ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

EFFICIENCY OF GAS FILLED DETECTOR FOR BETA AND GAMMA RADIATIONS

By

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Addis Ababa

EFFICIENCY OF GAS FILLED DETECTOR FOR THE DETECTION OF BETA AND GAMMA RADIATIONS

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For
The detection of Beta and Gamma Radiations

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Approved by the Board of Examiners

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Abstract

There are many forms of radiation –heat, light, radar, radio waves etc. differ from one another in frequency but not in kind. The so called “kinds” of radiation are characterized by the techniques used to produce and detect them; The classical theory of Maxwell applies to all these radiations and all are ultimately due to the acceleration of electrical charges. Except for differences of frequency, and observation made on one’Kind “of radiation must also be true of all other kinds.

Radiation is energy in the form of waves or particles. The great majority of it occurs naturally and we are all exposed to it all of the time .It is all around us-in atmosphere, the earth, our food our bodies and from cosmic rays, from outer space and medical X-rays. Radiation can be produced from a variety of sources. There are two broad types - ionizing and non-ionizing radiation - classified in terms of their effects on matter. Non-ionizing radiation includes some ultra violet light, visible and infrared light, microwaves, radar and radio waves. Ionizing radiation is that which has enough energy to remove an electron from an atom, thereby producing an ion - an electrically charged atom or grouping of atoms. Cosmic rays, x-rays and the radiation emitted by the decay of radioactive substances are examples of ionizing radiation. Although they are types of radiation, alpha and beta particles and neutrons are not parts of the electro-magnetic spectrum because they are particles not waves. We are most affected by ionizing radiation, which deposits some of its energy as a result of electrical interactions when it passes through matter. It can be harmful to the human body in excessive doses because it can damage individual cells, possibly resulting in damage to organs, or other long-term effects.

Radiologist discovered that repeated exposure of their hands to X-rays resulted in skin burns. This discovery led to the wide spread use of X-rays in the treatment of cancer. Also it was realized that excessive exposure of the body to radiation could result in radiation different in their biological effect on tissues even when the absorbed dose is the same. This basically depends on ionizing power of radiation. The relative biological effectiveness of electrons and positions are the same. Whereas, heavy ionizing particles such as alpha particles and fission fragments produce much greeter biological effect.

However, containing it, shielding against it, moving away from it, or removing the source can gain effective protection from radiation. Radiation has the same effect, whether from natural or man-made sources. Most people receive their greatest exposure to radiation from the naturally occurring radioactive gas radon. It is produced as a result of the decay of uranium - which is present in all rocks and soils. We all breathe it every day and it accounts for about 50 per cent of our total radiation dose. In fact, about 85 per cent of our total dose is the result of naturally occurring radiation. Medical sources, such as x-rays, account for a further 14 per cent. The fall-out from past nuclear weapons tests and incidents such as Chernobyl amount to 0.2 per cent and discharges from the nuclear industry total much less than 0.1 per cent

It may be wondered why it is, if the surfaces of all bodies are continually emitting radiant energy, that all bodies do not eventually radiate away all their internal energy and cool down to a temperature of absolute zero. The answer is that they would do so if energy were not supplied to them in some way. In the case of filament of an eclectic lamp, energy is supplied electrically to make up for the energy radiated. As soon as the energy supply is cut off, bodies do, infact, cool down very quickly to room temperature. The reason that they don not cool further is that their surroundings (the walls, and other objects in the room) are also radiating and some of this radiant energy is intercepted, absorbed and converted into internal energy. The same thing is true of all other objects in the room –each is both emitting and absorbing radiant energy simultaneously.

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INTRODUCTION

Nuclear Physics deals with the structure, properties & transformation of atomic nucleus. It is one of the most modern branches of science. Even at the end of 19 th century, the atomic nucleus had not been discovered and the atom was considered to be the smallest indivisible particle of matter. The discovery of cathode rays and x-rays in 1895 and natural radioactivity in 1896 showed that the atomic structure of all elements has something in common. They all contain electrons, which are emitted under certain conditions and the heaviest elements exhibit the properties of alpha, beta and gamma radioactivities.

The main objective of this work is primarily to study the radiations from radioactive nucleus and in particular to determine the efficiency of has detectors. The most impressing result of this project is its agreement with the expected result. The fact that detection efficiency of GM counter for beta-radiation is 88% and for gamma radiation 2% is a great achievement.

The whole work of the project can be seen from two angles. First I have tried to assess the theoretical background for the experiment as a literature survey and the second part is experimental part from the start to the end of the efficiency determination process.

The first chapter deals with atomic nucleus. Here the basic properties of atomic nucleus its size and shape, binding energy and nuclear stability are considered. In the second chapter I have touched the general case of radioactivity and then inclined to nuclear radiations. In this chapter the radioactive decay law, the three common types of nuclear radiations.

(Alpha beta and gamma) are given. In here I have discussed source of the common types of radiation & decay schemes and have tried to focus on the energy relation of these radiations, which is a key to understand the internal structure of the nucleus.

The third chapter is devoted to interaction of charged radiations and uncharged radiations in general and then focuses on beta-radiation & gamma radiation interactions in particular. In this chapter the four types of electron interaction with mater and the three common cases gamma interaction with matter are given. This is necessary as a part of this work because the origin and hence the nature of their interaction enable us to detect radiation.

The fourth chapter contains detectors. First the over view of detectors as a whole and then Gas filled detectors are given. Under this the commonly used detectors-Sodium Iodide (NaI), solid state detector-highly pure germanium (HPGe), and then gas filled detectors are given. General properties of gas filled detectors, ionization chambers, proportional counters and GM counters are discussed. Specially in the last part of this chapter basic features of GM counter, avalanche formation and detection efficiency are included.

In all cases I have tried to touch the related concepts without deviating from the main objective of the project as much as possible.
In the last chapter the details of the experiment are given, starting from the experimental set up to the determination of the efficiency of GM counter, the whole process is given. Then there are also result and discussion comments on the obtained result. Finally, with brief conclusion are recommendation & the whole work- completed.

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Chapter One

The Atomic Nucleus

2.1 Introduction

A very different atomic model was indicated by experiments performed by Rutherford and his associates in1911(H. Geiger and E. Marsden).According to Rutherford gold foil experiment, many of the alpha particles did go straight through the foil (deflected only by very small amounts) and amazingly some alpha particles were deflected through very large angles .A few even returned to the side of the gold foil from which they came .Rutherford 's astonishment at this is evident in his comment ,"It was quite the most incredible event that has ever happened to me in my life .It was almost as incredible as if you fired 15 –inch shell at a piece of tissue paper and it came back and hit you " .

For smaller separation, (less than 10^{-14} m) the prediction of coulombs is not obeyed because the nucleus no longer appears as a point charge to the alpha particle. Rutherford concluded that (1) the positive massive part of atom was concentrated in a very small volume at the center of the atom called nucleus, surrounded by a cloud of electrons. (2) Because the atom is mostly empty space, many of the alpha particles go through the foil with practically no deviation. But an alpha particle passes closer to the nucleus experiences a very large force exerted by a massive positive core and is deflected through large angles in a single encounter.

From alpha decay studies it was known that heavy nuclei can, to some extent, break up in to smaller and identical constituents. Clearly, it is therefore built up of more elementary particles. However, it was known before 1932 exactly what these particles were. In that year Chad wick discovered the neutron, and since that discovery, it has been generally accepted that the nucleus is built up of neutrons and protons. In beta and induced reactions at high energies, other particles may emerge from the nucleus. However, we now believe that these particles are created in the nucleus at the moment of emission and are therefore not to be considered as constituents of the nucleus.[7]

2.2 Nuclear Sizes and Shapes

Atoms of each element contain a number of protons in the nucleus equal to the atomic number, and a like number of orbital electrons. In addition, all nuclei of all atoms except hydrogen contain one or more neutrons. Since like electric charges repel each other, each proton is repelled by all other protons in the nucleus. As the number of protons increases, the magnitude of the force on any one proton increases becoming so large that all nuclei with more than 83 protons are radioactive. No nucleus with more than one proton can exist without neutrons. Neutrons are essential in such nuclei to bind together the positively charged protons.[4]

..... What is the nature of the force of attraction holding the nuclear properties together? The gravitational force is negligible, and the electric forces tend to disrupt the nucleus. One must assume that the nuclear binding force is a kind not previously encountered in nature. There is a great deal of evidence indicating that it is a short range force acting only between nucleons that are very close to each other, that is with less than two diameters between their centers. Because of the short range of nuclear forces, the nucleons are packed together much like marbles in a bag. This is not to say that protons and neutrons are actually round balls. Actually they are probably more like a cloud that is most dense at its center.

Both neutrons and protons tend to occur in pair in the nucleus. Although there is mutual attraction between neutrons and also a component of attraction between protons, the most important nuclear force is due to proton-neutron attraction. According to an approximate theory, this nuclear force, like chemical bonds in a molecule, can saturate. Just as oxygen atom binds to itself only two protons, each proton to two neutrons.

..... Nuclear sizes have in recent years been measured more accurately by scattering high energy electrons off various target elements through out the periodic table. If a nuclear radius is R, the corresponding volume is $4/3\,\Pi\,R^3$ and so, R^3 is proportional to A. This relationship is usually expressed in inverse form as: $R = R_0 A^{1/3}$ (2 . 1)

where $R_0 = 1.2 \times 10^{-15}$ m [5]

This means that the nucleus is something like 10,000 times smaller than the atom as a whole. Atoms are thus very empty structure and this explains why negatrons(β-particles), alpha particles, neutrons etc can pass through matter so readily.[2]

2. 3 NUCLEAR BINDING ENERGY

The nucleus contains 99.975% of the mass of an atom. Comparison ofthe separate mass of all the nucleons constituting the nucleus with the mass M of an atomic nucleus shows that mass of the nucleus is always less than mass of the separate nucleons. This is quite natural, since the nucleus is a tightly bound system of nucleons corresponding to the minimum energy. We can compute the nuclear binding energy as:

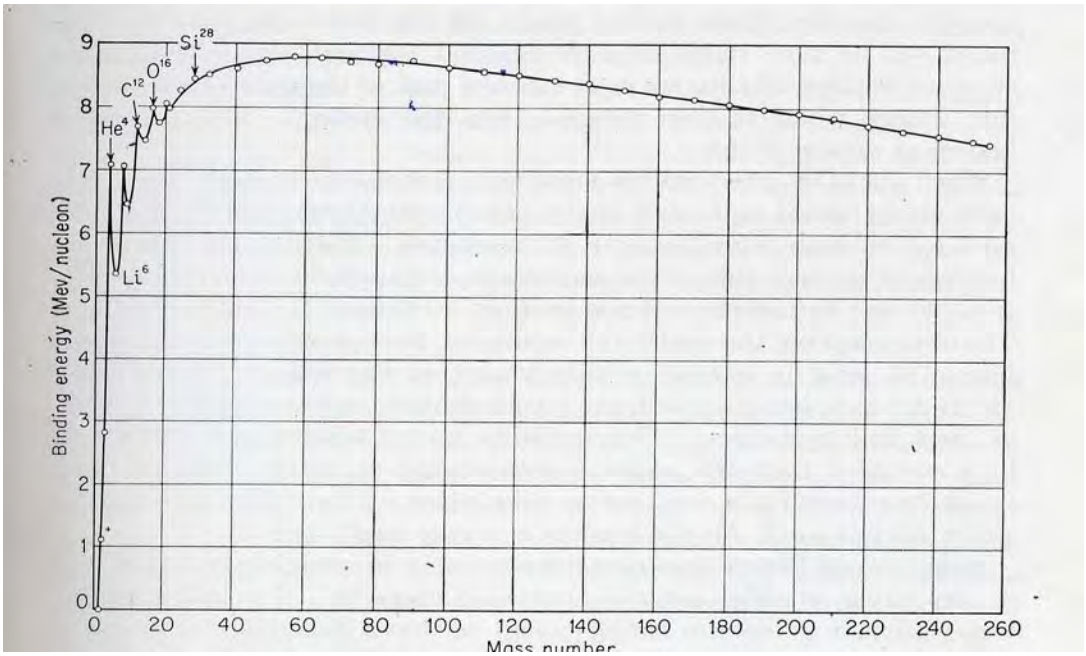
$$B.E = [ZM_P + (A - Z)M_n - {}_ZM^A]\, c^2 \qquad (2.2)$$

Where Z is the number of protons, A-Z is the number of neutrons and M_P, M_n & ${}_ZM^A$ represent masses of proton ,neutron, and the final nucleus respectively. The binding energy is a measure of energy which must be spent to split a given nucleus in to all its constituents nucleons.

The binding energy divided by the mass number A is called the specific binding energy of a nucleon in the nucleus or the binding energy per nucleon.

$$B^* = \varepsilon = B.E/A \qquad (2.3)$$

The plot of B^*or ε against A is shown in the figure 1.1 below. From the figure 1.1 it can be seen that ε(A) increases rapidly from ε = 0 for A = 1 to ε=8Mev for A=16,passes through its maximum value ε_{max}=8.8Mev for $A \approx 60$(^{58}Fe and ^{62}Ni) and then gradually decreases to ε=7.6Mev for the heaviest element encountered in nature, namely uranium. The average value ε^* is equal to 8Mevand $\varepsilon = \varepsilon^*$=8Mev for most of the nuclei. Hence, to a first approximation, the binding energy of atomic nuclei can be expressed in terms of the mass number through the relation



Mass number

Fig. 1.1 Binding energies of the nuclides.

B.E $\approx \varepsilon^{*}$A = 8AMev $\approx$ 0.0086Aamu.

(since 1amu = 1.66×10^{-27}kg = 931.5Mev)

Analysis of the curve leads to the following conclusions.

(1)The drop at small A has been interpreted by Wick (G.c Wick), on the liquid drop model, as a surface tension effect. Nucleons near the surface cannot interact with as many of their neighbours as can those in the interior, thus reducing the number of bonds. Also the study of binding energy of very light nuclei verifies that, nuclear forces are short-range forces; this means that the bond energy drops off rapidly as the particles are separated.

Some characteristics of very light nuclei are given in table 1.1 below

Nucleus	Binding Energy(Mev)	Number of bonds	Bond per nucleon	Energy per bond(Mev)
H	2.2	1	1	2.2
H	8.33	3	2	2.78
He	7.6	3	2	2.52

He	28.11	6	3	4.69

We see that the energy per bond increases as we go down the column. The bonds per nucleon also increase as we go down the column, which suggests that the nucleons are drawn together. [3] also we see that the peak at A = 4 corresponds to the exceptionally stable $_2He^4$ nucleus, the alpha particle.[5]

(2) The fact that B* or ε is nearly constant for intermediate masses allow us to say that nuclear forces are saturated. i.e. the ability of a nucleon to interact not with all nucleons surrounding it but just with a few of them. Indeed, if each nucleon in a nucleus interact with all the (A-1) remaining nucleons, the total energy would be proportional to A(A-1) $\approx A^2$ and not to A. Saturation is closely related to the short range nature of nuclear forces.[4]

(3)The positive value of B.E and ε for all nuclei implies that nuclear forces are attractive in nature, the energy of attraction being more than compensating the coulomb repulsion by protons. Moreover, the large value of the average binding energy per nucleon ε* = 8Mev means that nuclear interaction is extremely strong.[1]

(4)The binding energy ε per nucleon in a nucleus is a measure of its stability. The value of ε is especially large in even-even nuclei (even z and even n),which include the α-particle like nuclei ^{12}C, ^{16}O, etc (α-particle like nuclei are the ones containing A = 4n nucleons, of which there are z = 2n protons & N = 2n neutrons n being an integer).This circumstance indicates an additional (pairing) interaction between two nucleons)[1],for all the bonds of the four particles are used.[4]

(5)Nuclei with an odd mass number, i.e. even-odd (even z and odd N) and odd even (odd z and even N) nuclei have unpaired neutron (proton) and hence a somewhat lower value of ε. Finally an odd- odd nuclei (odd z and odd N) are β-radioactive as a rule, since they have two unpaired nucleons i.e. the lowest value of ε (only four such β-stable nuclei are known:$_1H^{2,}$ $_3Li^6$,$_5B^{10}$ and $_7N^{14}$.[1]

(6)A comparison of the value of ε for all even-even nuclei reveals that even against the background of α-particle like nuclei with a high stability, there are still higher values of ε for nuclei containing one of the following numbers of protons and/or neutrons: 2 , 8 , 20 , (28) , 50 , 82 , 126 (the last number corresponds to neutron only).These numbers are called magic nuclei. Nuclei having magic numbers of protons

and neutrons are called double magic nuclei. The unusually high stability of magic nuclei is explained in the shell model of the nucleus. Nucleon shells for protons and neutrons are filled independently. A simultaneous filling of proton and neutron shells indicates the formation of especially stable double magic nuclei.[1]

1 . 4 Nuclear stability

Not all combinations of neutrons and protons form stable nuclei. In general light nuclei ($A \leq 20$) contain approximately equal numbers of neutrons and protons,[5] while in heavier nuclei larger proportion of neutrons is required to produce increased separation between the protons.[4] Nucleons, which have spin of ½, obey the pauli exclusion principle. As a result each nuclear energy level can contain two neutrons of opposite spins and two protons of opposite spins. Energy levels in nuclei are filled in sequence just as energy levels in atoms are, to achieve configurations of minimum energy and therefore maximum stability.[5]

Sixty percent of stable nuclides have both even Z and even N,[5] and thereare 162 such stable nuclides. [4] Nearly all others have either even Z and odd N or odd Z and even N with the number of 54 and 50 respectively.[4]Only five stable odd- odd nuclei are known: ${}_1H^2$, ${}_3Li^6$, ${}_5Be^{10}$, ${}_7N^{14}$ and ${}_{73}Ta^{180}$.[5]

Nucleons inside the nucleus are more tightly bound than are those on the surface. In light nuclei most or all of the nucleons are on the surface. This tends to make the very light nuclides less stable than those of intermediate mass The very heavy nuclei are less stable than those of somewhat smaller mass because of the large disruptive force of their large electric charge. Nuclides of intermediate mass are therefore more stable than either the very light or very heavy nuclides.[4]

As shown in fig 1.2 at low Z values, stable nuclides contain roughly equal number of protons and neutrons. Nuclides just above or below the line of stability are unstable and decay by radioactive disintegrations, fission etc, while nuclides far from the line of stability on the chart are not observed. The line of stability ends at Z=83 and nuclides with atomic number greater than this are always unstable & undergo radioactive decay. [2]

Examination of the binding energy curve fig 1.1 shows that nuclides having mass numbers near 60 have the greatest nuclear stability, for they are the ones for which the energy release per nucleon in their formation was greatest. Stated in another way these are the nuclei with the lightest protons and neutrons, for energy release from any system is always accompanied by a decrease in mass.

The binding energy curve gives a clue to two methods for releasing nuclear energy. Light nuclei having low binding energy can be joined or fused together to form heavier, more stable nuclei. The mass of each nucleon decreases in the process, releasing energy. This is the process known as nuclear fusion. Energy is also released when heavy nuclei are split into two, three, or four pieces, for fig 1.1 shows that the fragments will be more stable than the original nucleus. Again the greater stability is achieved through conversion of part of the mass of the system into energy, which is then released, from the system. This process is known as nuclear fission.

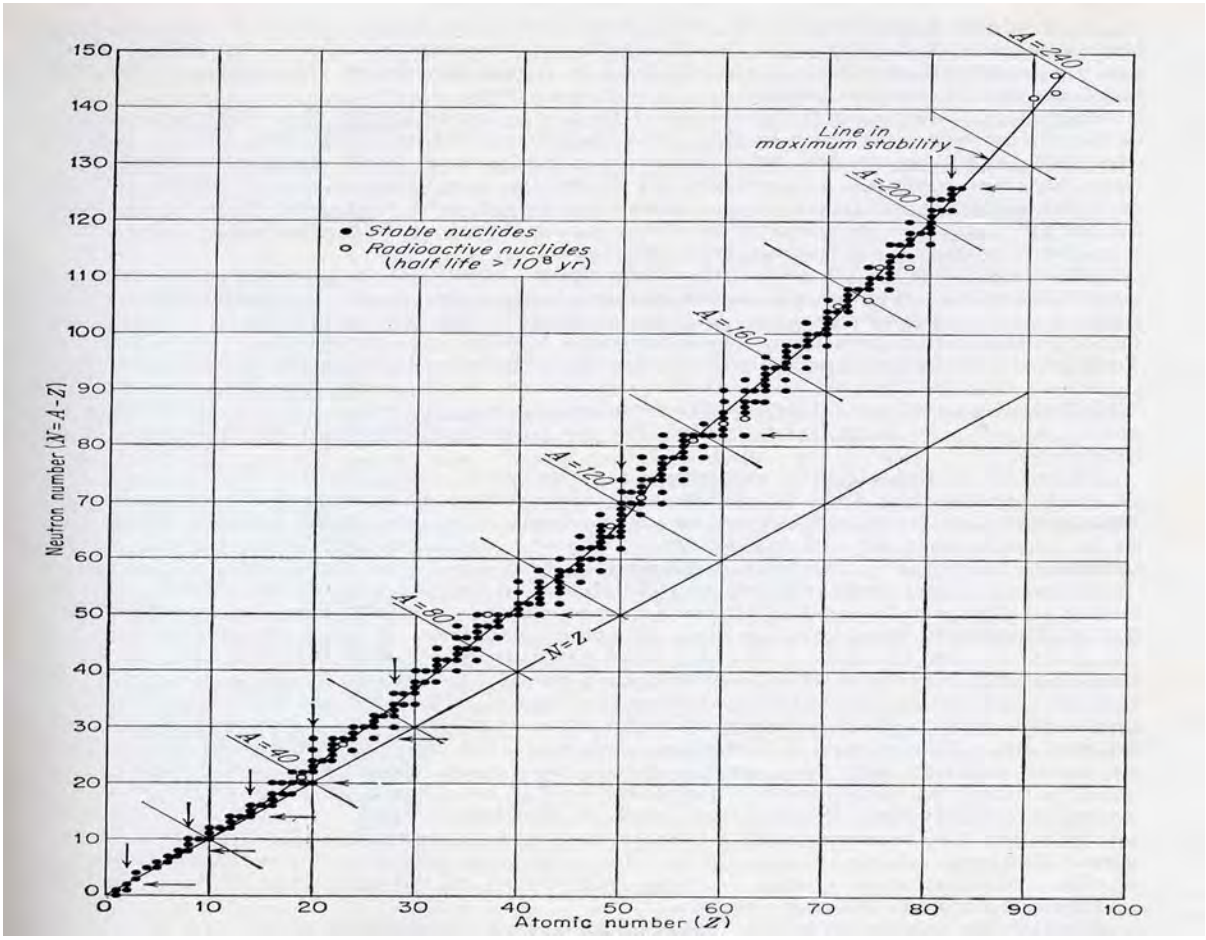


Fig. 1.2 Chart of the stable nuclides

It is well known fact that all three radioactive families existing in nature terminate at $_{82}$Pb. Among the nuclei encountered in nature those with $Z \leq 82$ are as a rule stable. Alpha particles with the highest energy (in comparison with the neighbouring nuclei) are emitted by radioactive nuclei with N = 128 , Z = 84 and N=84, which are transformed into the nuclei with N=126, Z=82 and N=82 respectively. Similarly, the highest energy of beta decay is observed in beta transitions to magic nuclei, while the beta particle emitted by magic nuclei have the lowest energy.[1]

CHAPTER TWO

RADIOACTIVITY

2.1 Discovery of Radioactivity

One of the most important discoveries in nuclear physics was made in 1896, quite by accident. Wilhelm Rontegen had discovered x-rays the preceding year. Henri Becquerel was trying to determine the relationship between the phosphorescence of certain salts after exposure to sunlight and the fluorescence of the glass in an operating x-ray tube. One of the salts used was potassium uranium sulphate, $K_2UO_2(SO_4)2H_2O$.After exposing some of this salt to sun light, Becquerel found that not only did it emit visible light, but also rays which, like x-rays, could penetrate through thick black paper and thin metal foils exposing photographic plates wrapped within. When cloudy weather intervened, he put the uranium salt and a photographic plate away in a drawer to wait for sunny weather. Later this plate was developed, and an intense image of the salt appeared although the salt had not been exposed to much sunlight. Becquerel then conducted further experiments showing that the intensity of the penetrating radiations was quite independent of any exposure to sun light and that they came from uranium in the salt.[4] If it were not for the fact that a few very long lived radio nuclides occur in nature, it is certain that radioactivity would not have been discovered as early as it was. Natural thorium minerals contain $_{90}$ Th^{232} and uranium minerals contain $_{92}U^{235}$ and $_{92}U^{238}$. The half lives of these naturally occurring radio nuclides are comparable with or greater than the age of the earth ($\approx 3\times10^{9}$years). It must be presumed, therefore, that when earth matter, as we now know it, was

created these radio nuclides were formed along with the stable nuclides and have been decaying very slowly ever since. The shorter lived radio nuclides would have decayed away long ago and are thus not found in nature.[2] Ernest Rutherford repeated Becquerel's experiments and showed that uranium emits two kinds of radiations, which he called alpha and beta rays. Rutherford found that the alpha rays are absorbed by very thin layers of matter, such as sheet of paper, but that the beta rays are able to produce the effects discovered by Becquerel. A third still more highly penetrating emission called gamma rays was discovered later. Rutherford's investigations led, several years later, to his nuclear model of the atom, and all three radiations were shown to come from the nucleus. Marie curie discovered that thorium has about the same degree of radioactivity, as does uranium. Her tests showed that the uranium ore, pitchblende, contained considerably more radioactivity than could be expected from its uranium content. She and her husband, Pierre, then succeeded in separating from the pitch blende the previously unknown elements is over a million times more radioactive than uranium.[4] therefore if uranium and thorium minerals were not radioactive, we would probably not know much about nuclear physics today. [3]

2.2 General Properties of Radiations

Radioactivity is spontaneous emission of nuclear radiation by a substance. This radiation occurs during α- or β- transformations of atomic nuclei as well as during other nuclear decays, i.e. in transitions of excited nuclei into their ground energy states, in spontaneous fission.[6] the basic properties of the three radiations are:

(1) from the deflection direction and the magnetic field direction, the α- and β- radiations are streams of high speed positively and negatively charged particles respectively. Further experiments involving the determination of charge to mass ratio of these particles show that the α- particles are helium nuclei and that the β- particles are negatrons. The third component called gamma radiation undeflected by a magnetic field. The γ-rays were recognized early on as being electromagnetic waves and similar to x-rays but with more energy.

