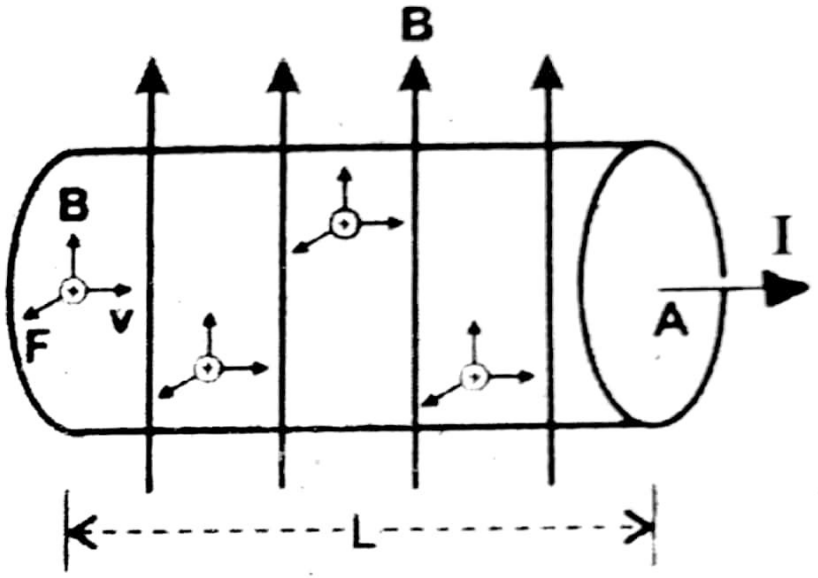
FORCE ON A MOVING CHARGE IN A MAGNETIC FIELD

When a current carrying conductor is placed in a magnetic field, it experiences a force. As current through the conductor is due to the motion of charges.

Actually, the magnetic field exerts force on these moving charges. We have to calculate the force acting on the moving charges.

Calculation of Force

Consider a portion of wire of length L placed in a magnetic field $\vec{B}$.



Let I be the current flowing through the wire.

Suppose there are n charge carriers per unit volume of the wire and each is moving with velocity $\vec{V}$.

Let, Length of the wire = L

Area of cross-section of the wire = A

Volume of the wire segment = AL

Number of charge carriers per unit volume = n

Total number of charge carriers in the segment = nAL

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Charge on each charge carrier = q

Total charge on nAL charge carriers = ΔQ = nALq

The time taken by the charge carrier from left side of the segment to reach the right hand face is given by

$$\Delta t = \frac{L}{V}$$

According to the definition of the current,

$$I = \frac{\Delta Q}{\Delta t} = \frac{nALq}{L/V}$$

$$I = nAqV \longrightarrow (1)$$

The force on a current carrying conductor is given by

$$\vec{F}_L = I(\vec{L} \times \vec{B}) \longrightarrow (2)$$

Putting value of I from equation (1)

$$\vec{F}_L = nAqV((\vec{L} \times \vec{B}) \longrightarrow (3)$$

The direction of the segment $\vec{L}$ is the same as the direction of velocity $\vec{V}$ of the charge carriers as shown in fig.

If $\hat{L}$ is a unit vector along the direction of $\vec{L}$

And $\hat{V}$ is a unit vector along the velocity vector $\vec{V}$.

Then $\hat{L} = \hat{V}$

$\therefore$ $V\vec{L} = V\hat{L}L$ as $\hat{L} = \hat{V}$

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

Putting in equation (3)

$$\vec{F}_L = nAq(V\vec{L} \times \vec{B}) = nAq\vec{V}L \times \vec{B}$$

Or $$\vec{F}_L = nAqL(\vec{V} \times \vec{B}) \longrightarrow (4)$$

This is the force experienced by total number of charge carriers (nAL).

Hence force experienced by a single charge carrier is

$$\vec{F} = \frac{\vec{F}_L}{nAL}$$

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Putting value of equation (4)

$$\vec{F} = \frac{nAqL}{nAL}(\vec{V} \times \vec{B})$$

$$\boxed{\vec{F} = q(\vec{V} \times \vec{B})} \longrightarrow (5)$$

This is the expression for the force experienced by a single charge carrier moving with velocity $\vec{V}$ in a magnetic field of strength $\vec{B}$.

Note

i) If an electron is projected in a magnetic field with velocity V, it will experience a force which is given by putting q = −e

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

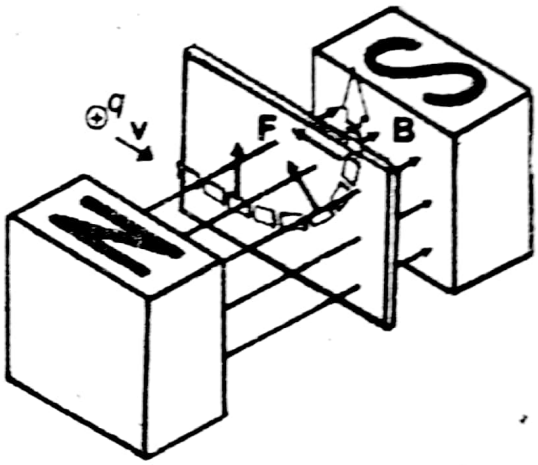
ii) In case of proton q = +e

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

Direction of force

The direction of force on the charge is given by **right hand rule**. Curl the fingers of right hand in the direction of the rotation $(\vec{V} \times \vec{B})$.

Thumb will point in the direction of the force. As a result of this force proton is deflected upward and electron is deflected in the downward direction as shown in fig.



Magnitude of Force

The magnitude of the force on a moving charge carrier is given by equation (5).

$$F = qVB\sin\theta$$

Where θ is the angle between $\vec{V}$ and $\vec{B}$.

Maximum Force

When θ = 90° i.e. when the charge particle is projected at right angles to the field, it will experience maximum force.

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$F = qVB\sin 90^\circ$ $\quad \sin 90^0 = 1$

$$\boxed{F = qVB}$$

Minimum (Zero) Force

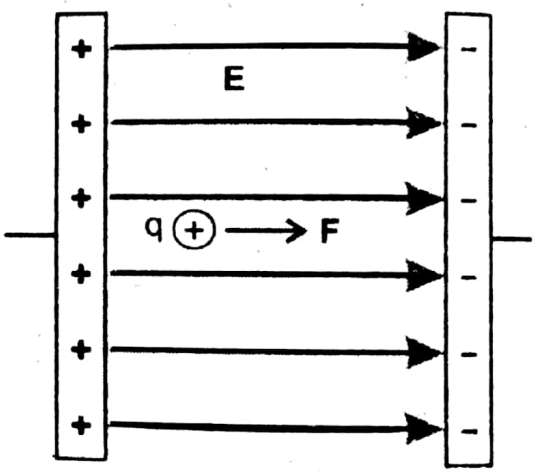
When $\theta = 0^\circ$, i.e. when the charge particle is projected in the direction of the field, it will experience no force

$F = qVB\sin 0^\circ$ $\quad \sin 0^\circ = 0$

$$\boxed{F = 0}$$

MOTION OF CHARGE PARTICLE IN AN ELECTRIC AND MAGNETIC FIELD

When an electric charge 'q' is placed in an electric field $\vec{E}$, it experiences a force $\vec{F}$ parallel to the electric field (Fig). It is given by



$$\vec{F} = q\vec{E}$$

If the charge is free to move, then according to Newton's 2nd law, the acceleration of charge is

$$\vec{a} = \frac{\vec{F}}{m}$$

Or $$\vec{a} = \frac{q\vec{E}}{m} \longrightarrow (1)$$

If electric field is uniform, then acceleration is also uniform.

When a charge particle 'q' is moving with velocity $\vec{V}$ in a region where there is an electric field $\vec{E}$ and magnetic field $\vec{B}$. Then total force $\vec{F}$ acting on the particle is the vector sum of electric force and magnetic force.

i.e. $$\vec{F} = \vec{F}_e + \vec{F}_b$$

$$\boxed{F = q\vec{E} + q(\vec{V} \times \vec{B})} \longrightarrow (2)$$

This force is known as the **Lorentz force**.

Note

The electric force does work only, while no work is done by the magnetic force, which is simply a deflecting force.

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DETERMINATION OF e/m OF AN ELECTRON

(LB.07A)

J.J. Thomson determines the charge to mass ratio of an electron.

Let a narrow beam of electrons moving with a constant speed 'V' be projected at right angles to a known uniform magnetic field $\vec{B}$ directed into the plane of paper.

The force acting on the electrons is given by

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

The direction of the force will be perpendicular to both $\vec{V}$ and $\vec{B}$.

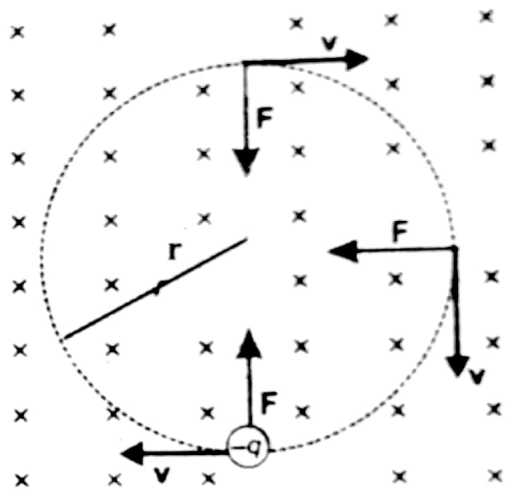
As electron is experiencing a force that acts at right angle to its velocity, so it will change the direction of the velocity. The magnitude of velocity will remain unchanged.

The magnitude of the force is given by

$$F = eVB\sin\theta$$

As $\theta = 90^\circ$ $\quad \sin 90^\circ = 1$

$$F = eVB \longrightarrow (1)$$



As both V and B donot change, the magnitude of force F is constant.

Under the action of this force the electrons will move in a circle of radius 'r' as shown in fig.

The magnetic force (F = BeV) will provide the necessary centripetal force $\left(\frac{mV^2}{r}\right)$ to the electron of mass 'm' moving along a circular path of radius r.

Therefore, Magnetic force = centripetal force

$$BeV = \frac{mV^2}{r}$$

$$\boxed{\frac{e}{m} = \frac{V}{Br}} \longrightarrow (3)$$

If V and r are known e/m of the electron is determined.

Determination of r

The radius 'r' is measured by making the electrons path visible, by filling a glass tube with hydrogen gas at low pressure. This tube is placed in a uniform magnetic field of known value. As electrons are shot into this tube, they begin to move along a circle under

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