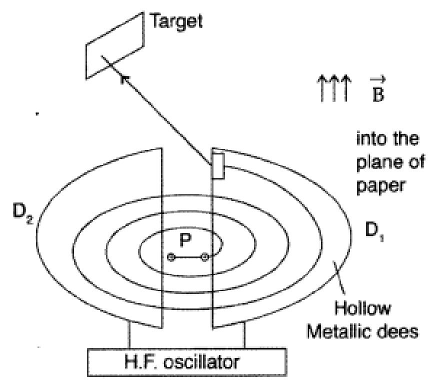
IMPORTANT QUESTIONS CLASS – 12 PHYSICS CHAPTER – 4 MOVING CHARGES AND MAGNETISM

Question 1.
Draw a schematic diagram of a cyclotron. Explain its underlying principle and working, stating clearly the function of the electric and magnetic field applied on a charged particle. Deduce an expression for the period of revolution and show that it does not depend on the speed of the charged particle.
Answer:
Principle : When a positively charged particle is made to move again and again in a high frequency electric field, it gets accelerated and acquires sufficiently large amount of energy.



Cyclotron

Working : Suppose a positive ion, say a proton, enters the gap between the two dees and finds dee D_1 to be negative. It gets accelerated towards dee D_1. As it enters the dee D_1, it does not experience any electric field due to shielding
effect of the metallic dee. The perpendicular magnetic field throws it into a circular path.
At the instant the proton comes out of dee D_1. It finds dee D_1 positive and dee D_2 negative. It now gets accelerated towards dee D_2. It moves faster through dee D_2 describing a larger semicircle than before. Thus if the frequency of the applied voltage is kept exactly the same as the frequency of the revolution of the proton, then everytime the proton reaches the gap between the two dees, the electric field is reversed and proton receives a push and finally it acquires very high energy. This proton follows a spiral path. The accelerated proton is ejected through a window by a deflecting voltage and hits the target.
Centripetal force is provided by magnetic field to charged particle to move in a circular back.

$$\frac{mv^2}{r} = qvB \quad \text{or} \quad v = \frac{qBr}{m}$$

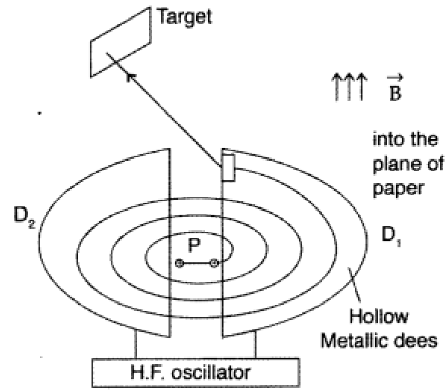
Period of revolution, $T = \frac{2\pi r}{v}$

$$T = \frac{2\pi r}{qBr} m \quad \text{or} \quad T = \frac{2\pi m}{qB}$$

Thus 'T' is independent of 'v'.

Question 2.
Draw a schematic sketch of a cyclotron. Explain briefly how it works and how it is used to accelerate the charged particles.
(i) Show that time period of ions in a cyclotron is independent of both the speed

and radius of circular path.
(ii) What is resonance condition? How is it used to accelerate the charged particles? (All India 2017)
Answer:
(i) Principle : When a positively charged particle is made to move again and again in a high frequency electric field, it gets accelerated and acquires sufficiently large amount of energy.



Cyclotron

Working : Suppose a positive ion, say a proton, enters the gap between the two dees and finds dee D_1 to be negative. It gets accelerated towards dee D_1. As it enters the dee D_1, it does not experience any electric field due to shielding effect of the metallic dee. The perpendicular magnetic field throws it into a circular path.
At the instant the proton comes out of dee D_1. It finds dee D_1 positive and dee D_2 negative. It now gets accelerated towards dee D_2. It moves faster through dee D_2 describing a larger semicircle than before. Thus if the frequency of the applied voltage is kept exactly the same as the frequency of the revolution of the proton, then everytime the proton reaches the gap between the two dees, the electric field is reversed and proton receives a push and finally it acquires very high energy. This proton follows a spiral path. The accelerated proton is ejected through a window by a deflecting voltage and hits the target.
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$$\frac{mv^2}{r} = qvB \quad \text{or} \quad v = \frac{qBr}{m}$$

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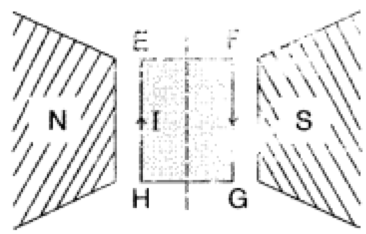
$$T = \frac{2\pi r}{qBr} m \quad \text{or} \quad T = \frac{2\pi m}{qB}$$

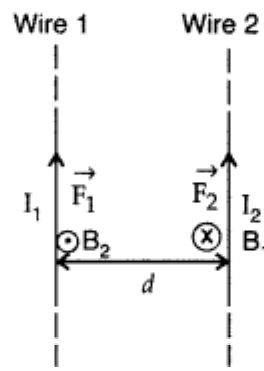
Thus 'T' is independent of 'v'.

(ii) The frequency v_a of the applied voltage is adjusted so that the polarity of the dees is reversed in the same time that it takes the ions to complete one-half of the revolution. The requirement $v_a = v_c$ is called the resonance condition.
The phase of the supply is adjusted so that when the positive ions arrive at the edge of D_1, D_2 is at a lower potential and the ions are accelerated across the gap.

Question 3.
(a) Two straight long parallel conductors carry currents I_1 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.
(b) A rectangular current carrying loop EFGH is kept in a uniform magnetic field as shown in the figure.
(i) What is the direction of the magnetic moment of the current loop?
(ii) When is the torque acting on the loop
(A) maximum,
(B) zero?



Answer:
Consider two infinitely long parallel conductors carrying current I_1 and I_2 in the same direction.
Let d be the distance of separation between these two conductors.



$$B_1 = \frac{\mu_0 I_1}{2\pi d}$$

$$F_2 = I_2 \times l_2 \times B_1 \sin\theta \quad \{\sin\theta = 1\}$$

$$\Rightarrow \quad F_2 = I_2 \times l_2 \times \frac{\mu_0 \times I_1}{2\pi d}$$

Force per unit length,

$$F = \frac{\mu_0 I_1 I_2}{2\pi d}, \quad B_2 = \frac{\mu_0 I_2}{2\pi d}$$

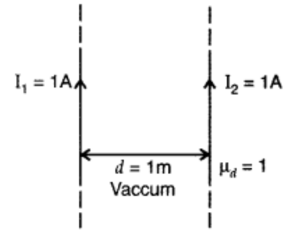
$$F_1 = I_1 \times l_1 \times B_2 \sin\theta \quad \{\sin\theta = 1\}$$

$$\Rightarrow \quad F_1 = \frac{\mu_0 I_1 I_2 l_1}{2\pi d}$$

$$\because \quad \text{Force per unit length, } F = \frac{\mu_0 I_1 I_2}{2\pi d}$$

Hence, force is attractive in nature.
Ampere : Ampere is that current which is if maintained in two infinitely long parallel conductors of negligible cross-sectional area separated by 1 metre in vacuum causes a force of 2×10^{-7} N on each metre of the other wire.
Then current flowing is 1A

(i) Magnetic moment will be out of the plane from the surface HEFG.
(ii) Torque
(A) Torque is maximum when MII B i.e., when it gets rotated by 90°.
(B) Torque is minimum when M and B are at 270° to each other.



$$F = \frac{\mu_0 \times 1 \times 1}{2\pi \times 1}$$

$$\therefore \quad F = \frac{\mu_0}{2\pi} = \mathbf{2 \times 10^{-7}\ N}$$

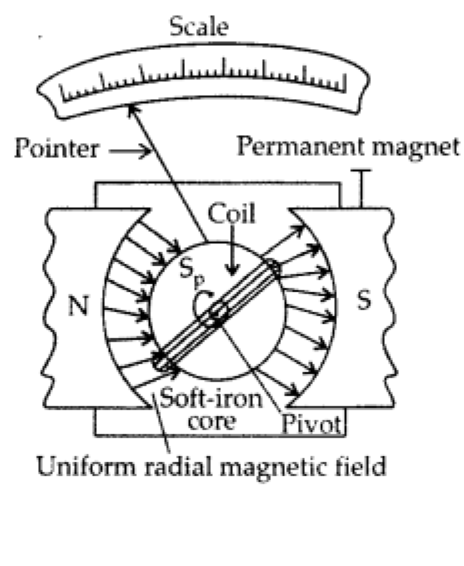
Question 4.
(a) With the help of a diagram, explain the principle and working of a moving coil galvanometer.
(b) What is the importance of a radial magnetic field and how is it produced?
(c) Why is it that while using a moving coil galvanometer as a voltmeter a high resistance in series is required whereas in an ammeter a shunt is used? (All India)
Answer:
(a) Principle : "If a current carrying coil is freely suspended/pivoted in a uniform magnetic field, it experiences a deflecting torque."
Working: As the pivoted coil is placed in a radial magnetic field, hence on passing current I through it, a deflecting torque acts on the coil which is given by, τ = NAIB

...where [N = total number of turns in the coil, A = area of coil, B = magnetic field.

The spring S_p attached to the coil provides the counter torque and in equilibrium state balances the deflecting torque. If φ is steady angular deflection then counter torque is kφ.
...where [k = torsional constant of the spring

In equilibrium state,

Thus, deflection is directly proportional to the current flowing in the coil.
(a) (i) Uniform radial magnetic field. It keeps the magnetic field line normal to the area vector of the coil.
(ii) Soft iron core in galvanometer. The cylindrical soft iron core, when placed inside the coil of a galvanometer, makes the magnetic field stronger



and radial in the space between it and pole pieces, such that whatever the position of the rotation of the coil may be, the magnetic field is always parallel to its plane.

$$NAIB = k\phi \quad \Rightarrow \quad \phi = \left(\frac{NAB}{k}\right)I$$

(b) (i) Current sensitivity is defined as the deflection produced in the galvanometer when unit current is passed through its coil.

$$I_s = \frac{\phi}{I} = \frac{nBA}{k} \text{ radian/ampere or division } A^{-1}$$

...where [n = Number of turns in the galvanometer. k = Restoring couple per unit twist or torsional constant.

(ii) Voltage sensitivity is defined as the deflection produced in the galvanometer when unit voltage is applied across the coil of the galvanometer.

$$V_s = \frac{\phi}{V} = \left(\frac{nBA}{k}\right) \times \frac{1}{R} \text{ radian/volt or div. } V^{-1}$$

...where [R = Resistance of the coil

Since $V_s = \frac{I_s}{R}$, increase in current sensitivity does not necessarily increase the voltage sensitivity. It may be affected by the resistance used.

(b) For radial magnetic field, sin θ = 1, so torque τ = NIAB.
Thus when radial magnetic field is used, the deflection of the coil is proportional to the current flowing through it. Hence a linear scale can be used to determine the deflection of the coil.

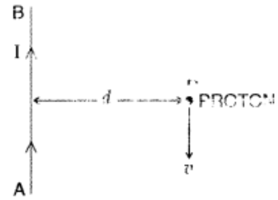
(c) A high resistance is joined in series with a galvanometer so that when the arrangement (voltmeter) is used in parallel with the selected section of the circuit, it should draw least amount of current. In case voltmeter draws appreciable amount of current, it will disturb the original value of potential difference by a good amount.

To convert a galvanometer into ammeter, a shunt is used in parallel with it so that when the arrangement is joined in series, the maximum current flows through the shunt, and thus the galvanometer is saved from its damage, when the current is passed through ammeter.

Question 5.
(a) Derive an expression for the force between two long parallel current carrying conductors.

(b) Use this expression to define S.I. unit of current.
(c) A long straight wire AB carries a current I. 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?

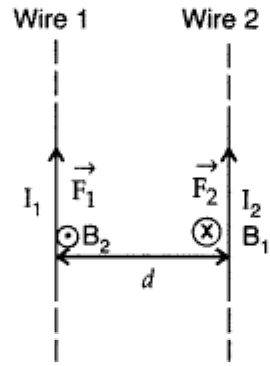


Answer:

(a) For (a) and (b) :

Consider two infinitely long parallel conductors carrying current I_1 and I_2 in the same direction.

Let d be the distance of separation between these two conductors.



$$B_1 = \frac{\mu_0 I_1}{2\pi d}$$

$$F_2 = I_2 \times l_2 \times B_1 \sin\theta \quad \{\sin\theta = 1\}$$

$$\Rightarrow F_2 = I_2 \times l_2 \times \frac{\mu_0 \times I_1}{2\pi d}$$

Force per unit length,

$$F = \frac{\mu_0 I_1 I_2}{2\pi d}, \; B_2 = \frac{\mu_0 I_2}{2\pi d}$$

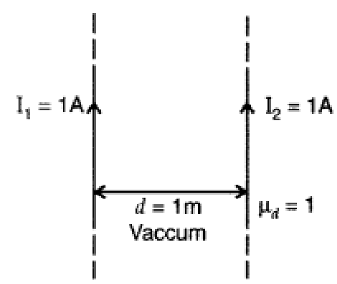
$$F_1 = I_1 \times l_1 \times B_2 \sin\theta \quad \{\sin\theta = 1\}$$

$$\Rightarrow F_1 = \frac{\mu_0 I_1 I_2 l_1}{2\pi d}$$

$$\because \text{Force per unit length, } F = \frac{\mu_0 I_1 I_2}{2\pi d}$$

Hence, force is attractive in nature.

Ampere : Ampere is that current which is if maintained in two infinitely long parallel conductors of negligible cross-sectional area separated by 1 metre in vacuum causes a force of 2×10^{-7} N on each metre of the other wire.



$$F = \frac{\mu_0 \times 1 \times 1}{2\pi \times 1}$$

$$\therefore F = \frac{\mu_0}{2\pi} = \mathbf{2 \times 10^{-7}\ N}$$

Then current flowing is 1A

(c) Force experienced by the proton,

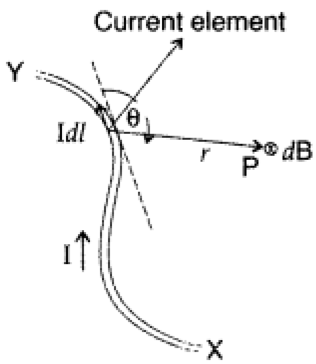
$$F = q\,(\vec{v} \times \vec{B})$$

As magnetic field due to the current carrying wire is directed into the plane of the paper (θ = 90°)

$$\text{Here } q = e \qquad B = \frac{\mu_0 I}{2\pi d}, \quad f = \frac{\mu_0 e v I}{2\pi d}$$

Force is directed away from the current carrying wire or in the right direction of observer.

Question 6.
State Biot-Savart law, giving the mathematical expression for it.
Use this law to derive the expression for the magnetic field due to a circular coil carrying current at a point along its axis.
How does a circular loop carrying current behave as a magnet?
(Delhi 2011)
Answer:
According to Biot-Savart's law, "magnetic field acting at a particular point due to current carrying element is proportional to the division of cross product of current element and position vector of point where the field is to be calculated from the current element to the cube of the distance between current element and the point where the field is to be calculated".

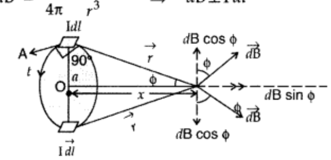


$$\vec{dB} = \frac{\mu_0}{4\pi}\frac{I\vec{dl}\times\vec{r}}{r^3} \Rightarrow dB = \frac{\mu_0}{4\pi}\frac{I\,dl\,r\sin\theta}{r^3}$$

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

Magnetic field on the axis of circular current loop :

$$\vec{dB} = \frac{\mu_0}{4\pi}\frac{I\vec{dl}\times\vec{r}}{r^3} \Rightarrow \vec{dB}\perp I\vec{dl}$$



$$\Rightarrow \vec{dB}\perp\vec{r}$$

$$B = \int dB\sin\phi$$

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

$$\therefore \quad B = \int\frac{\mu_0}{4\pi}\frac{I\,dl}{r^2}\sin\phi \qquad \text{As } \sin\theta = 1 \quad [\because \vec{r}\perp I\vec{dl}]$$

In ΔAOP, $\sin\phi = \frac{a}{r}$

$$B = \int\frac{\mu_0}{4\pi}\frac{I\,dl}{r^2}\frac{a}{r} \Rightarrow B = \int_0^{2\pi a}\frac{\mu_0}{4\pi}\frac{a}{r^3}I\,al$$

$$\Rightarrow B = \frac{\mu_0 a}{4\pi r^3}I\int_0^{2\pi a}dl \Rightarrow B = \frac{\mu_0 a}{4\pi r^3}aI\,[l]_0^{2\pi a}$$

$$\Rightarrow B = \frac{\mu_0}{4\pi r^3}aI\,[2\pi a - 0]$$

$$\Rightarrow B = \frac{\mu_0}{4\pi r^3}aI\times 2\pi a \Rightarrow B = \frac{\mu_0 a^2 I\times 2\pi}{4\pi r^3}$$

$$\Rightarrow B = \frac{\mu_0 I a^2}{2r^3} \qquad \cdots\left[\because r = \sqrt{a^2+x^2}\right]$$

$$\therefore \quad B = \boxed{\frac{\mu_0 I a^2}{2(x^2+a^2)^{3/2}}}$$

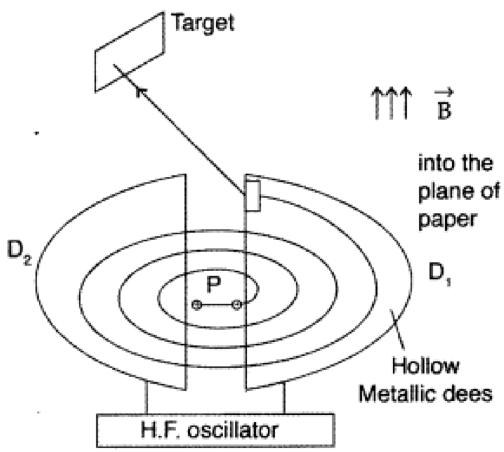
As in a special case we may obtain the field at the centre of the loop. Here x = 0, and we obtain

$$B_0 = \frac{\mu_0 I}{2R}$$

In a current loop, both the opposite faces behave as opposite poles, making it a magnetic dipole. One side of the current carrying coil behaves like the N-pole and the other side as the S-pole of a magnet.

Question 7.
With the help of a labelled diagram, state the underlying principle of a cyclotron. Explain clearly how it works to accelerate the charged particles. Show that cyclotron frequency is independent of energy of the particle. Is there an upper limit on the energy acquired by the particle? Give reason.

Answer:
Principle : When a positively charged particle is made to move again and again in a high frequency electric field, it gets accelerated and acquires sufficiently large amount of energy.



Cyclotron

Working : Suppose a positive ion, say a proton, enters the gap between the two dees and finds dee D_1 to be negative. It gets accelerated towards dee D_1. As it enters the dee D_1, it does not experience any electric field due to shielding effect of the metallic dee. The perpendicular magnetic field throws it into a circular path.

At the instant the proton comes out of dee D_1. It finds dee D_1 positive and dee D_2 negative. It now gets accelerated towards dee D_2. It moves faster through dee D_2 describing a larger semicircle than

before. Thus if the frequency of the applied voltage is kept exactly the same as the frequency of the revolution of the proton, then everytime the proton reaches the gap between the two dees, the electric field is reversed and proton receives a push and finally it acquires very high energy. This proton follows a spiral path. The accelerated proton is ejected through a window by a deflecting voltage and hits the target.
Centripetal force is provided by magnetic field to charged particle to move in a circular back.

$$\frac{mv^2}{r} = qvB \quad \text{or} \quad v = \frac{qBr}{m}$$

Period of revolution, $T = \frac{2\pi r}{v}$

$$T = \frac{2\pi r}{qBr} m \quad \text{or} \quad T = \frac{2\pi m}{qB}$$

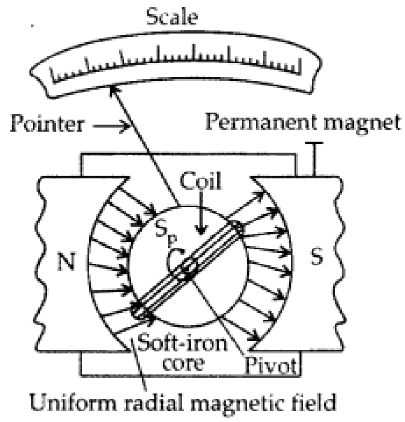
Thus 'T' is independent of 'v'.

Yes, there is an upper limit. The increase in the kinetic energy of particles is qv. Therefore, the radius of their path goes on increasing each time, their kinetic energy increases. The lines are repeatedly accelerated across the dees, untill they have the required energy to have a radius approximately that of the dees. Hence, this is the upper limit on the energy required by the particles due to definite size of dees.

Question 8.
(a) State the principle of the working of a moving coil galvanometer, giving its labelled diagram.
(b) "Increasing the current sensitivity of a galvanometer may not necessarily increase its voltage sensitivity." Justify this statement
(c) Outline the necessary steps to convert a galvanometer of resistance RG into an ammeter of a given range. (All India 2011)
Answer:
(a)
Principle : "If a current carrying coil is freely suspended/pivoted in a uniform magnetic field, it experiences a deflecting torque."
Working: As the pivoted coil is placed in a radial magnetic field, hence on passing current I through it, a deflecting torque acts on the coil which is given by, τ = NAIB

...where [N = total number of turns in the coil, A = area of coil, B = magnetic field.

The spring S_p attached to the coil provides the counter torque and in equilibrium state balances the deflecting torque. If φ is steady angular deflection then counter torque is kφ.
...where [k = torsional constant of the spring



In equilibrium state,

$$NAIB = k\phi \quad \Rightarrow \quad \phi = \left(\frac{NAB}{k}\right)I$$

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

(a) (i) Uniform radial magnetic field. It keeps the magnetic field line normal to the area vector of the coil.

$$I_s = \frac{\phi}{I} = \frac{nBA}{k} \text{ radian/ampere or division } A^{-1}$$

...where [n = Number of turns in the galvanometer.
k = Restoring couple per unit twist or torsional constant.

(ii) Soft iron core in galvanometer. The cylindrical soft iron core, when placed inside the coil of a galvanometer, makes the magnetic field stronger and radial in the space between it and pole pieces, such that whatever the position of the rotation of the coil may be, the magnetic field is always parallel to its plane.

(b) (i) Current sensitivity is defined as the deflection produced in the galvanometer when unit current is passed through its coil.

(ii) Voltage sensitivity is defined as the deflection produced in the galvanometer when unit voltage is applied across the coil of the galvanometer.

...where [R = Resistance of the coil

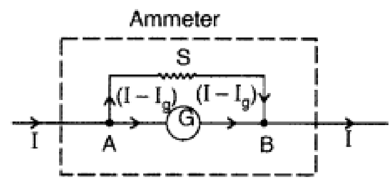
$$V_s = \frac{\phi}{V} = \left(\frac{nBA}{k}\right) \times \frac{1}{R} \text{ radian/volt or div. } V^{-1}$$

does not necessarily increase the voltage sensitivity. It may be affected by the resistance used.

Since $V_s = \frac{I_s}{R}$, increase in current sensitivity

(b) Since vs=IsR increase in current sensitivity may not necessarily increase the voltage sensitivity. It may be affected by the resistance used.

(c) Conversion of galvanometer into ammeter: By just connecting a low resistance known as shunt in parallel to the galvanometer, it can be converted into an ammeter.



Let G = resistance of the galvanometer.
I_g = the current with which galvanometer gives full scale deflection.
S = shunt resistance
I – I_g = current through the shunt.
As the galvanometer and shunt are connected in parallel,
Potential difference across the galvanometer = Potential difference across the shunt

$$I_g G = (I - I_g) S \Rightarrow S = \frac{I_g}{I - I_g} \times G$$

Question 9.
(a) Write the expression for the force, F→, acting on a charged particle of charge 'q', moving with a velocity latex]\overrightarrow{\mathbf{v}}[/latex] in the presence of both electric field E→ and magnetic field B→. Obtain the condition under which the particle moves undeflected through the fields.
(b) A rectangular loop of size l × 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 τ =m ×B→, where m→ is the magnetic moment of the loop. (All India 2011)
Answer:
(a) A charge q in an electric field E→ experiences the electric force, F→e=qE→

This force acts in the direction of field E→ and is independent of the velocity of the charge.

The magnetic force experienced by the charge q moving with velocity v→ in the magnetic field B is given by

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

This force acts perpendicular to the plane of V→ and B→ and depends on the velocity v→ of the charge.

$$\vec{F} = \vec{F}_e + \vec{F}_m$$

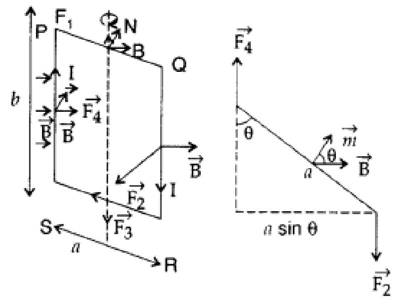
$$\therefore \quad \vec{F} = q(\vec{E} + \vec{v} \times \vec{B})$$

The total force, or the Lorentz force, experienced by the charge q due to both electric and magnetic field is given by

Hence, A stationary charged particle does not experience any force in a magnetic field. (b) Torque on a current loop in a uniform magnetic field.

Let I = Current flowing through the coil PQRS

Its magnitude is, F3 = IaB sin(90° + 0)



a, b = Sides of the coil PQRS

$A = ab$ = area of the coil

θ = angle between the direction of $\vec{B}$ and that of the vector $\vec{N}$ drawn normal to the plane of the coil.

$\therefore$ Force on side $\vec{PQ}$, $\vec{F_1} = I(\vec{PQ} \times \vec{B})$

Its magnitude is $F_1 = IaB \sin(90° - \theta)$
$= IaB \cos\theta$

Force on side $\vec{QR}$, $\vec{F_2} = (\vec{QR} \times \vec{B})$

Its magnitude is $F_2 = IbB \sin 90° = IbB$

Force on side $\vec{RS}$, $\vec{F_3} = I(\vec{RS} \times \vec{B})$
$= IaB\cos\theta$

Force on side $\vec{SP}$, $\vec{F_4} = I(\vec{SP} \times \vec{B})$

Its magnitude is $F_4 = IbB \sin 90° = IbB$

According to *Fleming's left hand rule,* the forces $\vec{F_1}$ and $\vec{F_3}$ act along the axis of the loop as shown in the figure. These forces are equal, opposite and collinear. So they give rise to no net forces or torques. The forces $\vec{F_4}$ and $\vec{F_2}$ on the sides $\vec{SP}$ and $\vec{QR}$ are equal and opposite but not collinear. So they form a couple. The perpendicular distance between the two forces is $a \sin\theta$.

τ = Force × perpendicular distance
$= IbB \times a \sin\theta$
$= IBA \sin\theta$ from the axis of rotation

$\tau = mB \sin\theta$

[where m = IA = magnitude of the magnetic dipole moment]

$\therefore \quad \vec{\tau} = \vec{m} \times \vec{B}$