Magnetic Force & Torque

1 Mark Questions

1.Using the concept of force between two infinitely long parallel current carrying conductors, define one ampere of current. [All India 2014]

Ans.

Force between two straight parallel current carrying conductors

$$F = \frac{\mu_0}{4\pi} \frac{2 I_1 I_2}{r}$$

Let $I_1 = I_2 = 1\,A$, $r = 1\,m$, then

$$F = 10^{-7} \times \frac{2(1)(1)}{(1)} = 2 \times 10^{-7}$$ **(2)**

One ampere One ampere is that value of current which flows through two straight, parallel infinitely long current carrying conductors placed in air or vacuum at a distance of 1 m and they experience a force of attractive or repulsive nature of magnitude 2×10^{-7} N/m on their unit length. **(1)**

2.Is the steady electric current the only source of magnetic field? Justify your answer.[Delhi 2013 C]

Ans. Yes, the net magnetic force acting on a wire carrying a steady (constant) electric current! in an external magnetic field Band is given F=IdlB

3.Why should the spring/suspension wire in a moving coil galvanometer have low torsional constant? [All India 2008]

Ans.Low torsional constant facilitates greater deflection (allpha) in coil for given value of current and hence, sensitivity of galvanometer increases,

4. Write two factors by which voltage sensitivity of a galvanometer can be increased.[Foreign 2008]

Ans.Voltage sensitivity of galvanometer can be increased by

(i) increasing the magnetic field (ii) decreasing the value of torsional constant,

5. Write two factors by which current sensitivity of a moving coil galvanometer can be increased. [Foreign 2008]

Ans.Current sensitivity of galvanometer can be increased by

(i) increasing the number of turns of coil.

(ii) increasing the magnetic field.

2 Marks Questions

6.A rectangular coil of sider l and b carrying a current I is subjected to a uniform magnetic field B acting perpendicular to its plane. Obtain the expression for the torque acting on it. [Delhi 2014 C]

Ans.

Equivalent magnetic moment of the coil

$$\mathbf{m} = IA\hat{\mathbf{n}}$$

$\therefore \quad \mathbf{m} = Ilb\,\hat{\mathbf{n}}$

Wher, $\hat{\mathbf{n}}$ = unit vector $\perp$ to the plane of the coil.

$\therefore$ Torque $= \mathbf{m} \times \mathbf{B}$

$= Ilb\,\hat{\mathbf{n}} \times \mathbf{B}$

$= 0$ **(1)**

As $\hat{\mathbf{n}}$ and $\mathbf{B}$ are parallel or antiparallel to each other.

7.A coil of N turns and radius R carries a current /. It is unwound and rewound to make a square coil of side a having same number of turns N. Keeping the current I same, find the ratio of the magnetic moments of the square coil and the Circular COil. [Delhi 2013 C]

Ans.

Ratio of the magnetic moments

$$\frac{M_s}{M_c} = \frac{2INA_s}{INA_c}$$

$$= \frac{2\left(\frac{R}{2}\right)^2}{(R)^2} = \frac{1}{2}$$

8.A steady current I1 flows through a long straight wire. Another wire carrying steady current I_2 in the same direction is kept close and parallel to the first wire. Show with the help of a diagram, how the magnetic field due to the current I_r exert a magnetic force on the second wire. Deduce the expression for this force. [All India 2011; Foreign 2008]

Ans.

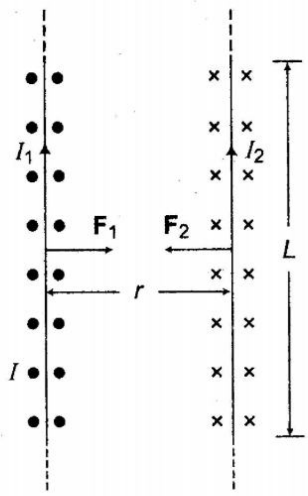
In these types of questions, we are calculating force on a wire in the field produced by the other current carrying wire.

Let two infinitely long straight current carrying conductor carry currents I_1 and I_2 in the same direction. Magnetic field B_1 due to first wire on seconds, i.e. **(1/2)**

$$B_1 = \frac{\mu_0}{4\pi}\frac{2I_1}{r} \quad \text{...(i)}$$

(1/2)

The magnetic field is perpendicular to the plane of paper and directed inwards i.e. (X) type.



Now, magnetic force on L length of second wire is given by **(1/2)**

$$F_2 = I_2 B_1 L \sin 90^\circ$$

$$\Rightarrow \quad F_2 = I_2 \left(\frac{\mu_0}{4\pi} \cdot \frac{2I_1}{r}\right) L$$

$$\Rightarrow \quad \frac{F_2}{L} = \frac{\mu_0}{4\pi} \cdot \frac{2I_1 I_2}{r} \quad \text{...(ii)}$$

By Fleming's left hand rule, the direction of force F_2 is perpendicular to the second wire in the plane of paper towards the first wire.

Similarly, magnetic force on Ist wire is given by

$$\frac{F_1}{L} = \frac{\mu_0}{4\pi} \cdot \frac{2 I_1 I_2}{r} \quad \text{...(iii)}$$

The force F_1 is directed towards the second wire.

Thus, two straight parallel current carrying conductor have the same direction of flow of currents attracting each other. **(1/2)**

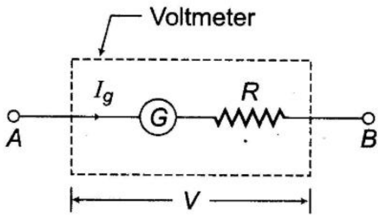
9.How is a moving coil galvanometer converted into a voltmeter? Explain giving the necessary circuit diagram and the required mathematical relation used. [All India 2011 C]

Ans.

> The resistance of an ideal voltmeter is infinity or very high in practical condition. So, to convert a galvanometer into voltmeter, its resistance needs to be increased, which can be done by a high resistance in series connection with it.

A galvanometer can be converted into a voltmeter by connecting a very high resistance R in series with it. **(1/2)**

Let R is so chosen that current I_g gives full deflection in the galvanometer where I_g is the range of galvanometer.



(1/2)

Let galvanometer of resistance G, range I_g is to be converted into voltmeter of range V (volt). Now,

$$V = I_g (G + R)$$

$$\Rightarrow \quad R + G = \frac{V}{I_g} \Rightarrow R = \frac{V}{I_g} - G$$

The appropriate scale need to be graduated to measure potential difference. **(1)**

10. A square coil of side 10 cm has 20 turns and carries a current of 12 A. The coil is suspended vertically and normal to the plane of the coil, makes an angle θ with the direction of a uniform horizontal magnetic field of 0.80 T. If the torque, experienced by the coil equals 0.96 N-m, find the value of θ. **[Delhi 2010C]**

Ans.

