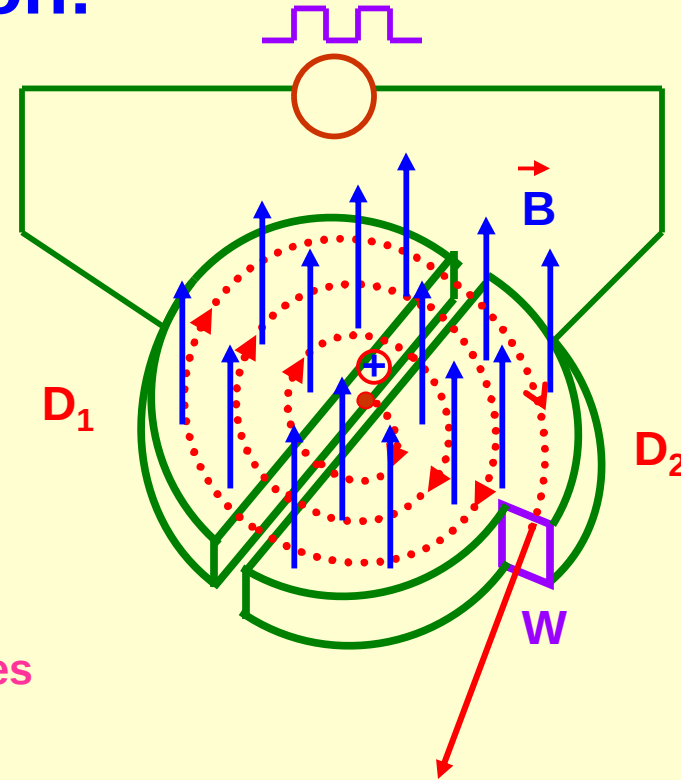
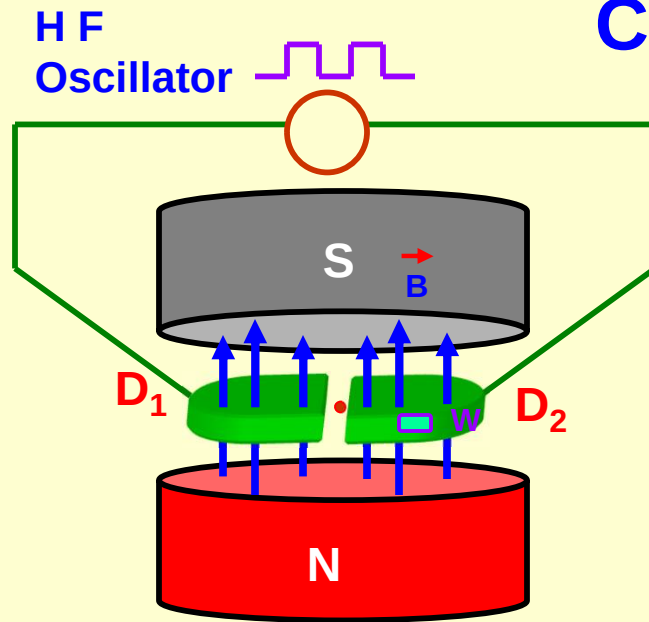


MAGNETIC EFFECT OF CURRENT - III

1. Cyclotron
2. Ampere's Circuital Law
3. Magnetic Field due to a Straight Solenoid
4. Magnetic Field due to a Toroidal Solenoid

Cyclotron:



D_1, D_2 – Dees N, S – Magnetic Pole Pieces
 W – Window B - Magnetic Field

Working: Imagining D_1 is positive and D_2 is negative, the +vely charged particle kept at the centre and in the gap between the dees get accelerated towards D_2 . Due to perpendicular magnetic field and according to Fleming's Left Hand Rule the charge gets deflected and describes semi-circular path.

When it is about to leave D_2 , D_2 becomes +ve and D_1 becomes –ve. Therefore the particle is again accelerated into D_1 where it continues to describe the semi-circular path. The process continues till the charge traverses through the whole space in the dees and finally it comes out with very high speed through the window.

