VERIFICATION OF INVERSE SQUARE LAW

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Masters Of Science In Physics

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GENERAL INTRODUCTION

For any isotropic emission of radiation from the source the intensity varies inversely as square of the distance from the source. This statement is called the inverse square law. The Knowledge of inverse square law is an important to determine the amount of solar energy reaching the top of the earth's atmosphere. The main objective of this project work is to confirm this law experimentally using radioactive source which emit gamma alpha and beta radiations. An understanding of properties of radiation, how they are emitted and interacts with matter is necessary for their detection. This project work has three section with four chapters. In the first two chapters the general properties of radiations, source of radiations and mechanisms of interaction of gamma and beta radiation with matter are included. In the third chapter techniques of measuring intensity of gamma and beta radiation using GM counter and method of verification of inverse square law are presented. The last chapter will be the experimental verification of inverse square law using the gamma and beta radiation sources.

CHAPTER ONE

RADIATION AND RADIOACTIVITY

1.1 INTRODUCTION

Nuclear radiation originates in atomic nuclei as a result of radioactive decay of the nuclei.

Un stable nuclei decay by emitting alpha, beta and gamma radiations. The emission of these radiations by un stable nuclei in their decay process is called radioactivity. The decay process is called radioactive decay. The nuclei, which emit these radiations, are called radioactive nuclei. If the nuclei that emit these radiations are found in nature, then their decay is called natural radioactivity; but if they are produced in laboratory, then their decay is called artificial radioactivity. The rate of emission of the primary radiations from any radioactive nuclei is not influenced by the physical or chemical state of the nuclei. That is they can neither retard nor accelerate the rate of radioactive decay by the use of heat, pressure, electric field, etc.

Not all the three radiations (alpha, beta and gamma) are emitted by the same nucleus in radioactivity. Usually, radioactive nucleus emits alpha particles and gamma rays or beta particles and gamma rays. That is; if a radioactive source emits α - particles, it also emit γ - rays. The same thing is true for beta active source also. Of course, there are several exceptions to this rule like ^{45}Ca, ^{35}S, ^{33}P, ^{14}C, ^{3}H, etc. these nuclei emit only beta rays and are called pure beta emitters [1].
The main emphasis in this chapter will be the properties of radiation, source of radiation and radioactive decay process.

1.2. General properties of radiation

Nuclear radiations alpha, beta and gamma, which are produced when radioactive elements decay collectively called ionisation radiations, have the following properties[3].
1. If the radiations from say, apiece of radium are collimated in to narrow beam then subjected to a magnetic field, it is found that they split in to three component, alpha radiation, Beta radiation and gamma radiation. From the deflection directions and the magnetic field direction it is correctly deduced that the alpha and beta radiations are streams of high speed appositely and negatively charged particles respectively. Further experiments involving the determination of charged to mass ration for these particles show that the α - particles are helium nuclei and that the β - particles are negatrons. The third component, called gamma (γ) radiation is undeleted 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. The nuclear γ-ray as emitted in radioactive processes produce diffraction effects with crystal gratings in the same way that x- rays do, and this can be taken some proof their identity. When the $\alpha, \beta, and \gamma$ radiations which occur in radioactivity are passed in to observing materials of different thickness, it is the γ - radiation which has the greatest penetrating power while the α - radiation is the most easily absorbed.

3. The gamma radiation is practically un affected by paper and aluminium sheet and only partly absorbed by the lead. The beta radiation is affected by the paper but absorbed by aluminium and lead. In general, the alpha and beta radiations completely absorbed by relatively thin layers of any materials but the gamma radiation is never quite completely absorbed by thin layers of the most dense materials.

4. When5 any radioactive radiations, but in particular alpha or beta is passed through a gas, produce ionisation of the gas molecules. If the gas is enclosed between two electrodes maintained at different potentials, ionisation current through the gas results.

1.3. Alpha rays

Alpha rays are positively charged particles and are identical with doubly ionised helium atom (He^{++}). Alpha rays strongly ionise the medium through which they travel and their

rate of energy loss being rapid. They come to rest in short distances. Alpha ray are emitted by nuclei as a result of alpha decay.

1.3.1. Alpha decay

Alpha decay is a radioactive process in which a particle with two neutrons and two protons is ejected from the nucleus of a radioactive atom. The particle is identical to the nucleus of the helium atom. Alpha decay which mostly occurs in heavy nuclei ($Z > 82$) can be expressed by the following equation.

$$_{Z}{}^{A}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He + Q$$

Where X and Y represent the chemical symbols for parent and daughter elements respectively and Q represents the amount of energy released in the transition. In principle this energy release shared among the decayed products as a kinetic, but since the mass of the alpha particle is much lower than the mass of the daughter nucleus, practically all decay energy is carried away with alpha particles.

1.3.1.1. Energetic of alpha decay

For alpha emission take place from the nucleus we have the equations

$$^{A}_{Z}x \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He$$

In terms of nuclear mass, the mass energy equation will be

$$M_nC^2 = M'_nC^2 + M\alpha\, C^2 + Q$$

Where M_n and M'_n are the rest mass of parent and daughter nucleus respectively, $M\alpha$ is the rest mass of the alpha particle; Q is as described in section (1.3.1.)

$$\Rightarrow \quad Q = (M_n - M' - M\alpha)\, C^2$$

Therefore, the alpha emission to be energetically possible, i.e. to occur spontaneously as radioactive decay, Q must be positive.

$$M > M' + M\alpha$$

Where M and M' are atomic mass of parent and daughter atom.

The mass (energy) of the parent nucleuses must exceeds the sum of the masses (energies) of the product nucleuses α - particle emitted by the parent nucleus.

Note that this condition is not fulfilled until the mass number A exceeds 150.eventhogh alpha decay becomes possible energetically the probability of observing it is negligible up to A≈ 200. This is because of the potential energy barrier, which must overcome by the α -particle before it can leave the nucleus.

The energy released (excesses energy of the parent)during the alpha decay in the form of kinetic energy:

$Q\alpha = T_\alpha + T_{nuc}$ * which is distributed between the α- particle and daughter nucleus in such away that the momentum conservation law is not violet:

$$\mathbf{P_c + P_{nuc} = P_{par}}$$

Assuming that the disintegrating nucleus is at rest, we obtain $P_\alpha = P_{nuc}$

From the definition of kinetic energy and equation ** we get

$T_{nuc} = T_\alpha M_\alpha / M_{nuc}$

Using this in equation (*) we get :

$Q\alpha \quad T_\alpha(1 + M_\alpha/M_{nuc})$

Or $T_\alpha = E_\alpha M_{nuc}/(M_{nuc}+ M_\alpha)$

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

1.4. Beta rays

Beta rays are nuclear radiations, which are corpuscular in nature, their name collectively stands for positrons or electrons (negatrons). Those beta rays have electrical charge either positive or negative and a mass, which is rest mass of electron (m_o). Normally the kinetic of electrons emitted in beta decay is of the

order of (0.3-2Mev) [4].Beta rays are emitted from a radioisotope that decay by beta particle emission..

1.4.1. Beta decay

Beta decay is the process of the spontaneous transformation of an unstable nucleuses in to isobaric nucleus with charge differing $\Delta Z = \pm 1.$

the following three processes are called beta decay

1. Emission of electron (β^-) by the nucleus
2. Emission of positron (β^+) by the nucleus
3. Electron capture (EC) by the nucleus

In nuclear stability, the neutron-proton ratio (N/P) ratio is crucial. If it is too high or too low, nucleus will eventually rearrange it self in to a more stable configuration. β^--decay which is the emission of energetic electrons, results when an N/P is too high for stability; positron emission or electron capture occurs when it is too low for stability. The half –life of β - radioactive nuclei varies from 10^{-2}s to 2 x 10^{15}years.The energy of β-decay lies between 18Kev (for $^{1}_{1}H$) and 16.6 Mev (for $^{12}_{7}N$)[9].

1.4.1.1. β^--Decay

During the β^--decay a neutron of a nucleus changes to a proton. The β^--decay process represented by the equation:

$$^{1}_{o}n \rightarrow {}^{1}_{1}p + \beta^- + \nu \text{ (antineutrino)}$$

Thus a parent nucleus undergoes β^--decay can be represented by the generalized equation

$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + \beta^- + \nu \text{ (antineutrino)} + Q\beta$$

Where $Q\beta^-$ is the energy released during the transition.

This energy is shared between the β^- and anti-neutrino. Unlike the alpha particles which are mono energetic from a given source, β^- particles are emitted with a range of energies lying between zero to maximum energy E_{max} (end point energy). The anti-neutrino corresponding to the electron of zero energy, takes away the total energy released in the β^--decay. Similarly, the anti-neutrino corresponding to the maximum energy E_{max} of the electron gets no energy.

Energetic of β^--decay

For a nuclide undergoes β^--decay we have the equation

$$^{A}_{Z}X \rightarrow {}^{A}_{Z+1}Y + \beta^- + \nu \text{ (antineutrino}$$

In terms of nuclear mass the mass energy equation will be

$$M_n C^2 = M_n^{/} C^2 + m_o C^2 + Q$$

Where m_o is the rest mass of electron, M and $M^{/}$ are rest mass parent nucleus and daughter nucleus respectively.

$$\Rightarrow Q = (M_n - M^{/}_o - m_o)C^2$$

If the small difference in the binding energy of the orbital electrons between the atom($_ZX$ and $^{A}_{Z+1}Y$)is neglected the above equation becomes

$$Q = [M - Zm_o - (M^{/} - (Z + 1)m_o + m_o)] C^2$$

$$\Rightarrow Q = (M - M^{/}) C^2$$

Where M and M’ are atomic mass of parent and daughter atom respectively.

For negatron emission to be energetically possible, i.e. to occur spontaneously as in radioactive decay become Q must be positive or $M > M^{/}$.

1.4.1.2. Positron emission (β^+-decay)

β^+ Emission occurs if N/P ratio is not enough for the stability of the nucleus. That is, those nuclei emit positrons, which are deficient in neutrons. The process is represented by

$$^{1}_{1}p \rightarrow {}^{1}_{0}n + \beta^+ + \nu \text{ (neutrino)}$$

This leads to the generalized equations

$$^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + \beta^+ + \nu + Q$$

Where Q is the amount of energy released in the β^+-decay is shared between β^+ and ν. Therefore, similar to the β^-, the spectrum of β^+ is also continuous. The positron is the anti particle of an electron and will enter an annihilation reaction when two particles meet. Since electrons are normally abundant in materials, positrons are annihilate soon after their emission. As a result two gamma rays each having energy 0.511Mev are released.

Energetic of β^+-decay

Similar to β^--decay, for β^+-decay we have the equation

$$^{A}_{Z}X \rightarrow {}^{A}_{Z-1}Y + \beta^+ + \nu \text{ (antineutrino)}$$

From the energy conservation we have

$$M_Z{}'_C{}^2 = M'_{(Z-1)}C^2 + m_oC^2 + Q$$

Where M'_Z and $M'_{(Z-1)}$ are nuclear mass of parent and daughter nucleus, Q is the energy released during the decay process.

$$\Rightarrow Q = (M'_Z - M'_{(z-1)} - m_o)C^2$$

In terms of atomic masses the above equation will be

$$Q = (M_z - M_{(z-1)} - 2m_o)C^2$$

Thus positron decay can occur if

$$M_Z > M_{Z-1} + 2m_0 \text{ or } M_Z - M_{Z-1} > 2m_o$$

It should be noted that the condition for positron decay includes a factor $2m_o$. this only because atomic masses have been used in stating the condition instead of nuclear masses. When a positron is emitted from the nucleus one unit of positive charge is carried away and an orbital electron must leave the parent atom also to keep the atom electrically neutral. Thus, two electron masses are lost and the parent atom must be at least $2m_o$ heavier than daughter atom for positron decay to be energetically possible.

