CBSE Class 12 physics
Important Questions
Chapter 4
Moving Charges and Magnetism

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1 Mark Questions

1. State two properties of the material of the wire used for suspension of the coil in a moving coil galvanometer?

Ans. (a) Non-Brittle conductor

(b) Restoring Torque per unit Twist should be small.

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2. What will be the path of a charged particle moving along the direction of a uniform magnetic field?

Ans. The path of a charged particle will be a straight line path as no force acts on the particle.

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3. Two wires of equal lengths are bent in the form of two loops. One of the loop is square shaped whereas the other loop is circular. These are suspended in a uniform magnetic field and the same current is passed through them. Which loop will experience greater torque? Give reasons?

Ans. since $\tau = NIAB$

Since Area of – circular loops is more Than of a square loop

$\Rightarrow$ Torque experienced by a circular loop is greater.

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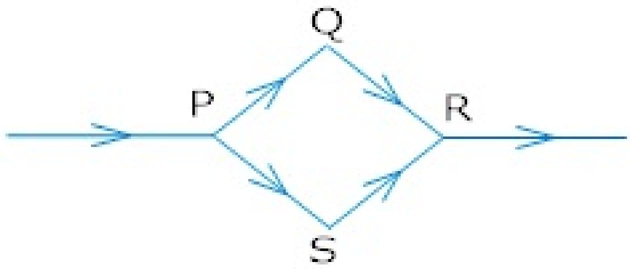
4. A cyclotron is not suitable to accelerate electron. Why?

Ans. A cyclotron is not suitable to accelerate electron because its mass is less due to which they gain speed and step out of the dee immediately.

2 Mark Questions

1. A steady current flows in the network shown in the figure. What will be the magnetic field at the centre of the network?



Ans. Zero, because magnetic field at the centre of the loop is just equal and opposite i.e. magnetic field due 1- PQR is equal and opposite to that of PSR.

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2. An $\propto$ - particle and a proton are moving in the plane of paper in a region where there is uniform magnetic field B directed normal to the plane of paper. If two particles have equal linear momenta, what will be the ratio of the radii of their trajectories in the field?

Ans. Since radius of the path (R) = $\frac{mv}{Bq}$

=> R $\propto \frac{1}{q}$

=> $\frac{R \propto}{RP} = \frac{qp}{q \propto} = \frac{e}{2e} = \frac{1}{2}$

=> R$\propto$: Rp = 1:2.

3. Give one difference each between diamagnetic and ferromagnetic substances. Give one example of each?

Ans. Diamagnetic substances are weakly repelled by a magnet eg. Gold.

Ferromagnetic materials are strongly attracted by a magnet eg. Iron.

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4. Write the expression for the force acting on a charged particle of charge q moving with velocity is in the presence of magnetic field B. Show that in the presence of this force.

(a) The K.E. of the particle does not change.

(b) Its instantaneous power is zero.

Ans. Since F = q ($\vec{v} \times \vec{B}$)

(a) Since direction of force is perpendicular to the plane containing ($\vec{v} \times \vec{B}$)

=> w = Fs cos θ $(=90^0)$

w = Fs $cos 90^0$ = 0

=> KE = 0

$\therefore$ KE will not – change

(b) since p = Fvcos θ = Fv $cos 90^0$ = 0

=> Instantaneous power is also zero.

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5. An electron of kinetic energy 25KeV moves perpendicular to the direction of a uniform magnetic field of 0.2 millitesla calculate the time period of rotation of the electron in the magnetic field?

Ans. B = 0.2 T = 0.2$\times$ 10^{-3}T

Time Period T = $\frac{2\pi M}{QB}$

$$T = \frac{2\times 3.14\times 9.1\times 10^{-31}}{1.6\times 10^{-17}\times 0.2\times 10^{-3}}$$

$T = 1.787\times\ 10^{-7}$ second

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6. It is desired to pass only 10% of the current through a galvanometer of resistance 90 Ω. How much shunt resistance be connected across the galvanometer?

Ans. IG = 10% of I = $\frac{10I}{100}$ $\quad$ $G = 90\Omega$

S = $\frac{IgG}{I-Ig} = \frac{\frac{1\cancel{0}I}{1\cancel{0}\cancel{0}}\times 9\cancel{0}}{I - \frac{1\cancel{0}I}{10\cancel{0}}}$

S = $\frac{9I}{\frac{10I-I}{10}}$

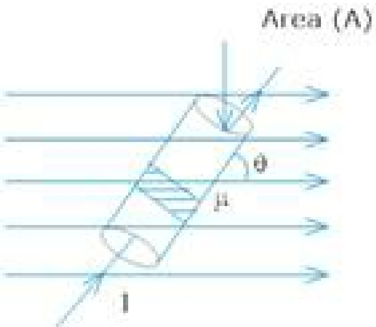
S = $\frac{90\cancel{I}}{90\cancel{I}} = 10$

=> $s = 10\Omega$

3 Mark Questions

1. Derive an expression for the force acting on a current carrying conductor placed in a uniform magnetic field Name the rule which gives the direction of the force. Write the condition for which this force will have (1) maximum (2) minimum value?

Ans. A conductor is placed in a uniform magnetic field $\vec{B}$ which makes and angle θ with $\vec{B}$. Let I current flows through the conductor.



