\,T$$ (Towards West)

Hence, net magnetic field can be obtained as:

$$B = B_2 - B_1 = 9\pi \times 10^{-4}\,T - 4\pi \times 10^{-4}\,T$$

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

$= 5 \times 3.14 \times 10^{-4} T = 1.57 \times 10^{-3} T$ (Towards west)

4.15) magnetic field strength, $B = 100 G = 100 \times 10^{-4} T$
No. of turns per unit length, $n = 1000$ turns m^{-1}
Current flowing in the coil, $I = 15 A$
Permeability of free space, $\mu_0 = 4\pi \times 10^{-7} TmA^{-1}$

Magnetic field is given by the relation,

$$\boxed{B = \mu_0 n I}$$

$$\Rightarrow nI = \frac{B}{\mu_0} = \frac{100 \times 10^{-4}}{4\pi \times 10^{-7}} = 7957.74 \approx 8000 \ Am^{-1}$$

If the length of the coil is taken as 50 cm, radius 4 cm, no. 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.

4.17) Inner radius of the toroid, $r_1 = 25 cm = 0.25 m$
Outer radius of the toroid, $r_2 = 26 cm = 0.26 m$
No. of turns on the coil, $N = 3500$
Current in the coil $= 11 A$

(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 relation

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

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

l = Length of toroid

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

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

$$= 0.51\pi$$

$$\therefore B = \frac{4\pi \times 10^{-7} \times 3500 \times 11}{0.51\pi}$$

$$\approx 3.0 \times 10^{-2}\ T$$

(c) magnetic field in the empty space surrounded by the toroid is zero.

18) (a) The initial velocity of the particle is either parallel to anti-parallel to the magnetic field. Hence, it travel 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 direction of velocity, but not its magnitude.

(c) An electron travelling from West to East enters a chamber having a uniform electrostatic field in the in the North-South direction. 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 a vertically downward direction.

4.19) Magnetic field strength, $B = 0.15T$
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 $= eV$

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

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

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

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

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

From eq. (1) and (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 eq. (2), we have the expression for new radius:
$$r_1 = \frac{mv_1}{Be}$$
$$= \frac{mv\sin\theta}{Be}$$
$$= \frac{9.1 \times 10^{-31}}{0.15 \times 1.6 \times 10^{-19}} \times \left[\frac{2 \times 1.6 \times 10^{-19} \times 2 \times 10^{3}}{9 \times 10^{-31}}\right]^{1/2} \times \sin 30°$$
$= 0.5 \times 10^{-3}$ m
$= 0.5$ mm Ans

4.20) Magnetic field, $B = 0.75$ T
Accelerating voltage, $V = 15$ kV $= 15 \times 10^{3}$ V
Electrostatic 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 $= eV$

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

$\therefore$ $e/m = v^2/2V$ —— (1)

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

$\therefore eE = evB$

$v = \frac{E}{B}$ ——— ②

Putting eq. ② in eq ①, we get

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

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

This value of specific charge e/m is equal to the value of deuteron or deuterium ions. Other possible answers are He^{++}, Li^{++}, etc.

4.24) magnetic field strength, $B = 3000G = 3000 \times 10^{-4} T = 0.3T$

Length of the rectangular loop, $l = 10cm$

Width of the rectangular loop, $b = 5cm$

Area of loop

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

Current in the loop, $I = 12A$

Now, taking the anti-clockwise direction of the current as positive and vise 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 the 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 negative y-direction
The force on the loop is zero because the angle b/w A and B is zero

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

(c) $T = IA \times B$
We observe that A is ⊥ to x-z plane and B is along z axis.
$\Rightarrow T = -12 \times (5 \times 10^{-3}) j \times 0.3k$
$\Rightarrow T = -1.8 \times 10^{-2}$ Nm i
and the force is zero

(d) magnitude of torque
$|T| = IA \times B$
$\Rightarrow |T| = 12 \times (50 \times 10^{-4}) m^2 \times 0.3T$
$\Rightarrow |T| = 1.8 \times 10^{-2}$ Nm
This torque is makes 240° with the positive x directio
The force again is zero. [because $\sin 240° = 0$]

(e) $T = IA \times B$
$= 12 \times (50 \times 10^{-4}) m^2 \times 0.3T$
$= 0$
Since cross section and magnetic field are in same direction net torque is zero. Net force is also zero.

(f) torque $= 12 (5 \times 10^{-3}) k \times 0.3k$
$= 0$ and force is also zero.

Stable equilibrium:
In case E, the angle b/w A and B is zero. If we displace the wire, it will come back in its position, hence it is the stable equilibrium condition.

Unstable equilibrium:
In case F, the angle b/w A and B is 180°. If the wire is displaced, it will not come back in this position so we can conclude that it is the case for unstable equilibrium

4.27) Resistance of the galvanometer coil, $G = 12\,\Omega$
Current for which there is full scale deflection
$I_g = 3\,mA = 3\times10^{-3} A$
Range of the voltmeter is 0, which needs to be converted to 18V.
$\therefore$ $V = 18\,V$

Let a resistance of resistance R be connected in series with the galvanometer to convert it into a voltmeter. This resistance is given

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

$$= \frac{18}{3\times10^{-3}} - R = 6000 - 12 = 5988\,\Omega$$

4.28) Resistance of the galvanometer coil, $G = 15\,\Omega$
Current for which galvanometer shows full scale deflection,
$I_g = 4\,mA = 4\times10^{-3} A$

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

A shunt resistor of resistance S is to be connected in parallel with the galvanometer, to convert it into an ammeter.

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

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

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

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

Hence, a shunt resistor is to be connected in parallel wi the galvanometer.