1.4.1.3. Electron capture (EC)

A nucleus can also relieve a low neutron-proton ratio (N/P) by capturing and absorbing an electron from a shell (mostly from K-shell). When the negative electron enters the nucleus, the positive charge of one proton is cancelled and proton is converted to a

neutron. During the electron capture process the only particle that is emitted the mono energetic neutrino. This process can be represented by

$^{1}_{1}P + ^{0}_{-1}e \rightarrow ^{1}_{0}n + \nu$ (antineutrino)

This leads to the generalized equation

$^{A}_{z}X + ^{0}_{-1}e \rightarrow ^{A}_{z-1}Y + \nu + Q$

EC and β^+-decay both results in reducing the charge number of decaying nucleus by one. Both these processes (EC and β^+-decay) usually occur in the same nucleus. In some cases where sufficient energy (1.022Mev) is not available for the creation of β^+, electron capture is the only process of the decay.

In an electron capture, radiation is not emitted directly from the nucleus but results from the changes within the electron shells. EC creates a vacancy in one shell, which is quickly filled by an electron from a higher energy location. As electron moves down to the K-shell, it gives off an amount of energy equivalent to the difference in binding energy of the two levels. This energy is emitted in a characteristic X-rays photon. For example, the decay of ^{55}Fe by EC results in the emission of the characteristic X-rays of Manganese. It is by means of X-rays that a nuclei decaying by EC can be detected. Auger effect competes with the emission of the X-rays in EC. Auger effect is the de-excitation of an atom by electron emission. The electron emitted in Auger effect is called auger electron. Most auger electrons have relatively low energies. Thus some radioactive nuclide, which decay by EC may give low energy gamma rays[1].

Energetic of EC

Electron capture can occur if $M_Z > M'_{Z-1}$

Where M_Z and M_{z-1} are atomic masses of parent and daughter atoms respectively.

From this condition, it can be seen that EC is energetically more favourable than positron decay but EC is not always observed even though the condition $M_Z > M'_{Z-1}$ may be satisfied. This is because even the inner most K-orbital electron, the one most likely to be captured, spends very little time close to the nucleus so that the probability of capture is

small. As soon as the available energy exceeds $2m_o$, positron emission becomes possible and is usually more probable than electron capture.

1.5 Gamma rays

1.5.1 Nature of gamma ray

Gamma rays are a short-wave electromagnetic radiation of nuclear origin. The energy of nuclear gamma –quantum usually varies from 10Kev to 5Mev ($10^{-8} \geq \lambda\ \gamma \geq\ 10^{-11}$)[9]. Thus gamma rays can be considered as hard X-rays. However, the origin of gamma rays is different. Gamma rays are emitted by the nucleus when it makes a transition from a higher excited state to a lower excited state. In radioactive decay, daughter nucleus usually left in an excited state. Subsequently the daughter nucleus de-excites from these higher levels by emitting gamma rays.

Gamma rays being electromagnetic radiation travels with speed of light. Gamma rays can be considered as a photon having a corpuscular nature with their energy being unitized.

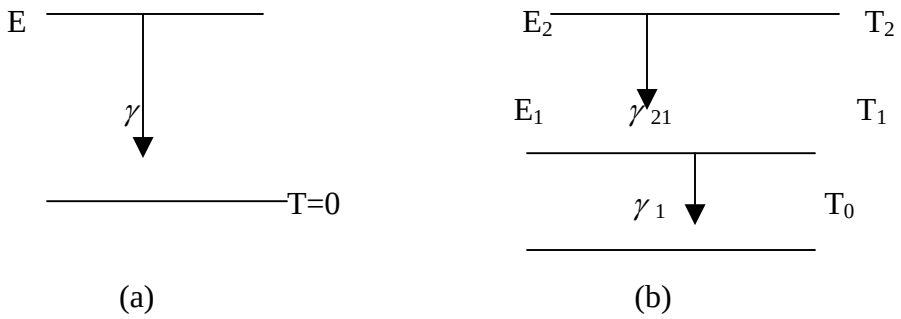
1.5.2 The nuclear de-excitation mechanism.

Excited nucleus may de-excite by different mechanism. If the energy of the excitation is less than the binding energy of the nucleon, nucleon emission is not possible. In such a case the excited nuclides are de-excited either by gamma decay or by another process, Internal conversion or pair production.

1.5.2.1 Gamma decay

It is one of the process in which the excess energy (excitation energy) Of the excited nuclides is removed. In particular radioactivity, decay of nuclides either by alpha or by beta decay process results in the formation of daughter nuclides more often in there excited states. These excited states usually decay instantaneously by gamma emission. There are one single radiation transition when the nucleus emit a single

quantum at once goes over to the ground state (Fig 1.1a), or cascade of several γ-quanta (Fig 1.1b). In both case the excess energy (excitation energy) is removed[9].



(a) (b)

Fig 1.1

1.5. 2.2 Internal conversion

The emission of gamma quantum is not the only process resulting in the release of energy excess from the nucleus. The coulomb field of nucleus can transfer all the excitation energy directly to the atomic electron. The nucleus transfer to the ground state with out emitting gamma quantum and the atom

ejects an electron of internal conversion. Most probable is the transfer of energy to K electron nearest to the nucleus. How ever, the emission of electron of internal conversions with L, M -----etc atomic shells is possible. Since the excitation energy of nucleus is strictly defined value, the kinetic energy of an electrons of internal conversion T_e is also the same in all cases of the electron emission from the given shall:

$Te^{(K)} = E^* - E_k$ where E^* is the excitation energy of the nucleus

$T_e^{(L)} = E^* - E_L$, E_K, E_L ------- are the bond energies of the electrons in the corresponding shells of the atom. If the excitation energy (E^*) of nucleus is less than the bond energy of K shell electron, then the separation of the K electron from the atom does not appear feasible and electrons of internal conversion can be ejected only from the subsequent electron shells. Apart from the possibility of the emitting γ - quanta, there is a probability of emitting electrons of internal conversion by the nucleus. Other wise stated, Part of the excited nuclei transfer their energy to γ -quanta, and others ,to the atomic electrons. The two processes compete in removing the excess energy of the nucleus. If the number of electrons observed per excited nucleus is N_e and the number of γ - rays is $N\gamma$,the internal conversion coefficient(α) is defined as

$$\alpha = N_e/N\gamma$$

where α may have any value between zero and infinity The absolute value of α is the higher, the longer the life time with respect to the emission of γ - quantum, the higher Z of the electron shells of the atom to the nucleus[6].

1.5.2.3 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 nucleus $E^* > 2\,mc^2 = 1.02$ MeV, then in the Coulomb field of the nucleus, an electron-positron pair may be produced which_car rise off all the excitation energy of the atomic nucleus. As the emission of conversion electrons, conversion with pair production is not the conversion proper, i.e., is not the transformation of a gamma-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 y-quant urn. Near the threshold, the fraction of the decays of the nuclear excited levels with pair production is ~ 10^{-4} of the decays with a gamma -quantum emission, and with the excitation energy close to the bond energy of the nucleon in the nucleus, it makes some tenths of per cent. 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 the increase of the nuclear transition multipolarity.

The kinetic energy released in the-process of pair production, $Ep = E^* - 2mc^2$, is distributed between the electron, the positron and the remaining atom. Since the atomic mass is large, all the released energy is practically carried off by the electron and the positron. Their energy distributions are continuous, are in the range from zero to the maximum value of *Ep* and are symmetric with respect to *Ep/2,* in neglecting the interaction of these particles with the Coulomb field of the nucleus.

1.5.3 Energetic of gamma decay.

Excited nuclei de-excited by emitting the energetic photon and goes over to the ground state.Scince mass and charge of photon are zero; in the process both atomic number and nucleon number are unchanged. But in these transition due to the re-arrangement of the nucleon with in the nucleus there is amass decrease. Thus for excited nuclei (${}^{A}_{z}X^{*}$) de-excited by photon emission we have an equation.

$$ {}^{A}_{z}X^{*} \rightarrow {}^{A}_{z}X + Q $$

In any reaction both momentum and energy must be conserved. There for; the above process , interims of nuclear mass. The total energy conservation will be

$$ M_o^{*}c^2 = M_oc^2 + E\gamma + T_{nu} \qquad (*) $$

Where $E\gamma$ is energy of emitted photon and T_{nu} is the kinetic energy of the recoil nucleus.

The above equation can be re written

$$ E = E_\gamma + T_{nuc} $$ where E is the excess energy of the nucleus.

From the conservation of linear momentum we can have:

$$ \mathbf{P\gamma + p_{nu} = 0} $$

$\Rightarrow \mathbf{p_{nu}} = \mathbf{- P}\gamma$

$\Rightarrow \mathbf{p = p}\gamma$

$\Rightarrow p_{nu} = p\gamma$

$\Rightarrow p_{nu} = E\gamma / c$ (**) since $p\gamma = E\gamma / c$

Since recoil energy is very small none relativistic expression can be used

$$\Rightarrow T_{nu} = \frac{P2_{nu}}{2M_o} \quad \text{----------} \quad (***)$$

Using the equation (**) in to the equation (***) gives :

$$T_{nu} = \frac{E\gamma}{2M_o c^2}$$

For nuclei with A=100 , T_{nuc} = 0.1- 10Kev which is very small. Thus the gamma quanta carries away on overwhelming part of the nuclear excitation energy[9].

1.5.4 Source of gamma rays

Gamma ray is emitted by excited nuclei in their transition to lower lying nuclear levels excited nuclei may be created during the α - decay and β - decay of radioactive nuclides(natural or artificial).creation of excited nuclei is also possible by varies nuclear reactions. In these case, if the excitation energy of the daughter product (excited nuclei) is less than the nucleon binding energy only gamma quanta is emitted in

the transition. There for radioactive nucleus and nuclear reaction can be considered as gamma ray sources.

1.5.4.1. Gamma ray following beta decay.

Most beta decays populate an excited state of the product nucleus, so that the subsequent de-excitation gamma rays are emitted together with beta particles in many common beta sources. Four common examples widely used isotopes for experiments as gamma ray source are: ${}^{137}_{55}Cs, {}^{57}_{27}Co, {}^{57}_{55}Coand\ {}^{22}_{11}Na$

The decay scheme of each of each of them are illustrated in fig (1. 2). For the examples shown the beta decay is a relatively slow process characterized by a half – life of hundreds of days or greater, where as the excited states in the daughter nucleus have a much short average life time (typically of the order of Pico seconds or less). De – excitation takes place through the emission of gamma – ray photon whose energy is essentially equal to the difference in energy between the initial and final nuclear states. The gamma rays there fore appears with a half life characteristic of the parent beta decay with an energy that reflects the energy level structure of the daughter nucleus [7].

i) In β^- - decay of ${}^{137}_{55}Cs$ there are two final state, the ground state and excited state of ${}^{137}_{56}Ba$ 92% of the case the final state is the excited state (${}^{137}_{56}Ba^*$). This transformation can be represented by the following equation.

