Motion of Electron in Uniform Magnetic Field

A magnetic field is induced around a charged particle in motion. When the electron having charge (e) moves in magnetic field (B) with velocity (v), its induced magnetic field interacts with the applied magnetic field which deflects the electron from its original path. The magnetic force experienced by the electron and its path of deflection can be explained at different angles of its projection in the field.

i. When electron enters the field parallelly or antiparallelly, i.e. ($\theta = 0^0$ or $\theta = 180^0$)

The magnitude of magnetic force is,

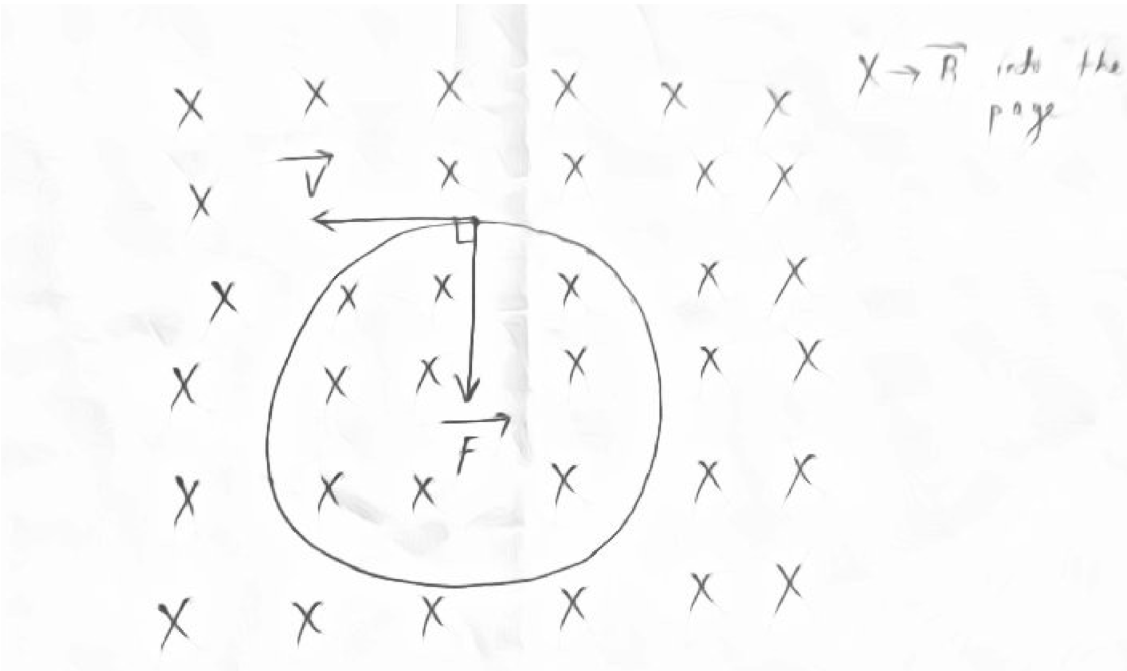
$F = Bev\sin\theta$..(i)

For $\theta = 0^0$ or $\theta = 180^0$, $\sin\theta = 0$

$\therefore F = 0$

So, if the electron enters into the field parallelly or antiparallelly, the electron does not experience any magnetic force.

ii. When electron enters the field perpendicularly, i.e. ($\theta = 90^0$)



Figure(i): Circular motion of electron in uniform magnetic field

Then, the magnetic force experienced by the electron is,

$F = Bev\sin 90^0$

$F = Bev$...(ii)

In this case, the electron experiences maximum force in the magnetic field. Since the force is perpendicular to velocity $\vec{v}$, the electron moves in a circular path as shown in the figure(i). Here, the magnetic force provides the centripetal force to the electron,

i.e. $Bev = \frac{mv^2}{r}$

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

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

Here, r is the radius of circular path followed by electron in magnetic field.

Also, from eqn. (iii),

$\frac{v}{r} = \frac{Be}{m}$

$\omega = \frac{Be}{m}$

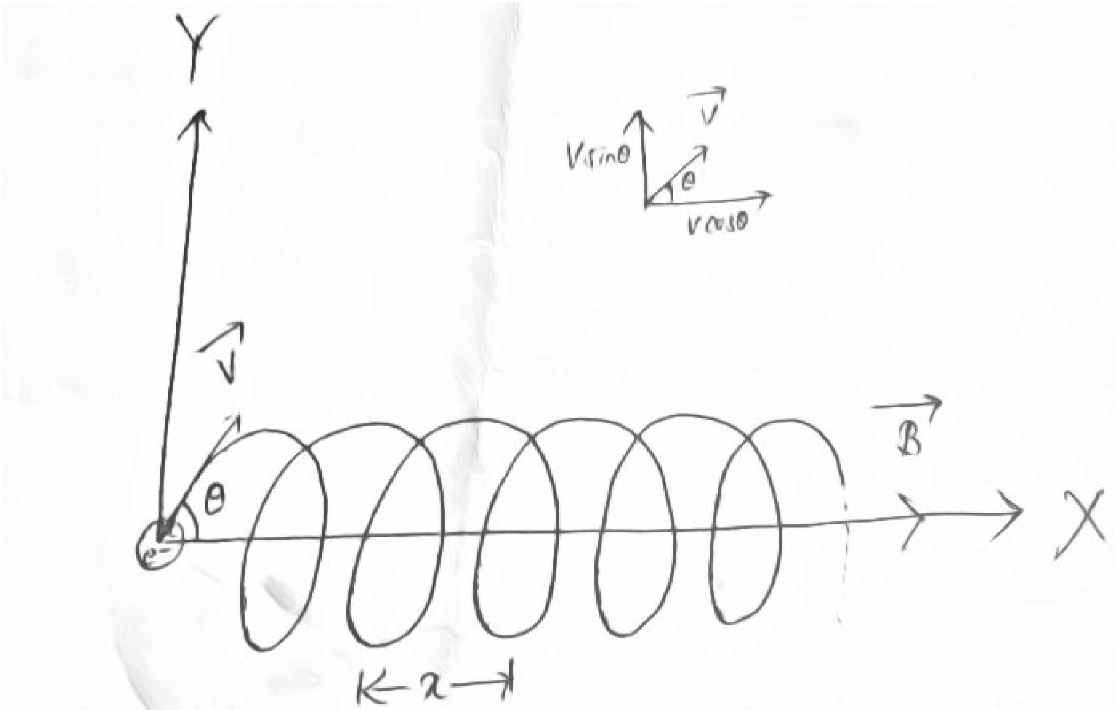
where, ω is angular velocity of the electron.

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

$T = \frac{2\pi m}{Be}$ ....(iv)

Here, T is the time period of revolution of electron in the uniform magnetic field. The frequency of revolution of electron is, $f = \frac{1}{T} = \frac{Be}{2\pi m}$.

<u>iii. When electron enters the magnetic field at any oblique angle θ</u>



Figure(ii): Helical (spiral) motion of electron in uniform magnetic field

In this condition, the component of velocity which is parallel to the magnetic field tends to move the electron in linear path, whereas the perpendicular component of velocity tends to move the electron in circular path. So, due to the combined effect, electron follows helical (spiral) path as shown in the figure(ii).

Let, the magnetic field (B) be in the X-direction and the electron enters the field with velocity (v) at an angle θ with the magnetic field (X-axis). The horizontal component of velocity, parallel to the magnetic field (along x-axis) $v_x = v\cos\theta$ tends to move the electron along the direction of magnetic field (linear path) and its vertical component, perpendicular to the magnetic field (along y-axis) $v_y = v\sin\theta$ tends to move the electron in circular path. This combined effect makes the electron move in a helical path.

The centripetal force provided by the magnetic field perpendicular to the velocity component (v_y) is

$\frac{mv_y^2}{r} = Bev_y$

$\frac{mv_y}{r} = Be$

$\therefore$ The radius (r) of the helical path is given by,

$r = \frac{mv_y}{Be}$

$r = \frac{mv\sin\theta}{Be}$.. (v)

Let T be the time period, then,

$T = \frac{\text{circumference of the circle}}{\text{speed along the circle}} = \frac{2\pi r}{v\sin\theta} = \frac{2\pi}{v\sin\theta} \times \frac{mv\sin\theta}{Be}$ [From eqn. (v)]

$\therefore T = \frac{2\pi m}{Be}$..(vi)

From equation (vi), it is clear that the time period of revolution of electron is independent of speed of the particle as well as angle of projection but depends on m, B and e.

The linear distance travelled by the particle during this time period is called the pitch of helix which can also be defined as the linear distance between two consecutive turns of a helical path. So,

Pitch(x) = horizontal velocity x time period (T)

= $v\cos\theta \times \frac{2\pi m}{Be}$

= $\frac{2\pi mv\cos\theta}{Be}$ ....(vii)