بسم الله الرحمن الرحيم

Sudan University of Science and Technology

College of Graduate Studies

Relation between Beta Energy Loss by Sr^{90} and Al Thickness

العلاقة بين طاقة بيتا المفقودة من الاسترانشيوم وسمك الالمونيوم

A Thesis Submitted in Partial Fulfillment for the Requirements of the Degree Master of Science in Physics

By

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الأية

بِسْمِ اللَّهِ الرَّحْمَنِ الرَّحِيمِ

وَ الْعَصْرِ (1) إِنَّ الْإِنْسَانَ لَفِي خُسْرٍ (2) إِلَّا الَّذِينَ آمَنُوا وَ عَمِلُوا الصَّالِحَاتِ وَ تَوَاصَوْا بِالْحَقِّ وَ تَوَاصَوْا بِالصَّبْرِ (3)

سورةالعصر

Dedication

I dedicate thesis To my family , To my collage , To my friends and for all. I gift this work

Acknowledgment

For must I would like to expires my sincere gratitude to supervisor Prof. MubarkDirar Abdallah for the continuous support of MCS study and research for his penitence, motivation.

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Last but not least I would like to thank my Family my mother, my father ,my Wife, my parents (Mohamed, Awab , Ahamed) for giving birth to me at the first place and supporting me spiritually throughout my life .

Abstract

The energy of beta decay by ^{90}Sr as a functionof Al absorber thickness was studied. It was found that the energy decreases as absorber thickness increases. This agrees with previous studies and theoretical relation.

المستخلص

تمت دراسة طاقة تحلل بيتا الصادرة من (^{90}Sr) كدالة في سمك امتصاص الالمونيوم (Al).وجد ان الطاقة تنخفض عندما يزداد سمك الامتصاص . وهذا يتفق مع الدراسات السابقة والعلاقات النظرية.

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1.1 Beta Decay:

Beta decay is a radioactive decay which take place when the protons and neutron number are not equal. The decay is accompanied by electron emission (β^--decay, a neutron in an atomic nucleus transforms into a proton), positron emission (β^+-decay, a proton in an atomic nucleus transforms into a neutron). Beta decay also may occur without emission of any charged particle. It is K-capture, when a proton in an atomic nucleus captures electron from atomic shell and transforms into a neutron. K Capture occurs mainly in heavy nuclei where the nuclear radii are larger, and the electronic orbits are more compact. Usually, the electrons are captured from innermost (the "K") shell since such K-electrons are closest to the nucleu. The lifetimes of β -unstable nuclei vary between a few milliseconds and 10^{16} years. They strongly depend on released energy and on the nuclear properties of the mother and daughter nuclei[1,2].

Beta-decay is mediated by weak force,existence of which was supposed to explain

Relatively large times and small probabilitiesof the corresponding reactions.

Beta decays are always accompanied by aneutrino or antineutrino radiation.In the beta decay a mother nucleustransforms into a daughter nucleus with thesame number of nucleons or the same massnumber [5] .

1.2 Research Problem

Radioactive materials are among the many kinds of hazardous substances emergency responders might have to deal with in an accident. It is prudent that they know their role in responding to a radiation accident should one occur in their communities.

The information provided here addresses not only basic explanations and definitions related to radiation but also offers guidance to those responding both at the scene of an accident (prehospital) and at the hospital

1.3 Literature Review:

- In 1900, Becquerel measured the mass-to-charge ratio (*m*/*e*) for beta particles by the method of J.J. Thomson used to study cathode rays and identify the electron. He found that *m*/*e* for a beta particle is the same as for Thomson's electron, and therefore suggested that the beta particle is in fact an electron.
- In 1901, Rutherford and Frederick Soddy showed that alpha and beta radioactivity involves the transmutation of atoms into atoms of other chemical elements. In 1913, after the products of more radioactive decays were known, Soddy and Kazimierz Fajansindependently proposed their radioactive displacement law, which states that beta emission from one element produces another element one place to the right in the periodic table, while alpha emission produces an element two places.
- In 2004Sarah Dean showed The beta-decay of neutron-deficient rhodium and ruthenium isotopes
- In 2007 Decay of 66-Fe studied with a new beta-gamma detection setup at LISOL Oleg V. Ivanov
- Beta-decay study of the halo nuclei ^{6}He, ^{11}Be and ^{11}Li - JeroenBuscher
- Recently nuclear decay law was derived by M.Dirar , Lutfi and Amna by using the laws of quantum mechanics , where they incorporate the friction effect in a modified version. [7,8]
- Some attempts was also made to use radioactive elements to detect plant contamination [5]

1.4 The Aim of the Study:

The study aim is recording beta spectra with different absorbers thicknes one also need toshows the βspectrum of ^{90}Sr measured with the scintillation counter beside determining the energy loss per path length

1.5 Research Layout

This research consists of four chapters in chapter one introduction of the problem which will be studied then the aim of the study, the problem and methodology in addition to previous study. In chapter two we explain and gave information about types of radiation specially beta particles. In chapter three the different types of detectors are considered. Chapter four concerned in the practical work in which beta spectrum has been recorded.

Chapter Two

Radioactive Decay

2.1 Introduction

Radioactive materials are among the many kinds of hazardous substances emergency responders might have to deal with in an accident. It is prudent that they know their role in responding to a radiation accident should one occur in their communities.

The information provided here addresses not only basic explanations and definitions related to radiation but also offers guidance to those responding both at the scene of an accident (prehospital) and at the hospital

2.2 Nature of Radiation

Radiation is energy that comes from a source and travels through some material or through space. Light, heat and sound are types of radiation. The kind of radiation discussed in this presentation is called ionizing radiation because it can produce charged particles (ions) in matter.

Ionizing radiation is produced by unstable atoms. Unstable atoms differ from stable atoms because they have an excess of energy or mass or both.

Unstable atoms are said to be radioactive. In order to reach stability, these atoms give off, or emit, the excess energy or mass. These emissions are called radiation. The kinds of radiation are electromagnetic (like light) and particulate (i.e., mass given off with the energy of motion). Gamma radiation an X-rays are examples of electromagnetic radiation. Beta and alpha radiation are examples of particulate radiation. Ionizing radiation can also be produced by devices such as X-ray machines [2] .

The radioactive decay law can be derived by using the fact that the ratio of decay rate [dN/dt] and number of Nuclei N at time t is constant and equal to

$$\frac{[\mathrm{dN/dt}]}{N} = -\lambda \qquad (2.1)$$

$$\int_{N_0}^{N} \frac{dN}{N} = -\lambda \int dt$$

$$\text{Ln}\frac{N}{N_0} = -\lambda t$$

$$N = N_0 e^{-\lambda t} \qquad (2.2)$$

The half life is defined as:

$$N = \frac{1}{2}N_0 \ , t = t_{\frac{1}{2}}$$

$$\frac{1}{2}N_0 = N_0 e^{-\lambda t_{\frac{1}{2}}}$$

$$\therefore\ t_{\frac{1}{2}} = \frac{\ln 2}{\lambda} \qquad (2.3)$$

2.3 Alpha Particle:

A specific particle ejected from a radioactive atom. It has low penetrating power and short range. Alpha particles will generally fail to penetrate the skin. Alpha-emitting atoms can cause health effects if introduced into the lungs or wounds.

The decay of alpha is

$$^{A}X_{Z} \longrightarrow {}^{A-4}Y_{Z-2} + \alpha \qquad (2.4)$$

$^{A}X_{Z}$ is a parent nucleus (A = mass number , Z= atomic number)
Y is the daughter nucleus.

2.3.1 Characteristics of Alpha Radiation:

1. Alpha radiation is not able to penetrate skin.

2. Alpha-emitting materials can be harmful to humans if the materials are inhaled, swallowed, or absorbed through open wounds.

3. A variety of instruments have been designed to measure alpha radiation. Special training in use of these instruments is essential for making accurate measurements.

4. A civil defense instrument (CD V-700) cannot detect the presence of radioactive materials that produce alpha radiation unless the radioactive materials also produce beta and/or gamma radiation [5] .

5. Instruments cannot detect alpha radiation through even a thin layer of water, blood, dust, paper, or other material, because alpha radiation is not penetrating.

