CH - 4

MOVING CHARGES and MECHANISM

Exercises

1 The circular coil of wire consisting of 100 turns, each of radius 8.0 cm carries a current of 0.40 A. What is the ~~magnetic~~ magnitude of the magnetic field B at the centre of the coil?

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 by the relation

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

where

μ_0 = permeability of free space
$= 4\pi \times 10^{-7}$ TmA^{-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 3.14×10^{-4} T

4.2 A long straight wire carries a current of 35 A. What is the magnitude of the B at a point 20 cm from the wire?

Ans: current of wire, $I = 35$ A
Distance from point from the wire
$r = 20$ cm $= 0.2$ m
magnitude of magnetic field at the point is given as:

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

where,

$$\mu_0 = \frac{4\pi \times 10^{-7} \times 2 \times 35}{4\pi \times 10 \times 0.2}$$

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

Hence, the magnitude of magnetic field at a point 20 cm from the wire is 3.5×10^{-5} T

classmate
Date
Page

4.6 A 3.0 cm wire carrying a current of 10A 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 of the wire?

As length of the wire, $l = 3\text{ cm} = 0.03\text{ m}$
current flowing through wire $I = 10A$

magnetic field, $B = 0.27T$

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

magnetic force exerted on the wire

$F = BIl \sin\theta$
$= 0.27 \times 10 \times 0.03 \sin 90^\circ$
$= 8.1 \times 10^{-2} N$

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

4.7 Two long and parallel straight

4.7 Two long and parallel straight wires A and B carrying current of 8.0 A and 5.0 A the the same direction and separated by a distance of 4.0 cm. Estimate the forces on a 10 cm section of wires A.

Current flowing ~~through~~ in wire A, $I_A = 8.0\,A$
current flowing in wire B, $I_B = 5.0\,A$

Distance between two wires, $r = 4.0\,cm = 0.04\,m$

length of a section of wire, $l = 10\,cm = 0.1\,m$

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

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

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

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

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.

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.

length of solenoid, l = 8cm = 0.8 m

There are five layers of windings of 400 turns each on the solenoid.

∴ The total number, N = 5 × 400 = 2000

Diameter of 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

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

$\cancel{\frac{\mu_0 N I}{l}}$

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

$$= 8\pi \times 10^{-3} = 2.512 \times 10^{-2}\ T$$

Hence, the magnitude of the magnetic field inside the solenoid near its centre is ~~2.512~~ 2.512 × 10^{-2} T

Date
Page

44. 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 $4.8 \times 10^6 ms^{-1}$ normal to the field. Explain why the path of the electron is a circle. Determine the radius of the circular orbit.
$e = 1.6 \times 10^{-19} C$, $m_e = 9.1 \times 10^{-31} kg$)

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 between the shot electron and magnetic field, $\theta = 90°$

Magnetic force exerted on the electron in 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.

$$F_c = F$$

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

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

$= \dfrac{9.1 \times 10^{-31} \times 4.8 \times 10^{6}}{6.5 \times 10^{-4} \times 1.6 \times 10^{-19} \times \sin 90^\circ}$

$= 4.2 \times 10^{-2}$ m $= 4.2$ cm

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

4.12 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.

magnetic field strength, $B = 6.5 \times 10^{-4}$ T
charge of the electron, $e = 1.6 \times 10^{-19}$ C
mass of electron, $m_e = 9.1 \times 10^{-31}$ kg

velocity of the electron, $v = 4.8 \times 10^{6}$ m/s
Radius of orbit, $r = 4.2$ cm $= 0.042$ m.

Frequency of revolution of 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 a circular orbit, the magnetic force on the electron is balanced by the centripetal force. Hence we can write

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

$eB = \dfrac{m}{r}(r\omega) = \dfrac{m}{r}(r 2\pi\nu)$

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

This expression for frequency is independent of the speed of the electron.

