SENGAMALA THAYAAR EDUCATIONAL TRUST WOMEN'S COLLEGE,

Class: III B.Sc., PHYSICS

Subject: NUCLEAR PHYSICS

Subject Code: 16SCCPH8

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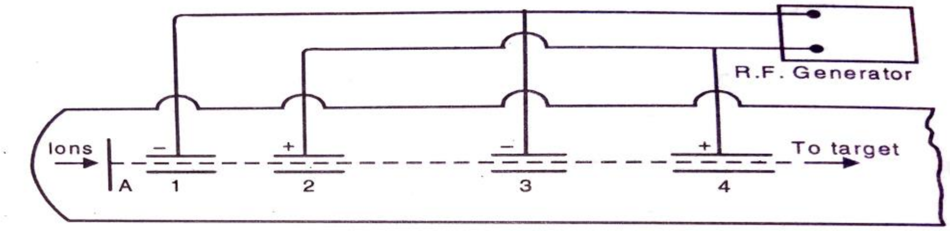
LINEAR ACCELERATOR

It consists of a series of coaxial hollow metal cylinders or drifts tubes 1, 2, 3, 4, etc. They are arranged linearly in a glass vacuum chamber. The alternate cylinders are connected together, the odd-numbered cylinders being joined to one terminal, and the even-numbered ones to the second terminal of an H.F. oscillator. 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. The ions are accelerated only in the gap between the tubes where they are acted upon by the electric field present in the gaps. The ions travel with constant velocity in the field-free space inside the drift tubes.



Positive ions enter along the axis of the accelerator from an ion source through an aperture A. Suppose a positive ion leaves A and is accelerated during the half-cycle, when the drift tube 1 is negative with respect to A. Let 'e' be the charge and 'm' the mass of the ion and V potential of drift tube 1 with respect to A. Then velocity v1 of the ion on reaching the drift tube is given by

$$\frac{1}{2}mv_1^2=Ve \quad \text{or} \quad v_1=\sqrt{\frac{2Ve}{m}}$$

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 (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. On reaching the tube 2, the velocity v2 of the positive ion is given by

$$\frac{1}{2}mv_2^2=2Ve \quad \text{or} \quad v_2=\sqrt{2}\sqrt{\frac{2Ve}{m}}=\sqrt{2}\, v_1$$

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 tube 2 positive, it must take the same time to travel through the tube 2. Since $v_2=\sqrt{2}v_1$, 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, etc., must have lengths proportional to 1, $\sqrt{2}$, $\sqrt{3}$ etc. ie., $l_1:l_2:l_3:1:\sqrt{2}:\sqrt{3}$

Energy of the ion:

If n = the number of gaps that the ion travels in the accelerator and v_n = the final velocity acquired by the ion, then

Velocity of the ion, as it emerges out of the n^{th} tube = $\sqrt{n}\sqrt{\frac{2Ve}{m}}$

K.E acquired by the ion $\frac{1}{2} mv_n^2=nVe$

Thus the final energy of the ions depends upon (i) the total number of gaps and (ii) the energy gained in each gap.

The limitations of this accelerator are:

(i) The length of the accelerator becomes inconveniently large and it is difficult to maintain vacuum in a large chamber.

(ii) (ii) The ion current available is in the form of short interval impulses because the ions are injected at an appropriate moment.

CYCLOTRON

Construction

The Figure shows the cyclotron consists of two hollow semicircular metal boxes, D1, D2 called "dees". A source of ions is located near the mid-point of the gap between the "dees". The "dees" are insulated from each other and are enclosed in another vacuum chamber. The "dees" are connected to a powerful radio-frequency oscillator. The whole apparatus is placed between the pole-pieces of a strong electromagnet. The magnetic field is perpendicular to the plane of the "dees".

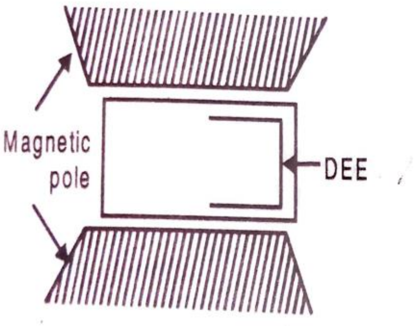


Fig. 30.6

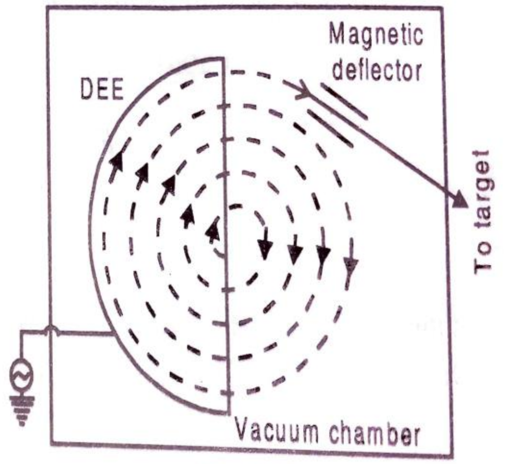


Fig. 30.7

Suppose a positive ion leaves the ion source at the center of the chamber at the instant when the "dees" D_I and D_2 are at the maximum negative and positive A.C. potentials respectively. The positive ion will be accelerated towards the negative dee D_I before entering it. The ions enter the space in-side the dee with a velocity v given by $Ve = 1/2\ mv^2$, where V is the applied voltage, and e and m are the charge and mass of the ion respectively. When the ion is inside the "dee" it is not accelerated since this space is field free. Inside the dee, under the action of the applied magnetic field, the ions travel in a circular path of radius r given by