6. Alpha radiation travels a very short distance through air.

7. Alpha radiation is not able to penetrate turnout gear, clothing, or a cover on a probe. Turnout gear and dry clothing can keep alpha emitters off of the skin.

2.4 Gamma rays, or Gamma Radiation:

Electromagnetic radiation of high energy. Gamma rays are the most penetrating type of radiation and represent the major external hazard.

2.4.1 Sources of Gamma Rays:

This animation tracks several gamma rays through space and time, from their emission in the jet of a distant blazar to their arrival in Fermi's Large Area Telescope (LAT).

Natural sources of gamma rays on Earth include gamma decay from naturally occurring radioisotopes such as potassium-40, and also as a secondary radiation from various atmospheric interactions with cosmic ray particles. Some rare terrestrial natural sources that produce gamma rays that are not of a nuclear origin, are lightning strikes and terrestrial gamma-ray flashes, which produce high energy emissions from natural high-energy voltages. Gamma rays are produced by a number of astronomical processes in which very high-energy electrons are produced. Such electrons produce secondary gamma rays by the mechanisms of bremsstrahlung, inverse Compton scattering and synchrotron radiation. A large fraction of such astronomical gamma rays are screened by Earth's atmosphere and must be detected by spacecraft. Notable artificial sources of gamma rays include fission such as occurs in nuclear reactors, and high energy physics experiments, such as neutral pion decay and nuclear fusion [1] .

The decay mode of γ ray is:

$$^{A}X_{Z} \longrightarrow {}^{A}X_{Z} + \gamma \qquad (2.5)$$

2.4.2 Characteristics of Gamma Radiation and X-Rays:

1. Gamma radiation and X-rays are electromagnetic radiation like visible light, radio waves, and ultraviolet light. These electromagnetic radiations

differ only in the amount of energy they have. Gamma rays and X-rays are the most energetic of these.

2. Gamma radiation is able to travel many meters in air and many centimeters in human tissue. It readily penetrates most materials and is sometimes called "penetrating radiation."

3. X-rays are like gamma rays. They, too, are penetrating radiation.

4. Radioactive materials that emit gamma radiation and X-rays constitute both an external and internal hazard to humans.

5. Dense materials are needed for shielding from gamma radiation. Clothing and turnout gear provide little shielding from penetrating radiation but will prevent contamination of the skin by radioactive materials.

6. Gamma radiation is detected with survey instruments, including civil defense instruments. Low levels can be measured with a standard Geiger counter, such as the CD V-700. High levels can be measured with an ionization chamber, such as a CD V-715.

7. Gamma radiation or X-rays frequently accompany the emission of alpha and beta radiation.

8. Instruments designed solely for alpha detection (such as an alpha scintillation counter) will not detect gamma radiation.

9. Pocket chamber (pencil) dosimeters, film badges, thermo luminescent, and other types of dosimeters can be used to measure accumulated exposure to gamma radiation [3] .

2.5 Beta Particle

In nuclear physics, beta decay (β -decay) is a type of radioactive decay in which a beta ray, which is either an energetic electron or positron, and a respective

Antineutrino or neutrino is emitted from an atomic nucleus.

By beta decay emission of an electron, a neutron within the nucleus is transformed into a proton, or by emission of a positron, a proton is converted into a neutron, changing the nuclide type. The beta particle and its associated

neutrino do not exist within the nucleus prior to beta decay, but are created. By the process of beta decay an unstable atom obtains a more stable ratio of protons and neutrons. The stability of this ratio forms the nuclear valley of stability.

Mode of beta particles is given by:

$$^{A}X_{Z} \rightarrow {}^{A}y_{Z+1} + \beta^{-} + \overline{\nu}$$

$$^{A}X_{Z} \rightarrow {}^{A}y_{Z-1} + \beta^{+} + \nu \qquad (2.6)$$

Where:

ν = neutrino , $\overline{\nu}$ = antineutrino

Decay times for many nuclides that are subject to beta decay can be thousands of years [4].

2.5.2 Description

The two types of beta decay are known as beta minus and beta plus. In beta minus (β−) decay a neutron is converted to a proton and the process creates an electron and an electron antineutrino, while in beta plus (β +) decay a proton is converted to a neutron and the process creates a positron and an electron neutrino. β + decay is also known as positron emission.

Beta decay conserves a quantum number known as the lepton number, or the number of electrons and their associated neutrinos (other leptons are the muon and tau particles). These particles have lepton number +1, while their antiparticles have lepton number1. Since a proton or neutron has lepton number zero, β + decay (a positron, or antielectron) must be accompanied with an electron neutrino, while β - decay (an electron) must be accompanied by an electron antineutrino.

An example of electron emission (β − decay) is the decay of carbon-14 into nitrogen-14 with a half-life of about 5,730 years:

$$C_{6}^{14} \longrightarrow N_{7}^{14} + e^{-} + \nu \qquad (2.7)$$

In this form of decay, the original element becomes a new chemical element in a process known as nuclear transmutation.

This new element has an unchanged mass number A, but an atomic number Z that is increased by one. As in all nuclear decays, the decaying element (in this case C_6^{14}) is known as the parent nuclide while the resulting element (in this case $^{14}_{7}N$) is known as the daughter nuclide.

An example of positron emission is the decay of magnesium-23 into sodium-23 with a half-life of about11.3 s:

$$^{23}_{12}Mg \rightarrow {}^{23}_{11}Na + e^{+} + \nu \qquad (2.8)$$

β+ decay also results in nuclear transmutation, with the resulting element having an atomic number that is decreased by one. Electron capture is sometimes included as a type of beta decay, because the basic nuclear process, mediated by the weak force, is the same. In electron capture, an inner atomic electron is captured by a proton in the nucleus, transforming it into a neutron, and an electron neutrino is released. An example of electron capture is one of the decay modes of krypton-81 into bromine-81:

1Electron capture is a competing (simultaneous) decay process for all nuclei that can undergo β+ decay. The converse, however, is not true: electron capture is the only type of decay that is allowed in proton-rich nuclides that do not have sufficient energy to emit a positron and neutrino.[3] A beta spectrum, showing a typical division of energy between electron and antineutrino The beta spectrum, or distribution of energy values for the beta particles, is continuous. The total energy of the decay process is divided between the electron, the antineutrino, and the recoiling nuclide. In the figure to the right, an example of an electron with 0.40 MeV energy from the beta decay of 210Bi is shown. In this example, the total decay energy is 1.16 MeV, so the antineutrino has the remaining energy: 1.16-0.40 = 0.76 MeV. An electron at the far right of the curve would have the maximum possible kinetic energy, leaving the energy of the neutrino to be only its small rest mass [4].

2.5.3 Types of Beta Decay Transitions Main Article

Beta decay transition Beta decays can be classified according to the angular momentum (L-value) and total spin (S-value) of the emitted

radiation. Since total angular momentum must be conserved, including orbital and spin angular momentum, beta decay occurs by a variety of quantum state transitions to various nuclear angular momentum or spin states, known as “Fermi” or “Gamow-Teller” transitions. When beta decay particles carry no angular momentum (L = 0), the decay is referred to as “allowed, otherwise it is“forbidden

2.5.4 Inverse Beta Decays (aka Electron Capture)

Although not really one of the main forms of decay, we are looking at these inverse beta decays

simply because of their similarity to beta negative decays.

• In this process a proton rich nucleus absorbs an electron from one of the inner energy levels.

$p^+ + e^- \rightarrow n^o + v$ (2.9)

• Shown with nucleons values to prove conservation of nucleons we would have...

$${}^{1}_{1}p + {}^{0}_{-1}e \rightarrow {}^{1}_{0}n + \nu \quad (2.10)$$

Rubidium-83 is known to go through electron captures. Write out the decay equation for this decay.

$${}^{83}_{37}Rb + {}^{0}_{-1}e \rightarrow {}^{83}_{36}Kr + \nu \quad (2.11)$$

2.6 Beta Spectrum:

Most experiments on radioactivity deal with the absorption properties of Materials without illustrating the quantitative difference between types of radiation. Beta and gamma radiation are absorbed by matter in a similar, although not identical, manner; beta being absorbed much more easily of course.

The two types of radiation have significant differences in that gamma rays or photons have no mass, nor charge and travel at the speed of light, however, beta radiation is composed of electrons with charge, mass and finite speeds.

