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Betatron :- It is a device to accelerate electrons (i.e, β- particles) to very high energies. It is based on the principle of electromagnetic induction. It was devised by D. W. Kerst in 1941. Unlike the cyclotron in which orbit radius of orbiting particles increases continuously the electrons in a betatron are kept in a stable orbit.

Construction :- It consists of a doughnut shaped vacuum chamber between the pole pieces of an electromagnet. The electromagnet is energised by an alternating current. The electrons to be accelerated, produced by an electron gun are allowed to move in a stable circular orbit in the vacuum chamber (fig 1). To make the electrons move in stable orbit the pole pieces of electro-magnet are so shaped that they produced a much stronger field in the central space than at its circumference.

The varying magnetic field, acting parallel to axis of vacuum tube causes two effects on electrons viz.

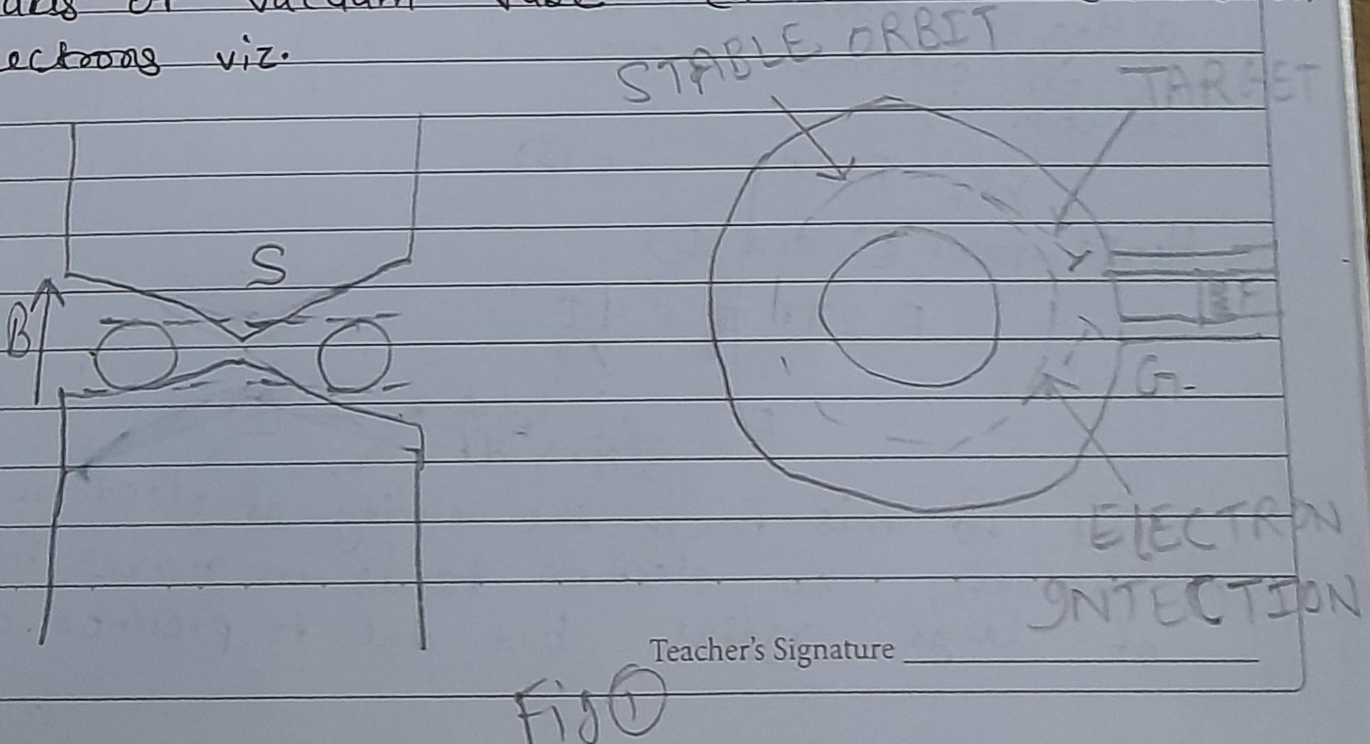

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Fig 1

(i) The changing magnetic flux, due to varying magnetic field, causes an induced e.m.f. which imparts energy to electrons.

(ii) The magnetic field deflects the electrons to confine them in a region of varying flux.

Theory:- Let us consider an electron moving in a circular orbit of radius r in a magnetic field at right angles to the plane of the orbit. The magnetic field is non uniform in space and due to flow of alternating current it varies with time. If ϕ is the magnetic flux linked with the orbit, then the flux increases at the rate of $\frac{d\phi}{dt}$, so that the induced e.m.f. in the orbit is given by

$$E' = \frac{d\phi}{dt} \quad \text{— (1)}$$

The work done in the electron of charge $(-e)$ in one revolution

$$W = -eE' = e\frac{d\phi}{dt} \quad \text{— (2)}$$

If E is tangential force acting on electron, then work down on electron in one revolution is

$$W = F\,2\pi r \quad \text{— (3)}$$

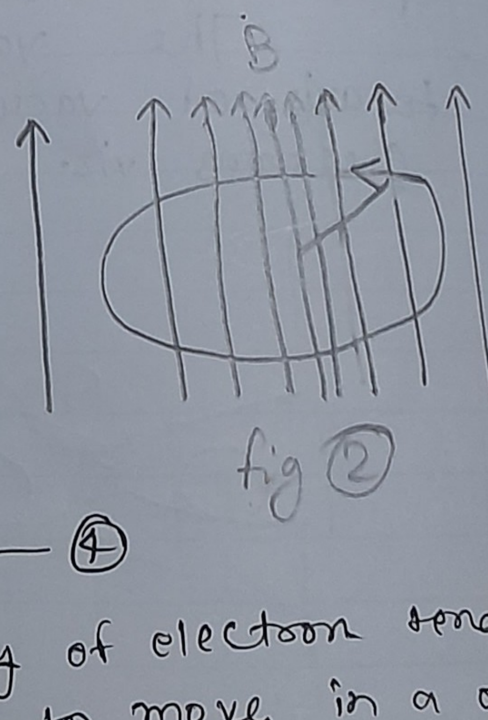

fig (2)

Hence from (2) and (3)

$$F\,2\pi r = e\frac{d\phi}{dt}$$

$$F = \frac{e}{2\pi r}\frac{d\phi}{dt} \quad \text{— (4)}$$

Dut to this force the velocity of electron tends to increase, so electron tends to move in a orbit of large radius, but due to presence of magnetic

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field the electron also experiences a radially inward force evB and for circular orbit

$$evB = \frac{mv^2}{r}$$

∴ momentum of electron, $p = mv = eBr$

From Newton's II law of motion

$$F = \frac{dp}{dt} = \frac{d}{dt}(eBr) = er\frac{dB}{dt} \quad \text{—— (5)}$$

To maintain a constant radius orbit, the values of F given by (4) and (5) must be numerically equal i.e,

$$\frac{e}{2\pi r}\frac{d\phi}{dt} = er\frac{dB}{dt}$$

$$\therefore \quad d\phi = 2\pi r^2 dB$$

Integrating $\int_0^{\phi} d\phi = \int_0^{B} 2\pi r^2 dB$

$$\boxed{\phi = 2\pi r^2 B} \quad \text{—— (6)}$$

If the field were uniform throughout the orbit, the flux would have been $\phi' = B \cdot \pi r^2$.

But eqn (6) represents the flux twice of this flux i.e, eqn (6) represents that in order to maintain a stable radius, we must arrange the magnetic field twice at the position of stable orbit what it

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would have been for uniform constant magnetic field.
That is why the pole pieces are so designed that they make the magnetic flux density at the centre of the orbit more than that at the edges. Eqn ⑥ is called the betatron condition.

Working :- Due to the flow of alternating current (ac) in electromagnet, the magnetic field produced varies as shown in fig ①. The electrons are injected into the chamber when magnetic field is instantaneously zero and just begins to rise. The electrons then move in increasing magnetic field which gives rise to induced emf responsible for accelerating electrons. During the time the magnetic field reaches its peak value, the electrons make several thousand revelutions and get accelerated. If they are allowed to accelerate more the decreasing magnetic field will cause the emf in reverse direction and hence will retard the electrons. Hence the electrons are extracted when the field becomes just maximum and tends to decrease by using auxiliary magnetic field to deflect them from their normal path.

These high energy electrons may be used to strike a target for production of X-rays or for transmutation work.

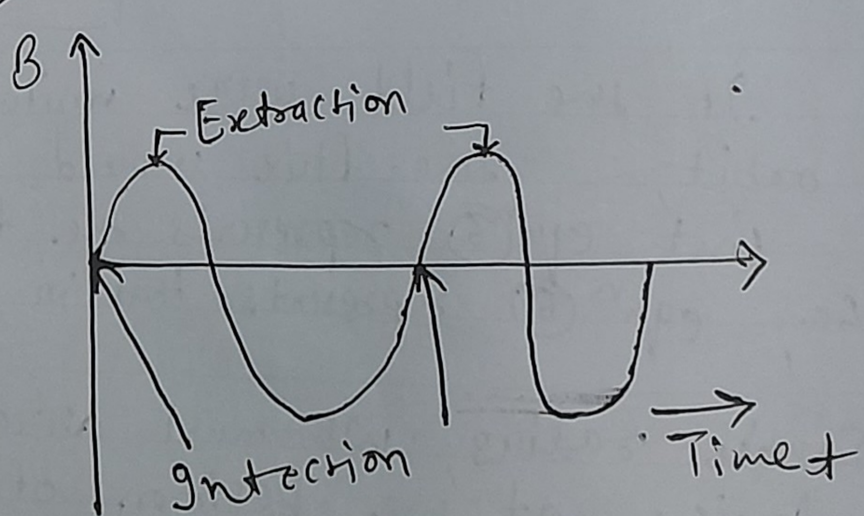

Fig ③