${}^{137}_{55}Cs \rightarrow {}^{137}_{56}Ba* + \beta^-(ie) + Ve, whichis 1\%$

${}^{137}_{55}Cs \rightarrow {}^{137}_{56}Ba + \beta^-(ie) + Ve, (whichis 8\%)$

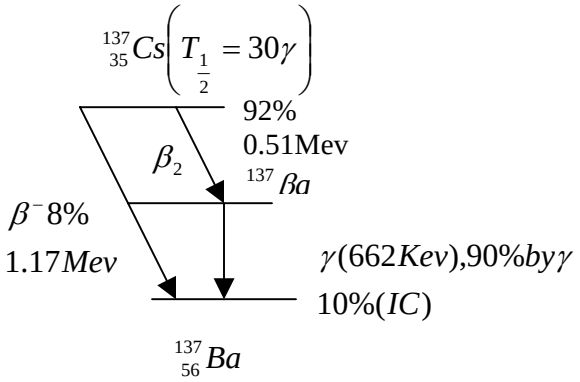
$The decoyschemof\ {}^{137}_{55}Csisshowninfig(\ )$

The decay scheme ${}^{137}_{55}Cs$ is shown in Fig(1. 2a)

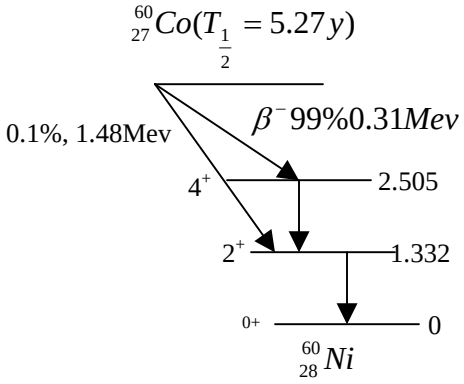
ii) In electron (β^-) decoy of isotopes of ${}^{60}_{27}Co$ 99% of the time it decays to 2.505Mev level (${}^{60}_{28}Ni*$). This level decay by emitting gamma ray (with energy 1.73Mev) in to 1.332 Mev level. This lower level again decoy by emitting r-ray in to the ground state (${}^{60}_{28}Ni$). The decoy scheme of ${}^{60}_{27}Co$ is shown in fig (1.2b)

iii) $^{22}_{11}Na$ – decoy via positron decay or electron capture. The isotope of $^{22}_{11}Na$ can decay via positron or electron capture positron decay is more probable than EC. 90% the time positron decay is occur. The decay scheme of $^{22}_{11}Na$ is shown in fig (1.2c)

iv) $^{57}_{27}Co$ Decay by EC to excited stores of iron ($^{57}_{26}Fe*$). 90% of transition goes to 0.927Mev level by emitting lower level (0.014Mev) goes to the ground state of $^{57}_{26}Fe$ by emitting gamma ray with energy 0.014Mev. Decay scheme of $^{57}_{27}Co$ is shown in fig (1.2d)



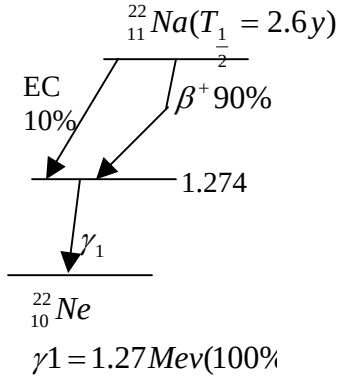
(a)



(b)

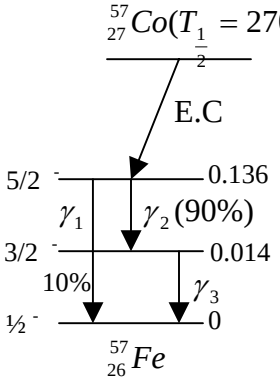
$\gamma_1 = 1.173Mev\gamma(100\%)$

$\gamma_2 = 1.332Mev\gamma(100\%)$



$\gamma 1 = 1.27Mev(100\%$

(c)



$\gamma_1 = 0.136Mev\gamma(11\%)$

$\gamma_2 = 0.122Mev\gamma(87\%)$

$\gamma_3 = 0.014Mev\gamma(9\%)$

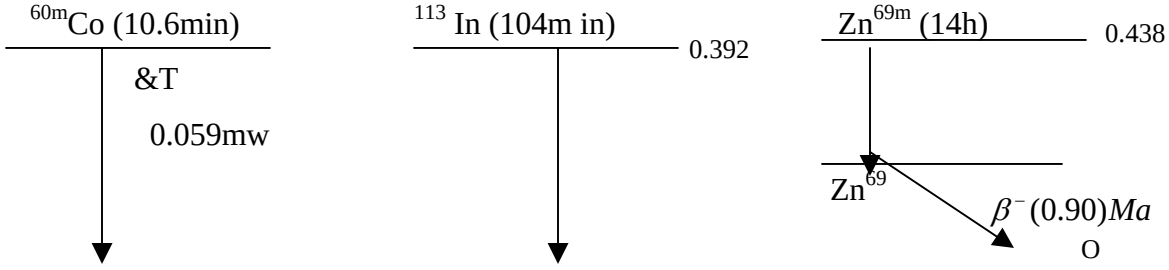
Figure 1.2 Decay of $^{137}Cs, ^{60}_{27}Co, ^{22}Naand\ ^{57}Co$.

1.5.4.2 Isomeric Transition (IT)

Nuclides having excited levels, which don't decay instantaneously, are called isomeric nuclei. These levels are celled isomeric levels. They decay either by r- emission or internal conversion. The transition leading to the de excitation of such levels are & isomeric level decays by r- emission to the ground level, which is stable.

a) The decay of ^{60m} Co by isomeric transition is shown in fig (1.3a.) The half life f ^{60m}Co isomeric level of ^{60} Co, is 10.6min after eradiation nucleus undergoes an isobaric (A & Z unchanged) transition, it usually contains too much energy to be is in final stable or daughter state. When the excited level only to be final state or daughter. When the exited level only decays by γ - emission to the ground level, as in the case shown bellow. The members of the isomeric pair are said to be genetically related

b) In^{113m}, with a half life of 104 min, emits a r-ray with an energy of 0.392 Mev and became stable In^{113} as shown in fig(1.3b)



a) ^{60}Co (5.27yrs) ^{113}In (b) c) Ga^{69}

Fig 1.3 Isomeric Transitions

c) In some Isomeric pairs the ground state, instead of being stable , may be radioactive and decay by β^- emission. They 14hr Zn69m emits a 0.438 Mev γ - ray and goes to the ground state of Zn^{69}. The decay scheme is shown in fig1.3c Generally, in must isomeric transitions, a nuclease will emit is excess energy in the form of gamma radiation.

1.5.4.3 Alpha decay: If the alpha particles emission leaves the daughter nucleus in an exited state, they drop to the ground state will be accomplished by the emission of one or more gamma rays. In many transitions only a fraction of the alpha particle emission leave the daughter in an exited state; the rest lead to the ground state directly, after the emission of a more energetic alpha. In some transitions there will be no gamma emission, in others several photons may follow the particle emission.

In general the photon emission will follow the particle in 10^{-6} seconds or less. Occasionally the exited state will be Meta stable, and gamma emission will be delayed four hours or even days. The diagram of alpha transition with possible formation of exit states of the product nucleus is given in figure (1.4).

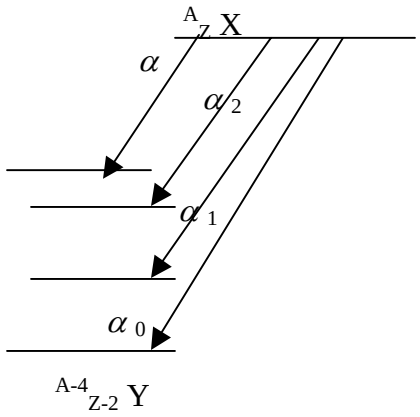


Fig1.4 alpha transition

The production of long-ranged particle during α - decay is possible in the natural α - radioactive substance, two are known Rac' and ThC' which have very short half –lives ($1.6x10^{-4}$ & $2x10^{-7}$ respectively and the nucleus of which result from the preceding β^- - decay, mainly in their excited states, the transition in to the ground state with γ -quantum emission is usually the first to take place, and then α -decay follows[6].

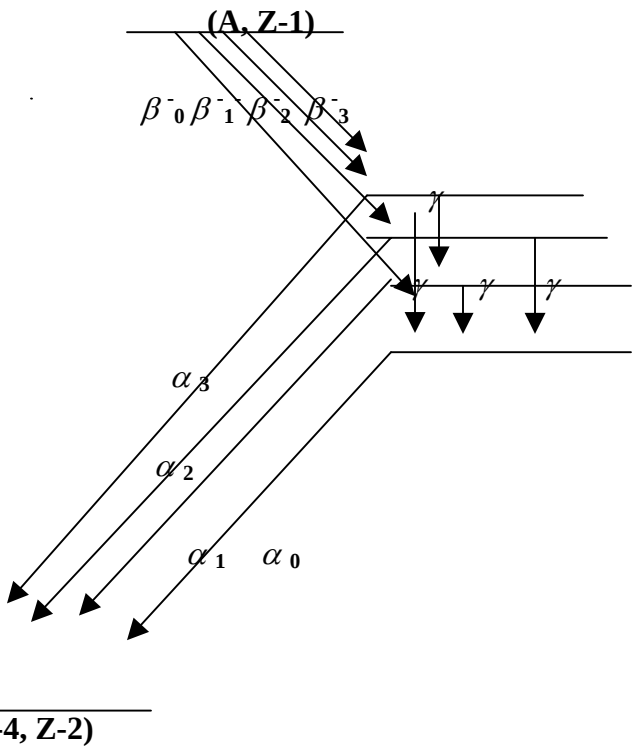


Fig 1.5 production of long rage α

1.5.4.4. Nuclear reaction involving radioactive captures.

In radiation capture reaction a nucleus (projectile) having some energy is captured by the target nucleus as result excited new system is formed, which de-excited by emitting gamma ray photons. The radiation capture reaction can be represented by the following equation:

$$X_{proj} + X_{targ} \rightarrow Y^{*} \rightarrow Y + \gamma$$

The two common types of radiation capture reactions are (p, γ) & (n , γ)reaction.

1. (p , γ) reaction

In this reaction the projectile (proton) is captured by the target nuclease; as a result an stable nucleus is formed which goes down to the ground state by emitting gamma ray photons. The reaction can be represented by

$$_{A}{}^{Z}X + {}_{1}{}^{1}H \rightarrow {}^{A+1}{}_{z+1}C^{*} \rightarrow {}^{A+1}{}_{z+1}C + \gamma$$

Examples of (p, γ) reaction $\rightarrow {}^{28}{}_{14}Si$

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

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

$${}^{7}{}_{3}Li + {}_{1}{}^{1}H \rightarrow {}^{8}{}_{4}Be^{*} \rightarrow {}^{8}{}_{4}Be + \gamma$$ -

2. (n , γ) reaction

(n , γ) reaction is another case of radioactive capture in which slow neutron interacts with target nucleus and excited compound nucleus loss its excess energy, by emitting gamma rays and become isotope of the target nucleus with mass number one unit greater. This represented by the equation:

$$^{A}_{Z}X + ^{1}_{0}n \rightarrow {}^{A+1}_{Z}X^{*} \rightarrow {}^{A+1}_{Z}X + \gamma$$

(n , γ) reactions have been observed nearly in all of the elements. Many **(n , γ) reaction** result in product nuclei which are negatron emitters due to the increased n/p ratio, in such a case neutron capture is radioactive capture. The sequence of event in neutron captures reaction or (n, gamma) reaction. When neutron interacts with target nucleus via a non – elastic collision, a compound nucleus form in excited state. The excitation energy of compound nucleus is due to the binding energy of neutron with nucleus. The compound nucleus will almost de-excite in to more stable configuration through the emission of one or more characteristic prompt gamma rays. In many cases, this new configuration yields a radioactive nucleus which also de-excite (or decay) by emission of one or more characteristic delayed gamma rays, but at much slower rate according to the unique half-life of radioactive nucleus.

Example of (n,γ)- reaction

$$^{27}_{13}al + ^{1}_{0}Al^{*} \rightarrow ^{28}_{13}Al + \gamma$$

$$^{115}_{49}In + ^{1}_{0}n \rightarrow ^{116}_{49}In^{*} \rightarrow ^{116}_{49}In + \gamma$$

$$^{63}_{29}Cu + ^{1}_{0}n \rightarrow ^{69}_{29}Cu^{*} \rightarrow ^{64}_{29}Cu + \gamma$$

$$^{107}_{47}Ag + ^{1}_{0}n \rightarrow ^{108}_{47}Ag^{*} \rightarrow ^{108}_{47}Ag + \gamma$$

$$^{103}_{45}Rh + ^{1}_{0}n \rightarrow ^{103}_{45}Rh^{*} \rightarrow ^{104}_{45}Rh + \gamma$$

CHAPTER TWO

INTERACTION OF NUCLEAR RADIATION WITH MATTER

2.1 INTERACTION OF GAMMA RAY WITH MATTER

In passing through a material substance a gamma ray, in principle , may interact with, (a) orbital electrons in the absorber atoms, (b) the nuclei of absorber atoms, and (c) the coulombs field of in the neighbourhood of the nucleus; arising from the electric charges of the protons[5] .In fact depending up of its energy a large number of possible interaction mechanisms are known for gamma rays in matter. For the typical energies of gamma rays encountered in nuclear spectroscopy (say from 0.1Mev to 10Mev) there are three important (major) processes by which gamma rays interact with matter and loss their energy. These are : photoelectric effect, Compton effect, and pair production. They result in sudden and abrupt changes in the gamma ray photon history, in that, the photon either disappears entirely or is scattered through the significant angle[4].

2.1.1 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 is given by

$$Ee= h \nu - E_b \text{ --------- } 2.1$$

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(2.1) 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 completely converted in to the kinetic energy of the electrons.