(2) When the α-, β- and γ-radiations which occur in radioactivity are passed into absorbing materials of different thickness, it is the gamma (γ) radiation which has the greatest penetrating power while the alpha (α) radiation is the most easily absorbed.

(3) The γ-radiation is practically unaffected by paper and aluminium sheet and is only partly absorbed by the lead. The β- radiation is hardly affected by the paper but is absorbed by aluminium and lead. In general, the α- and β- radiations can be easily and completely absorbed by relatively thin layers of any material while the γ- radiation is never quite completely absorbed even by the very thick layers of the most dense materials.

(4) When any radioactive radiation, but in particular α- or β- radiation is passed through a gas, it produces ionization of the gas molecules. If the gas is enclosed between two electrodes maintained at different potentials, an ionization current (I) through the gas results.

2.3 Radioactive Decay Law

If any radioactive sample is examined for its radioactivity, it is always observed that the strength or activity as measured by the rate of emission of α-, β- and γ-rays decrease with time. The time taken for the activity to decrease to one half of its initial value is called the half-life, $T_{1/2}$, and is characteristic of each radionuclide. Radionuclides are known with half-lives from 10^{-6} to 10^{10} years.

If at any time the number of radioactive atoms present is N(t), then it is an experimental fact that the disintegration rate R,or rate of change of N(t) with time is proportional to N, i.e. $R = \frac{dN(t)}{dt} = -\lambda N$……(2.1)

Where λ is the constant of proportionality, called the decay constant, and the negative sign indicates that the number of atoms N, is decreasing with time. Integration of Eq.2.1.yields directly the equation :

$N = N_o \exp(-\lambda t)$……(2.2)

Where N_o is the number of radioactive atoms at time t = 0, and N is the number at time t. Then for half life $T_{1/2}$ we have:$1/2\ N_o = N_o \exp(-\lambda\ T_{1/2}) \Rightarrow T_{1/2} = \frac{\ln 2}{\lambda}$

Or $T_{1/2} = \frac{0.693}{\lambda}$ ……(2.3)

If the unstable nuclei of a given species were identical clock like mechanisms obeying the laws of classical physics, we would expect all of them to decay at the same time after their formation. Instead, they are found to decay after a wide range of different times. The explanation of this behaviour lies in the probabilistic nature of quantum mechanics.

Radioactivity is a property of nuclear state. It is impossible to affect the process of radioactive decay without changing the state of the nucleus.consequently, the probability, λ of radioactive decay per unit time is constant for a given nucleus, in a given energy state (Isotope). Since λ is probability per unit time, λ dt is the probability that any nucleus will undergo decay in a time interval dt. If a sample contains N undecayed nuclei, the number dN that decay in a unit time dt is the product of the number of nuclei N(t) and the probability, λ dt that each will decay in dt . That is:

$dN = -\lambda N dt$……(2.4)

where the minus sign is required because N(t) decreases with increasing time, t. the disintegration probability λ appears in this equation as a coefficient called the decay constant. Equation 2.4 can be rewritten as:

$$\frac{dN}{N} = -\lambda\, dt$$

and integrating both sides, $\int_{No}^{N} dN/N = -\lambda \int_0^t dt$ gives , $\ln N - \ln N_o = -\lambda t$

i.e. $N = N_o e^{-\lambda t}$……(2.5)

this equation 2.5 which gives the variation of the number of radioactive nuclei with time is known as the exponential radioactive decay law.

Since it is the activity or counting rate, $(\frac{dN}{dt})$which is observed rather than N, differentiating equation 2.5 yields: $\frac{dN}{dt} = -\lambda N_o \exp(-\lambda t)$.

But $(-\lambda N_o)$ is the initial activity R_o at time t = 0, so that:

$R = R_O \exp(-\lambda t)$……(2.6)

From equation (3.5), it follows that the process of radioactive decay is described by an exponential function. Hence at any instant of time t, there always exist undecayed nuclei with lifetime exactly equal to The number of these nuclei will be:

$$dn(t) = \lambda N(t) = \lambda N_o \exp(-\lambda t)$$

We can calculate the average life time T of a given radioactive nucleus by calculating the average value of t as:

$$T = \bar{t} = \frac{\int_0^\infty t dN(t)}{\int_0^\infty dN(t)} = \frac{No\int_0^\infty \lambda t \exp(-\lambda t) dt}{No}$$

Putting $x = \lambda t$ gives $dx = \lambda dt$, or $dt = dx / \lambda$, so that we have

$$T = \frac{1}{\lambda}\int_0^\infty x \exp(-x) dx = \frac{1}{\lambda}$$

Or $$T = \frac{1}{\lambda} \qquad (2.7)$$

I.e. the average lifetime T of radioactive nucleus is the reciprocal of the decay constant. Note also that we can write the decay law as:

$$N(t) = \frac{No}{2^n} \qquad (2.8)$$

Where n is the number of half lives in time t and $n = t / T_{1/2}$ (since $T_{1/2} \ln 2 / \lambda$ or

$\lambda = \ln 2 / T_{1/2}$ and then $\exp(-\lambda t) = \exp(-t \ln 2 / T_{1/2}) = 2^{-t/T_{1/2}}$)

There are several ways to characterize the rate at which a radioactive nucleus decays. One is to give decay constant λ. The other is to give the reciprocal $1 / \lambda$ which is denoted by T. putting t = T, into the equation (3.5) gives:

$$N = N_o / e \qquad (2.9)$$

i.e., T is the time in which N drops to the fraction of 1/e of its original value.

For a general case when unstable nuclei decays in more than one fashion (say by beta decay as well as gamma decay) we denote the total decay constant λ as:

$$\lambda = \lambda_1 + \lambda_2 + \lambda_3 + \qquad (2.10)$$

Where $\lambda_{1,}\ \lambda_{2,}\ \lambda_3$ etc are partial decay constants of each specific mode. We can also write a mean lifetime T ($T = 1 / \lambda$) as:

$$1/T = 1/T_1 + 1/T_2 + 1/T_3 + \qquad (2.11)$$

and call T as the total mean life time and $T_{1,}\ T_{2,}\ T_3$ etc as partial mean life times.[9]

if in turn the nuclei N_2 appearing as a result of radioactive disintegration of nuclei N_1, are also radioactive , we must write a system of two differential equations to describe these two successive transformations instead of single differential equation. I.e. $dN_1(t) / dt = -\lambda_1 N_1(t)$

$$dN_2(t) /dt = \lambda_1 N_1(t) - \lambda_2 N_2(t) \qquad (2.12)$$

Where $\lambda_1$and λ_2 are disintegration constants of nuclei N_1 and N_2 respectively. The system of equations describing the mutual transformation of three, four, or more substances can be also written in an exactly similar manner. Solving this system of equations (3.12), we obtain the following result.

$$N_1(t) = N_{01} \exp(-\lambda_{1t})$$

$$N_2(t) = N_{02}\exp(-\lambda_2 t) + \lambda_1 N_{01} / (\lambda_2 - \lambda_1)[\exp(-\lambda_1 t) - \exp(-\lambda_2 t)] \qquad (2.13)$$

Where N_{01} and N_{02} are the values of $N_1(t)$ and $N_2(t)$ at t = 0. expressions (3.13) are considerably simplified if $T_1 >> T_2$ ($\lambda_1 << \lambda_2$) and time periods $t << T1$ are considered. in this case $N_1(t) \approx N_{01}$

$$N_2(t) \approx N_{02} \exp(-\lambda_2 t) + \lambda_1 N_{01} / \lambda_2 [1 - \exp(-\lambda_2 t)] \qquad (2.14)$$

If $N_{02} = 0$,we get $N_2(t) \approx \lambda_1 N_{01} / \lambda_2 (1 - \exp(\lambda_2 t)$ (2.15)

Then in the limiting case we get:

$$\lim_{t\to\infty} N_2(t) = \lambda_1 N_{01} / \lambda_2 = \text{const}$$

or $$\lambda_1 N_1 / N_2 \lambda_2 \qquad (2.16)$$

and this is called the secular equation. This indicates that the number of disintegrations, $N_2\lambda_2$ of the daughter material is equal to the number of disintegrations of the parent substance- which is secular equilibrium condition. This equation can be used to compare two interconvertible substances where half life of the second substance being much smaller than the first ($T_2 << T1$). Under the condition that this comparison is made at the instant $t >> T_2$ ($T_2 << t << T1$)

Some of the more often used units characterizing the activity are

1Curie = 1Ci = 3.7 x 10^{10} disintegrations / second

1Rutherford = 1R = 10^{6} dis / sec

1Becquerel = 1Bq = 1dis / sec [13]

2..4 NUCLEAR RADIATIONS

2.4.1 INTRODUCTION

The three common radiations from radioactive elements are alpha beta and gamma radiations. It was shown that the alpha particle is identical to helium nucleus, beta radiation consists of electrons, and that gamma radiation is electromagnetic wave. In natural radionuclides, alpha process and beta processes very often compete, that is they may both be energetically possible. Whether or not a given nuclide is observed to be simultaneously an alpha emitter and beta emitter depends on whether the probabilities of occurrence of the two processes are sufficiently close in order of magnitude.[7]

2.4.2 ALPHA- DECAY

Alpha rays are positively charged particles and are identical with doubly ionized helium atoms (He^{++}). They are emitted by nuclei as a result of alpha decay. Mostly heavy nuclei (Z > 82) undergo natural alpha decay. Usually alpha decay is accompanied by beta decay and/or gamma decay. In alpha decay, parent nucleus transforms into a daughter nucleus and an alpha particle; thus the mass number of the parent nucleus decreases by four units while atomic number decreases by two units.[9] The decay process is written schematically as:

$$ {}_{Z}X^{A} \longrightarrow {}_{Z-2}Y^{A-4} + {}_{2}\alpha^{4} \qquad \text{----------2.18} $$

Where X and Y are the initial and final nuclear species [11]

ENERGETICS OFALPHA DECAY: The energy mass equation for α-decay can be written as: $Mc^2 = M_1c^2 + m_ac^2 + Q_a$

where M&M_1 are the representative masses of parent nucleus and daughter nucleus.

Or $Q_a = (M - M_1 - m_a)c^2$ (Q – equation) ----------2.19

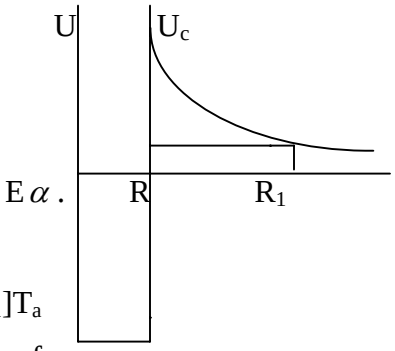
`Where Q is called the nuclear disintegration energy. Hence the possibility of α-decay interms of mass is expressed by the relation $M > M_1 + m_a$ (i.e. $Q_a > 0$) ---2.20

(i) From the conservation of momentum we can see that, the daughter nucleus M_1, recoils with equal momentum as alpha particle:

i.e. $P_a = P_{M-1}$ or $m_a v_a = M_1 v_1$

and then $v_1 = m_a v_a / M_1$

(ii) From the energy conservation, the excess energy of The parent nucleus is released during alpha decay In the form of kinetic energy is distributed between the α-particle & the daughter nucleus.



$Q_a = 1/2 m_a v_a^2 + 1/2 M_1 v_1^2 = 1/2 m_a v_a^2 \; 1/2 M_1 (M_a^2 v_a^2 / M_1^2)$

Or $Q_a = T_a + (m_a/M_1)T_a = (1 + m_a/M_1)T_a = [(M_1 + m_a)/M_1]T_a$

$\Rightarrow Q\alpha = (A/A-4)T\alpha$ where $T\alpha$ is kinetic energy of α-particle, A is atomic weight of parent nucleus and A-4 is atomic weight of the daughter nucleus

[Fig 2.1 Energy level d diagram of α-particle]

Thus, most of the kinetic energy released in heavy nucleus the process of α-decay is taken away by α-particle and only insignificant part (about 2% heavy α-radioactive nuclei) goes to the daughter nucleus.

However, the coulomb potential barrier U_e hinders the release of energy (see fig.2.1)The probability of the α-particle passage through the barrier is not great and quickly falls off as $E\alpha$ or $T\alpha$ decreases. Therefore equation 2.20 is not a sufficient condition for α-decay.

The height of the couloumb barrier for a charged particle penetrating into, or escaping out of the nucleus increases proportionally to its charge. Therefore, the coulomb barrier even prevents other tightly bound light nuclei such as ^{12}C, and ^{16}O from escaping out of heavy nucleus. The mean bond energy of the nucleon in these nuclei is even higher than in the He^4 nucleus. Therefore in some cases, the emission of ^{16}Onucleus would prove to be advantageous from the standpoint of energy, than the

successive escape of four alpha particles. However, the escape of the nuclei heavier than He^4 nucleus has not been observed.

2.4.2 Mechanisms of α -decay

From the point of view of classical physics, a body with energy $E\alpha$ ($\approx$4Mev) being in the region $0 \leq r \leq R$ separated from the outer space by an energy barrier of the height U_c and width $R_1 - R$, can never be beyond this region because on reaching the coordinate $r = R$, the kinetic energy of the body becomes equal to zero and its further motion into the region $r > R$ ceases. The only possible way to leave the potential is to get such a quantity of energy ΔE from outside that the total energy of the body $E + \Delta E$,becomes greater than the height of the barrier U_e.

The potential energy curve has a peak at r = R, called the coulomb potential barrier. Hence it is not surprising that α - decay does not occur instantaneously. What is surprising is the fact that it does occur at all, since the overcoming of a coulomb barrier of height U_c> 8.8Mev by an α - particle with a kinetic energy of 4Mev is forbidden in classical physics. Only quantum mechanics explains the α -decay mechanism. Actually in the world of microscopic particles (electrons, nucleons, α - particles) whose motion is described by quantum mechanics rather than by classical physics, there exists a possibility of the passage of a particle through a potential barrier – which is called tunneling.[1] Thus a particle possessing wave properties may be beyond the potential well even when its total energy $E\alpha < U_c$.

In nuclides with high atomic number, the mutual electrostatic repulsion of the protons is a powerful force tending to tear the nucleus apart. As a result, many of the heavier nuclei tend to stabilize by emitting part of their charge in the form of an alpha particle. For example when uranium-235 emits an alpha particle, thorium-231 is formed according to the equation: $_{92}U^{235} \longrightarrow {}_{90}Th^{231} + {}_2He^4 + \gamma + 4.67Mev.$

Where the 4.67Mev of energy is liberated in the reaction corresponds to a 0.00502amu decrease in the mass of the products as compared to the parent nucleus. Typical alpha emitter (source) with no gamma radiation is francium-220.

$$_{87}Fr^{220} \longrightarrow {}_{85}At^{216} + {}_2He^4 \ 6.81Mev$$

Here all the energy is carried by the particles as kinetic energy. The kinetic energy is divided in inverse proportion to the mass of the particles; so that alpha particle takes (216/220)6.81 = 6.69Mev and the remaining

(4/220)6.81 =.124Mev goes for the recoiling nucleus.

With many alpha emitters, all emitted alpha particles have exactly the same energy. Nearly all of the alpha particles have energy greater than 4Mev.[12] A plot of alpha rays emitted per unit time against $E\alpha$ the energy of alpha rays is called alpha ray spectrum and it usually shows a plot of similar to figure 2.2

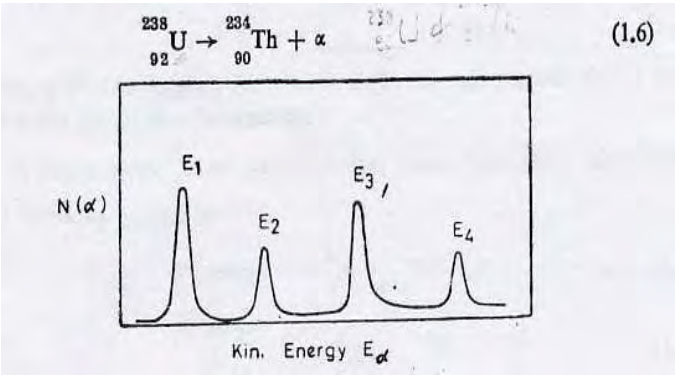


Fig. 2.2 Alpha ray spectrum

The various lines are attributed to the alpha decay leading to various excited states of daughter nucleus as shown in fig.2.3

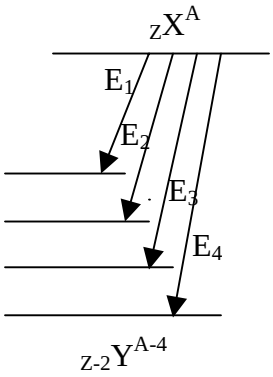


Fig. 2.3 Alpha decay

The greater the excess energy of an alpha emitter, the greater the decay energy and the shorter its half-life. Hans Geiger and J.M. Nuttal determined in 1911 the empirical relationship, which is fairly accurate for most alpha emitters:

$$\text{Log } T = 37.6 - 4.9E$$

Where T is a half life (sec) and E is alpha particle energy in Mev.

Also one may wonder why alpha particles rather than the protons/neutrons are emitted by heavy nuclei. This is of course due to the binding energy. The binding energy of the alpha particle is nearly as large as the binding energy of heavy nuclides, but the proton/neutron binding energy is zero. In terms of mass, the protons/neutrons in alpha particles are only slightly more massive than those in heavy nucleus, but an isolated proton/neutron is considerably more massive. As a result an alpha particle needs to acquire only a small amount of mass(energy) from the balance of the nucleus to be emitted, while a proton would have to acquire considerably more mass (energy) for emission to be possible.

2.5.2 Beta Decay

Many nuclides decay by an electron emission, positron emission, and orbital electron about energy levels and decay schemes of light and intermediate weight nuclide as well as those in the region of natural radioactive elements can be obtained by studying β -decay.[12]

2.4.2.1 Energetics of Beta decay

There are three types of beta decay. These are (i) β^--decay, (ii) β^+-decayand (iii) electron capture (K-capture)

(i) A parent atom ${}_ZX^A$ will be transformed during the β^--decay according to the equation: ${}_ZX^A \longrightarrow {}_{z+1}Y^A + \beta^- + Q_{\beta-}$

The energy liberated in the β^-- decay process (Q-equation) can be written as:

$$M_n c^2 = M_n' c^2 + m_e c^2 + Q_\beta$$

$$\text{Or} \qquad Q_{\beta-} = [M_n - M_n' - m_e]c^2$$

Adding Zm_e to the respective nuclear masses, equivalently interms of the mass of the atoms we can write :

$$Q_{\beta-} = [(M_n + zm_e) - (M_n' + zm_e + m_e)]c^2$$

$$= [M(A,Z) - M(A,Z+1)]c^2$$

Hence the energy condition for the possibility of the β^--decay process is :

$M(A,Z) > M(A,Z+1)$ (since $Q_{\beta-}$ has has to be positive).

(ii) For β^+-decay process also we can write an equation:

$$_ZX^A \longrightarrow {}_{Z-1}Y^A + \beta^+ + Q_{\beta+}$$

The energy liberated or the Q –equation for the process can be written as:

$$M_nc^2 = M_n'c^2 + m_ec^2 + Q_{\beta+}$$

$$\text{Or} \quad Q_{\beta+} = [M_n - M_n' - m_e]c^2$$

Again adding zm_e to both nuclei, we can go over from nuclear masses to atomic masses as: $Q_{\beta+} = [(M_n + Zm_e) - (M_n'' + m_e + Zm_e)]c^2$

$$Q_{\beta+} = [(M_n(A,Z) + Zm_e) - (M_n(A,Z-1) + (Z-1)m_e + 2m_e)]c^2$$

$$= [M(A,Z) - M(A,Z-1) - 2m_e]c^2$$

Then the energy condition for the β^+- decay can be written in analogy to the β^--decay as : $M(A,Z) > M(A,Z-1) + 2m_e$ (For $Q_{\beta+}$ to be positive)

(iii) The third type of beta radioactivity is electron capture (EC) involves the capture of an electron by the nuclei from its own electron shell.[1] This is an alternative mode of decay to positron emission and again causes an increase in the neutron to proton ratio of emitting nucleus.[2]

A parent atom $_ZX^A$ will be transformed during this decay (EC) according to the equation: $_ZX^A + e \longrightarrow {}_{Z-1}Y^A$ (EC decay). [9]

Then the energy released during electron capture (EC) is given by:

$$M_nc^2 + m_ec^2 = M_n'c^2 + Q_{EC}$$

$$\text{Or} \quad Q_{EC} = [M_n(A,Z) + m_e - M_n(A,Z-1)]c^2$$

Adding the mass of Z-electrons to both nuclei, we get :

$$Q_{EC} = [M_n(A,Z) + Zm_e + m_e - (M_n(A,Z-1) + (Z-1)m_e + m_e)]c^2$$

$$= [M(A,Z) - M(A,Z-1)]c^2.[9]$$

The energy condition for the electron capture is:

$$M_n(A,Z) + m_e > M_n(A,Z-1)$$

$$\text{Or} \quad M(A,Z) > M(A,Z-1)$$

The phenomenon of electron capture is quite significant for heavy nuclei whose k-shell is quite close to the nucleus. Besides the capture of an electron from the k-shell (k-capture), capture from L-shell (L-capture), capture from M-shell (M- capture)

(Of course with relatively less binding energy) are also observed.[1] The vacancy left behind in the k-shell etc is followed by higher orbital electrons cascading down with the emission of x-ray lines characteristic of the newly formed daughter atom (A,Z-1).The x-ray emission is the net result and the only observable phenomenon associated with the electron capture process.[2]

Finally, the fact that positrons and negatrons are emitted by the nuclei doesn't mean that they are present in nuclei as such. Their ejection results from an unknown process, but is due to an unstable ratio of neutrons to protons in nuclei. If the number of neutrons, (A-z) is greater than the number of protons, (z), an excess of neutrons can lead to negatron emission with net result of a decrease in the neutron to proton ratio

i.e. $_0n^1 \longrightarrow {}_1p^1 + \beta^-$

Similarly deficiency of neutrons can lead to positron emission, by which process the neutron to proton ratio increases. I.e. $_1P^1 \longrightarrow {}_0n^1 + \beta^-$

I n the electron capture process the nucleus captures one of the inner orbital electrons, usually a k-shell electrons, which effectively converts one of the nuclear protons into a neutron. I.e. $_1P^1 \longrightarrow {}_0n^1$.