Theory:

The magnetic force experienced by the charge provides centripetal force required to describe circular path.

$$\therefore mv^2 / r = qvB \sin 90^\circ$$

$$v = \frac{B q r}{m}$$

(where m – mass of the charged particle, q – charge, v – velocity on the path of radius – r , B is magnetic field and 90° is the angle b/n v and B)

If t is the time taken by the charge to describe the semi-circular path inside the dee, then

$$t = \frac{\pi r}{v} \quad \text{or} \quad t = \frac{\pi m}{B q}$$

Time taken inside the dee depends only on the magnetic field and m/q ratio and not on the speed of the charge or the radius of the path.

If T is the time period of the high frequency oscillator, then for resonance,

$$T = 2 t \quad \text{or} \quad T = \frac{2\pi m}{B q}$$

If f is the frequency of the high frequency oscillator (Cyclotron Frequency), then

$$f = \frac{B q}{2\pi m}$$

Maximum Energy of the Particle:

Kinetic Energy of the charged particle is

$$\text{K.E.} = \frac{1}{2} m v^2 = \frac{1}{2} m \left(\frac{B q r}{m} \right)^2 = \frac{1}{2} \frac{B^2 q^2 r^2}{m}$$

Maximum Kinetic Energy of the charged particle is when $r = R$ (radius of the D's).

$$\text{K.E.}_{\text{max}} = \frac{1}{2} \frac{B^2 q^2 R^2}{m}$$

The expressions for Time period and Cyclotron frequency only when m remains constant. (Other quantities are already constant.)

But m varies with v according to Einstein's Relativistic Principle as per

$$m = \frac{m_0}{[1 - (v^2 / c^2)]^{1/2}}$$

If frequency is varied in synchronisation with the variation of mass of the charged particle (by maintaining B as constant) to have resonance, then the cyclotron is called **synchro – cyclotron**.

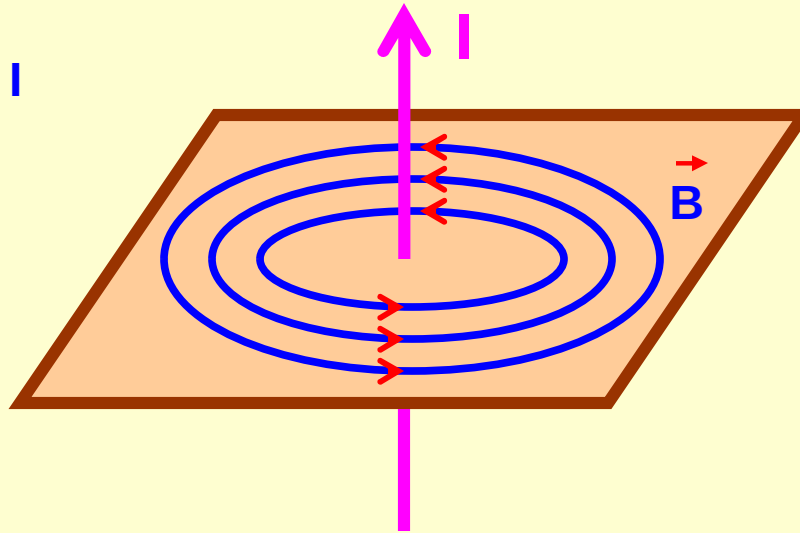
If magnetic field is varied in synchronisation with the variation of mass of the charged particle (by maintaining f as constant) to have resonance, then the cyclotron is called **isochronous – cyclotron**.

NOTE: Cyclotron can not be used for accelerating neutral particles. Electrons can not be accelerated because they gain speed very quickly due to their lighter mass and go out of phase with alternating e.m.f. and get lost within the dees.

Ampere's Circuital Law:

The line integral $\oint \vec{B} \cdot d\vec{l}$ for a closed curve is equal to μ_0 times the net current I threading through the area bounded by the curve.

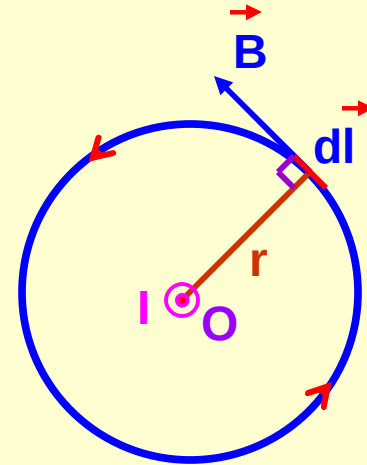
$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I$$



Proof:

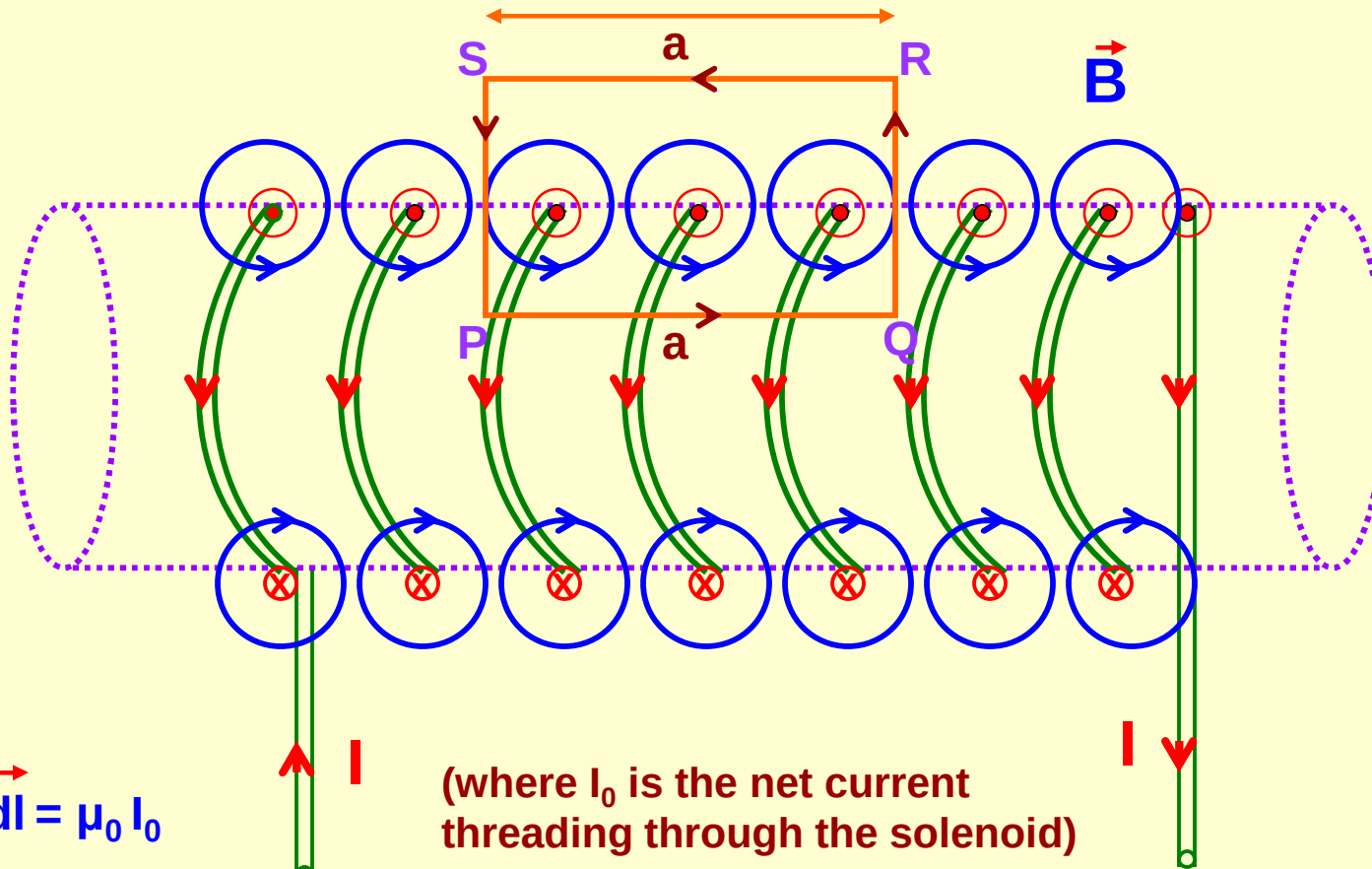
$$\begin{aligned} \oint \vec{B} \cdot d\vec{l} &= \oint \vec{B} \cdot d\vec{l} \cos 0^\circ \\ &= \oint \vec{B} \cdot d\vec{l} = B \oint dl \\ &= B (2\pi r) = (\mu_0 I / 2\pi r) \times 2\pi r \end{aligned}$$

$$\boxed{\oint \vec{B} \cdot d\vec{l} = \mu_0 I}$$



Current is emerging out and the magnetic field is anticlockwise.

Magnetic Field at the centre of a Straight Solenoid:



$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_0$$

(where I_0 is the net current threading through the solenoid)

$$\begin{aligned} \oint \vec{B} \cdot d\vec{l} &= \oint_{PQ} \vec{B} \cdot d\vec{l} + \oint_{QR} \vec{B} \cdot d\vec{l} + \oint_{RS} \vec{B} \cdot d\vec{l} + \oint_{SP} \vec{B} \cdot d\vec{l} \\ &= \oint \vec{B} \cdot d\vec{l} \cos 0^\circ + \oint \vec{B} \cdot d\vec{l} \cos 90^\circ + \oint \vec{B} \cdot d\vec{l} \cos 90^\circ + \oint \vec{B} \cdot d\vec{l} \cos 0^\circ \\ &= B \oint dl = B.a \quad \text{and} \quad \mu_0 I_0 = \mu_0 n a I \quad \therefore \boxed{B = \mu_0 n I} \end{aligned}$$

(where n is no. of turns per unit length, a is the length of the path and I is the current passing through the lead of the solenoid)

Magnetic Field due to Toroidal Solenoid (Toroid):

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I_0$$

$$\oint \vec{B} \cdot d\vec{l} = \oint B \cdot dl \cos 0^\circ$$

$$= B \oint dl = B (2\pi r)$$

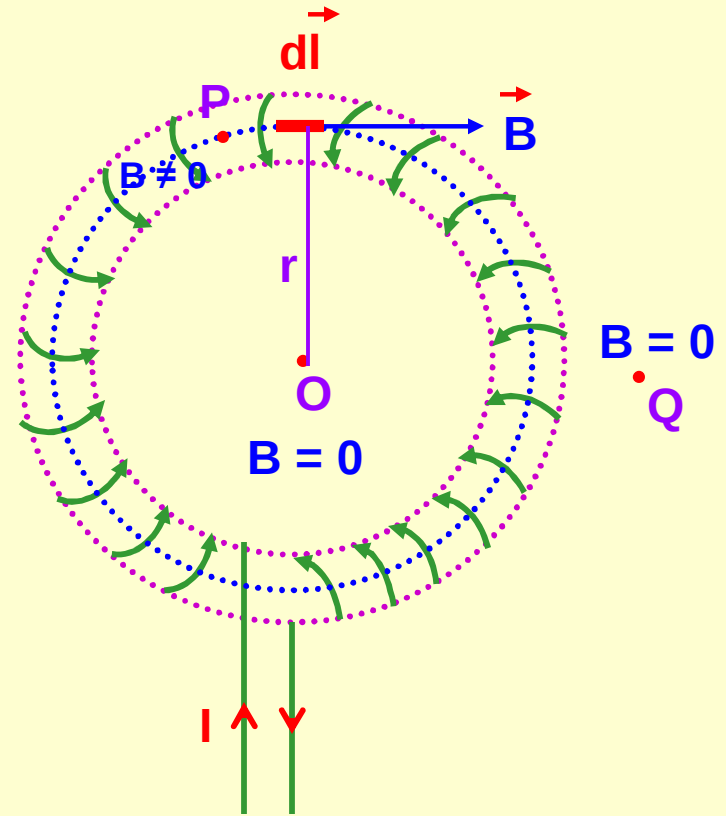
And $\mu_0 I_0 = \mu_0 n (2\pi r) I$

$$\therefore \boxed{B = \mu_0 n I}$$

NOTE:

The magnetic field exists only in the tubular area bound by the coil and it does not exist in the area inside and outside the toroid.

i.e. B is zero at O and Q and non-zero at P .



End of Magnetic Effect of Current !