CYCLOTRON

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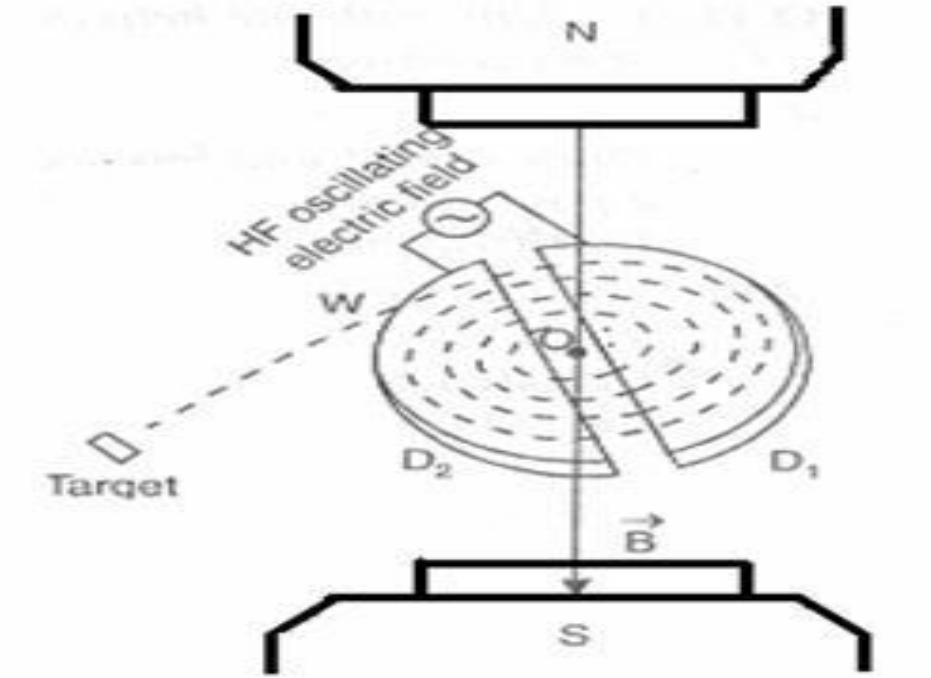
CONSTRUCTION

CYCLOTRON

➢The cyclotron is shown in fig. It consists of two hollow flats semicircular metal boxes. D_1 and D_2 called the Dees on account of their shape like the letter D. The two Dees are separated by a narrow parallel gap.

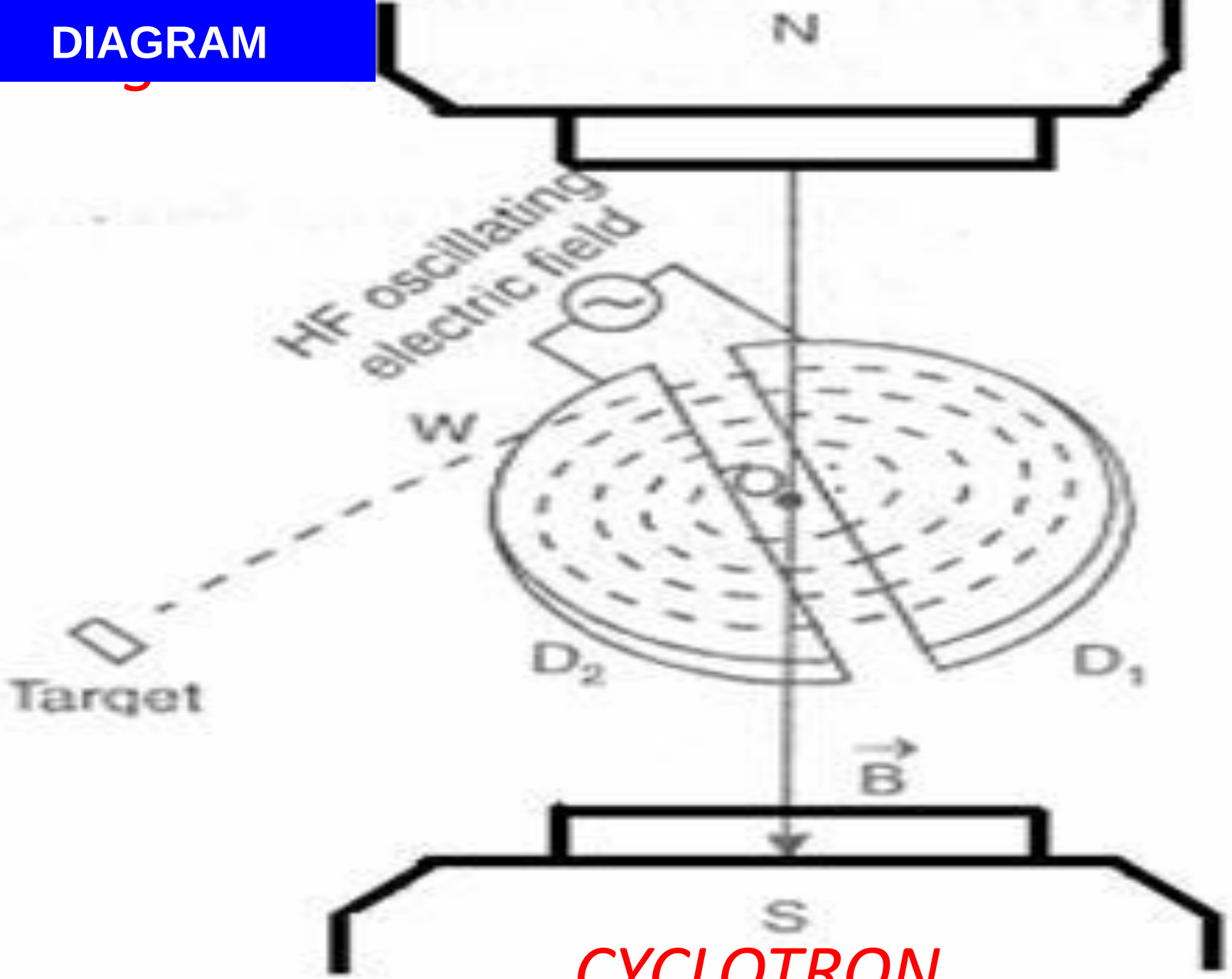
➢A high frequency oscillator, which provides an alternating potential of the order of 10^4 to 10^5 volts at a frequency and of 10^7 cycles, is connect between the two Dees.

➢The oscillator establishes an alternating electric field in the air gap i.e. the electric field is once directed towards D_1 and them towards D_2. Thus D_1 and D_2 becomes alternately positive and negative at the same rate as the frequency of the oscillator.



➢A source S is placed at the centre of the Dees which supplies the positive ions to be accelerated. These Dees are mounted inside a vacuum chamber. The chamber is mounted horizontally between the pole pieces of a huge electromagnet capable of producing a vertical field of about 1.6 $Wb.m^2$.

DIAGRAM



CYCLOTRON

WORKING

•The positive ions emitted from the source will be accelerated in the gap towards the Dee which is negative at the time. Let it be D_2.Since there is no electric field inside the Dees, the positive ions move with constant velocity along circles of constant radius under the influence of magnetic field which is perpendicular to the Dees.

•If by the time the ions emerge from D_2 , the polarity of the applied potential is reversed (i.e. the dee D_1 now becomes negative.) The positive ions will again face the negative dee and thus will be again accelerated by the field in the gap.

•Since their velocity is increased, they will now move through D_1 along circular arc of greater radius as shown in the Fig. 6.16.1. Here the time of passage to complete the semicircle in the dee remains the same as in D_2.

If the time of travel in D_1 is equal to half the time period of the oscillator voltage, the positive ions after coming from D_1 will find the reversed fielfd and hence they are accelerated again in the gap D_1, D_2.

•In this way, the positive ions move faster and faster moving in over expanding circles until they reach the outer edge of the dees where they are deflected by deflector plate and strike the target.

•Here it should be remembered that the time required for the positive ions to make one complete turn within dees is the same for all speeds, and is equal to the time period of the oscillator.

THEORY

- When a particle of mass **m** and charge **q** moves with a velocity **v** in the magnetic field of flux density **B**, then the radius **r** of the circular path is given by,

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

$$r = mv/qB \quad ----1$$

For resonance between the applied A. C. voltage and the moving particle the time taken by the particle to travel the circular arc within any of the dees must be equal to half the time period of the applied oscillator voltage.

$$\frac{\pi r}{v} = \frac{t_0}{2} \text{..or ..} t_0 = \frac{2\pi r}{v} \text{....2}$$

From Equations (1) and (2) we have.

$$\text{..} t_0 = \frac{2\pi}{v} . mv \Big/ qB = \frac{2\pi m}{qB} = cons \tan t ----3$$

Now the orbital frequency or the cyclotron frequency f_0 is given by

$$\text{..} f_0 = \frac{1}{t_0} = \frac{qB}{2\pi m} ----4$$

The value of q/m being fixed for an ion hence the value of f_0 is adjusted corresponding to B .

Now the ion will have maximum energy when it will travel at the boundary of dee. If the outside radius of dee is R_m then according to Equation (.1), the maximum velocity v_m of the ion may be written as,

$$V_m = \frac{R_m qB}{m} ----5$$

And so the maximum kinetic energy of the ion will be given by,

We know that MeV = 1.6×10^{-13} Joules,

$$E = \frac{1}{2} mV_m^2 = \frac{R_m^2 q^2 B^2}{2m} \text{.. joules} \quad ----6$$

We know that MeV = 1.6×10^{-13} Joules

$$E_m = \frac{R_m^2 q^2 B^2}{2m \times 1.6 \times 10^{-12}} .. MeV =$$

Conclusions regarding operation of cyclotron

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:

•From Equation (5), we have,

$$V_m = \frac{R_m qB}{m} - - - - 5$$

i.e. v ∝ R, if B and q/m are constant

.This means that the proton takes the same time to cover the 'dees' irrespective of whether it $\frac{q}{m}$ moves along a circle of smaller radius or larger radius, so long as the magnetic field B and mass/charge ratio of the moving proton, remains constant .

$$..t_0 = \frac{2\pi m}{Bq}. = \frac{1}{f_0}$$

. Form eq (6) therefore f is proportional to B constant value e/m .it explain that higher the cyclotron oscillating frequency , stronger will be the magnetic field required. But in practices f_0 is kept fixed value of magnetic field B is adjusted till resonance is obtained.

Limitation of Cyclotron :

•The maximum available particle energy from a cyclotron given by Equation (6)) is limited by various factors given below :

i) The maximum strength of the magnetic field which can be produced.

ii) The frequency and power limit of the cyclotron oscillator (as given by Equations (6)

iii) Apparently with increasing R the velocity of the moving proton increases, so that when it emerges from the window, it will have maximum energy. But this proton energy in a cyclotron is limited due to variation in mass of the proton with its velocity. According to Einstein`s theory of relativity, Substituting this value in Equation (6) we get.

$$..m = \frac{m}{\sqrt{1 - \frac{V^2}{c^2}}} = - - - - 7$$

$$..T = \frac{2\pi}{Bq} \frac{m_0}{\sqrt{1 - \frac{V^2}{c^2}}} = - - - - 8$$

Thus, with increase in the value of the velocity (v) of the proton, the time (T) required by the proton to complete the semicircular shaped 'deep' increases. Hence the proton would lag behind the applied a.c. voltage. T