2.4.2.2 The Neutrino Hypothesis

The energy spectrum of the beta rays is continuous in nature. (See fig.2.4)

In contrast to line spectrum of α-rays. The beta ray spectrum rises with energy, reaches a smooth maximum and then comes down to meet the energy axis at a point E_0,the maximum energy. T he maximum energy, E_0, also called the end point energy, is characteristic of a particular beta transition. (very small in number

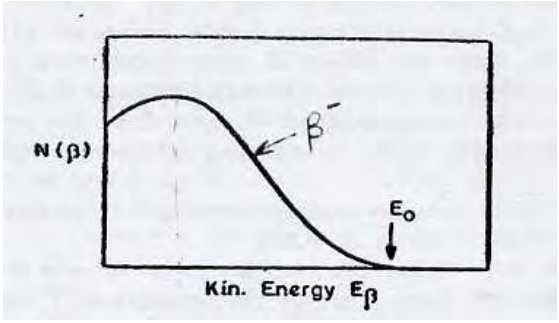


Fig. 2.4 A typical beta spectrum

The change of mass in any beta decay process is found to correspond to the sum of the maximum energy carried by any beta particle plus the emitted gamma ray (if any).The question then arises as what happens to the balance of the energy when beta particles having less than the maximum energy are emitted? Also protons, neutrons and electrons spin about their axes with an angular momentum given by $1/2\,\eta$. How then can angular momentum be conserved in beta emission, when a new particle (the electron) is suddenly created? The answer to these questions were suggested by Wolfgang Paul in 1927

In the investigations of the properties of elementary particles W.Pauli, theoretically predicted the existence of new particle namely neutrino – in 1931. By considering the beta decay of atomic nuclei, Pauli arrived at the conclusion that the existence of neutrino is inevitable. Ofcourse its existence was proved experimentally later. In the above discussion we have seen that beta energy spectrum is continuous where the energy from mass difference is fixed. Also the elementary act of beta decay seemed to violate simultaneously the laws of conservation of energy, momentum and angular momentum.

Inorder to explain the continuous nature of beta spectrum and to rescue the conservation laws, Pauli proposed that the emission of an electron(positron) during the beta decay of a nucleus is accompanied by the simultaneous emission of a neutral particle with a mass equal to zero and with a half integral spin.

It was agreed to call the particle formed together with a positron during the β^+decay: (A,Z) $\longrightarrow$ (A,Z-1) + e^+ + ν_e , the electron neutrino (ν_e) and the particle formed together with the electron during the β^--decay :

(A,Z) $\longrightarrow$ (A,Z+1) + e^- + $\bar{\nu}_e$, the electron anti neutrino($\bar{\nu}_e$)

The first process is reduced to the transformation of a nuclear proton into a neutron as

Per decay scheme: P $\longrightarrow$ n + e^+ +ν_e.

While the second process is reduced to the transformation of a nuclear neutron into a proton: n $\longrightarrow$ P + e^- + $\bar{\nu}_e$

Note the only difference between neutrino and antineutrino is in their helicity, i.e. right handedness (ν_e) and left handedness ($\bar{\nu}_e$)

Finally from neutrino hypothesis we have the following results.

(i) Energy is conserved since now there is another particle (neutrino/antineutrino) is emitted in each cases of beta decay. Thus we have, $E_\nu = E_{max} - E_\beta$

I.e. if $E_\beta = E_{max}$ then $E_\nu = 0$ and $E_\beta = 0$ for $E_\nu = E_{max.}$. Therefore this solves the question of β - energy spectrum and its conservation.

(ii) Angular momentum is also conserved. For example in ${}_1H^3 \longrightarrow {}_2He^3 + \beta^{-} + \nu$

(iii) Linear momentum is also conserved due to the presence of neutrino.

2.4.2.3. Energy levels and Decay schemes

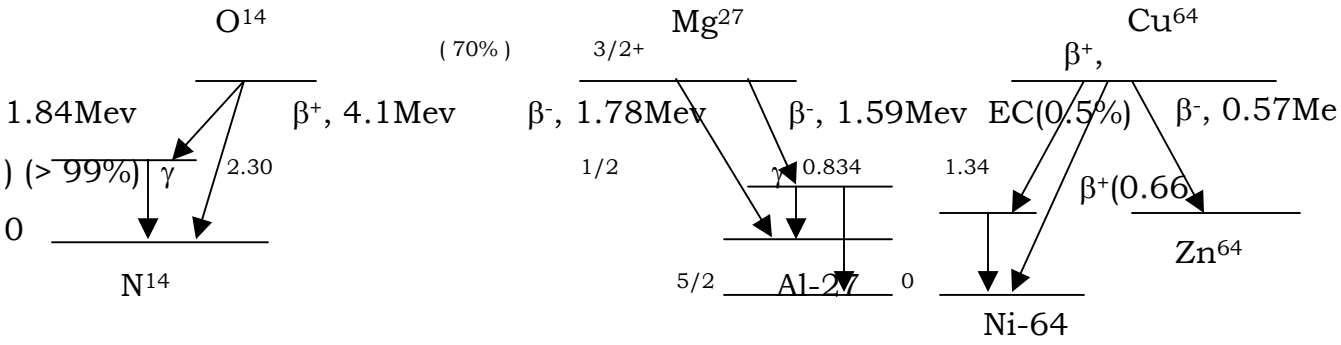
Beta transformations often yield information about the energy levels of the product nuclei and about decay scheme. These transformations are sometimes accompanied by γ- rays, and the presence of γ – radiation means that the product nucleus is formed in an exited state and pass to its ground state by emitting one or more γ- rays. If no γ -ray is emitted, the β-transition is directly to the ground state of the product nucleus.

(i) In the case of 0^{14}, in more than 99 % of disintegrations, positrons are emitted with an end point energy of 1.84 Mev; 2.30 Mev γ-rays are also observed. The total disintegration energy is 1.84 Mev + 1.02 Mev +2.30 Mev = 5.16 Mev, of which 2.86Mev is the difference in energy between the ground state of 0^{14} and the excited state of the product nucleus, N^{14} . The N^{14} nucleus passes to its ground state by emitting a 2.30 Mev γ-ray. In about 0.6% of the disintegrations 0^{14} undergoes a transition directly to the ground state of N^{14} by emitting 4.1 Mev positrons . The decay scheme is as showing Fig 2.6(a).

(ii) In electron (β) decay of Mg^{27}, about 70% of the disentegrations correspond to an end point energy of 1.78 Mev and about 30% to an end point energy of 1.59 Mev, γ -rays are observed with energy of 0.834Mev and 1.015Mev, respectively , and in less than 1% of the disintegration a γ- ray with an

(iii) by emitting 4.1 Mev positrons . The decay scheme is as showing Fig 2.6(a).

Fig. 2.6 –a) b) c)



energy of 0.18 Mev is observed. Coincidence experiment shows that the 1.78 Mev β – ray and the 0.834 Mev γ -ray belong to the same transition, and that the 1.59 Mev β-ray and the 1.05Mev γ- ray belong to the same transition . A decay scheme consistent with all of these data is shown in fig 2.6(b)

The direct transition from the ground state of Mg^{27} to the ground state of Al^{27} by electron emission of evidently highly forbidden. Values of angular momentum and parity assigned to a level are indicated at the left end of the horizontal line representing the level; the energy above that of the ground level is given at the right end of the line.

(iii) The Cu-64 nuclide is a particularly interesting case of β-decay because it emits both electrons and positrons and also undergo orbital electron capture. In 39% of the disintegrations, an electron is emitted, the β- - spectrum end point energy is 0.57 Mev. The product nucleus Ni-64 is formed in its ground state. In 19% of the disintegrations, the

positron is emitted with an end point energy of 0.66 Mev; the product nucleus Ni 64 is formed in its ground state. In 42% of this disintegrations, a k-electron is captured. In nearly all of the captures, the product nucleus, Ni 64 is formed in to ground state, but in a small fraction of the k-capture, a γ-ray is observed with an energy of 1.34Mev. There is, therefore, an excited level of Ni 64, 1.34Mev above the ground state. It has been shown that the γ-ray is observed only in coincidence with the orbital electron capture, and it is not associated with the emission of either the electron or the positron. The decay scheme of Cu 64 is shown in fig 2.6(c).

2.4.3 Gamma Radiation

2.4.3.1 Nature of Gamma Radiation

Gamma Radiation is spontaneous emission of γ-quanta by the nucleus. They are nothing but electromagnetic radiations of very small (10^{-10} to 10^{-12}m) wavelength (9). By emitting gamma quanta the nuncles goes over from one excited state to a state with a lower energy ((radiative transition). There are, single radiative transitions, when the nucleus emits a single quantum and at once goes over to the ground state (see Fig. 2.7(a) , or cascade transition when the excitation is removed by successive emission

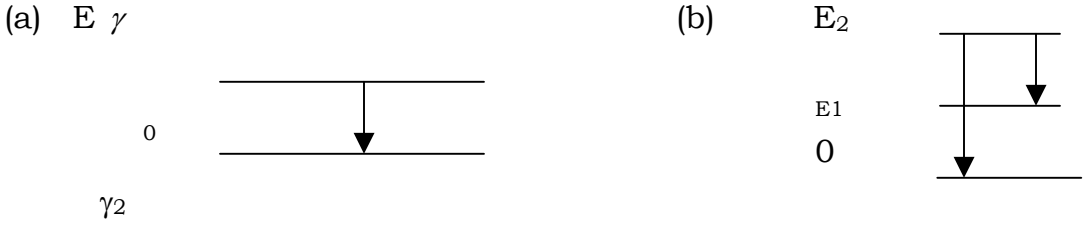


Fig2.7 (Radiative transitions)

of several γ- quanta (see Fig. 2.7(b)

Hence gamma radiation is a short wave electro magnetic radiation of nuclear origin whose energy usually varies from leker to 5 mcv in the electromagnet de exation process the nuclear drops to a lower edxcited state or to the ground state, in exact analogy with the emission of light from excited atoms how ever, the emerges of the electromagnitivc quanta emited by nuclei are mostly in the range 10^{14} to 10^{6} times the energy of a photos in the usable aspect rum.

According to the Maxwell's Electromagnetic theory, an oscillation of charged particle generals electromagnetic radiation given by

$$\frac{dE}{dt} = \frac{e^2 < a^2 >}{6\pi\varepsilon_0 c^2} \qquad (2.24)$$

This is the famous larmor equation, relating the radiated energy (dE/dt] to the acceleration $<a^2>$of a particle with charge (say Proton). Hence gamma rays being an electro magnetic wave can have electric as well as magnetic origin i.e. they are produced by magnetic or electric-dipoles, quadrupoles octupoles etc.

Multipole Radiation:

a) Under parity operation gamma ray emitted by electric dipole oscillations will have different parity (i.e. parity operator changes all coordinates into corresponding reflected value with respect to origin of (x,y,z) coordinate system). On the other hand γ-rays emitted by magnetic diploes will have no parity change. Generally if we use a subscript l=1 for dipole, l=2 for quadruprole, l=3 for octupole etc, then:

(i) For electrical transition parity change is given by $\Pi\gamma = (-1)^l$ and

(ii) For magnetic transition parity change is $\Pi\gamma = (-1)^{l+1}$ (2.25)

Then the first l-pole selection rule for gamma decay can be given by the equation $\Pi\gamma_e = (-1)^l$ (2.26) and

(iv) For magnetic transition parity change is $\Pi_{\gamma M} = (-1)^{l+1}$ .Then the first l-pole selection rule for gamma decay can be given by the equation:$\Pi_i = \Pi_\gamma \Pi_f$ (2.27)

Where the subscripts i and f stand for initial and final states.

(b) When transition takes place from an initial state of total angular momentum, I_i to a state of angular momentum I_f, then the difference in angular momentum is associated with gamma. As angular momentum is quantized gamma may have any value of l, l=0,1,2,---- and a selection rule II based on the change in I-value can be written as:

$$/I_f - I_i/ \leq l \leq I_f + I_i \qquad (2.28)$$

Where l being an angular momentum, l= 1,2,3 --- Shows the multipolity of the electric (El) or magnetic (Ml) transitions.

The first excited state of 60 -Co is 4+ state at 2.505 Mev. It decays to 2+ state at 1.332 Mev. Via E2 transition since the transition with the lowest l-value is faster than the others by several orders of magnitude (where $2 \leq l \leq 6$) and no parity change (+ to +) (see fig)

2.4.3.2 Energetics of Gamma decay

(**kinematics of photon Emission**)

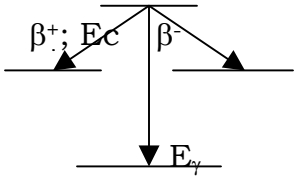
Emission of energetic photon – gamma radiation – is typical for a nucleus de exciting from some high – lying excited state to the ground state configuration. These transmutations take place within the same nucleus ${}_ZX^A$ in contrast to beta decay and alpha decay processes . They merely represent a re- ordering of the nucleons with in the nucleus with a lowering of mass from the excited ($M^* C^2$) to the lowest (MoC^2) Value . The total energy balance then reads .

$$M_0 * C^2 = Mo\ C^2 + E\gamma + T_0 \qquad (2.29)$$

With E_γ the energy of the emitted photon and T_0 the Kle of the recoiling nucleus. Linear momentum conservation leads to an expression.$M_o^* c^2$

$$P_0 = 0 \Rightarrow P_0 = P\gamma \qquad (2.30)$$

The recoil energy is very small, so non-relativistic expression can be used



i.e.$T_0 = P_o^2/2M_o = P_\gamma^2/2M_o = E_\gamma^2/2M_oc^2$,since $P_\gamma = E_\gamma/c$ (2.31)
Fig.2.8

2.4.3.3 The Nuclear Deexcitation mechanisms

Nuclear in highly excited states most often de excite themselves by the emission of heavy particle, whenever this is energetically possible. Particularly when the energy of excitation of nuclei is below the nucleon binding energy, nucleon emission is not observed. In such a case either gamma decay or another phenomena – internal conversion (IC), (some times) or pair production (with small probability) may take place.

(i) Gamma Decay: Gamma decay is a natural radioactive phenomenon, which is observed just like other decay as, α and β – decay. This is also observed when excited state of nucleus produced in nuclear reaction decides to ground state.

(ii) Electron of internal conversion: Sometimes it is possible for nuclear excitation energy to be removed by ejection of an atomic electron of internal conversion. The coalomb field of the nucleus transfers all of the excitation energy directly to the atomic electron, causing it to move in to unbound state with an energy balance of $Te = (Ei - Ef) - En$

$$\text{or} \quad = E^* - En \qquad (2.32)$$

where E^* or $= Ei - Ef$ is the nuclear excitation energy, En is the binding energy of electrons in the corresponding shells of the atom, and Te is the electron Kinetic energy. The energy is transmitted mainly through the columb interaction and a larger probability for k-electrons will result because k-electrons have a non-vanishing probability of coming into nuclear interior.

The total probability per unit time of decay of excited nucleus is given by Γ/h, where we write for bound state

$$\Gamma = \Gamma_\gamma + \Gamma_e \qquad (2.33)$$

which Γ is the width for emission of electron and Γ is width for r-emission. In both cases the total energy of nuclear excitation is removed and the two process must be regarded as competing alternatives. If the number of electrons observed per excited nucleus is Ne and the number of γ-rays is N_γ we define the internal conversion coefficient,α and as: $\alpha = N_e / N_\gamma = \Gamma_e / \Gamma_\gamma$ (2.34)

Where α may have any value between zero and infinity. The absolute value of the coefficient α is the higher, the longer the lifetime with respect to the emission of a γ -quantum, and the higher z of the nucleus. i.e. the close the electron shells of the atom to the nucleus.

X-radiation and Auger electrons

As a result of emission of the electron of internal conversion, the atomic nucleus passes to its ground state. The ground state by definition, is the neutral atom with all electrons in the lowest possible state. The atom, however, remains excited because of the lack of an electron in one of its shells. When a hole has been created in the 1s state, for instance, an electron from another state will drop down and fill the hole. Therefore, the emission of the internal conversion electron is accompanied by the radiation of the characteristics x-ray quanta or by the emission of the auger electrons.

The emission of the electron of internal conversion is most probable from the k-shell. In this case, the excitation energy of the atom is equal to the binding energy of the lost electron, Ek. Filling the vacancy in the K-shell occurs mainly in the transition of the electron from the nearest L- shell and the atom emits a K_α x-ray quantum. (The transitions are labeled K_α for transitions to L levels K_β for transitions to the M levels, and K_γ for transitions to the N- levels) When a hole is created in the L- Shell and the atom emits K_α radiation, an electron from the M,N,or O shells etc has much lower energy than the K radiation. Hence one electron hole, Originally, in the K shell, , for instance, may produce a cascade of x – ray , with rapidly decreasing quantum energies. In competition with this series of events is another interesting

process called auger effect in this process the available energy released in K to L transition is used not to emit a photon but to eject another L- electron. Hence two holes appear in the L- shell, more auger electrons and / or L- radiation etc. follow Conversion with pair production: one more mechanism of releasing the excess energy from the nucleus is called conversion with pair production. If the excitation energy of the nuclear exceeds 1.02 Mev ($E^*>2mc^2$) this is the coulomb field of the nucleus, an electron – positron pair may be produced as an alternative to γ-ray emission and electron internal conversion i.e. excited nucleus may emit a positron – electron pair which carries off all its excitation energy. As the emission of conversion electrons, conversion with pair production is not the conversion proper. i.e. is not the trans formation of a γ – quantum, previously emitted from the nucleus, into an electron positron pair, but is an additional method of giving off the nuclear energy into the outer space. The probability of this process is always low in comparison with the probability of emitting a γ – quantum. In contrast to the internal conversion coefficient, the probability of conversion with pair production is slightly lower with the increase of Z of the nucleus as well as with increase of the nuclear transition multipolarity (its being produced by diploe (l=1), quadrupole (l=2) or higher poles) the kinetic energy released in the process of pair production, $E_{pair} = E^* - 2mc^2$, is distributed between the electron, the position and the remaining of atom.

2.4.3. Sources of Gamma rays

In radioactive decay, daughter nucleus is usually left in an excited state as a result of the alpha or beta decay of the parent nucleus. Subsequently the daughter nucleus de-excites from these higher levels by emitting gamma rays. Thus, gamma rays usually follow the alpha or beta decay.(1) Alpha decay: In most (normal) cases of α-decay, the excess energy of the parent nucleus is released in the form of kinetic energy. i.e. $E_\alpha = T_\alpha + T_{nuc}$, which is distributed between alpha particle and daughter nucleus. But alpha spectra frequently contain groups of alpha particle with lower (fine structure of alpha spectra) and sometime even higher (Long range alpha particle) energies as compared to the normal α - decay.

While considering the α -decay process we have assumed that both nucleus are in the ground state. But in actual practice, each of these nuclei has its own system of excited states which are characterized by certain value of energy E, total angular momentum I, parity p etc. In principle, α -transaction between these states is also possible.

The main group (normal) α - particle have definite energy. (see fig 2.9) and corresponds to the energy transition between the ground states of the initial and final nucleiHowever, if a transition is to an excited state of the final (daughter) nucleus, the energy of α -particles will be lower than the normal value. This corresponds to a short range α- particle and the emission of short range α- particle is followed by γ – radiation (see fig 2 9 (b))

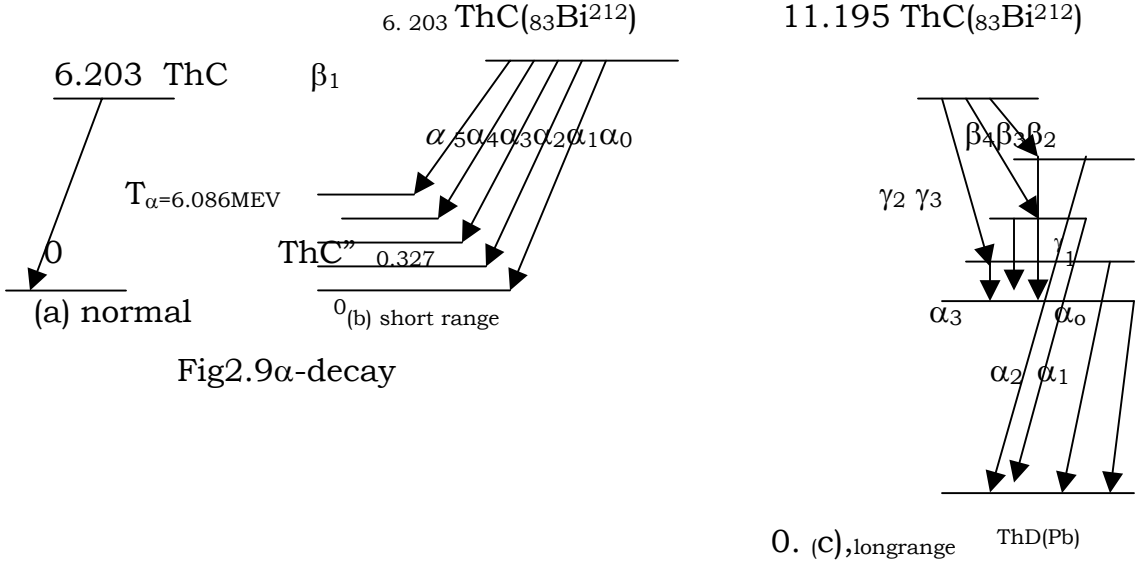


Fig2.9α-decay

(b) Conversely when the α – transition is from an excited state of the initial (parent) nucleus, α particles of higher energic are emitted. This corresponds to the long range α- radiation, hence γ quantum emission is followed by α – decay (see fig 2.9 (c). There fore as illustrated in the fig 2.9 above, for ThC, during short range and long range α – decay, γ-radiation is possible.

2/ Beta decay.

Since gamma rays result from the transition between excited nuclear state, they are mono energetic as given by equation (2.35). A general case of gamma decay following a beta decay is shown in feg 2.10 in this case

$E(\gamma_1) = E_2 - E_0$

$E(\gamma_2) = E_2 - E_1$

$E(\gamma_3) = E_1 - E$

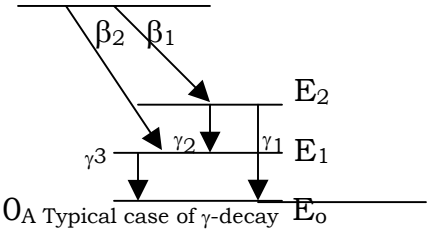


Fig.2.10 A Typical case of γ-decay

Four common examples Widely used as gamma ray calibration sources are illustrated is the decay scheme in fig (2.10). In each case, a form of beta decay leads to the population of the excited state in the daughter nucleus

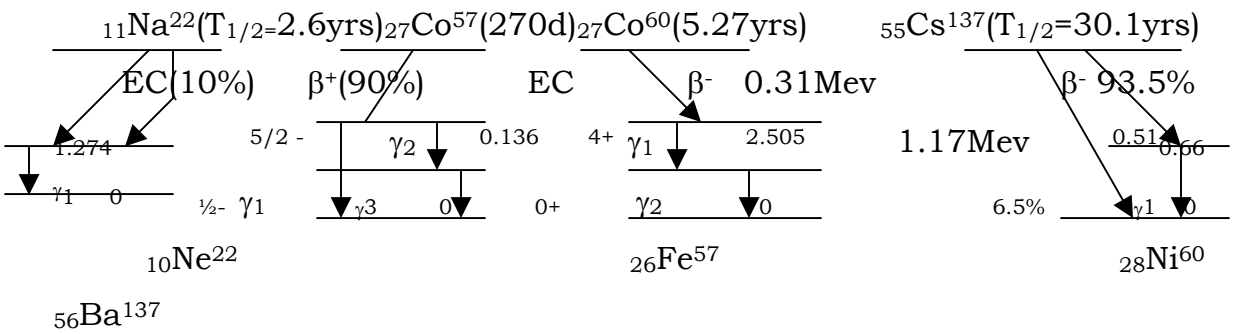


Fig. 2.11 Decay scheme of beta emitter (gamma calibration sources)

As it is shown, the beta decay is a relatively slow process, characterized by a half-life of hundreds of days or greater. Where as the excited state in the daughter nucleus have a much shorter average lifetime (typically of the order of picoseconds or less (11).

Gamma rays can be considered as photon having a corpuscular nature with their energy being quantized. Being an

electromagnetic radiation, it travels with the velocity of light. Thus a γ-ray having a wave frequency υ will have a quantum of energy hυ. (where h is Planck's constant=6.626×10^{34} Js = 4.134x 10^{-15} evs). The energy of gamma photon is determined by the difference in energy between intermediate and final state of the nucleus (undergoing isomeric transition). This difference is the same for all nuclei of a specific nuclide have more than one intermediate state or energy level. When this is the case, a radionuclide might emit gamma photons with several different energies. If gamma ray comes out as a result of transition from an initial nuclear state of energy. Ei to a final state of energy Ef. Then the energy of γ-ray is given by: $h\upsilon = Ei - Ef$ (2.35)

(3) Isomeric Transition (IT):

Nuclides having excited levels which do not decay instantaneously are called isomeric nuclei. These levels are called Isomeric levels. They decay either by γ-emission or by internal conversion. The transition leading to the de excitation of such levels is called isomeric transition (IT).

Examples of decay scheme for nuclear isomers: Unlike other decays these are isomeric level decays by γ-emission to the ground level, which is stable.

(a) The decay of ^{60m}Co, by isomeric transition is shown in fig 2.12(a). The half life of ^{60m}Co isomeric level of ^{60}Co, is 10.6Min. After a radioactive nucleus undergoes an isobaric (A & Z unchanged) transition, it usually contains too much energy to be in its final stable or daughter state. When the excited level only decays by γ-emission to the ground level, as in the case shown below, the members of the isomeric pair are said to be genetically related.

(b) In^{113m}, with a half of 104 min, emits a γ-ray with an energy of 0.392 Mev and becomes stable In^{113} as shown in fig 2.12 (b)

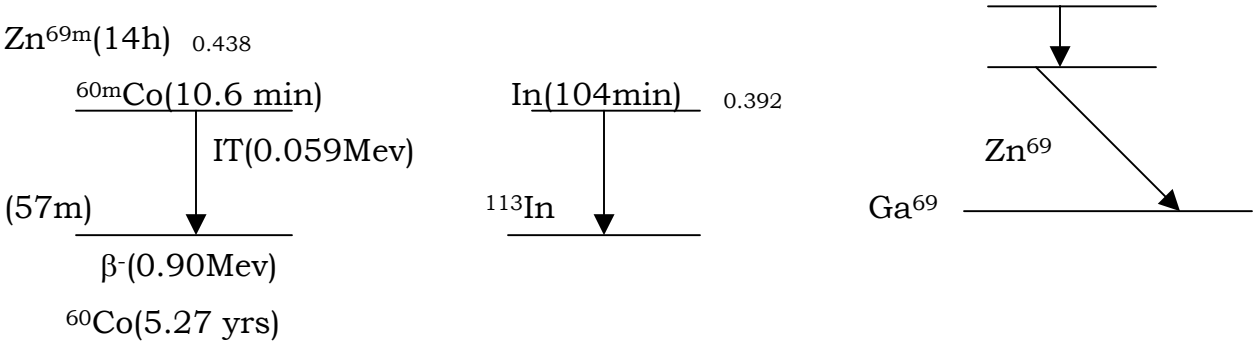


Fig. 2.12. Isomeric Transitions

(c) In some isomeric pairs the ground state, instead of being stable, may be radioactive and decay by β- emission. Thus 14 hr Zn^{69m} emits 0.438 Mev γ-ray and give to the ground state of Zn^{69}, which then decays by electron emission to the ground state of Ga-69. The decay scheme is shown in fig 2.12 (c). Generally, in most isomeric transitions, a nucleus will emit its excess energy in the form of gamma radiation.

(4) Nuclear Reactions

when a projectile, a single nucleon or combination having some energy (Velocity) is in close contact (near by) a nucleon (Nucleus) a new system may be formed or same system may be there, but with changed quantum mechanical state. Such types of interaction is termed as nuclear reaction.

A general process of nuclear reaction can be written as.

$$X + x = y + Y + Q$$

Where the bombarding particle x, strikes the target nucleus, X and produces the nucleus Y and the out going particle, y. The energy released in the reaction is Q, so that Q is positive for an exothermic reaction and negative for an endothermic reaction. The bombarding particle can be a neutron, proton, deutron, triton or alpha particle.

Some of the nuclear reactions are considered below:

(a) The possible, natural dcay processes, can be brought into the class of reaction process with the conditions of no incoming particle x, and Q>o. They are

(i) α-decay: $_{Z}X^{A} \longrightarrow {}_{Z-2}Y^{A-4} + {}_{2}He^{4}$

(ii) β-decay: $_{Z}X^{A} \longrightarrow {}_{Z+1}Y^{A} + e^{-} + \overline{\upsilon_e}$ (β^- decay)

$_{Z}X^{A} \longrightarrow {}_{Z-1}Y^{A} + e^{+} + \upsilon_e$ (β^+-decay)

$_{Z}X^{A} \longrightarrow {}_{Z-1}Y^{A} + \upsilon_e$ (electron capture)

(iii) γ-decay: $_{Z}X^{A*} \longrightarrow {}_{Z}X^{A} + \gamma$

(b) Elastic scattering: this is represented by: $x+X \longrightarrow x+X$

Here the out going particle and the target nucleus remain the same after interaction.

Ex. $_{2}He^{4} + {}_{79}Au^{197} \longrightarrow {}_{79}Au^{179} + {}_{2}He^{4}$

Note there is no appreciable energy loss of the energy of the projectile.

(c) In elastic scattering (Collision):

$$x+X \longrightarrow X^* + x/$$

The resultant nucleus X is the same, but now is excited state. But this remains only for sometime so that it decays to the ground state by γ-ray emission.

i.e. $X^* \longrightarrow X + \gamma$

Ex :$H + {}_{3}Li^{7} \longrightarrow {}_{3}Li^{7*} + :H$

(d) Radiative capture: $x+x \longrightarrow y^* \longrightarrow y + \gamma$ (representation)

In this case the target nucleus captures the projectile so that a new system y is formed and it in excited state a gamma ray will be emitted. This two common case of such reactions are (p,γ) and (n,γ) reaction.

(1) (p,γ) reaction: Here the bombarding proton is captured by the nucleus. The compound nucleus, which is formed, is unstable, and goes down to the ground state by emitting γ-ray protons. The reaction is of the type

$$_{Z}X^{A} + {}_{1}H^{1} \longrightarrow (_{Z}Y^{A+1})^{*} \longrightarrow {}_{Z+1}Y^{A+1} + \gamma$$

Some examples of (p,γ) reactions are:

$$_{3}Li^{7} + {}_{1}H^{1} \longrightarrow (_{4}Be^{8})^{*} \longrightarrow {}_{4}Be^{8} + \gamma$$

$$_{6}C^{12} + 1H^{1} \longrightarrow (_{7}N^{13})^{*} \longrightarrow {}_{7}N^{13} + \gamma$$

$$_{7}N^{14} + {}_{1}H^{1} \longrightarrow (_{8}O^{15})^{*} \longrightarrow {}_{8}O^{15} + \gamma$$

$$_{12}Mg^{24} + {}_{1}H^{1} \longrightarrow (_{13}Al^{25})^{*} \longrightarrow {}_{13}Al^{25} + \gamma$$

$$_{13}Al^{27} + {}_{1}H^{1} \longrightarrow (_{14}Si^{28})^{*} \longrightarrow {}_{14}Si^{28} + \gamma$$

(iii) (n, γ) reaction. The other case of radiative capture is (n, γ) reaction. In this case the target nucleus captures neutron and the compound nucleus is formed in excited state. The reaction can be represented by.

$$_{Z}X^{A} + {}_{0}n^{1} \longrightarrow (_{Z}X^{A+1})^{*} \longrightarrow {}_{Z}X^{A+1} + \gamma$$

The simplest example fir (n,r) reaction is the reaction of hydrogen as a target with slow neutrons $_{1}H^{1} + {}_{0}n^{1} \longrightarrow (_{1}H^{2})^{*} \longrightarrow {}_{1}H^{2} + \gamma$

Other examples of (n, γ) reaction are:

$$_{13}Al^{27} + {}_{0}n^{1} \longrightarrow {}_{13}Al^{28})^{*} \longrightarrow {}_{13}Al^{28} + \gamma$$

$$_{29}Cu^{63} + {}_{0}n^{1} \longrightarrow {}_{29}Cu^{64})^{*} \longrightarrow {}_{29}Cu^{64} + \gamma$$

$$_{47}Ag^{107} + {}_{0}n^{1} \longrightarrow (_{47}Ag^{180})^{*} \longrightarrow {}_{47}Ag^{108} + \gamma$$

$$_{49}In^{115} + {}_{0}n^{1} \longrightarrow (\,_{49}In^{116})^{*} \longrightarrow {}_{49}In^{116} + \gamma$$

Therefore we can see there are nuclear reactions in which γ-ray photons are emitted. i.e. radiative capture, inelastic scattering and γ-decay.

Chapter Three- Interaction of nuclear radiation with Matter

3.1. Introduction

Nuclear radiations (alpha, beta, proton, neutron, gamma ray, etc) are emitted as a result of various transformations and adjustments that take place inside the nucleus. Any radiation is detected by its interaction with matter. If this interaction is very small as in the case of neutron, the detection of radiation becomes extremely difficult. It is necessary to study

the manner in which nuclear radiation interact with matter in order to understand the methods and instruments used for the detection, measurement and characterization of nuclear radiation. (13) We shall confine our discussion to incident energy of the order 0.1-5Mev. For these energies, coulomb force are mainly responsible for these interactions (we shall not deal with those interactions which arise from specifically nuclear force) & they give rise to ionization, scattering and radiative loses. (9)

The harmful effects of the radiations on tissues are highly dependent on the ability of the radiations to ionize the matter. Further, the selection of proper shielding material for the safe handling of radiation substance is based on our knowledge of the penetration of nuclear radiation in matter. Nuclear radiation can be classified in the following groups.

(1) Charged radiation a) Heavy charged particles (alpha, proton, deutron etc)

b) light charged particles (mainly electron).

(2) Uncharged radiation a) Electro magnitude radiation gamma rays

b) Neutral particles (Mainly neutron)

The passage through matter of charged particle, (mainly electron) and uncharged radiation (mainly gamma radiation) will be treared in the next section.

3.2. Interaction of Heavy charged particles

(i) Nature of the interaction

Heavy charged particles such as the alpha particle interact with matter primarily through coulomb's force between their positive charge and the negative charge of the orbital electron, within the absorber atoms. Although interactions of the particle with nucleus are also possible, such encounters occur only rarely and they are not normally significant in the

response of radiation detectors. This is basically due to the size relation of atoms (10^{-10}m) and nuclear (10^{-15}m). Due to this the probabilities of collision of heavy particle with nucleus is much smaller than the collision with atom.

Upon entering any absorbing medium, the charged particle immediately interacts simultaneously with many electrons in any one such encounters, the electron feels an impulse from the attractive coulombs force as the particle passes its vicinity. Depending on the proximity of the counter, this impulse may be sufficient either to raise the electron to a higher-lying shell with in the absorber atom (excitation) or to remove completely the electron from the atom (ionization). The energy that is transferred to the electron must come at the expense of the charged particles, and its velocity there fore decreased as a result of the encounter.Consider a heavy particle moving towards a light particle (electron) hit a heavy particle of mass M, moving with velocity V collides with light particles (electron) of mass, m_e that is stationary. After collision M goes in the direction having angle and with the initial direction, with velocity Ve and heavy Particle in the direction and with the velocity, Vi

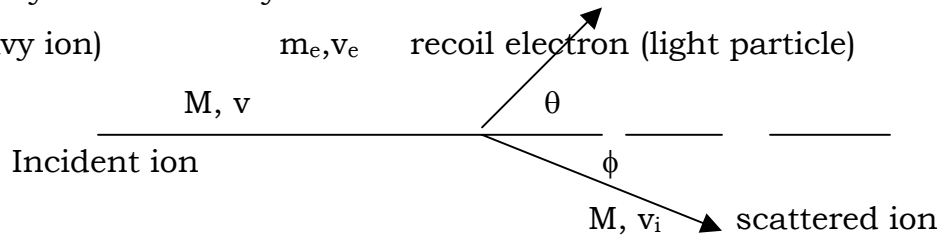


Fig. Interaction of heavy ion with electron.

(i) From the law of conservation of energy we have:

$$1/2\ Mv^2 = 1/2\ Mv_c^2 + 1/2\ Mv_i^2 \qquad (3.1)$$

(a) Also since momentum is conserved in the process:

- Conservation of linear momentum in the x-direction is :

$$Mv = M\ v_e \cos\theta + M\ v_i \cos\phi$$

or $$M\ v_i \cos\phi = (Mv - M\ v_e \cos\theta) \qquad (3.2)$$

and conservation of linear momentum in y direction gives:

$$O = M v_i \sin \phi - M v_e \sin \theta$$

or $$M v_i \sin 4 = M v_e \sin \theta \qquad (3.3)$$

But since we are intersected in the direction, θ, to eliminate ϕ, squaring and adding questions (3.2) and (3.3)

$M^2 v_i^2 = (Mv - M v_e \cos \theta)^2 + m^2 v_e^2 \sin^2 \theta$

$M^2 V_i^2 = M^2 V^2 + M^2 v_e^2 - 2Mm\, v\, v_e \cos \theta$, dividing by M_2 we get

$V_i^2 = V^2 + (m/M)^2 + Ve^2 - 2\, m/M\, V\, V_e \cos \theta \qquad (3.4)$

From equation (1), $V_i^2 = V^2 - m_e/M\, V_e^2 \qquad (3.5)$

Now equating equations (3.4) and (3.5): we have:

$$Ve\,(1+ m_e/M) = 2v \cos \theta$$

or $$Ve = \frac{2v\cos\theta}{(1+m_e/M)} \qquad (3.6)$$

We are intersected in the maximum value of Ve, and hence taking, θ =o (recoil in forward direction) and M>>m,

$$(Ve)_{Max} = 2v \qquad (3.7)$$

This shows that the maximum energy that can be transferred from a charged particle of mass M with kinetic energy E to an electron of mass m_e in a single collision is

4Emo/m, (or about 1/500 of the particle energy per nucleon)

$$(½\, m_e V_e^2 = ½\, (m_e\, 4\, v^2) = 4\, m_e/M)\, E.$$

Because this is a small fraction the total energy, the primary particle must lose its energy in many such interactions during its passage through an absorber. At any given time, the particle is interacting with many electrons, so the net effect is to decrease its velocity continuously until the particle is stopped. Therefore charged particles are characterized by a definite range in a given absorber material, distance beyond which no particles will penetrate.

(2) Stopping power

The linear stopping power for charged particle in a given absorber is simply defined as the differential energy loss for that particle with in the material divided by the corresponding differential path length.

$$S = -\frac{dE}{dx} \qquad (3.8)$$

The value of $-\frac{dE}{dx}$ along a particle track is also called its specific energy loss or, more casually, its rate of energy loss.[11].

If the incident particle has mass M and energy E and collides with an electron of mass m_e, then the maximum energy, which the electron can acquire, is:

$$(Te)_{Max} = 1/2\ m_e\ (V_e)^2{}_{Max} = 1/2m_e\ [\ Mv\ /\ (m_e + M)\ ]^{\ 2}$$

$$\text{or} \qquad (Te)_{\ Max} = (4m\ M/(m + M)^{\ 2})\ E \qquad (3.9)$$

or approximately (Te) max = 4 mE/M, When M>>m as derived above (eq. 6). For light particle of several Mev this energy is of the order 10Kev so that it is justifiable to neglect the electronic binding energy and consider the collisions to occur with free electrons. The more energetic recoiling electrons resulting from such collisions are often called 'delta rays'. Since their appearance in early cloud chamber experiments led to the mistaken idea that they were a fourth type of radiation.

The transfer of energy at each collision is thus generally a small fraction, of the order 10^{-3} times the particle energy, so that the deflections from a straight line path are small. The range, determined by a large number of events, is well defined. Calculation of the energy loss per unit path length have been made by livingston and Bethe with a result expressed by:

$$-\frac{dE}{dx} = \frac{-4\pi e^4 z^2 ZN}{mv^2} B \qquad 3.(10)$$

Where e & m are electronic charge and mass, ze and v are the particle charge and velocity, Z in the atomic number of the absorber and N the number of absorber atoms per Cm^3. B, sometimes called the stopping number, is the logarithmic function.

$B = \text{Log}_e (2nv^2/I) - \text{Log}_e (1-v^2/c^2) - V^2/C^2)$ 3. (11)

Here I is the mean ionization potential of the– absorber atoms and C is the velocity of light. The first term in the expression predominates up to 1000 Mev. B therefore varies rather slowly with particle energy, and approximately, from equation (3.10).

$$\frac{dE}{dx} \propto \frac{z^2}{v^2} \propto \frac{z^2}{E} \qquad (3.12)$$

This is to be expected since the slower the particle the greater is the time for which its coulomb field acts upon the electron and the greater impulse imparted gives an increased probability of excitation.

The range, R, of a particle is given by the integral

$$R = \int_0^E \frac{dE}{(dE/dx)} = \frac{mM}{4\pi e^4 z^2 NZ} \int_0^v \frac{v^3 dv}{B(v)}$$

(3.13)

It is convenient to use this equation to relate the range of one particle to that of another of the same initial velocity. We may write

$$R(V) = M/z2.\ f(v).$$

where f(v) involves only the particle velocity. Thus for the range of proton and deuterons (Z=1) $R(E) = \frac{M}{M_d} R_d \left(\frac{M_d}{M} \times E \right)$ 3.(14)

$$R(E) = 0.50\ Rd\ (2.0E)$$

For particles of different z there is a small correction term, c, owing to the different rate of capture and loss near the end of the range. Thus, for proton and alphas,

$R_p(E) = 1.007\ R_d\ (3.972\ E) - C$

Where C = 0.2 Cm in air, and microns in silicon.

3.3. Interaction of light charged particles with matter

3.3.1. Electrons

Beta rays are fast electrons, which may be emitted, in natural radioactivity of induced activity following nuclear transmutation that is caused by another nuclear radiation. They may also be produced by the acceleration in an electric field of electrons emitted from a heated filament. Electrons differ from heavy particles in that their paths in solids are not straight and their ranges is therefore rather indefinite. This is because their mass is the same as that of the electron in the absorber so that as much as half the initial energy may be lost in a single collision. The deflections and the statistical straggling in range are therefore large, as has been revealed by cloud chamber experiments in which the track of a single electron can be made visible. The high velocities often attained by electron, quite commonly an appreciable fraction of the velocity of light, makes it necessary to describe their motion relativistically. Following are the four important processes by which electrons lose their kinetic energy during their passage through matter.

(i) In-elastic collision of electrons: In-elastic collision of incident electrons with bound atomic electrons in the matter is the most important mechanism by which incident electron loses their energy in their passage through matter. During such in-elastic collision, incident electron transfers part of its energy to a bound atomic electron taking it to an excited state (excitation) or an unbound state (ionization).

For electrons of up to 10 Mev the dominant mode of energy loss are excitation and ionization of the electron of the absorber, just as in the case of heavy particles. The rate of energy loss is therefore given by the same formula, with z=1.

$$-\frac{dE}{dx} = \frac{-4\pi e^4 z^2 ZN}{mv^2} B \qquad 3.(15)$$

For v<< c the stopping number, B, is given bt a formula due to Bethe.

$$B = \text{Loge}\ (0.583\ \text{Me}\ V^2/I)$$

This differs from the expression (3.11) owing to the impossibility of distinction between the two electrons, which result from a collision;

The one which reactions the higher energy is defined to be the primary one for which the subsequent behavior is followed.

At higher energy B increase more rapidly, in a manner given by Moller's formula.

$$2B = \text{Log}_e\ (\text{Mev2}\ E\beta/2I^2\ (1-\beta^2) - \{\text{Log}_e 2)\ (2\sqrt{(1-\beta^2)})\ -1+\beta^2\} + 1-\beta^2)$$

In which B is equal to V/c. The first term in this expression is the most important up to electron energy of about 5 Mev. These calculations show that, as has been observed experimentally, the rate of energy loss passes through a broad minimum at about 1 Mev, above which it rises slowly and logarithmically with energy. In fact, this behaviour is general for all charged particles and may be pictures physically as due to relativistic in the contraction of the coulomb field of the moving particle along its direction of motion. The resulting bunching of the lines of forces increases the strength of the interaction with stationary electron. In this way proton exhibit a region of minimum ionization at about 1300 Mev, and M-mesons at about 200 Mev energy (143).

(ii) Radiative collision of electron with atomic nucleus. Above 10 Mev electron can also lose energy by classical radiation of electromagnetic energy due to deceleration in matter, since it suffers (experience) deflection while passing through the field of a nucleus. This mechanism is usually called bremsstrahlung or breaking radiation. This leads to a loss of Kintic energy of the incident electron. (14) This can be considered as a radiative type of in-elastic collision between the electron and an atomic nucleus. The rate of energy loss by the interaction is proportional to Z^2, where Z is the atomic number of the target atom. Actually the rate of such radiative loss is given by

$$\frac{dE}{dx} \propto \frac{z^2 N}{A}(E + m_e c^2) \qquad (3.17)$$

Where E is the energy of the electron, N the atomic density and A the mass number of the absorber. In addition there is also a probability that the electron can excite the nuclei in a similar in-elastic collision.

However, the cross-action for the process is generally very low at the energies of the order 0.1 to 5 Mev.

(iii) Elastic collision of electrons: The incident electron can have an elastic collision with a nucleus resulting in a deflection of electron.

With out any radiative loss or excitation of nucleus. The cross section for this process is of the order of $(e^2/M_eV^2)^2$ (Where V=Velocity of incident electron) and it increase with Z^2.

For practical purpose, the total energy loss per unit path length of the electrons is the sum of ionization and radiation losses i.e.

$$(dE/dX)_{Total} = (dE/dx)_{ionization} + (dE/dx)_{radiation} \qquad 3.(18)$$

Empirically, the following relation is found to be approximately true.

$$\frac{(dE/dx)_{rad}}{(dR/dx)_{ion}} = \frac{EZ}{800} \qquad 3.(19)$$

Where E= electron energy in Mev, and Z=atomic number of absorber.

(IV) Multiple scattering:1 A charged particle moving in a dense medium experience a large number of successive scattering acts at very small angle along its track. This process is called multiple coulomb scattering.

As long as the absorber thickness is quite small, there will be a single scattering and we can neglect the possibility that the same electron is scattered twice. For thicker absorber one has to consider plural scattering in which case the incident electron undergo a small number of collision. When the letter number become large scattering is more complicated.

Since multiple scattering is caused by the coulomb interaction of a particle with the nuclei of the medium. The experimental characteristics of multiple scattering must be associated with the partners of the particle as well as the medium. Hence an investigation of the experimental regulatory of multiple scattering of a particle can provide information about the properties of this particle.

3.3.2. Range of Electrons

Unlike heavy ions, due to their very small masses, electron is scattered more and penetrate relatively deeper into matter and has a lower specific ionization. The interaction of electron with matter coupled with the fact that beta particle emitted from radioisotopes have a continuous spectrum of energy up to a maximum of E_m, lead to an approximately experimental absorption law for beta particle of a given maximum energy. Then intensity of the transmitted beta particle in approximately given by the equation. $I = I_0 e^{-\mu x}$ (3.20)

where Io is the intensity of incident beta particles,

I = is the intensity of transmitted beta particle

μ = is called the beta absorption coefficient of the absorber,

x = is the thickness of the absorber.

Equation (3.20) is similar to radioactive decay equation. Therefore, when the transmitted intensity is plotted as a function of the absorber thickness on semilog paper, nearly a straight line is obtained over a portion of curve as shown in fig (3.1)

The curve becomes practically horizontal at "R" the range of beta Particle. Although, all the beta rays are stopped at the absorber thickness one still find some transmission of radiation. This is because of the non-characteristic –x rays (bremsstrahlung) produced by the beta particle in the stopping material.

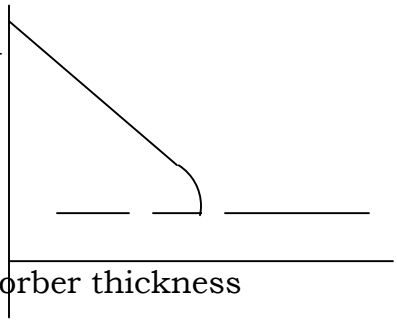


Fig. 3.2 β-absorption curve

The empirical relation between the maximum energy of beta particles and their range given by: $R = 412\ E_m^n$ (3.21)

for $E_m < 2.5$Mev where $n = (1.265 - 0.0954 \ln E_m)$

and $R=530\ E_m - 106$ (3.22)

for E_m >2.5 MevWhere the unit of range R is (mg/cm3) while that for E_m is (Mev)

3.3.2. Positrons

The interaction of positrons with matter is almost identical with that of electron but for some minor differences. However, there is a very important way in which positrons can annihilate with the electrons in matter. This annihilation can either be a free annihilation with an electron or *via* the formation of a (e+ e-) hydrogen-like atom called positron. The positron annihilation leads to 2 photons if the electron-positron spin is anti parallel and into 3 photons if the spin orientation is parallel.

3.4 INTERACTION OF GAMMA RAY WITH MATTER

Gamma rays interact with matterby one of the three typpes of process, namely the photoelectric effect, compton scattering and pair production.

(i) in photoelectric effect the photon of energy E_γ with a whole atomof the absorber, and the whole energy is used to eject an electron, usually from one of the inner electron orbits, and $E_\beta = E_\gamma - \mathbf{E_b}$ **(3.23)a**

Where E_b is the binding energy of the electron. the original gamma ray disappears in this process, but the excited atom will subsequently emit one or more x-rays of total energy E_b

(ii) the compton scattering processmay be considered as an elastic collission between a photon and an electron , in which the electron binding energy is very small compared with the photon energy. The energy is shared between the scattered photon and the recoilking electron.

(iii) In pair production the photon dis appears and an electron positron pair is created with total kinetic energy kinetic energy equal to the photon energy less the rest energy of the two particles.

3.4.1 **THE PHOTOELECTRIC EFFECT**

In the photoelectric absorption process, a photon undergoes an interaction with an absorber atom in which the photon completely disappears. In its place, an energetic photoelectron is ejected by the atom from one of its bound shells. The interaction is with the atom as a whole and cannot take place with free electrons. Because of the necessity to conserve energy and momentum, a free electron cannot wholly absorb a photon, hence for gamma rays of sufficient energy, the most probable origin of the photoelectron is the most tightly bound or K- shell of the atom, since then momentum is most easily conveyed to the atom. The kinetic energy of the electron is then given by

$$E_e = h\nu - E_b \text{ ---------- } (3.23)b \text{ -}$$

Where E_b represent the binding energy (ionization energy) of the photoelectron in its original shell. $E_\gamma = h\nu$ is the incident photon energy. It is clear from equation(3.23)b that the processes will take place only if $h\nu > E_b$.

After the atomic electron is ejected by a photoelectric effect, the vacancy in that shell is filled up by another electron from the outer shell. This is followed by emission of x- ray photon or Auger electrons consuming the binding energy E_b. The configuration of the atomic shell recovers with in a very short time after the photoelectric emission. The atomic x-ray produced as a flow-up of a photoelectric effect are almost completely absorbed by the matter surrounding the point emission, giving rise to further electrons. Thus the total energy of the incident gamma ray is completely converted in to the kinetic energy of the electrons in photo electric effect.

The probability of photoelectric absorption depends on the gamma ray energy, the electron binding energy, and the atomic number (Z) of the atom. The probability is greater the more tightly bound the electron; therefore K-shell electrons are most affected (over 80 % of the interaction involves K- electrons), provided the gamma ray energy

exceeds the K – electron binding energy. The vacancy in the K-shell is mainly filled by L- shell electron and energy of this quanta is the difference of the binding energy of the electron in the two shell, for the heaviest atom the amount will be 0.1Mev (for lead 0.075Mev). For energies far above the K- absorption edge and in none relativistic range ($h\nu << 0.511$Mev) the cross-section for photoelectric effect (the total photoelectric absorption cross-section per atom) from K-shell is given by;

$$\sigma_{ph} = \sigma_e Z^5 \alpha^4 4\sqrt{2}\,(m_o c^2/h\nu)^{7/2} \qquad \text{----------(3.24)}$$

where $\sigma_e = 8/3\ \Pi\ r_o^2$ is the Thomson scattering cross-section .

$R_o = e^2/4\Pi\varepsilon m_o c^2 = 2.82 \times 10^{-15}$m is the classical electron radius; $\alpha = 1/137$ is the Sommer field's fine structure constant and Z is atomic number of absorber. The above expression for photoelectric absorption cross section can be written as

$$\sigma_{ph} \sim Z^5 / (E\ \gamma)^{7/2} \text{ ----------(3.25)}$$

where $E\gamma = h\ \nu$

Equation 3.24 shows that the photoelectric process is the predominant mode of interaction for gamma rays (or X rays) of relatively low energy and absorber material of high atomic Z material.

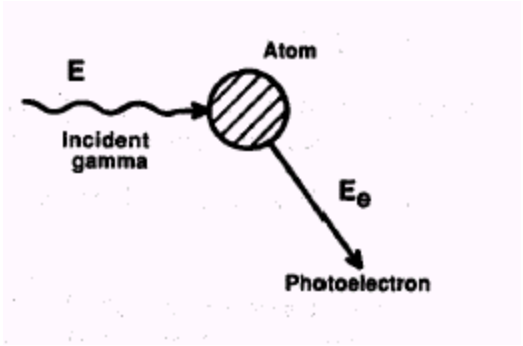


Fig 3.1 A schematic representation of the photoelectric absorption process

3.4.2 THE COMPTON SCATTERING

If a photon energy E_γ with an atomic electron it suffers a simple scattering process and is deflected through some angle θ to its original direction of motion. Assuming the electron binding energy to be negligible, Compton showed that the scattered photon energy, E_γ', is given by: $E_\gamma' = E_\gamma / [1 + (1 - \cos\phi) E_\gamma / mc^2]$. [14]

and the electron energy is: $E_\beta = E_\gamma - E_\gamma'$, which can be derived as follows.

According to the quantum theory of light, photons can behave like particles except for the absence of the rest mass.

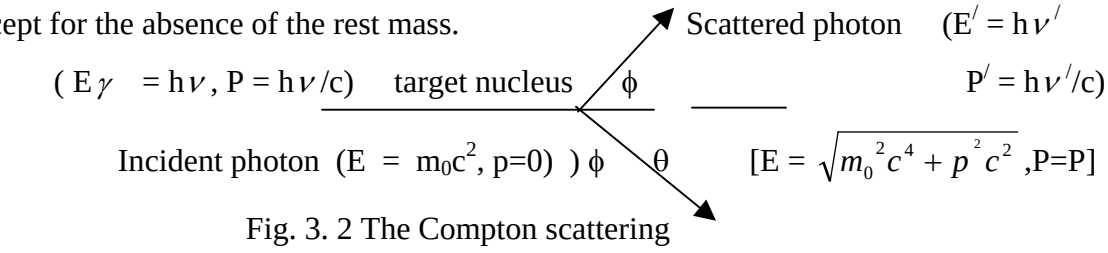


Fig. 3. 2 The Compton scattering

Scattered photon in this process the incident photon interacts with a free electron and is scattered with a loss of energy. (see Fig.3.2)

As the energy of gamma ray increases, the bound electron appears relatively to be free and outer most electrons is having least binding energy or almost free, and hence Compton effect takes place with outer most electrons mostly. If the initial photon has the lower frequency, v associated with it, the scattered photon has the lower frequency ν', where: loss in photon energy = gain in electron energy

$$(h\nu - h\nu') = E_e$$

or the energy conservation can be written as: $E\gamma + m_oc^2 = E' + mc^2$ (3.26)

for a mass less particle momentum is related to its energy according to the relation

$$E = Pc \qquad (3.27)$$

But since energy of a photon is $E\gamma = h\nu$, its momentum is

$$P = h\nu/c \quad \text{(photon momentum)} \qquad (3.28)$$

(1) From the energy conservation $E\gamma + m_oc^2 = E' + mc^2$

Or we have $h\nu + m_o c^2 + h\nu' + mc^2$ (3.28)

This also can be written as $mc^2 = E\gamma - E' + m_oc^2$ (3.29)a

Or $\sqrt{m_0^2c^4 + p^2c^2} = = h(\nu - \nu') + m_oc^2$ (3.29)b

(since energy of electron $E = E = \sqrt{m_0^2c^4 + p^2c^2} = mc^2$)

for mass less particle momentum is related to its energy by the for

E = Pc and for the photon E_γ = $h\nu$, its momentum is, P = $h\nu$/c

(2) for the above process the conservation of momentum gives:

(i) for the x- direction: $h\nu/c = h\nu'/c\cos\Phi + p\cos\theta$ (3.30)

(ii) for the y- direction; $0 = (h\nu'/c)\sin\phi - p\sin\theta$ (3.31)

(where m = $m_0\sqrt{1-\frac{v^2}{c^2}}$ is the relativistic mass of the recoil electron where

C = 2.988 x 10^{-8} m/s is the speed of light and h = 6.66 x 10^{-34}Js is the planck's constant

ν and ν' are frequency of incident gamma ray and scattered gamma ray respectively)

To eliminate θ we can write the above equations as follows:

Squaring and adding equations 3.30 and 3.31 we obtain:

$P^2c^2 = (h\nu/c)^2 + (h\nu'/c)^2 - 2\, h\nu/c(h\nu'/c)\cos\Phi$ (3.32)

Also squaring and adding equations 3.29a and 3.29b, we have:

$$P^2c^2 + (m_oc^2)^2 = (h\nu - h\nu')^2 + 2m_oc^2(h\nu - h\nu') + m_o^2c^4$$

$$P^2c^2 = (h\nu)^2 + (h\nu')^2 - 2h\nu(h\nu') + 2m_oc^2(h\nu - h\nu') \quad (3.33)$$

Finally equating equations 3.32 and 3.33 we obtain:

$$2m_oc^2(h\nu - h\nu') - 2h\nu(h\nu') = -2h\nu(h\nu')\cos\Phi$$

or $2m_oc^2(h\nu - h\nu') = 2h\nu(h\nu')(1 - \cos\Phi)$

this can be written in a convenient form as

$$(\nu - \nu')/\nu\nu' = [h/m_oc^2](1 - \cos\Phi) \quad (3.34)a$$

$$(1/\nu - 1/\nu') = h/m_oc^2(1 - \cos\Phi) \quad (3.35)b$$

This relationship is simpler when expressed in terms of wave length rather than frequency. From c = $\lambda\nu$, substituting 1 / ν = λ/c into equation 3.35b, we get:

$$(\lambda'/c - \lambda/c) = h/m_oc^2(1 - \cos\Phi) \quad (3.36)a$$

$$(\lambda' - \lambda) = h/m_oc(1 - \cos\Phi) \quad (3.37)b$$

or $\Delta\lambda = h/m_oc(1 - \cos\Phi)$

where λ is wave length of primary gamma ray photon, λ' is wave length of scattered gamma ray photon and $\lambda - \lambda'$ is the change in wavelength of Compton scattered gamma ray or Compton shift This equation (3.37) b was derived by Arthur H Compton in the early 1920s, and the phenomenon which it describes, which he was first to observe is known as the Compton effect

$h / m_o c = 0.0242\ A^o$ is called Compton wavelength.

The wave length shift or Compton shift $\lambda' - \lambda$, thus depends on the angle of scattering angle ϕ and can be written as;

$$\Delta \lambda = 0.0242 (1-\cos\phi) \qquad (3.38)$$

where λ is measured in angstroms (A^o) . It does not depend on the scattering material (Z) and energy of incident gamma ray. From this relation we see that, (i) For $\phi = 0$, $\Delta\lambda = 0$ and no Compton effect. This is the case for low incident gamma ray energy ($h\nu << m_o c^2$)

(ii) For $\phi = 90^o$, $\Delta\lambda = h / m_o c = 0.0242A$ and

(iii) For $\phi = 180$, $\Delta\lambda = 2\ h / m_o c = 0.0484\ A^o$, corresponds to maximum change in back scattered gamma ray, which means that the change in wave length of gamma radiation interacting with electron never exceed $0.0484A^o$. Energy of scattered photon is minimum but never zero, so that complete absorption is not possible. Compton effect is the process of partial scattering and partial absorption as a part of the energy is transferred to an electron.

(2) In Compton process the dependence of both kinetic energy of recoiling electron and energy of scattered gamma ray on the scattering angle (ϕ) and energy of incident gamma ray can be found follows: From equation 3.35b

$$1 / \nu' = 1 / \nu = h/m_o c^2(1 - \cos\Phi)$$

$$\text{i.e. } 1 /\nu' = [1 + h\nu /m_o c^2 (1 - \cos\Phi)] / \nu$$

$$\text{or } \nu' = \nu / [1 + h\nu /m_o c^2 (1 - \cos\Phi)] \qquad (3.39)$$

Then introducing this result, the energy of the scattered photon (kinetic energy) which is given by $E' = h\nu'$, becomes: $E' = h\nu' = h\nu / [1 + (h\nu /m_o c^2) (1 - \cos\Phi)]$ (3.40)

This also gives the minimum energy of photon to be,

$$E'_{min} = h\nu / [1 + 2h\nu /m_o c^2] \qquad (3.41)$$

$$= m_o c^2/2 = 255.5\text{Kev} ; \text{ if } h\nu >> m_o c^2/2 .$$

(3) Then the kinetic energy of the recoiling electron, introducing the result from part 2 can be expressed as: : $E_\beta = E\gamma - E\gamma' = h\nu - h\nu/[1 + h\nu/m_oc^2 (1 - \cos\Phi)]$

or $E_\beta = [h\nu / m_oc^2 (1 - \cos\Phi)] h\nu / [1 + h\nu/m_oc^2 (1 - \cos\Phi)]$

This result shows that `the recoil electrons may have any energy between zero and a maximum corresponding to a minimum value of $E\gamma'$, which occurs for a back scattered photon($\phi = 180^o$). Then or $(E_\beta)_{max} = [2(h\nu)^2/m_oc^2] / (1 + 2(h\nu)/m_oc^2$

or $(E_\beta)_{max} = 2(E\gamma)^2 / (m_oc^2 + 2E\gamma)$ (3.42)a

or $= h\nu/[1+ m_oc^2/2h\nu]$ (3.42)b

The relation between the angle θ at which the recoil electron leaves and the angle ϕ at which the scattered gamma ray leaves can be easily obtained by taking the ratio of equation 330 and 3.31 together with the trigonometric identity, is given by;

$$\mathrm{Cot}\,\theta = (1+h\nu/m_oc^2)\tan(\phi/2) \qquad (3.43)$$

Where $\tan\phi/2 = (1-\cos\phi)/\sin\phi$

From this relation (3.43), as the gamma ray scattered in the range, from $\phi = 0$ to $\phi = 180$; the recoiling electrons can emitted in the range from $\theta = 90$ to 0. For backward scattered gamma ray

($\phi = 180$) , the electron scattered forward ($\theta = 0$) .For these cases the energy of scattered gamma ray which is minimum , given by equation 3.41 and energy of the scattered electron ,which is maximum , given by equation (3.42). Every electron in the absorber can contribute independently to this process, so that the Compton absorption coefficient is proportional to the electron density NZ. Klein and Nishina showed that at high energies ($E\gamma > 1$Mev) the absorpt6ion coefficient is given by

$$\mu_{compton} \approx 1.25 \times 10^{-25} (NZ / E\gamma)[\log_e(2E\gamma/mc^2) + 1/2]\ cm^{-1} \qquad (3.44)$$

which approximates to an inverse dependence on $E\gamma$

Also the Compton scattering cross sections have been theoretically calculated by the Klein and Nishina From this formula for energy photon (α <<1) the scattering cross section per electron is given by:

$$_e\sigma_c = \sigma_e (1- 2\alpha + 26/5\ \alpha^2 \text{ ---------}) \qquad (3.45)$$

where $\alpha = h\nu / m_o c^2$ and $\sigma_e = 8/3\ \pi\ (e^2/ m_o c^2)^2 = 6.651 \times 10^{-28}\ m^2$ is Thomson cross section and for high energy photon ($\alpha > 1$) the scattering cross section per electron is given by

$$_e\sigma_c = \frac{8/3\sigma_C \ln(2\alpha) + 1/2}{\alpha} \qquad (3.46)$$

The above asymptotic expression for σ_c shows that at low energy $_e\sigma_c$ decreases with increasing photon energy, and at high energy it falls off more rapidly with increasing photon energy. In Compton process the assumed electrons are free. For photon energies of well above the binding energies it assumes that all atomic electrons are available for the process, and Compton cross section per atom is given by

$$\sigma_c = Z\ _e\sigma_c \qquad (3.47)$$

where Z is atomic number of scatter;

2.1.3 Pair production

Pair production is the third mechanism by which gamma ray interact with matter with the production of an electron- positron pair ($\gamma \rightarrow e^- + e^+$). For pair production to occur the gamma ray energy must exceed the rest energy of the electron and positron, i.e. 1.02 Mev. In order that the momentum and mass energy may both be conserved; the process can take place only in the field of the third particle. This is generally an atomic nucleus, although the effect can occur in the field of an electron. The excess energy appears as kinetic energy, E_{kin}, of the electron positron pair, and a very small recoil energy is imparted to the nucleus.

$$E_{kin} = E_\gamma - 1.02\ Mev \qquad (3.48)$$

At energies near the threshold, the absorption coefficient depends linearly upon the photon energy the absorption coefficient depends linearly upon the photon energy.

$$\mu_{pair} \propto NZ^2(E_\gamma - 2mc^2) \qquad (3.49)$$

while at higher energies the dependence becomes logarithmic.

$$\mu_{pair} \propto NZ2\log_e E_\gamma$$

A gamma ray with energy of at least twice the rest mass energy of electron ($2m_oc^2$ = 2. 02 Mev) can create an electron –positron when it is under the influence of the strong magnetic field in the vicinity of nucleus (see Fig. 3.3) In this interaction the nucleus receive a very small amount of recoil energy to conserve momentum,but the nucleus is otherwise unchanged and the gamma ray photon completely disappears and is replaced by an electron – positron pair . The probability of this interaction remains very low until the gamma ray energy approach several Mev and there for pair production is predominantly confined to high energy gamma rays. The electron positron from pair production is rapidly slowed down in the absorber. After losing its kinetic energy , the positron combines with electron in an annilation process ,which releases two gamma rays with energy of 0.511Mev . This lower energy gamma rays may interact further with absorbing material or may escape.

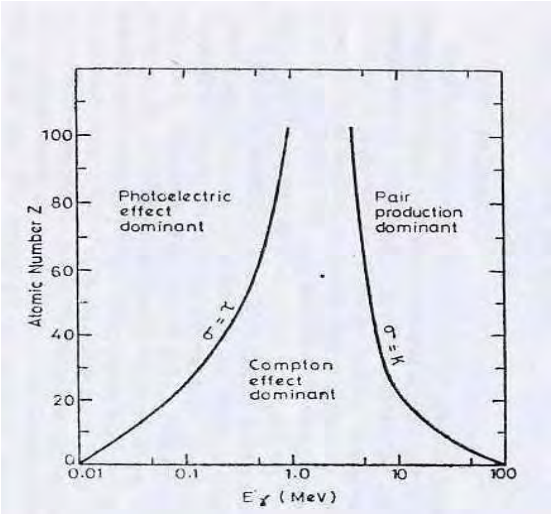


Fig. 3.3

In this interaction the nucleus receive a very small amount of recoil energy to conserve momentum,but the nucleus is otherwise unchanged and the gamma ray photon completely disappears and is replaced by an electron – positron pair . The probability of this interaction remains very low until the gamma ray energy approach several Mev and there for pair production is predominantly confined to high energy gamma rays. The electron positron from pair production is rapidly slowed down in the absorber. After losing its kinetic energy , the positron combines with electron in an annilation process ,which releases two gamma rays with energy of 0.511Mev . This lower energy gamma

rays may interact further with absorbing material or may escape. If the photon energy is greater than the bond energy of electron (above 0.1Mev) it can be absorbed in matter mainly through the above mentioned processes. Combining the three absorption process, the total absorption coefficient. μ(which is a function of energy),at any energy is given by

$$\mu=\mu_{pe}+\mu_c+\mu_{pp}$$

where the terms on the right represent the partial coefficients due to photoelectric effect, the Compton effect, and pair production. In relation to absorption cross-section we can write the partial linear absorption coefficient as:

$$\mu_{pe} = n_a\sigma_{pe}$$

$$\mu_c = n_e\sigma_e$$

$$\mu_{pp}. = n_n\sigma_{pe}$$

Here n_n, n_n and n_n are the number of atoms, electrons and nuclei per unit volume of the absorber being related as

$$n_a = n_n = N_A\,\rho / w, \text{ and } n_c = Zn_a$$

where N_A is avogadros number, ρ the mass density, w atomic weight, and z the atomic number of the absorber. These attenuation coefficients are given in Fig.

The dependence of the cross section upon the energy is such that at low energies the photo effect predominates in photon absorption. With extremely high energies, photons are absorbed in the main on account of the pair production. In the intermediate region, the Compton effect is dominant as shown in Fig.(3.4)

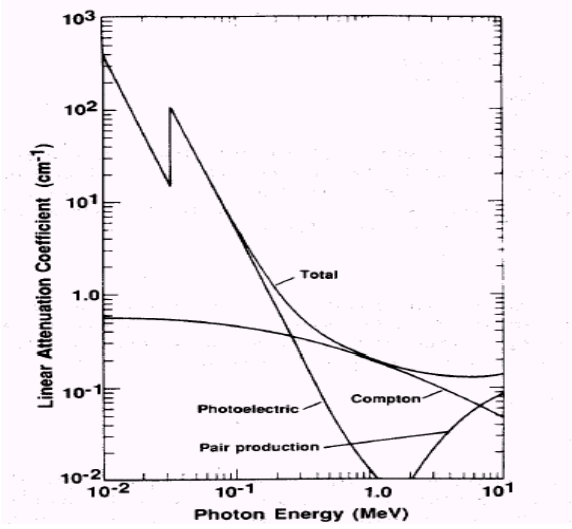


Fig. 3.4 Attenuation coefficients of Gamma rays in sodium iodide.

CHAPTER FOUR

NUCLEAR RADIATION DETECTION AND MEASUREMENT

4.1 Introduction

A number of factors are common to different methods of detection of nuclear radiations. In general detection methods are based on the processes of ionization and excitation of atom in the detection medium by the passage of a charged particle. Neutral particles or electromagnetic radiation must interact first with the detection medium or with an adjoining converter in order to produce the charged particles required for ionization. The methods by which the ions, electrons, or excited atoms are subsequently made apparent vary widely and have been adapted to many different types of system, solid, liquid and gaseous, either with or without an applied electric field.

In both gaseous and solid counters charged particles liberated by ionization can be collected by ionization can be collected at boundary electrodes under an applied electric field. In the other important types of solid state detector, the scintillation counter, use is made of emission of light by excited atoms, detected by conversion of a stream of electron from the photo sensitive cathode of a photo multiplier tube

Nuclear radiation detectors can be divided into two main groups:

(1) Electrical pulse detectors,

(2) Track detectors.

(1) In the electrical pulse detectors, a nuclear particles detected by the electrical pulse generated by the particle in the detector and the mean level of radiation flux is measured.[14] they give information about nuclear radiation quickly and easily.

(2) In the second type, the track (path) of the particle is recorded. Such detectors can give more information about the nuclear radiation (particle) because one can see the actual path of the nuclear particle and can have permanent record of this path (by photography), which can be analyzed at any later time. Though they are slow and tedious, it is possible to distinguish individual particles using track detectors.

Generally electrical pulse detectors are used for the measurement of activity from radioisotopes. The counters that are commonly used to detect nuclear radiation by the electrical pulse generated by radiation can be categorized as:

(1) Gas Filled detectors (counters)
(2) Scintillation counters (detectors)
(3) Semiconductor detectors

In this chapter first I will describe the last two detectors shortly and then discuss about the gas filled detectors.

4.2 Detector Overview

Since we cannot see, smell or taste radiation, we are dependent on instruments to indicate the presence of ionizing radiation. Most nuclear measurements involve the detection of particles –particles ejected from the radioactive nuclei, particles produced from accelerators probe nuclei, and particles created in nuclear reactions. In addition to detecting these particles, one must usually measure some of their properties – their mass, charge, energy momentum and so on. In the coarse of detecting and measuring particles, there is a sharp distinction between charged and neutral particles. when a charged particle passes through matter (solid liquid or gas) it can ionize or raise them to excited states. This ionization or excitation is easily detected and is the basis for most detectors of charged particles. Neutral particles, such as the photon (γ-ray) and neutron, are usually not easily detected, and most detectors of neutral particles work by having the neutral produce a charged particle and then detecting the charged particle.

(1) Gas Filled Detectors: the most common type of instrument is gas filled detector. This instrument works on the principle that as radiation passes through air or specific a gas, ionizing of the molecules in the air occur. When a high voltage is placed between two areas of the gas filled space, the positive ions will be attracted to the negative side of the detector.(the cathode) and free electrons will travel to the positive side (the anode). These charges are collected by the anode and cathode, which then form a very small current in the wires going to the detector. By placing a very sensitive currnt-measuring device between the wires from the cathode and anode, the small current is measured and displayed as a signal. The more radiation which enters the

chamber, the more current displayed by the instrument. This will be treated in the next section in detail.

(2) Scintillation detectors: The second most common type of radiation detecting instrument is the scintillation detector. When charged particle passes through matter they not only ionize atoms; they also elevate atoms to excited states. These excited atoms then give off light as they fall back to the ground state, and this light is exploited in the scintillation detector. One of the earliest such detectors was the zinc sulfide screen used by Rutherford in many of his experiments with α - particles. Each time an alpha hits the screen, the tiny flash of light that it produced was observed by the experimenter – a tedious and tiring job, which could only be done in a totally dark room.

Today, the light from a scintillation detector is monitored automatically. A photoelectric cell converts the light into an electric pulse, which, amplified by a photo multiplier if necessary, can beefed directly into a computer for processing and recording.

The basic principle of this instrument is the use of special material, which glows or scintillates when radiation interacts with it. Most modern scintillation detector use materials, such as NaI (a type of salt called sodium iodide), and certain plastics, that are transparent to the light which they produce.(see Fig. 4.1).

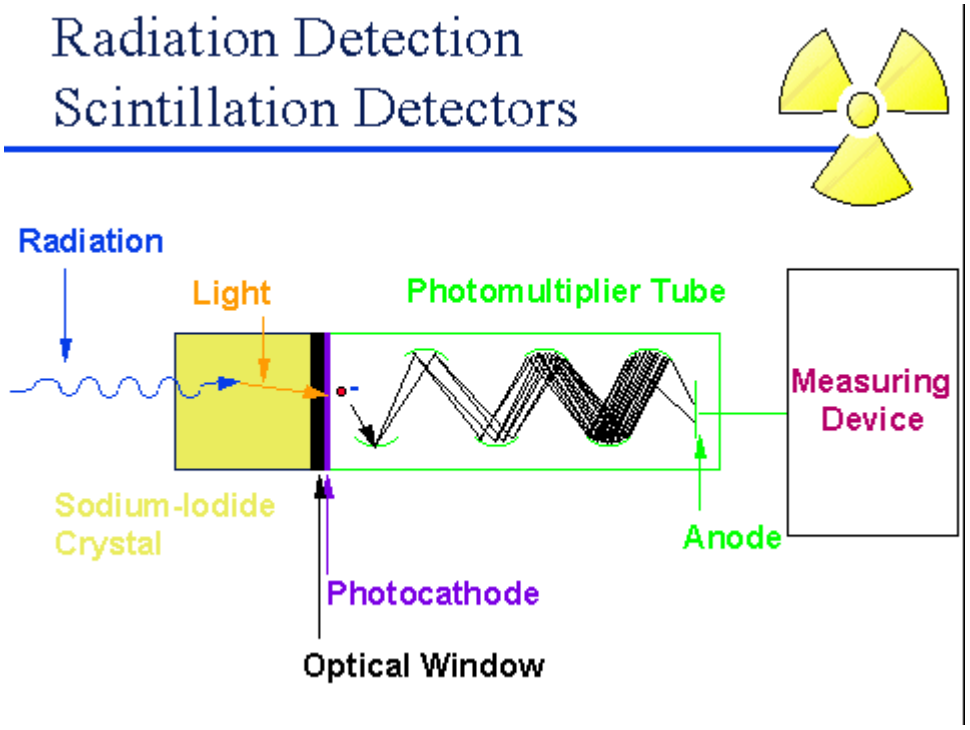


Fig.4.1 The Scintillation Detector

The light produced from the scintillation process is reflected through a clear window where it interacts with device called photomultiplier tube. The first part of the photomultiplier tube is made of another special material called photocathode. The photo cathode has a unique characteristic of producing electrons when light strikes its surface. The electrons are then pulled towards a series of plates called dynodes through the application of a positive high voltage. When electrons from the photocathode hit the first dynode, several electrons are produced for each initial electron hitting its surface. This "bunch" of electrons is then pulled towards the next dynode, where more electron "multiplication" occurs. The sequence continues until the last dynode is reached, where the electron pulse is now millions of times larger than it was at the beginning of the tube. At this point the electrons are collected by an anode at the end of the tube forming an electron pulse. The pulse is then detected and displayed by a special instrument.

NaI scintillation detectors use a block of material that is thick enough to stop the particles and hence to measure their energy. Some detectors use a liquid scintillator, to improve the chance of detecting weak or low energy signals.

(3) Solid state /semiconductor) detectors:

One cannot simply replace the gas of an ion chamber by any solid. If the solid is an insulator, the charges produced by ionization cannot flow to the collecting plate; if the solid is a conductor a current will flow all the times, making it difficult to detect the small extra current caused by a passing particle. There are however, certain materials called semiconductors that can be arranged to act as insulators except when a charged particle passes through them. by placing a suitable semiconductor or between two collecting plates, one can make a solid state that acts much like a gas filled chamber, but can stop a high energy particle and hence measure its energy – in a much smaller volume.

The solid-state counters are ionization chambers in which the charges released during the absorption of radiation constitute the signals by which the radiation is detected. The process by which the radiation is absorbed all involves the production of one or more high-energy secondary electrons by the primary radiation. The secondaries in turn produce further ionization and the cascade process continue until no electron has enough energy to cause further impact ionization.

In a semiconductor detector, ionizing radiation produces ion pairs (hole- electron pair), which are collected by the electric field applied externally, and the detector gives an electrical pulse, which is proportional to the energy of ionizing radiation. It follows that the number of ion pairs produced will depend only on the energy deposited by the primary radiation, and will be independent of the type of radiation. This gives the ion chamber its characteristic linear relation between signal amplitude and energy deposited, for all particles above certain low threshold energy.

The energy bands in a semiconductor arise from the allowed energy levels of the electrons in the individual atoms, which make up the crystal. Semiconductors and insulators have the property that, at the absolute zero of temperature, where the available electrons fill the lowest available energy levels, one or more energy bands are completely full, and the highest filled band is separated from the next higher band by an energy interval E_g in which there are no allowed levels.

In a pure semiconductor, the number of holes and electrons are equal in pure semiconductor (intrinsic). But impurities or departures from perfect lattice structure modify this simple picture by introducing localized energy levels, usually in the forbidden energy gap. Localized centers may become ionized either by donating an electron to the conduction band (donors) or accepting onefrom the valence band (acceptors), and the energy needed for these processes will be less than the energy gap E_g

Lithium drifted germanium (GeLi) detectors are more suitable than silicon detectors for the detection of electromagnetic radiation. It may be recalled that the photoelectric absorption cross section for gamma rays is proportional to z^5 and therefore germanium (z = 32) is more efficient than silicon (z = 14) for detection of gamma rays. The Ge (Li) detector is always maintained in a low temperature environment to keep up the intrinsic characteristic of germanium. In practice, the low temperature environment is maintained by a cryostat and liquid nitrogen (77k) dewar which together with the Ge (Li) detector from a complete detector system.

4.3 Gas Filled Detectors

4.3.1 Introduction

Gas filled detectors were the first nuclear radiation detectors to be developed. They are basically metal chambers filled with gas and containing a positively biased anode wire. The oldest type of gas filled detectors, which still have important use in nuclear radiation are:(i) Ionization chambers, (ii) Proportional counters and

(ii) Geiger-Muller counters

In each case of the above type of gas filled detector, an electric field is applied to a volume of gas enclosed in a chamber. Also RC circuit is connected for the pulse formation.

They work on the basis of the effect produced when a charged particle passes through a gas. The primary mode of interaction involves ionization and excitation of gas molecules along the particle track. The majority of gas filled detectors are based on sensing the direct ionization created by the passage of the radiation. Their out put signal that

originates from the ion pairs formed with in the gas filling the detector are derived in different ways in all the three cases. Gas filled detectors can be operated in current or pulse mode. In most applications, ion chambers are used in current or pulse mode. In most applications, ion chambers are used in current mode, as dc device. In contrast, proportional counters or Geiger tubes are always used in pulse mode.

4.3.2 General Properties of Gas filled Detectors:

A schematic diagram of gas filled detector is shown in Fig. 4.1 External voltage V is applied between the wall of the gas filled chamber (cathode) and the central wire (which acts as anode) through an external resistance R. The capacity of the electrode and the counting system is Co. In the way an electronic field is set in the volume of the gas.

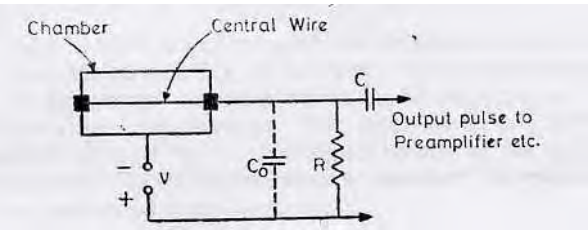


Fig. 4.1 A schematic diagram of Gas filled detector

Exposed to nuclear radiation, charged particles either primary alpha rays or beta rays or secondary electrons formed in the gas during the ionization by gamma rays-will travel through the gas and produce positive and negative ions by inelastic collisions with atoms or molecules. In the absence of the electric field, the ion pairs thus created will just recombine. However, in the presence of the applied eclectic field the positive and negative ions will move along the radial eclectic lines of force towards the outer wall (cathode) and the central wire (anode) respectively. Normally the negative ions (usually electrons) move with much faster draft velocities (10^6cm/s) as compared to the positive ions. The net result is that a charge Q collects on the anode, thus changing its potential by Q/C. The change in the potential drop across R will give rise to an electrical pulse signal. Thus the passage of a nuclear radiation through the detector will give rise to a pulse signal, which can be processed by the pre- amplifier etc for counting.

The out put pulse height at the anode (relative number of ions collected by the anode will depend on (i) external voltage applied and (ii) The initial ionizing event-the type incoming radiation (whether pulse is initiated by alpha -particle of beta- particle)

The variation of the number of ions collected with the applied voltage is usually described by dividing the graph into four regions as shown in Fig. 4.2.

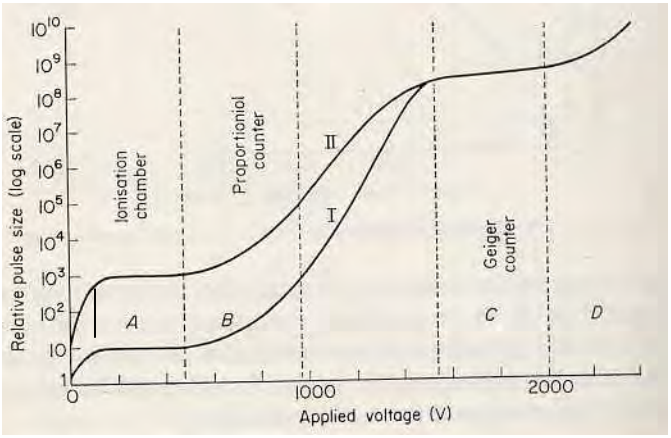


Fig. 4.2 The variation of pulse height with applied voltage

(i) Region A (the first part): Initially, when the applied voltage is less, the eclectic field is not so effective in removing the ions for collection at the electrodes. In region A, therefore, the ions face a competition between two processes, (i) loss of ion pairs through recombination and (ii) removal to the electrode by the eclectic field. Hence at low voltage, the electrons may recombine with the ions. But as the eclectic field is increased, the ion move faster leaving less time for possible recombination and thus a relatively larger number of ions reach the electrode. This region (A) is called recombination region.

(ii) Region A (the second part)- As the voltage increases, at the on set of region B, recombination gradually disappears and the ions produced are collected at the respective electrodes. The ions colleted at the electrodes give rise to a pulse signal. This region is called the ion chamber or saturation region. As pulse height depends on the initial number of ion pairs produced the gas filled counter operating in this region is called ionization counter (chamber).Due to the fact that the pulse height depends upon the initial number of ion pairs, different particular (events) –say particle I(beta) or particle II(alpha) may be identified in ionization chamber. Pulse height or current remains constant is the region.

(iii) In region B, the phenomenon of gas multiplication sets in. Because of the increased voltage, the electrons which are liberated by the primary ionizing event get sufficient kinetic energy to cause secondary ionization. This secondary ionization increases the amount of collected charge. In the first part of the region B, the gas multiplication factor M is strongly dependent on the particle energy for a given applied voltage. In other words, in this region, the detector will give rise to pulses of different heights depending on whether; the initial ionization is caused by alpha particle or beta particle. This proportionality between the pulse height and the initial ionization allows us to use the detector to distinguish between particles of different energies and ionizing powers. The gas filled counter operating in this region is called proportional counter. As the applied voltage is increased this proportionality breaks down. The region B is called proportional region, while at its upper ends it's called region of limited proportionality.

(iv) Beyond the proportionally region, the pulse size is completely in dependent of the initial ionization and all particle produce pulse of the same height irrespective of their energy and primary ionization. I.e. Event r minimum ionizing particle will produce a very large pube. Pubes here can be recorded with out amplification. This region C is called Geiger-Muller region. If the voltage is increased beyond the region C there will be an on set of continuous electrical discharge. The gas filled counter operating is this region is called Geiger counter or Geiger Muller counter or G.M counter.

4.3.3 Ionization Chambers

Ion chambers in principle are the simplest of all gas filled detectors. Their normal operation is based on collection of the entire charges created by direct ionization with in the gas through the application of an eclectic field. Exclusively the term ionization chamber is used for type detectors in which ion pairs are collected from gases.

As fast charged particles passes through a gas they create both exited molecules and ionized molecules along its path due to the Collision. After the neutral molecule is ionized, the resulting positive ion and free electron are called an ion pair, and it serves as the basic constituent of the electrical signal developed by the ion chamber. Ions

can be formed either by direct integration with the incident partied or through a secondary process in which some of the particle energy is first transferred to an energetic electrons or delta rays.

At a minimum, the particle must transfer and amount of energy equal to ionization energy of the gas molecule to permit the ionization process to occur. In most gases used for radiation detectors, the ionization energy of least tightly bound electron shells is between 10 and 25 ev. However there are other mechanisms by which the incident particle may lose energy with in the gas that do not create ions. Examples are the excitation process in which an electron may be elevated to a higher bound state in the molecule without being completely removed. Therefore, the average energy lost by the incident particle per ion pair formed (defined as w-value) is always substantially greater than the ionization energy. The W- value in principle is a function of a species of gas involved, the type of radiation, and its energy. Empirical observations, however, show that it is not a strong function of any of these variables and is remarkable constant parameter of value 25-35 per ion pair for many gases.

Assuming that W is constant for a given type of radiation, The deposited energy will be proportional to the number of ion pairs formed and can be determined if a corresponding measurement of the number of ion pairs is carried out. For example in the case of argon gas, $Ar \longrightarrow Ar^{+}+e^{-}$ (ion pair formation). If E is the energy loss, then the ion pairs produced can be found by the relation,

$$\text{Ion pairs} = E/w \qquad (4.1)$$

Were W is the energy required to produce one ion pair (W=30ev) If V is an applied voltage across the electrode, the electric field between the two electrode is

$$E = V/d. \qquad (4.2)$$

An ionization chamber can have various geometries, The basic systems being similar to shown in Fig. 4.1 .The external voltage applied between the two electrodes is properly adjusted for operation in region A (second part) .The gas used in the chamber is either dry air at normal pressure or some other suitable gas (dense gas such as argon). The fill gas pressure is often1atmosphere, although higher pressure is sometimes used to increase the sensitivity. When the ionization chamber is to be used for intensity measurements one usually measures its ionization current with a system.

The ionization current of chamber exposed to nuclear radiation first increases with applied voltage but soon saturates to a saturation current value, I_S because at this voltage all the primary ions are collected before they can recombine.

The voltage at which saturation sets in is determined by the intensity of the incident nuclear radiation. If the number of ion pairs produced per second in N, the average ionization current I_S at saturation is given by Is= Ne, where e is the electronic charge. Then measurements of I_S can give us the integrated effect of the total ionization events or the intensity of ionizing radiation. The ionization current is measured either by a micro ammeter or by some other sensitive method.

4.3.4.1 Proportional Counters

A proportional counter is a type of gas filled detector that was introduced in the late 1940s. It is usually built in a cylindrical geometry, with a hollow metal cylinder forming the outer electrode (cathode) while a fine tungsten wire (diameter of about 0.1mm) running along the axis forming the central electrode (anode). The applied voltage is adjusted so as to be in the proportionality region B (Fig. 4.2)

For a cylindrical geometry, the strength of the electric field at a radial distance r from the central wire is given by: $E = \frac{Vo}{r \ln(b/a)}$ (4.3)

Where Vo is the applied voltage and a and b are the radii of the central wire and the cylindrical electrodes respectively. The electric field in the neighbourhood of the central wire is very high and such high electric field causes gas multiplication. Gas multiplication is a consequence of increasing the electric field within the gas to sufficiently high value. Because electrons are attracted to the anode, they will be drawn toward this high field region.

Free electrons can be easily accelerated by the applied electric field & may have significant kinetic energy when undergoing collission. If its kinetic energy is greater than the ionization energy of the neutral gas molecule, it is possible for additional ion pairs to be created in the collisions. In a typical gases at atmospheric pressure the threshold field is of the order of 10^6v/m. If the field is above the threshold field for the secondary ionization, the electrons liberated by the secondary ionization process will

also be accelerated by the electric field. During its subsequent drift, it undergoes collisions with other neutral gas and thus can create additional ionization.

When the electrons of the initial ionization reach the region of high field strengths, they can pick up enough kinetic energy between collisions to make more ions; electrons so formed can continue the process. This is called an avalanche. Avalanche effects were first used to detect single particles by Rutherford and Geiger in 1908. If there were n_o ion pairs initially, Mn_o electrons & Mn_o positive ions will be formed, mostly in the space very close to the wire when the avalanche has stopped. The avalanche terminates when all free electrons have been collected at the anode. As we raise the counter potential, the avalanches are more effective so that M is larger. One usually gets multiplication factors M in the range of 10^2-10^4.

To understand the gas multiplication let us assume that every electron produced in the primary ionization gives rise to a total of n secondary electrons by collisions. The production of secondary electrons during the collisions in the gas will also give rise to photons, which in turn can produce photoelectrons in the volume of the counter. Let p be the probability that each secondary electron will give rise to a photoelectron. Thus there will be np photoelectrons, in turn, produces n electrons by further collissions. We shall have a second generation avalanche of n^2p electrons, which in turn give rise to more photo electrons and so on. Finally, the total number of electrons will be: $M = n + n^2p + n^3p^2 + \ldots\ldots\ldots\ldots$ (4.4)

Where M is the gas multiplication factor. For practical proportional counter, $np < 1$ and the above series converges so that M can be written as a sum of geometric series,

$$\text{.e.} \quad M = n\,(1 + n^2p^2 + n^3p^3 \ldots\ldots\ldots\ldots\ldots)$$

$$= \frac{n}{1-np} \qquad (4.5)$$

It is thus seen from the result that in a proportional counter the total number of secondary electrons is proportional to the number of initial or primary ion pairs, but with the total number of ions multiplied by a factor of M.This charge amplification within the detector itself reduces the demands on external amplifiers and can result in significantly improved signal to noise characteristics compared with pulse type ion chambers.

According to Townsend avalanche, each free electron created in a collission can potentially create more free electrons for additional ionization in the form of cascade of gas multiplication process. Hence the fractional increase in the number of electrons per unit path length is governed by the Townsend equation;

$$\frac{dn}{n} = \alpha \, \mathrm{dx} \qquad (4.6)$$

where α is called the first Townsend coefficient. Its value is zero for electric field values below the threshold and generally increases with increasing field strength above this minimum. For spatially constant field (as in parallel plate geometry), α is a constant in Townsend equation Its solution then predicts that the density of electrons grows exponentially with distance as the avalanche progresses:

$$n(x) = n(0)\, e^{\alpha x} \qquad (4.7)$$

one of the important application of proportional counters has been in the detection and spectroscopy of low energy x-radiation. Also they are widely applied in the detection of neutrons. In addition proportional counters can be applied to situations in which the number of ion pairs generated by the radiation is too small to permit satisfactory operation in the pulse type ion chambers due to their considerably larger pulse formation.

4.3.5GEIGER MULLER COUNTERS

The Geiger Muller counter (commonly referred to as the G.M. counter, or simply a G.M. tube) is one of the oldest radiation detector types in existence, having been introduced by Geiger and Muller in 1928.

If the anode potential of a proportional counter is raised sufficiently the output pulse fails to remain proportional to the primary ionization and finally become of uniform amplitude, irrespective of the type of energy of the incident particle or photon. The counter is then said to be operating in Geiger region.(C)

G.M.counters are usually filled with noble gases like argon, neon, helium etc. In the Geiger Muller region C (Fig.4.2) np < 1and the series in equation 4.4 diverges. We have therefore a new phenomenon in the Geiger region. It is the spread of the discharge along the wire by the action of photon generated in the avalanche. The result is that the discharge spreads all along the wire forming an ion sheath and an out put pulse of the order of few volts is obtained, (independent of the primary ionization). This discharge has to be quenched. Otherwise it can sustain itself and multiple pulses can occur. There are two ways in which this discharge can be quenched, (i) externally- by suitable electronic

circuit or (ii) more simply in an internal way by adding a poly atomic gas, like ethyl alcohol vapour, to the argon gas (ratio argon 90% by weight, ethyl alcohol 10%).Let me explain the above two cases in detail.

(i) External Quenching: The mechanism of operation depends upon emission of ultraviolet radiation (photons) from many atoms excited during the avalanche of electrons towards the anode wire. In the earlier forms of Geiger counter these photons eject photoelectrons from the metal walls of the counter. The photoelectrons are accelerated towards the anode, near which they produce further avalanche, which spread in this manner along the entire length of the anode. The process ceases only when the space charge of slowly moving

Positive ions reduce the electric field sufficiently to limit the number of electrons and excited atoms in the avalanche. When, eventually, positive ions reach the cathode they also may eject photoelectrons and so initiate a self-sustaining discharge in the counter. A number of electronic circuit arrangements have been devised to prevent secondary pulses due to positive ion impacts. This may be accomplished electronically by lowering the voltage v after each count, which in turn lowers the speed of the counter. Such counters are called non- self-quenching.

To decrease the attracting potential, which is responsible for motion&multiplication of electrons emitted from the cathode, we can use (apply) an external resistance.

If v_o is an applied voltage which is creating high field, it is decreased when a current I flows through the resistance R. Then the potential at the central wire becomes v_o-IR. If the resistance is made very high, now Since the potential is v_o-IR rather than Vo there is no electron reaching the central wire.

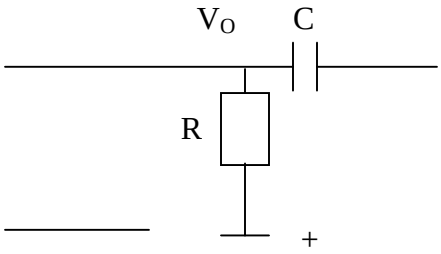


Fig. 4.3 External quenching circuit

Therefore in external quenching (i) we can use high value of resistance, R or (ii) we can use some electronic circuit which are called quenching circuit, that dis connects the voltage for a moment from the central wire.

(ii) Internal Quenching: More elegantly the quenching is done in a gas itself. For discharge to maintain itself, either one or more of the huge number of positive ions

formed in an avalanche or a photon must release a new electron in the gas or at the cathode to start the process over again.

When a positive argon ion, is neutralized on a metallic surface a considerable amount of energy is released that may be used to expel an electron from the surface. This makes using argon alone difficult. But polyatomic gases do not behave this way.

Here I consider only counters filled with mixtures of mono atomic gas (commonly argon) and a polyatomic gas such as ethyl alcohol. An argon pressure of 9cm of mercury (Hg) and alcohol pressure of 1cm Hg are common. Counters containing polyatomic gases are called self-quenching; they will operate without need for external circuit. A small amount of polyatomic vapour such as alcohol or acetone is introduced into the gas filling. This causes photons from the electron avalanche to be strongly absorbed in the vapour, owing to its low ionization potential, and photoelectrons are produced close to the anode wire.

The quenching action of alcohol is as follows: the ionization potential of alcohol (11.3ev) is lower than that of argon (15.7). As a result the ions moving out towards the outer cathode consist mostly of alcohol ions. These alcohol ions, however do not give rise to secondary avalanche when they are neutralized at the cathode. Thus there is no multiple pulsing and the discharge is quenched soon (fraction of a millisecond) after the initial ionization.

Since the ionization energy of alcohol is less than that of argon, we get :

$$Ar^{+} + C_2H_5OH \longrightarrow Ar + (C_2H_5OH)^{+},$$

While going towards cathode Ar^{+} loses their charge to alcohol. When alcohol molecules, $(C_2H_5OH)^{+}$ reach the cathode they become neutral by absorbing electrons from the cathode. But since dissociation energy of alcohol molecules is very low ($\approx$ 3ev) they dissociate into $C_2H_5^{+}$ and OH^{-} and no photon emission that can lead to photoelectrons. So, that way secondary discharge is quenched. However, gradually alcohol molecules can be exhausted and result in poor characteristics of G.M.tube because gas pressure slowly increases due to the increase in molecular fragments.

Therefore, self-quenching has got a lifetime, i.e. lifetime not in terms of time but in terms of number of particles due to the gradual decomposition of organic vapour. This depends upon the utilization of alcohol molecule (dissociation). Organic quenched tubes have a useful lifetime of about 10^{10} counts. To solve this problem halogen quenching gases such

as chlorine, bromine, etc are used. In the halogen- quenched tube, the quenching gas is apparently not consumed in the quenching process. It appears that the diatomic halogen gas molecules are dissociated in the quenching, and that there is a recombination mechanism present to replenish the supply of quenching gas. Unlike alcohol after dissociation chlorine is regained so that the problem of exhaustion is solved. This not only extends greatly the life of the tube for a normal use, but also makes possible to run the tube at higher voltages without sacrificing the life of the tube. This later feature means that the out put voltage pulse of 10volts or more can be obtained from the tube in normal operation. But the halogen vapours cannot be used with some cathode materials because of chemical action. Cathodes of stainless steel have proved satisfactory. Self-quenching counters containing halogen fillings have indefinite lives because the halogen ions are neutralized at the walls without dissociation (or electron emission). Nearly all-modern Geiger counters are of this type.

4.5.1 Some Basic Features of G.M.counter

(1) Design Features: Geiger Muller counter (G.M.) can be built in various geometries. Atypical design of Geiger tube is the end window type. (Illustrated in. Fig. 7.6). The anode wire is supported at one end only and is located along the axis of the cylindrical cathode made of metal or glass with a metallized inner coating. Radiation enters the tube through the entrance window, which may be made of mica or other material that can maintain its strength in thin sections. Because most Geiger tubes are operated below atmospheric pressure, the window may have to support substantial differential pressure. The window should be as thin as possible when counting short-range particles, such as alphas, but may be made robust for applications that involve beta particles or gamma rays.

(2) Time behavior: immediately following the Geiger discharge, the electric field has been reduced below the critical point by the positive space charge. If another ionizing occurs under these conditions, a second pulse will not be observed because gas multiplication is prevented. During this time the tube is therefore ‘dead’ and any radiation interactions that occur in the tube during this time will be lost. Technically, the dead time of the Geiger tube is defined as the period between the initial pulse and the time at which the second Geiger discharge, regardless of its size can be developed. In most Geiger

tubes, this time is of the order of 50-100 μ s. In any practical counting system, some finite pulse amplitude must be achieved before the second pulse is recorded, and the elapsed time required to develop a second discharge that exceeds this amplitude is sometimes called the resolving time of the system. In practice, these two terms are often used interchangeably and the term dead time may also be used to describe the combined behavior of the detector- counting system. The recovery time is the time interval required for the tube to return to its original state and become capable of producing a second pulse of full amplitude.

(3) The Geiger counting plateau: because the Geiger tube functions as a simple counter, its application requires only that operating conditions be established in which each pulse is registered by the counting system. in practice, this operating point is normally chosen by recording plateau curve from the system under conditions in which the radiation source generates events at a constant rate within the tube, the counting rate is recorded as the high voltage applied to the tube is raised from an initially low value.

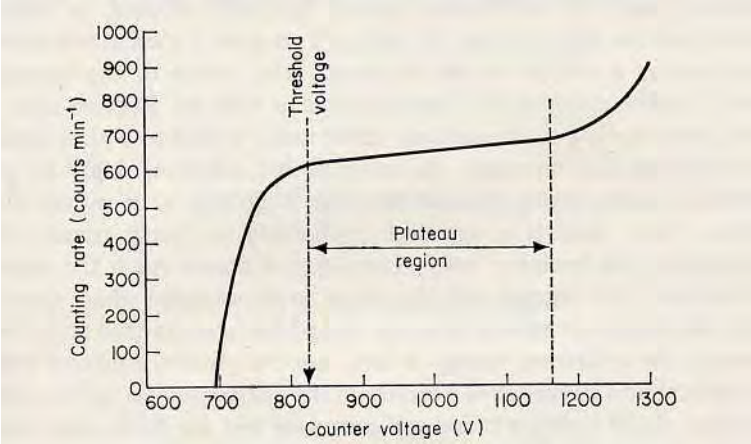


Fig. 4.4 The plateau characteristic of GM counter

The voltage, which must be applied to produce pulse of equal amplitude, can be found in the following way. The Geiger counter is exposed to a constant radiation flux containing particles or photons of different energies. The voltage across the counter is gradually increased and the counting rate measured as a function of the voltage. A plot of the counting rate against voltage then gives a characteristic curve like that shown in fig.11.8.for low voltages only the most energetic particles initiate avalanches which result in detectable pulses. As the voltage increases more and more particles are counted until the threshold voltage is reached. Beyond the threshold and throughout the plateau range

all pulses are of approximately the same amplitude and the counting rate remains almost constant. Infact the plateau has a positive slope corresponding to about a 1percentrise in the counting rate over the plateau length. The working voltage of the counter is taken to be midway along the plateau so that variations in the supply voltage do not greatly affect the counting rate.

4.3.5.2 Detection Efficiency

All radiation detectors will, in principle, give rise to an out put pulse for each quantum of radiation that interacts within its active volume. For primary charged radiation such as alpha or beta particles, interaction in the form of ionization or excitation will take place immediately upon the entry of the particles into the active volume. After traveling a small fraction of its range, a typical particle will form enough ion pairs along its path to ensure that the resulting pulse is large enough to be recorded. thus it is often easy to arrange a situation in which a detector will see every alpha or beta particle that enters its active volume. Under these conditions, the detector is said to have a counting efficiency of 100%

On the other hand, uncharged radiations such as gamma rays or neutrons must first undergo a significant interaction in the detector before detection is possible. Because these radiations can travel large distance between interactions, detectors are often less than 100% efficient. It then becomes necessary to have a precise figure for the detector efficiency in order to relate the number of pulses counted to the number of neutrons or photons incident on the detector.

It is convenient to subdivide counting efficiencies into two classes: absolute and intrinsic.

Absolute efficiencies are defined as:

$$\varepsilon_{abs} = \frac{number of pulses recorded}{number of radiation quanta emitted by the source} \qquad (4.8)$$

and are dependent not only on detector properties, but also on the details of counting geometry (primarily the distance from the source to the detector).the intrinsic efficiency is defined as :

$$\varepsilon_{int} = \frac{number of pulses recorded}{number of radiation quanta incident on the detector} \qquad (4.9)$$

and no longer includes the solid angle subtended by the detector as an implicit factor. the two efficiencies are simply related to isotropic source by $\varepsilon_{int} = \varepsilon_{abs}(4\pi/\Omega)$, where Ω is the solid angle of the detector seen from the actual source position.

Usually, not all the particles reaching the detector are counted. Some are missed because they don't produce enough excitation to be counted. Which of them will be missed

cannot be predicted, because excitation and ionization of the counter media by the incident particle is a random phenomenon. The efficiency of the detector gives, the probability that a given detector will count the incident particle

The intrinsic efficiency of a detector usually depends primarily on the detector material, the radiation energy and the physical thickness of the detector in the direction of the incident radiation. A slight dependence on the distance between the source and detector does remain, however, because the average path length of the radiation through the detector will change somewhat with this spacing.

Counting efficiencies are also categorized by the nature of the event recorded. If we accept all pulses from the detector, then it is appropriate to use total efficiencies. In this case all interactions no matter how low in energy, are assumed to be counted. In terms of a hypothetical differential pulse height distribution, the entire area under spectrum is a measure of the number of all pulses that are recorded, regardless of the amplitude, and would be counted in defining the total efficiency. In practice, any measurement system always imposes a requirement that pulses be larger than some finite threshold level as low as possible. the peak efficiency, however, only those interactions assumes that deposit of the full energy of the incident radiation are counted. in a differential pulse height distribution, these full energy events are normally evidenced by a peak that appears at the highest end of the spectrum. Events that deposit only part of the incident radiation energy then will appear further to the left in the spectrum. the number of full energy events can be obtained by simply integrating the total area under the peak. The total and the peak efficiencies are related by the peak to total ratio: $r = \varepsilon_{peak}/\varepsilon_{total}$

Which is sometimes tabulated separately. It is often preferable from an experimental standpoint to use only peak efficiencies, because the number of the full energy events is not sensitive to some perturbing effects such as scattering surrounding objects or spurious noise. Therefore, values for the peak efficiency can be compiled and universally applied to a wide variety of laboratory conditions, whereas total efficiency values may be influenced by variable conditions.

To be complete, a detector efficiency should be specified according to both of the above criteria. for example, the most common type of efficiency tabulated for gamma ray detectors is the intrinsic peak efficiency.

A detector with known efficiency can be used to measure the absolute activity of a radioactive source. Let us assume that a detector with an intrinsic peak efficiency ε_{ip} has been used to record N events under the full energy peak in the detector or spectrum. For simplicity, we also assume that the source emits radiation isotropically and that no attenuation takes place between the source and the detector. From the definition of intrinsic peak efficiency, the number of radiation quanta, S, emitted by the source over the measurement period is then given by : $S = N4\pi/\varepsilon_{IP}\Omega$ (4.10)

Where Ω represents the solid angle (in steradians) subtended by the detector at the source position. I.e. $\varepsilon_{IP} = \varepsilon_{AP}(4\pi/\Omega)$ & $\varepsilon_{AP} = \frac{N}{S} \Rightarrow S = N/\varepsilon_{AP}$

$$\Rightarrow S = 4\pi N/\varepsilon_{IP}\Omega \qquad (4.11)$$

Where ε_{AP} is absolute peak efficiency.

The solid angle is defined by an integral over the detector surface that faces the source, of the form: $\Omega = \int (\cos\alpha / r^2) Da$ (4.12)

Where r represents the distance between the source and the surface element dA, and α is the angle between the normal to the surface element and the source direction. If the volume of the source is not negligible, then a second integration must be carried out over all volume elements of the source.for the common case of a point source located along the axis of a right circular cylindrical detector, Ω is given by :

$$\Omega = 2\pi[1 - d/\sqrt{(d^2 + a^2)}] \quad (4.13)$$

where the source detector distance d and detector radius a , for d >>a, the solid angle reduces to the ratio of the detector plane frontal area A visible at the source to the square of the distance: $\Omega \approx A/d^2 = \pi a^2/d^2$ (4.14)

(as $d/\sqrt{(d^2 + a^2)} = 1/\sqrt{(1 + a^2/d^2)} = (1 + a^2/d^2)^{-1/2} \approx 1 - a^2/2d^2$

$\Omega = 2\pi [1 - (1 - a^2/2d^2)] = 2\pi a^2 / 2d^2 = \pi a^2 / d^2$)

hence for a point source at a distance d from the counter window of the radius r, the variation of the solid angle is related to the geometric factor G_P according to the equation

$$G_P = \Omega / 4\pi = \frac{1}{2}(1 - d/\sqrt{(d^2 + r^2)}$$

$$= \Omega/ 4\pi = r^2 / 4 d^2 \quad (4.15)$$

Therefore including the geometric factor and taking into account the property of the material (absorption coefficient) for a given beta and gamma source

(i) the efficiency for gamma of GM counter is given by the formula:

$$\varepsilon_\gamma = [(I_\gamma (1 + \mu x) / 2AG_P] \times 100\% \quad (4.16)$$

and (ii) efficiency for β-rays is given by the relation :

$$\varepsilon_\beta = [2I_{\beta\gamma} / 3I_\gamma (1+ \mu x)] \times 100\% \quad (4.17)$$

where I_γ = Intensity of γ-source (or the number of counts per unit time) with absorber.

$I_{\beta\gamma}$ =Intensity of gamma source without absorber,

μ = absorption coefficient of an absorber,

x = thickness of the absorber,

A = Present day activity of the absorber,

& G_P = geometric factor.

The intrinsic efficiency of a Geiger Muller counter is equal to the probability that at least one ion pair will be produced by a particle passing through it. Suppose that, on average, N primary ion pairs are produced by the particle. The chance that no ion pair will be produced is e^{-N}. The efficiency is then $1 - e^{-N}$, because only if no ion pair will be produced will a count fail to occur. For N = 4 this quantity is 98 %; beta and alpha efficiencies can thus easily be made close to unity. On the other hand the efficiency of a Geiger Muller counter for photons is normally about 1%, varying appreciably with energy.

CHAPTER FIVE
EFFICIENCY OF GAS FILLED DETECTOR FOR THE DETECTION OF BETA AND GAMMA RADIATION

5.1 THE EXPERIMENT

This study was performed using cobalt (co-60), and caesium (cs-137) sources. I have experimentally determined the efficiency of commonly used Gas Filled Detector, the GM counter. Theoretically the efficiency of gas filled detector, (GM-counter)is relatively large (about 100%) for charged particles (beta radiation) and very small (about 1%) for gamma radiation (uncharged). This experiment has proved this fact and also in addition it is shown that there exists efficiency variation with relative distance of separation between the source and detector. Further details of the experiment are given below.

5.2 EXPERIMENTAL SET UP

The basic parts of the experimental set up are the GM tube, GM counter, high voltage power source, sources of gamma (γ) and beta (β) – radiations ,co-60 and cs-137 respectively. This is shown in block diagram as shown in Fig 5.1

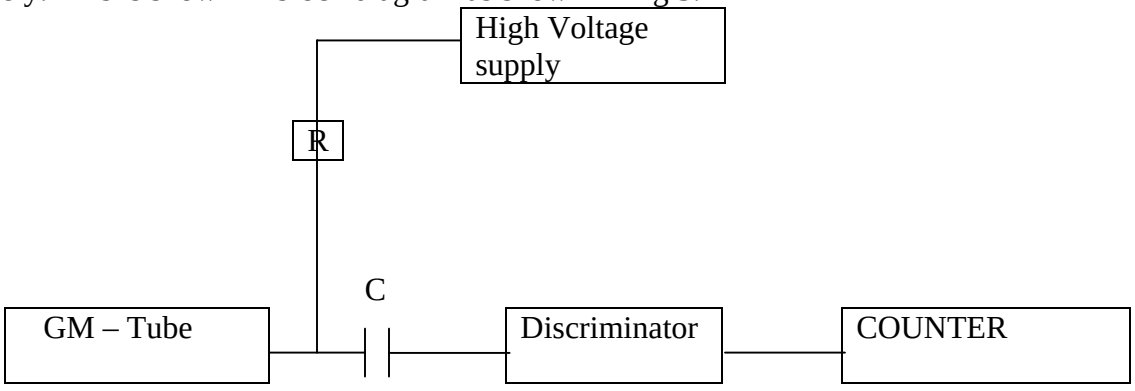


Fig. 5.1 Block diagram of counting electronics associated with a GM – tube..

5.3 EXPERIMENTAL TECHNIQUES (Methods)

To achieve the desired result, measurement of efficiency, there are some basic techniques (methods) that I used before experiment (as a pre condition)and in the experiment. I have mentioned the steps that I have followed orderly.

Step 1: *calculations of activities of the sources used in the experiment.*

The experiments in nuclear physics lab (AAU) started in Dec.1993 there were caesium and cobalt sources by that time. I used the same source for this experiment. Based on evidences, I have come to the conclusion that the initial activities of the respective sources are

(i) For cobalt source (co-60), $A_0 = 1\mu Ci$

(ii) For caesium source (Cs – 137), $A_0 = 5\mu Ci$

Based on this, taking the data of manufacture to be in 1993, the total time of decay upto now will be 13.5 yrs. Using this the activities can be calculated as follws.

(i) For cobalt source (Co – 60):

- Half life, $T_{1/2} = 5.27$yrs
- Time of decay, t = 13.5 yrs

From the exponential decay relation, the present activity of cobalt is defined by the formula : $A = A_0e^{-\lambda t}$ (2.6)

Where λ is decay constant and t is time of decay. But for cobalt source (Co – 60)the decay constant is, $\lambda = \frac{0.693}{T_{1/2}} \Rightarrow \lambda = \frac{0.693}{5.27yr} = 0.131/yr$ (2.3)

Then the present activity becomes, $A = A_0e^{-\lambda t} = 1\mu Ci \times e^{-1.775}$

$= 0.1695\mu Ci$

since 1curie = $1Ci = 3.7 \times 10^{10}$disintegrations /sec we can also write the activity as,

$A = 0.1695 \times 10^{-6} \times 3.7 \times 10^{10}$

$=0.2715 \times 10^4$ dis / sec

$= 6,271.5$ dis / sec

(ii) For caesium source (Cs – 137)

- Half life, $T_{1/2} = 30.1$yrs
- Decay time, t = 13.5 yrs

Again from the exponential decay relation, the present activity of caesium is given by the equation (2.6), where the decay constant, λ for caesium is :

$\lambda = \frac{0.693}{T_{1/2}} \Rightarrow \lambda_{CS} = \frac{0.693}{30.1yrs} = 0.023023$ / yrs

Then taking the initial activity , $A_0 = 5\mu$ Ci, the present activity of caesium source can be calculated to be ; $A = A_0e^{-\lambda t} \Rightarrow A = 5\mu Ci \times e^{-0.3108}$

$=5\mu Ci \times 0.73285$

$= 3.66425\mu Ci$

but since $1\mu Ci = 3.7 \times 10^{10}$ dis / sec, we can also write this as

$A = (3.664251037 \times 10^{-6})(3.7 \times 10^{10}$dis /sec)

$= 13\ 55772884 \times 10^4$ dis / sec

$= 135,577.2884$ dis / sec.

Therefore I used : $A_{CO} = 6,271.5$ dis / sec for cobalt source (Co – 60),

and $A_{CS} = 135{,}577.2884$ dis / sec for caesium (Cs – 137) as a present day activity.

Step 2 Calculation of the proper absorber thickness for beta absorption and absorption coefficient

(a) Energy relations of the sources used is shown in table 5.1 below.

S. No.	Source	Type of Radiation	Energy β- rays (maximum)	Of Emitted γ - rays
1	Cobalt (Co – 60)	β & γ radiations	**0.31Mev**	1.17 & 1.33
2	Caesium(Cs 137)	β & γ radiations	0.51 Mev	0.66 Mev

Table 5.1

(b) according to the equation (3.21) the range of beta rays in a given material (absorber)is related to its maximum energy according to :

$$R_0 = 412\,E^n \quad \text{for } 0.01 < E < 3\text{Mev} \quad (3.22)$$

$$\text{And } n = 1.265 - 0.0954\ln E$$

Since the energy of both beta sources are within this range.

(i) for cobalt (co – 60): E = 0.31Mev

$$n = 1.265 - 0.0954\ln E$$
$$= 1.265 + 0.111730856$$
$$n = 1.37673$$

then from $R = 412\,E^n$ we obtain, $R_{01} = 412\,(0.31)^{1..37673}$

$$= 412 \times 0.1994$$
$$= 82.15 \text{ mg / cm}^3$$

this is the range of cobalt source (Co – 60) in any absorber thickness that can absorb beta rays totally.

But since I used aluminium in this experiment, as an absorber the corresponding proper absorber thickness will be:

$$X_1 = \frac{Ro1}{\rho} = \frac{82.15mg}{2.73g} \ (\text{cm}^3 / \text{cm}^3) = 30.09 \times 10^{-3} \text{ cm}$$

$$= 30.09 \times 10^{-2} \text{ mm} = 0.3009 \text{ mm}$$

(ii) for caesium(Cs – 137): E 0.51 Mev

$$n = 1.265 - 0.095 \ln E = 1.265\ 0.0954\ln(0.51)$$
$$= 1.265 + 0.0642$$
$$= 1.32923707$$

this gives, $R_{CS} = 412 \times (0.51)^{1\,32923707}$

$$= 412 \times 0.040859$$
$$= 168.3405159 \text{ mg / cm}^3$$

this is caesium – 137 beta range in any absorber. It also gives the absorber thickness for its total absorption. Then the equivalent proper thickness of aluminium absorber can be calculated to be: $x_{CS} = \frac{Rcs}{\rho} \Rightarrow x_{CS} = \frac{168.34mg}{2.73g} = 61.663 \times 10^{-3}$ cm

$$= 61.663 \times 10^{-2} \text{ mm}$$
$$= 0.61663 \text{ mm.}$$

Based on the above results I used:

(i) x_{CO} = 0.315 mm (combination of absorbers – [0.27mm + 0.045mm]) for cobalt and
(ii) x_{CS} = 0.67 mm (again combination of two absorbers [0.40mm + 0.205]) for caesium as absorber thickness to totally block beta radiation.

(C) Also I have calculated the mass absorption coefficient s using the equation given by:

$$\mu_m = 17(E)^{-1.43}\ cm^2 / gm. \qquad (3.21)$$

where μ_m is mass absorption coefficient and E is energy of β - emitter in Mevs.

(i) thus for cobalt, $\mu_m = 17(0.31)^{-1.43}\ cm^2 / gm$

$= 17(5.337682999)$

$= 90.74\ cm^2 / gm.$ (mass absorption coefficient)

& equivalently we can define the linear absorption coefficient corresponding to this for aluminium as: $\mu = \mu_m \rho \quad \Rightarrow \quad \mu = 90.74\ cm^2 / gm \times 2.73\ g / cm^3$

or $\quad \mu = 247.721868\ cm^{-1}$

(ii) for caesium (Cs – 137): E = 0.51Mev.

then $\mu_m = 17(0.51)^{-1.43} = 17(2.619) = 44.527\ cm^2 / g$

equivalently the linear absorption coefficient for this case will be:

$$\mu = \mu_m \rho = 121.5587475\ cm^{-1}.$$

5.4 Experiment II

<u>Title</u>: The plateau characteristic of GM counter

<u>Objective</u>: to determine the operating voltage of GM counter

5.4.1 Experimental procedure:

(1) Clamp the Geiger tube to a retort stand and then connect the GM counter (scaler) & high voltage supply for normal counting. Make sure that the voltage is set at its lowest value. – I set the time of counts to be 100sec & started from 300 v.

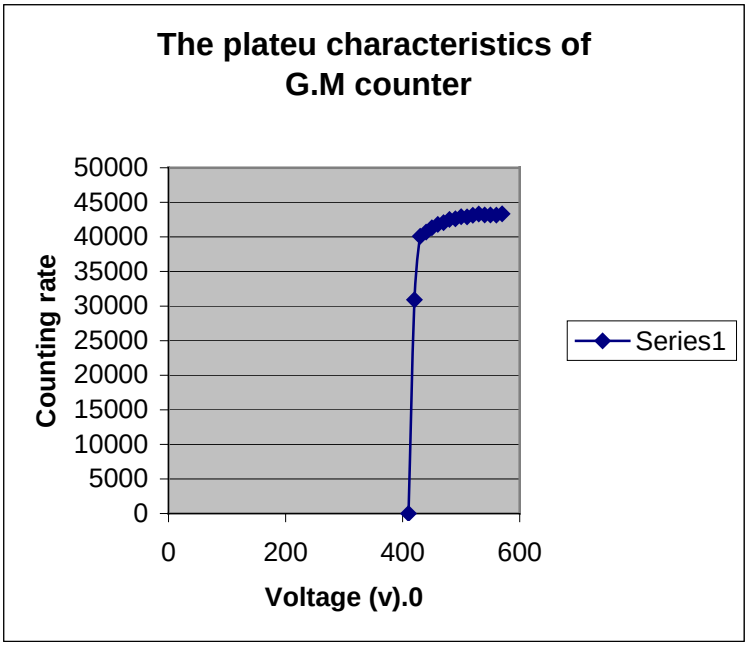
(2) Place cobalt / caesium source (Cs – 137) at a fixed distance on the source holder. I used caesium source (Cs – 137) at a distance of 3 cm from the source (without correction factor)

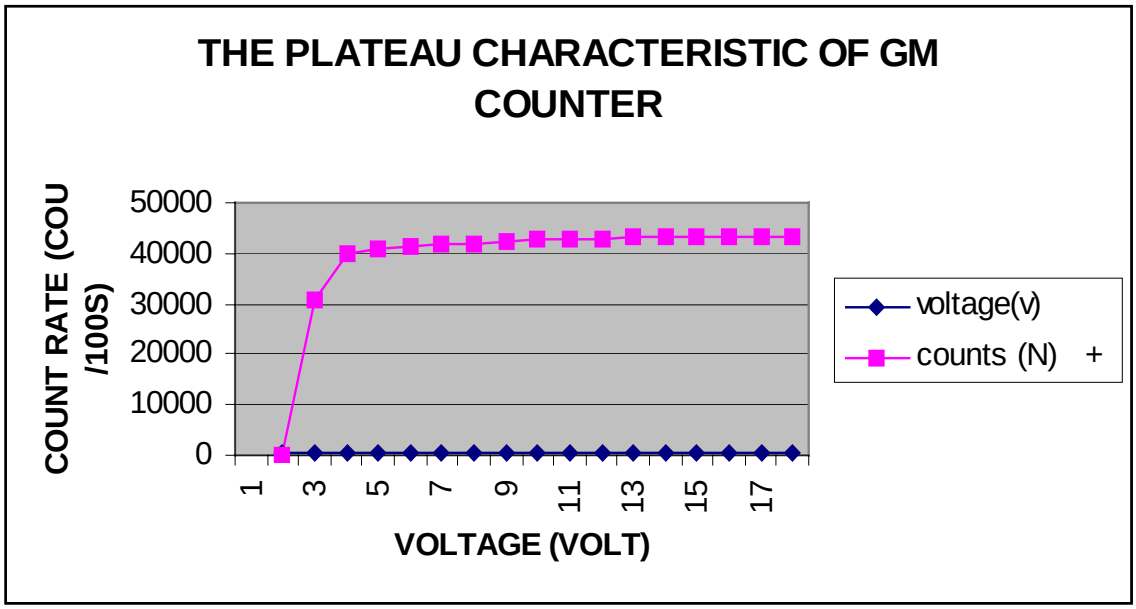
(3) Gradually increase the voltage until the scaler begins to register pulses. I varied the voltage at 10-v interval and repeated the intensity measurement at least five times for each voltage.

(4) Measure the counting rate at various voltages, until the counting rate begins to rise rapidly. Do not allow the counter to operate for prolonged periods in the continuous discharge region, as this will damage the counter.

.Table 5.2. the plateau characteristic of GM counter.

S. No.	voltage(v)	counts (N)	$\pm\sqrt{N}$
1	410	0	0
2	420	30902	176
3	430	40088	200
4	440	40694	201
5	450	41312	203
6	460	41812	202
7	470	42066	205
8	480	42518	206
9	490	42614	206
10	500	42922	207
11	510	42884	207
12	520	43126	208
13	530	43306	208
14	540	43176	208
15	550	43177	208
16	560	43150	208
17	570	43323	208





As it can be seen from the graph the slope of the graph is less than one for the plateau region of the counter that is very nice. Therefore, it is possible to use 460 v as an operating voltage for the safety of the GM counter. Now after fixing the operating voltage proceeding to the next experiment is possible.

5.5 Experiment II

Title**: Determination of efficiency of gas filled detector (GM counter**)

Objective: to determine the efficiency of GM (gas filled detectors)using beta and gamma sources.

5.5.1 Experimental procedure:

(1) Clamp the GM tube to the stand and set the proper connection of GM tube, counter and high voltage supply.

(2) Place cobalt source (CO – 60)or caesium source (Cs – 137) in the source holder at the nearest distance and choose that as a reference (zero position) point.

(3) Adjust the operating voltage counting time etc and start counting. I used operating voltage of 460 v, which is in the plateau region of the GM counter & constant counting time of 100 sec.

(4) Repeat step-3 (procedure-3) using the proper absorber thickness, to absorb beta radiation from the source. I placed the absorber on the top of the source and measured the corresponding intensity, ofcourse repeating (the experiment) about five times in each case for better accuracy.

(5) By varying the distance between the source and the end window of the tube, measure (radiation intensity) counting rate at constant time. Repeat the above steps for each case of distance taken.

(6) Measure the background radiation by removing the sources. I kept the sources far away so that no source influence & it is almost background radiation only.

5.5.2. Determination of correction factor for distance (r_0).

For an isotropic emission, the intensity at any given point is given by :

$$I_i = I_0 / 4\pi d^2 \qquad (5.1)$$

Where I_i is intensity at distance r_i and I_o is the distance between the top of the source holder and the window of the tube.

But since the source holder may not coincide with the active window surface of the source and also the window may not coincide with the point where ionization actually takes place inside the detector. Hence a correction for distance has to be made. Thus we can write : $d = r_I + r_0$ (5.2)

Substituting this into equation (5.1), for two different cases; I.e. $r_I = 0$ and $r_i \neq 0$, we get: (i) for $r_i = 0$, $I = I_0 / 4\pi d^2 = I_0 / 4\pi(0 + r_0)^2 = I_0 / 4\pi r_0^2$

$$\Rightarrow \quad I_0 = 4\pi r_0^2 I. \qquad (5.3)$$

where I is intensity (counts) at $r_i = 0$

(ii) for $r_i \neq 0$, $I_I = I_0 / 4\pi d_i^2 = I_0 / 4\pi (r_i + r_0)^2$

$$\Rightarrow \quad I_0 = 4\pi (r_i + r_0)^2 \qquad (5.4)$$

equating equations 5.3 & 5.4 one can get,

$4\pi r_0^2 I = 4\pi (r_i + r_0)^2 I_i$, that can be rearranged and written as:

$r_0^2(I_0 - I_i) - 2 r_i r_0(I_i) - r_i^2 I_i = 0$ (5.5)

which can be solved very easily by applying quadratic formula as:

$$r_0 = r_i (1 \pm \sqrt{I / I_I}) / (I / I_I - 1) \qquad (5.6)$$

I have used this formula to determine the correction factor for distances between the source and detector for both sources (Co – 60 & Cs – 137)

5.5.3 Data Acquisition

(a) Intensity using Cobalt source

operating voltage time of counts

source cobalt-60 aluminium absorber thickness = 0.315mm

Table 5.3 Measurement of count rate with cobalt source

Distance (in cm)	Counts Without absorber	average
r_i =o	4840+4650+5120+4778+5038	4885
1cm	1979+2047+2010+1950+2022	2002
2cm	840+1030+929+934+939	934
3cm	571+564+558+558+540	555
4cm	382+360+354+374+360	366
5cm	245+280+245+284+257+320	262
7cm	162+152+148+160+130	150
Background radiiation	49+45+47+54+46	48

Distance (cm)	Counts with absorber	Average
0	660+653+683+570+660	645
1	310+400+300+276+326+332	324
2	177+187+191+170+200+190	186
3	110+147+132+138+168+	139
4	100+99+99+90+100+180	111
5	70+80+100+93+85+96	91
7	70+90+81+70+59	70

5.3.4 Data Analysis and Discussion:

Source time of counts 100sec

Operating voltage average background counts = 48

a) Table4.1Determination of distance of correction:

r_i (cm)	Average count $I_{\beta\gamma}$ (total)	rates of radiation I_γ (total)	Corrected average $I_{\beta\gamma}$	Counts I_γ	I / I_i	r_0
0	4885	645	4837	597		
1	2002	324	1954	276	2.48	1.744
2	934	186	886	138	5.45	1.496
3	564	139	516	91	9.37	1.455
4	366	111	318	63	15.21	1.379
5	262	91	214	43	22.60	1.332
7	150	70	102	22	47.42	1.189

Result: Average distance of correction, $r_0 = 1.391$

(b) **Efficiency calculations**:

As a sample I have shown calculation of efficiency at the relative nearest distance and others are so calculated similarly.

As it was shown previously, from the decay scheme of cobalt source (CO – 60), since two gamma rays are emitted for each beta rays, the correct efficiency of gamma radiation can be found by including a multiplicative factor of 1 / 2 or half.

Thus (i) for gamma: $e_\gamma = 1 / 2\, e_\gamma^* \Rightarrow 1 / 2[I_\gamma^*(1 + \mu x) / 2 AG_P] \times 100\%$

$e_\gamma = I_\gamma(1 + \mu x) / 4AG_P$

Where I_γ^* is an intensity or counts per 100 seconds corresponding to the measured data directly.

Geometric factor: (G_P) for $r_i = 0$, since $d = r_0 = 1.391 \Rightarrow G_P = r^2 / 4d^2$, where r is the radius of the GM tube and r = 0.9cm will be, $G_P = 0.2025 / d^2 = 0.104710772$

The absorber thickness I used in this experiment is:

$X_{CO} = (0.40 = 0.12 + 0.105)$ mm = 0.625 mm

And as calculated previously the coefficient of absorption for beta radiation is

$\mu = \mu_m \rho = 247.721868\ cm^{-1}$

This gives ($1+ \mu x$) = 8.803238842, I used this value in this calculation throughout.

Then $e\gamma = \dfrac{597(8.803239)100\%}{4(6271.51225)Gp} = 2.000756\%$

(iii) for beta (β-) radiation: using the previously defined formula, Eq.( )

$e\beta = 2I\beta\gamma\,(100\%) / 3I\gamma\,(1 + \mu x)$

$= [2(I\beta\gamma\,^*/ 100)x\ 100\%] / [3(I\gamma\,^*/100)(1 + \mu x)$

$= (2I\beta\gamma\ x\ 100\%) / 3I\gamma\,(1 + \mu x)$

where $I\beta\gamma$ and $I\gamma$ are the count rates measured. Therefore for r = 0 case one can find beta efficiency as : $e\beta = \dfrac{2(4837)x100\%}{3(597)8.8032388} = 61.36\%$

5.5.4(e)

Table: Efficiency of Gm counter using a cobalt (co-60) source

Time of counts 100sec

S.No.	Distance between the source and counter (in cm)	Average counts with absorber $I_{\beta\gamma}$	Average count with out absorber I_{γ}	Efficiency in Percents	
				e_{β}%	e_{γ}%
1	1.39	4837	597	61.36	2.00
2	2.39	1954	276	53.61	2.73
3	3.39	886	138	48.62	2.75
4	4.39	516	91	42.94	3.04
5	5.39	318	63	38.23	3.17
6	6.39	214	43	37.69	3.04
7	8.39	102	22	35.11	2.68

Table Efficiency of GM counter for Beta and gamma radiation from caesium source (Cs-137)

Time of counts 100 sec

S.No	Distance between the source and counter (in Cm)	Average counts with absorber $I_{\beta\gamma}$	Average counts with out absorber I_{γ}	Efficiency in percents	
				e_{β}%	e_{γ}%
1	2596	36001	3179	87.81	3.36
2	3596	18669	2167	66.80	4.39
3	4.596	11031	1805	47.39	5.97
4	5.596	718.8	1558	35.78	7.64
5	6.596	5071	1453	27.06	9.9
6	7.596	3941	1409	21.68	12.73
7	8.596	3109	1342	17.95	15.53

5.5.5 Results and Discussion

Result: The efficiency of GM. counter for beta and gamma rays have been calculated by placing the source at different distances from the detector. The efficiencies are shown in the above table.

It is possible to consider three basic cases of interest based on the results obtained. They are (i) The nearest distance case, (ii) Efficiency variation with distance and

(iii) Efficiency comparison of the two sources. I will discuss this as follows:

(A**) Efficiency at the nearest point:**

From the results obtained for beta and gamma radiation, when there sources are placed at the closest distance from the detector (GM-tube), it is clear that efficiency for charged particle (Beta-rays) is the highest while that for gamma radiation (neutral gamma-rays) is the lowest. This has shown that efficiency for beta (Beta- radiation) to be about 88% and that for gamma about 2%, which is an interacting result. Further, one can think of the possibility for better result by putting the source closer to the detector.

Theoretically, the efficiency of GM-Counter is 100% for ionizing particles, but it depends on penetrating power of charged particle and absorption coefficient of the medium. Hence efficiency of beta (β) is less than 100% because it is not mono energetic as neutrinos are also emitted along with Beta radiation. The Beta- energies, 0.31 Mev for cobalt source (Co- 60) and 0.51Mev for caesium source are the maximum possible (end point) energies in the energy spectrum. Therefore there is a possibility for some betas to be absorbed and as well to be blocked at the end window of the GM tube. Here the prevailing interaction responsible for the detection process is in-elastic scattering that can produce excitation and ionization and also there is a room for elastic scattering for betas to return back. Any way the result has proved that GM counter is a very good detector for charged particles.

(B) **Efficiency variation with distance**: The second basic fact is the variation of efficiency with distance of separation. The result shows that the efficiency of beta radiation decreases with increasing distance, where as that of γ-radiation rather increases. This is most probably due to the following reasons

a)Beta- radiation decreases as distance increases because; (i) since it can be absorbed by the air medium , the beta rays from the cobalt source can not enter the counter as it is only 0.31 Mev only.

(ii) Due to solid angle for which no correction is applied the results can be as observed. As distance increases, the intensity reaching the active volume of the detector decreases since the solid angle between source and detector decreases. The geometric factor takes into account the variation of intensity with distance form the source only and it depends on geometry of this source and detector. Thus as distance increases we are losing a number of betas.

(ii) Since we have not used collimator to direct the radiation toward the detector (end window) this is an expected result.

(a) For gamma radiation on the other hand is relatively it increasing unlike beta radiation. γ- radiation is not absorbed in air and as well it is not affected by window of the detector even. But here it is observed that the efficiency of γ-radiation is increasing (relatively) with increasing distance. This can be due to the following reason. From the very nature of the gas filled detector, γ-radiation does not interact with argon gas, but interacts with copper cathode. Since γ-radiation is energetic at lower distances (when nearer to detector). The interaction probability with cathode is relatively small and the rest pass without interaction. As distance increases the relative number of γ- rays that can interact with the cathode (which is the cylindrical part found at the side of the detector increases. Then the increased interaction. Hence, here as angle subtended (should angle) decreases the efficiency increases due to the increased interaction probability.

(C) The third basic fact that I want to touch is the effect of using two different sources. The nature of the energy emitted by the radioactive source is also responsible for the relative changes in efficiency of the two sources. This also proves that Beta rays coming from cobalt (Co-60) are weaker as compared to that coming from cesium (Cs- 137).

Efficiency comparison for gamma –rays of the two sources show that γ-efficiency is relatively higher for cesium and lower for cobalt. For cesium it increases with increasing distance relatively at higher rate as compared to that of cobalt, which is almost in

dependent of distance. This is indication of energetic gamma rays coming from cobalt source and relatively weaker γ -rays from cesium.

The effect of using two different sources reinforces the same fact that GM counter efficiency is low for unchanged (γ - rays) radiation and high for changed particle radiation. This also proves that GM-is not a good detector for γ - radiation as such. However, one can conclude that we have different efficiencies (relatively) but showing the same pattern both for cobalt and caesium

5.5.6 Sources of Error

The sources of error can be many. But the prevailing sources of error in this experiment are:

(1) Instrumental error=The Gm counter that I used was old, that has been used for long time. Thus as time passes its detection efficiency can decrease.

(2) The problem of the sources used as radiation sources: The sources used in this experiment are not point sources as such, where the relations used are valid specially for point sources. Therefore, the fact that the sources are extended sources can add to the error.

Also the sources have been used for long time and their activities are relatively low .In addition the fact that exact manufacture date is not known can contribute to the error.

(3) Personal error-There is inherent error in distance measurement and adjustment, as it is difficult to measure distance using local ruler. The measurement of absorber thickness using micrometers cannot be 100% accurate. Specially as distances increase putting the source directly below the detector (window) and accurate distance measurement is difficult.

(4) Absorbers: There is a problem in using absorbers since aluminum absorbers of the right thickness for this experiment are not available .As a result I have used combination of absorber whose thickness is more than the required. Using absorber thickness more than the required can contribute to the error in this experiment.

5. 5.6. .conclusion.

Radiation detectors are used to detect the radiation that cannot be sensed by our sense organs. As a detector in this project I used a Gas filled detector, which is called GM-counter. This is the most common detector and it can be used for the detection of charged

radiation & uncharged radiations In this experiment the detection of beta and gamma radiations has been made. Not only detection but also I have succeeded in determining the efficiency of GM counter.

Despite all the limitations mentioned as sources of error, the experimental result achieved is very interesting. The fact that I used an old GM tube that has worked for a long time and also sources that have been used long since also can contribute to the lesser accuracy. Of course I have tried my best to be as accurate as possible. Therefore the achievement of this work has shown: That

(i) Efficiency for beta radiation is about 88%, where it is expected to be around 100% and

(ii) For gamma radiation 2% where it is expected to be around 1%.

Based on the achieved result the following conclusions can be made:.

(1) It is possible to use GM counter as a charged radiation (Beta radiation) detector as it has high efficiency for detection.

(2) It can also be used to detect unchanged radiation, such as gamma radiation though its efficiency is low.

(3) Beta radiation is weak and can be absorbed very easily as it can be blocked using thin aluminum.

(4) Gamma radiation is energetic radiation that can produce low ionization that can not be absorbed easily. it can be blocked by using lead and thick absorbers.

5.5.7 Recommendations:

Of course, we have as a scintillation detector-sodium iodide (NaI) detector, as a solid state (semiconductor) detector Highly pure Germanium (HPGe) detector ,and as a gas filled detector –GM counter in our nuclear physics lab (AAU).Which are very helpful for different nuclear experiments. I see that there is a possibility of continuing in this field.

There is a good ground for this field to grow. But this needs due attention of furnishing the laboratory with necessary equipment. .I have observed that there are no spare parts for the detectors and also there are no reserve detectors if it happened that they are damaged. If due attention is given to this field (Nuclear physics), it can contribute to the development of our country. Recently manufactured radio active source of differently types and different laboratory equipments at least two or more in number

for each case should be there since nuclear physics can be used for the benefit of man kind. The presence of detectors as a sample in our lab is good but not enough. It needs due attention of the concerned body since this field has wide application.

Specially to solve the crucial energy problem of finding replaceable energy source, the knowledge of nuclear physics and hence radiation as a whole is important. The knowledge of nucleus and then the properties of materials can play role in energy conversion and looking for alternate energy sources such as sun light it self. Physics as a whole and also nuclear physics in particular can play its role in this aspect if planned activity is made in this sphere.

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