Q 4.1) 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?

Answer 4.1:

Given:

The number of turns on the coil (n) is 100

The radius of each turn (r) is 8 cm or 0.08 m

The magnitude of the current flowing in the coil (I) is 0.4 A

The magnitude of the magnetic field at the centre of the coil can be obtained by the following relation:

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

where

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

hence,

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

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

The magnitude of the magnetic field is

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

Q 4.2) 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?

Answer 4.2:

The magnitude of the current flowing in the wire (I) is 35 A

The distance of the point from the wire (r) is 20 cm or 0.2 m

At this point, the magnitude of the magnetic field is given by the relation:

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

where,

μ_0
= Permeability of free space
=

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

Substituting the values in the equation, we get

$$|\bar{B}| = \frac{4\pi\times10^{-7}}{4\pi} \times \frac{2\times35}{0.2}$$
=

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

Hence, the magnitude of the magnetic field at a point 20 cm from the wire is

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

Q 4.3) A long straight wire in the horizontal plane carries a current of 50 A in the north-to-south direction. Give the magnitude and direction of B at a point 2.5 m east of the wire.

<u>Answer 4.3:</u>

The magnitude of the current flowing in the wire is (I) = 50 A.

Point B is 2.5 m away from the east of the wire.

Therefore, the magnitude of the distance of the point from the wire (r) is 2.5 m

The magnitude of the magnetic field at that point is given by the relation:

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

where,

μ_0
= Permeability of free space
=

$$4\pi \times 10^{-7}\ T\ m\ A^{-1}$$
$$|\bar{B}| = \frac{4\pi\times10^{-7}}{4\pi} \times \frac{2\times50}{2.5}$$

=

$$4 \times 10^{-6}\ T$$

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 Maxwell's right-hand thumb rule, the direction of the magnetic field at the given point is vertically upward.

Q 4.4) A horizontal overhead power line carries a current of 90 A in the east-to-west direction. What is the magnitude and direction of the magnetic field due to the current 1.5 m below the line?

Answer 4.4:

The magnitude of the current in the power line is (I) = 90 A

The point is located below the electrical cable at a distance (r) = 1.5 m

Hence, the magnetic field at that point can be calculated as follows,

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

where,

μ_0
= Permeability of free space
=

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

Substituting values in the above equation, we get

$$|\bar{B}| = \frac{4\pi\times10^{-7}}{4\pi} \times \frac{2\times90}{1.5}$$

=

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

The current flows from east to west. The point is below the electrical cable.

Hence, according to Maxwell's right-hand thumb rule, the direction of the magnetic field is towards the south.

Q 4.5) 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?

Answer 4.5:

In the problem,

The current flowing in the wire is (I) = 8 A

The magnitude of the uniform magnetic field (B) is 0.15 T

The angle between the wire and the magnetic field,

$$\theta = 30^\circ$$

.

The magnetic force per unit length on the wire is given as F =

$$BIsin\theta$$

=

$$0.15 \times 8 \times 1 \times sin30^\circ$$

=

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

Hence, the magnetic force per unit length on the wire is

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

.

Q 4.6) 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?

Answer 4.6:

In the problem,

The length of the wire (l) is 3 cm or 0.03 m

The magnitude of the current flowing in the wire (I) is 10 A

The strength of the magnetic field (B) is 0.27 T

The angle between the current and the magnetic field is

$$\theta = 90^\circ$$

.

The magnetic force exerted on the wire is calculated as follows:

$$F = BIlsin\theta$$

Substituting the values in the above equation, we get

=

$$0.27 \times 10 \times 0.03 \times sin90^\circ$$

=

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

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.

Q 4.7) 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.

Answer 4.7:

The magnitude of the current flowing in the wire A (

I_A) is 8 A
The magnitude of the current flowing in wire B (

I_B) is 5 A
The distance between the two wires (r) is 4 cm or 0.04 m

The length of the section of wire A (L) = 10 cm = 0.1 m

The force exerted on the length L due to the magnetic field is calculated as follows:

$$F = \frac{\mu_o I_A I_B L}{2\pi r}$$

where,

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

Substituting the values, we get

$$F = \frac{4\pi\times10^{-7}\times8\times5\times0.1}{2\pi\times0.04} = 2\times10^{-5}\ N$$

The magnitude of the force is

$2\times10^{-5}\ N$.
This is an attractive force normal to A towards B because the direction of the currents in the wires is the same.