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 electrons; 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 filed 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;

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

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; α=1/137 is the Summer field's fine structure constant and Z is atomic number of absorber.

The above expression for photoelectric absorption cross section can be written as

$$\sigma_{ph} \sim Z^5 / (E\gamma)^{7/2} \text{ ---------- } 2.2$$

where $E\gamma = h\nu$

Equation 2.2 show 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 .

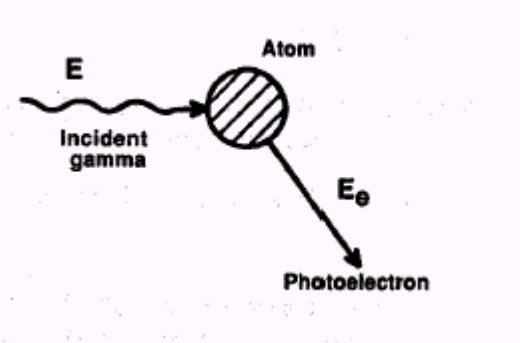


Fig 2.1 Schematic representation of the photoelectric absorption Process.

The plot of the photoelectric absorption coefficient of gamma ray energy shows that sharp discontinuity at the minimum energy (critical absorption energy) required to remove the electron in the K, L, M shells .As a gamma ray energies increases above the K –absorption edge which appears at higher energy relative to the anthers (L edge, M-edge -------) there is a fast decrease in value of photoelectric coefficient, hence photoelectric effect is the predominant mode of interaction at low energy gamma ray.

2.1.2 COMPTON EFFECT

Compton effect is elastic scattering of gamma quanta (incident photon) by free electrons are bounded in the atom, but appears relatively to be free and the outer most electrons are having least binding energy or almost free and hence Compton effect takes place with outer most electron. In this process (Compton scattering) incident gamma ray (primary photon), which considered as the particle collides with a free or weakly bound electron ($E\gamma > E_b$) and transfer parts of its energy to the electron, and scattered with reduced energy. conservation of energy and momentum allows only partial energy transfer when the electron is not bound tightly enough for the atom to absorb recoil energy . This is way the interaction
Involves the outer, least tightly bound electrons in the scattering atom.

To have in formation about the process consider the incident photon (primary photon) or gamma quanta having energy $E\gamma = h\nu$ and momentum $P = h\nu/c$ collide with electron at rest having rest mass m_o , after collision the scattered photon (secondary photon) with reduced energy ($E^{/} = h\nu^{/}$) and momentum $P^{/} = h\nu_{/}c$ travels at angle ϕ from the initial direction , while the recoil electron which aquairs the recoil momentum P = mv at the expense of the decrease of the photon energy travels in the direction at angle θ from the initial direction as shown in Fig 2.2

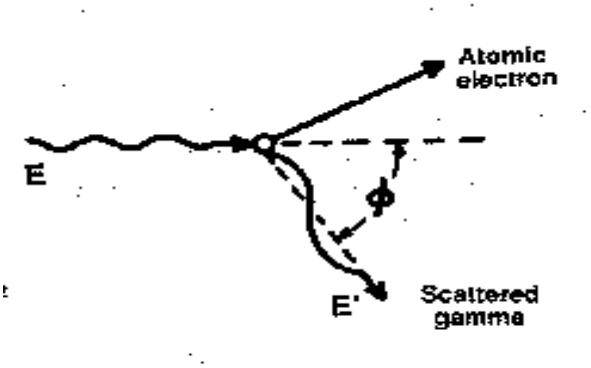


Fig 2.2 A schematic representation of Compton scattering

Since both momentum and total energy is conserved in Compton collision ;

From the conservation of energy we have

$$E\gamma + m_o c^2 = E^{/} + mc^2$$

$$\text{Or} \quad h\nu + m_o c^2 + h\nu^{/} + mc^2 \quad \text{---------- 2.3}$$

Where $m = m_0 / \sqrt{1-u^2/c^2}$ 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 plank constant ν and $\nu^{/}$ are frequency of incident gamma ray and scattered gamma ray respectively.

From the conservation of momentum: Liner momentum conservation in the X direction gives

$$h\nu /c + h\nu^{/} /c \cos\Phi + mv\cos\Phi \text{ ----------*}$$

Linear momentum conservation in y direction gives

$0 = h\ V^{/}/c \sin\phi$ - mv sin θ ------- ----------* *

To eliminate θ we can write the above equations (* **) as follows

$mvcos\Phi = + h\nu/c - + h\nu^{/}/c\ cos\Phi$ ----------2.4

$mv \sin\theta = + h\nu^{/}/c \sin\phi$ ----------2.5

By squaring and adding equation 2.4 and 2.5 we get

$m^2u^2 = (hv/c - h\nu^{/}/c\ cos\Phi)^2 = (+ h\nu^{/}/c \sin\phi)^2$

$\Rightarrow m\ u\ c^2 = (+ h\nu)^2 + (h\nu^{/})^2 - 2h\nu\nu^{/} \cos\phi$ ----------2.6

From equation 2.3 we have $mc^2 = h(\nu - \nu^{/}) + m_oc^2$

Squaring equation 2.3 gives

$m^2c^2 = h^2(\nu^2 + \nu^{/2} - 2\nu\nu^{/})\ 2h((\nu - \nu)m_oc^2 + m^2_o\ c^4$ -------2.7

Subtraction of 2.6 from 2.7 gives

$m^2\ c^2\ (c2 - u^2) = mo^2\ c^4 - 2h^2\ \nu\nu^{/}\ (1 - cos\Phi) + 2h\ (\nu - \nu^{/})\ m_oc^2$ ---2.8

Substitution of expression $m = m_o/\sqrt{\ }\ (1 - u^2/c^2)$ in to equation 2.8 gives

$M^2_oc^2/\ 1\text{-}u^2/c^2\ [c2 - u^2] = m_o^2\ c^4 - 2h^2\ \nu\nu^{/}\ (1\text{-}cos\Phi) + 2h\ (\nu - \nu)\ m_oc^2$

$\Rightarrow\ 2h\ (\nu - \nu)\ m_oc^2 - 2h^2\ \nu\ \nu^{/}\ (1 - \cos\Phi) = 0$

$\Rightarrow\ \nu - \nu/\nu\nu/ = h/moc2\ (1 - cos\Phi)$

$\Rightarrow \quad 1/\nu' - 1/\nu = h/m_oc^2 (1- \cos\Phi)$----------2.9

Multiplying both side of equation 2.9 by c gives

$c/\nu - c/\nu = h/m_oc^2 (1- \cos\Phi)$, or

$\lambda - \lambda = h/m_oc(1- \cos\Phi)$----------2.10

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

h/m_oc =0.0242 A^o is Compton wavelength

The wave length shift or Compton shift $\lambda' - \lambda$, thus dependent on the on the angle of scattering angle ϕ and can be written as; $\Delta\lambda = 0.0242 (1-\cos\phi)$ where measured in A^o. It does not depend on the scattering material(Z) and energy of incident gamma ray . From this relation we see that, for $\phi = 0$, $\Delta\lambda = 0 \Rightarrow \lambda = \lambda'$ or $h\nu = h\nu'$, there is no Compton effect; this is for very low incident gamma ray energy ($h\nu << m_oc^2$) which described latter.

For ϕ =90; $\Delta\lambda = 0.0242A^o$

For $\phi = 180$; $\Delta\lambda = 0.0484\ A^o$ 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 apart of the energy is transferred to an electron. 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 from equation (2.9) follows:

The kinetic energy of the scattered gamma ray is given by:

$E' = h\nu'$ ----------a

By solving for frequency of scattered gamma ray from equation 2.9 we get;

$\nu' = (m_oc^2\nu)/(m_oc^2+h\nu(1-\cos\phi))$----------b

Substitution of equation (b) in to equation (a) gives:

$$E' = h\nu\, m_o c^2/m_o c^2 + h\nu\,(1-\cos\phi)$$

$$\Rightarrow \quad E' = h\nu\,/[1+h\nu\,/m_o c^2(1-\cos\phi) \text{----------2.11}$$

where $m_o c^2$ is the rest mass energy of electron = 0.511Mev

The kinetic energy of recoiling electron is given by:

$$T_e = h\nu - h\nu' \text{ ----------c}$$

Using equation 2.11 in to equation (c)

$$T_e = h\nu - h\nu\,/[\,1+ h\nu\,/m_o c^2(1-\cos\phi\,)]$$

$$\Rightarrow \quad T_e = [(h\,\nu\,)^2/m_o c^2(1-\cos\phi)]/\,[1+h\nu\,/m_o c^2(1-\cos\phi\,)] \text{ ----------2.12}$$

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 2.4 and 2.5 together with equation (b) , the relation is given by ;

$$\text{Cot}\,\theta \;= (1+h\nu\,/m_o c^2)\,\text{Tan}(\phi/2) \text{ ---------- 2.13}$$

Where $\text{Tan}\phi/2 = (1-\cos\phi)/\sin\phi$

From this relation (2.13), 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 causes the energy of scattered gamma ray which is minimum , given by equation 2.14 and energy of the scattered electron ,which is maximum , given by equation 2.15 :

$$E'_{(min)} = h\nu\,/[1+2h\nu\,/m_o c^2] \text{ ----------2.14}$$

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

$T_e = h\nu/[1+ m_oc^2/2h\nu]$----------2.15

$= h\nu - m_oc^2/2 = h\nu$ - 256 Kev; if $h\nu >> m_oc^2/2$

For forward scattered gamma ray ($\phi = 0$) , the electron recoil in the direction of ($\theta = 90$); for this case the energy of scattered gamma ray is equal to the energy of incident gamma ray and energy transferred to the electron is zero ; which means there is no interaction.
The energy given to the scattered electron ranges from zero to the maximum given by equation 2.15.

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

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

where $\alpha = h\nu / m_oc^2$ and $\sigma_e = 8/3\ X\ (e^2/ m_oc^2)^2 = 6.651\ x10^{-28}\ m^2$ is Thomson cross section and for high energy photon ($\alpha > 1$) the scattering cross section per electron is given by

$${}_e\sigma_c = 8/3\ \sigma_c \ln (2\alpha) + ½ \quad \text{----------} \quad \alpha$$

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

$$\sigma_c = Z\ {}_e\sigma_c$$

where Z is atomic number of scatter;

Thus the probability of Compton scattering per atom of the absorber depends on the number of the electrons available as scattering targets and therefore increases linearly with Z . The Compton mass scattering coefficient is given by

$$(\mu_c)_m = [N_A Z\, {}_e\sigma_c]/M$$

Where N_A is Avogadro's number and M is atomic mass .

The variation of σ_c and $(\mu_c)_m$ with energy of incident photon is the same as the energy variation of ${}_e\sigma_c$ which described above

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 ($\gamma \rightarrow e^- + e^+$). 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 2.3)

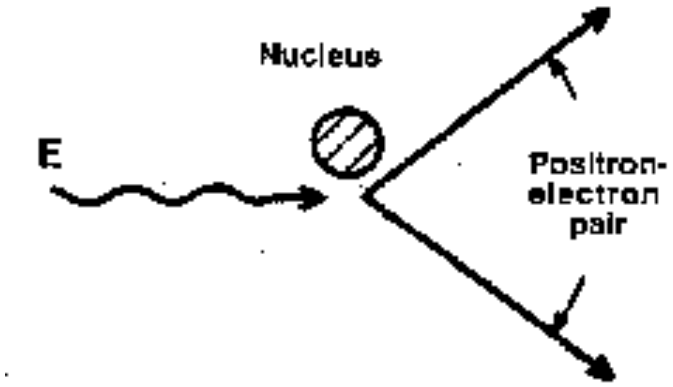


Fig. 2.3 A schematic representation of pair production.

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 .This interaction has a threshold of 1.02Mev because that is the minimum energy required to create the electron and positron. If the incident gamma ray energy ($h\nu$) exceeds this value (1.02Mev) the excess appears in the form of kinetic energy shared by he electron – positron pair. Therefore, the process consists of converting the incident gamma ray photon into electron and positron kinetic energies, which total

$$T_- + T_+ = h\nu - 2moc^2 \quad \text{2.16}$$

Where T_- and T_+ are kinetic energy of electron and positron respectively. 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 annulations 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. The relative importance the three process for different absorber material and gamma ray energies conventionally illustrated in fig (2.4) .The line at the left represents the energy at which photoelectric absorption and Compton scattering are equally probable as a function of absorber atomic number.