Although these differences may not be of great importance in some radiation experiments, they do have a great effect on how the two types of radiation

interact with matter. We will use a beta spectrograph to show the difference between these radiation types [2].

2.6.1 Energy Spectrum

So you may wonder what a beta energy spectrum is. Simply put, it is the Intensity of the beta beam at different particle energy. The intensity is proportional to the number of counts registered by the Geiger counter while the energy of the beta particles can be derived from the angle by which they deflect under a magnetic field.

In this lab, beta particles from a source are collimated and directed through a magnetic field provided by a pair of ceramic magnets, which deflect them into a detector. The beam deflection varies from 0° to 90° depending upon the energy of the particles as shown in Figure 2.1 The beam intensity is measured by a Geiger tube mounted in the magnet support structure. The source is mounted on a rotating arm so that the beam passes through the magnetic field and enters the Geiger tube through an aperture in the cast iron frame. Rotating the arm permits the measurement of the intensity as a function of angle. The deflection angle is inversely related to the energy of the beta particles so that the beam intensity as a function of energy can be determined from the data.

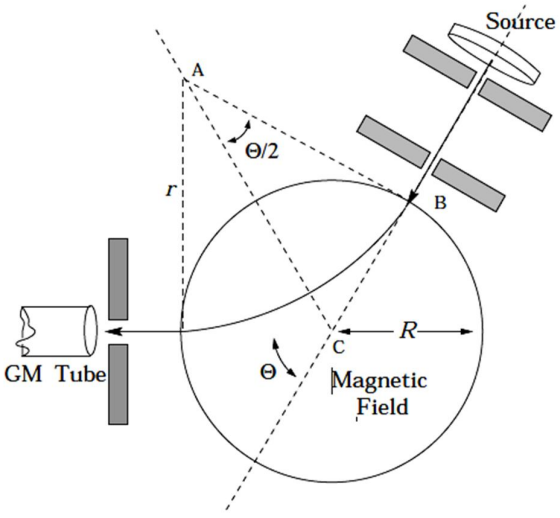

Figure 2.1. Experimental Setup

2.6.2 Operation of the Equipment:

For this lab you will need:

- A Geiger Tube
- A Geiger Counter
- Radioactive Sources
- A Computer and Counting Software

Part I in Appendices of the last lab handout, Geiger-Müller Counters and Radiation Event Counting Software provides more detail about operation of the Geiger counter and counting software.

1. Set the magnet frame on a level table with space around it for the other pieces of apparatus. The source should be mounted in the arm. It is attached with double-sided foam tape to the back of the rotating arm. It should be centered on the vertical part of the arm and in line with the aperture in the lead absorber.

Two sources are recommended for use with the apparatus; either ^{90}Sr or ^{204}Ti give good results. ^{14}C, which is a good beta emitter, does not work because its beta particles have low energy and are deflected out of the magnetic field before they can reach the Geiger tube. Since the count rate is much higher with ^{204}Ti, it is suggested that this source be used.

2. Carefully place the Geiger tube into a pocket provided for it in the back of the magnet frame. Don't let the window of the tube touch the end of the cavity. Tighten the nylon screw on the top of the frame to hold it in place.

3. Connect the coaxial cable of the Geiger tube to the rear BNC connector of the Geiger counter.

4. Turn on the Geiger counter to the continuous mode.

The Counter is continuously active in this mode and should show a few counts from the source or from background radiation.

Make sure all of the connections are correct. The easiest way to do this is to hold a gamma radiation source, if you have one, near the side-wall of the

Geiger tube. This will cause the tube to count rapidly and verify that all connections are correct.

To start the measurements, remove the gamma source and anything else that might add to the background count.

Rotate the source arm to 90° to the right. Using one of the counting programs on the computer, record the number of counts detected during a three minutes period.

6. Move the source arm to the 90° left position and repeat the measurement.

The count rate will be higher on one side than the other. This will enable you to determine in which direction the beta particles are deflected. The deflection is determined by the polarity of the magnetic field and the charge on the beta particle.

Now we enter the key stage of this lab, measurement of the intensity of angle. It is convenient to measure the count for 5° increments in angle. Smaller steps than this are close to the resolution of the apparatus and waste time. Larger steps have too few points to make a convincing graph. If time is limited, 10° steps can be used without too great a sacrifice in credibility.

7. Set the Source arm on the side that gives the higher intensity as measured in the first part of the experiment. Time the count for 5 minutes.

For weak sources and large angles, the count can be very low so that the time it takes to collect large counts is quite long. Since laboratory time is very limited, it is best to decide on a data collection procedure that can be completed in the available time. Usually, counting for fixed time intervals is best, say three or five minutes, so that the total time is predictable even though the accuracy will not be very high for the low count rates.

8. Measure the count for each five degrees interval starting at 90°. The count rate will change significantly between settings. Continue until 10 points have been measured.

9. Measure the background radiation. This measurement is important, since the background count must be subtracted from all of the other readings.

Count for at least four times as long as the time period used for the angle measurements. The source arm should be set to 80° on the opposite side. The magnetic field will sweep the beta particles away from the Geiger tube so that the tube will be responding to cosmic ray and environmental radiation rather than the source.

The background is usually fairly constant for a given Geiger tube and amplifier in the same environment. After the background has been measured by several groups in the laboratory and found constant, its value can be used so that later measurements are unnecessary, thus saving laboratory time. It is always safest to measure the background before and after the measurements, if serious work is undertaken.

If the EN-30 Precision Geiger Counter is used, all of the measurements can be made to fixed accuracy. The Precision Geiger Counter will measure the count 4 rate for a fixed number of counts. This is very convenient for measurement of the low count rates and background count that can take almost three hours to reach 4000 counts. The EN-30 holds the measured count rate until the operator comes to retrieve it [5].

2.6.3Calculation of the Beta Energy Spectrum (from the data):

Plotting the count rate minus the background is the first plot that should be made. It will show if an error has been made and a particular point should be measured again. A sample of data plotted this way is shown in Figure 2. This figure2.2 shows two sources, Thallium204 and Strontium90, both good sources of beta radiation. It can be seen that the peak intensity for Sr90 occurs at a smaller deflection angle than for^{204} Ti. This suggests that the beta particles from ^{90} Sr are more energetic than those from ^{204}Ti. This is indeed true.

You may find that the points on your curve are more scattered than those in Figure 2.2 This is because the data are based on the count rate for 4000 counts, so that the points are very accurate, but it took several days to

collect the data. You may not have time to use this many counts. The curve is a sample of what you could achieve if you had the time to do it.

A second comment should also be made about the figure. The ^{90}Sr source used had only 1% of the intensity of the ^{204}Ti source. This does not change the results but it makes the data difficult to plot. To correct this, the ^{90}Sr data were increased by a factor that made the two sources have the same apparent intensity.

Of greater interest than the count rate, which is after all only characteristic of the source and the apparatus, is the count rate versus angle which is equivalent to the count rate as a function of energy. It was shown earlier that with a knowledge of the magnetic field, the deflection angle could be used to determine the energy of the particle. The $^{204}T1$ data plotted in Figure 2 are tabulated in Table 1, together with the energy and the rate of change of energy with angle.

It can be seen from this table that the energy increases with angle in a very nonlinear manner. The energy increase for a change in angle becomes very large, as the energy is greater. Since the geometry of the collimator and collector in the Spectrograph have a fixed collection angle of about 5°, the result is that the range of energies collected for a given angle changes with the angle. The data that has been taken gives the relative amount of radiation directed into each 5° angle increment (0-5°, 5-10°, 10-15°, ...),

However, our true interest is in finding the beta radiation energy spectrum for the source, i.e. the relative number of beta particles emitted as a function of particle energy.