Q 4.8) 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.

Answer 4.8:

Solenoid length (l) = 80 cm = 0.8 m

Five layers of windings of 400 turns each on the solenoid.

∴
Total number of turns on the solenoid, N = 5 x 400 = 2000
Solenoid Diameter (D) = 1.8 cm = 0.018 m

The current carried by the solenoid (I) = 8.0 A

The relation that gives the magnitude of the magnetic field inside the solenoid near its centre is given below:

$$B = \frac{\mu_0 NI}{l}$$

Where,

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

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

=

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

Hence, the magnitude of B inside the solenoid near its centre is

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

Q 4.9) 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 30º with the direction of a uniform horizontal magnetic field of magnitude 0.80 T. What is the magnitude of torque experienced by the coil?

Answer 4.9:

In the given problem,

The length of a side of the square coil (l) is 10 cm or 0.1 m

The magnitude of the current flowing in the coil (I) is 12 A

The number of turns on the coil (n) is 20

The angle made by the plane of the coil with B (Magnetic field),

$$\theta = 30^\circ$$

The strength of the magnetic field (B) is 0.8 T

The following relation gives the magnitude of the magnetic torque experienced by the coil in the magnetic field:

$$\tau = n\ BIA\ sin\theta$$

Where,

A = Area of the square coil

= 1 x 1 = 0.1 x 0.1 = 0.01 m^2

So,

$$\tau = 20 \times 0.8 \times 12 \times 0.01 \times sin30^{\circ}$$

= 0.96 N m

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

Q 4.10) Two moving coil meters, M_1 and M_2, have the following particulars:

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

,

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

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

,

$$A_2 = 1.8 \times 10^{-3}\ m^2,\ B_2 = 0.5\ T$$

(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.

<u>Answer 4.10:</u>

Given data:

	Moving Coil Meter M_1	Moving Coil Meter M_2
Resistance	�1=10Ω	�2=14Ω

Number of turns	�1=30	�2=42
Area	�1=3.6×10−3�2	�2=1.8×10−3�2
Magnetic field strength	B_1 = 0.25 T	B_2 = 0.5 T
Spring constant	K_1 = K	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:

$$I_{s2} = \frac{N_2 B_2 A_2}{K_2}$$

$$\therefore Ratio \frac{I_{s2}}{I_{s1}} = \frac{N_2 B_2 A_2}{N_1 B_1 A_1} = \frac{42 \times 0.5 \times 1.8 \times 10^{-3} \times K}{K \times 30 \times 0.25 \times 3.6 \times 10^{-3}} = 1.4$$

Hence, the ratio of the 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:

$$V_{s1} = \frac{N_1 B_1 A_1}{K_1 R_1}$$

$$\therefore Ratio \frac{I_{s2}}{I_{s1}} = \frac{N_2 B_2 A_2 K_1 R_1}{N_1 B_1 A_1 K_2 R_2} = \frac{42 \times 0.5 \times 1.8 \times 10^{-3} \times 10 \times K}{K \times 14 \times 30 \times 0.25 \times 3.6 \times 10^{-3}} = 1$$

Hence, the ratio of voltage sensitivity of M_2 to M_1 is 1.

Q 4.11) 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 x 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. (

$$e = 1.6 \times 10^{-19}\ C,\ m_e = 9.1 \times 10^{-31}\ kg$$

)

Answer 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) =

$$9.1 \times 10^{-31}\ kg$$

The angle between the shot electron and magnetic field,

$$\theta = 90^{\circ}$$

The relation for 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, the centripetal force exerted on the electron,

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

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

$F_e = F$

=>

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

=>

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

So,

$$r = \frac{9.1\times10^{-31}\times4.8\times10^{6}}{6.5\times10^{-4}\times1.6\times10^{-19}\times sin90^{\circ}} = 4.2\times10^{-2}\ m = 4.2cm$$

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

Q 4.12) In Exercise 4.11, find the frequency of revolution of the electron in its circular orbit. Does the answer depend on the speed of the electron? Explain.