Here, Area (A) of coil

$$= 10 \times 10 = 100 \text{ cm}^2 = 10^{-2} \text{ m}^2$$

Number of turns, $N = 20$ turns

Current, $I = 12$ A

Number of the coils make angle with magnetic field $= \theta = ?$

Magnetic field, $B = 0.8$ T

Torque, $\tau = 0.96$ N-m **(1/2)**

∵ Torque (τ) experienced by current carrying coil, the magnetic field is

$$\tau = NIAB \sin\theta \quad \textbf{(1)}$$

$$0.96 = 20 \times 12 \times 10^{-2} \times 0.8 \times \sin\theta$$

$$\Rightarrow \quad \sin\theta = \frac{0.96}{1.92} = \frac{1}{2}$$

$$\Rightarrow \quad \theta = \frac{\pi}{6} \text{ rad}$$

(1/2)

11.Define current sensitivity and voltage sensitivity of galvanometer. Increasing the current sensitivity may not necessarily increase the voltage sensitivity of a galvanometer, justify your answer. [All India 2009]

Ans.

Current sensitivity The deflection produced in the coil of galvanometer per unit flow of electric current through it, i.e.

Current sensitivity,

$$I_g = \frac{\theta}{I} = \frac{NBA}{K}$$

where abbreviations are as usual. **(1/2)**

Voltage sensitivity The deflection produced in the galvanometer per unit applied potential difference across it.

∴ Voltage sensitivity

$$V_s = \frac{\theta}{V} = \frac{\theta}{IR} = \frac{NBA}{KR}$$

where abbreviations are as usual.Its unit is rad|A or div|A **(1/2)**

Increasing the current sensitivity may not necessarily increase the voltage sensitivity, because the current sensitivity increases with the increase of number of turns of the coil but the resistance of coil also increases which affect adversely on voltage sensitivity. **(1)**

3 Marks Questions

12.A metallic rod of length / is rotated with a frequency v with one end hinged at the centre and the other end at the circumference of a circular metallic ring of radius r about an axis passing through the centre and perpendicular to the plane of the ring. A constant uniform magnetic field B parallel to the axis is present everywhere. Using Lorentz force, explain how emf is induced between the centre and the metallic ring and hence obtained the expression for it.[Delhi 2013]

Ans.

Suppose, the length of the rod is greater than the radius of the circle and rod rotates anti-clockwise and suppose, the direction in the rod at any instant be along $+Y$-direction. Suppose, the direction of the magnetic field is along $+Z$-direction.

Then, using Lorentz law, we get the following

$$\mathbf{F} = -e(\mathbf{v} \times \mathbf{B})$$

$$\Rightarrow \quad \mathbf{F} = -e(v\,\hat{\mathbf{j}} \times B\,\hat{\mathbf{k}})$$

$$\Rightarrow \quad \mathbf{F} = -evB\,\hat{\mathbf{i}} \qquad \textbf{(1)}$$

Thus, the direction of force on the electrons is along X-axis.

Thus, the electrons will move towards the centre, i.e. the fixed end of the rod. This movement of electrons will result in current and hence, it will result in current and hence, it will produce emf in the rod between the fixed end and the point touching the ring.

Let θ be the angle between the rod and radius of the circle at any time t. **(1)**

Then, area swept by the rod inside the circle

$$= \frac{1}{2}\pi r^2\theta$$

Now, induced emf $= B \times \dfrac{d}{dt}\left(\dfrac{1}{2}\pi r^2\theta\right)$

$$= \frac{1}{2}\pi r^2 B\frac{d\theta}{dt} = \frac{1}{2}\pi r^2 B\omega$$

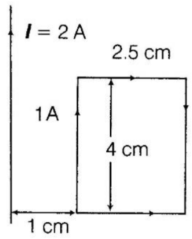
$$= \frac{1}{2}\pi r^2 B(2\pi v)$$

$$= \pi^2 r^2 B v \qquad \textbf{(1)}$$

NOTE There will be an induced emf between the two ends of the rods also.

13. A rectangular loop of wire of size 2.5 cm × 4 cm carries steady current of 1 A. A straight wire carrying 2 A current is kept near the loop as shown. If the loop and the wire are coplanar, find the (*i*) torque acting on the loop and (*ii*) the magnitude and direction of the force on the loop due to the current carrying wire.

[Delhi 2012]



Ans.

There will be force of attraction between the straight wire and 4 cm long arm of loop nearer to the straight conductor.

$$F_1 = \frac{\mu_0}{4\pi} \frac{2 \times 2 \times 1}{(2 \times 10^{-2})} \times (4 \times 10^{-2})$$

[towards straight conductor]

$$F_1 = 8 \times 10^{-7} \text{N} \quad \text{...(i)} \quad \textbf{(1)}$$

Similarly, force on other 4 cm arm of loop, away from the straight conductor

$$F_2 = \frac{\mu_0}{4\pi} \times \frac{2 \times 2 \times 1}{(4.5 \times 10^{-2})} \times (4 \times 10^{-2})$$

$$F_2 = 3.55 \times 10^{-7} \text{N} \quad \text{...(ii)} \quad \textbf{(1)}$$

[away from conductor]

(*i*) Since, F_1 and F_2 are of different magnitudes, therefore, do not form couple and hence **(1/2)**

Torque, $\tau = 0$

(*ii*) Net force on loop,

$$F = F_1 - F_2$$

[towards straight conductor]

$$F = 8 \times 10^{-7} - 3.55 \times 10^{-7}$$

$$F = 4.45 \times 10^{-7} \text{N}$$

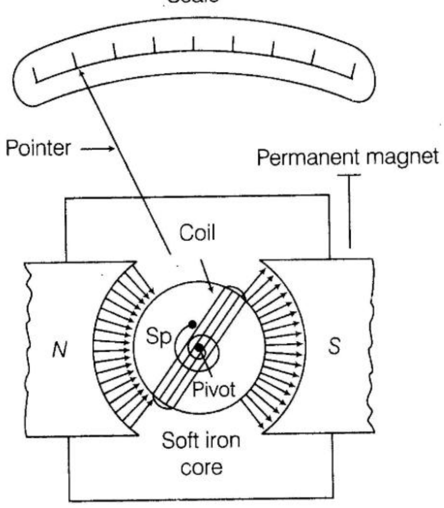
The forces on two branches of loop are equal in magnitude and opposite in the directions, hence they balance each other. (1/2)

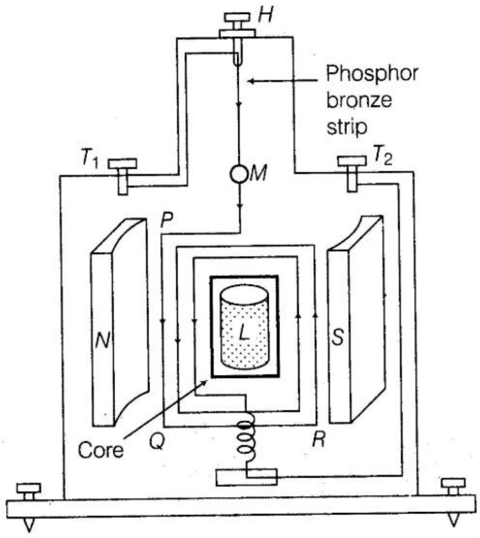
14.Draw a labelled diagram of a moving coil galvanometer and explain its working. What is the function of radial magnetic field inside the coil?[Foreign 2012]

Ans.