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

Where B= the flux density of the magnetic field

$$r = mv/Be \qquad \text{--------} \ (2)$$

The angular velocity of the ion in its circular path

$$\omega = \frac{v}{r} = \frac{Be}{m} \qquad \text{-------} \ (3)$$

The time taken by the ion to travel the semicircular path

$$t = \frac{\pi}{\omega} = \frac{\pi m}{Be} \qquad \text{-------} \ (4)$$

Suppose the strength of the field (B) or the frequency of the oscillator (f) are so adjusted that by the time the ion has described a semicircular path and just enters the space between D_I and D_2, D_2 has become negative with respect to D_1. The ion is then accelerated towards D_2 and enters the space inside it with a greater velocity. Since the ion is now moving with greater velocity, it will describe a semicircle of greater radius in the second dee. But from equation $t = \frac{\pi m}{Be}$ .It is clear that the time taken by the ion to describe a semicircle is independent of both the radius of the path (r) and the velocity of the ion (v). Hence the ion describes all semicircles, whatever are their radii, at exactly the same time. This process continues until the ion reaches the periphery of the dees. The ion thus spirals round in circles of increasing radius and acquires high energy. The ion will finally come out of the dees in the direction indicated, through the window.

The energy of an ion:

Let r_{max}, be the radius of the outermost orbit described by the ion and v_{max}, the maximum velocity gained by the ion in its final orbit. Then the equation for the motion of the ion in a magnetic field is

$$Bev_{max} = \frac{mv_{max}^2}{r_{max}} \qquad \text{---------} \ (5)$$

$$v_{max} = B\frac{e}{m}r_{max}$$

The energy of the ion

$$E=\frac{1}{2}mv_{max}^{2}=\frac{B^{2}rmax^{2}}{2}\frac{e^{2}}{m} \qquad \text{--------} \ (6)$$

The condition for acceleration of the ion in the inter-dee gap is that

The time taken by the ion to travel the semicircular path = Half the time period of oscillation of the applied high frequency voltage

$$\frac{\pi m}{Be}=\frac{T}{2} \text{ or } T=\frac{2\pi m}{Be}$$

Frequency of the oscillator

$$f=\frac{Be}{2\pi m} \qquad \text{------------} \ (7)$$

Hence the energy of the ion is given by

$$E=2\pi^{2}r_{max}^{2}f^{2}m \qquad \text{-------} \ (8)$$

The particles are ejected out of the cyclotron not continuously but as pulsed streams.

Limitations of the Cyclotron

The energies to which particles can be accelerated in a cyclotron are limited by the relativistic increase of mass with velocity. The mass of a particle, when moving with a velocity v is given by $m=\frac{m_o}{\sqrt{1-v^2/c^2}}$ where m_o is the rest mass and c the velocity of light.According to equation (4),

The time taken by the ion to travel the semicircular path

$$t=\frac{\pi m}{Be}=\frac{T}{2}$$

Frequency of the ion $n=\frac{1}{T}=\frac{Be}{2\pi m}$ or $n=\frac{Be}{2\pi m_{o}}\sqrt{1-\frac{v^{2}}{c^{2}}}$

Therefore, the frequency of rotation of the ion decreases with an increase in velocity. The ions take a longer time to describe their semicircular paths than the fixed period of the oscillating electric field. Thus, the ions lag behind the applied potential and finally, they are not accelerated further. Due to this reason, the energy of the ions produced by the cyclotron is limited. This limitation can be overcome in the following two ways.

Now the frequency of the ion$\frac{Be}{2\pi m_{o}}\sqrt{1-\frac{v^{2}}{c^{2}}}$

Field variation

The frequency of the ion can be kept constant by increasing the magnetic field (B) at such a rate that the product B$\sqrt{1-\frac{v^2}{c^2}}$ remains constant. For this purpose, the value of the magnetic field B should increase, as the velocity of the ion increases, so that the product B$\sqrt{1-\frac{v^2}{c^2}}$ remains unchanged. This type of machine in which the frequency of the electric field is kept constant and the magnetic field is varied is called a synchrotron.

Frequency modulation

In another form of apparatus, the frequency of the applied A.C. is varied so that it is always equal to the frequency of rotation of the ion. This type of machine in which the magnetic field is kept constant and the frequency of the applied electric field is varied is called a frequency-modulated cyclotron or synchro-cyclotron

Betatron

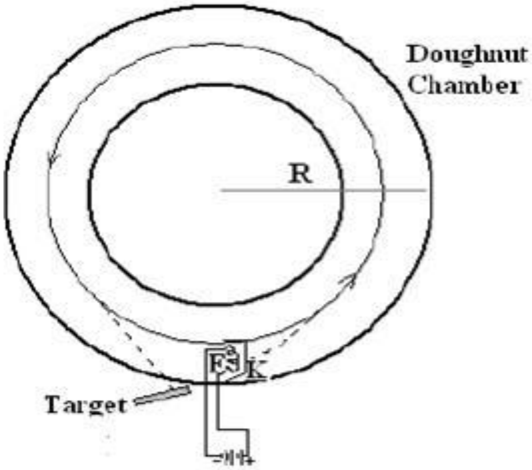
A Betatron was developed by D W Kerst to accelerate the electrons to high energies.

Principle

The principle of the Betatron is same as that of the transformer. In transformer, if an alternating current is passed through the primary coil an alternating magnetic field will appear in the coil. This field produces an induced *e.m.f.* in the secondary coil. Similarly the changing magnetic flux induces an *e.m.f.* tangentially along a circular path for the electron which accelerates the electrons to high energies. The electrons is kept accelerating in circular path of constant radius with the help of increasing magnetic field.

Construction

The Betatron is consists of an evacuated doughnut chamber in which electrons are produced by indirectly heated cathode. The doughnut tube is placed between two strong electromagnet such that, when the a.c current is passed in the electromagnets the flux increases in the centre of doughnut (single coil).



Working

When the electron appears at K (cathode) in doughnut tube and the electromagnets are energized the magnetic field increases, the increasing magnetic field has two effects

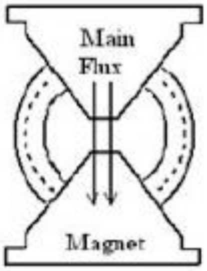
(i) Induced e.m.f. is produced in electron orbit by changing magnetic flux that gives an additional energy to electron. According to Faraday's law

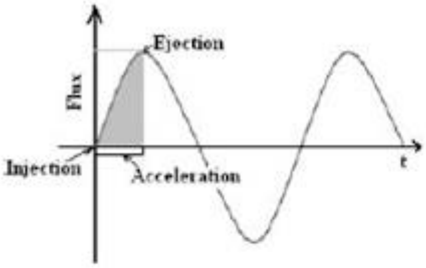
induced $e.m.f = -\frac{d\phi}{dt}$........(1)

(ii) A radial force (magnetic force) is produced by action of magnetic field whose direction is perpendicular to the electron velocity which keeps the electron moving in circular path. The force is balanced by centripetal force, i.e.,

$qvB = \frac{mv^2}{r}$,............(2)

The particle acceleration occurs only with increasing flux (the duration when the flux increases from zero to a maximum value) i.e., the first quarter of the a.c. cycle (T/4 sec), after this the flux starts decreasing which result in decreasing velocity therefore the electron is kept in the tube only for T/4 sec. As the electrons get faster they need a larger magnetic field to keep moving at a constant radius, which is provided by the increasing field.





Betatron Condition

Induced e.m.f in the coil from Faraday's law of electromagnetic induction

$$e.m.f = -\frac{d\phi}{dt}$$

Work done on an electron in one revolution

$$W = e.m.f \times chargeofelectron$$

$$W = e\frac{d\phi}{dt}$$

Work done = tangential Force 'F' on electron x distance traveled in one revolution

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

$$F = \frac{e}{2\pi r}\frac{d\phi}{dt} \text{..................................(3)}$$

The electron moves in circular path. The magnetic force is balanced by centripetal force, i.e.,

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

$$eBr = mv = p \text{.........................(4)}$$

From Newtons second law radial force

$$F = \frac{dp}{dt} = \frac{d(mv)}{dt}$$

$$F = \frac{d(eBr)}{dt}$$

In order to maintain path of constant radius (r is constt.)

$$F = er\frac{dB}{dt} \text{ ....(5)}$$

Equations 3.13 and 3.15 are equal, equating both

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

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

Integrating the above equation

$$\phi = 2\pi r^2 B \text{.............(6)}$$

The relation is known as Betatron condition**.** It shows that to ensure that the electron moves in circular path of constant radius, the magnetic flux within the orbit of radius R is always twice what it would have been if magnetic field were uniform throughout the orbit.

Energy Gained by Electron

The particles have maximum energy when the magnetic field is at its strongest value but the formula used for the cyclotron will not work for Betatron because the electron motion is relativistic. However, if the total energy is much greater than the rest energy then

$E = pc$....................(7)

As the centripetal force is again provided by the Lorentz force, The momentum of the electron will

$eBr = mv = p$

and hence Energy

$\boldsymbol{E = Berc}$...........(8)

Number of Revolutions Taken by Electron

In T/4 seconds if the electron takes N revolutions in circular path of constant radii then the total distance traveled by the electron in gaining the maximum energy E is

$$S = N \times 2\pi r$$
$$N \times 2\pi r = c \times \frac{T}{4}$$
$$N = \frac{c}{4 \times 2\pi f \times r}$$

$\boldsymbol{N = \frac{c}{4\omega r}}$.............(9)

Average Energy Gained per Revolution

Average energy gained per revolution (E_{av}) will be given as

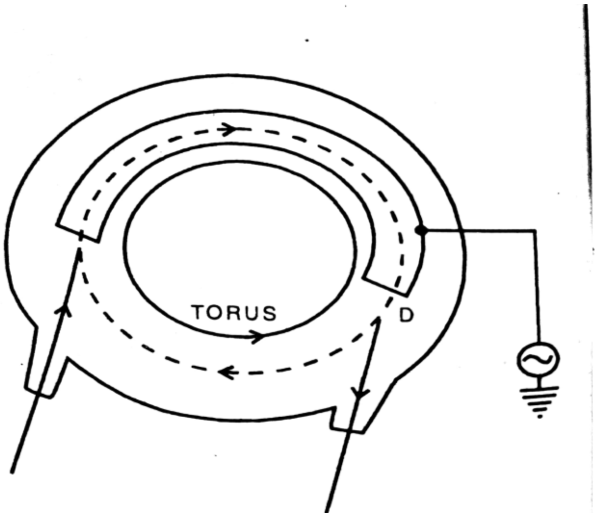
$\boldsymbol{E_{av} = \frac{E}{N}}$.......(10)

where E =Total energy gained by electron and

N = Number of Revolutions taken

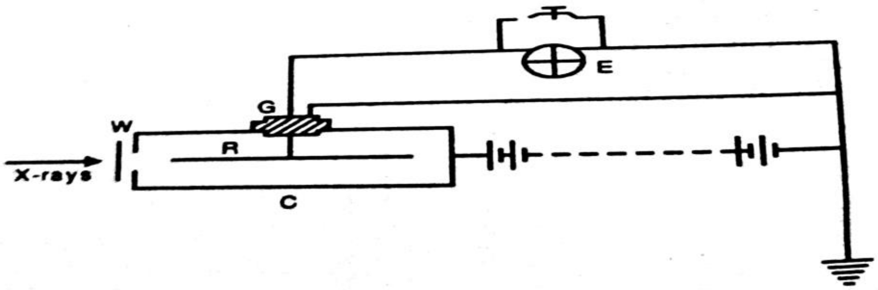
Electron synchrotron

The electron synchrotron is based on the principle of the combined working of Betatron and cyclotron. Electrons are injected into an orbit of fixed radius at an initial energy of about 50 t0 80kev. The main accelerating tube, the torus, is made of glass or some plastic with a circular dee (D) made of a metal. An alternating potential is dee (D) made of metal. An alternating potential is applied to the dee as shown in fig. A varying magnetic field is applied perpendicular to the torus. The radius of the orbit is kept constant by increasing the magnetic field as in a Betatron. The increments of energy are given, as in a cyclotron, at the beginning and ending of the D. the electrons, after acceleration, are made to strike the required target. Using tungsten as target, very hard X rays of energy about 300 Mev have been produced.



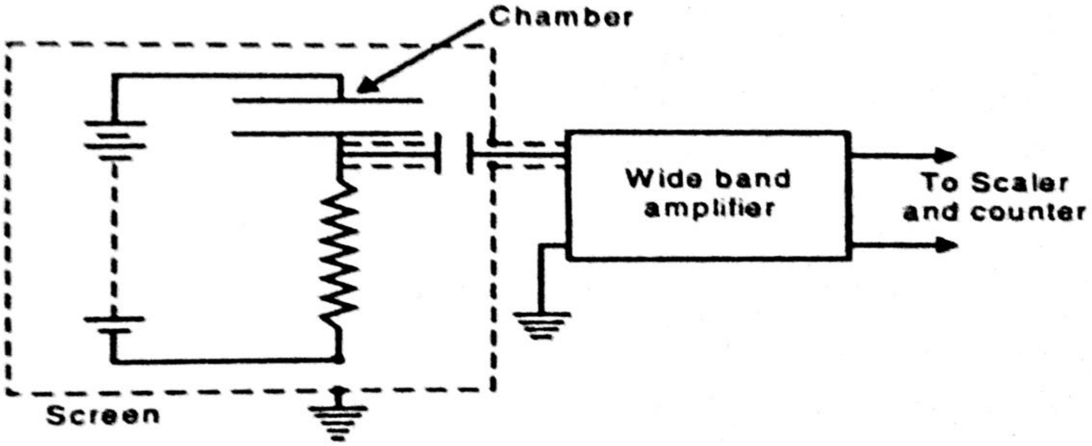
IONIZATION CHAMBER

The principle employed here is that charged sub atomic particles can ionic gases. The number of ion pairs produced gives us information not only on the nature of the incident particles, but even on their energy. The ionization chamber consists of a hollow metallic cylinder C, closed at both ends, with a window W at an end for the entry of the ionizing particles or radiation. A metal rod R, well insulated from the cylinder, is mounted coaxially within the cylinder. R is connected to quadrant electrometer E. A p.d of several hundred volts is maintained between C and R. An earthed guard ring G prevents leakage of charge from the cylinder to the rod. The chamber contains some gas like sulphur dioxide or methyl bromide .when a charged particles enters the chamber; it produces a large number of ion pairs in the enclosed gas, along its path. Positive ions move towards R and negative ions towards C.



The quadrant electrometer E measures the rate of deposition of positive charges on R. The ionization currents produced are quite small= 10-12 – 10-15 amperes. Special electrometers and D.C amplifying devices have to be employed to measure such small currents.

If individual particles are to be counted, then the pulses of current, produced are fed to a pulse amplifier, which is joined to the ionization chamber by a coupling capacitor.



Uses

- Ionisation chambers have been used to study α particles, β particles, protons, electrons and nuclei of lighter elements. Ionisation chambers were extensively used in the early studies of cosmic ray phenomena.
- Ionisation can also be used for measurements on X rays and γ rays. For neutron detection, the chamber is filled with boron compound in the form of a paste.
- An ionization chamber is much less sensitive to β particles because β particles produce fewer pairs of ions in their passage through the chamber.
- For detecting γ rays, an ionization chamber of thick wall made of high atomic number material is employed. The γ rays impinging on the walls of the chamber eject high speed electrons which produce ionization in the gas.

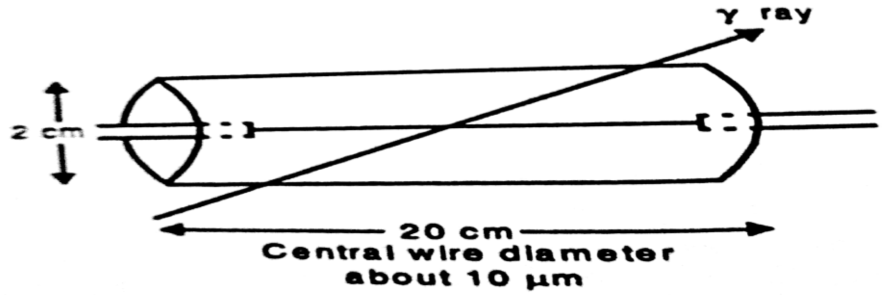
PROPORTIONAL COUNTER

The proportional counter consists of a cylindrical gas filled tube with a very thin central wire which serves as the anode. The outer cylinder serves as a cathode. The outer cylinder serves as a cathode. In the case of the simple ionization chamber, the pulse height generated by an event is proportional to the intensity of the beam. But because of the comparatively low applied voltages, the current produced is always very small.

If the voltage applied to an ionization chamber is increased past a certain value, the electrons acquire enough energy while moving toward the anode to create further ion pairs along the way. Resulting avalanche of secondary electrons that reaches the anode may represent a multiplication factor of as much as 1000 with a correspondingly larger output pulse. In a certain range of applied voltages, the pulse size is proportional to the original number of ion pairs, and the device is called a proportional counter.

Since the central wire is very thin and the p.d fairly large, the electric field E= dV/dr at a distance r from the centre is very high. If b is the radius of the cylinder and a the radius of the wire, the radial field E at a distance r from the centre is given by

$$E = \frac{v}{r\log_e(\frac{b}{a})}$$

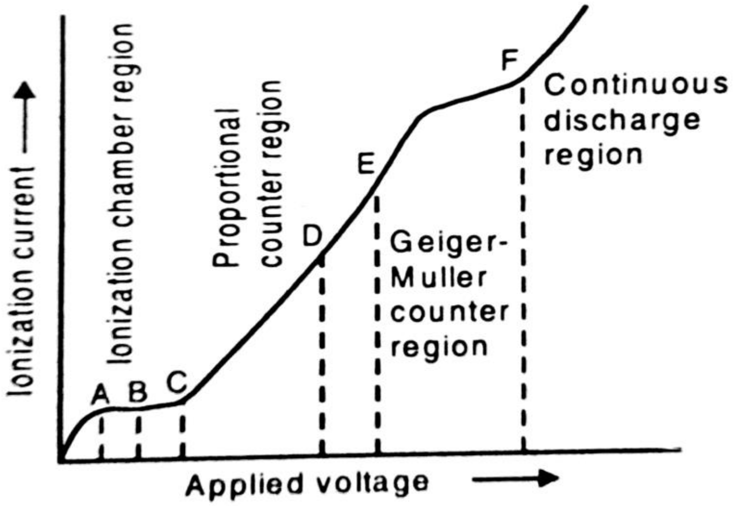


Where V is the positive voltage of the central wire relative to the outer cylinder. Thus in a proportional counter, the field strength near the wire is very great. Hence electrons travelling towards the wire are rapidly accelerated when near it, and produce additional electrons in that region due to the phenomena of ionization by collision. This process is called the gas multiplication.

The complete voltage pulse characteristics of this type of tube are shown in fig. The main regions used for measurements are

1. The ionization chamber region AB
2. The proportional counter region CD
3. The Geiger Muller region EF.
4. After the point F, the tube becomes a simple discharge tube in which the current is produced even after the ionization event has ceased.

Like the ionization chamber, the proportional counter gives single pulses of height proportional to the ionizing power of the radiation.



The G.M. Counter

Principle

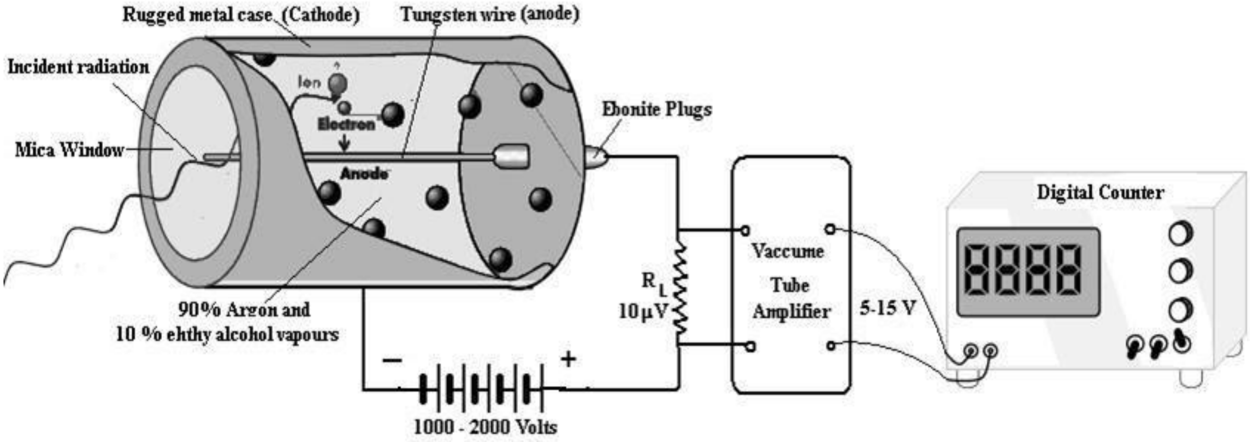
Radiation ionizes the gas through which they pass and produces few ions. If the applied voltage is strong enough, these ion produce a secondary avalanche and small voltage drop is recorded across the load. This voltage is amplified so that the counter can record it.

Construction

The G. M. tube consists of a rugged metal cylinder which acts as cathode. A wire of tungsten runs through the axis of the tube, it acts as anode. Cathode and anode are separated by ebonite plugs. Both the cathode and anode are connected with high DC battery (1000 – 2000 Volts). Heavy load is connected in series. At one end a thin window of mica is arranged to allow the entry of radiation in the tube. The tube is evacuated then is filled with 90% Argon at 10 cm pressure and 10% ethyl alcohol vapors at 1 cm pressure.

A dc potential about 1200 volt is applied between the cathode and anode. When the radiation enters in the GM tube through the mica window it ionizes few argon atoms. If the applied voltage is strong enough, these ion produce a secondary avalanche that causes a current pulse. The current through R_L produces a voltage pulse of the order of 10 □V. This voltage is amplified upto 5 -15 Volt by vacuum tube amplifiers and is then applied to the counter.

As each incoming radiation produces a pulse the number of radiation are counted.



Characteristic of G M Counter

The characteristic shows the plot of count / min as a function of voltage

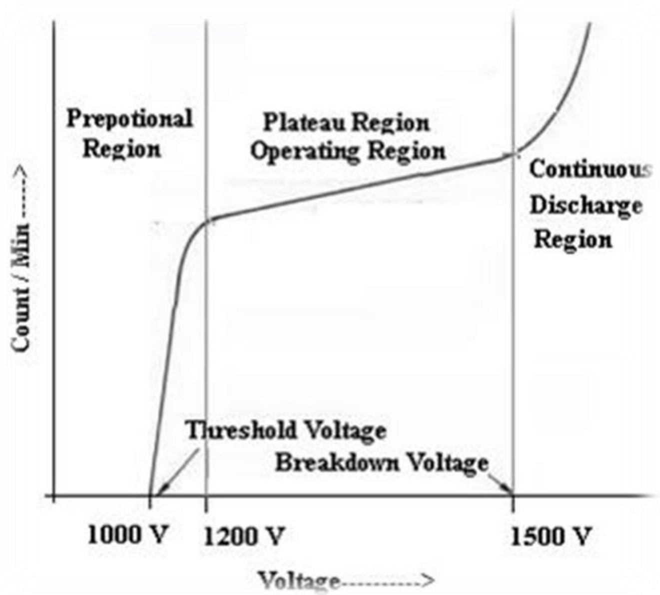
- For voltage less than 1000 Volt there is no discharge and hence no counts.
- Between 1000 – 1200 Volts, the number of count increases linearly with the applied voltage. The region is called proportional region
- Above 1200 Volt upto 1500 Volt the count rate shows least variation, almost constant the region is called the plateau region or Geiger region or Operating region.
- If the voltage is applied above 1500 volt a continuous discharge will take place, count rate increases rapidly due to discharge of Argon gas which is undesirable.

Quenching

It is the process to prevent the continuous discharge. Self quenching is done by vapors of ethyl alcohol because its ionization energy is less than the ionization energy of Argon atom.

Counting rate

The G M Counter can count about 5000 particles / sec. The counting rate depends upon the death and recovery time of G M Counter.



Death time

In the counter, the slowly moving positive argon ion takes 200 μsec to reach the cathode. If the second radiation enters the tube during this time, it will not be registered this time is called death time of the counter

Recovery time

After death time the tube takes another 200 μsec to regain the original working condition. This time is called recovery time of the counter.

Paralysis time

The sum of death and recovery time is known as paralysis time, which is 400 μ sec. The tube can respond to the second radiation after 400 μsec

True Count Rate

If the death time of the counter is τ and the count which is measured by the counter is n_o then, the true count rate n,

$$n = \frac{n_o}{1 - n_o\tau}$$

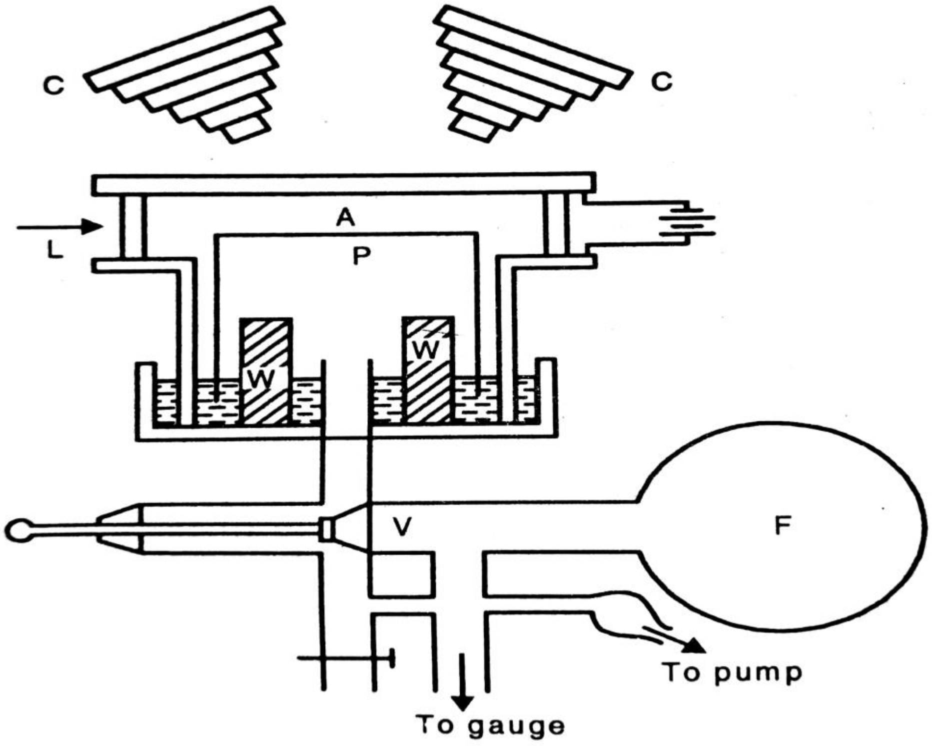
Cloud Chamber

Cloud chambers, also known as Wilson cloud chambers, are particle detectors that were essential devices in early nuclear and particle physics research. Cloud chambers, one of the simplest instruments to study elementary particles, have been substituted by more modern detectors in actual research, but they still remain very interesting pedagogical apparatus.

Like all elementary particles, electrons exhibit properties of both particles and waves: they can collide with other particles and can be diffracted like light.

Principle of Operation

The fundamental principle behind them is the super saturation of a vapor substance, a state in which the air, or any other gas, contains more vapour of that substance than it can hold in a stable equilibrium. An energetic charged particle (for example, an alpha or beta particle) interacts with the vapor mixture and creates a track of ions, which under super saturation conditions act as condensation nuclei around which a mist-like trail of small droplets form if the gas mixture is at the point of condensation.



Description:

The apparatus consists of a large cylindrical chamber A, with walls and ceiling made of glass .It contains dust free air saturated with water vapour. P is a piston working inside the chamber. When the piston moves down rapidly, adiabatic expansion of the air inside the chamber takes place. The piston is connected to a large evacuated vessel F through a valve V. When the valve is opened, the air under the piston rushes into the evacuated vessel F, thereby causing the piston to drop suddenly. The wooden blocks WW reduce the air space inside the piston. Water at the bottom of the apparatus ensures saturation in the chamber. The expansion ratio can be adjusted by alternating height of the piston.

As soon as the gas in the expansion chamber is subjected to sudden expansion, the ionizing particles are shot into the chamber through a side window. A large number of extremely fine droplets are formed on all the ions produced by the ionizing particles. These droplets form a track of the moving ionizing particles. At this stage, the expansion chamber is profusely illuminated by powerful beam of light L. Two cameras CC are used to photograph the tracks. The process of expansion, shooting of the ionizing particles into the expansion chamber, illuminating the chamber and clicking the camera must all be carried out in rapid succession in order to get satisfactory results.

The ionising agent can be easily identified from its path in the cloud chamber, ɑ particles, being comparatively massive, go straight and their paths are thick, straight and sharply defined particles being lighter, are easily deflected by collision and their paths are thin and crooked. The cloud chamber has led to the discovery of many elementary particles like positron, meson etc

Advantages

- cloud chambers can be used to study the variation of specific ionization along the track of a charged particle and the range of such particles.
- the sign of the electric charge and the momentum p of the particles can be determined if the chamber is placed in a strong magnetic field. Let a particle of mass m and charge q move with a velocity v perpendicular to the direction of the magnetic field of flux density B. the particle will be forced by the field to follow circular path of radius R. The magnetic force Bqv is exactly balanced by the centrifugal force mv^2/R

  Thus $Bqv = Mv^2/R$ or $mv = P = BRq$

The K.E of the particle can be calculated, if the rest mass energy m_oc^2 of the particle is known, by the relation.

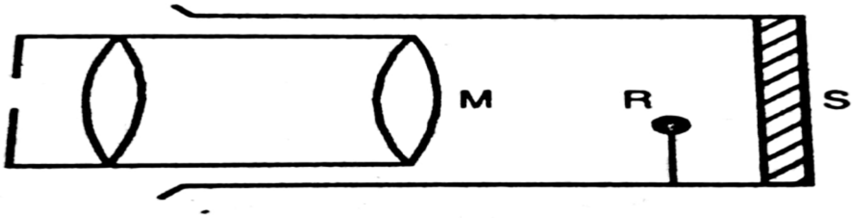
$$K.E = E_k = \surd(p^2c^2 + \surd(m_oc^2)^2 - m_oc^2$$

Limitations:

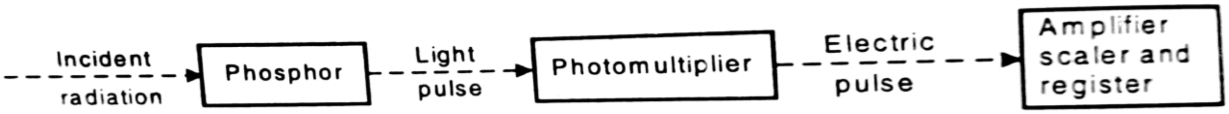
- one is not only sure of the sense of track photographed
- the range of the particle may exceed the dimensions of the chamber so that the whole track is not photographed.
- there remains a certain amount of uncertainty about the nature of the nuclei constituting the arms of the forked tracks.

THE SCINTILLATION COUNTER

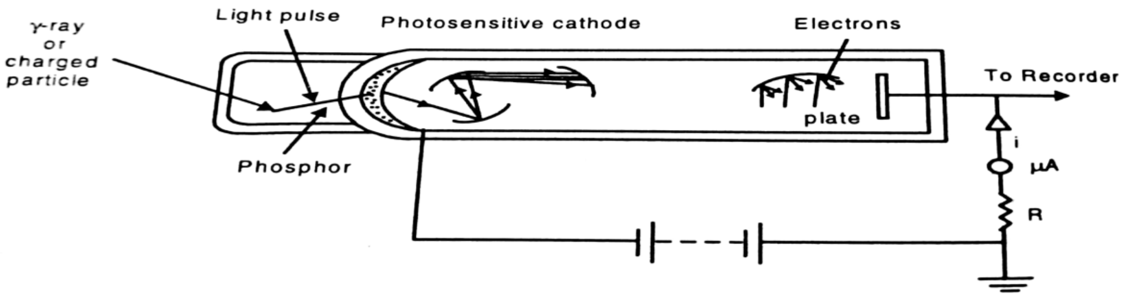
One of the earliest methods of radiation detection was the spinthariscope. It consists of a small wire, the tip of which is dipped in Radium bromide(R) or any other radioactive salt. It is placed in front of a zinc sulphide screen S and viewed through a microscope. When an α or β particles falls on the zinc sulphide screen, they produce light flashes which can be seen by a microscope (M) in a dark room. The visible luminescence excited in zinc sulphide by α particles was used by Rutherford for counting the particles.



The process of counting these scintillations through a low power microscope is tedious one and the limitations of observation with the eye restrict the counting rate to about 100 per minute. This process, whereby the energy of the particle is converted to light, is the basis of scintillation counter.



The main parts of a scintillation counter are shown in fig. the atoms of the phosphor are excited or ionised by the energy loss of an impinging α, β or γ ray. When the atoms return to their ground states, photons are emitted, in the blue and ultraviolet regions of the optical spectrum. The phosphor is optically coupled to the envelope of a photomultiplier tube. The photons strike the photocathode, causing the ejection of photoelectrons. As these photo electrons leave the photocathode, they are directed by a focusing electrode to the first multiplier electrode or dynode. This electrode has the property of emitting three, four or five electrons for every single electron strike its surface. There may be from 10 to 14 such multiplier stages in a given tube. Hence, from the emission of one single electron from the cathode, a burst of one million electrons may impinge on the final stage in the tube. The output pulse from the photomultiplier is fed to a pulse amplifier followed by a scalar circuit.



Solid state detector

A p-n junction, used as a particle detector is shown in fig. it consists of a p-n junction between p type and n type silicon. Contact is made with the n type silicon layer by a thin evaporated film of gold. In order to minimize the current flowing in the detector. When no radiation is striking it, a reverse biased diode is always used. The bias applied to the gold film will push all the positive charge carriers away from the junction and produce a depletion layer, indicated in the figure. the depletion layer contains almost no carriers of either sign. When an energetic charged particle travels through the depletion layer, its interaction with the electrons in the crystal, produces electron hole pairs. There is an electron hole pair for every 3.5 ev of energy lost by the charged particle. The electrons and holes are swept away by the applied electric field and registered as a voltage pulse over the resistor R. the number of charge carrier pairs produced in a semiconductor material is approximately 10 times as large as the number of ion pairs produced in a gas ion chamber. i.e., the energy extended per pair is about 3.5 eV in silicon, compared to about 30 eV for gases. The voltage pulse will therefore be about 10 times larger. Hence this detector has much better energy resolution than other radiation detectors. In solid state detectors for charged particles, silicon has been used most because of its low intrinsic conductivity. This means that the detector can be operated at room temperature without excessive leakage current. For gamma ray work, germanium detectors are much better than silicon because of the larger density of germanium.