On substitutive, we get the frequency

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

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

$= 18$ MHz

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

4.13

(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~~ magnetic field of magnitude 1.0 T. The field lines make an 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?

classmate
Date
Page

(a) Number of turns on the circular coil,
$n = 30$

Radius of coil, $r = 8.0$ cm $= 0.08$ m

Area of 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 applied to prevent the coil from turning is given by the relation,

$T = n I B A \sin\theta \quad \cdots (i)$

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

$= 3.133$ Nm

(b) It can be inferred from ~~relation~~ 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 planer coil of some irregular shape that encloses the same area.

4.14 Two concentric circular coil 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 current 16 A. Coil Y has 25 turns and carries current 18 A. ...... magnetic field due to the coils at their centre.

Radius of coil X, $r_1 = 16 \text{ cm} = 0.16 \text{ m}$
Radius of coil Y, $r_2 = 10 \text{cm} = 0.1 \text{ m}$

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

$$B_1 = \frac{\mu_0 n_1 I_1}{2r_1}$$

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

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

$$= 4\pi \times 10^{-4} \text{ T} \quad \text{(Towards East)}$$

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

$B_2 = \frac{\mu_0 n_2 I_2}{2r_2}$

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

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

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 (towards west)

4.15 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 capacity of a given coil of wire is 15 A. and number of turns .... Assume the core is not ferromagnetic.

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

magnetic field is given by the relation,

$B = \mu_0 n I$

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

$= \frac{100 \times 10^{-4}}{4\pi \times 10^{-7}} = 7957.74 = 8000\ A/m$

If the length of the coil is taken as 50cm radius 4cm, number of turns 400, and current 10A; then these values are not unique for the given purpose. There is always a possibility of some adjustments with limits.

4.17 A toroid has a core (non-ferromagnetic) of inner radius 25cm and outer radius 26 cm. around which 3500 turns of a wire are wound. If the current in the wire is 11A 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.

Inner radius of the toroid, $r_1 = 25cm = 0.25\ m$
outer radius of the toroid, $r_2 = 26\ cm = 0.26\ m$

Number of turns on the coil, $N = 3500$
current in the coil, $I = 11A$.

(a) magnetic field outside the 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

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

$= \pi (0.25 + 0.26)$

$= 0.51\pi$

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

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

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

4.12 Answer the following questions:

(a) The initial velocity ~~of the~~ ~~along~~ 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.

classmate
Date
Page

(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.

4.19 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 30° with the initial velocity.

magnetic field strength, $B = 0.15\ T$
Charge on the electron, $e = 1.6 \times 10^{-19} C$
mass of 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

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

$v = \sqrt{\frac{2eV}{m}}$ ..... (i)

where
v = velocity of the electron.

(a) magnetic force on the electron provides the required centripetal force on the electron.

Hence, the electron traces a circular path of radius r.

magnetic force on the electron is given by the relation

~~Bev~~ Bev

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

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

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

from eq (i) and (ii)

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

$= \frac{9.1 \times 10^{-31}}{0.15 \times 1.6 \times 10^{-19}} \times \left[\frac{2 \times 1.6 \times 10^{-19} \times 2 \times 10^{3}}{9.1 \times 10^{-31}}\right]^{\frac{1}{2}}$

$= 100.55 \times 10^{-5}$

$= 1.01 \times 10^{-3}$ 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 can write the expression for new radius as:

$$r_1 = \frac{mv_1}{Be}$$

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

$$= \frac{9.1 \times 10^{-31}}{0.15 \times 1.6 \times 10^{-19}} \times \left[\frac{2 \times 1.6 \times 10^{-19} \times 2 \times 10^{3}}{9 \times 10^{-31}}\right]^{\frac{1}{2}} \times \sin 30^\circ$$

$= 0.5 \times 10^{-3}$ m
$= 0.5$ mm.

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

4.20 A magnetic field set up using Helm... coil (describe in exercise 4.16) in uniform in a small region and has a magnitude of 0.75 T. .... make a simple guess to what the beam contains why is the answer not a unique?