If n is the no. of electrons per unit volume of the conductor, then Total no. of electrons in small current element dℓ = nAdl

=> θ = Ne

=> θ = nAdl e

$\vec{f}$ be the force experienced by each electron

$\vec{f}$ = e $(\vec{vd} \times \vec{B})$

Force experienced by small current element

$$\overrightarrow{dF} = neAdl\ (\vec{vd} \times \vec{B})$$

dF = neAvd dl B sinθ

(I = neAvd)

=> df = IdlBsin θ

Hence total force experienced

$$F = \int_0^l dF = \int_0^l IdlB \sin\theta$$

F = IBl $\sin\theta$

In vector form $\vec{F}$ = I $(\vec{l} \times \vec{B})$

(a) Force will be maximum when $\theta = 90^0$

(b) Force will be minimum when $\theta = 0^0$

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2. A straight wire carries a current of 10A. An electron moving at $10^7\,m/s$ is at distance 2.0 cm from the wire. Find the force acting on the electron if its velocity is directed towards the wire?

Ans. Here I = 10A

$V = 10^7\,m/s$

R = 2.0 cm = $2 \times 10^{-2}\,m$

Force acting on moving electron (F) = qVB sin θ

$$=> B = \frac{\mu 0}{4\pi}\frac{2I}{r}$$

$B = \dfrac{10^{-7} \times \cancel{2} \times 10}{\cancel{2} \times 10^{-2}} = 10\text{-}4$ tesla and $\perp$ to the plane of paper and directed downwards.

Now $F = 1.6 \times 10^{-19} \times 10^7 \times 10^{-4}\,sin\ 90^0$

$F = 1.6 \times 10^{-16}$ Newton.

3. State Biot- Savarts law. Derive an expression for magnetic field at the centre of a circular coil of n-turns carrying current – I?

Ans. Biot – Savart law states that the magnetic field db due to a current element $\vec{dl}$ at any point is

ie dB $\propto$ I

dB $\propto$ dl

dB $\propto$ $\sin\theta$

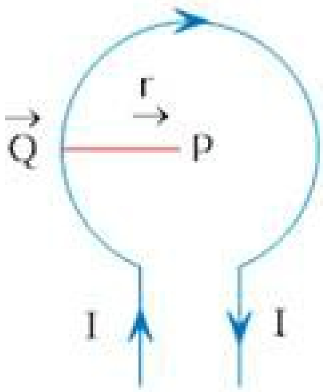
dB $\propto$ $\frac{1}{r^2}$

Combining all we get

dB $\propto$ $\frac{Idl\sin\theta}{r^2}$

$$dB = \frac{\mu 0}{4\pi}\frac{Idl\sin\theta}{r^2}$$

Consider a circular loop of radius r carrying a current I.



Since dl $\perp \vec{r}$

=> $\theta = 90^0$

Applying Biot Savart law

dB = $\frac{\mu 0}{4\pi} \frac{Idl \sin 90^0}{r^2}$

For entire closed circular loop

B = $\int_0^{2\pi r} \frac{\mu 0}{4\pi} \frac{Idl \sin 90^0}{r^2}$

B = $\frac{\mu 0}{4\pi} \frac{I}{r^2} \int_0^{2\pi r} dl = \frac{\mu o}{4\pi} \frac{I}{r^{\cancel{2}}} \times 2\pi \cancel{r}$

For n turns of a coil $B = \frac{\mu 0}{4\pi} \frac{2\pi nI}{r}$

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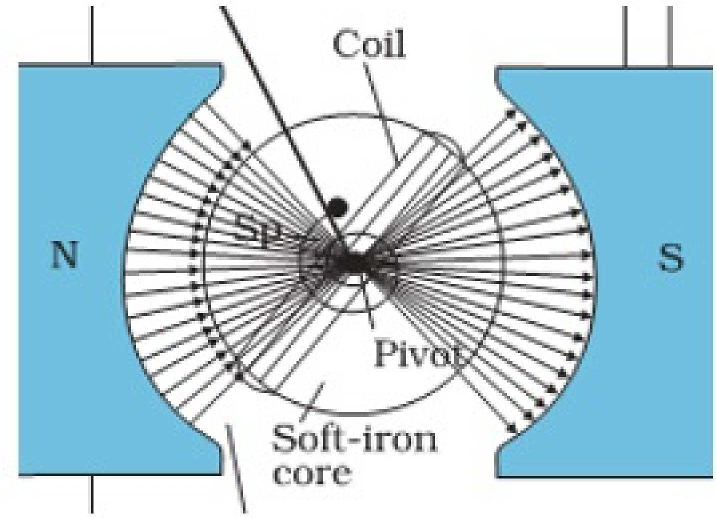
4. What is radial magnetic field? How it is obtained in moving coil galvanometer?

Ans. A radial magnetic field is one in which plane of the coil always lies in the direction of the magnetic field. It can be obtained by

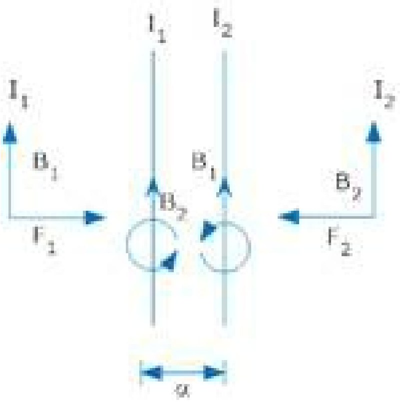


(a) Properly cutting the pole pieces concave in shape.

(b) Placing soft iron cylindrical core between the pole pieces.

5. Two straight parallel current carrying conductors are kept at a distanced r from each other in air. The direction for current in both the conductor is same. Find the magnitude and direction of the force between them. Hence define one ampere?

Ans. Consider two parallel conductors carrying or current $-I_1$ & I_2 and is separated by a distance 'd'.