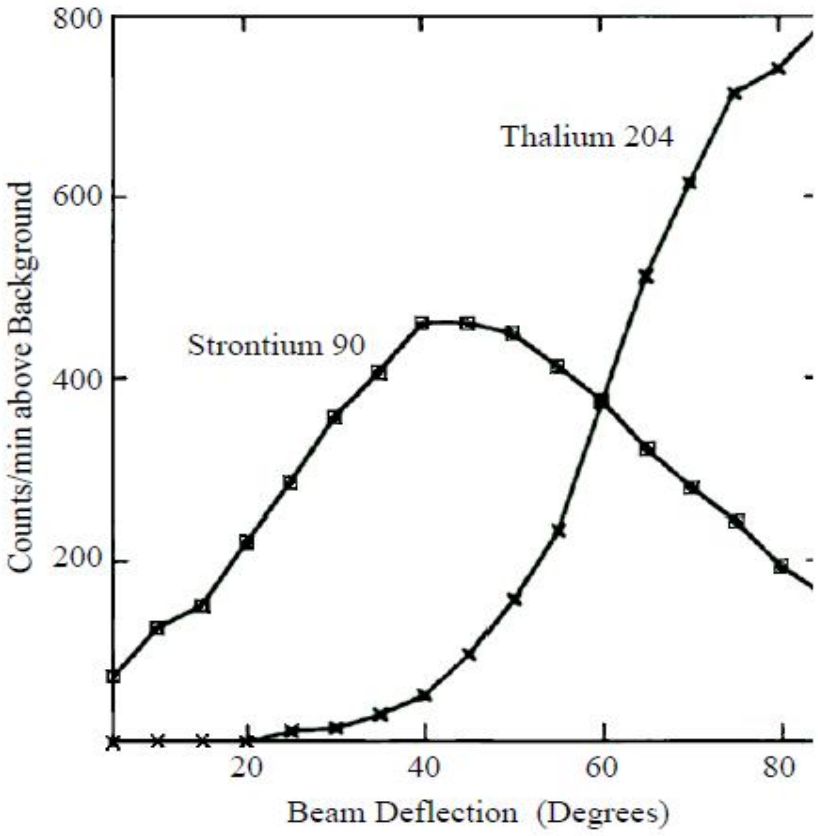

Figure 2.2. Measured Energy Spectrum of Thallium204 and Strontium90

Source: Thallium209

Background Count: 24/m

Angle	Energy (MeV)	ΔE/ΔΘ (relative)	Count/min	(C/min-Bkgd)	(C/min-Bkgd) / ΔE/ΔΘ
90	.343				
85	.394	.051	816	792	792
80	.452	.058	767	743	657
75	.517	.065	739	715	555
70	.592	.075	639	615	417
65	.679	.087	536	512	300
60	.780	.101	398	374	188
55	.900	.120	258	234	99
50	1.044	.144	183	159	56
45	1.219	.175	121	97	28
40	1.438	.219	77	53	12
35	1.720	.282	55	31	6
30	2.095	.375	39	15	2
25	2.620	.525	35	11	1

obtain this information. Thus we need to multiply each measurement by

$$\frac{\Delta\boldsymbol{\theta}}{\Delta\boldsymbol{E}(\boldsymbol{\theta})}$$

The simplest correction has been used in Table 1. The differences for successive energies in column two are tabulated in column three. The (Count/min Background) value is divided by this number and then normalized by multiplying by the value for 85°, i.e., .041. A sample calculation for 50° gives

$$\frac{(183\ \text{Counts/min}) - (24\ \text{Background})}{0.144\ (\Delta E / \Delta\theta\ \text{at}\ 50°)} \times 0.051 = 56(\frac{\text{Counts/min}}{\Delta E}) .$$

This correction makes the data comparable to other published beta spectrum data.

The spectrum of ^{204}Ti and ^{90}Sr are shown in Figure 2.3 corrected by the above procedure. As before, the ^{90}Sr curve is adjusted upward to plot with the ^{204} Ti curve.

The most significant characteristic of the beta spectrum is the energy cutoff value. This is the value referred to in tables of energy of beta radiation. From Figure 2.3, it is clear that most of the energy of the radiation occurs at lower energies than this cutoff value. The nature of the spectrum was difficult to understand, since there seems to be no other change in the nucleus except that it changes to the next higher positive species. But if the beta particles emerge with a wide range of energy.

Conservation was maintained by the additional emission of a very hard to detect particle, the neutrino, which carried off the balance of the energy and spin. A beta particle emerging at maximum energy takes it all. For lesser energies, the balance is carried off by the neutrino. So this little experiment establishes the charge of the beta particle and gives the experimental basis for the existence of the neutrino [3].

Sections of this Lab were taken from:

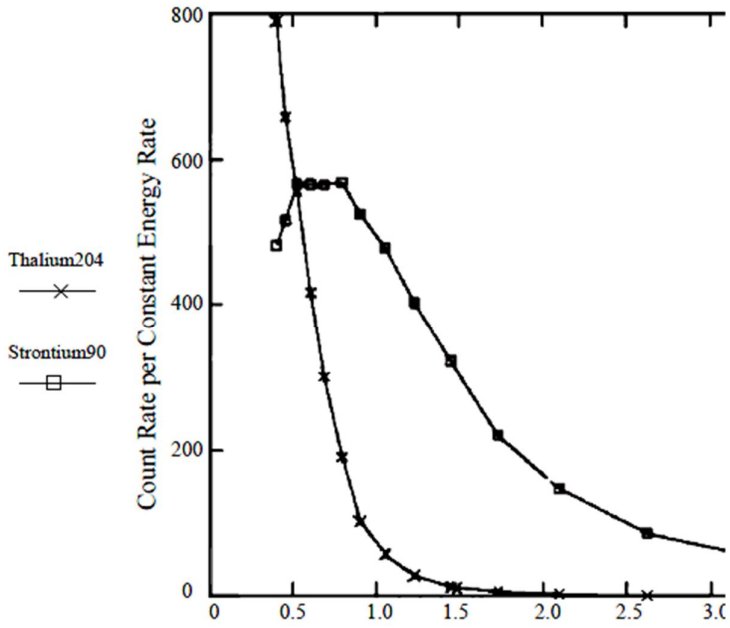

Figure 2.3. Beta Radiation Energy Spectrums for T1204 and Sr9 0

2.6.4 Theoretical Relation:

The determination that beta radiation consists of charged particles is the most significant conclusion of this experiment because it establishes the nature of this fundamental type of radiation. The measurement of the energy spectrum of the beta particles is of almost equal importance, for the nature of the energy spectrum led to the discovery of the neutrino by Fermi in 1934.

It is intuitively clear that the slower a beta particle is moving, the more strongly it will be deflected by a magnetic field. The path of charged particles of any energy will bend but the radius of curvature will depend upon the energy.

By measuring the strength of the magnetic field and the radius of the path of the beta particle, the energy the particle had can be determined. To derive the required formula, let us start by determining the radius of the path through the field by measurement of the deflection angle. The geometry of the beam passing through the field is shown in Figure 1. The beam enters the magnetic field at point *B* and follows a circular until it leaves and enters the Geiger tube. The radius of the arc *r* can be determined from the radius of the field *R* and the deflection angle.

The angle ACB is seen to be (180° - q) = (90° - q/2). Therefore the angle CAB

= (180° - 90° - ACB) = q/2. In the triangle ABC,

$$\tan\frac{\theta}{2} = \frac{R}{r} \tag{2.12}$$

so that

$$r = \frac{R}{\tan\frac{\theta}{2}} \tag{2.12}$$

The total energy of a beta particle is the sum of the potential and kinetic energy and is given by:

$$E = \sqrt{(pc)^2 + (m_0c^2)^2} - m_0c^2 \tag{2.13}$$

where *c* is the velocity of light and 0 *m* is the rest mass of the electron. Dividing through by 2:

$$E = m_0c^2\left(\sqrt{\frac{p}{m_0c^2} + 1} - 1\right) \tag{2.14}$$

The centripetal force required to keep a particle moving on a circular path is given by

$$F = \frac{mv^2}{r} \tag{2.15}$$

This force is produced by the charge of the particle e moving through the magnetic field B. so that

F = eBv.

These two expressions for the force are equal so,

$$\frac{mv^2}{r} = eBv \tag{2.16}$$

giving,

$$mv = eBr.$$

But *mv = p* the momentum of the particle, so that we can substitute in the energy equation and obtain,

$$E = m_0c^2\left(\sqrt{\left(\frac{eBr}{m_0c}\right)^2 + 1} - 1\right) \tag{2.17}$$

and substituting for *r*,

$$E=m_0c^2\left(\sqrt{\left(\frac{eBR}{m_0c\tan\frac{\theta}{2}}\right)^2+1}-1\right) \quad (2.18)$$

All of the quantities in this equation are known or may be measured by our experiment.

