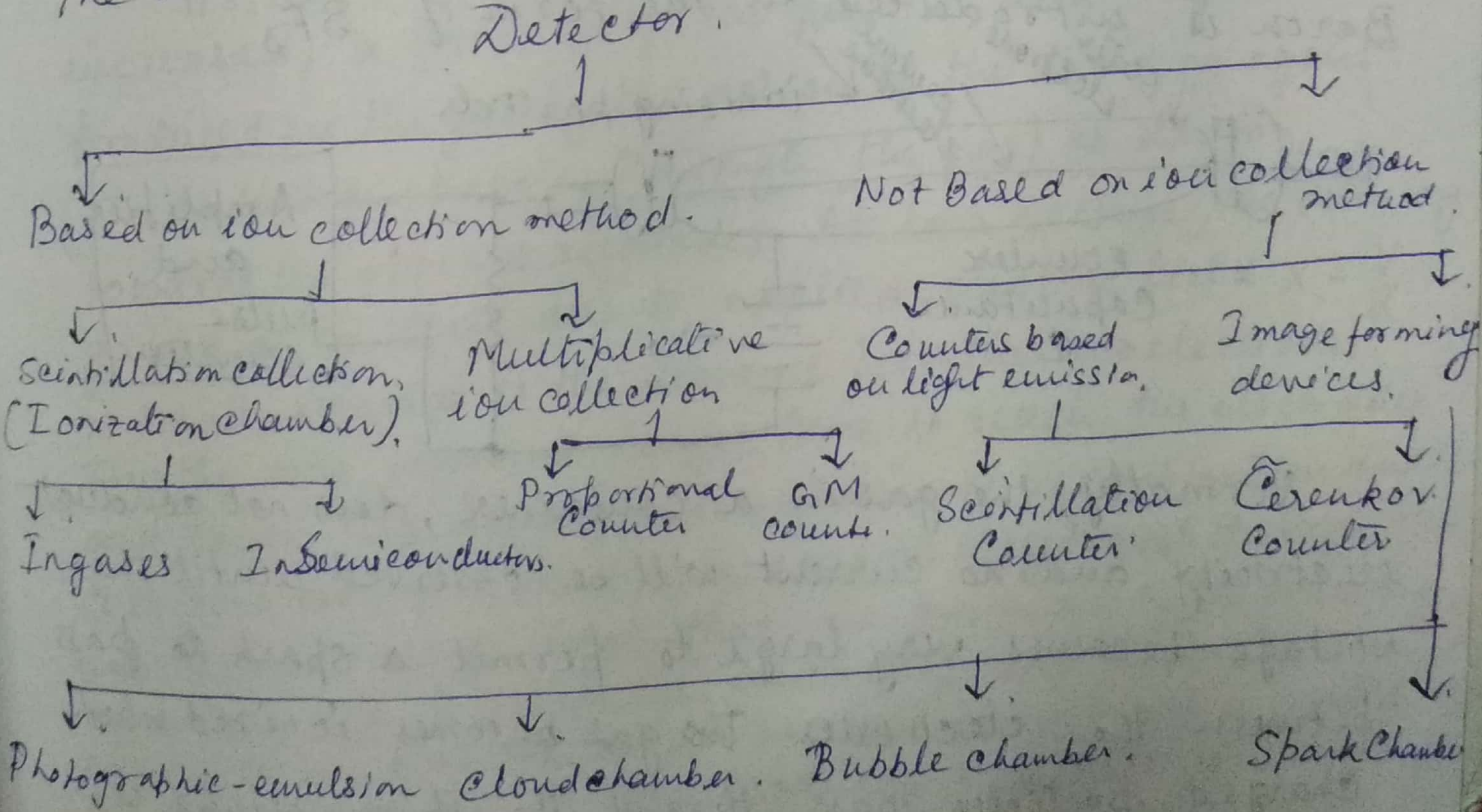
Detector of Nuclear Radiation:-

The radiations coming out of the nucleus, such as the α, β or γ rays in spontaneous transformations or various types of subatomic particles (both charged and uncharged) in induced transformations are the signals which carry with them information about the properties of the nucleus. Hence their detection and measurement are of prime importance in understanding the structure of the nucleus.

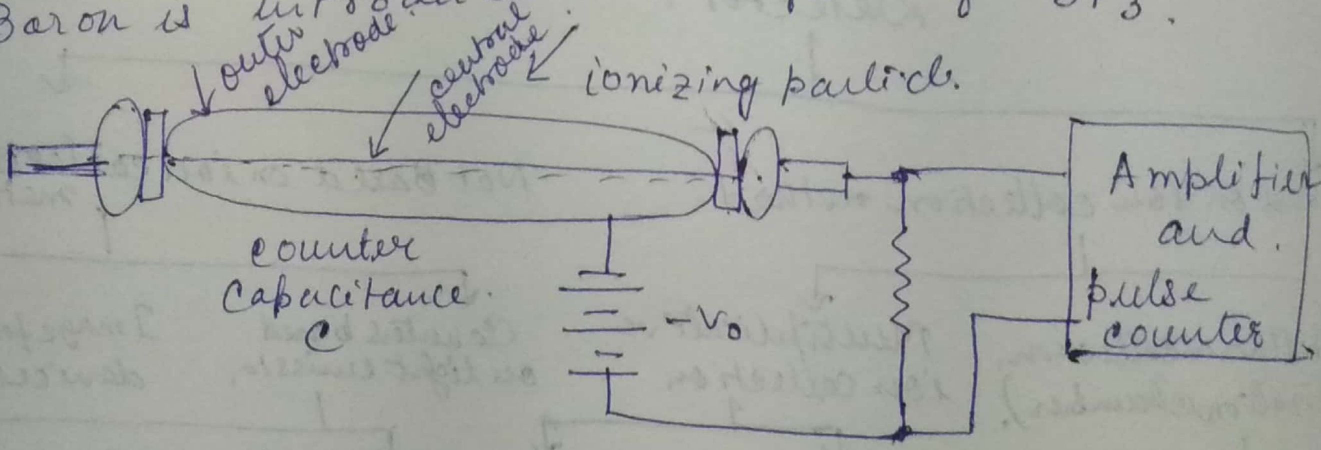
A detector is defined as a device which converts the energy of nuclear particle or radiation into a useable electrical signal. An ideal detector would be able to differentiate various types of radiation ~~&~~ and particle and would give a signal which is proportional to their energy.