Magnetic field due to current I_1 at any paint on conductor (2) is

$$B_1 = \frac{\mu 0}{4\pi}\frac{2I1}{d} \quad \text{----(1)}$$

($\perp$ to the plane & Downwards $(\times)$)

Since current carrying conductor is placed at right angles to the magnetic field

=> F = BI l $sin\ 90^0$

F = B I l

=> Force experienced per unit length of conductor ----(2)

$Is\ F_2 = B_1 I_2 1$

$F_2 = \frac{\mu 0}{4\pi} \frac{2I_1\ I_2}{d}$ ----(2)

Fleming's left hand Rule says F_2 is directed towards conductor (1)

Similarly $F_1 = \frac{\mu 0}{4\pi} \frac{2I_1\ I_2}{d}$ (Directed Towards conductor (2))

Since $F_1 and\ F_2$ are equal and opposite so two parallel current carrying conductor attract each other.

Since F = $\frac{\mu 0}{4\pi}\left(\frac{2I_1\ I_2}{d}\right)$

If $I_1 = I_2$ = 1A d = 1m

$F = 2\times10^{-7} m.$

Thus one ampere is that current which is flowing in two infinitely long parallel conductors separated by a distance of 1 meter in vacuum and experiences a force of $F = 2\times10^{-7} m.$ on each meter of the other wire.

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6. A circular coil of wire consisting of 100 turns, each of radius 8.0 cm carries a current of 0.40 A. 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,

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

Where,

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

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

μ_0 = Permeability of free space

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

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

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

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

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

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

Where,

μ_0 = Permeability of free space = $= 4\pi\times10^{-7}\,TmA^{-1}$

$$B = \frac{4\pi\times10^{-7}\times2\times35}{4\pi\times0.2}$$

$$= 3.5\times10^{-5}\,T$$

Hence, the magnitude of the magnetic field at a point 20 cm from the wire is $= 3.5\times10^{-5}\,T$

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8. A long straight wire in the horizontal plane carries a current of 50 A in north to south direction. Give the magnitude and direction of B at a point 2.5 m east of the wire.

Ans. Current in the wire, I = 50 A

A point is 2.5 m away from the East of the wire.

$\therefore$ Magnitude of the distance of the point from the wire, r = 2.5 m.

Magnitude of the magnetic field at that point is given by the relation, $B = \dfrac{\mu_0 2I}{4\pi r}$

Where,

μ_0 = Permeability of free space = $4\pi\times10^{-7}\,T\,m\,A^{-1}$

$$B = \frac{4\pi\times10^{-7}\times2\times50}{4\pi\times2.5}$$

$$= 4\times10^{-6}\,T$$

The point is located normal to the wire length at a distance of 2.5 m. The direction of the current in the wire is vertically downward. Hence, according to the Maxwell's right hand thumb rule, the direction of the magnetic field at the given point is vertically upward.

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9. A horizontal overhead power line carries a current of 90 A in east to west direction. What is the magnitude and direction of the magnetic field due to the current 1.5 m below the line?

Ans. Current in the power line, I = 90 A

Point is located below the power line at distance, r = 1.5 m

Hence, magnetic field at that point is given by the relation,

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

Where,

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

$$B = \frac{4\pi \times 10^{-7} \times 2 \times 50}{4\pi \times 1.5}$$

$1.2 \times 10^{-5} T$

The current is flowing from East to West. The point is below the power line. Hence, according to Maxwell's right hand thumb rule, the direction of the magnetic field is towards the South.

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10. What is the magnitude of magnetic force per unit length on a wire carrying a current of 8 A and making an angle of 30º with the direction of a uniform magnetic field of 0.15 T?

Ans. Current in the wire, I = 8 A

Magnitude of the uniform magnetic field, B = 0.15 T

Angle between the wire and magnetic field, θ = 30°.

Magnetic force per unit length on the wire is given as:

$f = BI \sin\theta$

= $0.15 \times 8 \times 1 \times sin 30°$

= $0.6\ N\ m^{-1}$

Hence, the magnetic force per unit length on the wire is $0.6\ N\ m^{-1}$.

11. A 3.0 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 cm = 0.03 m

Current flowing in the wire, I = 10 A

Magnetic field, B = 0.27 T

Angle between the current and magnetic field, θ = 90°

Magnetic force exerted on the wire is given as:

$F = BIl \sin\theta$

$= 0.27 \times 10 \times 0.03\ sin 90°$

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

Hence, the magnetic force on the wire is $8.1 \times 10^{-2} N$. The direction of the force can be obtained from Fleming's left hand rule.

12. 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 between 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:

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

Where,

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

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

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

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

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13. 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 × 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 = $4\pi \times 10^{-7} T\ m\ A^{-1}$

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

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

$$= 2.512 \times 10^{-2} T$$

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

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14. A square coil of side 10 cm consists of 20 turns and carries a current of 12 A. The coil is suspended vertically and the normal to the plane of the coil makes an angle of $30°$ with the direction of a uniform horizontal magnetic field of magnitude 0.80 T. What is the magnitude of torque experienced by the coil?

Ans. Length of a side of the square coil, *l* = 10 cm = 0.1 m

Current flowing in the coil, *I* = 12 A

Number of turns on the coil, *n* = 20

Angle made by the plane of the coil with magnetic field, $\theta = 30°$

Strength of magnetic field, *B* = 0.80 T

Magnitude of the magnetic torque experienced by the coil in the magnetic field is given by the relation,

T = *n BIA* sin*θ*

Where,

A = Area of the square coil

$$\Rightarrow l \times l = 0.1 \times 0.1 = 0.01\ m^2$$

$$\therefore T = 20 \times 0.8 \times 12 \times 0.01 \times sin30°$$

= 0.96 N m

Hence, the magnitude of the torque experienced by the coil is 0.96 N m.