For the EN-08 Beta Spectrograph apparatus used in this lab, R = 5.7 x 10-2 m and

B = 6.9 x 10-2 T. The remaining values can be taken from tables of physical constants. Making these substitutions gives,

$$E=0.511\left(\sqrt{\left(\frac{1.34}{\tan\frac{\theta}{2}}\right)^2+1}-1\right)\ \text{MeV} \quad (2.19)$$

This is the required formula relating the energy of the beam in units of MeV, as a function of the deflection angle of the beam for the particular equipment used in this lab (EN-08 Beta Spectrograph). Remember that this equation is derived from an apparatus that had a field of 6.9 x 10-2 T. This value should not deviate strongly from device to device but it would be well to check the assumption. If a flux density meter is available, the field can be measured by placing the probe in the gap between the magnets. Take several measurements and average your results .

Chapter three

Radiation Detectors

3.1 Introduction

Radiation detectors are devices that measure this ionization and produce an observable output. Early detectors used photographic plates to detect "tracks" left by nuclear interactions. Advances in electronics, particularly the invention of the transistor, allowed the development of electronic detectors. Scintillation-type detectors use vacuum tubes to perform the initial conversion of light to electrical pulses. The amplification and storing these data follow the advances in transistor electronics. Miniaturization in electronics has revitalized types of gas-filled detectors. This chapter exhibits some of these detectors

3.2 Geiger Counter:

The detector most common to the public is the Geiger-Mueller counter (see figure 3.1) , commonly called the Geiger counter. It uses a gas-filled tube with a central wire at high voltage to collect the ionization produced by incident radiation. It can detect alpha, beta, and gamma radiation although it cannot distinguish between them. Because of this and other limitations, it is best used for demonstrations or for radiation environments where only a rough estimate of the amount of radioactivity is needed.

Scintillation detectors: Scintillators are usually solids (although liquids or gases can be used) that give off light when radiation interacts with them. The light is converted to electrical pulses that are processed by electronics and computers. Examples are sodium iodide (NaI) and bismuth germanate (BGO). These materials are used for radiation monitoring, in research, and in medical imaging equipment [1].

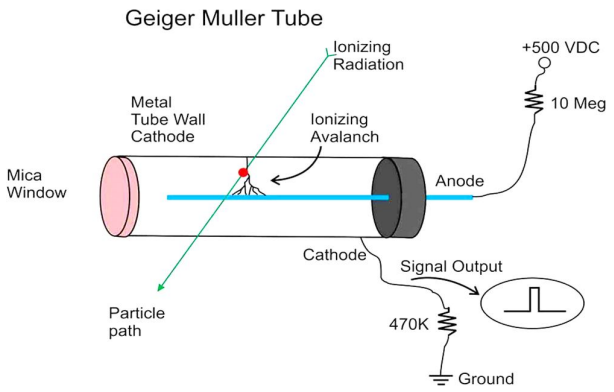

Figure 3.1. Geiger counter

3.3 Solid state X-ray and gamma-ray detectors:

Silicon and germanium detectors, cooled to temperatures slightly above that of liquid nitrogen (77 K), are used for precise measurements of X-ray and gamma-ray energies and intensities (see figure 3.2). Silicon detectors are good for X-rays up to about 20 keV in energy. Germanium detectors can be used to measure energy over the range of >10 keV to a few MeV. Such detectors have applications in environmental radiation and trace element measurements. Germanium gamma ray detectors play the central role in nuclear high-spin physics, where gamma rays are used to measure the rotation of nuclei. Large gamma-ray detection systems, such as Gammasphere and Eurogam are made of these detectors[1].

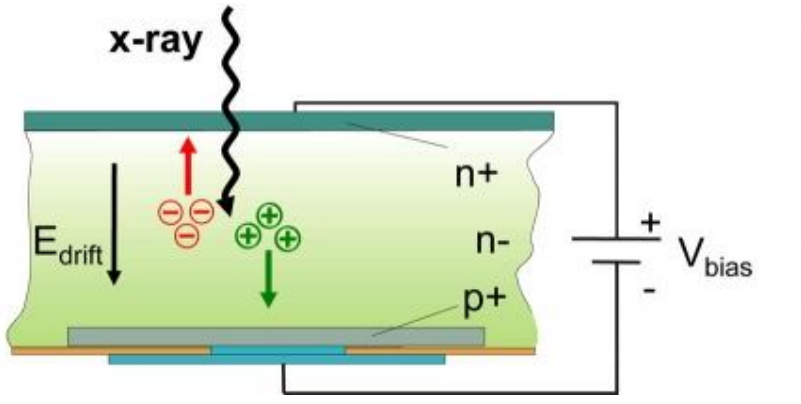

Figure 3.2. x-ray counter

3.4 Low-energy charged particle detectors:

Silicon detectors, normally operated at room temperature, play a major role in the detection of low-energy charged particles (see figure 3.3). Singly, they can determine the energy of incident particles. Telescopes (combinations of two or more Si detectors) can be used to determine the charge (Z) and mass (A) of the particle. This type of detector is used in environmental applications to look for alpha-particle emitters (such as radium) in the environment[1].

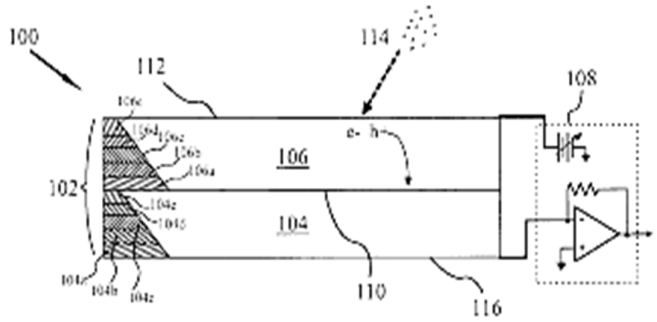

Figure 3.3.Low-energy charged particle detectors

3.5 Neutron detectors:

Neutrons are much harder to detect because they are not charged. They are detected by nuclear interactions that produce secondary charged particles. Often one uses a moderator, such as paraffin, to slow the neutrons and thus increase the detection efficiency. These detectors are used to monitor the neutron fluxes in the vicinity of a reactor or accelerator(see figure 3.4). Liquid scintillations can measure both neutrons and gamma rays. By carefully measuring the shape of the electronic signal, scientists can and distinguish between these two types of particles[1].

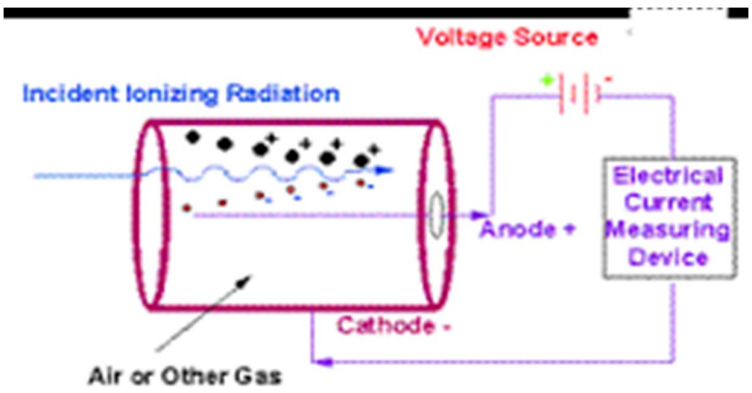

Figure3.4. Neutron detectors

3.6 Neutrino Detectors:

Neutrinos interact very weakly with matter and are therefore very hard to detect. Thus, neutrino detectors must be very large. The Sudbury Neutrino Observatory in Canada, was developed to understand the solar neutrino problem (too few neutrinos come out of the Sun than expected) and contains an active volume of 1000 tonnes (metric tons) of deuterium oxide (heavy water). This is a Cerenkov counter in which the interaction of the neutrino with the heavy water produces an electron moving faster than the speed of light in the water. The moving electron generates a cone of light that can be observed with photomultiplier tubes. Information from these tubes will be used to determine the energy and direction of the incident neutrino[1].

3.7 High-energy charged particle detectors:

As the energy increases, large and even more complex detection systems are needed, some involving thousands of individual detectors. These detectors typically involve the "tracking" of large numbers of particles as they pass through the detector. Large magnets are required to bend the paths of the charged particles. Multi-wire detection systems with nearly a quarter of a million channels of electronics provide information on these tracks. High speed computer systems process and store the data from these detectors. Similarly, powerful computer systems are needed to analyze these data so that a scientific discovery can be made[1].

3.8 Scintillation Detectors:

Scintillates are one of the oldest types of radiation detector because measurements could be made with photographic film. Images could be collected or intensity measurements could be made. Measurements were also made with the human eye observing the brightness of frequency of flashes in the scintillator. Nowadays the light output is converted into voltage pulses that are processed in the same way as pulses from proportional counters, semiconductor detectors etc (see figure 3.5).

The whole point of scintillation detectors is that we want to produce a large light output in the visible range.

There are two commonly used types of scintillators, inorganic crystals and organic scintillators. The scintillation mechanism is different for these two types [6].

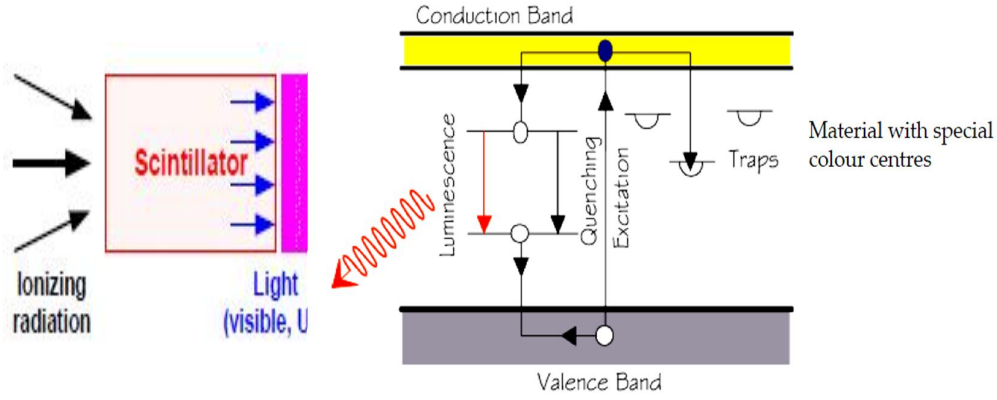

Fig 3.5. Principle of the scintillation detectors.

3.9 Scintillator Types

- organic scintillators
- inorganic crystals
- gases

3.10 Inorganic Scintillators:

The scintillation mechanism depends on the structure of the crystal lattice. In a pure inorganic crystal lattice such as NaI, electrons are only allowed to occupy selected energy bands. The forbidden band or band gap is

the range of energies in which electrons can never be found in the pure crystal.

In the pure crystal, absorption of energy can elevate electrons from the valence band to the conduction band leaving a gap in the valence band. However, the return of an electron to the valence band with the emission of a photon is an inefficient process. Few photons are released per decay, the energy is emitted by other mechanisms. In addition, band gap widths in pure crystals are such that the resulting emitted photon is too high to lie within the visible range.

Small amounts of impurities are therefore added to the crystal. Tl is added to NaI in trace amounts. The impurities are called activators, they create special sites in the lattice at which the band gap structure, the energy structure, is modified. The energy structure of the overall crystal is not changed, just the energy structure at the activator sites (see figure 3.6).

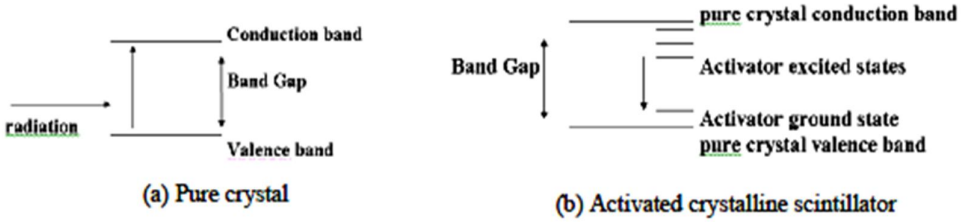

Fig 3.6. Energy band structure of an inorganic scintillator.

At the few activator sites within the sample, the energy structure is modified. Energy states are created within what would be the forbidden band in the pure crystal. The electron can de-excite through these levels back to the valence band.

The energy levels created by the activator's presence within the crystal are narrower than in the pure crystal.

The photons emitted by the transitions of electrons from upper to lower states will be lower in energy than in the pure crystal: The emission spectrum is shifted to longer wavelengths and will not be influenced by the optical absorption band of the bulk crystal.

The photons are emitted in the visible range.

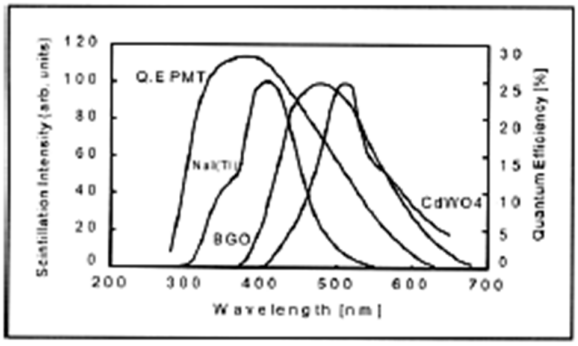

Fig. 3.7. The emission spectra of several common scintillators.

A charged particle (e.g. a photoelectron) passing through the crystal will create a large number of electron-hole pairs.

• The positive hole quickly drifts to the location of an activator site and the site is ionized. The activator sites are preferentially ionized because the ionization energy of the activator is less than a typical lattice site.

• The electron elevated to the conduction band is free to migrate through the crystal and will do so until it encounters an ionized activation site.

• The electron drops into the impurity site, creates a neutral impurity configuration with its own set of excited states.

• Excited configuration $\xrightarrow{\text{transition}}$ ground state

• De-excitation occurs quickly with a high probability of photon emission.

• The activator is chosen so that the photon is visible.

• The typical half-life of the activator excited states are 10-7 seconds with the migration of the electrons through the crystal taking a much shorter time. The timing of the light output is therefore dependent on the half-life of the state.

3.10.1 Types of inorganic scintillators:

- Alkali halide: NaI(Tl), CsI(Tl), CsI(Na), LiI(Ei)
- Other slow Inorganics: BGO, CdWO4, ZnS(Ag)
- Cerium-Activated Fast Inorganics: GSO, YAP, YAG, LSO, LuAP, LaBr3

3.10.2 Advantages of Inorganic Scintillators :

- high light yield [typical ε ~ 0.13]
- high density [e.g. PWO ~ 8.3 g/cm3]
- good energy resolution

3.10.3 Disadvantages of Inorganic Scintillators :

- complicated crystal growth
- large temperature dependence

3-11 Organic Scintillators

The scintillation mechanism in organic materials is quite different from the mechanism in inorganic crystals. In inorganic scintillators, e.g. NaI, CsI the scintillation arises because of the structure of the crystal lattice.

The fluorescence mechanism in organic materials arises from transitions in the energy levels of a single molecule and therefore the fluorescence can be observed independently of the physical state. For example anthracene is observed to fluoresce as

• a polycrystalline material

• a vapor

• part of a mixed solution

Practical organic scintillators are organic molecules which have symmetry properties associated with the electron structure.

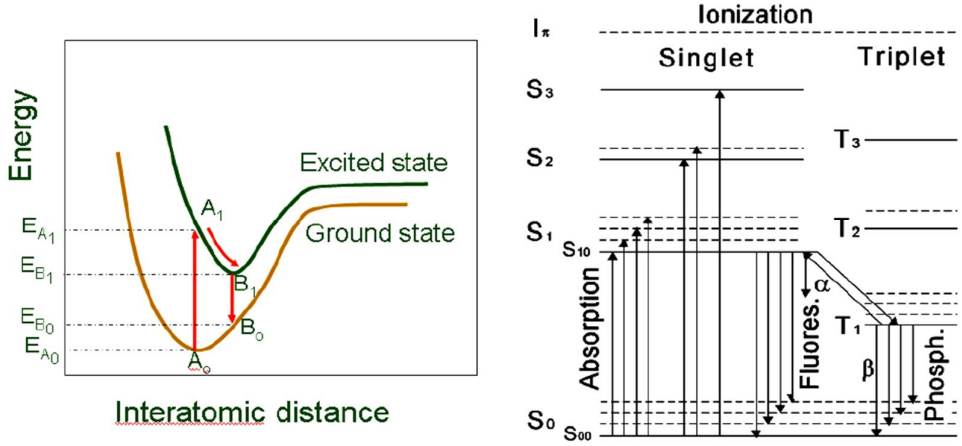

Fig3.8. Energy Levels of Organic Molecules.

Energy from a charged particle is absorbed and excites the electron into a variety of excited states - the singlet states (spin = 0) are labeled S1, S2, S3 in Fig. 4.5. For organic scintillators the spacing between S0 and S1 is 3 to 4 eV, the spacing between the upper states is much smaller.

Each of the S levels is subdivided into a series of levels with much finer structure (corresponding to the vibrational states of the molecule). The typical spacing is 0.15 eV. The 2nd subscript denotes the fine structure level. Spacing between S states is 3-4 eV, spacing in vibrational structure is 0.15 eV

3.11.1 Types of Organic Scintillators:

- Pure organic crystals: Anthracene, Stilbene
- Liquid organic solutions: by dissolving an organic scintillator in a solvent
- Plastic scintillators: dissolving & polymerizing

3.11.2 Advantages of Organic Scintillators:

- very fast.
- easily shaped.
- small temperature dependence.

3.11.3 Disadvantages of Organic Scintillators

- lower light yield [typical $\varepsilon \sim 0.03$].
- radiation damage.

3.12 Scintillation Mechanism

• At room temperature, average energy is approximately 0.025 eV so all molecules are in the S00 state.

• When the charged particle passes through, kinetic energy is absorbed by the molecules, and electrons are excited to the upper levels.

• The higher states S_2, S_3, de-excite quickly (picoseconds) to S_1 state through radiationless transitions (internal conversion).

• States such as S_{11}, S_{12} that have extra vibrational energy and are not in thermal equilibrium with neighboring molecules, quickly lose energy.

 After negligibly short time a population of excited molecules in S_{10} state is produced as the net effect of the excitation process.

Scintillation light, prompt fluorescence, is emitted in transitions between S10 and the ground state.

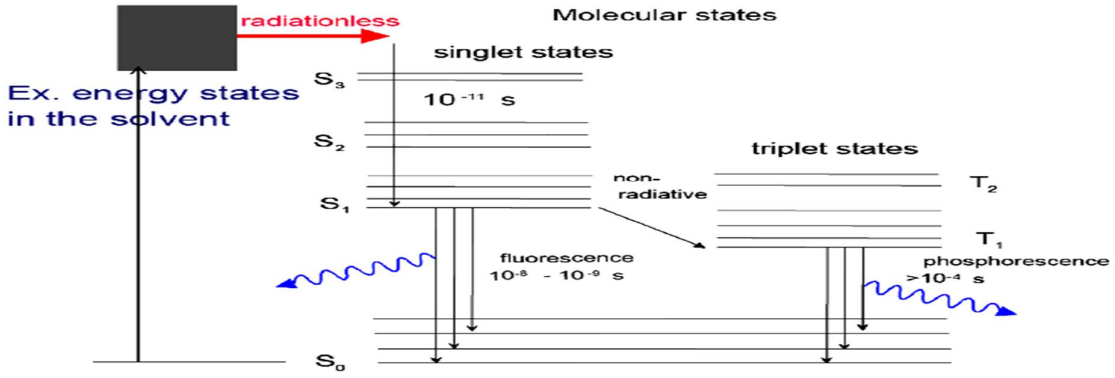

Fig.3.9. Scintillation Mechanism

The prompt fluorescence intensity at time t following excitation is described by

$$I=I_0e^{-t/\tau} \qquad (3.1)$$

where τ is the fluorescence decay time for the S10 level.

In most organic scintillators, τ is the order of a few nanoseconds therefore organic scintillators are fast.

The lifetime for the T1 state is much longer than the S1 state. T1 is populated by a transition called an intersystem crossing. The lifetime of the T1 state can be ms.

$T_1 \rightarrow S_0$ transitions give rise to phosphorescence (delayed light emission).

T1 lies below S_0, therefore the wavelength of the emitted phosphorescence is longer than the wavelength of the fluorescent light. The phosphorescent light can be discriminated from the scintillation light on the basis of timing and wavelength.

The energy level scheme explains why organic scintillators can be transparent to their own fluorescence emission. All fluorescence emissions

(except $S_{10} \rightarrow S_{00}$) have a lower energy than the minimum required for absorption. There is little overlap between emission and absorption spectra, therefore the emitted light mostly passes straight on through the scintillation medium [4].

Chapter four

The practical work

4.1 Introduction:

In this chapter the experiment of beta decay has been conducted using scintillation counter in order to calculate its energy .

The experiment was conducted at nuclear lab of physics at faculty of science (SUST) , on December 2016,as shown in figure 4.1.

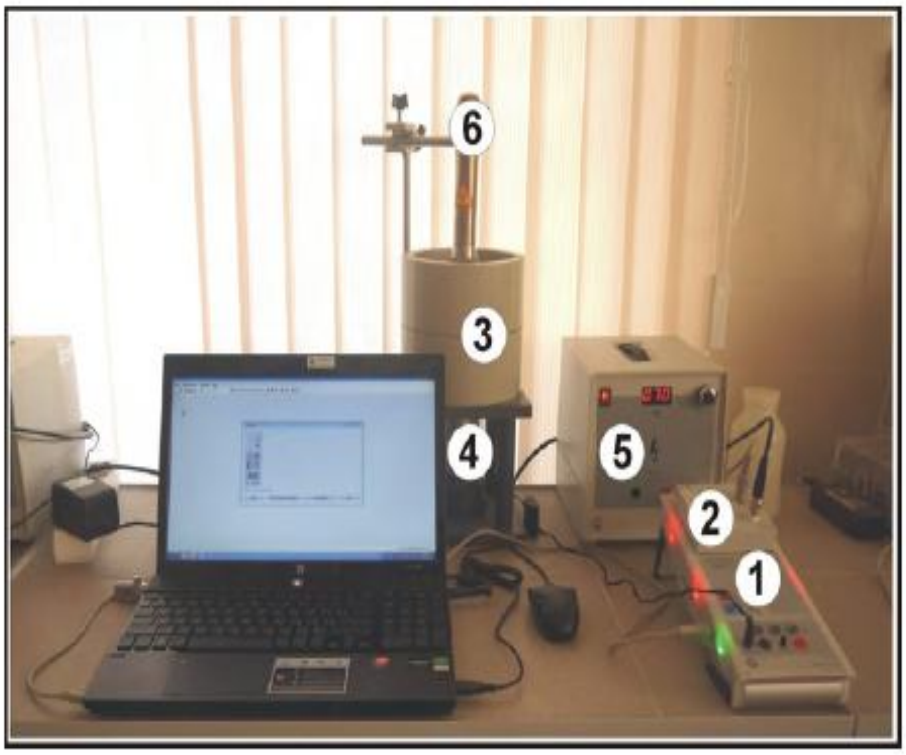

Figure (4.1). The experimental setup.

4.2. Equipment Used:

1 – the CassyLab2 data acquisition unit.

2 – the multichannel analyzer module.

3– the scintillator screening.

4 – the scintillation detector;

5 – the high-voltage scintillator power supply.

6 – the holder for the beta radioactive source

4.3. Theory:

$$E = E_o\, e^{-\mu d} \quad (4.1)$$

$$E_\beta + E_\nu = E_o \quad (4.2)$$

$$E_\nu = \frac{d\,E}{d\,x}\, d_o \quad (4.3)$$

Where:

E ≡ Beta energy at thickness d.

E_o≡ Beta energy at thickness zero.

μ ≡ Attenuation coefficient.

d ≡ Al thickness.

E_ν ≡ Neutrino energy.

4.4. Procedure

4.4.1. Energy calibration

The equipment was connected and the other preparation from the vicinity of scintillation counter was removed, the" MCA" program was started and sated, the voltage was slowly increased to adjust the ^{90}Sr spectrum distributed over all canals, after that replaced ^{90}Sr with ^{22}Na.