The detectors are broadly classified as:-



Ionization Chamber.

An ionization chamber, used to detect radiation like Xray, gamma ray, beta particles, is a closed, vessel. filled with a suitabe gas having two electrodes within it with a potential difference of the order of a few hundred to few thousand volts between them, Commonly used ionization chambers have either parallel plate geometry or cylindrical geometry. In the former there are two parallel metallic plates separated by a distance. In cylindrical geometry, Ionization chamber consists of a cylindrical chamber containing a central conducting electrode insulated from it. The gases used in it are usually air, hydrogen carbon dioxide, nitrogen, argon or methane at atmospheric for or at greater pressures for γ ray detection. For the detection of thermal neutron. Boron is introduced in the form of BF_3.



Normally, the gas in a container, does not conduct electricity and no current will be observed until the voltage becomes very large to permit a spark to pass between the electrodes. The gas becomes ionized when charged particles pass through it. If no voltage is applied to the container, there will be no directing force acting the ions and no current will flow through the gas.

The electric field within the ionization chamber being relatively low, the primary ions produced in the chamber gas do not gain sufficient energy between successive collisions, with the gas molecules to produc secondary ions. Because, the mean free path λ bet successive collisions is very small at the relatively high gas pressure within the chamber.

Thus, there is no gas amplification in the ionization chamber and the gas amplification factor $A = 1$.

As the p.d. between the electrodes is gradually increased, a fraction of the positive and negative ions produced in the gas by the action of the ionizing agent (The radiation passing through the gas) is drawn towards the opposite electrodes. At low voltage, the velocit gained by the ions due to applied electric field $X = \frac{V}{d}$ is small, where d is the distance betn the two electrodes. Thus the ions required longer time to reach the electrodes and hence they have greater chance of recombination due collisions betn. +ve and −ve ions as they travel through the gas. Thus not all the ions, that are produced by the ionizing agent are able to reach the electrodes and hence the ion current is less than the maxm possible current which would be obtained if all the ions produced were able to reach the electrodes.

As V increased, a larger fraction of ions is able to reach the electrodes since the chance of recombination becomes less. Ultimately, when V is sufficiently high, all the ions produced in the gas are drawn to the electrodes and I reaches the max^{m} (saturation) value. This induced current due to motion of ions generate a volt or charge pulse in ext ckt which can be amplified. The further increase in voltage does not change the current. The voltage range over which the pulse size is const, depends on many factors, such as the nature and pressure of gas, shape and size of the electrodes.

The strength of the ionization current density is $ne(v_i + v_e)$. where e is ionic charge, v_i and v_e the mean drift velocities of the two types of ions. In the absence of external electric field, the ions have random thermal velocities. When the field X is applied, they are accelerated towards the opposite electrodes. The acceleration is $f = Xe/m$ due to which the ionic velocity increases as the ion moves in the field direction. However, this increase does not continue indefinitely since the ion suffers collisions repeatedly, the mean time between successive collisions being $\tau = \lambda/c$, where λ is the mean free path and c is the mean thermal velocity, which is large compared to the drift velocity due to the field. Since the ion travels a distance $s = \frac{1}{2}ft^2$ in time t, its mean velocity is $v = s/t$, so that the gain in velocity of an ion between successive collision is, $v = \frac{s}{\tau} = \frac{f\tau^2}{2\tau} = \frac{Xe\tau}{2m} = \frac{Xe\lambda}{2mc}$,

$v = KX$ where $k = \frac{e\lambda}{2mc}$ = ionic mobility.

hich is the mean vel gained by an ion (drift vel) per unit field $(X = 1)$

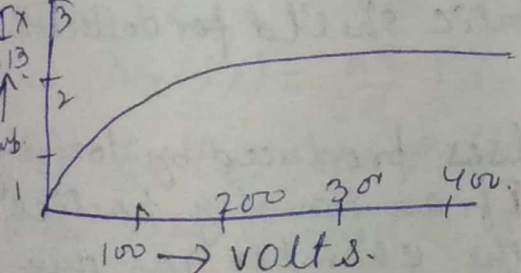
Thus the strength of the ion current is determined by the ionic mobilities of the two types of ions. The electrons being much lighter have much greater mobilities, k_e being of the order of 100 $m^2/s\,V$. For positive ions, the mobilites are much smaller. For Ar^+ in argon gas, $k_i \sim 0.2\ m^2/s\,V$. Thus the ion current is determined mainly by the mobility of the electrons. The ion current density can be written as,

$$I = (k_e + k_i) X n e = (k_e + k_i) n e V/d.$$

for low applied voltage $n = n_0$ = const, since only a very small fraction of the ions are drawn towards the electrodes, thus $I \propto V$.

When the voltage is high, all the ions produced by the action of the ionizing radiation are drawn towards the electrodes, there being very little recombination.

Hence in this case, $I = I_s$ = const.

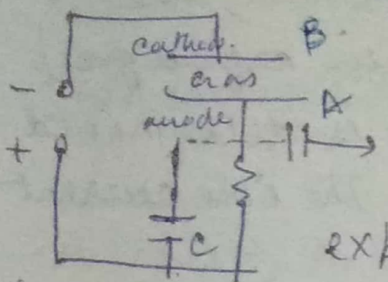


Ionization chamber may be grouped in two categories depending on the values of time const RC of the system relative to the freq of arrival of ionizing event. If RC is long compared to time between ionizing events a steady state is reached and a direct current may be measured. This is dc mode or integrating mode. On the other hand, If RC is small, each pulse produced by an ionizing event may be detected separately. This is pulse mode/non integrating mode.