Answer 4.12:

Magnetic field strength (B) =

$$6.5\times10^{-4}\ T$$

Charge on the electron (e) =

$$1.6\times10^{-19}\ C$$

Mass of the electron (m_e) =

$$9.1\times10^{-31}\ kg$$

Speed 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 = v

Angular frequency of the electron =

$$\omega = 2\pi v$$

The 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:

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

=>

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

=>

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

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:

$$v = \frac{6.5\times10^{-4}\times1.6\times10^{-19}}{2\times3.14\times9.1\times10^{-31}} = 1.82\times10^{6}\ Hz \approx 18\ MHz$$

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

Q 4.13) (a) A circular coil having a radius of 8.0 cm, the number of turns as 30 and 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 60^0 with the normal of the coil. To prevent the coil from turning, determine the magnitude of the counter-torque that must be applied.

(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.)

Answer 4.13:

(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

The angle between the field lines and normal with the coil surface,

$$\theta = 60^\circ$$

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,

$$\tau = nIBA\ sin\theta$$

=

$$30 \times 6 \times 1 \times 0.0201 \times sin60^\circ$$

= 3.133 N m

(b) It can be inferred from the 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.

Q 4.14) 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.

Answer:

Radius of the coil X, r_1 = 16 cm = 0.16 m

Number of turns in coil X, $n_1 = 20$

Current in the coil X, $I_1 = 16$ A

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

Number of turns in coil Y, $n_2 = 25$

Current in the coil Y, $I_2 = 18$ A

The magnetic field due to the coil X at the centre is given as

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

Here, μ_0 is the permeability of the free space = $4\pi \times 10^{-7}$ Tm/A

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

= $4\pi \times 10^{-4}$ T (Towards east)

The magnetic field due to the coil Y at the centre is given as

$$B_2 = \frac{\mu_0 N_2 I_2}{2r_2}$$
$$B_2 = \frac{4\pi \times 10^{-7} \times 25 \times 18}{2 \times 0.10}$$

= $9\pi \times 10^{-4}$ T (Towards west)

Therefore, the net magnetic field is given as

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

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

= $5 \times 3.14 \times 10^{-4}$

= 1.57×10^{-3} T (Towards west)

Q 4.15) A magnetic field of 100 G (1 G = 10^{-4} T) is required, which is uniform in a region of linear dimension of about 10 cm and an area of cross-section of 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 around 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.

Answer:

Magnetic field strength, B = 100 G = 100×10^{-4} T

Number of turns per unit length, N = 1000 turns/m

Current carrying capacity of the coil = 15 A

Permeability of free space, $\mu_0 = 4\pi \times 10^{-7}$ TmA^{-1}

The magnetic field is given as

$B = \mu_0 NI/l$

$\Rightarrow NI/l = B/\mu_0$

$= (100 \times 10^{-4})/(4\pi \times 10^{-7})$

$NI/l = 7961$

Now, we can consider a possible combination. Let the current, I = 10 A and the length of the solenoid, l = 0.5 m

So we get

$(N \times 10)/0.5 = 7961$

N = 398 turns ≈ 400 turns

Length about 50 cm, number of turns about 400, current about 10 A. These particulars are not unique. Some adjustment with limits is possible.

Q 4.16) 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,

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

(a) Show that this reduces to the familiar result for the 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,

$$B = 0.72\frac{\mu_0 NI}{R}$$ **, approximately.**

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

Answer:

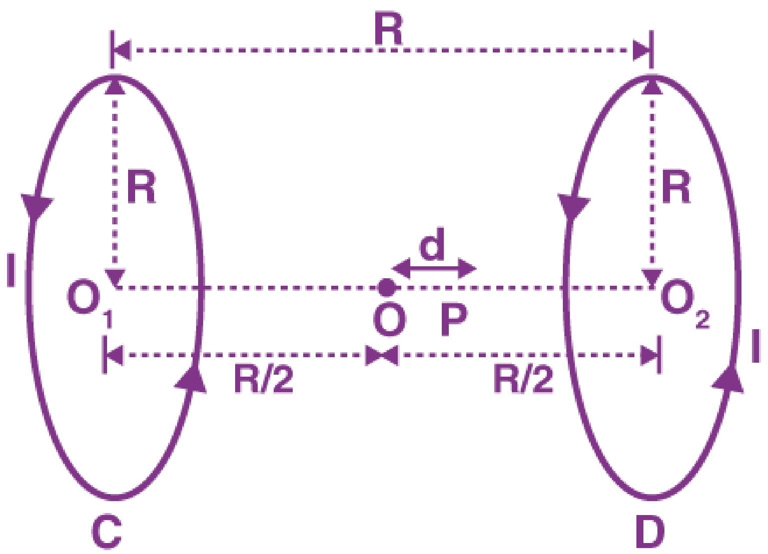
(a) Given,

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

At the centre of the coil, x = 0

Therefore, the magnetic field at the centre is

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



(b) Let the small distance between the points P and O be d.

