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Detection of Gamma Rays Using a Sodium Iodide Detector Doped with Thallium Nal(TI)

الكشف عن اشعة كاما باستخدام كاشف يوديد الصوديوم المطعم بالثاليوم Nal(TI)

by student

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Supervisor Certification

I certify that the subject of the research titled “Detection of gamma rays using a sodium iodide detector doped with thallium (Nal(TI))” and completed by the student Baneen Hussein Kadhim Abdullah was prepared under my supervision at the Department of Physics / College of Science /University of Babylon, as partial fulfillment of the requirements for the bachelor's degree of science in physics. This is for the period from 10/1/2023 until 4/1/2024

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the date:

بسم الله الرحمن الرحيم

(وَرَحْمَتِي وَسِعَتْ كُلَّ شَيْءٍ فَسَأَكْتُبُهَا لِلَّذِينَ يَتَّقُونَ وَيُؤْتُونَ الزَّكَاةَ وَالَّذِينَ هُمْ بِآيَاتِنَا يُؤْمِنُونَ)

(الأعراف 156)

May God grant us success in completing this humble research, and we can only extend our sincere thanks and great gratitude to everyone who provided us with a helping hand to complete this work and provided us with advice, guidance, and direction during the research, study, and preparation of this research.

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Abstract

NaI(Tl) scintillation detectors operate on the principle of scintillation, where incoming gamma rays interact with the NaI crystal, causing it to emit flashes of light (scintillations). These scintillations are then converted into electrical signals for analysis.NaI(Tl) detectors are effective in detecting gamma rays with energies ranging from a few keV to several MeV.The detector consists of a NaI crystal doped with thallium (Tl), which enhances the scintillation process. The crystal is coupled to a photomultiplier tube (PMT) that converts the light into an electrical signal.NaI(Tl) detectors are highly sensitive to gamma rays, making them suitable for a wide range of applications, from medical imaging to environmental monitoring.They offer good energy resolution, meaning they can distinguish between gamma rays of different energies. This is important for identifying specific isotopes emitting gamma radiation.

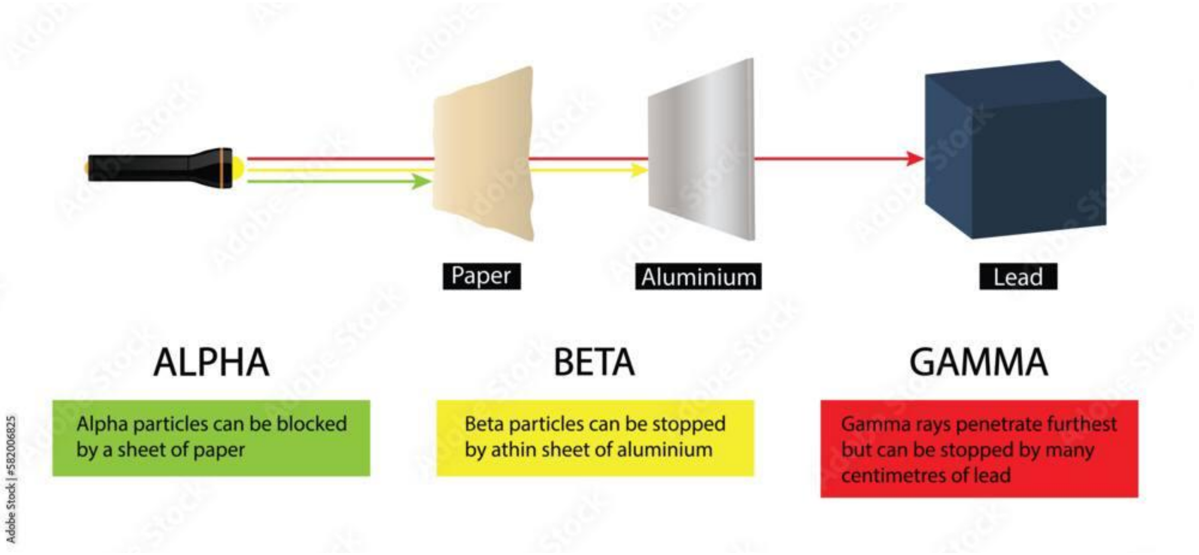
Keywords: scintillator,scintillation detector, ionizing radiation,Non Ionization Radiation,

Contents

Chapter One

1 . Introduction

Radiation is the emission or transmission of energy as waves or particles through space or through a material medium which is able to penetrate various materials and is often categorized as either ionizing or non-ionizing depending on the energy of the radiated particles. Radiation processing can be defined as exposure of materials with high energy radiation to change their physical, chemical, or biological characteristics, to increase their usefulness, and safety purpose, or to reduce their harmful impact on the environment. Ionizing radiation is produced by radioactive decay, nuclear fission, and fusion, by extremely hot objects, and by particle accelerators. The radiation coming from the sun is due to the nuclear fusion; therefore, we are living in a natural radioactive world. Radioactive substances are common sources of ionized radiation that emit α, β, or γ radiation, consisting of helium nuclei, electrons or positrons, and photons, respectively. Alpha rays are the weakest form of radiation and can be stopped by paper. Beta rays are able to pass through paper but not through aluminum. Gamma rays are the strongest radiation. They are able to pass through paper and aluminum, but not through a thick block of lead or concrete. Alpha and beta radiation are the high energy subatomic particles where gamma radiation is a form of high energy electromagnetic waves. This review presents the fundamental introduction of radiation, the three types of radiation, and their applications [1].



Figur (1.1) illustration of chemistry and physics, three types of radiation are alpha particles, beta particles, and gamma rays, They differ in mass, energy and how deeply they penetrate people and objects

1 .1 Types of Radiation

The word radiation is associated with three words: emission, transmission, and absorption, and therefore the precise definition, The word radiation means energy in a state of transfer (Energy in Transient), and radiation takes the form waves or particles, and their energy depends on their source. Radiation is generally of two types (ionizing and non-ionizing).

1.1.1 Non Ionization Radiation

Non-ionizing radiation means any type of radiation that does not have enough energy to cause a compositional change in Atoms or molecules, meaning that it does not cause complete separation of the electron of the atom or molecule, and therefore it is ot produced It has ions with a charge, but it may only cause instability resulting from moving the electron to another orbit with the acquisition of higher energy, however, there are some effects of some types of radiation onizing radiation, especially when exposed to a lot of it. In general, non-ionizing radiation causes heat the tissue exposed to it. Non- ionizing radiation is emitted from natural sources such as sunlight and man-made sources such as wireless communications and from the use of some industrial, scientific and medical applications, examples of which are: Radio, microwave, light, infrared, ultraviolet and laser radiation[2].

1.1.2 Ionization Radiation

Ionizing radiation is a term used for any radiation that is capable of ionizing (i.e., removing electrons from) atoms or molecules of the medium being traversed. Ionizing radiations are usually classified as either electromagnetic or particulate. X-rays and γ-rays are both electromagnetic radiations. They do not differ in nature, but their designation reflects their origin; X-rays are produced by extranuclear processes and γ-rays by intranuclear processes. These types of radiation are often classified as indirectly ionizing, because the chemical and biological damage is dominated by the charged particles (mainly electrons) produced as a result of interactions within the medium. Neutrons are also classified as indirectly ionizing. They deposit energy and cause damage through recoil protons, α-particles, and nuclear fragments that result from neutron interactions. Particulate radiations include electrons, positrons, protons, neutrons, α-particles, and other ions. With the exception of neutrons, all of these particles are charged and are classified as directly ionizing (if they have sufficient energy) because they directly ionize the medium they are traversing, producing chemical and biological damage. The human body can be irradiated either from external sources or through internal exposure as a result of ingestion, inhalation, dermal absorption, or injection of radionuclides. The effects of radiation are directly related to the dose received by individual cells or organs, and by the radiation quality. Therefore, these effects can vary significantly, depending on the resulting dose distribution or distribution of radionuclides throughout the body. The dose distribution may vary from being essentially uniform after whole-body exposure to being highly heterogeneous in the case of non-uniform distribution of internal radionuclides that emit short-range α-particles or β-particles. Medium- to high-energy X-rays, γ-rays, and neutrons are typically highly penetrating and will traverse the body, whereas α-particles and β-particles typically have a short range (for α-particles, less than 100 µm, and for β-particles, from less than 1 µm to several millimetres). In general, the penetration range of charged particles can vary significantly depending on their energy and the type of particle[3].

A - Particles or particles, which are divided into

1 - Alpha Ray

Alpha particles, also knowing as alpha rays or alpha radiation, consisting of two protons and two neutrons bound together into a particle identical to a helium-4nucleus. They are generally created in the course of alpha decay, but may also be produced in other ways. It was named after the first letter in the Greek alphabet, α. As they are identical to helium nuclei, they are also denoted as He^{2+} or ${}^{4}_{2}He$ indicating a helium ion with a +2 charge. The alpha particle becomes a normal helium atom ${}^{4}_{2}He$ by getting electrons from the external source. The net spin of alpha particle is zero. By following the mechanism of their production in standard alpha radioactive decay, alpha particles automatically charged with a kinetic energy of about 5 MeV, and a velocity in the vicinity of 4% in comparison with the speed of light. Although they are a highly ionizing form of particle radiation, have low penetration depth. However, long range alpha particles from ternary fission are considered three times as energetic, and penetrate three times as far. The helium nuclei forming 10–12% of cosmic rays are usually much higher energy than those produced by nuclear decay processes, and thus may have highly penetration and able to traverse the human body and also many meters of dense solid shielding, depending on their energy. To a lesser extent, this is also applicable to the very high energy helium nuclei produced by particle accelerators[4]

2 - Beta Ray

A beta particle (β) is either an electron or a positron that is ejected from the nucleus in the process of nuclear decay. The β-particle is typically an electron formed by the decay of a neutron (yielding both an electron and proton). A beta particle an also be a positron (a positively charged electron), but the lifetime of the positron (which is essentially an anti-electron) is very short. Beta particles have very low mass. Emission of a beta particle results in the transformation of the beta-emitting parent atom into a daughter, the atomic number of which is one greater; the atomic mass remains unchanged (because a neutron and proton have nearly identical mass). For example, 90Sr decays via beta particle emission to 90Y, which has an atomic number one greater but the same atomic mass. Beta particles emitted by radioisotopes exhibit a range of energies that extends from near zero to a maximum, which is characteristic of that radioisotope. These maximum energies extend from several kilo electron volts (keV) to several mega electron volts (MeV)[5].

3 - Neutrons

Neutrons are considered the second component of the nucleus, in addition to protons. They are almost similar to protons in their mass and size. They are an electrically neutral particle that is released with nuclear energy from the unstable nucleus during its fission. The danger of neutrons lies in the fact that they are electrically neutral particles, as they can penetrate the nuclei of atoms very easily and can be obtained from nuclear reactions, And fission[2].

B - Electromagnetic rays are divided into:.

1 - Gamma Ray

The gamma radiations are transmitted from the radioactive nuclide as photons, not particles; that implies that they haven't a mass or charge. The radionuclides are decayed in the form of gamma radiations, the process not accompanied by any change in the atomic number or the atomic mass. Being radiation, the gamma rays have no mass so have high penetration power more the beta particles. Due to the absence of the charge, the gamma radiations have no destructive effect. Technetium-99m is an example of a radionuclide which decayed in form of gamma radiation [7]. Gamma ray energies range from 104 to 107 eV. They are often emitted as a part of a nuclear reaction, when an atomic nucleus is left in an excited state, or during an isomeric transition. Gamma rays also can be emitted following alpha-particle decay, beta-particle decay, or orbital electron capture, if the daughter nuclide is left in an excited state [6]. Gamma radiation passes through living materials easily. Also referred to as "photons" they travel at the speed of light. Gamma rays have sufficient energy to ionize matter. Isotopes of elements that are emitters are radionuclides important in fission products from nuclear testing, nuclear power plant disasters or waste [6].

2 - X-Ray

X-rays agree with gamma rays in nature and properties, as they are electromagnetic waves and differ only in their origin and energy. X-rays are generated artificially, and their energy and frequency are slightly lower than gamma rays. Due to their high penetration ability, Lead is considered suitable for manufacturing radiation-protective shields [7].

1 .1.3 Natural radiation sources

There are about 340 isotopes of various elements in nature. 20% of these are active, and most of the radioactive isotopes are heavy elements. Every element with an atomic number of more than 80 has radioactive isotopes. Natural sources of nuclear rays on the surface of the Earth are classified into two types:

1 - Cosmic rays

Cosmic rays are a population of energetic elementary particles and nuclei with a steeply falling near-power law spectrum extending from a few MeV to tens of Joules per particle. Primary cosmic rays can be measured directly by experiments in space or on balloons at energies where there is sufficient flux. Atmospheric interactions of primary cosmic rays produce fluxes of secondary elementary particles which can be detected in the atmosphere, at the Earth’s surface, and underground. At high energies, air showers of particles generated by a single primary can be detected. These showers can be reconstructed to determine the energy, direction,

and composition of the incident particle. Energetic neutrinos are closely linked to high energy cosmic rays, both through their production at astrophysical sites of particle acceleration and by production during propagation of extremely high energy cosmic rays[8].

2 - Terrestrial Radiation

Natural radioactive materials are widely spread in the Earth's crust, as the Earth contains many radioactive sources, several of which have decayed with the time estimated for the Earth's age (about four thousand years). The remaining radioactive sources on Earth to this day must have a half-life longer than the age of the Earth, and this type is called primary terrestrial sources. As for what currently exists of radioactive materials with half-lives that are much less than the age of the Earth, which are called secondary, they are derived in a different way from sources. Home or from cosmic rays[9].

1 .1.4 Industrial Sources of Radiation

Other sources of radiation include emissions of radioactive materials from nuclear facilities such as uranium mines, fuel processing plants, and nuclear power plants; emissions from mineral extraction facilities; and the transportation of radioactive materials. Workers in certain occupations may also be exposed to radiation due to their jobs. These occupations include positions in medicine, aviation, research, education, and government [8].

1 .2 Interaction of radiation with matter

Gamma rays interact with materials through three main phenomena, which are: -

1 - Photoelectric Effect

The photoelectric effect is a cornerstone textbook experiment in any Modern Physics or Advanced Laboratory course, designed to verify Einstein’s theory of the photoelectric effect, with the implicit determination of an experimental value for Planck’s constant and the demonstration of the particle nature of light. The standard approach to the experiment is to illuminate the light-sensitive cathode of a vacuum-tube photocell with monochromatic light of known wavelengths; a reversed-voltage is then applied to the photocell and adjusted to bring the photoelectric current to zero. The stopping voltage is then plotted as a function of the inverse wavelength or frequency of the incident light, and Planck's constant is determined from the slope of the graph. The photoelectric effect is a cornerstone textbook experiment in any Modern Physics or Advanced Laboratory course, designed to verify Einstein's theory of the photoelectric effect, with the implicit determination of an experimental value for Planck's constant and the demonstration of the particle nature of light. The standard approach to the experiment is to illuminate the light-sensitive cathode of a vacuum-tube photocell with monochromatic light of known wavelengths; a reversed-voltage is then applied to the photocell and adjusted to bring the photoelectric current to zero. The stopping voltage is then plotted as a function of the inverse wavelength or frequency of the incident light, and Planck's constant is determined from the slope of the gradient[10].

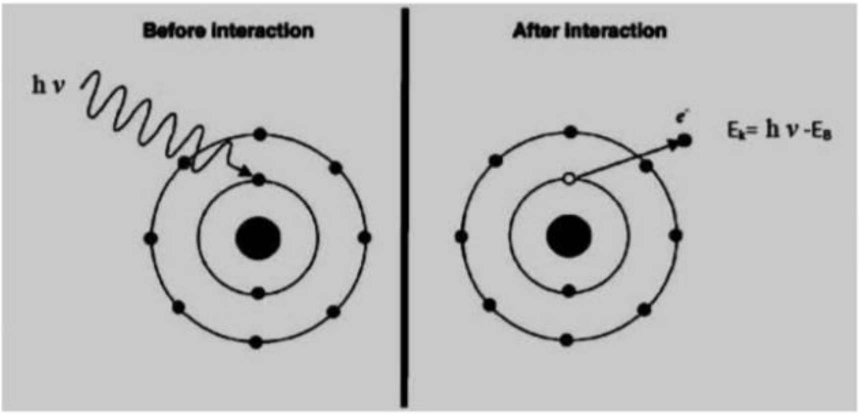


Figure (1.2) represents an illustration of the photoelectric phenomenon

2 -Compton effect

Compton scattering has been a key concept in atomic and molecular physics, material science, condensed matter physics, and other fields ever since it was originally discovered by Arthur H. Compton in 1923. Additionally, the Compton camera, one of the applications of Compton scattering can gather sufficient data and information about photons with energies above 500 keV, which is important for scientific research into astronomy, medical imaging, and the visualization of radioactive materials. The free electron approximation, the impulse approximation, and the scattering matrix are some of the methods used to arrive at the Compton formula and the underlying[11].

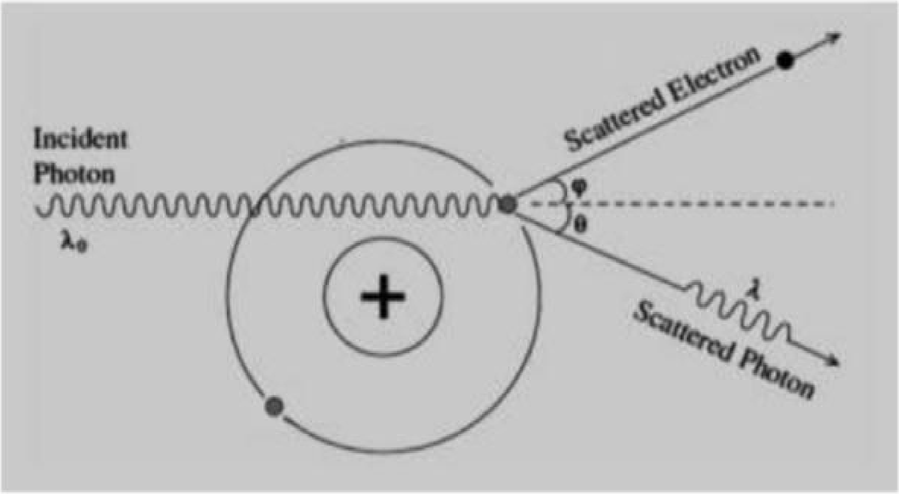


Figure (1.3) represents an illustration of the Compton effect

3 -Pair Production

This interaction occurs in the nucleus field of the absorbing medium, and at this location the electron will create a positron, as the photon is completely absorbed. The static energy ($m_o c2$) for both the electron and the positron is equal to (0.511

MeV). Therefore, the production of an electron-positron pair requires that the energy of a gamma ray photon be at least equal to 1022 20.51. Any increase in the photon energy over this amount appears in the form of kinetic energy for the electron and positron and is given by the following formula [12].

$T_{e^-} + T_{e^+} = E_\gamma - (m_o c^2)_{e^-} - (m_o c^2)_{e^+}$ ---------------- (1.1)

$T_{e^-} + T_{e^+} = E_\gamma - 1.022\,\text{MeV}$ ---------------------- (1.2)

1 .3 The Basic Dosimetric Quantity and effectiveness

1.3.1 Absorbed, equivalent and effective dose

The main dosimetric quantities used in radiological protection are absorbed dose (D), with the unit of gray (Gy), and equivalent dose (H) and effective dose (E), both with the unit of sievert (Sv); the SI base unit is J kg-1 in each case. Absorbed dose is calculated for protection purposes as an average over organs and tissues or regions within tissues and is the primary scientific quantity from which E is calculated. The ICRP protection quantities – equivalent dose (H) and effective dose (E) – enable the summation of doses from external sources and from internal emitters to provide a single number for comparison with dose limits, dose constraints and reference levels that relate to potential stochastic effects of uniform whole-body radiation exposure; that is, risks of developing cancer and of heritable effects. The primary application of E is in the planning of protection and demonstration of compliance in various situations of exposure of workers and members of the public. Two risk-adjustment steps are taken in the calculation of E from D. Because radiation types differ in their ability to cause biological effects including cancer, calculated values of absorbed dose are multiplied by radiation weighting factors (wR) that take account of the greater effectiveness of densely ionising radiations including alpha particles and neutrons compared to sparsely ionising beta particles and gamma rays. The result is termed equivalent dose, with the unit: sievert (Sv). The final step is to sum the equivalent doses to individual organs and tissues, multiplying each by a tissue weighting factor (wT) that represents its contribution to total detriment from uniform whole-body irradiation. Thus, effective dose is a doubly weighted average of organ/tissue absorbed doses. The intention is that the overall risk per Sv should be comparable irrespective of the type and distribution of radiation exposure.

$$\begin{aligned} E &= \sum_{\mathrm{T}} w_{\mathrm{T}} \sum_{\mathrm{R}} w_{\mathrm{R}} D_{\mathrm{T,R}} \\ &= \sum_{\mathrm{T}} w_{\mathrm{T}} H_{\mathrm{T}} \end{aligned} \qquad \text{------------------} \quad (1.3)$$

where D_T, R is absorbed dose from radiation, R, to organ/tissue, T, and HT is equivalent dose to organ/tissue[13].

1.3.2 Effective dose

The fundamental physical quantity used in radiological protection for quantifying exposure to all types of ionising radiation is the absorbed dose, expressed in joules per kilogram (J/kg); more specifically, the mean absorbed dose in an organ or tissue T, called the ‘tissue absorbed dose’, D_T. It is assumed that, for low doses, the mean value of absorbed dose resulting from exposure to ionising radiation in a specific organ or tissue can be correlated with radiation detriment from stochastic effects in that organ or tissue with sufficient accuracy for the purposes of radiological protection. The quantity ‘equivalent dose’ in an organ or tissue, H_T, has been introduced in order to account for radiation quality (i.e., for differences in biological effectiveness of different types of ionising radiation). HT is defined as the sum of products of the radiation weighting factors, w_R, and D_T, R, where the sum is taken over radiations of type R. The values of w_R have been selected by ICRP based on radiobiological information. Only three discrete values (1, 2, 20) are used (except for neutrons for which wR is given by an energy-dependent function) (ICRP, 2007). Effective dose, E, as defined in Publications 60 and 103 (ICRP, 1991, 2007), is the sum of organ and tissue equivalent doses, H_T, each weighted by a specific tissue weighting factor, w_T

$$E = \sum_T w_T \sum_R w_R D_{T,R} = \sum_T w_T H_T \qquad \text{---------------- (1.4)}$$

The concept on which E is based includes the assumptions that:

-at low doses, the total radiation detriment to the exposed person is given by the sum of radiation detriments to the single organs/tissues; and

-equivalent dose to organs/tissues is linearly correlated with detriment and there is no dose threshold: a linear non-threshold dose–response model [14].

1 .4 Previous studies

Khaled Hussein Attia and Yousef Habib Kadhim Al-Sultani in 2017 studied the angle between the detector and the radioactive source on the energy spectrum using a scintillation detector Nal(TI) . The results of this study were that The effect of the angle between the detector and the radioactive source on the energy spectrum using an electronic counting and analysis system using a flash detector crystal Nal(TI) with a size of (2*2) and at angles (˚,90˚,70˚,40˚,20˚0), and the distance between the radioactive source and the detector was 30 cm, the two radioactive sources ^{22}Na and ^{137}Cs were used in this study. It was found from the current study that the total area of the spectrum (area total) and the area under the optical peak, which represents the complete absorption of energy a gamma ray photon inside the detector crystal, and the interaction that results in that peak is the photoelectric interaction and it is the most important part of the spectrum regions where most calculations are determined by determining its location or mid width, because its location and mid-width changes (increases) depending on the energy of the photon interacting with it.The detector material (directly proportional) or by changing (increasing) high voltages, amplification, or the number of analyzer channels, and thus is considered the basis for determining the ability to analyze

The energy of the detector in the energy spectrum for gamma rays was found to decrease when the angle between the radiating source and the detector was changed. When the angle between the radiating source and detector reduce the number of photons reaching the detector, and the angle 90˚ records the least number of photons reaching the detector.

In 2011, Lewis R. Dartnell studied Ionizing Radiation and Life and the results he obtained were as follows: Ionizing radiation is a ubiquitous feature of the Cosmos, from exogenous cosmic rays (CR) to the intrinsic mineral radioactivity of a habitable world, and its influences on the emergence and persistence of life are wideranging and profound. Much attention has already been focused on the deleterious effects of ionizing radiation on organisms and the complex molecules of life, but ionizing radiation also performs many crucial functions in the generation of habitable planetary environments and the origins of life. This review surveys the role of CR and mineral radioactivity in star formation, generation of biogenic elements, and the synthesis of organic molecules and driving of prebiotic chemistry. Another major theme is the multiple layers of shielding of planetary surfaces from the flux of cosmic radiation and the various effects on a biosphere of violent but rare astrophysical events such as supernovae and gamma-ray bursts.

The influences of CR can also be duplicitous, such as limiting the survival of surface life on Mars while potentially supporting a subsurface biosphere in the ocean of Europa. This review highlights the common thread that ionizing radiation forms between the disparate component disciplines of astrobiology.

1.5 Objective of the research

Research in this field aims to expand our understanding of the interaction of gamma rays with nuclear materials and use this knowledge to develop new technologies and applications and study the calibration of the detector.

Chapter Two

2.1 General Introduction

Reagents are substances or compounds that are used in chemical reactions to bring about a chemical change or to detect another substance. They are typically added to a chemical reaction to cause a chemical transformation, to test for the presence of specific chemicals, or to help analyze the properties of a substance. Reagents are an essential part of chemical reactions and are used in various fields such as chemistry, biology, medicine, and industry. In this chapter, we will learn about scintillation detectors, the usefulness of the scintillation detector, the scintillation process, and the photomultiplier.

2.2 Detectors

All nuclear measurements require special devices to detect and record different types of nuclear radiation. These devices are known as radiation detectors. These detectors are generally used to determine the type of radiation. Radiation, measuring its quantities and determining its energy. The type of detector used depends on several factors, the most important of which are:

A. The type of particles or radiation to be detected (heavy charged particles or electrons, x-rays, gamma radiation, or neutrons).

B. The energy of these radiations.

C. The intensity of radiation or its flux density

D.The nature of the place in which the specific detector will be placed.

The principle of radiation detection in many detectors is based on the use of ionization or excitation phenomenon Radiation of atoms or molecules of matter when passing through it. As for the resulting secondary particle or rebound nucleus, and this particle or nucleus carries a large portion of energy The incident neutron thus ionizes the substance and forms electron-ion pairs.

In the case of gamma radiation or X-rays, the secondary electrons resulting from the impact or effect compton, or the production of pairs by the process of ionization of matter and the formation of electron-ion pairs from it. Therefore, all heavy charged particles such as alpha particles, protons, ions and fragments belong nuclear fission, charged particles such as electrons, etc., X-rays, and gamma radiation What is known as ionizing radiation, and there are other types of detectors that depend on their work to occur Some chemical changes in its substance. By measuring these resulting changes, the amount of radiation can be detected. These types of detectors are characterized by weak sensitivity, so they are only used in very intense radiation fields[15].

Types of detectors

1 - Gas-filled detectors.

2 - Neutron Detectors.

3 - Semiconductor Detectors.

4 - Scintillation and Cherenkov detectors.

5 - Solid Scintillators.

6 - Liquid Scintillators.

7 - Inorganic scintillators.

8 - Organic scintillators.

9 - Cherenkov detectors.

10 - Advanced Detectors[16].

Detection methods can be classified as follows:

(a) Collection of the ionization produced in a gas or solid.

(b) Detection of secondary electronic excitation in a solid or liquid scintillator.

(c) Detection of specific chemical changes induced in sensitive emulsions[15].

2.3 Scintillation Detector NaI(Tl)

Scintillation detectors are considered one of the most important types of detectors used in detecting ionizing radiation. Their work depends on the fact that when some materials pass through ionizing radiation, they emit flashes of light, which in turn fall on the photocathode, which emits an electron. The amount of electrons generated is usually small, so their number must be increased or They are amplified before they are recorded as a pulse, and the amplification or doubling of these electrons is done using a device called a photomultiplier tube, which has a power of amplifying the pulse to about 10^6 times, and when this detector is connected to an amplifying device such as a photo amplifier, these flashes can be converted into an electronic pulse to give information about the radiation. The fallen one[10].

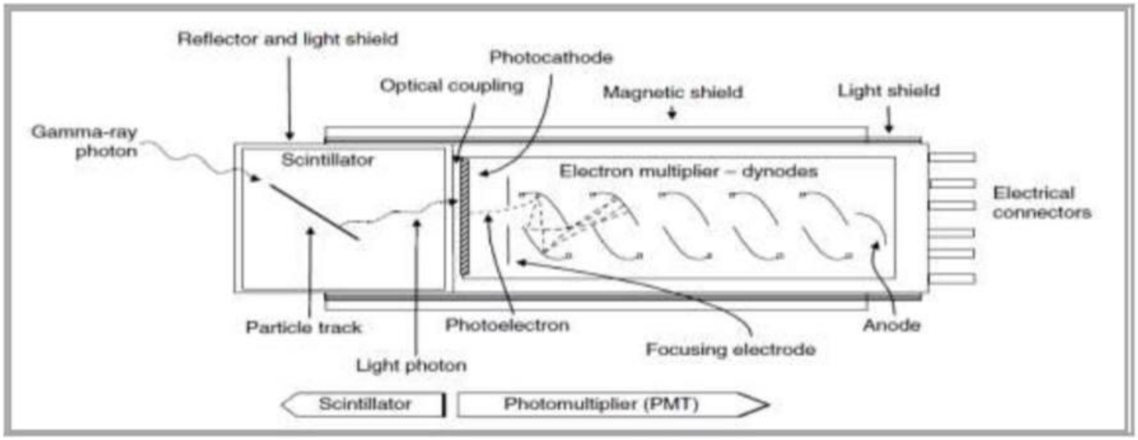


Figure (2.1) Installation of the flashing detector

Thus, the detection process using a scintillation detector can be summarized into six stages arranged as follows:

1 - Absorption of the energy of a nuclear particle within the scintillating material, which leads to the excitation or ionization of this material The energy absorbed in matter is converted into light during the flash process

2 - The transfer of light photons to the photocathode of the multiplier tube.

3 - The cathode absorbs the energy of light photons and emits electrons from it.

4 - The number of electrons inside the photomultiplier tube doubles.

5 - These electrons are collected at the tube anode and form a large electrical charge

6 - The signal is amplified and collected at the anode and then passed to the measurement circuit

7 - Inorganic crystals are among the preferred materials in such reagents because they have good properties such as their density. for example. Sodium iodide and cesium iodide doped with thallium (Nal(TI) and (CSI(TI)) are types Suitable for

detecting gamma rays because they have high detection efficiency. Scintillation detectors are used to detect all types of ionizing radiation, and an iodide detector has been used Sodium doped with thallium to detect gamma rays due to its high efficiency due to its large density and large the atomic number of thallium and iodine (which is considered higher than the efficiency of other meters for this type of radiation by about several tens or even several hundred times[17].

2.4 The photodetection process

The photodetector converts scintillation photons into photoelectrons at a photocathode or into electron–hole pairs in a semiconductor. This process is essentially instantaneous and occurs with a probability called the quantum efficiency. These conversion products are then drifted and amplified by electric fields to produce useful pulses. For estimating timing precision, the most important characteristics of the photodetector are the quantum efficiency as a function of photon wavelength, the shape of the single photoelectron output pulse, and the output pulse time jitter. Specific examples are given in later sections[18].

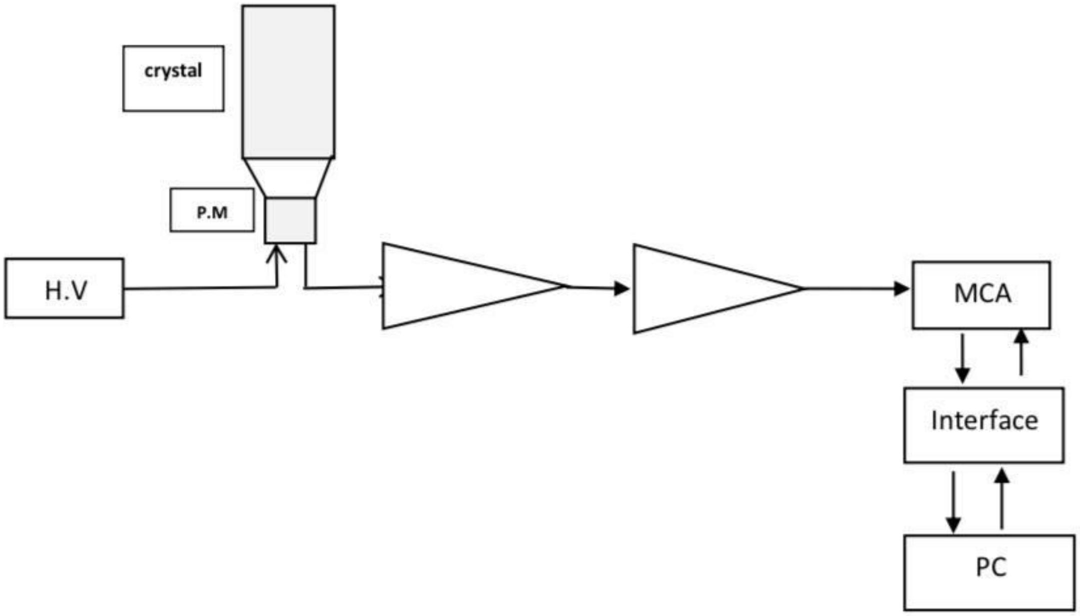


Figure (2.2) Thallium-Grained Sodium Iodide Reagent System Nal(TI) (3”x3”)

2.5 Photomultiplier

Photomultipliers (the devices are often abbreviated to PMT) convert light into an electrical signal; they are available in numerous configurations and unsurpassed in their versatility and in many instances in their sensitivity. Despite being devices requiring an evacuated enclosure, i.e. they are not solid-state devices, they are still widely used when high speed photon counting is required. Photomultipliers consists of a photocathode, where photons are converted into electrons, making use of the photoelectric effect), a multiplier chain (strings of successive electron absorbers with enhanced secondary emission, called dynodes, the entire string using electric fields to accelerate electrons), and an anode, which collects the resulting charge or current. PMTs vary in speed and linearity of response, in the time fluctuations of the signal, in amplification factor i.e. gain, in the wavelength spectrum accepted, etc. The photocathode is typically held at a potential of -500 to

-2000 volts relative to the anode. The photoelectron is accelerated towards a series of additional electrodes called dynodes. These electrodes are each maintained at successively less negative potentials. Additional electrons are generated at each dynode. This cascading effect creates 105 to 107 electrons for each photoelectron that is ejected from the photocathode. The output signal is collected at an anode maintained at ground potential. The principle advantage of a PMT is that it provides almost noiseless amplification of light signals –but remember that light consists of quanta and hence Poisson noise is inevitable[19].

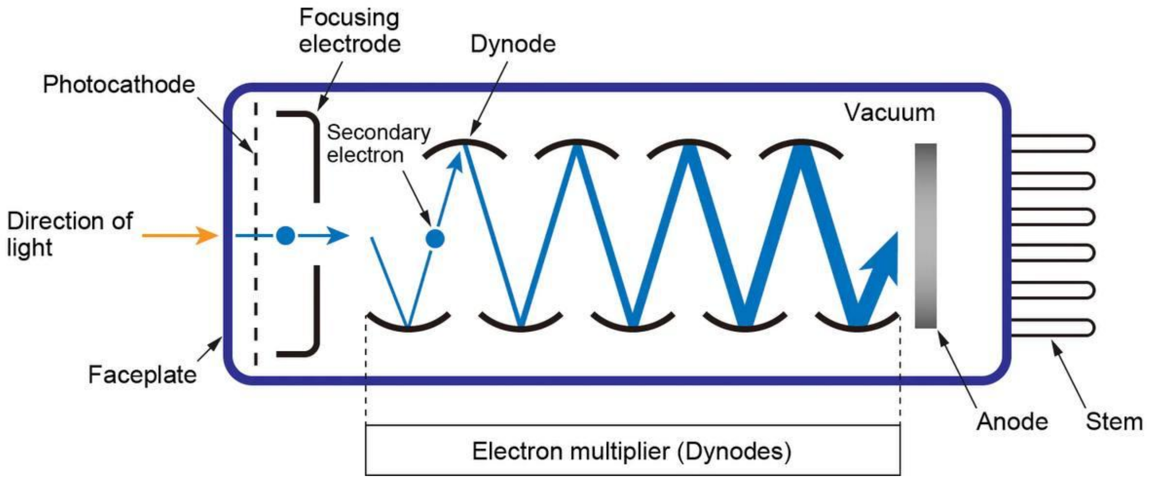


Figure (2.3) Construction of a photomultiplier tube

2.6 Detector efficiency

Organic reagents are used to detect beta rays and inorganic reagents are used to detect photons because of their high efficiency. The detection efficiency for the first is 100%, while the second depends strongly on the energy of gamma rays. The efficiency of photon detection can be determined by calculating the absorbed portion inside the crystal and based on the decreasing exponential relationship of absorption. Photons in matter are:

$$I = I_o e^{-MX} \quad \text{-------------------} \quad (2.1)$$

Whereas the absorption coefficient M strongly depends on the energy of the photons, and X represents the thickness of the crystal. What is absorbed inside the crystal is the difference between the incident rays 1 and the transmitted rays[20].

2.7 Features of the scintillation detector

1- Its high density makes it easy to measure gamma rays, as it has a high absorption of gamma rays the sensitivity of the meter increases to measure the commonly used crystals: sodium iodide crystals Activated with thallium

2- The sensitive crystal is located in the head of the meter in a thin metal case that protects it from falling light and from the entry of moisture that may spoil the crystal consisting of sodium iodide[20].

Chapter Three

3.1 Introduction:

The scintillation detector is considered an important tool and has many uses, which we will discuss later. We will also discuss the calibration of the scintillation detector in terms of efficiency and energy, as the scintillation detector is considered highly efficient, as it can detect other quantities of compounds accurately.

3.2 Applications of Scintillation Detectors

3.2.1 Detection Principle of Charged Particles

Charged particles are principally detected through excitation and ionization or Cherenkov effect. When they enter atoms of target material, they interact with orbiting electrons under Coulomb force. According to theories regarding atomic structure, the energy state is discrete with multiple energy levels, and electrons absorb certain energy to jump to higher energy levels. This process is called excitation of electrons. As electrons gain enough energy to overcome the attractive pull from nucleus, it jumps out to become free electrons, and this is called ionization. Different kinds of detectors adopt three ways to detect charged particles using excitation and ionization: gas, semiconductor and liquid detectors collect ions during ionization; scintillators collect photons multiplied by photomultiplier tube and emitted when excited electrons de-excite and fall to lower energy levels; track detectors like cloud chamber use ion groups as track center to trace charged particles. Cherenkov effect refers to the situation when a charged particle is moving faster than the relative speed of light inside a medium and emits a faint radiation in the range of visible light. As a result, Cherenkov detectors are invented to detect high speed charged particles using photomultiplier tube to magnify the faint radiation[21].

3.2.2 Detection Principle of X or γ rays

X or γ rays are photon beams. These high energy electromagnetic waves cannot be directly detected through excitation or ionization process inside detectors. Rather, they interact with electrons or atomic nucleus through three electromagnetic effects, producing secondary electrons. Detecting these secondary electrons using excitation or ionization inside detectors provides an indirect way to detect X or γ rays. The first interaction is photoelectric effect. The photoelectric effect is the emission of electrons or other free carriers when light shines on a material. γ rays consist discrete quantum called photons, and the energy of each photon is

$E = hf$ --------------------- (3.1)

$h = 6.63 \times 10^{-34}$

where h is known as Planck's constant, and f is the frequency of that single photon as well as the light. When light beam shines on detection material, a single photon of frequency f is absorbed by a single electron in the material, so the electron's energy increases by hf, allowing it to jump to higher energy levels. If the acquiring energy is enough for electrons to overcome the attractive nuclear force with frequency greater than a certain value, secondary electrons will be ejected and excited or ionized in the detector for detection. Where h is known as Planck's constant, and f is the frequency of that single photon as well as the light. When light beam shines on detection material, a single photon of frequency f is absorbed by a single electron in the material, so the electron's energy increases by hf, allowing it to jump to higher energy levels. If the acquiring energy is enough for electrons to overcome the attractive nuclear force with frequency greater than a certain value, secondary electrons will be ejected and excited or ionized in the detector for detection. The last kind of interaction is electron pair effect. When the energy of incident photon is greater than 1.02MeV, it may react with the nucleus, forming an electron and a positron with itself disappearing. The 1.02MeV part of photon energy produces the electron pair based on Einstein's mass-energy equation, and the rest constitutes the original kinetic energy of the electron pair, as shown in the equation below:

$KE_e \pm KE_e + 2m_ec^2 = E_\gamma \; 2m_ec^2 = 1.02MeV$ ------------ (3.2)

Both energy and momentum are conserved during this process, and γ rays are detected by detecting resultant electron pairs. Detecting these secondary electrons produced during photoelectric effect, Compton effect or electron pair effect by ionization and excitation in detectors, the information of original γ rays is collected. Roughly speaking, photoelectric principally happens when the photon energy is low and the number of protons of the interaction atom is high; Compton effect mainly occurs when the proton number is low with intermediate photon energy; electron pair effect mainly occurs when the energy of photon as well as the proton number of reacting atom are high. Since emitting electrons of photoelectric and electron pair effect are of single energy, they are easily detected. Therefore, detection material for γ rays should have possibly great proton number, whether of scintillators (NaI), semi-conductors (Ge) or gas detectors(Xe)[21].

3.2.3 Detection Principle of neutrons

Neutrons carries no charge. With electric neutrality, there’s no Coulomb interaction and negligible electromagnetic interaction due to magnetic moment between neutrons and electrons. Otherwise, neutrons do not experiment Coulomb repulsion from the nucleus, making it easy for strong interaction to occur when neutrons enter the nucleus. The reaction cross section is exceptionally large especially for slow neutron as the long residence time increases the probability for strong interaction to happen. There are multiple interaction types and resultant secondary particles for the strong interaction between the nucleus and neutrons. Therefore, there exist multiple neutron detection ways based on different interaction type and secondary particles.

The first way is nuclear reaction method, which use excitation or ionization of secondary charged particles like protons or alpha particles produced in strong interaction for detection. Since neutrons with low speed and low energy have much greater reaction cross section, this method is mainly used to detect slow neutrons with energy lower than 1MeV. B is the most widely used element as detection material in this case with low cost and relatively good detection efficiency.

The second method is through nuclear recoil. When the energy of incident neutron is large, neutron is elastically scattered away by the nucleus, changing its direction of moving and thus losing a certain amount of energy. This part of energy is transported to the nucleus, so detecting the nucleus allows the detection of neutrons as well as their energy. When the atomic number of the nucleus is low, the recoil energy is the greatest and observations are easily made, so hydrogen atom is the mostly used. This method is principally applied to detect fast neutrons with energy higher than 0.3MeV.

The third means is by nuclear fission. As neutrons and the nucleus underdo nuclear fission, a significant amount of energy will be released. Since the emission energy is much greater than the energy of incident neutrons, this method is mainly adopted to measure the flux rather than the energy of neutrons. Through different nuclear fission material, the detection of both slow and fast neutrons is possible.

The last way is called activation method. When neutrons enter the nucleus, there's possibility for the nucleus to absorb neutrons and becomes a different nuclide of the same element. Since the original nucleus is usually stable, the new nuclide will be radioactive to emit β or γ rays. As a result, β or γ detectors are applied to indirectly detect neutrons, and this method can also be used to produce β or γ emission nuclide. If the effective capture cross section for a single atom is denote by σ, A represents the number of captured neutrons in unit time and unit area 1cm^2 , f is the flux of neutron, the number of neutrons that pass through 1cm2 of target in unit time, N represents the number of atoms in 1cm2 of target, and d is the width of the target, then the relation is summarized below.

$$A = fN\sigma d \quad \text{----------------------} \quad (3.3)$$

These four methods are adopted for neutron detection by detecting secondary particles produced in the interaction between the neutron and the nucleus, and different methods are more suitable for neutrons of different properties[21].

3.2.4 Detection Principle of high energy particles

Particles mentioned above are all in the low energy range, with relatively simple interaction mechanism. For high energy particles, the interaction is much more complicated. Generally speaking, secondary charged particles' average multiplicity increases with energy, and the number of charged particles is Poisson distributed around the average multiplicity. For high energy electrons and γ rays, they produce huge number of secondary particles through cascade shower. During this process, photons and electron pairs are repeatedly converting to each other until the eventual particle energy is too low to support further conversion. The result is lots of low energy electrons and γ rays. When the incident particles have even higher energy, high energy nucleons and mesons will undergo secondary nuclear reaction or decay, and this reaction may happen for many times. The resultant secondary particles can be classified into three categories: nuclear component, meson component, and electromagnetic component, all with very low energy. By detecting the secondary particles produced in various kinds of showers, high energy particles can be measured. Usually, detection of high energy particles happens in high energy physics or detection of cosmic rays[21].

3.3 Scintillation signal provides

1- Sensitivity to energy of the particle striking the scintillator:

Most scintillators have linear response to energy deposited light output $\propto$ exciting energy If photomultiplier is also operated linearly, then scintillator detector can be used as energy spectrometer

2- Fast signal response:

Response and recovery time is short wrt other detectors. Time between two events can be determined very precisely (~100 ps) AND they can also accept very fast counting rates

3- Pulse shape discrimination:

shape of emitted light pulses is different for different particles, in some scintillators. Due to excitation of different fluorescence mechanisms by articles with different ionizing power. Scintillator materials show property called luminescence. When hit by radiation, an ionizing particle, they absorbe and re-emit energy in form of visible light

If re-emission is fast ($<10^{-8}$ sec)the phenomenon is called fluorescence

If re-emission is slower (>10^{-6} sec)the phenomenon is called Phosphorescence[22].

Not all scintillating materials will do a good detector.

Requirements are:

1- High efficiency for conversion of exciting energy of incident particle to fluorescent radiation

2- Transparency of detector to its own fluorescent radiation, so light can be propagated

3- Light emission in spectral range that matches photomulitplier

4- Short decay constant τ

5- types of scintillator materials are used:

Organic crystals, organic liquids, plastics, inorganic crystals, gases, glasses[22].

3.4 Scintillation detector efficiency calibration and Energy calibration

3.4.1 Scintillation detector efficiency calibration

Site in Detector	Conversion Factor	Information Carriers for Tc-99m	Information Carriers forISTRIBUT Cs-137
Scintillation crystal	Scintillation efficiency = 12%	140 keV photon 16.8 keV converted to	662 keV photon 79 keV converted to scintillation photons
Scintillation photons	Each scintillation photon has energy of 3 eV	scintillation photons 5600 scintillation photons	26,480 scintillation photons
PMT at front of photocathode PMT after photocathode	75% absorption at photocathode Photocathode efficiency = 20%	4200 scintillation photons absorbed 840 electrons emitted into PMT spacelott Publish	19,860 scintillation photons absorbed 3972 electrons emitted into PMT space
Dynodes	Multiplication factor = 10^8	84 trillion	400 trillion

[23].

3.4.2 Energy calibration

The energy calibration is relationship between the number of channels and the energy absorbed in the detector[24]. The energy calibration of the NaI(Tl) spectroscopy system is established by measuring the position of selected full-energy gamma-ray peaks with large peak-height to background ratios, and whose energies are known precisely[25]. That how every linear response in its full MCA and directly proportional to the energy absorbed in the detector there for multi-channel analyzer (MCA) is good. The spectrometer was calibrated for energy by acquiring a spectrum from radioactive standard sources of known energies and gamma-ray 1μCi such as ^{60}Co, ^{137}Cs, ^{22}Na, ^{54}Mn, ^{133}Ba, ^{57}Co and ^{109}Cd the energy calibration curve that it found in present study see figure (3.1).

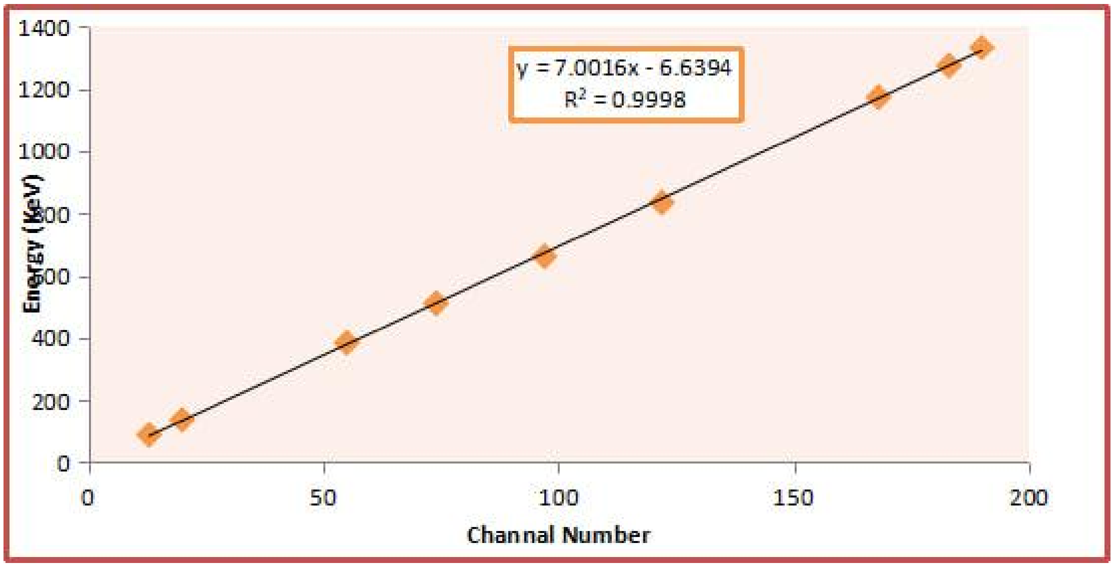


Figure (3.1): Energy Calibration Curve of NaI(Tl) (3" x 3")

that the linear relation equation with correlation (99%) between energy of standard source and channel number is given by

$$E = 7.0016 \times X - 6.6394 \qquad \text{-------------------- (3.4)}$$

Where: E represents the energy, X represents the channel number.

3.4.3 Efficiency Calibration

Definition of efficiency detector as the ratio between the number of photons of gamma rays falling upon the number of pulses emerging from it which is always less than 100%, it is necessary to know that the accuracy and the following equation [26, 27]:

$$\varepsilon = \frac{C}{A \cdot I_{\gamma} \cdot t} \times 100\% \qquad \text{---------------------} (3.5)$$

C: Count (area under the photo peak after subtract background radiation).

t : Measurement time per second.

I_{γ} : The percentage of the intensity of gamma rays emitted energy for each of the radioactive source energies.

A: Activity of samples of measured time.

Which is measure from the following equation:

$$A = A_{o} e^{-\lambda t} \qquad \text{---------------------}(3.6)$$

A_o: Elementary effectiveness at time zero.

λ : decay constant.

Calibration efficiency detector system sodium iodide restaurant thallium NaI(Tl) used standard sources with energies known table (3.2) also used decay equation (3.6) to measure final radioactive and the radioactive sources of activity, as the radioactivity is also registered by the detector for each energy from the energies of radioactive sources for a period of 500 seconds following this account measure efficiency (Ɛ%) through the equation (3-5) and figure (3-1) shows the relationship between energy efficiency and the standard sources used.

Table (3.1): standard sources with energies known and efficiency

No.	Source	Energy(keV)	Efficiency
1	Ba-133	383.7	0.1599855
2	Na-22	511	0.1407364
		1274.5	0.049574
3	Cs-137	661.6	0.1396449
4	Mn-54	834.8	0.1014497
5	Co-60	1173.24	0.0495744
		1332.5	0.041331
		2505.74	0.004099

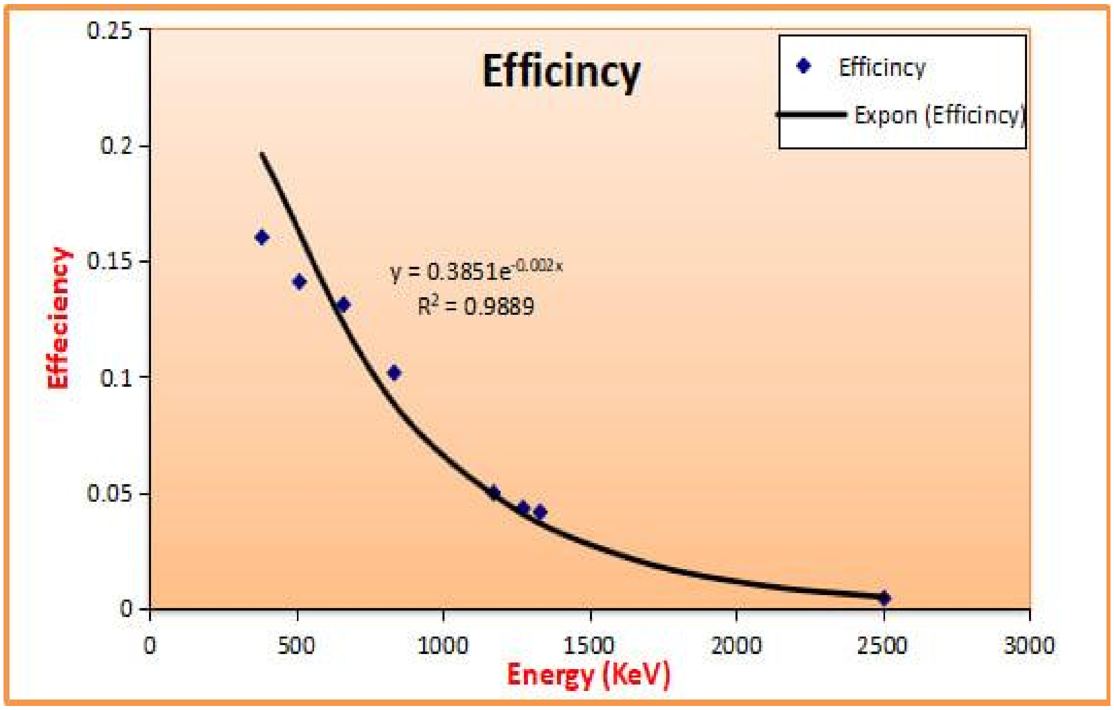


Figure (3.2): The relationship between efficiency and energy.

the relationship between efficiency and energy was represented by the following equation:

$\mathcal{E} = 0.3851 \times e^{-0.002 \times E}$ ----------------------(3.7)

Where: Ɛ is represents the efficiency, E is representing the energy

from above (3.4) equation, it can be found the efficiency in ^{214}Bi (^{238}U) ^{208}Tl (^{232}Th) and ^{40}K as shown in table (3.2)

Table (3.2) The efficiency values for U-238, Th-232 and K-40

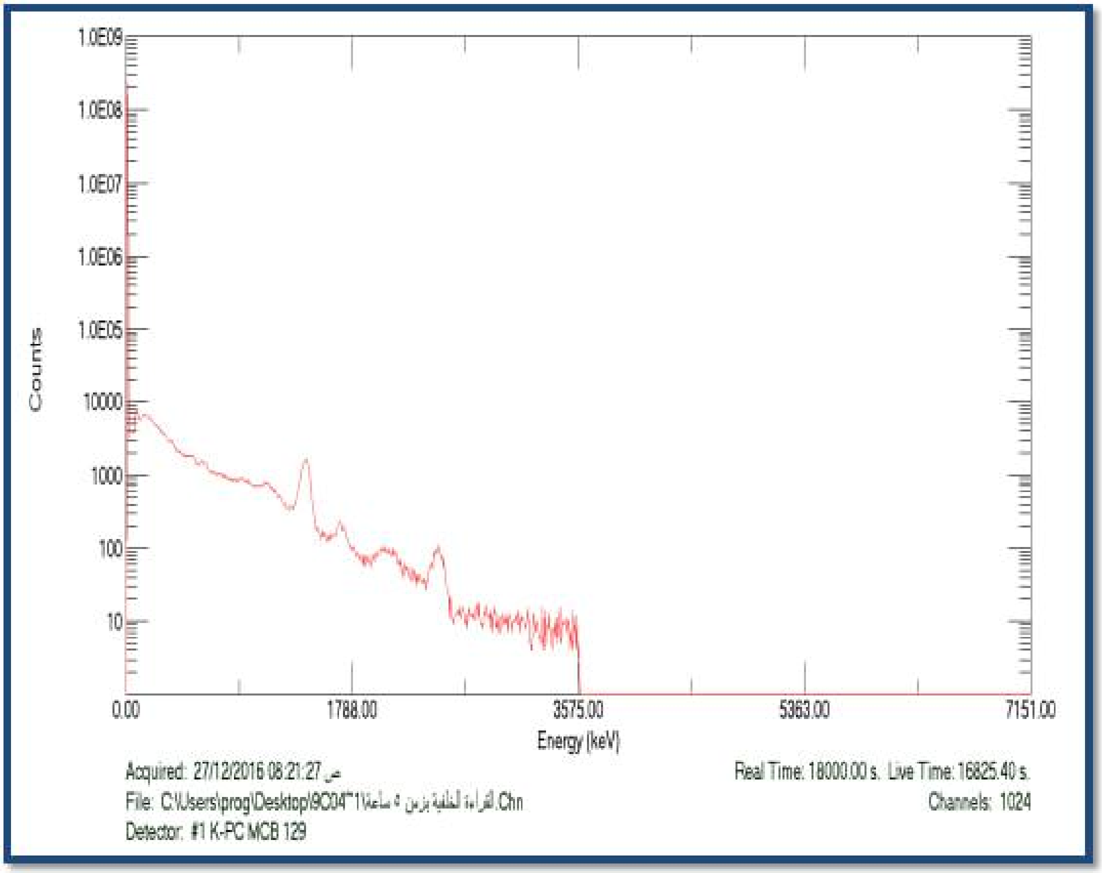
Isotopes	Energy (keV)	$\mathcal{E}$
^{238}U (^{214}Bi)	1764	0.0113
^{232}Th (^{208}Tl)	2614	0.002
^{40}K	1460	0.0207

3.4.4 The Measurements of Sample

In this study a gamma spectrum was recorded from each sample by using the existing computer Multi-channel process. The samples are placed on the detector and measuring of 18000 seconds, as shown in figure (3.3)

Figure(3.3): The gamma spectrum recorded using the MAESTRO-32 Software

To calculate the specific activity for each samples, the net area under the corresponding peaks in the energy spectrum was computed by subtracting count due to background sources from the net area of a certain peak using MAESTRO-32 data analysis package. The background spectrum was measured using a 1-liter plastic container on the detector and counting at the same time for sample measurements. Figure (3-4) shows the background spectrum within the research laboratory in the Physics Department, College of Science, and University of Babylon. Because of the poor resolution of NaI(Tl) detector, at low gamma energies which haven't well-separated photo-peaks, thus the measuring of the specific activity concentrations is possible at a good separated photo-peaks at high energies as that obtained in our results from the gamma rays emitted by the progenies of ^{238}U and ^{232}Th which are in secular equilibrium with them while, ^{40}K was estimated directly by its gamma-line of 1460 keV (11% possibility). Hence the specific activity of ^{238}U were determined using the gamma-lines 1765 keV ^{214}Bi (15.96% possibility). The corresponding results of ^{232}Th were determined using the gamma-ray lines 2614 keV ^{208}Tl (99% possibility).



Acquired: 27/12/2016 08:21:27 ص
File: C:\Users\prog\Desktop\9C04~1\القراءة الخلفية بزمن ٥ ساعة.Chn
Detector: #1 K-PC MCB 129
Real Time: 18000.00 s. Live Time: 16825.40 s.
Channels: 1024

Figure (3.4): Background spectrum inside the laborator

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الخلاصة

تعمل كاشفات الوميض NaI(Tl) على مبدأ التلألