Lorentz force

(and applications)

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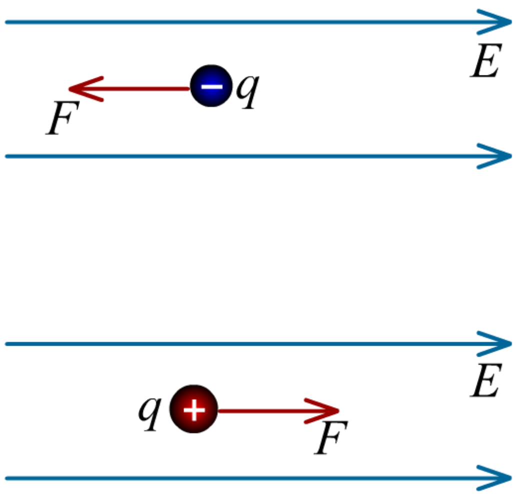
Note : The notes given in this file is no substitute to the much detailed discussion held in the online/contact classes with active participation of students. It , at best, serves the purpose of ready reference for important concepts/derivations covered in the classes.

Motion of a charged particle in a region of E

$$\boxed{\overline{F} = q\,\overline{E}}$$

$$\overline{F} = m\overline{a}$$

$$\overline{a} = \frac{q\overline{E}}{m}$$

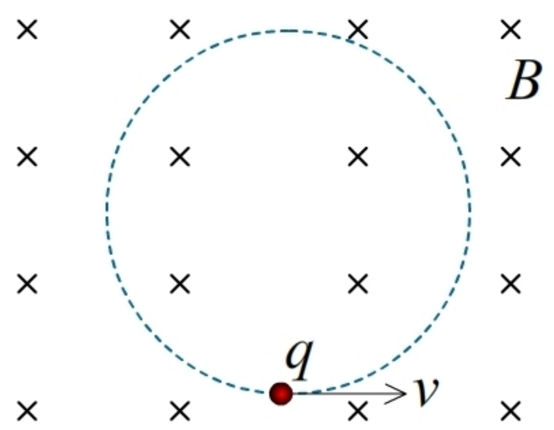


- Force on a positive charge is in the direction of the electric field
- Force on a negative charge is in a direction opposite to the electric field
- Work is done on the charge by the electric field intensity and hence it results in change in kinetic energy of the particle

Motion of a charged particle in a region of uniform B

$$\boxed{\overline{F} = q\,\overline{v} \times \overline{B}}$$

- Direction of force is given by right hand thumb rule
- Force due to B is always at right angles to the direction of instantaneous velocity vector.
- Force due to B acts as a centripetal force and causes the body to move along a circular path
- Work done by this force (for any part of the circular path) is <u>zero</u>
- There is <u>no change in the kinetic energy</u> of the particle



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Radius of the circular path (R)

Force on the particle of charge q and mass m, entering a region of uniform magnetic field $\boldsymbol{B}$ is given by the relation

$$\boldsymbol{F} = q\,\boldsymbol{v}\times\boldsymbol{B}$$

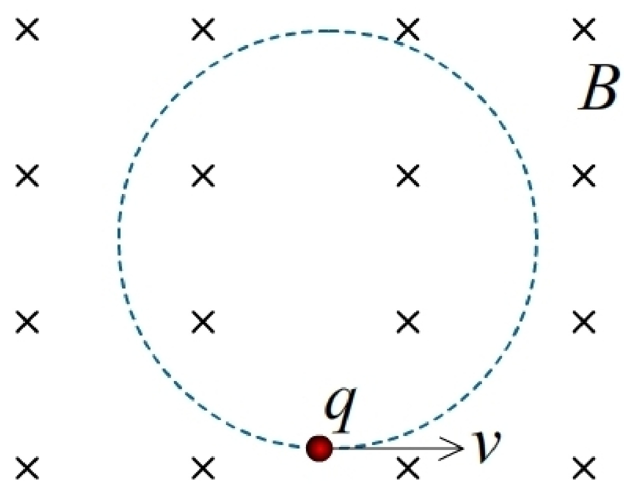
For normal incidence ($\theta = 90^{o}$) therefore the magnitude of force is

$$F = q\,v\,B$$

This force acts as a centripetal force. Therefore

$$\frac{mv^2}{R} = q\,v\,B$$

$$R = \frac{mv}{q\,B}$$



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- Radius of circular path depends on velocity of the particle
- Radius increases with increase in velocity (or momentum & KE)

Frequency of revolution (n)

Radius of the circular path is given by

$$R = \frac{mv}{qB}$$

Using the relation $v = r\omega$, we get

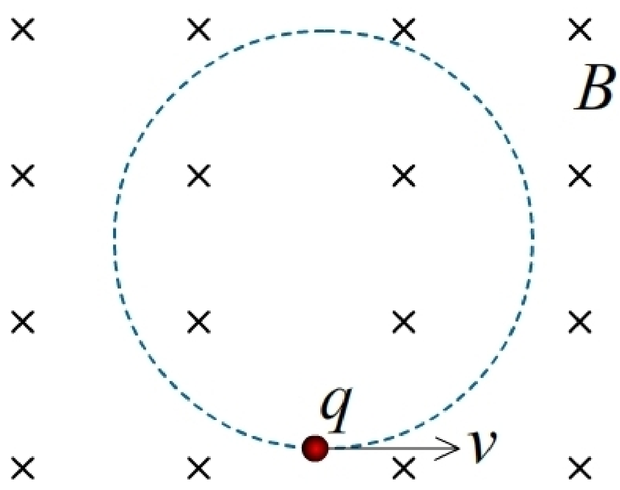
$$R = \frac{mR\omega}{qB}$$

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

Using the relation $\omega = 2\pi n$, we get

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

$$\boxed{n = \frac{qB}{2\pi m}}$$



- This frequency (n) is called **cyclotron frequency**
- It depends only on the properties of particle (m and q) and the magnetic field
- It is independent of the velocity or momentum or KE of the particle !

Velocity selector

It is a device that is used to obtain particles of specific velocity from a given source. Velocity selector works on the principle of Lorentz force.

Consider a stream of charged particles emitted with a range of velocities from a source. A fine beam of these particles is obtained by passing them through a collimator. The beam passes through crossed electric and magnetic fields.

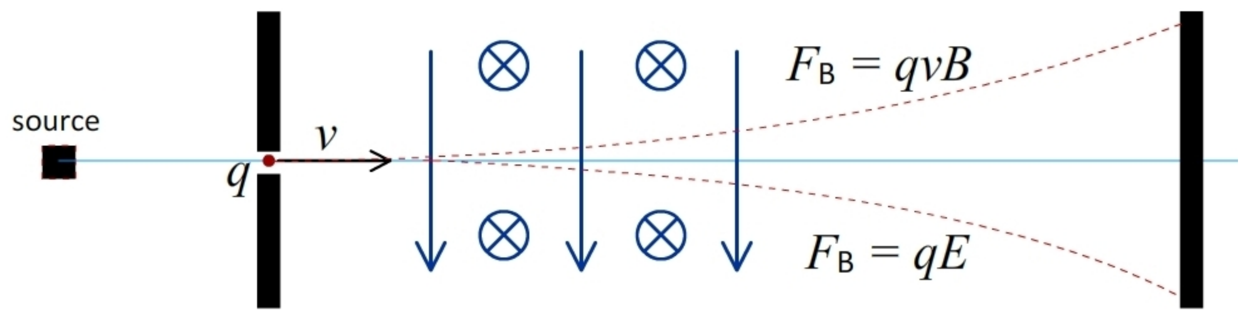
Force (F_E) is exerted on the particles in the downward direction due to the electric field.