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15. (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.

(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

Magnetic field strength, B = 1 T

Angle between 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,

$T = nIBA sin\theta$ … (*i*)

= $30 \times 6 \times 1 \times 0.0201 \times sin 60°$

= 3.133 N m

(b) It can be inferred from relation (*i*) 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.

16. 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 and 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

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

Magnetic field is given by the relation, $B = \mu_0 nI$

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

$$= \frac{100 \times 10^{-4}}{4\pi \times 10^{-7}} = 7957.74$$

$$\approx 8000 A/m$$

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.

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17. 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 relation,

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

Where,

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

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.

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18. Answer the following questions:

(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 constant speed. What can you say about the initial 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 magnitude and 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?

(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.(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 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 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.

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19. A straight horizontal conducting rod of length 0.45 m and mass 60 g is suspended by two vertical wires at its ends. A current of 5.0 A is set up in the rod through the wires.

(a) What magnetic field should be set up normal to the conductor in order that the tension in the wires is zero?

(b) What will be the total tension in the wires if the direction of current is reversed keeping the magnetic field same as before? (Ignore the mass of the wires.)
$g = 9.8\ m\,s^{-2}$.

Ans. Length of the rod, l = 0.45 m

Mass suspended by the wires, m = 60 g = $60 \times 10^{-3}\ kg$

Acceleration due to gravity, $g = 9.8\ m\,s^{-2}$

Current in the rod flowing through the wire, I = 5 A

(a) Magnetic field (B) is equal and opposite to the weight of the wire i.e., BIl + mg

$$\therefore B = \frac{mg}{Il}$$

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

A horizontal magnetic field of 0.26 T normal to the length of the conductor should be set up in order to get zero tension in the wire. The magnetic field should be such that Fleming's left hand rule gives an upward magnetic force.

(b) If the direction of the current is revered, then the force due to magnetic field and the weight of the wire acts in a vertically downward direction.

∴Total tension in the wire = $BIl + mg$

$$0.26 \times 5 \times 0.45 + \left(60 \times 10^{-3}\right) \times 9.8$$

= 1.176 N

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20. The wires which connect the battery of an automobile to its starting motor carry a current of 300 A (for a short time). What is the force per unit length between the wires if they are 70 cm long and 1.5 cm apart? Is the force attractive or repulsive?

Ans. Current in both wires, I = 300 A

Distance between the wires, r = 1.5 cm = 0.015 m

Length of the two wires, l = 70 cm = 0.7 m

Force between the two wires is given by the relation,

$$F = \frac{\mu_0 I^2}{2\pi r}$$

Where,

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

$$\therefore F = \frac{4\pi \times 10^{-7} \times (300)^2}{2\pi \times 0.015}$$

=1.2 N/m

Since the direction of the current in the wires is opposite, a repulsive force exists between them.

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21. A circular coil of 20 turns and radius 10 cm is placed in a uniform magnetic field of 0.10 T normal to the plane of the coil. If the current in the coil is 5.0 A, what is the

(a) total torque on the coil,

(b) total force on the coil,

(c) average force on each electron in the coil due to the magnetic field?

(The coil is made of copper wire of cross-sectional area $10^{-5}\ m^2$, and the free electron density in copper is given to be about $10^{29}\ m^{-3}$.)

Ans. Number of turns on the circular coil, n = 20

Radius of the coil, r = 10 cm = 0.1 m

Magnetic field strength, B = 0.10 T

Current in the coil, I = 5.0 A

(a) The total torque on the coil is zero because the field is uniform.

(b) The total force on the coil is zero because the field is uniform.

(c) Cross-sectional area of copper coil, A = $10^{-5}\ m^2$

Number of free electrons per cubic meter in copper, N = $10^{29}\ m^{-3}$

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

Magnetic force, $F = Bev_d$

Where,

v_d = Drift velocity of electrons $= \frac{I}{NeA}$

$\therefore F = \frac{BeI}{NeA}$

$= \frac{0.10 \times 5.0}{10^{29} \times 10^{-5}}$

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

Hence, the average force on each electron is $5 \times 10^{-25} N.$

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22. galvanometer coil has a resistance of 12 Ω and the metre shows full scale deflection for a current of 3 mA. How will you convert the metre into a voltmeter of range 0 to 18 V?

Ans. Resistance of the galvanometer coil, *G* = 12 Ω

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 18 V.

$\therefore V = 18V$

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

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

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

= $5988\,\Omega$

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

---

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

Ans. Resistance of the galvanometer coil, G = 15 Ω

Current for which the galvanometer shows full scale deflection,

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

Range of the ammeter is 0, which needs to be converted to 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:

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

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

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

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

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

5 Mark Questions

1. (a) What is cyclotron? Explain its working principle?

(b) A cyclotron's oscillator frequency is 10MHz what should be the operating magnetic field for accelerating protons? If radius of its dees is 20cm, what is the K.E. of the proton beam produced by the accelerator? ($e = 1.6\times10^{-19}c$ **,** $mp = 1.6\times10^{-27}kg$ **,** $1Mev = 1.602\times10^{-13}J$ **)?**

Ans. (a) It is a device used to accelerate charged particles like protons, deuterons, $\propto$ - particle etc.

It is based on the principle that a charged particle can be accelerated to very high energies by making it pass through a moderate electric field a number of times and applying a strong magnetic field at the same time.