4.4.2. Beta Spectrum of ^{90}Sr:

Measured the background radiation and but the ^{90}Sr and measured the maximum energy (at thickness = 0) , after that lay a 0.5 mm thick aluminum plate as an absorber over the scintillation counter and measured energy passed throw it and repeat the measured with other absorber thickness and recorded the result in the table (5.1)

Chapter Five

Results and Discussion

5.1 Results :

The experimental results were shown in the table below

Table (5.1) Maximum βenergy E as a function of the absorber thickness(d).

$\boldsymbol{d}\ (\pm 1\ \boldsymbol{mm})$	$\boldsymbol{E}\ (\pm 1 \boldsymbol{kev})$
0.0	1840
0.5	1540
0.1	1310
1.5	1160
2.0	870
2.5	620
3.0	496

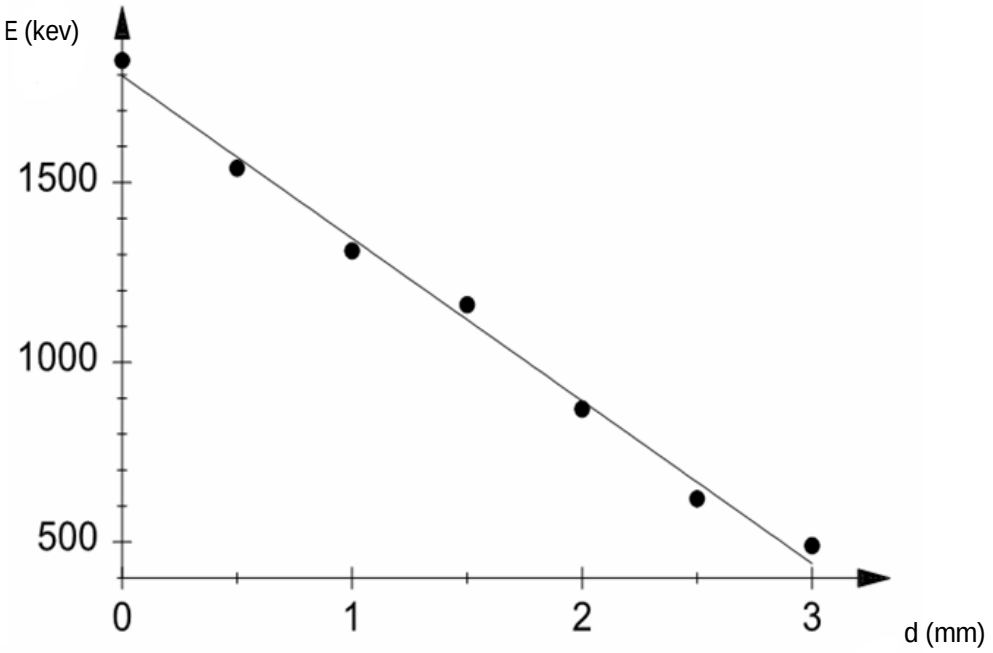

Figure (5.1) Maximum β energy E as a function of the absorber thickness d.

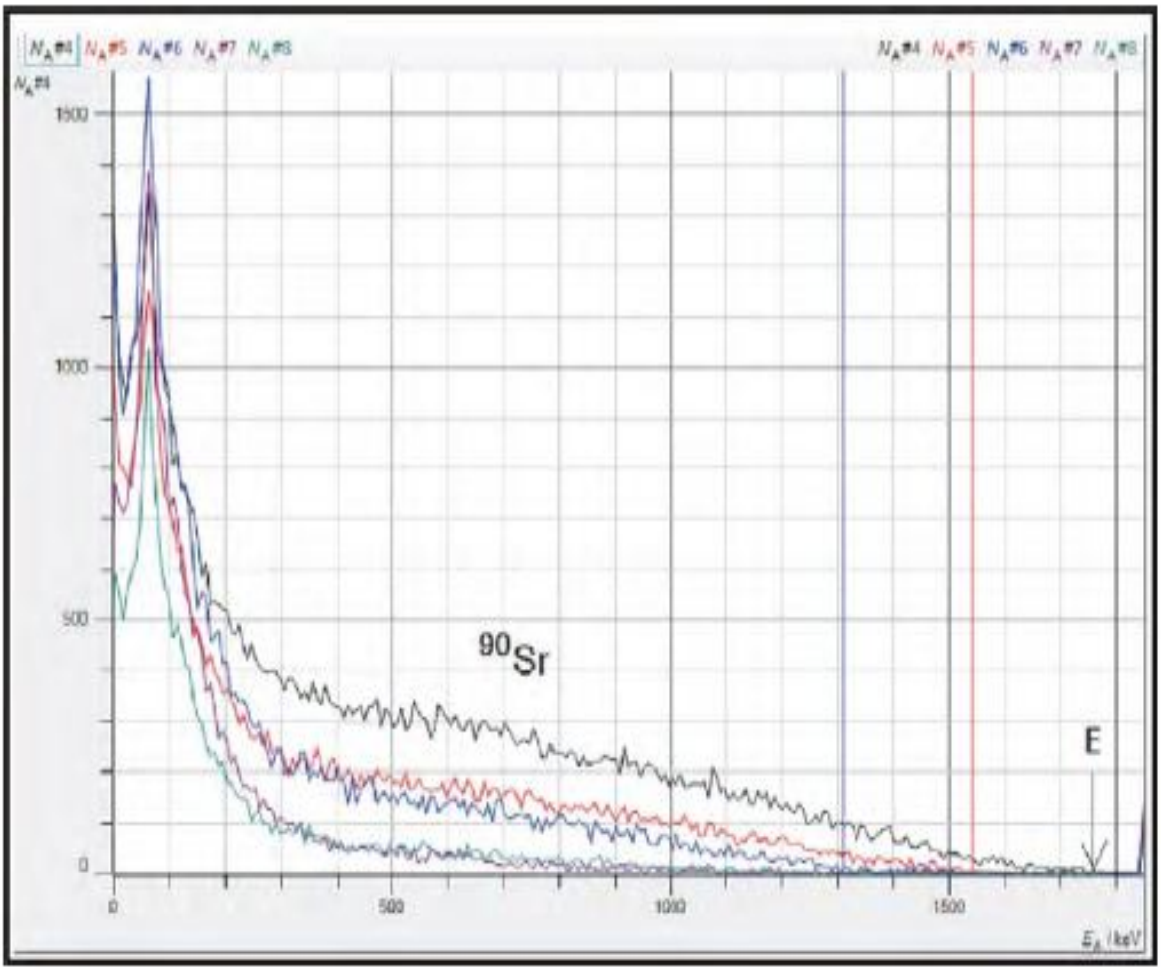

Figure (5.3) : Beta spectrum of Sr^{90} without absorber (black line) and with an aluminum absorber (colored lines) of different thickness.

5.2 Discussion:

Figure(5.1) shows the βspectrum of ^{90}Sr measured with the scintillation counter. The relation between energy and penetration depth is linear. transition from ^{90}Y to ^{90}Zr

Fig (5.2) shows the spectrum of ^{90}Sr for deferent Al having deferent thickness. It is clear from figures (5.1) and (5.2) that increasing thickness decrease energy.

In Fig.(5.1) the dependence of the maximum β energy E on the thickness d of theAluminum absorber is shown graphically. The slope of the straight line drawn in the plot corresponds to the energy loss per path length of theβ-particles in aluminum: $\frac{dE}{dx}$ = 452 keV/mm

Value quoted in the literature

$$\frac{dE}{dx} = 410 \text{ keV/mmat} E_\beta 2000\text{keV}.$$

Thus the empirical value obtained in this work conforms with that in the lifetime.

The aluminum screening of the scintillation counter (d_0 = 0.4 mm) causes a further energy loss of the βparticles:

$$\Delta E = \frac{dE}{dx} d_0 = 180\text{keV}$$

The maximum energy of the βparticle escaping from the ^{90}Sr radioactive source

thus is:

$$E_\beta = 1840 \text{ keV} + 180 \text{ keV} = 2020 \text{ keV}.$$

5.3. Conclusion

The spectrum of β from ^{90}Sr s

hows inverse linear relation between maximum energy and absorber increase.

5.4. Recommendations:

From the results above we recommended to use Aluminum thickness about 4 cm to stopped beta for passed throw it.

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