For the coil C, the distance $O_1P = x_1 = (R/2) + d$

For the coil d, the distance $O_2P = x_2 = (R/2) – d$

The magnetic field on the axis at a distance x from the centre of the circular coil having a radius a, with n number of turns and having a current I is given by

$$B = \frac{\mu_0}{4\pi} \frac{2\pi n I a^2}{(x^2+a^2)^{3/2}}$$
$$B = \frac{\mu_0}{2} \frac{n I a^2}{(x^2+a^2)^{3/2}}$$

The magnetic field at P due to coil C

$$B_1 = \frac{\mu_0}{2}\frac{NIR^2}{(x_1^2+R^2)^{3/2}}$$
$$B_1 = \frac{\mu_0}{2}\frac{NIR^2}{((\frac{R}{2}+d)^2+R^2)^{3/2}}$$
$$B_1 = \frac{\mu_0}{2}\frac{NIR^2}{((\frac{R^2}{4}+d^2+Rd)+R^2)^{3/2}}$$

d^2 can be neglected when compared to R^2

$$B_1 = \frac{\mu_0 NIR^2}{2}\frac{1}{(\frac{5R^2}{4})^{3/2}}\left[(1+\frac{4d}{5R})^{-3/2}\right]$$

It acts along PO_2

The magnetic field at P is given by

$$B_2 = \frac{\mu_0}{2}\frac{NIa^2}{(x_2^2+R^2)^{3/2}}$$
$$B_2 = \frac{\mu_0}{2}\frac{NIR^2}{((\frac{R}{2}-d)^2+R^2)^{3/2}}$$
$$B_2 = \frac{\mu_0 NIR^2}{2}\frac{1}{(\frac{5R^2}{4})^{3/2}}\left[(1-\frac{4d}{5R})^{-3/2}\right]$$

It acts along PO_2

The total Magnetic field at the point P due to the current through the coils $B = B_1 + B_2$

$$B = \frac{\mu_0 NIR^2}{2}\frac{1}{(\frac{5R^2}{4})^{3/2}}\left[(1+\frac{4d}{5R})^{-3/2}+(1-\frac{4d}{5R})^{-3/2}\right]$$
$$B = \frac{\mu_0 NIR^2}{2\left(\frac{5R^2}{4}\right)^{3/2}}\left[1-\frac{6d}{5R}+1+\frac{6d}{5R}\right]$$
$$B = \frac{\mu_0 NIR^2}{2\left(\frac{5R^2}{4}\right)^{3/2}}\times 2$$
$$B = \frac{\mu_0 NI}{R}\left(\frac{4}{5}\right)^{3/2}$$
$$B = (0.72)\frac{\mu_0 NI}{R}$$

Q 4.17) 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.

Answer:

The inner radius of the core, r_1= 25 cm = 0.25 m

The outer radius of the core, r_2= 26 cm = 0.26 m

Number of turns of the wire, N= 3500 turns

Current in the wire, I = 11 A

(a) The magnetic field outside the toroid is zero.

(b) Inside the core of the toroid, the magnetic field induction is

B = $\mu_0 NI/l$

Mean length of the toroid,

$$l = 2\pi\left(\frac{r_1+r_2}{2}\right)$$
$$= \pi\,(r_1 + r_2) = \pi\,(0.25 + 0.26) = \pi \times 0.51$$

So, B = $\mu_0 NI/l$

$$B = \frac{(4\pi\times10^{-7})\times3500\times11}{\pi\times0.51} = 3.02\times10^{-2}T$$

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

Q 4.18) 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 the 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.

Answer:

(a) Initial velocity is either parallel or antiparallel to the magnetic field. There is no magnetic force acting on the particle when it is parallel or antiparallel, and it moves undeflected.