Moving Coil Galvanometer
Principle

Its working is based on the fact that when a current carrying coil is placed in a magnetic field, it experiences a net torque. **(1)**





(1/2)

Working

Suppose, the coil $PQRS$ is suspended freely in the magnetic field.

Let l = length PQ or RS of the coil
b = breadth QR or SP of the coil
n = number of turns in the coil

Area of each turns of the coil, $A = l \times b$

Let B = strength of the magnetic field in which coil is suspended.

I = current passing through the coil in the direction of $PQRS$

Let at any instant of time, α be the angle which the normal drawn on the plane of the coil makes with the direction of magnetic field. The rectangular current carrying coil when placed in the magnetic field experiences a torque whose magnitude is given by $\tau = NIBA \sin\alpha$ **(1/2)**

Due to this deflecting torque, the coil rotates and suspended wire gets twisted. A restoring torque is set up in the suspension wire.

Let θ be the twist produced in the phosphor bronze strip due to rotation of the coil and k be the restoring torque per unit twist of the phosphor bronze strip.

Then,
total restoring torque produced $= k\theta$

In equilibrium position of the coil,
Deflecting torque = Restoring torque

$$\therefore NIBA = k\theta \text{ or } I = \frac{k}{NBA}\theta = G\theta$$

where, $\frac{k}{NBA} = G$

[constant for a galvanometer]

It is known as galvanometer constant.

- Current sensitivity of the galvanometer is the deflection per unit current.

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

- Voltage sensitivity is the deflection per unit voltage.

$$\therefore \quad \frac{\phi}{V} = \frac{NAB}{k}\left(\frac{I}{V}\right)$$

$$= \frac{NAB}{k}\frac{1}{R} \qquad [\because V = IR]$$

The uniform radial magnetic field keeps the plane of the coil always parallel to the direction of the magnetic field, ie. the angle between the plane of the coil and the magnetic field is zero for all the orientations of the coil. **(1)**

15.Depict the magnetic field lines due to two straight, long, parallel conductors carrying currents 1\ and 1_2 in the same direction. Hence, deduce an expression for the force per unit length acting on one of the conductors due to the other. Is this force attractive or repulsive? [Delhi 2011 c]

Ans.

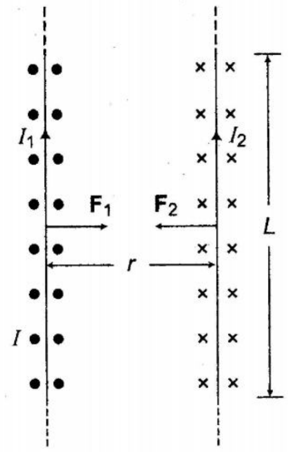
> In these types of questions, we are calculating force on a wire in the field produced by the other current carrying wire.

Let two infinitely long straight current carrying conductor carry currents I_1 and I_2 in the same direction. Magnetic field B_1 due to first wire on seconds, i.e. **(1/2)**

$$B_1 = \frac{\mu_0}{4\pi}\frac{2I_1}{r} \quad \text{...(i)}$$

(1/2)

The magnetic field is perpendicular to the plane of paper and directed inwards i.e. (X) type.



Now, magnetic force on L length of second wire is given by **(1/2)**

$$F_2 = I_2 B_1 L \sin 90°$$

$$\Rightarrow \quad F_2 = I_2\left(\frac{\mu_0}{4\pi}\cdot\frac{2I_1}{r}\right)L$$

$$\Rightarrow \quad \frac{F_2}{L} = \frac{\mu_0}{4\pi}\cdot\frac{2I_1 I_2}{r} \quad \text{...(ii)}$$

By Fleming's left hand rule, the direction of force F_2 is perpendicular to the second wire in the plane of paper towards the first wire.

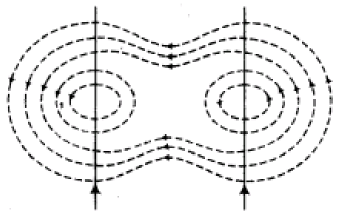
Similarly, magnetic force on Ist wire is given by

$$\frac{F_1}{L} = \frac{\mu_0}{4\pi}\cdot\frac{2\,I_1 I_2}{r} \quad \text{...(iii)}$$

The force F_1 is directed towards the second wire.

Thus, two straight parallel current carrying conductor have the same direction of flow of currents attracting each other. **(1/2)**

(*i*). **(1)**



Magnetic field lines due to both conductors

Current-carrying conductors having same direction of flow of current, so the force between them will be attractive. **(1)**

16.Find the expression for magnetic dipole moment of a revolving electron. What is Bohr magneton?

Ans.

As electric current associated with the revolving electron

$$I = \frac{e}{T} = \frac{ev}{2\pi r}$$

where, time period $T = \frac{2\pi r}{v}$

r = radius of orbit

v = velocity of electron

The magnetic moment due to the current,

$$\mu = IA = \frac{ev}{2\pi r} \times \pi r^2 \Rightarrow \mu = \frac{evr}{2} \quad \textbf{(1)}$$

If electron revolves in anti-clockwise sense, the current will be in clockwise sense. Hence, according to right hand rule, the direction of magnetic moment must will be perpendicular to the plane of orbit and directed inwards to the plane.

So, $$\mu = \frac{evrm}{2m} = \frac{el}{2m}$$

where, $vrm = l$ = angular momentum orbital of electron and in vector form,

$$\mu = -e\frac{l}{2m}$$

negative sign indicates μ and l are in mutually opposite directions. From Bohr's postulates, $l = mvr = \frac{nh}{2\pi}$, where $n = 1, 2, 3\ldots\ldots$

$$\therefore \quad \mu = \frac{e}{2m} \cdot \frac{nh}{2\pi} = n\mu_{min} \quad \textbf{(2)}$$

where, $\mu_{min} = \frac{eh}{4\pi m}$ called Bohr's magneton.

17.State the underlying principle of working of a moving coil galvanometer. Write two reasons why a galvanometer cannot be used as such to measure the current in a given circuit. Name any two factors on which the current sensitivity of a galvanometer depends. [Delhi 2010]

Ans.

Principle The current carrying coil placed in normal magnetic field experiences a torque which is given by

$$\tau = NIAB$$

where, N = number of turns
I = current
A = area of coil
B = magnetic field **(1)**

The galvanometer cannot be used to measure the current because

(*i*) all the currents to be measured passes through coil and it gets damaged easily as hair line spring or

(*ii*) its coil has considerable resistance because of length and it may affect original current. $\left(\frac{1}{2} \times 2 = 1\right)$

18. A moving coil galvanometer of resistance G gives its full scale deflection when a current I_g flows through its coil. It can be converted into a ammeter of range (0 to I) ($I > I_g$) when a shunt of resistance S is connected is converted into an ammeter of range 0 to 1, find the expression for the shunt required in terms of I_g and G. **[Delhi 2010 C]**

Ans.