(b) v = 10MHz = 10$\times$ 10^6 Hz

$e = 1.6\times10^{-19}c$

$mp = 1.6\times10^{-27}kg$

r = 20cm = $20\times10^{-2}m$

KE = $\frac{q^2B^2r^2}{2m}$

Using $v = \frac{qB}{2\pi m}$

$$B = \frac{2\pi mV}{q}$$

$$B = \frac{2\times3.14\times1.6\times10^{-27}\times10^{7}}{1.6\times10^{-19}}$$

$$B = 0.628\ T$$

$$KE = \frac{(1.6\times10^{-19})^2\times(0.66)^2\times(0.2)^2}{2\times1.67\times10^{-27}}$$

$$KE = 13.35\times10^{-13}\ \text{J}$$

$$1.602\times10^{-13}\ Joules = 1\text{MeV}$$

Since $\Rightarrow 12.02\times10^{-13}\text{J has } \frac{12.02\times10^{-13}}{1.602\times10^{-13}} MeV$

$$KE = 8.3 MeV$$

---

2. (a) Draw a labelled diagram of a moving coil galvanometer. Prove that in a radial magnetic field, the deflection of the coil is directly proportional to the current flowing in the coil.

(b) A galvanometer can be converted into a voltmeter to measure upto

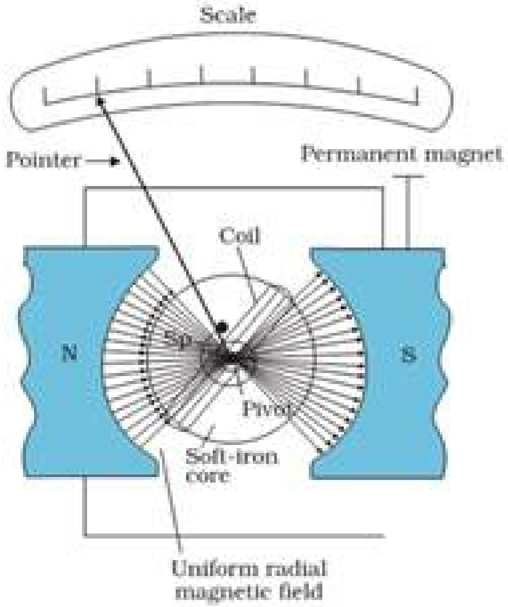
(i) V volt by connecting a resistance R_1 series with the coil

(ii) $V/2$ volt by connecting a resistance R_2 in series with coil Find R in terms of $R_1 and\ R_2$ required to convert – it into a voltmeter that can read upto '2v' volt.

Ans. (a) When a current I is passed through a coil two equal and opposite forces acts on the arms of a coil to form a couple which exerts a Torque on the coil.

=> $\tau = \text{NIAB} \sin\theta$

If $\theta = 90^0\ (sin90^0 = 1)$



θ is the angle made by the normal to the plane of coil with B

τ = NIAB ----(1)

This is called as deflecting torque

As the coil deflected the spring is twisted and a restoring torque per unit twist then the restoring torque for the deflecting & is given by

τ' = k ϕ ----(2)

In equilibrium

Deflecting Torgue=Restoring Torgue

NIAB = Kϕ

I = $\frac{K\phi}{NAB}\phi$

I = Gϕ where G = $\frac{K}{NAB}$ (galvanometer constant)

=> $I \propto \phi$

Thus deflection of the coil is directly proportional to the current flowing in the coil.

(b) We know Ig = $\frac{V}{R+R_G}$

=> Ig = $\frac{V}{R_1+R_G}$ -----(1)

And Ig = $\frac{\frac{v}{2}}{R_2+R_G}$ -------- (2)

Equating (1) & (2)

$$\frac{V}{R_1+R_G}=\frac{\frac{v}{2}}{R_2+R_G}$$

$$Ie\ R_1+R_G = 2\left(R_2+R_G\right)$$

$$R_G = -2R_2 + R_1$$

For conversion Ig = $\frac{2V}{R+R_G}$

=> Ig $\frac{V}{R1+R_G}=\frac{2V}{R+R_G}$

$$Ig = 2R_1 + 2R_G = R + R_G$$

$$R = 2R_1 + R_G$$

$$R = 2R_1 + R_1 - 2R_2$$

$$R = 3R_1 - 2R_2$$

3. Two moving coil meters, M_1 and M_2 have the following particulars:

$R_1 = 10\Omega$, $N_1 = 30$,

$A_1 = 3.6 \times 10^{-3}\ \mathrm{m}^2$, $B_1 = 0.25\ T$

$R_2 = 14\,\Omega$, $N_2 = 42$,

$A_2 = 1.8 \times 10^{-3}\ \mathrm{m}^2$, $B_2 = 0.50\ T$

(The spring constants are identical for the two meters).

Determine the ratio of (a) current sensitivity and (b) voltage sensitivity of $M_2\ and\ M_1$.

Ans. For moving coil meter M_1:

Resistance, $R_1 = 10\Omega$

Number of turns, $N_1 = 30$,

Area of cross-section, $A_1 = 3.6 \times 10^{-3}\ m^2$

Magnetic field strength, $B_1 = 0.25\ T$

Spring constant $K_1 = K$

For moving coil meter M_2:

Resistance, $R_2 = 14\,\Omega$

Number of turns, $N_2 = 42$,

Area of cross-section, $A_2 = 1.8 \times 10^{-3}\ m^2$

Magnetic field strength, $B_2 = 0.50\ T$

Spring constant, $K_2 = K$

(a) Current sensitivity of M_1 is given as:

$$I_{s1} = \frac{N_1 B_1 A_1}{K_1}$$

And, current sensitivity of M_2 is given as:

$$I_{s1} = \frac{N_2 B_2 A_2}{K_2}$$

$\therefore$ Ratio $\frac{I_{s2}}{I_{s1}} = \frac{N_2 B_2 A_2 K_1}{K_2 N_1 B_1 A_1}$

$$= \frac{42 \times 0.5 \times 1.8 \times 10^{-3} \times K}{K \times 30 \times 0.25 \times 3.6 \times 10^{-3}} = 1.4$$

Hence, the ratio of current sensitivity of M_2 to M_1 is 1.4.