(b) Yes, because magnetic force can change the direction of velocity but not its magnitude.

(c) Magnetic field should be in a vertically downward direction.

Q 4.19) An electron emitted by a heated cathode and accelerated through a potential difference of 2.0 kV enters a region with a 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.

Answer:

Magnetic field, B = 0.15 T

Potential difference, V = 2.0 kV

An electron gains kinetic energy, which is given by

E = (1/2) mv^2

eV = (1/2) mv^2

$$v = \sqrt{\frac{2eV}{m}}$$
$$v = \sqrt{\frac{2\times1.6\times10^{-19}\times2\times10^{3}}{9.1\times10^{-31}}} = 2.652 \times 10^{7} m/s$$

(a) When the field applied is transverse to the initial velocity, the force F_1 acting on the electron is perpendicular to the direction of the magnetic field and the direction of motion of the electron. The perpendicular force provides the centripetal force F_2 to the electron and makes it move in a circular path.

The forces F_1 and F_2 are equal

F_1 = evB

F_2 = $mv^2/2$

$F_1 = F_2$

evB = $mv^2/2$

⇒ r = mv/eB

$$r = \frac{9.1\times10^{-31}\times2.652\times10^{7}}{0.15\times1.6\times10^{-19}}$$

= 10^{-3} m = 1 mm

The electron will move in a circular path with a radius of 1 mm in the direction perpendicular to the magnetic field.

(b) The applied force is inclined to the initial velocity. The velocity of the electron is resolved into two components, V cos θ and V sin θ. V cos θ is along the direction of the field, and it causes the electron to move in a straight line. V sin θ is along the normal, and it causes the electron to move in a circular path. Therefore, the electron moves in a helical path. The radius of the helical path is given as, r = mV sin θ/Be

$$r = \frac{9.1\times10^{-31}\times2.652\times10^{7}\times sin30^{0}}{0.15\times1.6\times10^{-19}}$$

$= 50.25 \times 10^{-5}$ m

r = 0.5 mm

The helical trajectory of radius 0.5 mm along the direction of the magnetic field.

Q 4.20) 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 9.0×10^{-5} V m^{-1}, make a simple guess as to what the beam contains. Why is the answer not unique?

Answer:

Magnetic field, B = 0.75 T

Accelerating voltage, V = 15 kV = 15×10^{3} V

Electrostatic field, E = 9.0×10^{-5} V m^{-1}

Kinetic energy of the electron, E = (1/2) mv^2

eV = (1/2) mv^2

Therefore, (e/m) = (v^2/2V)

Here,

Mass of the electron = m

Charge of the electron = e

The velocity of the electron = v

The particles are not deflected by the electric field and the magnetic field. So the force on the particle due to the electric field is balanced by force due to the magnetic field.

eE = evB

⇒ v = E/B

Therefore, (1/2) $m(E/B)^2$ = eV

$e/m = E^2/2VB^2$

$$= \frac{(9.0\times10^5)^2}{2\times15000\times(0.75)^2} = 4.8\times10^7 C/kg$$

The beam contains Deuterium ions or deuterons

The answer is not unique because only the ratio of charge to mass is determined. Other possible answers are He++, Li++, etc.

Q 4.21) 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 the current is reversed, keeping the magnetic field the same as before?
(Ignore the mass of the wires.) g = 9.8 m s^{-2}.

Answer:

Length of the rod, l = 0.45 m

Mass suspended, m = 60 g = 60 x 10^{-3} Kg

Current, I = 5 A

(a) Tension in the wire is zero if the force on the current-carrying wire due to the magnetic field is equal and opposite to the weight on the wire.

$BIl = mg$

$B = mg/Il$

$$= \frac{60\times10^{-3}\times9.8}{5\times0.45}$$
$$=0.26133\ T$$

The magnetic field set up normal to the conductor is 0. 26133 T

(b) When the direction of the current is reversed, B*Il* and mg will act vertically downwards; the effective tension in the wire is

$T = BIl+mg$

= (0. 26133 x 5.0 x 0.45) + (60 x 10^{-3} x 9.8) = 0.587 + (0.588) = 1.176 N

Total tension in the wire = 1.176 N

Q 4.22) 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?