> The resistance of an ideal ammeter is zero or very low in practical condition, so to convert a galvanometer into ammeter its resistance needs to be decreased which can be done by connecting a low resistance in its parallel order.

A moving coil galvanometer of range I_g and resistance G can be converted into ammeter by connected very low resistance shunt in parallel with galvanometer.

∵ To convert a galvanometer into an ammeter, shunt resistance is connected in parallel with the galvanometer, so the potential difference across the combination is same. **(1)**

∴ PD across galvanometer = PD across shunt S

$$I_g G = I_s S \quad \textbf{(1)}$$

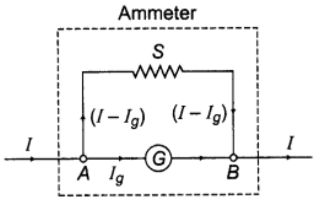
But $I_s + I_g = I$

⇒ $I_s = I - I_g$

⇒ $I_g G = (I - I_g) S$

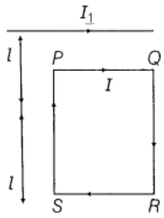
⇒ $S = \dfrac{I_g G}{I - I_g}$ **(1)**

The shunt resistance S to be connected to convert galvanometer into an ammeter.



19.Write the expression for the magnetic moment (m) due to a planar square loop of side / carrying a steady current / in a vector form. In the given figure, this loop is placed in a horizontal plane near a long straight conductor carrying a steady current at a distance l as shown. Give reasons to explain that the loop will experience a net force but no torque. Write the

expression for this force acting on the loop. **[Delhi 2010]**



Ans.

The magnetic moment of a current carrying loop

$$\mathbf{m} = I\mathbf{A}$$

where, $\mathbf{A}$ = area of the loop (square)

$\therefore \quad \mathbf{A} = l^2\hat{\mathbf{n}}$

Here, $\hat{\mathbf{n}}$ is a unit vector normal to the direction of area vector.

The forces acting on the arms QR and SP of given (in question figure) loop are equal, mutually opposite and collinear. Hence, they are balanced by one another. **(1)**

Force on arm PQ, $F_1 = B_1 Il = \frac{\mu_0 I_1}{2\pi l}; Il = \frac{\mu_0 I_1 I}{2\pi}$

Obviously, F_1 is of the attractive nature and directed towards MN.

Again, force on arm RS,

$$F_2 = B_2 I l = \frac{\mu_0 I_1 I l}{2\pi(2l)} = \frac{\mu_0 I_1 I}{4\pi} \quad \textbf{(2)}$$

F_2 is perpendicular to wire RS and directed away from the conductor MN.

$\therefore$ Net force on loop $PQRS$, $\mathbf{F}_{net} = \mathbf{F}_1 + \mathbf{F}_2$

$$\Rightarrow \mathbf{F}_{net} = \mathbf{F}_1 - \mathbf{F}_2 = \frac{\mu_0 I_1 I}{2\pi} - \frac{\mu_0 I_1 I}{4\pi}$$

or $F_{net} = \frac{\mu_0 I_1 I}{4\pi}$ [attractive]

As, $\mathbf{F}_1$ and $\mathbf{F}_2$ are collinear, hence does not produce torque on the loop $PQRS$.

20.Derive the expression for force per unit length between two long straight parallel current carrying conductors. Hence, define one ampere. [Delhi 2009]

Ans.

Force between two straight parallel current carrying conductors

$$F = \frac{\mu_0}{4\pi} \frac{2I_1 I_2}{r}$$

Let $I_1 = I_2 = 1\,A, r = 1\,m$, then

$$F = 10^{-7} \times \frac{2(1)(1)}{(1)} = 2 \times 10^{-7}$$

(2)

One ampere One ampere is that value of current which flows through two straight, parallel infinitely long current carrying conductors placed in air or vacuum at a distance of 1 m and they experience a force of attractive or repulsive nature of magnitude 2×10^{-7} N/m on their unit length. **(1)**

21.Deduce the expression for the torque experienced by a rectangular loop carrying a steady current I and place'4 in a uniform magnetic field B. In dicate the direction of the torque acting on the loop. [Foreign 2009]

Ans.

- Let a current carrying rectangular loop $PQRS$ carrying a steady current I placed in a uniform magnetic field B keeping axis of the coil perpendicular to field as shown in figure. Let at any instant the area vector **A** makes an angle θ with the direction of magnetic field **B**. **(1)**

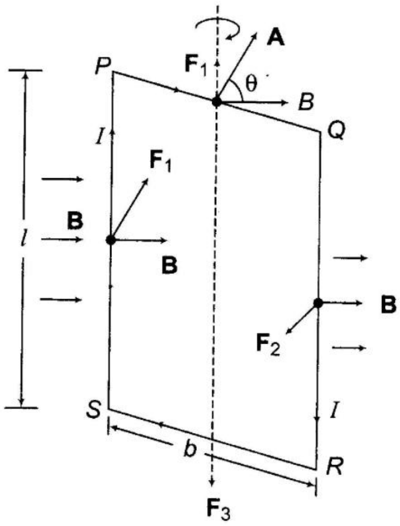


Fig. (a)

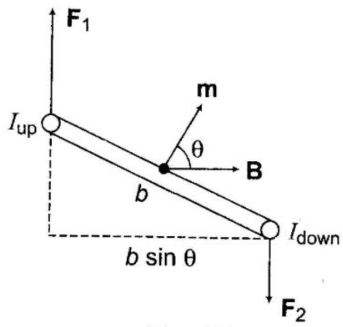


Fig. (b)

Let length and breadth of coil are l and b, respectively.

Now, magnetic force on PS arm of the coil is given by

$$F_1 = IBl \sin 90^\circ$$

$$[\because PS \parallel \text{axis of coil}, \therefore \theta = 90^\circ]$$

$$F_1 = IBl \quad \text{...(i)}$$

By Fleming's left hand rule, the direction of force is perpendicular to SP and B is along upward direction. Similarly, force of QR arm of the coil.

$$F_2 = IBl \sin 90° \quad \text{...(ii)}$$

The direction of force is perpendicular to QR and B is along downward direction.

$\because$ F_1 and F_2 are equal in magnitude, opposite in direction, parallel to each other acting on the loop forms a couple which try to rotate the coil. **(1)**

Now, force on RS part of the coil

$$F_3 = IBb \sin(90° + \theta)$$

$$F_3 = IBb \cos\theta$$

and force on PQ part of the coil

$$F_4 = IBb \sin(90° - \theta) = IBb \cos\theta$$

But Fleming's left hand rule, F_3 and F_4 are equal in magnitude and opposite in direction along the same line of action. Therefore, they balance each other. (cancel out)

Now, torque due to F_1 and F_2 is given by

τ = Force × perpendicular distance between lines of action of F_1 and F_2.

$$\tau = F \times b \sin\theta$$

But, $F_1 = F_2 = F = IBl$

$$\tau = (IBl) \times (b \sin\theta)$$

$$\tau = IB(lb) \sin\theta$$

$$\tau = IBA \sin\theta$$

where, $A = lb$ = area of coil for N turns of coil

$$\tau = NIAB \sin\theta \quad \textbf{(1)}$$

22. A circular coil of 200 turns and radius 10 cm is placed in a uniform magnetic field of 0.5 T, normal to the plane of the coil. If the current in the coil is 3.0 A, calculate the

(*i*) total torque on the coil

(*ii*) total force on the coil

(*iii*) average force on each electron in the coil due to the magnetic field. Assume the area of cross-section of the wire to be 10^{-5} M^2 and the free electron density is 10^{29} /M^3.

[All India 2008]

Ans.

Given, $N = 200$, $r = 10$ cm $= 0.1$ m, $B = 0.5$ T

NOTE Magnetic field is normal to the plane of coil. Therefore, area vector of coil (which is normal to plane of coil) is along the direction of magnetic field.

$\therefore \quad \theta = 0°$ Also $I = 3$ A

(*i*) As, $\quad \tau = NIAB$

$$= 200 \times 3 \times [\pi (0.1)^2] \times 0.5$$

$[\because A = \pi r^2]$

$\Rightarrow \quad \tau = 9.42$ N-m **(1)**

(*ii*) The net magnetic force on circular loop is zero. **(1/2)**

(*iii*) $\because$ Average force on electron,

$$F = (-e)(v_d) B \sin 90°$$

But, $\quad I = -ne Av_d$

$$v_d = \frac{I}{-neA}$$

$$\therefore \quad F = (-e)\left(\frac{I}{neA}\right)B$$

$$F = \frac{I_B}{nA} = \frac{3 \times 0.5}{10^{29} \times 10^{-5}}$$

$$F = \frac{1.5}{10^{24}}$$

$\Rightarrow \quad F = 1.5 \times 10^{-24}$ N **(1½)**

5 Marks Questions

23.(i)Draw a labelled diagram of a moving coil galvanometer. Describe briefly its principle and working.

(ii) Answers the following questions.

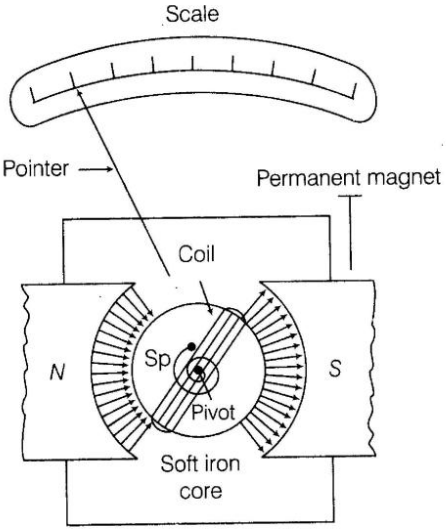
(a) Why is it necessary to introduce a cylindrical soft iron core inside the coil of a galvanometer?

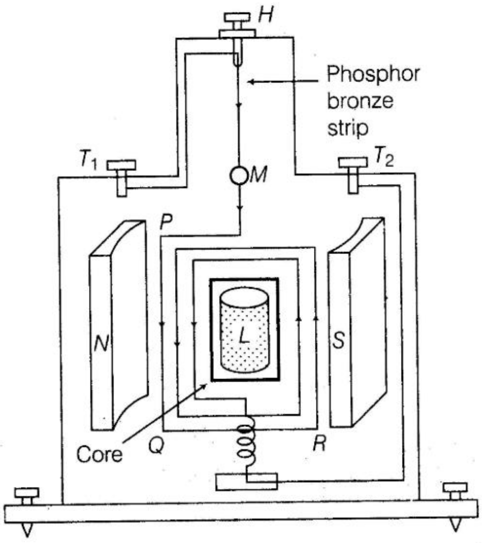
(b)Increasing the current sensitivity of a galvanometer may not necessarily increase its voltage sensitivity. Explain giving reasons. [All India 2014]

Ans.(i)

Moving Coil Galvanometer
Principle

Its working is based on the fact that when a current carrying coil is placed in a magnetic field, it experiences a net torque. **(1)**





(1/2)

Working

Suppose, the coil *PQRS* is suspended freely in the magnetic field.

Let l = length *PQ* or *RS* of the coil

b = breadth *QR* or *SP* of the coil

n = number of turns in the coil

Area of each turns of the coil, $A = l \times b$

Let B = strength of the magnetic field in which coil is suspended.

I = current passing through the coil in the direction of *PQRS*

Let at any instant of time, α be the angle which the normal drawn on the plane of the coil makes with the direction of magnetic field. The rectangular current carrying coil when placed in the magnetic field experiences a torque whose magnitude is given by $\tau = NIBA \sin\alpha$ **(1/2)**

Due to this deflecting torque, the coil rotates and suspended wire gets twisted. A restoring torque is set up in the suspension wire.

Let θ be the twist produced in the phosphor bronze strip due to rotation of the coil and k be the restoring torque per unit twist of the phosphor bronze strip.

Then,

total restoring torque produced $= k\theta$

In equilibrium position of the coil,

Deflecting torque = Restoring torque

$$\therefore NIBA = k\theta \text{ or } I = \frac{k}{NBA}\theta = G\theta$$

where, $$\frac{k}{NBA} = G$$

[constant for a galvanometer]

It is known as galvanometer constant.

- Current sensitivity of the galvanometer is the deflection per unit current.

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

- Voltage sensitivity is the deflection per unit voltage.

$$\therefore \quad \frac{\phi}{V} = \frac{NAB}{k}\left(\frac{I}{V}\right)$$

$$= \frac{NAB}{k}\frac{1}{R} \qquad [\because V = IR]$$

The uniform radial magnetic field keeps the plane of the coil always parallel to the direction of the magnetic field, ie. the angle between the plane of the coil and the magnetic field is zero for all the orientations of the coil. **(1)**

(ii) (a) It is necessary to introduce a cylindrical soft iron core inside the coil of a galvanometer because magnetic field is increased, so its sensitivity increases and magnetic field becomes radial. So, angle between the plane of coil and magnetic line of force is zero in all orientations of coil. **(2)**

(b) The relation between current sensitivity and voltage sensitivity is given by

$$\text{Voltage sensitivity} = \frac{\text{Current sensitivity}}{\text{Resistance of coil}}$$

$$\Rightarrow \quad V_S = \frac{I_S}{R_C} \quad \textbf{(1)}$$

If R_C is constant, then $V_S \propto I_S$

This means if V_S increases, I_S also increases.

But, if R_C increases in the given ratio, then V_S is a constant. **(1)**

24.(i) State using a suitable diagram, the working principle of a moving coil galvanometer. What is the function of a radial magnetic field and the soft iron core used in it? (ii) For converting a galvanometer into an ammeter, a shunt resistance of small value is used in parallel, whereas in the case of a voltmeter a resistance of large value is used in series. Explain why? [Delhi 2014C]

Ans.(i)

Principle The current carrying coil placed in normal magnetic field experiences a torque which is given by

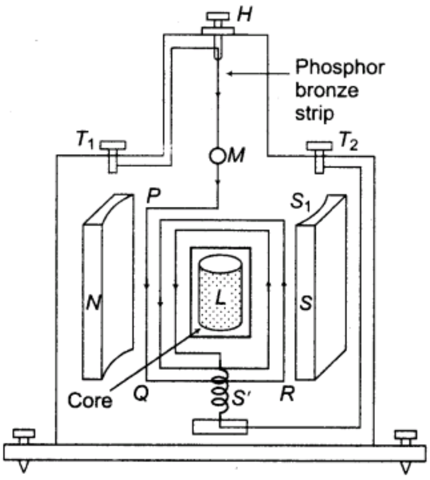
$$\tau = NIAB$$

where, N = number of turns
I = current
A = area of coil
B = magnetic field **(1)**

The galvanometer cannot be used to measure the current because

(i) all the currents to be measured passes through coil and it gets damaged easily as hair line spring or

(ii) its coil has considerable resistance because of length and it may affect original current. $\left(\frac{1}{2} \times 2 = 1\right)$



(1/2)

The coil remains suspended in radial magnetic field so that it always experiences maximum torque.

When current passes through the coil, deflection torque $\tau(\theta)$ is produced given by

$$\tau_{deflection} = NIAB \sin 90° \quad \text{...(i)}$$

As a result, coil rotates and phosphor bronze strip gets twisted. As a result restoring torque given by

$$\tau_{restoring} = k\theta \quad \text{...(ii)}$$

where, k = torsional restoring constant

$\therefore$ In equilibrium,

$$t_{deflecting} = \tau_{restoring}$$

$$NIAB = k\theta$$

$$I = \left(\frac{k}{NAB}\right)\theta$$

$$I \propto \theta$$

greater the current, greater the deflection.

(1)

(*ii*) In radial magnetic field, the plane of the coil is always parallel to the plane of the magnetic field and area vector of coil is perpendicular to magnetic field. It is always exerts maximum torque on the coil. **(1)**

(*iii*) The voltmeter connected in parallel with the electrical circuit elements to measure potential difference. For exact measurement of PD voltmeter must draw minimum current which is possible only when it has high resistance. Ammeter is connected in series with the electrical circuit and current to be measured passes through it.

In order to protect the galvanometer, a feeble current must pass through the galvanometer, it is possible only when a low resistance (shunt) is connected in parallel with galvanometer to allow the major part of the current to pass through it. **(2)**

(ii)

(*i*) A galvanometer of range I_g and resistance G_1 can be converted into

(a) a voltmeter of range V by connecting a high resistance R in series with it where value is given by

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

25.(i) Explain giving reasons, the basic difference in converting a galvanometer into (a) a voltmeter and (b) an ammeter.(ii) Two long straight parallel conductors carrying steady currents and I_2 are separated by a distance d. Explain briefly with the help of a suitable diagram, how the magnetic field due to one conductor acts on the other. Hence, deduce the expression for the force acting between the two conductors. Mention the nature of this force. [All India 2012]

Ans.

(*i*) A galvanometer of range I_g and resistance G_1 can be converted into

(*a*) a voltmeter of range V by connecting a high resistance R in series with it where value is given by

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

(*b*) an ammeter of range I by connecting a very low resistance (shunt) in parallel with galvanometer whose value is given by

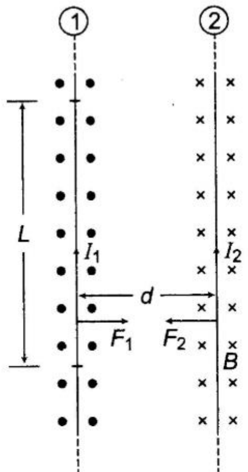
$$S = \frac{I_g G}{I - I_g}$$ **(1)**

(*ii*) Let two straight wires of infinite length are carrying currents, I_1 and I_2 in the same direction and separated by distance d apart from each other. **(1)**

The magnetic field due to wire 1 at any point on wire 2,

$$B_1 = \frac{\mu_0}{4\pi}\frac{2I_1}{d} \quad \text{...(i)}$$

The distance of B_1 is perpendicular to plane of paper and directed inward.



(1/2)

Magnetic force on wire 2 in L length of it

$$F_2 = I_2 B_1 L \sin 90° = I_2\left(\frac{\mu_0}{4\pi}\cdot\frac{2I_1}{d}\right)L \times 1$$ **(1/2)**

$$\therefore \quad F_2 = \frac{\mu_0}{4\pi}\frac{2I_1 I_2}{d} \quad \text{...(ii)}$$

[towards wire]

By Fleming's left hand rule.

Similarly, force on wire 1 due to wire 2 can be proved $F_1 = \frac{\mu_0}{4\pi}\frac{2\,I_1 I_2}{d}$ ...(iii)

Thus, the nature of force is attractive.

When direction of flow of current gets in opposite direction, the nature of force becomes repulsive. **(2)**

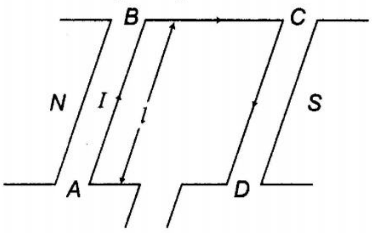
26. A rectangular loop of size $l \times b$ carrying a steady current I is placed in a uniform magnetic field **B**. Prove that the torque τ acting on the loop is given by $\boldsymbol{\tau} = \mathbf{m} \times \mathbf{B}$, where is the magnetic moment of the loop.

[All India 2012]

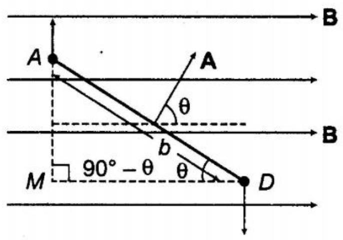
Ans.

Magnetic force on AB and CD parts of wire

$$F_1 = F_2 = IBl \text{ as } \theta = 90^\circ \quad \textbf{(1/2)}$$



(1)



(1)

The magnetic force on BC and DA part of wire are equal in magnitude, opposite in direction along the same line. Therefore, they balance each other. **(1/2)**

Let at any instant area vector of coil made an angle θ with the direction of magnetic field.

$\therefore$ F_1 and F_2 form couple which try to rotate the coil.

From figure,

$\therefore$ Torque, τ = force × arm of the couple

$$= (IBl) \times MD$$

$$= IBl \times b \sin\theta = IB\,(lb)\sin\theta$$

$$\tau = IB\,A \sin\theta \quad \textbf{(1)}$$

where, $A = lb$ = area of coil

$$\therefore \quad \tau = IAB\sin\theta$$

But, $m = IA$

$$\therefore \quad \tau = mB\sin\theta$$

In vector form,

$$\boldsymbol{\tau} = \mathbf{m} \times \mathbf{B} \quad \textbf{(1)}$$

27. (*i*) Show that a planer loop carrying a current I, having N closely wound turns and area of cross-section A, possesses a magnetic moment $\mathbf{m} = NI\mathbf{A}$.

(*ii*) When this loop is placed in a magnetic field **B**, find out the expression for the torque acting on it.

(*iii*) A galvanometer coil of 50 Ω resistance shows full scale deflection for a current of 5 mA. How will you convert this galvanometer into a voltmeter of range 0 to 15 V? **[Foreign 2011]**

Ans.

(*i*) Torque on rectangular loop,

$$\tau = NIAB \sin\theta \quad \text{...(i)}$$

where, symbols are as usual.

Also, torque experienced by magnetic dipole of moment m are placed in a uniform magnetic field.

$$\tau = mB \sin\theta \quad \text{...(ii)}$$

Comparing Eqs. (i) and (ii), we get

The magnetic dipole moment,

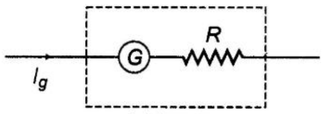
$$m = NIA$$

Also, **m** is along **A**.

$$\Rightarrow \quad \mathbf{m} = NI\mathbf{A} \quad \textbf{(2)}$$

(*ii*) Refer to ans. 21. **(1/2)**

(*iii*) $G = 50\ \Omega, I_g = 5 \times 10^{-3}$ A, $V = 15$ V



$$\because \quad V = I_g (G + R)$$

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

$$= \frac{15}{5 \times 10^{-3}} - 50$$

$$R = 2950\ \Omega \quad \textbf{(1)}$$

A resistance $R = 2950\ \Omega$ is to be connected in series with galvanometer to convert it into a desired voltmeter. **(1½)**

28.(i) With the help of a diagram, explain the principle and working of a moving coil galvanometer.

(ii)What is the importance of radial magnetic field and how is it produced?

(iii)Why is it that while using a moving coil galvanometer as a voltmeter, a high resistance in series is required whereas in an ammeter a shunt is used?[All India 2010; Delhi 2009]

Ans.(i)

Principle The current carrying coil placed in normal magnetic field experiences a torque which is given by

$$\tau = NIAB$$

where, N = number of turns

I = current

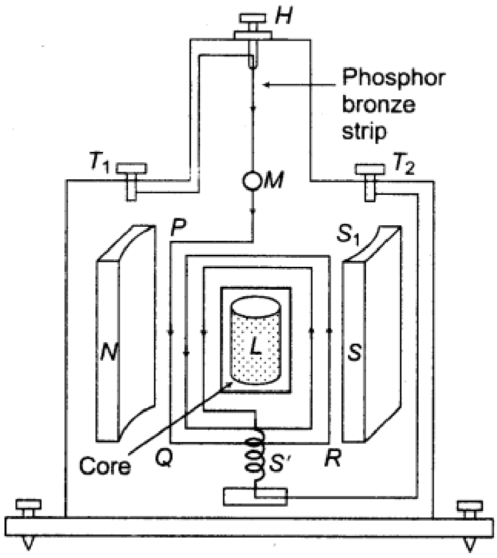
A = area of coil

B = magnetic field **(1)**

The galvanometer cannot be used to measure the current because

(*i*) all the currents to be measured passes through coil and it gets damaged easily as hair line spring or

(*ii*) its coil has considerable resistance because of length and it may affect original current. $\left(\frac{1}{2} \times 2 = 1\right)$



(1/2)

The coil remains suspended in radial magnetic field so that it always experiences maximum torque.

When current passes through the coil, deflection torque $\tau(\theta)$ is produced given by

$$\tau_{deflection} = NIAB \sin 90° \quad \text{...(i)}$$

As a result, coil rotates and phosphor bronze strip gets twisted. As a result restoring torque given by

$$\tau_{restoring} = k\theta \quad \text{...(ii)}$$

where, k = torsional restoring constant

∴ In equilibrium,

$$t_{deflecting} = \tau_{restoring}$$

$$NIAB = k\theta$$

$$I = \left(\frac{k}{NAB}\right)\theta$$

$$I \propto \theta$$

greater the current, greater the deflection.

(1)

(*ii*) In radial magnetic field, the plane of the coil is always parallel to the plane of the magnetic field and area vector of coil is perpendicular to magnetic field. It is always exerts maximum torque on the coil. **(1)**

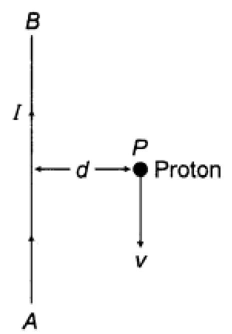
(*iii*) The voltmeter connected in parallel with the electrical circuit elements to measure potential difference. For exact measurement of PD voltmeter must draw minimum current which is possible only when it has high resistance. Ammeter is connected in series with the electrical circuit and current to be measured passes through it.

In order to protect the galvanometer, a feeble current must pass through the galvanometer, it is possible only when a low resistance (shunt) is connected in parallel with galvanometer to allow the major part of the current to pass through it. **(2)**

29.(i) Derive an expression for the force between two long parallel current carrying conductors.

(ii) Use this expression to define SI unit of current.

(iii) A long straight wire AB carries a current /. A proton P travels with a speed v, parallel to the wire at a distance d from it in a direction opposite to the current as shown in the figure. What is the force experienced by the proton and what is its direction?[All India 2010; Foreign 2008]



Ans.(i)

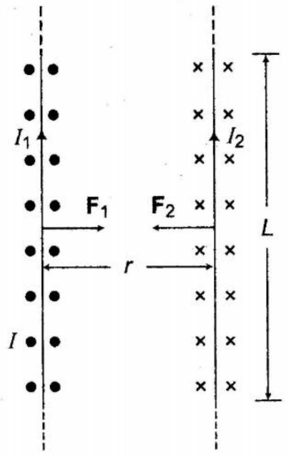
In these types of questions, we are calculating force on a wire in the field produced by the other current carrying wire.

Let two infinitely long straight current carrying conductor carry currents I_1 and I_2 in the same direction. Magnetic field B_1 due to first wire on seconds, i.e. **(1/2)**

$$B_1 = \frac{\mu_0}{4\pi}\frac{2I_1}{r} \qquad \text{...(i)}$$

(1/2)

The magnetic field is perpendicular to the plane of paper and directed inwards i.e. (X) type.



Now, magnetic force on L length of second wire is given by **(1/2)**

$$F_2 = I_2 B_1 L \sin 90°$$

$$\Rightarrow \quad F_2 = I_2\left(\frac{\mu_0}{4\pi}\cdot\frac{2I_1}{r}\right)L$$

$$\Rightarrow \quad \frac{F_2}{L} = \frac{\mu_0}{4\pi}\cdot\frac{2I_1I_2}{r} \qquad \text{...(ii)}$$

By Fleming's left hand rule, the direction of force F_2 is perpendicular to the second wire in the plane of paper towards the first wire.

Similarly, magnetic force on Ist wire is given by

$$\frac{F_1}{L} = \frac{\mu_0}{4\pi}\cdot\frac{2\,I_1I_2}{r} \qquad \text{...(iii)}$$

The force F_1 is directed towards the second wire.

Thus, two straight parallel current carrying conductor have the same direction of flow of currents attracting each other. **(1/2)**

(ii) As, $\frac{F}{L} = \frac{\mu_0}{4\pi} \frac{2 I_1 I_2}{r}$

$I_1 = I_2 = 1\,A$

$\frac{F}{L} = 2 \times 10^{-7}$ N/m

$r = 1$m

For definition Refer to ans. 20. **(1)**

(iii) Here, magnetic field due to the current carrying conductor at a distance d from it is given by

$$B = \frac{\mu_0}{4\pi} \frac{2I}{d}$$ **(1/2)**

∴ Force on proton,

$$F = (e)(v) B \sin 90°$$

$$F = evB$$

$$F = eV\left(\frac{\mu_0}{4\pi} \frac{2I}{d}\right)$$

$$F = \frac{\mu_0}{4\pi} \cdot \frac{2IeV}{d}$$ **(1)**

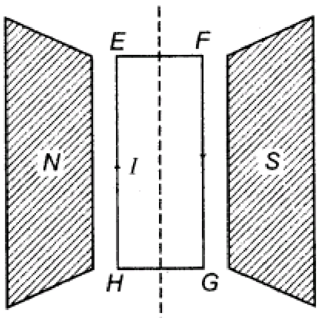
The proton is directed perpendicular to straight conductor and away from it. **(1/2)**

30.(i) Two straight long parallel conductors carry currents !$_x$ and I_2 in the same direction. Deduce the expression for the force per unit length between them. Depict the pattern of magnetic field lines around them.

(ii) A rectangular current carrying loop EFGH is kept in a uniform magnetic field as shown in the figure.

(a) What is the direction of the magnetic moment of the current loop?

(b) What is the torque acting on the loop maximum and zero?



[Foreign 2010; Delhi 2009]

Ans.(i)

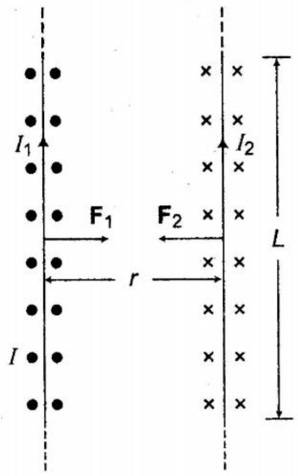
In these types of questions, we are calculating force on a wire in the field produced by the other current carrying wire.

Let two infinitely long straight current carrying conductor carry currents I_1 and I_2 in the same direction. Magnetic field B_1 due to first wire on seconds, i.e. **(1/2)**

$$B_1 = \frac{\mu_0}{4\pi} \frac{2I_1}{r} \quad \text{...(i)}$$

(1/2)

The magnetic field is perpendicular to the plane of paper and directed inwards i.e. (X) type.



Now, magnetic force on L length of second wire is given by **(1/2)**

$$F_2 = I_2 B_1 L \sin 90°$$

$$\Rightarrow \quad F_2 = I_2 \left(\frac{\mu_0}{4\pi} \cdot \frac{2I_1}{r}\right) L$$

$$\Rightarrow \quad \frac{F_2}{L} = \frac{\mu_0}{4\pi} \cdot \frac{2I_1 I_2}{r} \quad \text{...(ii)}$$

By Fleming's left hand rule, the direction of force F_2 is perpendicular to the second wire in the plane of paper towards the first wire.

Similarly, magnetic force on Ist wire is given by

$$\frac{F_1}{L} = \frac{\mu_0}{4\pi} \cdot \frac{2\,I_1 I_2}{r} \quad \text{...(iii)}$$

The force F_1 is directed towards the second wire.

Thus, two straight parallel current carrying conductor have the same direction of flow of currents attracting each other. **(1/2)**

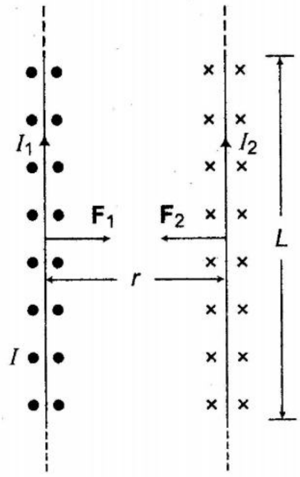
In these types of questions, we are calculating force on a wire in the field produced by the other current carrying wire.

Let two infinitely long straight current carrying conductor carry currents I_1 and I_2 in the same direction. Magnetic field B_1 due to first wire on seconds, i.e. **(1/2)**

$$B_1 = \frac{\mu_0}{4\pi} \frac{2I_1}{r} \quad \text{...(i)}$$

(1/2)

The magnetic field is perpendicular to the plane of paper and directed inwards i.e. (X) type.



Now, magnetic force on L length of second wire is given by **(1/2)**

$$F_2 = I_2 B_1 L \sin 90^\circ$$

$$\Rightarrow \quad F_2 = I_2 \left(\frac{\mu_0}{4\pi} \cdot \frac{2I_1}{r} \right) L$$

$$\Rightarrow \quad \frac{F_2}{L} = \frac{\mu_0}{4\pi} \cdot \frac{2I_1 I_2}{r} \quad \text{...(ii)}$$

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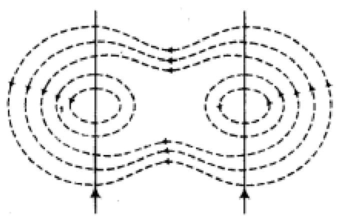
The force F_1 is directed towards the second wire.

Thus, two straight parallel current carrying conductor have the same direction of flow of currents attracting each other. **(1/2)**

(*i*). **(1)**



Magnetic field lines due to both conductors

Current-carrying conductors having same direction of flow of current, so the force between them will be attractive. **(1)**

(*ii*) (*a*) Perpendicular to the plane of the paper and directed inward. **(1)**

(*b*) When angle between area vector of coil and magnetic field is 90°, then maximum torque experienced by the coil.

When $\theta = 0°$ or $180°$, then torque will be minimum, i.e. zero. **(1)**