A uniform magnetic field, perpendicular to electric field and beam is applied such that the force due to magnetic field (F_B) is equal and opposite to F_E . Under equilibrium we get

$$F_B = F_E$$

$$qvB = qE$$

$$\boxed{v = \frac{E}{B}}$$



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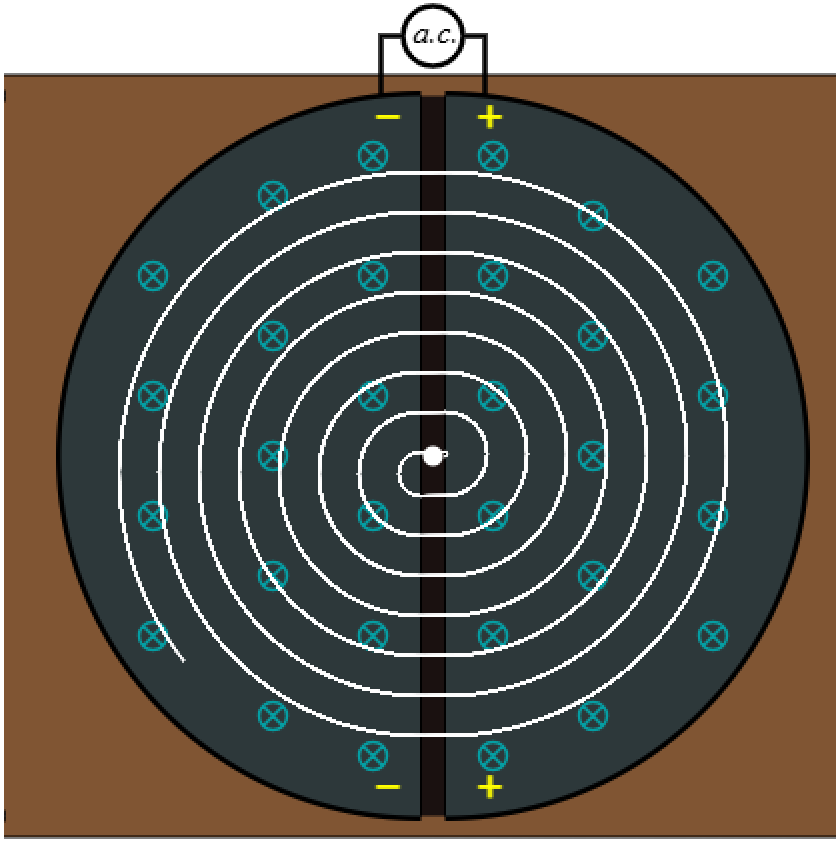
Cyclotron

It is a device that is used to obtain particles of high energy.
It works on the principle of Lorentz force on a particle due to $\boldsymbol{E}$ and $\boldsymbol{B}$.

A cyclotron consists of two coplanar semi-circular Dees. A uniform magnetic field exists in a direction perpendicular to the plane of the Dees. A high frequency a.c. power supply is provided in the gap between the Dees.

Electric field due to the high voltage accelerates the particles (resulting in an increase in their KE) and the magnetic field in the Dees confines the particles to a circular path.



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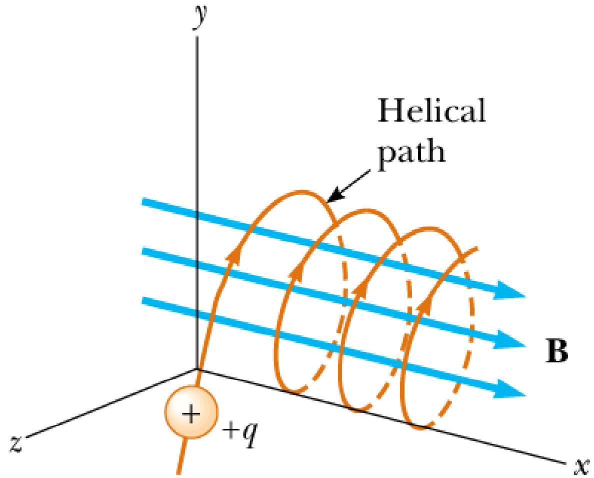
As cyclotron frequency is independent of the energy of the particle, the particles can be accelerated using the same frequency until it emerges from the cyclotron.

Helical path of a particle in a region of uniform B

Consider a particle entering at an angle other than 90° .
The parallel component of velocity causes the particle to move in that direction. Perpendicular component o the magnetic field makes it move along the circular path. This combination results in the helical path of the particle.

$v_{\text{perpendicular}} = v \sin(\theta)$

$v_{\text{parallel}} = v \cos(\theta)$



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

Displacement = $v_{\text{parallel}} \times T$

$$\text{pitch} = \frac{2\pi m}{qB} v \cos(\theta)$$