Answer:

Current in the wires, I = 300 A

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

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

The force between the two wires, $F = \mu_0 I^2/2\pi d$

Here,

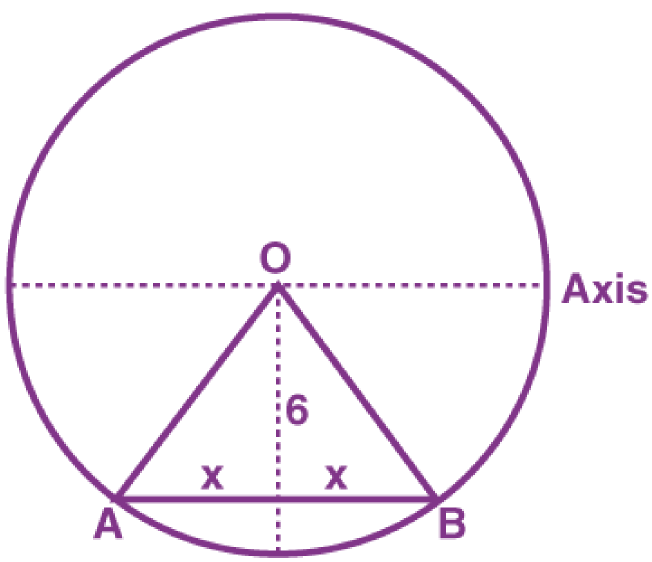
μ_0 = permeability of the free space = $4\pi \times 10^{-7}$ Tm/A

$$F = \frac{4\pi\times10^{-7}\times(300)^2}{2\pi\times0.015} = 1.2N/m$$

Since the direction of the wires is opposite, the force will be repulsive.

Q 4.23) A uniform magnetic field of 1.5 T exists in a cylindrical region of a radius of 10.0 cm, its direction parallel to the axis along east to west. A wire carrying a 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 the northeast-northwest direction
(c) the wire in the N-S direction is lowered from the axis by a distance of 6.0 cm?

Answer:



(a) Magnetic field, B = 1.5 T

Current in the wire, I = 7.0 A

Radius, r = 10 cm = 0.1 m

Diameter, l = 2 x r = 0.2 m

A force 2.1 N acts vertically downward on the wire

(a) The wire intersects the axis, $\theta = 90^0$

$F = BIl\sin\theta = 1.5 \times 7 \times 0.20 \times \sin 90^0$

= 2.1 N

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

$F = BIl_1 \sin\theta$

The length of the wire after turning to the northeast-northwest direction is $l_1 = l/\sin\theta$

Therefore, $l = l_1 \sin\theta$

$F = BIl$

= 1.5 x 7 x 0.20= 2.1 N

A force 2.1 N acts vertically downward on the wire

(c) When the wire is lowered by 6 cm, then

Then,

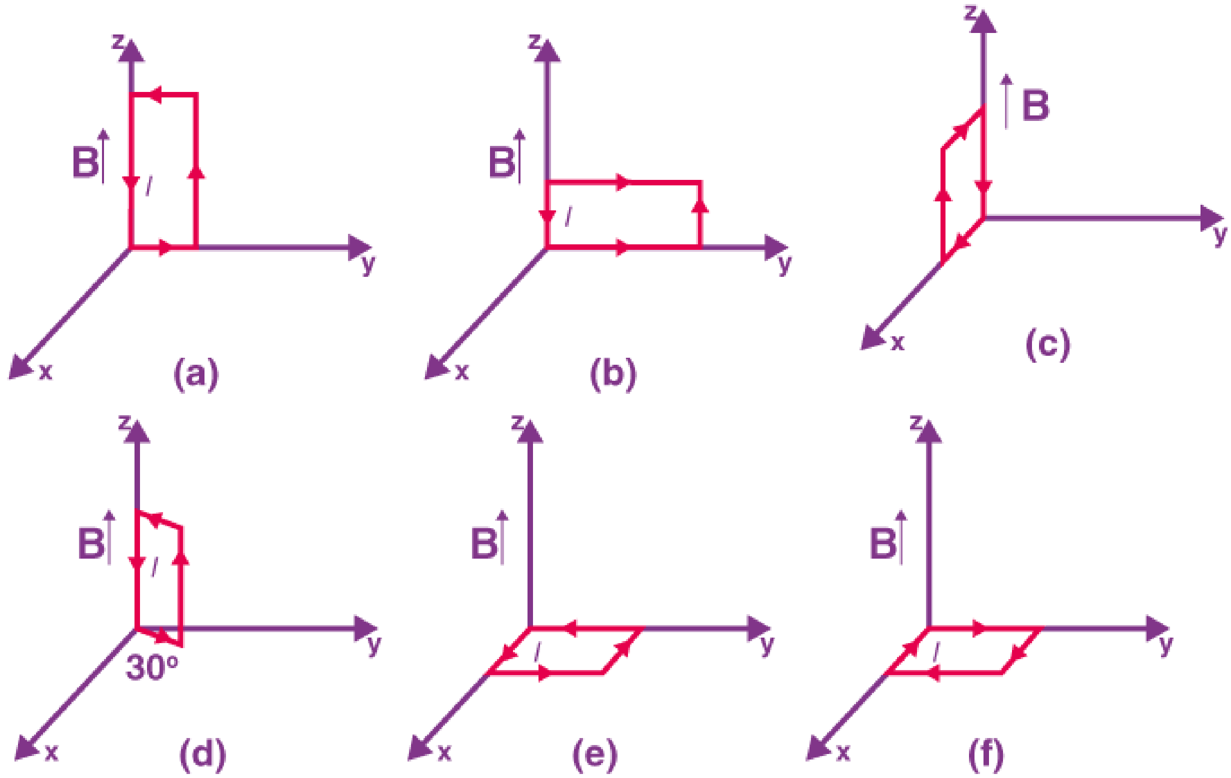
$$x = \sqrt{(10)^2 - (6^2)} = \sqrt{64} = 8\,cm$$

$$2x = l_2 = 16\text{ cm}$$

$F_2 = BI\,l_2 = 1.5 \times 7 \times 0.16 = 1.68$ N

The force is directed vertically downwards.

Q 4.24) 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 the figure? What is the force in each case? Which case corresponds to stable equilibrium?



Answer:

Magnetic field strength, B = 3000 G = 0.3 T

Area of the loop, A = 10 x 5 = 50 cm^2 = 50 x 10^{-4} m^2

Current in the loop, I = 12 A

(a) Torque,

$$\vec{\tau} = I\vec{A} \times \vec{B}$$

A is normal to the y-z plane, and B is directed along the z-axis

$$\vec{A} = 50 \times 10^{-4}\hat{i}$$
$$\vec{B} = 0.3\hat{k}$$
$$\vec{\tau} = 12 \times (50 \times 10^{-4})\hat{i} \times 0.3\hat{k}$$
$$= -1.8 \times 10^{-2}\hat{j}Nm$$

The torque is 1.8 x 10^{-2} N m along the negative y-direction. The net force on the loop is zero since the opposite forces acting on the two ends of the loop will cancel each other.

(b) This is the same as (a). Therefore, the torque is 1.8 x 10^{-2} N m along the negative y-direction. The net force is zero.

(c) A is normal to the x-z plane, and B is along the z-axis

$$\vec{A} = -50 \times 10^{-4}\hat{j}$$
$$\vec{B} = 0.3\hat{k}$$
$$\vec{\tau} = 12 \times (-50 \times 10^{-4})\hat{j} \times 0.3\hat{k}$$
$$= -1.8 \times 10^{-2}\hat{i}Nm$$

Therefore, the torque is 1.8 x 10^{-2} N m along the negative x-direction. The net force is zero.

(d) Torque,

$$\vec{\tau} = I\vec{A} \times \vec{B}$$

From the given figure, it can be observed that A is normal to the coil. Since the coil makes an angle of -30° with the y-axis, A will make an angle of 30^0 with the positive x-axis in the negative y-direction, and B will be directed along the z-axis. The angle between A and B is θ = 90^0. Therefore,

Accordingly, the magnitude of torque will be,

τ = 12×50 × 10^{-4}× 0.3

= 1.8×10^{-2} N m

The direction of the torque is (90° + 30°) from the negative x-axis or 360°−120° = 240° from the positive x-axis. The net force on the loop is zero.

