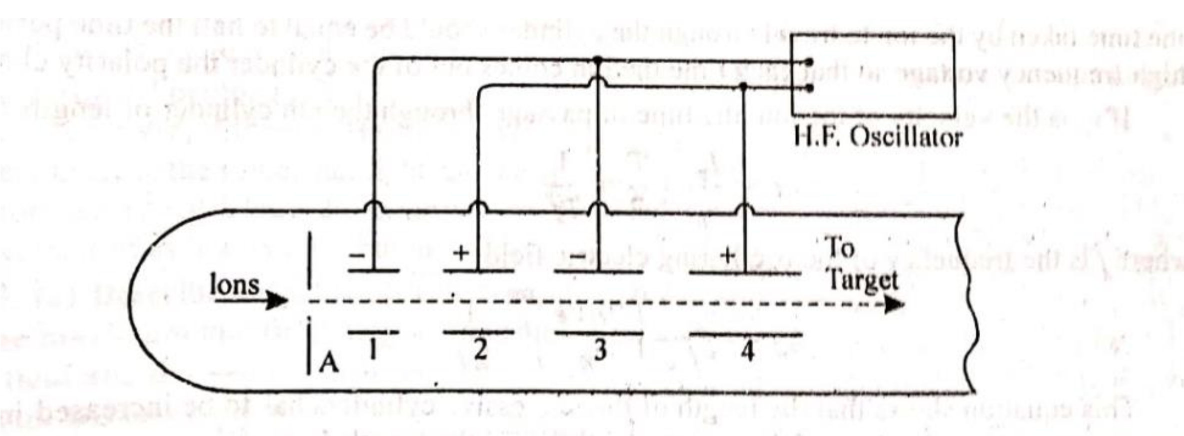
PARTICLE ACCELERATORS

A particle accelerator is a device which is used to impact high kinetic energy to the charged particles like electrons, protons, deutrons, alpha particle etc.

Radiations from certain natural radioactive sources cannot be of much use when the particles are used in certain nuclear targets. For this purpose very high cles are energy particles are required. Such high energy particles can be produced by particle accelerators. Using these accelerations particles of hundreds or thousands of Mev. Energies can be produced.

Different types of particle accelerators are Linear Accelerator(LINAC) and Circular Accelerator(CYCLOTRON)

A linear **accelerator** (LINAC) is a device which accelerates charged particles in a straight line by means of oscillating electric field that provides either a series of steady accelerating steps in correct phase at a series of gaps between electrodes the charged particles as a travelling wave.



In a linear accelerator, a moderate accelerating potential is applied a number of times so that the charged particles are accelerated along a straight line. A simple form of the linear accelerator is shown in the figure. The charged particles or ions travel through an aperture A and move along the axis of a series of coaxial cylindrical electrode 1,2,3,4 etc. These cylindrical electrodes are known as drift tubes. The drift tubes are connected to an A.C. source of very high frequency oscillator so that alternate tubes have potentials of opposite sign. Thus in one-half cycle if tubes 1 and 3 are positive, 2 and 4 will be negative. After half a cycle the polarities are reversed i.e., 1 and 3 will be negative and 2 and 4 positive. Suppose a positive ion leaves A and is accelerated during the half cycle when the drift tube No 1 is negative with respect to A. If V is the potential of drift tube 1 with respect to A, then velocity v_1 of the ion on reaching the drift tube is given by

$$\frac{1}{2}mv_1=Ve$$

$$v_1=\sqrt{\frac{2Ve}{m}}$$

where e is the charge and m the mass of the ion. It is supposed that v_1 is small as compared to c the velocity of light so that the change in mass due to relativity effect is negligible. The ions are accelerated in the gap between the tubes but travel with constant velocity in the field free space within the tubes themselves. The length of the tube 1 is so adjusted that as the positive ions come out of it, the tube has a positive potential and the next tube No.2 has a negative potential, i.e., the potentials change sign. The positive ion is again accelerated in the space between the tubes 1 and 2 and on reaching the tube 2 its velocity v_2 is given by

$$\frac{1}{2}mv_2^2=2ve$$

$$V_2=\sqrt{2}\sqrt{\frac{2Ve}{m}}=\sqrt{2}\,v_1$$

This shows that $v_2$is $\sqrt{2}$ times v_1. In order that this ion on coming out of tube 2 may find tube 3 just negative and the 2 positive, it must take the same time to travel through the tube 2. As the velocity is $\sqrt{2}v_2$ the length of tube 2 must be $\sqrt{2}$ times the length of tube 1. For successive accelerations in successive gaps the tubes 1,2,3,4 etc., must have lengths proportional to 1,$\sqrt{2}$,$\sqrt{3}$,$\sqrt{4}$ etc.

Energy of the ion. If n is the number of gaps that the ion travels in the acceleration and v_n is the final velocity acquired by it, then velocity of the ion as it emerges out of the nth tube

$$V_n=\sqrt{n}\sqrt{\frac{2Ve}{m}}$$

Kinetic energy of the ion $\frac{1}{2}mv_n^2=nVe$

The final energy of the ions when they strike the target depends upon the overall length of the accelerator i.e., the total number of gaps and on the energy gained in each gap. The beam striking the target consists of pulses of particles. The number of pulses per second is equal to the frequency of the alternating voltage applied to the drift tubes.

Length of the cylinder. As the ion is accelerated in the gap between two cylindrical electrodes, the time taken by the ion to travel through the cylinder should be equal to half the time period of the high frequency voltage so that each time the ion comes out of the cylinder the polarity changes,

If v_n is the velocity of the ion, the time of passage through the nth cylinder of length L_n ,

$$t=\frac{Ln}{vn}=\frac{T}{2}=\frac{1}{2f}$$

where f is the frequency of the oscillating electric field.

Therefore $$L_n=\frac{vn}{2f}=\left(\frac{2nVe}{m}\right)^{1/2}\frac{1}{2f}$$

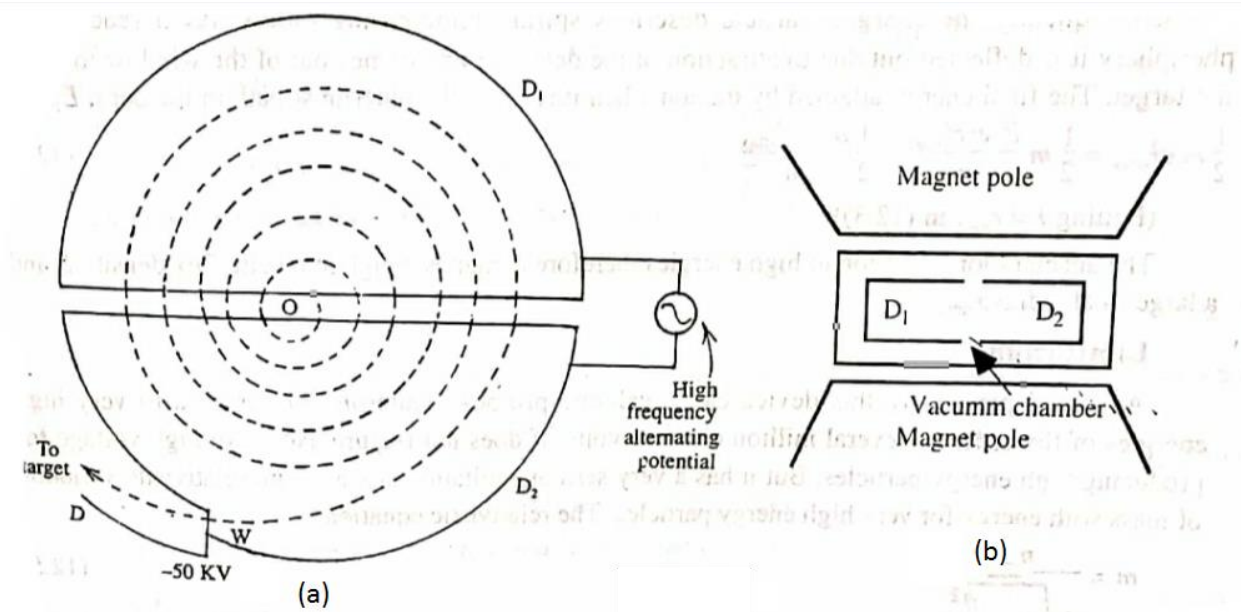
This equation shows that the length of the successive cylinders has to be increased in order to get a resonance acceleration of the ion at each gap and the length $L_n \propto n^{1/2}$

CYCLOTRON :-

This instrument for acceleration of charged like proton, deuteron, α-particle etc. was first devised in 1932. It is also known as magnetic resonance accelerator.

The principle of action of cyclotron can be explained with help of fig. (a) and (b).

It essentially consists of two flat semi-circular hollow metal boxes D_1, D_2 which are called dees because of their shapes. Across the dees is maintained a high frequency alternating potential difference. The dees are kept within an evacuated cylindrical steel tank placed between the poles of a powerful electromagnet which provides a uniform magnetic field [Fig.(b)]. The ion source O is situated near the mid point of the gap between the dees. After the acceleration is complete the ions are brought out of the chamber through a window W by the attraction of a deflecting metal plate D raised to a high negative potential.



Principle of operation

Let us consider a particle of charge e and mass m to be introduced with a velocity v into a uniform magnetic field of flux density B so that initially it travels normally to the field lines. Under the action of the force due to the magnetic field it will describe a circular path of radius r given by

$$\frac{mv^2}{r}=Bev \qquad \text{---------------(1)}$$

The frequency of revolution of the particle in the circular orbit is

$$f=v/2\pi r=Be/2\pi m \qquad \text{--------------(2)}$$

The frequency is constant for given values of B and e/m and is independent of the speed of the ion and the radius of the path. If the electric field reverses regularly at a frequency exactly equal to f, the field in the gap between the dees is always in right direction to accelerate the charged particle by an impulse each time the gap is crossed. This is known as the condition of resonance. But when the particle is inside the dees, it is in field free region and it describes a circular path of constant radius with uniform speed. As it crosses the gap between the dees it gets a kick and becomes accelerated and moves to semicircular path of larger radius given by

$$r=mv/Be \qquad \text{----------------}(3)$$

Consequently the charged particle describes spiral of increasing radius. As it reaches the pheriphery it is deflected out due to attraction of the deflector and comes out of the window to strike the target. The final energy attained by the ion when it reaches the outermost path in the dees,

$$E_{max} = ½\, mv^2_{max} = ½\, m\, B^2e^2r^2_{max}/m^2 = ½\, B^2e^2r^2_{max}/m \quad \text{--------}(4)$$

Putting $r = r_{max}$ in equation (3)

The acceleration of an ion to high energies therefore demands a high magnetic flux density B and a large final radius r_{max}.

Limitations

As stated previously this device can accelerate protons, deuterons, α-particles to very high energies of the order of several million electron volts. If does not require excessive high voltage for producing high energy particles. But it has a very serious limitation arising from relativistic variation of mass with energy for very high energy particles. The relativistic equation

$$m = m_0/\sqrt{1-v^2/c^2} \qquad \text{--------------}(5)$$

when used in equation (2)

$$f = e/m * Bc^2/2\pi\, c^2 = ½\pi * Bec^2/(m_0 + E_k) \qquad \text{---------}(6)$$

where m_0 is the rest mass of the particle and E_k its kinetic energy when the velocity is v.

Thus as the speed of the particle increases, f decreases and the spiraling particle lags in phase behind the accelerating voltage. Hence the acceleration stop. The relativistic mass increase with velocity thus limits the maximum energy attainable for a particle. In order that the resonance condition still remains valid and the particle gets accelerated, it is necessary to modify the frequency of oscillation of the alternating potential difference applied suitably. This is achieved in the modification known as synchrocyclotron. The above discussion will also apply to the case of electron which is impractical to be accelerated by cyclotron. In this case the relativistic mass increase over the rest mass is considerable and the resonance condition fails for electrons of moderate energies.