The ionization current is usually measured by observing the volt developed across a high resistance (10^{12}– 10^{13} ohm) as the output is converted into a.c. and then is amplified by amplifier. The pulse which is detected by connecting collector plate through a high resistance forms part of input circuit of amplifier together with capacity C of chamber

d c. mode

In d c. mode / integrating chamber, very high resistance ($\sim 10^{15}$ ohms) is used in parallel to the chamber electrodes.



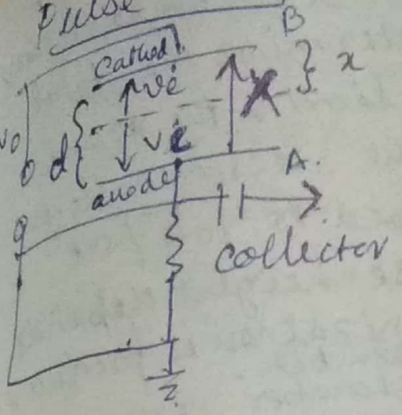
C denotes all the distributed capacitances (depends on geometry) in the ckt. The time const RC is >> time of collection of ions by respective electrodes $\sim 10^4$ sec. The ion collecting electrodes experience a progressive change of potential. The potential is measured at suitable interval and thus indicates the total charge q collected during the interval.

The very small charge collected in ionization chamber is measured with the help of electroscope / electrometers (femto or pico amp). Since the ionization current is extremely feeble (10^{-13} amp) most ionization chambers use a guard ring which surrounds a part of the collecting electrode, being usually kept at ground potential. Besides preventing surface leakage and volume leakage currents between the anode and cathode of the chamber, it stops the fluctuations due to polarization of the dielectric and provide electrostatic shield for collector.

Pulse Chamber:-

This can count individual pulses produced by ionizing particles passing through the chamber. If an ionizing particle spends an amount of energy E within the chamber gas, then the number of ion pairs produced by it in the gas $n = E/I$ where I is mean energy spent in producing an ion-pair. If C is the distributed capacitance of the chamber and wiring, then the volt across the chamber electrodes is changed by $\Delta V = \frac{qE}{IC}$ due to passage of any type of ions. Thus the pulse size is proportional to energy E of the particle and hence it is possible to measure the particle energy from the pulse size.

Pulse size :-



Let us take a parallel plate chamber Consider n ion-electron pairs formed at a distance x from the cathode B, the anode cathode separation being d. If $X = \frac{V_0}{d}$ and q the charge of each ion, then the decrease in electrostatic potential energies of the electron and +ve ion at time t are respectively $Xnq \times V_e t$ and $Xnq \times v_i t$ where v_e and v_i are repective velocities. From energy balance eqn :-

$$\frac{1}{2} C V_0^2 = \frac{1}{2} C V^2 + Xnq(v_e + v_i)t$$

where C is capacitance of collector electrode and V is the potential at time t.

Because of collection of charge, the potential of the collector has decreased below V_0 i.e. $V < V_0$. Since the drop in potential is small, $V_0 + V \cong 2V_0$ so from the previous eqn. $\frac{1}{2} C(V_0+V)(V_0-V) = Xnq(v_e+v_i)t$

$$V_C = V_0 - V = \frac{Xnq}{CV_0}(v_e + v_i)t$$

$\because X = V_0/d$ and $v_e >> v_i \Rightarrow V_c(t) = \frac{nq}{Cd}(v_e + v_i)t \cong \frac{nqv_e t}{Cd}$.

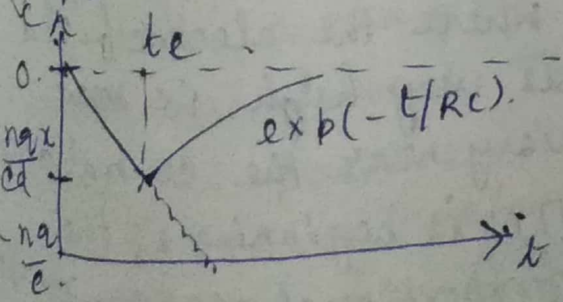
This shows a linear change in $V_C(t)$ with proportion to v_e when $t < t_e$. At $t = t_e = (d-x)/v_e$, the collector potential becomes

$$V_c(t_e) = \frac{nq}{Cd}(d - x) = \frac{nq}{C}\left(1 - \frac{x}{d}\right) \simeq \frac{nqx}{Cd}$$

after $t = t_e$, the collector potential $V_c(t > t_e) = \frac{nq}{Cd}(d - x + v_i t)$. So the rise of $V_c(t)$ for $t > t_e$ is proportion to $v_i << v_e$.

at $t = t_i = x/v_i$, $V_c(t_i) = \frac{nq}{C} = (V_c)_{max}$.

It is to be noted that the potentials V_0, V, V_c all are (-ve)

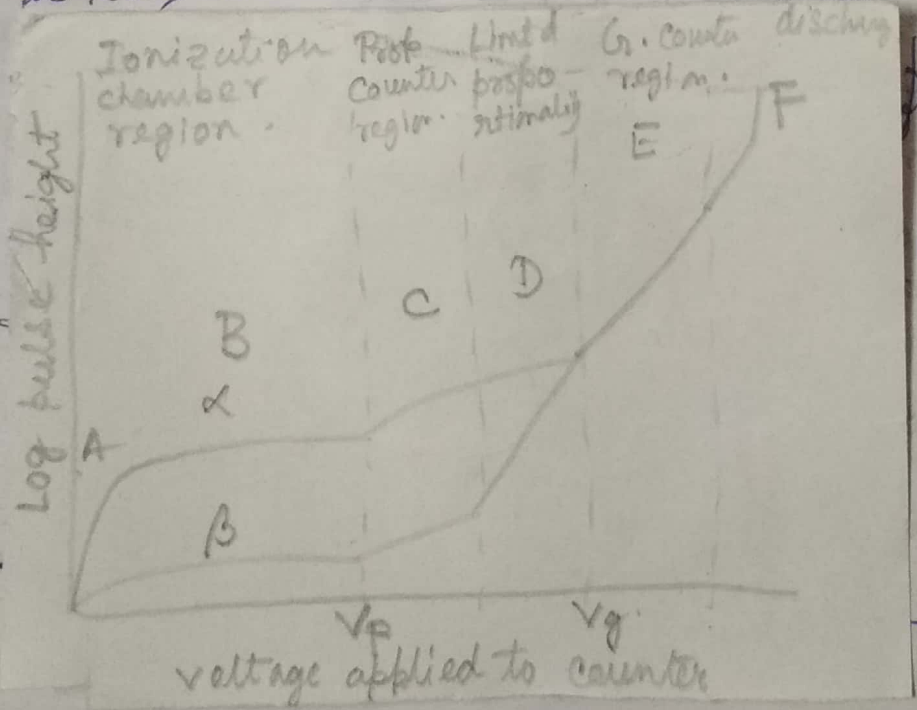


After the charge has been collected at collector A, it begin to leak through the resistor R with time const RC. If this is large compare to t_e ($\sim 10^{-3}$ s or more) Then the voltage pulse after attaing the max^m value falls off exponentially. $V_C = (V_c)_0 \exp(-t/RC)$

Since the +ve ions move much more slowly compared to electrons their transit time is $\sim 10^{-3}$ sec. which determines the total effective time for collection of charges. and it limits the count rate ~ few hundred counts/second. If only the electron collection rate are considered then the rate increased to 10^5/sec. But this suffers from the defect that the pulse height depends on the position in the chamber where the ionization is produced which degrades the energy resolution of the chamber. To avoid this, a gridded ionization chamber is used where a grid is placed in between, parallel to anode and cathode and -ve potential V_g is applied whose magnitude is less than the -ve cathode volt, the anode being grounded through R. The grid shields the collector

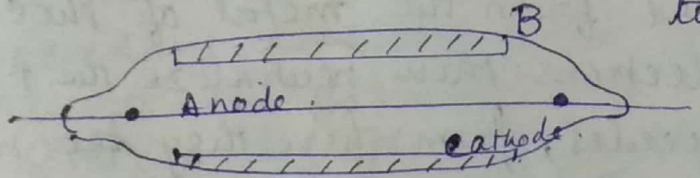
G M counter → (It is used for detecting and measuring ioninizing radia such as α, β, γ rays.)

If the variation of output pulse height with applied voltage in a gas filled detector with cylindrical geometry is examined, it is found that, when the applied voltage is low, there is no avalanche ionization as in region A and B. This is the region of Ioniz Chamber. As the volt is increased gradually the secondary ionization by collision or the avalanche ioniz takes place in the region where the electric field is very high i.e very near the central wire. This is beginning of the proportional region, mark ⓒ, where the voltage is just sufficient for the electron to produce secondary ions in the last free path before the central wire. The cumulative increase of ionization by collisions is known as Townsend ionization. With further increase of volt, the avalanche

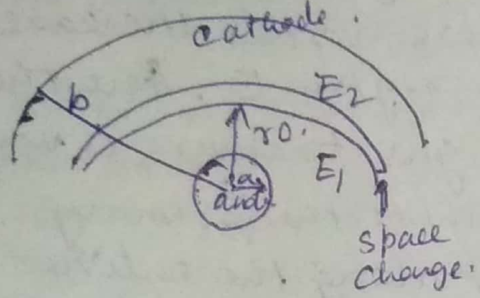


formation begins farther and farther away from the centr wire and the number of secondary ions produced by each primary ion pair gradually increases. In this region gas amplification factor A is $\sim 10^3$. and is const for a given volt, Next region is limited proportionality region denote by D. Then comes Geiger region where volt is increase further, here A $\sim 10^8$, marked by region E. Here th mean free path λ is ~~very too~~ large as the gas pressure is ve low. The avalanche is not confined where the primary ionization takes place, but spreads along the entire wire. The ~~outp~~ size of the output pulse is independ of the number of primary ions

(GM counter consists of a cylindrical sealed gla tube B of radius ~~2~~ 2 to 3 cm enclosing a coaxial metal cylinder serving as cathode., Along the axis of the cylind is stretched a very thin metal wire. (usually tungsten diameter 0.1 mm which serve as anode. Electrical connections are provide to C and A by metallic leads sea through the glass tube. Genera the tube is filled with a mixtu of Argon at 10 cm pressure and ethyl alcohol vapour at 1 c pressure.



When a charged particle passes through the counter, io pairs are formed. The electrons move towards the central wir and the positive ions move slowly towards cathode. After the Townsend avalanche has spread along the whole anode an the electrons having a small mass are collected on the anode in a very short time. Because of their greater mass (+ve) ions move much more slowly. towards the cathode cylinder so that immediately after the electrons have been collected there is a sheath of +ve ions around the central wire. As the collection of electrons will be complete only in about 10^{-5} sec, the (+ve) ion cloud or sheath will still close to the wire. Casider the situation when the space charge has moved outside to a radius r_0. Let there be q charge per unit length on the wire and Q charges per unit length in the space. The field strength inside and outside the sheath are : $X_1 = q/2\pi\epsilon r$



$$X_2 = (q+Q)/2\pi\epsilon r.$$

$$v = \int_a^{r_0} \frac{q}{2\pi\epsilon r}\,dr + \int_{r_0}^{b} \frac{q+Q}{2\pi\epsilon r}\,dr.$$

$$= \frac{q}{2\pi\epsilon_0}\log_e\frac{b}{a} + \frac{Q}{2\pi\epsilon_0}\log_e\frac{b}{r_0}.$$

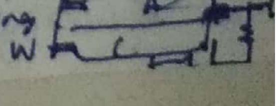
$$\therefore q = \frac{2\pi\epsilon}{\log_e b/a}\left[v - \frac{Q}{2\pi\epsilon_0}\log_e\frac{b}{r_0}\right], \rightarrow (a)$$

As the +ve ion sheath moves towards cathode r_0 increases. −ve term in eqn (a) decreases so q and hence X_1 increases and attains its max^m initial value. The +ve ion sheath will reach the cathode in about 10^{-4} sec. As the positive ions reach the wall and are about 10^{-7} cm from it, they cause electrons to be liberated from the metal of the cathode by field emission. These electrons then neutralize the +ve ions, leaving the excited molecules, from where they went to ground state radiating characteristic spectral lines. Some of these ~~electrons~~ lines are in ultraviolet region and liberate photoelectrons from the cathode. These secondary electrons are accelerated towards the central wire, they start a new avalanche which produces a new sheath and the discharge will continue.

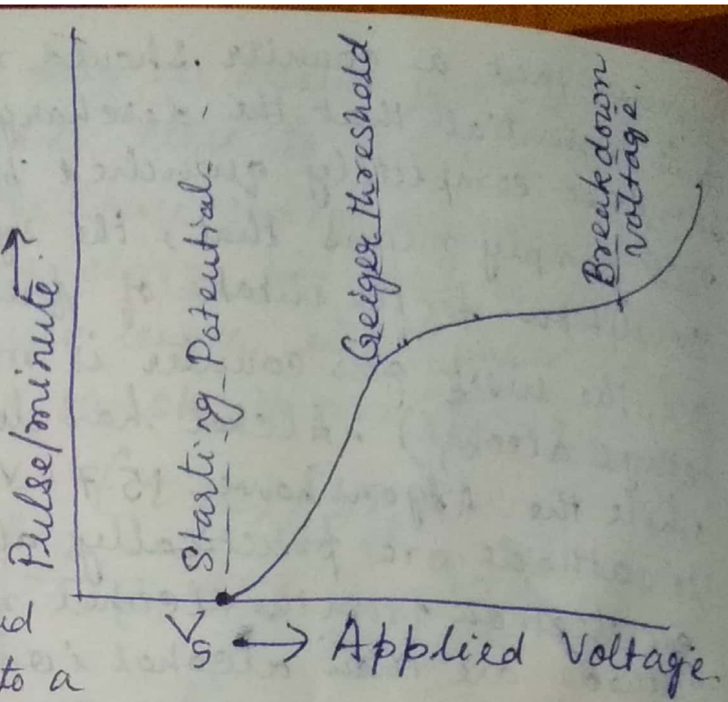
For a given voltage, on the anode, the voltage pulse produced at anode is determined by the space change collected around the anode wire to stop the discharge. It does not depend on the size of primary ionization and is determined by the applied voltage. The pulse size thus depends upon the excess voltage above the threshold for initiating the Geiger discharge.

In order that a counter should record a chain of nuclear particles,
it is essential that the discharge caused by the first particle
should be completely quenched before the arrival of a new particle.
This simply means that, the system should be reset in proper
condition for the intake of fresh instalment of charged particles
So, the inert gas counter is mixed with some organic vapour
(ethyl alcohol). Alchol has low ionizing potential (11.3eV)
while the Argons have 15.7 eV. Argon ions on their journey
to cathode are practically all neutralized by acquiring
an electron from the alcohol molecule. The ions reaching the
cathode are then alcohol ions and. they are completely
neutralized at the cathode. The excess energy 4.3 eV
liberated during the neutralization is absorbed in dissociating
the alcohol molecules rather than in producing
further electrons from the cathode. The discharge thus
ceases when the central field has fallen sufficiently. The alcohol
vapour will also absorb the ultraviolet photon emitted during
the avalanche stage and prevent them from ejecting. the
photoelectrons from the cathode. The role of ethyl alcohol vapour
is thus two fold → 1) It prevents photoelectric effect of
the quanta at the cathode and 2) prevents the creation of.
secondary electrons when the positive ions impinge on the cathod
Due to the dissociation of alcohol molecules, the counter has
a limited life time. In the halogen quenched counters,
the halogen molecules. (Br2) dissciate into halogen atoms
which again recombine - So these counters have very long
lives. These type of counters are called <u>self-quenching</u>.

In non self quenching counter, which does not use any
quenching vapour, repeated discharge can be prevented by the
use of very high resistance ($\sim 10^9 \Omega$) in the anode circuit. The IR
drop across the ressistor is very large and accordingly the volt acro
the counter tube falls so much that gas amplification factor is redu
below the level required to start a second Geiger discharge. But wit
high resistance the time const RC is very large, so fast counting is not
possible with this instrument.
For counting less penetrating radiation e.g α or β rays (compared to γ) a th
window W made of mica or other material is provided for entering



Characteristic Curves:-



When the voltage is increased from a low value, the pulses are too small to be detected. When the voltage reaches a certain value say starting potential, also knownas Geiger threshold, the pulse can be counted. With rising potential, gas amplification increases and number of pulses rise rapidly to a flat ~~potio~~ portion of the curve called plateau. This is the Geiger tube region for which, the count rate is nearly independent of the potential difference across the tube. Beyond the plateau, the applied electric field is so high that a continuous discharge takes place in the tube and the count rate increases very rapidly. Slope of the plateau $= \frac{n_2 - n_1}{n_{av}} \times \frac{100}{V_2 - V_1} \times 100\%$ per 100 volt.

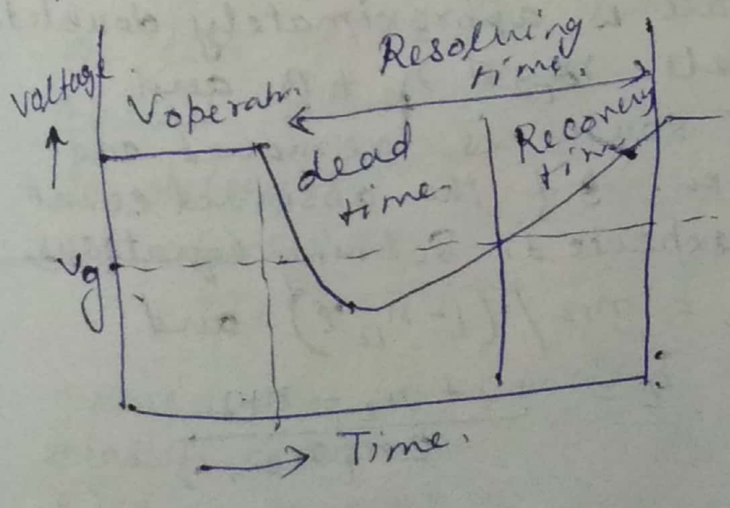
The plateau has a width (or length) of a few hundred volts. A good tube often have a plateau length of 100 to 200 volts or more with a slope of about 5% counts per 100 volts applied. The slope for halogen filled tube is greater that for organic gas filled tubes. The plateau of a halogen tube may extend over 150 V with a slope of 10% per 100 V, while an organic gas tube it is 300 V. with a slope of 2% per 100 V. When the plateau becomes notably shorter and steeper it is a sign that a counter tube is nearing the end of its useful life. Again the starting potential is a f^n of the pressure of the gas in the counter. The starting potential increases ~~[illegible]~~ practically linearly with the pressure of the filled gas.

Efficiency:- The efficiency of the counter is defined as the ratio of the observed count/sec. to the number of ionizing particles entering the counter per sec. Counting efficiency is defined as the ability of its counting if atleast one ion pair is produced in it.

Counting efficiency $= (1 - e^{-slp})$

where s is the specific ionization at one atmosphere, p the pressure in the atmosphere and l, the path length of the ionizing particle in the counter.

Dead Time and Recovery time:- Dead time ~~this~~ is defined as the time interval between the production of the initial pulse and the initiation of the second Geiger discharge. which is usually ~50 to 100 μs. The dead time arises due to slow movement of the heavier positive ions from the anode region to the cathode. Since the positive ionsheath around the anode lowers the electric field below the Geiger threshold, the counter can record another ionizing particle only after the field has been restored to a value above than Geiger threshold $V_{th} = V_S$. The time during which the counter is incapable of responding to a second ionizing event, is known as ~~incapable of~~ dead time (~~[illegible]~~) (~200 μsec). As the space charge moves further toward the cathode, the counter sensitivity gradually returns to its original value and second pulse can now be recorded. This time, during which pulses of reduced size are produced, is known as recovery time. The dead time plus recovery time corresponds to the time which positive ion sheath takes to reach the cathode, is known as resolving time of the counter. This is the time between just recorded pulses.



Pulse counting ckt:- The pulses obteined from the GM tube are too small to count directly. It requires amplification, which is done frequently in two steps. The counter is immediatly followed by a preamplifier which has little gain but produces an output signal across a relatively low impedance. This signal is then fed into the main amplifier, which has a gain strictly independent of the size of the input pulse. The output signal is then fed into the sealing circuit.

Resolving Time and actual counts:- Let us assume that a counting system with a resolving time τ responds at a rate n counts per unit time when exposed to N initiating events per unit time. In unit time the total insesitive time will be $n\tau$ and the number of counts missed will be $Nn\tau$. As the number of counts missed it is the error in counting

$$\therefore \quad Nn\tau = N - n$$

Actual count rate $N = n/(1-n\tau)$. Thus the actual count rate canbe calculated if we know τ.

The most usual method for determining resolving time involves the measurement of counts using two radioactive sources. The background count (which is counts without any source) rate B is first found. Then with one source count rate is determined. Let the observed count rate be $n_1 + B$ and expected $N_1 + B$. With the first source still present, the second source is introduced and adjusted until the count rate is approximately doubled. Now let the observed count rate $n_{12} + B$ and expected $N_2 + N_1 + B$.. The first source is removed and the second is left in position. If the observed count rate is $n_2 + B$ and $N_2 + B$ expected. Solving equations,

$$N_1 = n_1/(1-n_1\tau), \quad N_1 + N_2 = n_{12}/(1-n_{12}\tau) \text{ and}$$

$$N_2 = n_2/(1-n_2\tau) \quad \text{we get} \quad \tau = \frac{n_1 + n_2 - n_{12}}{2n_1 n_2}.$$

Scintillation Detector:- (Method Based on Light Sensing).

A charged particle passing through the detector produces a momentary flash of light (visible or ultraviolet) which can be detected by special light sensitive phototubes which converts the light signal into electrical signal that can be amplified and detected by electronic ckts.

USES:- Besides the detection of charged particles like α or β rays, high speed protons, deuterons etc, the method has been found to be specially useful for γ ray detection with very high efficiency. Whereas the intrinsic γ efficiency of GM counter is only of the order of 0.1%, that of the scintillation detector can be as high as 20%. The method can also be used for neutron detection.

Scintillators:- The principal methods of excitation are incandescence and luminescence. The former refers to the radiation due to the temp of the source and the latter refers to all types of radiation due to causes other than temp. The luminescence caused by photons are named as photo luminescence and further divided into phosphorescence and fluorescence. When the visible or ultraviolet light is emitted within 10^{-8} sec or less after the radiation absorption, the emission is called fluorescence, whereas phosphorescence refers to delayed light emission, which may follow the radiation absorption by minutes, days or even years.

The substance which scintillate (production of flashes of light) by radiations are named as scintillators also called phosphors and are classified as — a) Inorganic crystal b) organic crystal c) organic liquid d) Inert gases.

a) <u>Inorganic crystal</u>:- ~~ZnS (usually activated~~ This type of crystals do not scintillate when it is in pure form. So some impurity should be added. e.g. ZnS (usually activated with traces of silver) is the most useful crystal used as phospor for α particle detection. Ionic crystal such as Sodium Iodide activated with thallium NaI(Tl) is widely used for γ ray detection, CsI(Tl) for γ detection ~~are used for particle detection~~ and stilbene

b). <u>Organic crystal</u>:- Anthracene is used as phosphor for detection of β rays. These are solid organic crystal. The organic crystalline scintillators have a faster decay time (~10^{-8} sec), high transparency but poorer conversion efficiency especially for heavy particles. These are not useful for γ and x rays. They are very good for recoil neutron detection.

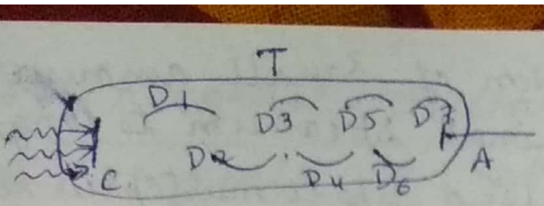
c) <u>Organic liquid</u>:- Certain solutions of organic compounds are also capable of acting as phosphors although they are not as efficient as the best pure crystals. The liquid scintillator has two main components:- 1) solvent (e.g. toluene, phenyl cyclohexane or xylene) and 2) primary solute (e.g. a few percent of diphenyloxazole or terphenyl). Most of the nuclear radiation energy is absorbed by the solvent which is not a scintillator and is then transferred to the solute which actually emits light. When the scintillation occurs in the extreme ultraviolet region, one uses a wavelength shifter or solute to increase the also called secondary scintillator (to be added in small amount) wavelength of the emitted light. e.g. α-napthyl phenyloxazole, diphenyloxazole benzene and bibiphenyl oxazole.

d) <u>gases</u>:- Some inert gases, eg. argon, krypton and xenon have found applications as scintillator. They are useful for charged particle detection. They have very fast response time. Normally the emission spectrum lies in the vacuum in ultraviolet region. Addition of small amount of Xe to Ar or Kr shifts the original spectrum to longer wavelengths to match the commonly used photomultiplier tubes. Noble gases in condensed state (e.g liquid or solid Xe) have also found useful applications as scintillator.

Modes of energy transfer in case of inorganic crystal.

In a crystal, the atoms are arranged in a regular array in the form of a lattice. In the ionic crystal, the alternate sites are occupied by the (+ve) and (−ve) ions [eg. Na^+ and I^-]. There is strong electrostatic interaction betn the adjacent ions. As a result, the energy levels of ~~the~~ individual valence electrons coalesce to produce broad energy band. These are valence band. Above the valence band there is conduction band, separated by energy gap, called forbidden energy gap. In halogen halide crystal this gap is nearly 6 to 8 MeV. When a high speed charged particle passes through the crystal lattice, it may transfer a small fraction of its energy to an electron in the valence band as a result the electron will go to conduction band. The electron now moves through the crystal till it comes across an electron trap or a crystal imperfection due to structural defect or due to added impurity. The hole left in valence band also move through the lattice. When the electron in the conduction band goes back to valence band, it emits light in the form of fluorescence radiation. The light so emitted has too high an energy (6 to 8 eV) to lie in visible region. However the presence of an activator like thalium in NaI shifts the emission spectrum to the visible region in the de excitation process. Some impurity levels now appear in the forbidden zone through which the electron can deexcite to the valence band. As a result, the photon has much lower energy and lies in the visible region.

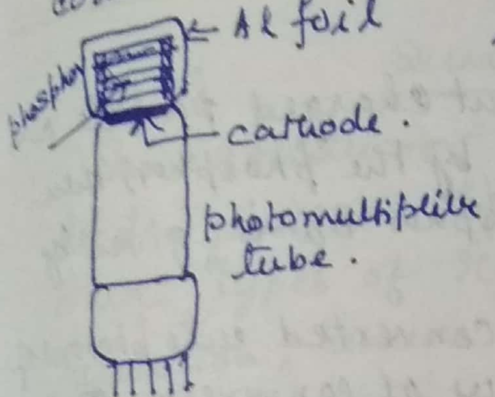
Photomultiplier tubes:— The method of scintillation counting is done by photomultiplier tube.



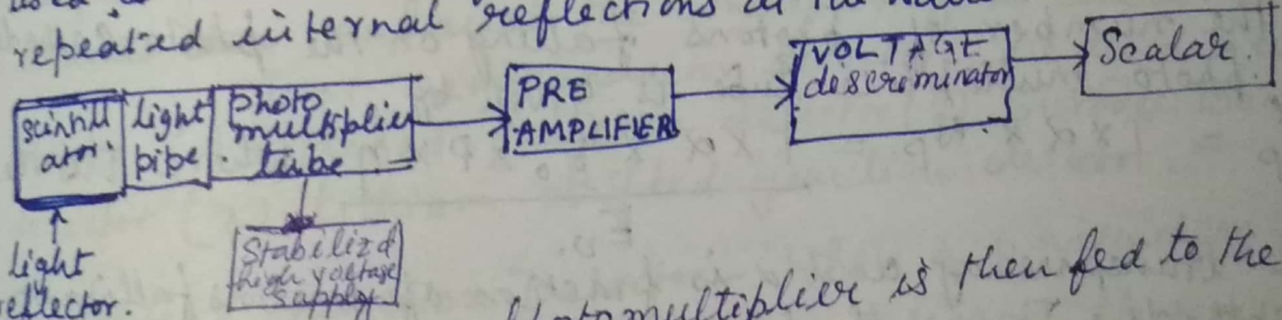
T is a sealed tube made of glass or quartz. At one end semitransparent layer of some photosensitive material e.g. Cs_3Sb is coated. This is known as photocathode designated by C. Facing the photocathode C, there is a series of secondary electron emitting surfaces D_1, D_2, D_3 etc. known as <u>dynodes</u>. The presence of dynodes give rise to multiplication in the number of electrons finally collected at the anode A for each electron emitted from the ~~cathode~~ photocathode due to the incidence of a scintillation photon on the latter. The first dynode D_1 is kept at a positive potential of about 80 to 100 volts w.r.t. C. The successive dynodes are also kept at similar positive potentials w.r.t. the dynodes immediately preceeding them. The anode A is at the same potential at the last dynode.

When an energetic electron falls on the sensitive surface of a dynode, secondary electrons are emitted from the latter by a process similar to the process of photoelectron emission. The ratio of the number of electrons emitted from the sensitive surface of a dynode for each electron striking it is known as <u>secondary electron emission co-eff</u>. This is greater than unity, which makes it possible to achieve a very large multiplication in the number of electrons by the photo multiplier tube. If secondary electron emission co-eff is N and the no. of stages of multiplication is n the multiplication factor is N^n, provided there is no loss in the electron number as they travel from one dynode to the next.

Scintillation counting arrangement :- A scintillation detector must be coupled to a photomultiplier in order to transform the light pulses produced in the former into electrical pulses which can then be amplified and recorded by suitable electronic devices. For the purpose of spectrometry, the amplified pulses are fed into an electronic pulse height analyser which can be either of the multichannel type (MCA) or single channel type. In MCA pulses in different amplitude ranges are simultaneously recorded and their numbers counted.



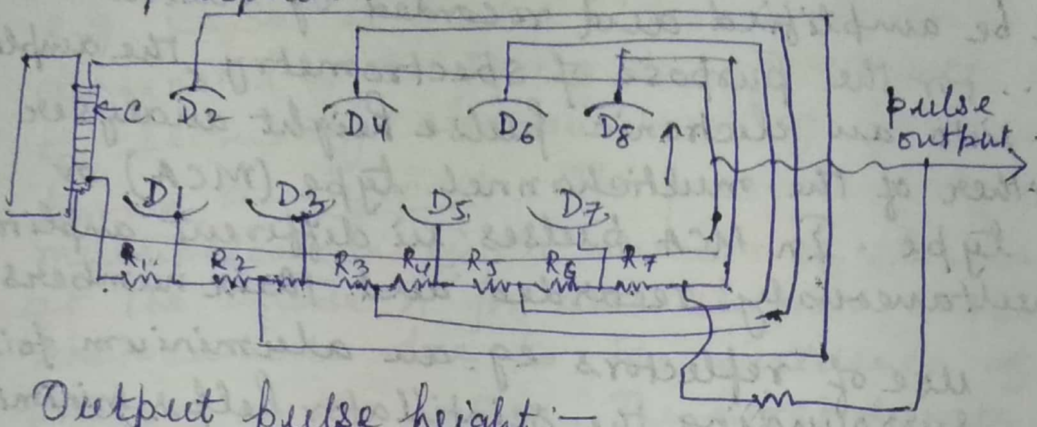
Use of reflectors eg. an aluminium foil surrounding the scintillator helps minimise the loss of light reaching the photocathode. All scintillators must be housed in light-tight container to avoid stray light falling on the photocathode. Further a hygroscopic crystal e.g. NaI(Tl) must be kept in a sealed container to prevent entry of moisture. When direct mounting of the scintillator on the photomultiplier type is not possible, a light pipe, made of polymerized methyl methacrylate can be used. The weak light pulses are transmitted along the pipe by repeated internal reflections at the walls.



The output from a photomultiplier is then fed to the amplifier, scalar and recorder.

<u>Electrical Pulse formation</u>:- The successive dynodes are kept at about 80 to 100 volts (+ve) w.r.t. the immediate previous stage. The electrons collected at the anode due to each scintillation pulse falling on the photocathode are allowed to leak through a high resistance of the order of 1 MΩ. If C be the distributed capacitance of the anode and associated wiring and Q is the charge collected at the output points, the pulse height V could be $V = Q/C$ → ①

Q can be directly correlated with the energy of the incident charged particle of the γ-ray passing through the phosphor.



Output pulse height:-

If E_0 represents the energy of the incident charged particle and P, the probability of energy absorption by the phosphor, then the amount of energy lost in the phosphor E_d is given by

$$E_d = E_0 \times P \longrightarrow \textcircled{2}$$

This energy loss in the phosphor is then converted into photons of energy E_ν depending upon the efficiency of conversion η

Thus the number of photons formed (N_P) is given by,

$$N_p = \frac{E_0 \times P \times \eta}{E_\nu} \longrightarrow \textcircled{3}$$

Hence the number of photons falling on the photo-cathode of the photo-multiplier tube is given by,

$$N_p' = T \times \alpha \times N_p = \frac{T \times \alpha \times E_0 \times P \times \eta}{E_\nu}$$

where T is the optical transparency and α is fraction of photons falling on photo cathode. The no of photoelectrons emitted (N) due to these photons is a fn of photo electric conversion efficiency of the cathode (η_e) and the relative freq response q_ν.

$$N = \eta_e \times q_\nu \times N_p'$$

So the total no of electrons reaching the anode

$$N_I = f \times R \times N = \frac{f \times R \times \eta_e \times q_\nu \times T \times \alpha \times E_0 \times P \times \eta}{E_\nu}$$

where f is the fraction of photoelectrons reaching first dynode and R the electron multiplication factor. Hence the total charge at the output pulse is

$$q = N_T \times e$$

and pulse height $V = \frac{q}{C} = \frac{N_T \times e}{C} = \frac{e \times f \times R \times \eta_e \times q_v \times T \times \alpha \times E_0 \times P \times \eta}{C \times E_v}$

$N \propto E_0$ i.e the height of the output pulse depends on the incident particle energy E_0