(e) From the given figure, we can see that A is normal to the x-y plane in the positive z-direction and B is directed along the z-axis.

$$\vec{A} = 50 \times 10^{-4}\hat{k}$$
$$\vec{B} = 0.3\hat{k}$$

Accordingly,

$$\vec{\tau} = 12 \times (-50 \times 10^{-4})\hat{k} \times 0.3\hat{k}$$
$$= 0$$

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

(f) From the given figure, we can see that A is normal to the x-y plane in the negative z-direction and B is directed along the z-axis. The angle between A and B is θ = 180°. Therefore,

$$\vec{A} = -50 \times 10^{-4}\hat{k}$$
$$\vec{B} = 0.3\hat{k}$$
$$\vec{\tau} = 12 \times (-50 \times 10^{-4})\hat{k} \times 0.3\hat{k}$$
$$= 0$$

Therefore, torque and force is zero.

Case (e) corresponds to stable, and case (f) corresponds to unstable equilibrium.

Q 4.25) A circular coil of 20 turns and a radius of 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
(a) the total torque on the coil
(b) the total force on the coil
(c) the average force on each electron in the coil due to the magnetic field? (The coil is made of copper wire of a cross-sectional area of 10^{-5} m^2, and the free electron density in copper is about 10^{29} m^{-3}.)

Answer:

Number of turns, n = 20 turns

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

Current in the coil, I = 5 A

Magnetic field strength, B = 0.10 T

The cross-sectional area of the wire, a = 10^{-5} m^2

The angle between

$\vec{A}$
and
$\vec{B}$
is θ = 0
(a) Total torque on the coil

$$\vec{\tau} = NI\vec{A} \times \vec{B}$$
$$\Rightarrow \tau = NIAB \sin 0 = 0$$

Therefore, the torque is zero.

(b) Equal and opposite forces act on opposite sides of the coil. Therefore, the total force on the coil is zero.

(c) Average force on the moving electron

F = B e v_d

v_d is the drift velocity of the electrons

v_d = I/N e A

Therefore, F = B e I/ N e a

F = B I/n a

=

$$\frac{0.1 \times 5}{10^{29} \times 10^{-5}} = 5 \times 10^{-25} N$$

The average force on each electron is 5 x 10^{-25} N

Q. 4.26) 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 an appropriate sense of circulation) in the windings of the solenoid can support the weight of the wire? g = 9.8 m s^{-2}?

Answer:

Length of the solenoid, l = 60 cm

Layers of windings = 3

Each layer has 300 turns

Number of turns per unit length, n = (3 x 300)/0.6 = 1500 m^{-1}

The magnetic field inside the solenoid is given by, $B = \mu_0 nI$

$\mu_0 = 4\pi \times 10^{-7}$ T

B = $(4\pi \times 10^{-7}) \times 1500 \times I$

= $6\pi \times 10^{-4}$I————-(1)

Force due to magnetic field, F = I'B*l*

I' = Current in the wire = 6 A

l = length of the wire = 2 cm

The windings of the solenoid would support the weight of the wire when the force due to the magnetic field inside the solenoid balances the weight of the wire.

I'B*l = mg*

m = mass of the wire = 2.5 g

B = mg/I'*l*

From equation (1), we get

$6\pi \times 10^{-4}$ I= mg/I'*l*

⇒ I = mg/($6\pi \times 10^{-4}$) I'*l*

$$I = \frac{2.5\times10^{-3}\times9.8}{6\times0.02\times4\pi\times10^{-7}\times1500} = 108.37A$$

A current of 108.37 A will support the wire.

Q 4.27) A 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?

Solution:

Resistance of the galvanometer coil, G = 12 Ω

Current for which there is full-scale deflection, I = 3mA

A resistor with a resistance R is connected in series with the galvanometer to convert it into a voltmeter. The resistance R is given as

R = (V/Ig) – G

=

$$\frac{18}{3\times10^{-3}} - 12 = 6000\text{–}12 = 5988\Omega$$

A galvanometer can be converted into a voltmeter by connecting a resistor of 5988 Ω.

Q 4.28) 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?

Solution:

Resistance of the galvanometer, G = 15 Ω

Current through the galvanometer, I_g = 4 mA = 4 x 10^{-3} A

Ammeter range = 0 to 6 A

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

Therefore, S =

$$S = \frac{4\times10^{-3}\times15}{6-0.004}$$

= 10 x 10^{-3} A

S = 10 mA

A 10 mA resistor must be connected in parallel to the galvanometer.