MOVING CHARGES AND MAGNETISM

NCERT EXAMPLES

Topic .... Date ....

Example 4.1 A straight wire - - - - - - magnetic field?

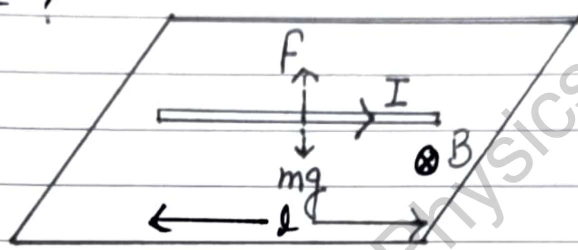
Solution: Given,

$m = 200\,g = 200 \times 10^{-3}\,kg$
$= 0.2\,Kg$

$l = 1.5\,m$

$I = 2\,A$

$B = ?$



From figure and by using Fleming's left hand rule we find that there is an upward magnetic force F of magnitude IlB. For mid-air suspension this must be balanced by force due to gravity:

Force due to gravity = Magnetic force

$$mg = IlB$$

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

$$= \frac{0.2 \times 9.8}{2 \times 1.5}$$

$$= \frac{98}{150} = 0.653\ T$$

i.e. the magnitude of magnetic field = 0.65 T

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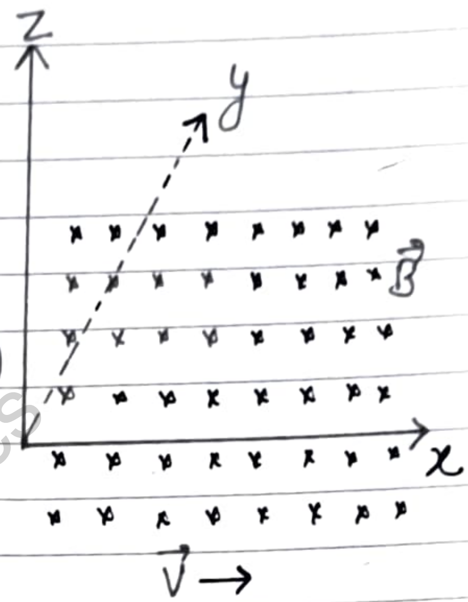
Example 4.2 If the magnetic field - - - - - - - (b) a proton.

Solution: **I Method**



(a) For electron (-ve charge)

Given,

$\vec{V} = -V\hat{i}$

$\vec{B} = B\hat{j}$

By $\vec{F} = q(\vec{V} \times \vec{B})$

direction of $\vec{F}$ = direction of $(\vec{V} \times \vec{B})$

By using screw rule or right hand thumb rule $(\vec{V} \times \vec{B})$ is along -z axis.

So for electron force will be along -ve z axis.

(b) For proton (+ve charge)

Given

$\vec{V} = V\hat{i}$

$\vec{B} = B\hat{j}$

by $\vec{F} = q(\vec{V} \times \vec{B})$

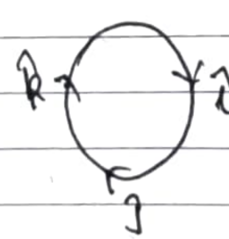
$(\vec{V} \times \vec{B})$ is along +z axis [by screw rule]

So for proton force will be along +ve z axis.

II Method

We have,

$\vec{F} = q(\vec{V} \times \vec{B})$



(a) For electron

$\vec{F} = q(-V\hat{i} \times B\hat{j})$

$= qVB(-\hat{i} \times \hat{j})$

or $\vec{F} = qVB(-\hat{k})$

Hence Lorentz force will be along -z axis.

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(b) for proton

$$\vec{F} = q(V\hat{i} \times B\hat{j})$$

or $$\vec{F} = qVB(\hat{i} \times \hat{j})$$

or $$\vec{F} = qVB(\hat{k})$$

Hence Lorentz force will be along +z axis.

III Method

By using Fleming's Left hand rule

(a) for electron we get the direction of thumb along -z axis. So direction of force will be along -z axis.

(b) For proton we get the direction of thumb along +z axis. So direction of force will be along +z axis.

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Example 4.3

What is the radius - - - - - - - - - its energy in keV

Solution :

Given,

Mass of electron $m_e = 9 \times 10^{-31}$ kg

charge $e = 1.6 \times 10^{-19}$ C

speed $V = 3 \times 10^{7}$ m/s

magnetic field $B = 6 \times 10^{-4}$ T

radius $r = ?$, frequency $\nu = ?$ and

$K.E = ?$

We have

$$r = \frac{mV}{qB}$$

$$= \frac{9 \times 10^{-31} \times 3 \times 10^{7}}{1.6 \times 10^{-19} \times 6 \times 10^{-4}}$$

$$= \frac{9}{3.2} \times 10^{-31+7+19+4}$$

or $$r = \frac{9}{3.2} \times 10^{-1} = 0.28 \text{ m}$$ Ans

Now by

$$\nu = \frac{qB}{2\pi m}$$

$$= \frac{1.6 \times 10^{-19} \times 6 \times 10^{-4}}{2 \times 3.14 \times 9 \times 10^{-31}}$$

or $$\nu = \frac{1.6}{9.42} \times 10^{8} = 0.17 \times 10^{8}$$

or $$\nu = 1.7 \times 10^{7} \text{ Hz}$$ Ans

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and $K.E = \frac{1}{2} m v^2$

$$= \frac{1}{2} \times 9 \times 10^{-31} \times (3 \times 10^{7})^2$$

$$= \frac{81}{2} \times 10^{-31+14}$$

$$= 40.5 \times 10^{-17}\ J$$

or $K.E = 4.05 \times 10^{-16}\ J$

or $K.E = \frac{4.05 \times 10^{-16}}{1.6 \times 10^{-19}}\ eV$

$$= \frac{4.05}{1.6} \times 10^{+3}$$

$$= 2.531 \times 10^{3}$$

$$= 2531\ eV$$

or $K.E = 2.531\ KeV$

$\simeq 2.5\ KeV$ Ans

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Example 4.4 - - - - - of 0.5 m. $\Delta x = 1cm$.

An element $\Delta l = \Delta x \hat{i}$ - - - -

Solution:

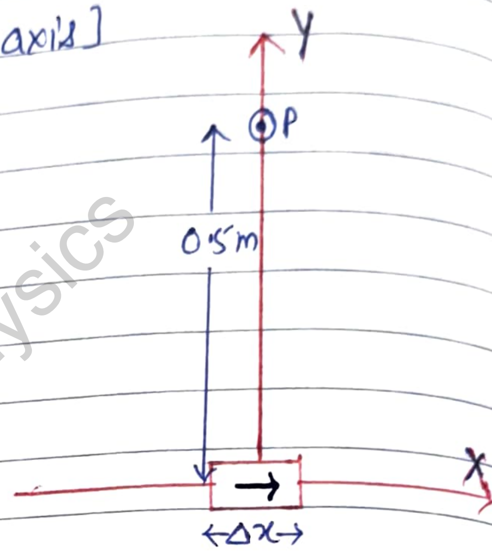
Given,

$dl = \Delta x = 1\,cm = 10^{-2}\,m$

$I = 10\,A$

$r = 0.5\,m$ [on the y axis]

$\theta = 90^\circ$, $\sin 90^\circ = 1$



According to Biot Savarts law

$$dB = \frac{\mu_0}{4\pi} \frac{I\,dl \sin\theta}{r^2}$$

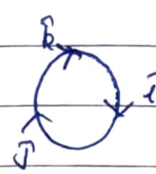
or $$dB = \frac{10^{-7} \times 10 \times 10^{-2}}{(0.5)^2}$$

$$= \frac{1}{0.25} \times 10^{-8}$$

or $dB = 4 \times 10^{-8}\,T$ Ans

→ Direction of magnetic field:

By using right hand thumb rule we find the direction of magnetic field in +z axis



OR

$\vec{dl} \times \vec{r} = \Delta x \hat{i} \times y \hat{j}$ $\left[\vec{dB} = \frac{\mu_0}{4\pi} \frac{I(\vec{dl} \times \vec{r})}{r^3} \right]$

$= y\Delta x (\hat{i} \times \hat{j})$

$= y\Delta x (\hat{k})$

i.e direction is along +z axis.