(b) Voltage sensitivity for M_2 is given as:

$$V_{s2} = \frac{N_2 B_2 A_2}{K_2 R_2}$$

And, voltage sensitivity for M_1 is given as:

---

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

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

Speed of the electron, *v* = 4.8×10^6 m/s

Charge on the electron, *e* = 1.6×10^{-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 exerted on the electron is equal to the magnetic force i.e.,

$$F_c = F$$

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

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

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

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

= 4.2 cm

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

---

5. 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, $e = 1.6 \times 10^{-19}\ C$

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 = ν

Angular frequency of the electron = ω = 2nv

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, we get the frequency as:

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

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

$$\approx 18\ MHz$$

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

---

6. Two concentric circular coils X and Y of 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 relation,

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

Where,

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

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

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

Magnetic field due to coil Y at their centre is given by the relation, $B = \frac{\mu_0 n_2 I_2}{2r_2}$

$$B_2 = \frac{4\pi \times 10^{-7} \times 25 \times 18}{2 \times 0.10}$$

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

Hence, net magnetic field can be obtained as:

$$B = B_2 - B_1$$

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

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

$$= 1.57 \times 10^{-3} T \left(towards\ west\right)$$

---

7. For a circular coil of radius *R* and *N* turns carrying current *I*, the magnitude of the magnetic field at a point on its axis at a distance *x* from its centre is given by,

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

(a) Show that this reduces to the familiar result for field at the centre of the coil.

(b) Consider two parallel co-axial circular coils of equal radius *R*, and number of turns *N*, carrying equal currents in the same direction, and separated by a distance *R*. Show that the field on the axis around the mid-point between the coils is uniform over a distance that is small as compared to *R*, and is given by, $B = 0.72 - \frac{\mu_0 BNI}{R}$ **,**

approximately. [Such an arrangement to produce a nearly uniform magnetic field over a small region is known as *Helmholtz coils*.]

Ans. Radius of circular coil = *R*

Number of turns on the coil = *N*

Current in the coil = *I*

Magnetic field at a point on its axis at distance *x* is given by the relation,

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

Where,

μ_0 = Permeability of free space

(a) If the magnetic field at the centre of the coil is considered, then $x = 0$.

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

This is the familiar result for magnetic field at the centre of the coil.

(b) Radii of two parallel co-axial circular coils = R

Number of turns on each coil = N

Current in both coils = I

Distance between both the coils = R

Let us consider point Q at distance d from the centre.

Then, one coil is at a distance of $\frac{R}{2} + d$ from point Q.

$\therefore$ Magnetic field at point Q is given as:

$$B_1 = \frac{\mu_0 N I R^2}{2\left[\left(\frac{R}{2} + d\right)^2 + R^2\right]^{\frac{3}{2}}}$$

Also, the other coil is at a distance of $\frac{R}{2} - d$ from point Q.

∴ Magnetic field due to this coil is given as:

$$B_1 = \frac{\mu_0 NIR^2}{2\left[\left(\frac{R}{2}-d\right)^2 + R^2\right]^{\frac{3}{2}}}$$

Total magnetic field, $B = B_1 + B_2$

$$= \frac{\mu_0 IR^2}{2}\left[\left\{\left(\frac{R}{2}-d\right)^2 + R^2\right\}^{-\frac{3}{2}} + \left\{\left(\frac{R}{2}+d\right)^2 + R^2\right\}^{-\frac{3}{2}}\right]$$

$$= \frac{\mu_0 IR^2}{2}\left[\left\{\frac{5R^2}{4} + d^2 - Rd\right\}^{-\frac{3}{2}} + \left\{\frac{5R^2}{4} + d^2 + Rd\right\}^{-\frac{3}{2}}\right]$$

$$= \frac{\mu_0 IR^2}{2}\times\left(\frac{5R^2}{4}\right)^{-\frac{3}{2}}\left[\left(1 + \frac{4}{5}\frac{d^2}{R^2} - \frac{4}{5}\frac{d}{R}\right)^{-\frac{3}{2}} + \left(1 + \frac{4}{5}\frac{d^2}{R^2} + \frac{4}{5}\frac{d}{R}\right)^{-\frac{3}{2}}\right]$$

For d << R, neglecting the factor $\frac{d^2}{R^2}$, we get:

$$\approx \frac{\mu_0 IR^2}{2}\times\left(\frac{5R^2}{4}\right)^{-\frac{3}{2}}\times\left[\left(1-\frac{4d}{5R}\right)^{-\frac{3}{2}} + \left(1+\frac{4d}{5R}\right)^{-\frac{3}{2}}\right]$$

$$\approx \frac{\mu_0 IR^2 N}{2R^3}\times\left(\frac{4}{5}\right)^{-\frac{3}{2}}\times\left[1-\frac{6d}{5R}+1\frac{6d}{5R}\right]$$

$$B = \left(\frac{4}{5}\right)^{\frac{3}{2}}\frac{\mu_0 IN}{R} = 0.72\left(\frac{\mu_0 IN}{R}\right)$$

Hence, it is proved that the field on the axis around the mid-point between the coils is uniform.

8. An electron emitted by a heated cathode and accelerated through a potential difference of 2.0 kV, enters a region with uniform magnetic 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 30º 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

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

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

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,

$B\ ev$

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

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

$r=\frac{mv}{Be}$ ......(2)

From equations (1) and (2), we get

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

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

$$=100.55\times10^{-5}$$

$$=1.01\times10^{-3}m$$

= 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 $\theta\, of\ 30^{\circ}$ with initial velocity, the initial velocity will be,

$$v_1=v\sin\theta$$

From equation (2), we can write the expression for new radius as: $r_1=\frac{mv_1}{Be}$

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

$$=\frac{9.1\times10^{-31}}{0.15\times1.6\times10^{-19}}\times\left(\frac{2\times1.6\times10^{-19}\times2\times10^{3}}{9\times10^{-31}}\right)^{\frac{1}{2}}\times\sin30^{\circ}$$

$$=0.5\times10^{-3}m$$

= 0.5 mm

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

9. A magnetic field set up using Helmholtz coils (described in Exercise 4.16) is uniform in a small region and has a magnitude of 0.75 T. In the same region, a uniform electrostatic field is maintained in a direction normal to the common axis of the coils. A narrow beam of (single species) charged particles all accelerated through 15 kV enters this region in a direction perpendicular to both the axis of the coils and the electrostatic field. If the beam remains undeflected when the electrostatic field is $9.0\times10^{-5}\ \mathrm{V\ m^{-1}}$, make a simple guess as to what the beam contains. Why is the answer not unique?

Ans. Magnetic field, *B* = 0.75 T

Accelerating voltage, *V* = 15 $kV = 15\times10^{3}\ V$

Electrostatic field, *E* = $9.0\times10^{-5}\ \mathrm{V\ m^{-1}}$

Mass of the electron = *m*

Charge of the electron = *e*

Velocity of the electron = *v*

Kinetic energy of the electron = *eV*

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

$$\therefore \frac{e}{m} = \frac{v^2}{2V} \quad \ldots\ldots (1)$$

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

$$\therefore eE = evB$$

$$v = \frac{E}{B} \quad \ldots\ldots\ldots(2)$$

Putting equation (2) in equation (1), we get

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

$$=\frac{\left(9.0\times10^5\right)^2}{2\times15000\times(0.75)^2}$$

$$=4.8\times10^7\ C/kg$$

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

---

10. A uniform magnetic field of 1.5 T exists in a cylindrical region of radius10.0 cm, its direction parallel to the axis along east to west. A wire carrying current of 7.0 A in the north to south direction passes through this region. What is the magnitude and direction of the force on the wire if,

(a) the wire intersects the axis,

(b) the wire is turned from N-S to northeast-northwest direction,

(c) the wire in the N-S direction is lowered from the axis by a distance of 6.0 cm?

Ans. Magnetic field strength, B = 1.5 T

Radius of the cylindrical region, r = 10 cm = 0.1 m

Current in the wire passing through the cylindrical region, I = 7 A

(a) If the wire intersects the axis, then the length of the wire is the diameter of the cylindrical region.

Thus, l = 2r = 0.2 m

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

Magnetic force acting on the wire is given by the relation,

$F = BIl \sin\theta$

$= 1.5 \times 7 \times 0.2 \times \sin 90°$

= 2.1 N

Hence, a force of 2.1 N acts on the wire in a vertically downward direction.

(b) New length of the wire after turning it to the Northeast-Northwest direction can be given as:

$$l_1 = \frac{l}{\sin\theta}$$

Angle between magnetic field and current, θ = 45°

Force on the wire,

$F = BIl_1 \sin\theta$

$= BIl$

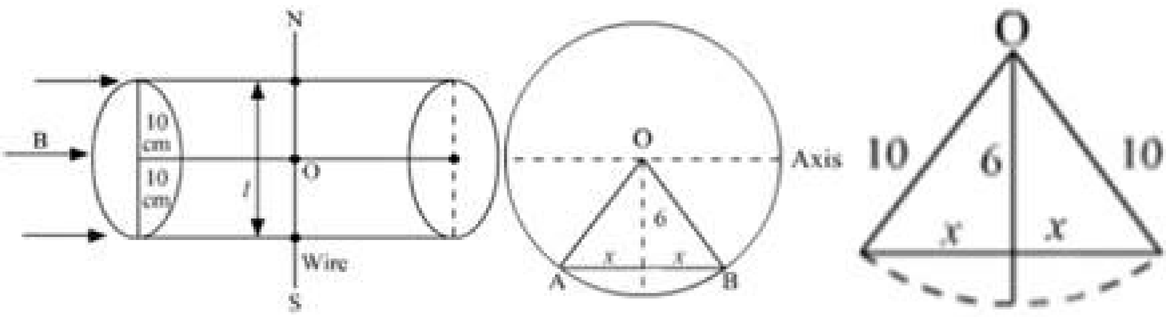
$= 1.5 \times 7 \times 0.2$

=2.1 N

Hence, a force of 2.1 N acts vertically downward on the wire. This is independent of angle θ because $l \sin\theta$ is fixed.

(c) The wire is lowered from the axis by distance, d = 6.0 cm

Suppose wire is passing perpendicularly to the axis of cylindrical magnetic field then lowering 6 cm means displacing the wire 6 cm from its initial position towards to end of cross sectional area.



$x = \sqrt{10^2 - 6^2}$

= 8cm

Thus the length of wire in magnetic field will be 16 cm as AB= L =2x =16 cm

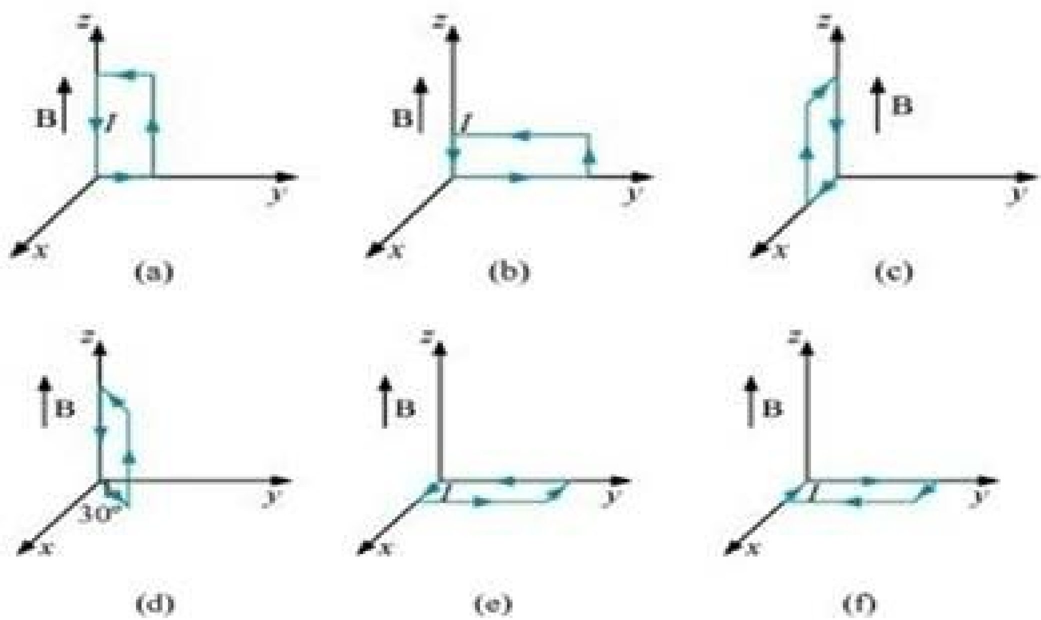
Now the force,

$F = iLB\ \sin 90^\circ$ as the wire will be perpendicular to the magnetic field.

$F = 7 \times 0.16 \times 1.5 = 1.68\ N$ The direction will be given by right hand curl rule or screw rule i.e. vertically downwards.

---

11. A uniform magnetic field of 3000 G is established along the positive *z*-direction. A rectangular loop of sides 10 cm and 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?



Ans. Magnetic field strength, B = 3000 G = $3000\times10^{-4}T$ = 0.3 T

Length of the rectangular loop, l = 10 cm

Width of the rectangular loop, b = 5 cm

Area of the loop,

$$A=l\times b = 10\times5=50\ cm^2 = 50\times10^{-4}m^2$$

Current in the loop, I = 12 A

Now, taking the anti-clockwise direction of the current as positive and vise-versa:

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

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.

$$\therefore\tau=12\times\left(50\times10^{-4}\right)\hat{j}\times0.3\hat{k}$$

$$1.8\times10^{-2}\hat{j}\,Nm$$

The torque is $1.8\times10^{-2}\,Nm$ along the negative y-direction. 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 $\tau=I\bar{A}\times\bar{B}$

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.

$$\therefore\tau=-12\times\left(50\times10^{-4}\right)\hat{j}\times0.3\hat{k}$$

$$1.8\times10^{-2}\hat{i}\,Nm$$

The torque is $1.8\times10^{-2}\,Nm$ along the negative x direction and the force is zero.

(d) Magnitude of torque is given as:

$|\tau| = IAB$

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

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

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

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

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

= 0

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

(f) Torque $\tau = I\bar{A} \times \bar{B}$

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

= 0

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

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

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

---

12. A solenoid 60 cm long and of radius 4.0 cm has 3 layers of windings of 300 turns each. A 2.0 cm long wire of mass 2.5 g lies inside the solenoid (near its centre) normal to its axis; both the wire and the axis of the solenoid are in the horizontal plane. The wire is connected through two leads parallel to the axis of the solenoid to an external battery which supplies a current of 6.0 A in the wire. What value of current (with

appropriate sense of circulation) in the windings of the solenoid can support the weight of the wire? $g = 9.8\ m\ s^{-2}$

Ans. Length of the solenoid, L = 60 cm = 0.6 m

Radius of the solenoid, r = 4.0 cm = 0.04 m

It is given that there are 3 layers of windings of 300 turns each.

$\therefore$ Total number of turns, $n = 3 \times 300$ = 900

Length of the wire, l = 2 cm = 0.02 m

Mass of the wire, m = 2.5 g = $2.5 \times 10^{-3}\ kg$

Current flowing through the wire, i = 6 A

Acceleration due to gravity, $g = 9.8\ m/s^2$

Magnetic field produced inside the solenoid, $B = \frac{\mu_0 n I}{L}$

Where,

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

I = Current flowing through the windings of the solenoid

Magnetic force is given by the relation, F = Bil

$$= \frac{\mu_0 n I}{L} il$$

Also, the force on the wire is equal to the weight of the wire.

$$\therefore mg = \frac{\mu_0 n I i l}{L}$$

$$I = \frac{mgL}{\mu_0 n i l}$$

$$= \frac{2.5 \times 10^{-3} \times 9.8 \times 0.6}{4\pi \times 10^{-7} \times 900 \times 0.02 \times 6} = 108 A$$

Hence, the current flowing through the solenoid is 108 A.