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 $= eV$

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

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

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

$$\therefore eE = evB$$

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

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

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

This value of specific charge e/m is equal to the value of deuteron or deuterium ions.

This is not unique answer; other possible answers are He^{++}, Li^{++}, etc.

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. What is the force on each case? Which case corresponds to stable equilibrium?

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

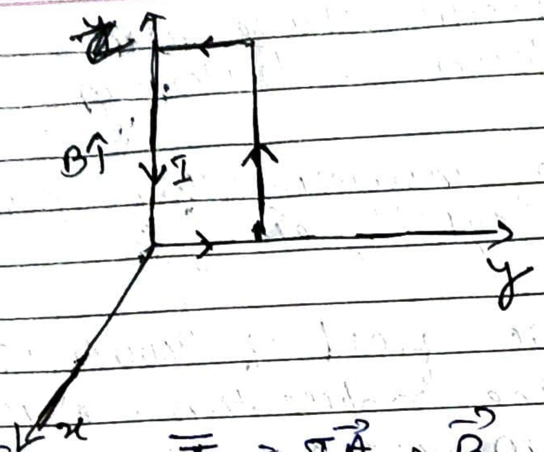
length of the rectangular loop, $l = 10 cm$

width of the rectangular loop, $b = 5 cm$
Area of the loop,

$A = l \times b = 10 \times 5 = 50 cm^2 = 50 \times 10^{-4} m^2$
current of the loop, $I = 12 A$

Now taking anti clockwise direction of the current as positive and vice-versa.

(a)



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

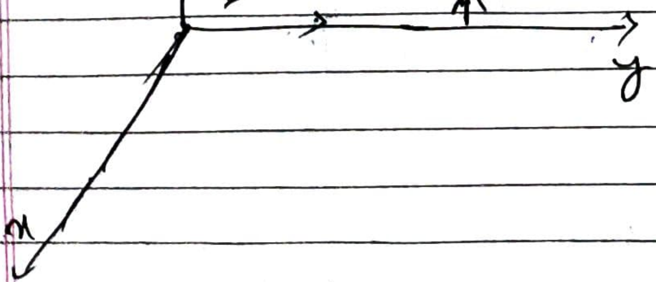
From the given figure, it can be observed that A is normal to the Y-Z plane and B is directed along the Z-axis.

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

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

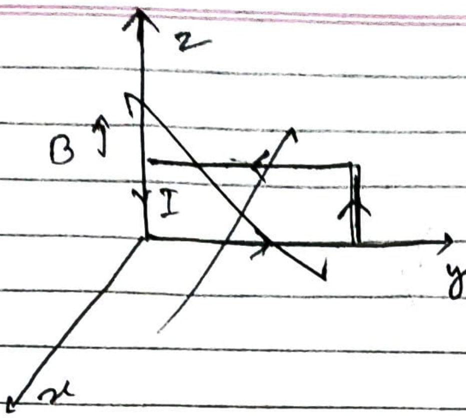
The torque is 1.8×10^{-2} Nm along the negative y-direction. The force on the loop is zero because the angle between A and B is zero.

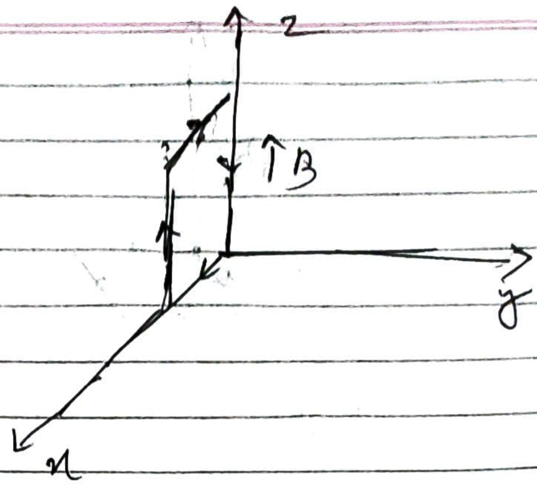
(b)



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

(c)





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

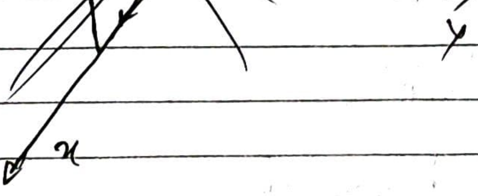
From the given figure it can be observed that A is normal to the x-z plane and B is directed along the z-axis

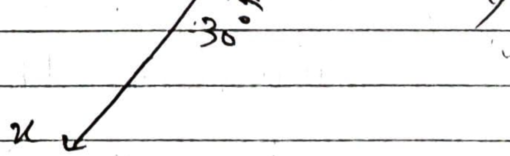
$\therefore \tau = -12 \times (50 \times 10^{-4})\,\hat{j} \times 0.3\hat{k}$

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

The torque is 1.8×10^{-2} Nm along the negative x direction and force is zero

(d)





magnitude of torque is given as:

$|\tau| = IAB$

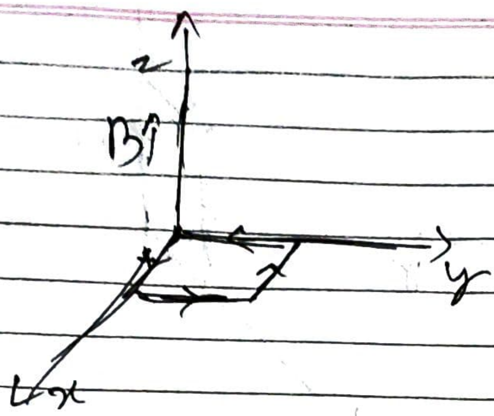
$= 12 \times 50 \times 10^{-4} \times 0.3$

$= 1.8 \times 10^{-2}$ NM

~~Torque is $1.8 \times 10^{-4} \times 12)\hat{k} \times 0.3k$~~

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

(e)

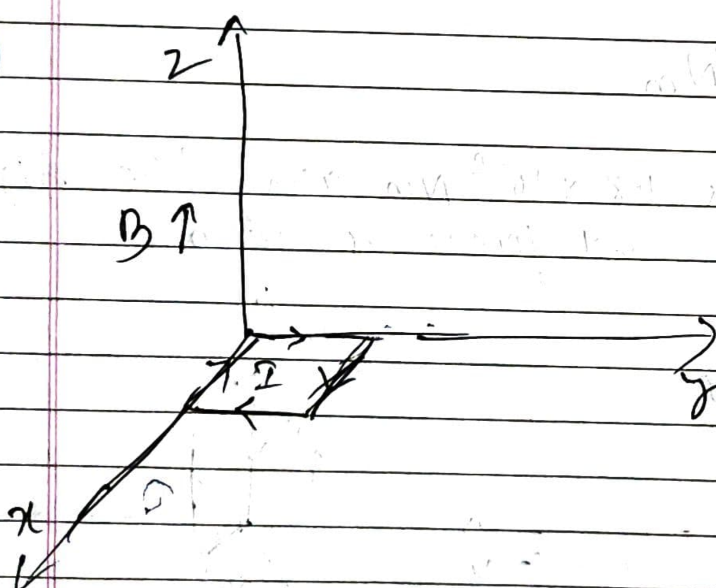


Torque $\tau = I\vec{A} \times \vec{B}$

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

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

(f)



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

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

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

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

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

4.27 A galvanometer coil has a resistance of $12\ \Omega$ and the meter shows full scale deflection for a current of 3mA. How will you convert the meter into a voltmeter of range 0 to 18 V?

Resistance of the galvanometer coil, $G = 12\ \Omega$
Current for which is full scale deflection,
$I = 3mA = 3\times10^{-3} A$

Range of the voltmeter is 0, which needs to be converted to 18 V

$\therefore V = 18\ V$

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

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

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

Hence a resistor of resistence ~~of 11 Ω~~ 5988 Ω is to be connected in series with the