The line at which the right represents the energy at which the Compton scattering and pair production are equally probable. Three areas are thus defined on the plot with in which photoelectric absorption, Compton scattering and pair production each predominate [7].

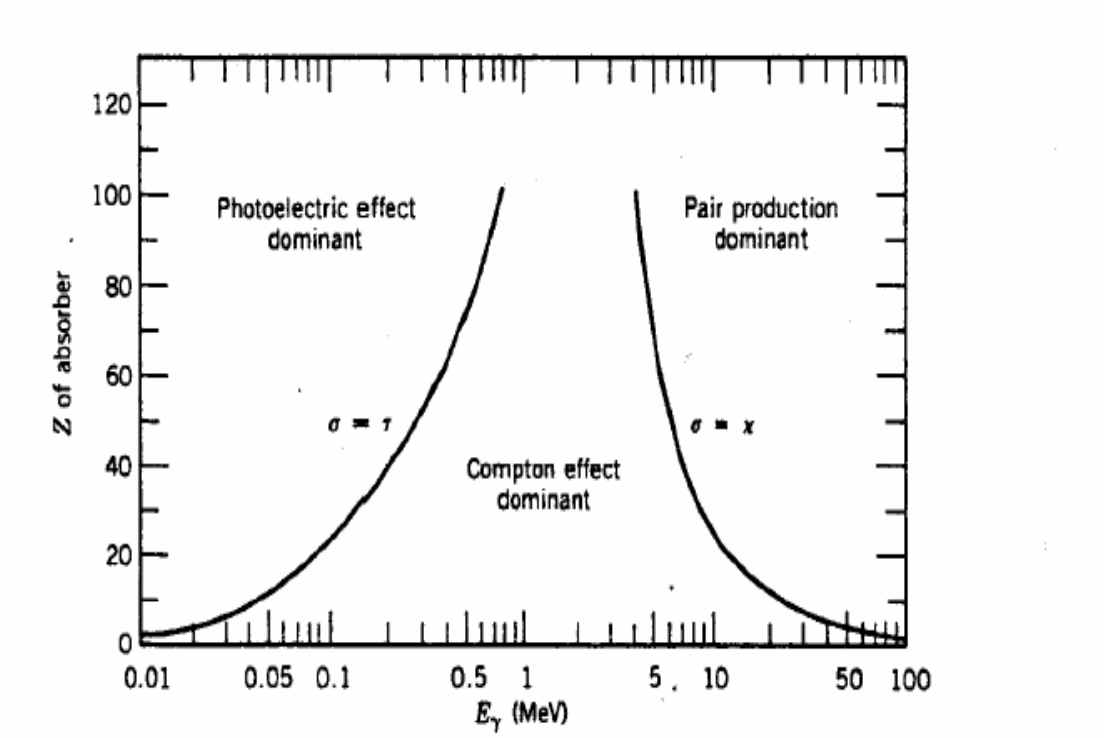


Fig 2.4 The relative importance of the three major types of gamma ray interaction. The line show the values of Z and hν for which the two neighboring effects are just equal.

2.2 IN TERACTION OF LIGHT CHARGED PARTICLES WITH MATTER

Electrons (β^- - particle and positrons are classified as light charged particles.

These particles interacts with matter through different process. The following dissections are for the incident energies of the order 0.1- 5MeV.for these energies, Coulomb forces are mainly responsible for the interaction.

2.2.3 Interaction of electron with matter

Following are the four important processes by which electrons lose their kinetic energy during their passage through matter:

(i) *Inelastic collisions of electrons:* Inelastic collisi0ns of incident electrons with bound atomic electrons in the matter is the most important mechanism by which incident electrons lose their energy in their passage through matter. During such inelastic collisions incident electron transfers part of its energy to a bound atomic electron taking it to an excited state (excitation) or an unbound state (ionization). This problem has been treated quantum mechanically and it has been shown that the mean energy Joss due to inelastic collisions is given by the following formula for electron energies $E < m.\ C^2$*:*

$$-\frac{dE}{dx} = \frac{4\pi e^4 nZ}{m_0 V^2} In\left(\frac{1.16 m_0 V^2}{2I}\right)$$

Where n = number of atoms per cm^3, Z = atomic number of the absorber, e, m_O = charge and rest mass of the electron respectively, 1 = mean excitation energy of the atomic electrons.

(ii) ***Irradiative collisions*** *of electrons with atomic nucleus:* Incident electron passing through the field of a nucleus experiences a deflection with a resultant emission of radiation. This process is known as *bremsstrahlung.* This leads to a loss of kinetic energy of the incident electron. This can be considered as a irradiative type of inelastic collision between the electron and an atomic nucleus. The rate of energy loss by this interaction is proportional to Z^2, where Z is the atomic number of the target atom. Actually
the rate of such irradiative loss is given [I] by

$$\left(\frac{dE}{dx}\right)_r \alpha \frac{Z^2 n}{A}\left(e + m_0 c^2\right)$$

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 electrons can excite the nuclei in a

similar inelastic collision. However the cross section for this process is generally very low at the energies, which we are considering.

(iii) Elastic collisions of electrons: The incident electrons can have an elastic collision with a nucleus resulting in a deflection of electron without any radiative loss or excitation of nucleus. The cross section for this process is of the order of $(e^2/mo\ V^2)^2$ (where V = velocity of incident electron) and it increases with Z^2.

For practical purposes, the total energy loss per unit path-length(the total linear stopping power) of the electrons is the sum of ionization and radiation loss, i.e.

$$\left(\frac{dE}{dx}\right)_{Total} = \left(\frac{dE}{dx}\right)_{ionization} + \left(\frac{dE}{dx}\right)_{radiation}$$

Empirically, the following relation is found to be approximately true

$$\frac{(dE/dx)_{rad}}{(dE/dx)_{ion}} = \frac{EZ}{800}$$

Where E = electron energy in Me V, and Z = atomic number of absorber. For the electron of interest here(such as beta particles)typical energies are less than a few Mev.Ther for radiative loss are always a small fraction of energy losses due to ionization and excitation.

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 electrons undergo a small number of collisions. When the latter number becomes large. (> 20) we speak in terms of multiple scattering. The theory of plural and multiple scattering is more complicated. As beta particle travels through matter, their negative charge interacts with the negative charge of orbital electrons, ejecting them from their orbits (producing ion pairs) or causing excitation. This process will continue until the electron has lost enough energy to be captured by a nucleus

Beta particles with their small mass, high velocity and single charge will travel through matter further than an alpha particle before producing ionization. Therefore, a beta particle will deposit their energy over a greater range than alpha particles of comparable energy Since its mass is equal to that of an electron, a large deflection.

2.2.2. 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.

2.3 INTENSITY OF RADIATION

Intensity of radiation is defined as the amount electro magnetic energy incident on the surface per unit area per unit time .In particular the intensity of gamma rays is given by the amount of photons (quanta) passing through a unit area per unit time. Most radioactive sources are isotropic in nature ,this means that radiation (from a radiation source) are given equally in all direction. The intensity of radiation (gamma rays) at a given distance from a radiation source can be determined by the inverse square law.

The inverse square law is used to calculate the decrease in radiation intensity due to an increase in distance from the radiation source.

Inverse square law : $I = I_o / 4\Pi R^2$

I = Intensity at a distance D from a surface of radiation source

I_o = Intensity at the surface of the source

CHAPTER TREE

DETECTION OF GAMMA AND BETA RADIATION

3.1 INTRODUCTION

There are three method of nuclear radiation detection :

I) method based on the collection of charge produced by the radiation : when ionization radiation passed through the media ion pairs are produced and detected. These method are applicable for both charged and uncharged partecle.Inusterement based on these method includes : Gas-filled detector and solid sate detector.(II) method based on the visualization of the path (truck) of the particles (radiation) these method are used for the detection of charged particles. The instrument based on these methods are: solid state truck detectors ; Wilson cloud chamber; bubble chamber and nuclear emulsion plate spark chamber. (III) method based on collections of the scintillation: these methods are applicable both for charged and un charged particles; the instrument based on the this method are ; scintillation detectors and ceenkov detector.In this chapter only the first method and the basic function of gas-filled detectors are discussed. Again, the method of verification of inverse square law is included in this chapter.

3.2 THE GAS-FILLED IONIZATION DETECTOR

The ionization chamber, proportional counter and Geiger-Muller counter, which are very similar in their construction and operation, are called gas-filled counters. They are one of the oldest and simplest detectors of nuclear radiation. A gas filled detector is basically a metal chamber filled with a gas (mostly Argon) at normal pressure or less and an electric field is applied to a volume of gas enclosed in the chamber. A schematic diagram of a gas filled detector is shown in fig 3.1.External voltage Vis applied between the wall of the gas filled chamber (cathode) and the central wire (which act as anode) through an external resistance R.The capacity of the electrode and the counting system is C_o In this way an electric field is set up in the volume of the gas.

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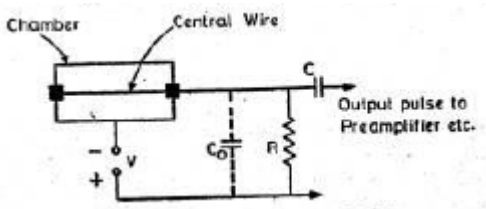

Fig 3.1 A schematic diagram of a gas- filled detector

An ionizing radiation (gamma or beta negative particle) passing through the gas have ionization energy loss in the detector in producing in the free electrons and positive ions for example if the filled gas is argon , a positive argon and an electron is produced ($Ar \rightarrow Ar^{+} + e^{-}$). These ion pairs are produced either by the direct interaction of incident beta particle with gas atom or by a secondary electrons formed during the gamma ray interaction with in the detector.

If E the average energy loss then the ion produced will be E / W. Where W is the average energy required to produce one ion pair, for most of the gas W = 32eV/ ion pair. In th absence of the electric filled ,the ion pairs thus created will just recombine. How ever, in the presence of the applied electric filed the positive and negative ions will move along the radial electric liens of force towards the outer wall (cathode) and the central wire (anode) respectively. Normally the negative ions (electrons) moves with much drift velocities (10^{-6}) as compared to the positive ions. The net result is that a charge Q collects on the anode, thus a changing its potential by Q/C_0.The change in the potential drop across R will give rise to an electric pulse signal. Thus the passage of a nuclear radiation (γ-ray or β^{-} - ray) through the detector will give rise to a pulse signal, which can be processed by a preamplifier etc. for counting. A plot of out put pulse height at the anode (or relative number of ions collected by the anode) will depend on (i) external voltage applied (ii) initial ionizing event.

The difference between varies types of gas counters operated in pulse mode are illustrated in fig 3.2. The amplitude of the observed pulse from the detector is plotted versus the applied voltage or electric field within the detector. At low anode voltage, the electrons may recombine with the ions. Recombination may also occur for high density. As the voltage increases the recombination decreases. At sufficient high voltage nearly all the electrons are collected and the detector is known as ionization chamber (region A). In the ionization chamber, as the voltage increases pulse height remains constant. Pulse height in this detector depends on the initial number of ions produced (energy loss). As the voltage increases (electric field with in the chamber) still further electrons are accelerated towards the anode at energies high enough to ionize other atoms of the gas, those creating a large electrons (secondary electrons) and thus multiplication starts. The

collected charge then begins to multiply, and the observed pulse amplitude will increase. Over some regions of the electric field(region B), the gas multiplication will be linear and the collected charge will be proportional to the number of original ion pair created by incident radiation (gamma rays or beta rays). This is the region of true proportionality and represents the mode of operation of conventional proportional counters. In this counter, under constant operating conditions, the observed pulse amplitude still indicates the number of ion pairs created with in the counter. Although their charge has been greatly amplified, simply the voltage pulse proportional to the energy of the particles generating the pulse. Increasing of the applied voltage further can introduce non-linear effects. This is due to the space charge created by the positive ion, which alter the electric field. Because, further gas multiplication is dependent on the magnitude of electric field, some non-linear ties will begin to be observed. Their effects make the one set of the region of limited proportionality in which the pulse height (amplitude) still increases with increasing number of initial ion pairs, but not in a linear fashion. At further higher voltages (region C) the electron multiplication is even greater number of electrons collected is independent of the initial ionization. This detector is known as the Geiger-Muller counter in which the output pulse is the same for all particles. At still higher voltage, continuous discharges occur.

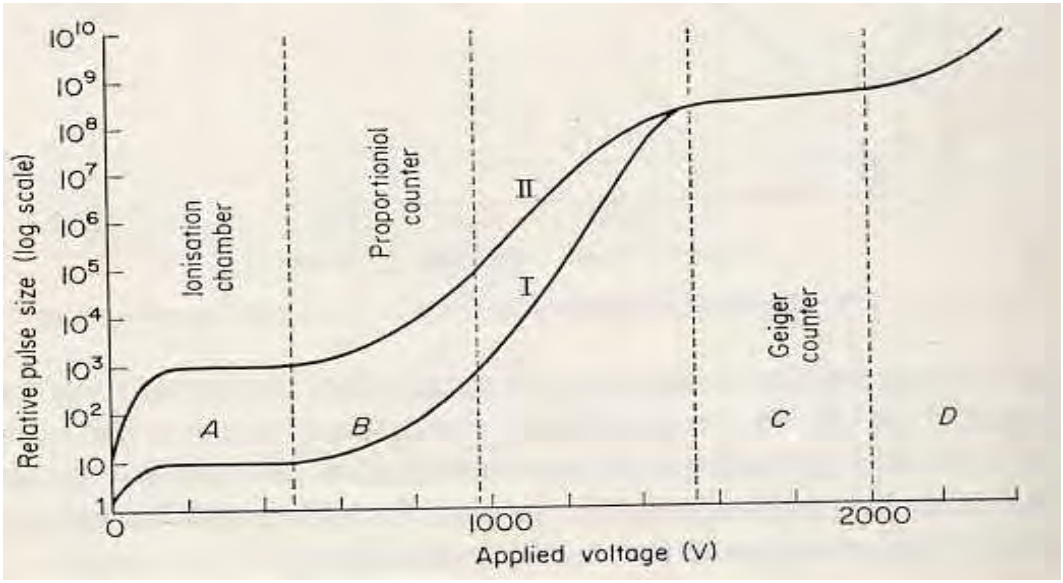

Fig 3.2 **O**utput pulse height from a gas – filled detector verses the applied voltage. Curve (I) and (II) refers to two different ionizing events

Gas multiplication and Avalanche formation

Most o the gas filled chamber has cylindrical geometry. For this cylindrical geometry the strength of the electric field at a radial distance r from the central wire is given by:

$$E = \frac{Vo}{r \ln(b/a)}$$

Where Vo is the applied voltage and a and b are the radii of the central wire and the cylindrical electrodes respectively. I n The high voltage region such as region B and C (fig 3.2) t he electric field in the neighborhood of the central wire is very high and such high electric field causes gas multiplication. When the electrons of the initial ionization reach the region of high field strengths, they can pick up enough kinetic energy between collision s 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 se 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 collision in the gas will also give rise to photons which in turn can produce photo electrons 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 all.If each photoelectron, intern, produces n electrons by further collisions, 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 : $M = n + n^2p + n^3p^2 + \ldots\ldots\ldots\ldots$

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,

$$M = n(1 + n^2p^2 + n^3p^3 \ldots\ldots\ldots\ldots\ldots)$$

$$= \frac{n}{1-np}$$

It is thus seen 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. multithread 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,

.e. $M = n(1 + n^2p^2 + n^3p^3 \ldots\ldots\ldots\ldots\ldots)$

$$= \frac{n}{1-np}$$

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.

According to Townsend avalanche, each free electron created in a collision 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;

$$\frac{dn}{n} = \alpha \, \mathrm{dx}$$

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:

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

3.3. The Geiger-Muller counter

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

In the GM tube, substantially higher electric fields are created that enhanced the intensity of each avalanche. Under proper conditions a situation is created that in which one avalanche can it self trigger a second avalanche at a different position with in the tube. At a critical value of the electric filed, each avalanche can create, and on the average at least one more avalanche, and a self – propagation chain reaction results. At still greater value of the electric fields, the process becomes rapidly divergent and, in principle, an exponentially growing number of avalanche could be created with in a very short time. Once this Geiger discharge reaches a certain sizes, however, connective effects of all the individual avalanches come in to play and ultimately terminate chain reaction. Because this limiting point always reached after about the same number of avalanches have been creased. All pulses form a Geiger tube are of the some amplitude regardless of the number of original ion pairs that initiated the process. A Geiger tube can therefore function only a simple counter of radiation – induced events and can not be applied in direct radiation spectroscopy because all information on the amount of energy

deposited by the incident radiation is lost. Atypical pulse from a Geiger tube represents an unusually large amounts of collected charge, about 10^9-10^{10} ion pairs being formed in the discharge. Therefore the out put pulse amplified is also large (typically of the order of volts). This high level signal allows considerable simplification tube made in the associated electronics, often completely eliminating the need for external amplification

3.3.1. The Geiger-Muller counting plateau

In using the a Geiger counter for measurement of counting rates, operating voltage should be determined. Because, the Geiger tube functions as a simple counter. It application requires only that operating conditions be established in which each pulse is registered by counting system. This operating point is normally chosen by recording a plateau curve from the system under conditions in which a radiation source generates events of 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. An operating point is then selected that normally corresponds to flat region or “plateau” on the resulting rate versus voltage curve. An operating point on the counting plateau then ensures that all the pulse of interest from the detector is counted [7].

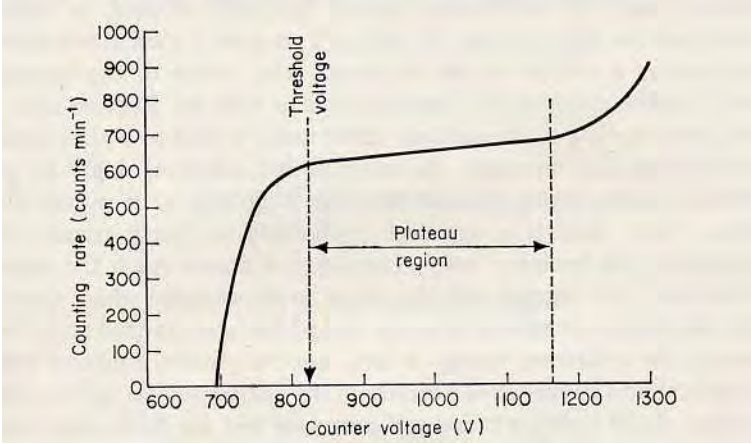

Fig 3.3 Plateau characteristics of GM counter

1 Geiger discharge

G.M.counters are usually filled with noble gases like argon, neon, helium etc.ln the Geiger Muller region C (Fig.3.2) np < 1and the series in equation 4.6 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. This discharge has to be quenched. Otherwise it can sustain itself and multiple pulses can occur. his discharge has to be quenched. Otherwise it can sustain itself and multiple pulses can occur.

2 Quenching of discharge

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 vapor, to the argon gas (ratio argon 90% by weight, ethyl alcohol 10%)

(a) 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 reduces 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 photo electrons 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 done by lowering the voltage v after each count, which intern 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 an external resistance.

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 poly atomic gases do not behave this way. Counters containing poly atomic gases are called self-quenching.
A small amount of poly atomic vapor such as alcohol or acetone is introduced into the gas filling. This causes photons from the electron avalanche to be strongly absorbed in the vapors, owing to its low ionization potential, and photoelectrons are produced close to the anode wire.
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. Thus 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 vapors 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.

3. **Time behavior:** 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 μs. 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.

3.3.2 Measuring the intensity 0f gamma rays and beta rays using the Geiger counter.

G.M counter which is based on the principle of charge collection, at its operating voltage will give an out put pulse for each of quantum radiation (γ - ray photon or β^-- particle) that interact with in its active volume. γ - Rays or β^-- particles, which are emitted at a constant, rate from a point source, are inters the G.M tube and produce ion pairs in the active volume of the tube. For each ion pair produced the charge is collected at the anode wire and creates electric pulse, which are counted by the counter.

This counting rate is scales with the intensity of the radiations (gamma rays and beta rays) that interact with counter gas. This counting rate is scales with intensity of radiations interacting with the gas of the tube. In measuring the intensity of nuclear radiation of interest care must be taken for the irrelevant radiation, which contributes for the measured counts. This irrelevant radiation, which may be from the cosmic rays or from the environmental radioactive sources. Hence to find the effective intensity (intensity of nuclear radiation of interest) the background count is measured for along period of time and subtracted from the measured counts. The resultant counting rate is the intensity of the nuclear radiation.

In order to measure the intensity of nuclear radiations (gamma or beta) at different distance from the source the counting rate is recorded for each position of the source and with back ground rate subtract, the resultant counting rate represent the intensity of a nuclear radiation from the corresponding position of the source.

3.3.3 Method of verification of inverse square law

The inverse square law is used to calculate the decrease in radiation intensity due to an increase in distance from the radiation source. Since all the radioactive sources are isotropic in nature their radiation intensity obeys this law. In order to verify this law the intensities of radiation are measured using the GM counter (as in section 3.3.2) and for each measured intensities the corresponding distance, may be the distance from the source holder to the window of the tube or to any fixed arbitrary point are measured using the distance measuring device. Having the measured intensities and distance; for isotropic emission the intensity at any point is given by:

$$I = I_o / 4\pi D^2 \quad \text{----------} \quad 3.1$$

Where D is the actual distance from active surface of the source to the point at which the intensity is measured. But the distance measured is the distance between the top of the Source holder and window of the tube. The top of the source holder may not coincide with the active surface of the source and also the window may note coincide with the point where the actually ionization take places in side the detector. Hence the correction for the measured distance has to be made.

Correction for the measured distance:

This correction for the measured distance can be done by the following two methods.

Method – 1

Let $D = R_i + R_o$ ---------- 3.2

Where R_o is the correction factor

R_i is the distance measured

D is the distance after correction

Substitution of equation (3 .2) in to equation (3.1) gives

$$I_i = I_0 / 4\pi (R_i + R_o)^2 \text{ ---------*}$$

Let assume that at the minimum measurable distance ($R_i = 0$) ,the corresponding measured intensity is I'_o and given by

$$I'_o = I_o/4\pi R_o^2 \text{ ----------**}$$

The intensity for $R_i \neq 0$ will be

$$I_i = I_o / 4\pi (R_o + R_i)^2 \text{ --------***}$$

Taking the both side ratio of equation (**) and equation (***) results in

$$(Io'/I_i - 1)R_o^2 - 2R_iR_0 - R_i^2 = 0$$

Which is quadratic equation. Its solution is given by

$$R_o = R_i (1 \pm \sqrt{ I_o' /I_i}) / (I_o'/I_i - 1) \quad \text{---------- 3.4}$$

All quantities in right hand side of equation 3.4 are measurable. Thus using this equation the R_o values is computed for each vales of $R_i \neq 0$ and the corresponding intensity ($I_i \neq I_o'$) and its average is taken .If this R_o is added to the all measured distance (R_i), the distance (D) in equation (3.2)represents the actual distances between the effective surface of the source and the point at which the ionization is takes place in the tube (Intensity is measured).

Method 2

This correction factor (R_o) can also found graphically by substituting equation(3.2) in to equation(3.1) and solving for R, which gives

$$R = \text{constant} \times 1/\sqrt{I} - R_o \quad \text{----------} \quad 3.5$$

Where the constant $= \sqrt{\ } I_o/ 4\pi$

This is the form of y = mx + c (c = $-R_o$). There fore a graph R verses $1/\sqrt{I}$ is a straight line with intercept R_o , and this R_o value is added to all values of R.

Now we have the measured intensities and corresponding corrected distances. From equation 3.1, taking natural logarithms of on both sides we have :

$\text{LnI} = \text{Ln}(I_o)/4\pi - 2\text{InD}$. This is in the form y = c + mx (m = -2) . There fore a graph of LnI verses LnD is straight line with slope –2.This verifies inverse square law.

CHAPTER 4

EXPERIMENTAL VERIFICATION OF INVERSE SQUARE LAW

4 .1 Objective of the experiment:

To show the intensity of radiation (gamma –rays and beta rays) emitted isotropic ally from a point source varies inversely as a square of the distance from the source

4.2 Equipment

GM counter

Gamma ray and Beta ray source ($^{137}C_S$)

0.8mm tick Aluminum foil

Ruler

4.3 Equip mental set up

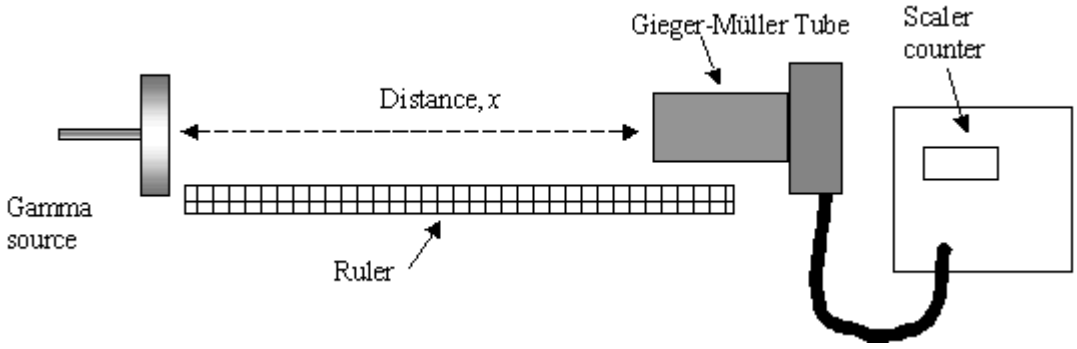

Fig 4 .1 Experimental set up

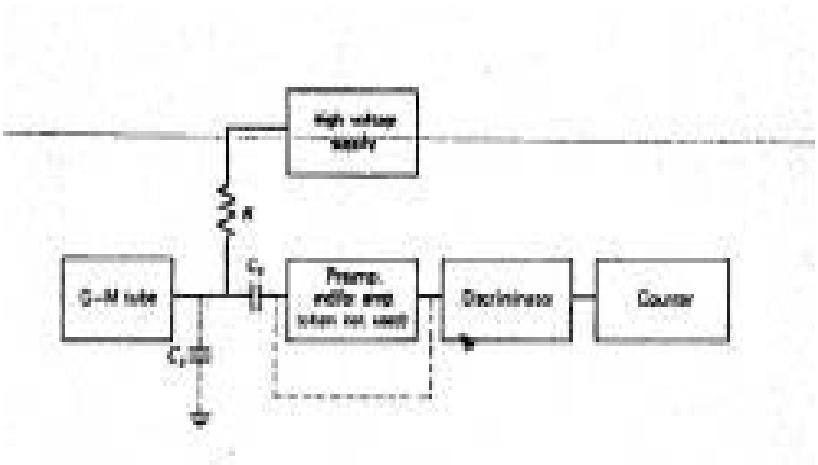

Fig 4.2 Block diagram of GM counter

4.4 Experimental Procedure:

1 Plateau characteristic of GM counter is plotted and from this the operating voltage is determined.

2 Obtaining pure gamma rays from the source, this can be done by placing the beta negative absorber (Al foil) on the surface of source.

3 To find the intensity of the gamma rays at varies distance from the source, starting from the minimum measurable distance between windows of GM tube and the source holder at each varies distance of the source record the count for 100sec or greater .In this measurement at each distance the active surface of the source must be parallel to the windows of the tube.

4 Repeat the measurement many times to determined the variation of intensity with distance.

5 Repeat the above procedure with beta negative absorber removed.

6 Record the bock ground counting with source removed. This bock ground counting which is irrelevant to my experiment may come from environment radioactivity, cosmic rays etc.

7 Subtract the back ground count rate from each measured count rate

.8 Platte graph of lnI vs lnD , the slop should be –2

4.5 Experimental result

Part I Determination of plateau characteristics G M counter

The recorded Data for the determination of plateau characteristics of GM counter (β -counter) is shown in table-1. Th is data is taken under constant radiation from radiation source (^{137}Cs).

Time of counting 100 sec

V	410	420	430	440	450	460	470	480	490	500	510	520	530	540	550	560	570
C	0	30902	40088	40694	41312	41812	42066	42518	42614	42922	42884	43126	43306	43176	43177	43150	43323

Table 1.Recorded counting rate and voltage applied

For the recorded data in table- 1 the plot of counting rate verses the applied voltage is shown in fig 4.3

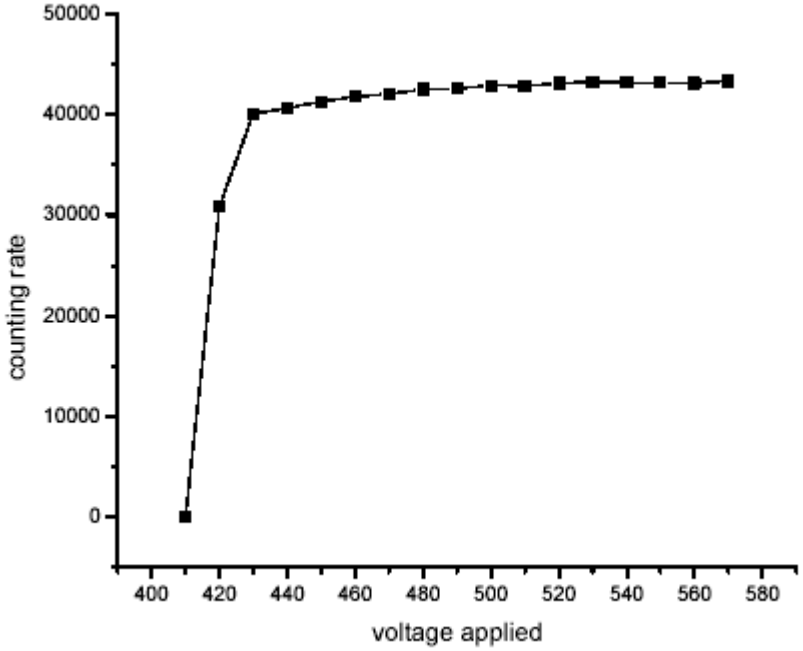

fig –4.3 graph of counting rate verses applied voltage

From fig 4.3 the plateau curve almost flat for a voltage range of 420 v- 490v There fore the working voltage of this GM tube will be 460v.which is the average value of the two extreme point of the flat region.

At this value of voltage all the pulse of interest from the detector are collected.

Part II

1. Data measured for variation of intensity of pure gamma rays with distance.

Operating voltage 460v

Back ground counting 100

0.8mm thick Al foil

Source of gamma rays 137Cs

Time of counting 100 sec

Distance in cm (R)	**Counting rate**			
	Decrease	**Increase**	**Average ©**	**Corrected I = C-B**
0	2058	2066	2062	1962
0.5	1239	1235	1237	1133
1	830	834	832	732
1.5	615	610	614	514
2.0	479	483	481	381
2.5	377	397	387	287
3.0	333	323	328	228
3.5	277	285	281	181
4.0	242	252	247	147
4.5	221	229	225	125
5.0	207	206	205	105
5.5	190	186	188	88
6.0	171	168	174	74
6.5	161	167	163	63
7	151	159	155	55

Table 2. The recorded counting rate and corresponding possible measured distance.

2. Data measured for variation of intensity of gamma rays and beta rays $(\gamma + \beta)$ with distance

Operating voltages 460v.

Source of gamma and beta 137Cs.

Back ground counting (B) 106

Time of counting 100 sec.

Distance in cm (R)	**Counting rate**			
	Decrease	**Increase**	**Average ©**	**Corrected I = C-B**
0	95500	95300	95400	95294
0.5	49200	49200	49200	49094
1	36800	36800	36800	36694
1.5	22840	22880	22860	22754
2	17670	17650	17660	17554
2.5	13030	13010	13020	12941
3	9800	9800	9800	9694
3.5	7400	7400	7400	7294
4	6260	6300	6280	6174
4.5	4950	4930	4940	4834
5	3738	3756	3747	3641
5.5	3300	3306	3303	3197
6	2910	2930	2920	2814
6.5	2581	2611	2596	2490
7	2315	2325	2320	2214

Table 3. The recorded counting rate and corresponding possible measured distance.

In the above two tables (table-2 and table-3) the intensities of radiation are calculated by subtracting the back ground counting rate from each of the average recorded counting rate.

4. 5 Data analysis and discussion

Data analysis

In the above data the measured distance is the distance between the source (^{137}Cs) holder and the point near to the window of GM tube. This distance is not represent the distance between the active surface of the source (^{137}Cs) and the point at which the intensity of the radiation is measured (the point at which the actual ionization take place in side the tube) so that correction should be made for the measured distance. Correction factor for the measured distance can be found from a graph of R (distance) verses intensity ($1/\sqrt{I}$) .For measured intensity of gamma rays and corresponding distance R in table 2 . (The values for $1/\sqrt{I}$ are tabulated in table-6), the plot R verses $1/\sqrt{I}$ is shown in fig 4.4.similarly using the data in table-3(The values for $1/\sqrt{I}$ are tabulated in table-7), a plot of R verses $1/\sqrt{I}$ is shown in fig 4.5 .In both case the graph is straight line, this is a good agreement theory. The correction factor can be found by extra plot. By using this extra plot the value of the correction factor (R_o) may be 0.75cm.

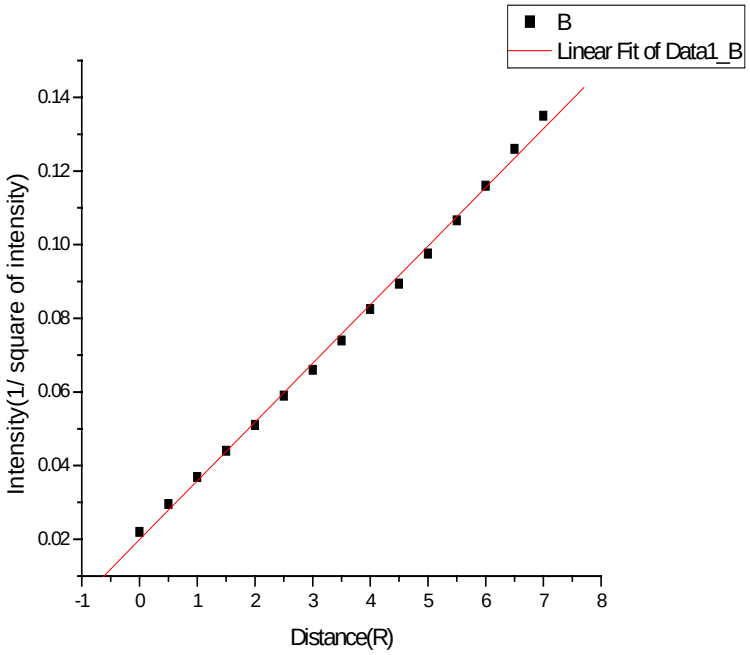

Fig 4.4 Plot of $1/\sqrt{I(\gamma)}$ verses distance (R)

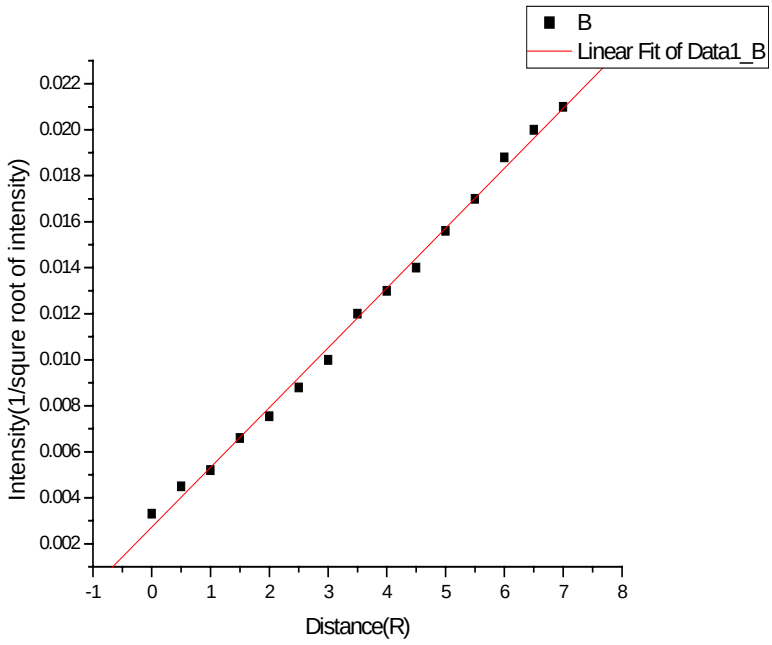

Fig 4.5 plot of $1/\sqrt{I(\gamma+\beta)}$ (verses distance D)

Alternatively this correction factor can be found by simple calculation as follows.

using equation (3.4)

$$R_o = R_i \left(1 \pm \sqrt{ I_o'' / I_i} \right) / \left(I_o''/I_i - 1 \right)$$

The calculated correction factor (R_o) for measured distance in table-2 and table-3 are tabulated in table –4 and table-5.

R_i(cm)	.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
R_o(in cm)	1.58	1.57	1.57	1.57	1.55	1.55	1.53	1.51	1.52	1.51	1.48	1.45	1.42	1.41

Table 4 . The calculated correction factor for intensity of gamma rays in table 2

R_i (cm)	.5	1	1.5	2	2.5	3	3.5	4	4.5	5	5.5	6	6.5	7
R_o(cm)	1.44	1.77	1.53	1.59	1.53	1.46	1.4	1.42	1.36	1.36	1.33	1.29	1.3	1.3

Table 5. The calculated correction factor for gamma and beta rays in table 3

The calculated correction factors for each measured distance are almost constant. From table –4 and table-5 the average values of R_o are 1.51cm and 1.43cm.These value of R_o is added to all measured distance in table-2 and table-3 and tabulated in table-6 and table-7.Know the corrected distance is the distance from the active source of ^{137}Cs to the point at which the intensity is measured. The value of measured intensities of gamma ray in table-2 and corresponding corrected distance are calculated in natural logarithm scale as shown in table-6 .similarly for intensity of gamma ray together with beta negative (rays) these values are tabulated in table-7

Operating voltage 460v

Bock ground counting 100

Source of gamma rays 137Cs

Time of counting 100sec

R	D = R+R	Counting rate C	I=C-B	$1/\sqrt{I}$	Ln I	LnD
0	1.51	2062	1962	0.022	7.58	0.412
.5	2.01	1237	1133	0.0296	7.036	0.698
1	2.51	832	732	0.0369	6.59	0.92
1.5	3.01	614	514	0.044	6.24	1.102
2	3.51	481	381	0.051	5.94	1.256
2.5	4.01	387	287	0.059	5.71	1.389
3	4.51	328	228	0.066	5.429	1.506
3.5	5.01	281	181	0.074	5.199	1.611
4	5.51	247	147	0.0825	4.99	1.706
4.5	6.01	225	125	0.0894	4.828	1.793
5	6.51	205	105	0.0976	4.65	1.873
5.5	7.01	188	88	0.1066	4.477	1.947
6	7.51	174	74	0.116	4.3	2.016
6.5	8.01	163	63	0.126	4.143	2.081
7	8.51	155	55	0.135	4	2.141

Table 6 . The summarized data table for gamma ray

Operating voltage 460v

Back ground counting 106

Source of gamma rays and beta particles ^{137}Cs

Time of counting 100sec

R(cm)	$D = R_o + R$	Counting rate C	I = C - B	$1/\sqrt{I}$	Ln I	Ln D
0	1.4	89400	89294	0.0033	11.4	0.34
0.5	1.9	49200	49094	0.0045	10.8	0.64
1	2.4	36800	36694	0.0052	10.5	0.84
1.5	2.9	22860	22754	0.0066	10.03	1.065

2	3.4	17660	17554	0.00755	9.77	1.22
2.5	3.9	13020	12914	0.00879	9.466	1.36
3	4.4	9800	9694	0.01	9.179	1.48
3.5	4.9	7400	7294	0.012	8.894	1.59
4	5.4	6280	6174	0.013	8.728	1.69
4.5	5.9	4940	4834	0.014	8.483	1.775
5	6.4	4200	4094	0.0156	8.31	1.86
5.5	6.9	3540	3434	0.017	8.141	1.93
6	7.4	2920	2814	0.0188	7.94	2
6.5	7.9	2596	2490	0.02	7.83	2.07
7	8.4	2320	2214	0.021	7.7	2.13

Table 7. The summarized data table for gamma and beta radiation

From the above data's it is observed that both intensity of pure gamma ray photon (shown in table-6) and intensity of gamma ray-photon together with negative beta particles (table-7) emitted from ^{137}Cs decreases as the distance of the source (^{137}Cs) from the windows of the tube increases. This shows that as the source move away from the iterance windows of the tube the number of ionizing radiation (γ - ray photons and β^- particles) interring through the windows of the tube decreases

Our aim is to confirm (to verify) the inverse square law, which state that the intensity of radiation from radiation source (point of emission) falls off as $1/D^2$ or intensity of radiation at any point from the source is given by:

$$I = I_o / 4\pi D^2$$

For the above equation taking natural logarithm on both sides give:

$\ln I = \ln (I_o / 4\pi) - 2 \ln D$. This is a form of linear equation in which the plot of $\ln I$ verses $\ln D$ is the straight line with slope -2.

From the present data, for intensity of gamma ray-photon and corresponding distance (corrected) in table-6, the plot of intensity verses distance is shown in fig –4.6. For intensity of gamma ray-photon together with beta negative particles and corresponding distance in table -7 ,the plot of intensity verses distance in natural logarithm scale is shown in fig-4.7.

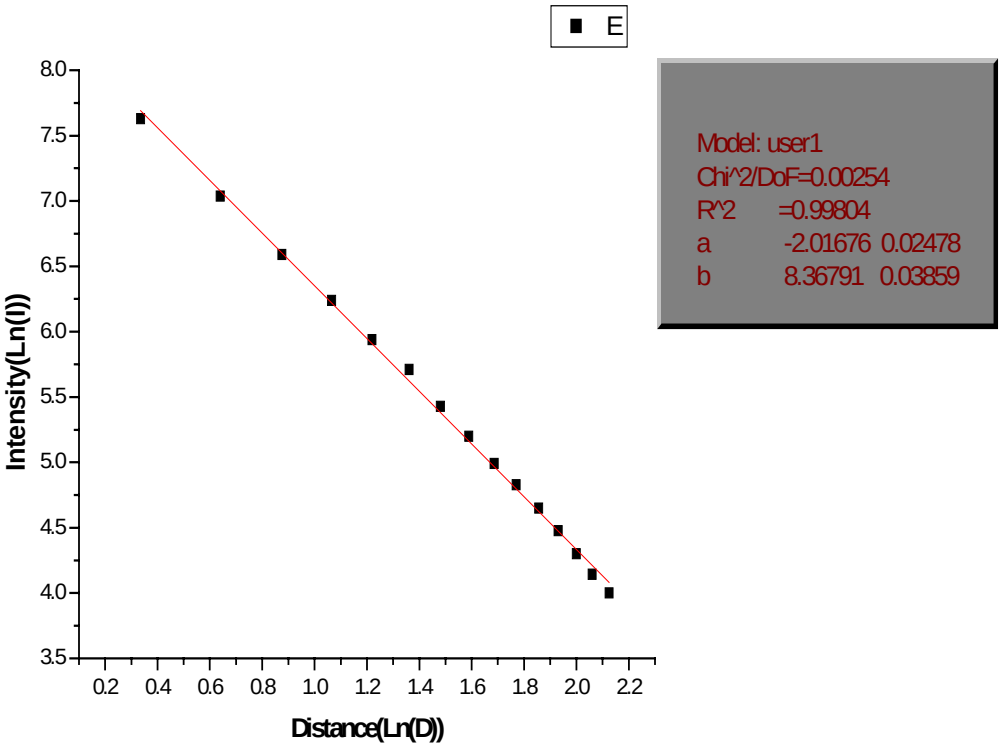

Fig –4 .6 The graph of measured intensity of gamma ray –photon from ^{37}Cs verses distance in natural logarithm

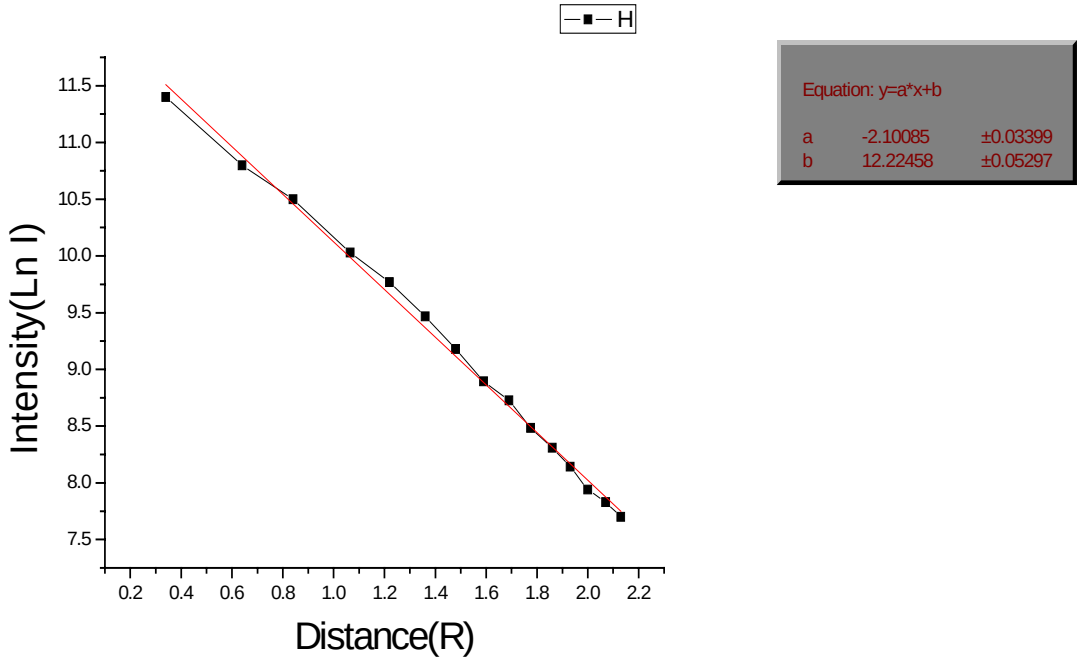

Fig-4.7 .The measured intensity of gamma ray-photon and beta particles from ^{137}Cs verses distance in natural logarithm scale.

Discussion

Fig-4.5 shows the result of the linear fit of measured intensity of gamma rays and distance. the calculated average slope of this curve is –2.01676± 0.02478.The theoretical value of the slope is –2.In comparison with this theoretical, the above experimentally determined value of the slope has 4% error. The above result indicate that the intensity of gamma- rays from the source(^{137}Cs) varies inversely as square of the distance from the source.

Fig- 4.6. Shows the result of linear fit of measured intensity of radiations (gamma rays together with negative beta particles or negatrons) and distance. The calculated average slope of the curve is –2.1008 ± 0 .03399. In comparison with theoretical value, the calculated present slope shows 2.45 % error. This result indicate that intensity of radiations ($\gamma + \beta^-$) from ^{137}Cs falls off as 1/ D^2. In both case the inverse square law is verified.

4.7 Conclusion

The theory say that for radiation emitted from a point source its intensity falls off as inverse of square of the distance from the source. The plot of measured intensity verses distance in natural logarithm scale is straight and slop of the line is –2.In this experiment, for radiation ($\gamma - raysand\beta - particles$) emitted from ^{137}Cs source the slop of measured intensity verses distance (in natural logarithm scales) is straight line. In the case of gamma rays the calculated average slop of the line is –2.01676 ± 0.02478 and for the case in which both γ - rays and β^- - particles are considered the calculated average slope of the line is –2.1008 ±0.03399. These value of the slop with small error agrees with the theoretical value. The error may arises from the measurement of the distance and stastical fluctuations of the counting rate. The same reason may given for the observed uncertainty. The above value of the slop tells as that the intensity of radiation (($\gamma - raysand\beta - rays$) from ^{137}Cs source falls off as inverse of the square of the distance from the source. From this experiment I can further conclude that for any radiation emitted isotropic ally from the source the intensity of radiation varies inversely as the square of the distance from the source.

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