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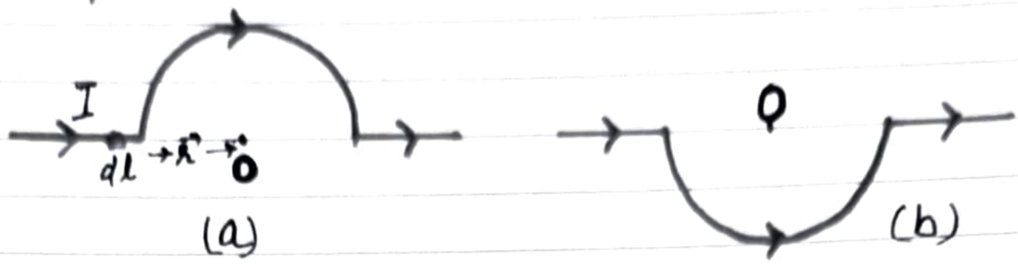
~~4.6~~ 4.5 (New book) 5

Example ~~4.6~~ 5

A straight wire - - - - - - - - - - - as shown in fig.



Solution : According to Biot-Savart law

$$d\vec{B} = \frac{\mu_0 I (d\vec{l} \times \vec{r})}{4\pi \; r^3}$$

(a) For point O, dl and r for each element of straight segments are parallel.

Therefore $d\vec{l} \times \vec{r} = 0$ $[\because \theta = 0^\circ \text{ and } \sin 0^\circ = 0]$

i.e. straight segments do not contribute to $\vec{B}$.

or magnetic field due to straight segments is zero

Ans

(b) Magnetic field at the centre of a circular wire

$$\vec{B} = \frac{\mu_0 I}{2r}$$

and magnetic field at the centre of semicircular wire

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

i.e.

$$\frac{B_{circular}}{2} = B_{semicircular}$$

This is the difference between both the fields.

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The direction of magnetic field B is given by right hand rule for both - circular and semicircular wire and direction of B is same for both.
This is the similarity.

(c) Magnitude of B for fig (a)

$$B = \frac{\mu_0 I}{4r} = \frac{4\pi \times 10^{-7} \times 12}{4 \times 2 \times 10^{-2}}$$

or $$B = 6\pi \times 10^{-5}$$
$$= 6 \times 3.14 \times 10^{-5}$$
$$= 1.88 \times 10^{-4}\ T$$

Now magnitude of B for fig (b)

$$B = \frac{\mu_0 I}{4r} = 1.88 \times 10^{-4}\ T$$ [$\because$ I and r_1 are same for both fig.]

Hence magnitude of B is same in both fig.
Now by right hand thumb rule direction of magnetic field -
for fig. (a) is into the page at the centre O.

for fig (b) is out of the page at the centre O.
It is clear that direction is opposite in both figures (a) and (b)

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Example 4.6

consider a tightly- - - - - - - - - - of the coil?

Solution:

Given,

Radius of each circular element $R = 10\,cm = 0.1\,m$

No. of turns $N = 100$

The magnitude of magnetic field,

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

$$= \frac{\cancel{4}^{2}\pi \times 10^{-7} \times 10^{2} \times 1}{\cancel{2} \times 10^{-1}}$$

$$= 2 \times 3.14 \times 10^{-4}$$

$$B = 6.28 \times 10^{-4}\,T$$ Ans

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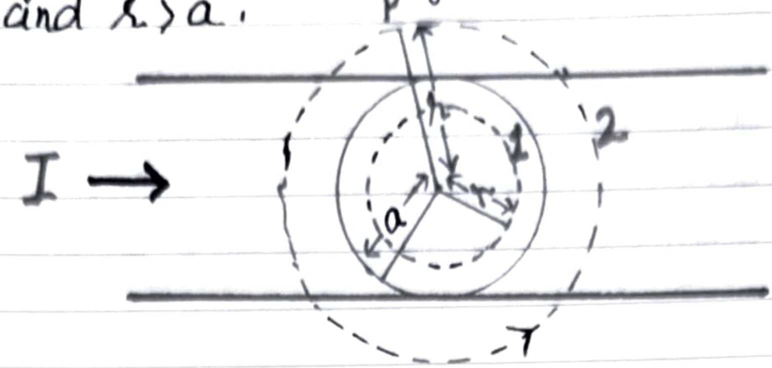
Example ~~4.8~~ 4.7 (New book)

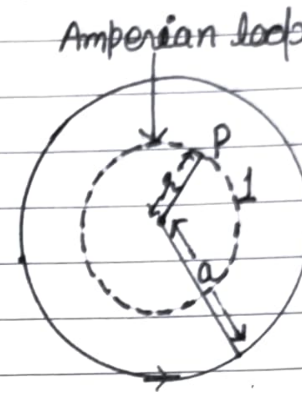
Fig 4.15 shows a long - - - - - - - the region $r<a$ and $r>a$.



Solution:

(I) Magnetic field in the region $r<a$
(Inside the wire)

Inside the wire the current enclosed is not I. It is less than I



For area πa^2, current $=$ I

so for area πr^2, current $= \frac{I}{\pi a^2} \times \pi r^2$

i.e. current enclosed $I_e = \frac{I r^2}{a^2}$

Now by Ampere's circuital law

$$\oint \vec{B} \cdot \vec{dl} = \mu_0 I_e$$

or $\oint B \cdot dl \cos 0^\circ = \mu_0 I_e$ $\quad [\because \theta = 0^\circ]$

or $B \oint dl = \mu_0 \times \frac{I r^2}{a^2}$

or $B \times 2\pi r = \mu_0 \times \frac{I r^2}{a^2}$ $\quad [\because \oint dl = 2\pi r]$

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or $B = \frac{\mu_0}{2\pi} \cdot \frac{Ir}{a^2}$

or $B = \left(\frac{\mu_0 I}{2\pi a^2}\right) r$

Thus for $r < a$, $\boxed{B \propto r}$

(II) Magnetic field in the region $r > a$ (outside the wire)

Here the current enclosed

$I_e = I$

Now by Ampere's law

$\oint \vec{B} \cdot \vec{dl} = \mu_0 I_e$

or $\oint B\,dl \cos 0^\circ = \mu_0 I_e$

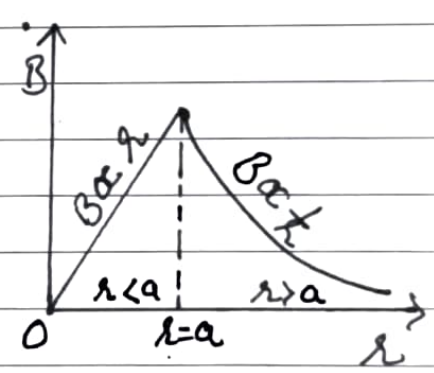
or $B \oint dl = \mu_0 I$

or $B \times 2\pi r = \mu_0 I$

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

Thus for $r > a$ $\boxed{B \propto \frac{1}{r}}$

→ Graph between magnetic field B and distance r from the centre of the wire –



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Example ~~4.9~~ 4.8

A solenoid - - - - - - - - - inside the solenoid?

Solution :

Given,

Length of solenoid $l = 0.5$ m

radius $r = 0.01$ m

number of turns $N = 500$ turns

current $I = 5A$

Magnetic field inside the solenoid $B = ?$

We have

$$B = \mu_0 n I \quad \text{[for long solenoid]}$$

here $n = \frac{N}{l}$ = number of turns per unit length.

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

$$= \frac{4\pi \times 10^{-7} \times 500 \times 5}{0.5}$$

$$= 4\pi \times 10^{-7} \times 500 \times 10$$

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

$$= 6.28 \times 10^{-3}$$

or $B = 6.28 \times 10^{-3}$ T

i.e. magnetic field inside the solenoid $= 6.28 \times 10^{-3}$ T

Ans

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Example ~~4.10~~ 4.9

The Horizontal component - - - - - - (b) South to North?

Solution:

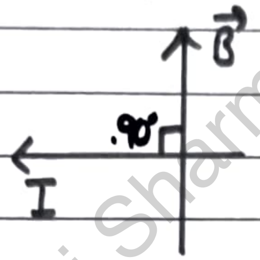
Given,

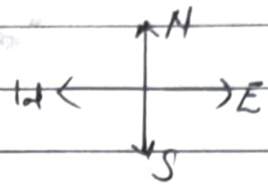
Magnetic field $B = 3.0 \times 10^{-5} T$ ($S_g \rightarrow N_g$)

current $I = 1A$

force per unit length $\frac{F}{l} = ?$

(a) Direction of current is east to west





We know force on a current carrying conductor is given by

$$F = I l B \sin\theta \Rightarrow \vec{F} = I(\vec{l} \times \vec{B})$$

or $$\frac{F}{l} = I B \sin\theta$$

or $$\frac{F}{l} = 1 \times 3.0 \times 10^{-5} \times \sin 90°$$

$$= 3 \times 10^{-5} \ N m^{-1}$$

By Fleming's left hand rule we find the direction of force is downwards.

(b) Direction of current is south to north

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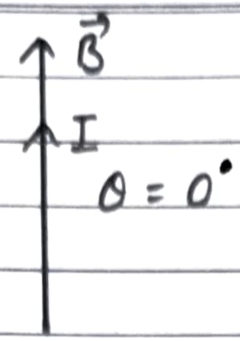

When magnetic field and current both are from south to north,

$$\theta = 0^\circ$$

so $\frac{F}{l} = IB \sin 0^\circ$

or $\frac{F}{l} = 0$ $[\because \sin 0^\circ = 0]$

or $F = 0$

Hence no force on the conductor.

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Example ~~4.11~~ 4.10

A 100 turn closely - - - - - - - coil is 0.1 kg m^2.

Solution:

Given,

Number of turn $N = 100$ turns

radius $r = 10\,cm = 10\times10^{-2}\,m$

current $I = 3.2\,A$

(a) Field at the centre of the coil $B = ?$

we know, magnetic field due to a circular wire is given by

$$B = \frac{\mu_0 N I}{2r}$$

$$= \frac{4\pi\times10^{-7}\times100\times3.2}{2\times10\times10^{-2}}$$

$$= 2\times3.14\times3.2\times10^{-7}\times10^{3}$$

$$= 6.28\times3.2\times10^{-4} = 20.09\times10^{-4}$$

$$B = 2.0\times10^{-3}\,T \quad \text{Ans}$$

The direction is given by right-hand thumb rule.

(b) Magnetic moment of the coil

$$m = NIA$$

$$= N\times I\times\pi r^2$$

$$= 100\times3.2\times3.14\times(10\times10^{-2})^2$$

$$= 3.2\times3.14\times10^{4}\times10^{-4}$$

$$m = 10.0\ A\text{-}m^2$$

The magnetic moment is $10\,Am^2$ Ans

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so we can write

$$I\omega \frac{d\omega}{d\theta} - mB\sin\theta$$

or $I\omega\, d\omega = mB\sin\theta\, d\theta$

On integrating from $\theta = 0$ to $\theta = \frac{\pi}{2}$

$$I\int_0^{\omega_f} \omega\, d\omega - mB\int_0^{\pi/2} \sin\theta\, d\theta$$

or $I\left[\frac{\omega^2}{2}\right]_0^{\omega_f} = mB\left[-\cos\theta\right]_0^{\pi/2}$

or $\frac{I\omega_f^2}{2} = -mB\left[\cos\frac{\pi}{2} - \cos 0^\circ\right]$

or $\frac{I\omega_f^2}{2} = -mB[0-1]$

or $\frac{I\omega_f^2}{2} = mB$

or $\omega_f^2 = 2mB/I$

$$= \frac{2 \times 10 \times 2}{0.1}$$

$\omega_f^2 = 400$

or $\omega_f = 20\ s^{-1}$

Thus the angular speed of the coil when it has rotated 90° is $20\ s^{-1}$ Ans

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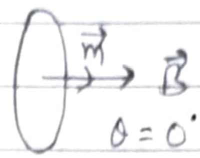
(c) Uniform magnetic field $B = 2\,T$ (In the horizontal dir^n)

Initially $\theta_i = 0°$

and coil rotates the angle $\theta_f = 90°$

Magnitudes of torque $\tau = ?$



$\theta = 0°$

We know

$$\tau = mB\sin\theta$$

when $\theta_i = 0 \Rightarrow \tau_i = 0$ $[\because \sin 0° = 0]$

i.e. initial torque $\tau_i = 0$

when $\theta_f = 90°$

$\theta = 90°$

$$\tau_f = 10 \times 2 \sin 90°$$

$$= 20\ N\text{-}m$$

i.e final torque $= 20\ Nm$ Ans

(d) Moment of inertia of the coil $I = 0.1\ kg\text{-}m^2$

Angular speed $\omega = ?$

We have

$$\tau = mB\sin\theta$$

also we have $\tau = I\alpha$

where I is moment of inertia and

α is angular acceleration

so,

$$I\alpha = mB\sin\theta$$

or $I\dfrac{d\omega}{dt} = mB\sin\theta$ $\left[\because \alpha = \dfrac{d\omega}{dt}\right]$

Now $\dfrac{d\omega}{dt} = \dfrac{d\omega}{d\theta}\cdot\dfrac{d\theta}{dt}$

$= \dfrac{d\omega}{d\theta}\cdot\omega$ $\left[\because \omega = \dfrac{d\theta}{dt}\right]$

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Example ~~4.12~~ 4.11 11

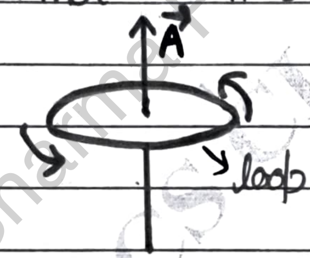
(a) A current carrying - - - - - - - - turns around itself.

Solution : No.

As the loop is placed in horizontal plane, so area vector is along vertical direction. We know,

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

as area vector $\vec{A}$ is in vertical direction, $\vec{\tau}$ would be in the plane of loop only. Hence rotation of loop is not possible about the vertical axis. ($\vec{\tau}$ cannot be $\parallel$ to $\vec{A}$)



(b) A current carrying - - - - - - - - is maximum.

Solution:

The torque of current loop is given by -

$$\tau = MB\sin\theta$$

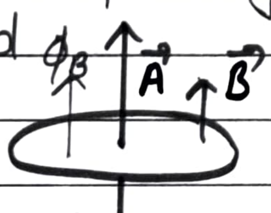
or $\tau = IAB\sin\theta$ $[\because M = IA]$

here θ is the angle between $\vec{M}$ and $\vec{B}$.

For stable equilibrium

$$\tau = 0 \Rightarrow \theta = 0°$$

i.e $\vec{A}$ and $\vec{B}$ are in same direction and $\vec{B}$ is perpendicular to the plane of loop. So external magnetic field and magnetic field of the coil are in same direction.



Hence magnetic flux is maximum.

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(c) A loop of irregular shape - - - - circular shape.

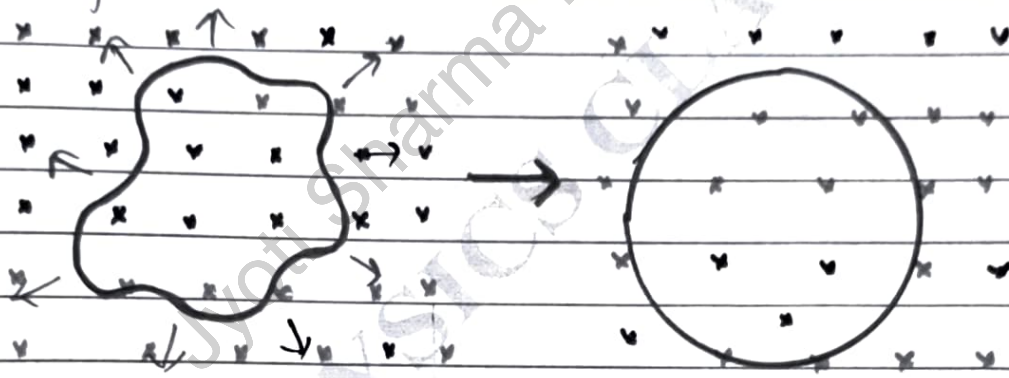
Solution:

The potential energy of the loop placed in a magnetic field is given by

$$U = -\vec{M}\cdot\vec{B}$$

this will be minimised if $\vec{M}$ and $\vec{B}$ are in the same direction and $|M|$ is maximum.

For a flexible loop M is maximum for maximum area which is of a circle. Hence it expands to form a circle.



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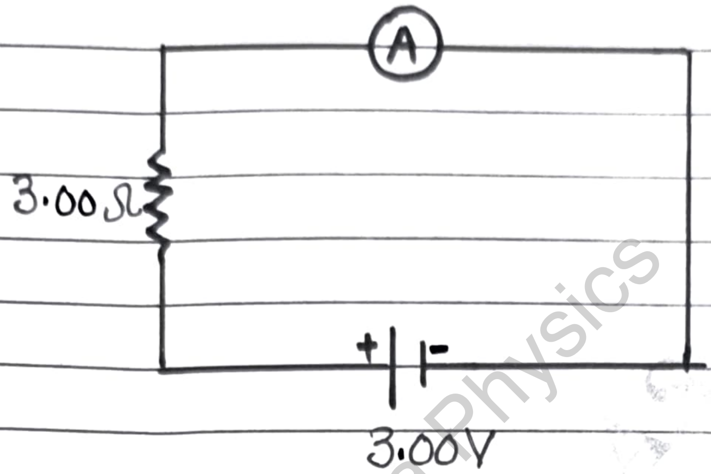
Example ~~4.13~~ 4.13

In the circuit - - - - - - - - zero resistance?

Solution :



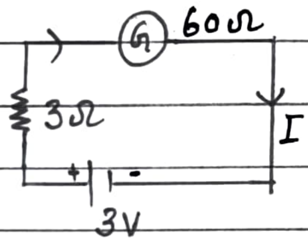
Given,

Resistance of galvanometer $R_G = 60.00\,\Omega$

Shunt resistance $r_s = 0.02\,\Omega$

and Voltage $V = 3.00\,V$

(a) Here



$R_{eq} = 60+3$

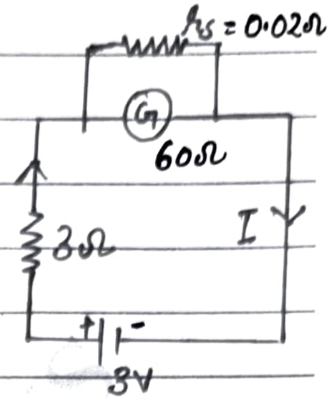
$= 63\,\Omega$

so the current in the circuit $I = \dfrac{V}{R_{eq}}$

$= \dfrac{3}{63} = \dfrac{1}{21} = 0.0476\ A$

or $I = 0.048\ A$ Ans

(b) Here the galvanometer is converted into an ammeter by shunt resistance r_s.



$r_s = 0.02\Omega$

$R_G = 60\Omega$

We know, if $R_G >> r_s$, then

$$r_s \simeq \frac{R_G r_s}{R_G + r_s}$$

so $R_{eq} = r_s + 3 = 0.02 + 3 = 3.02\Omega$

Now

$$I = \frac{V}{R_{eq}} = \frac{3}{3.02} = 0.99 \text{ A}$$

or $I = 0.99$ A

i.e. current in the circuit is 0.99 A. Ans

(c) For an ideal ammeter with zero resistance current in the circuit

$$I = \frac{V}{R_{eq}} = \frac{3}{3+0}$$

or $I = \frac{3}{3} = 1$ A

i.e current in the circuit is 1.00 A. Ans

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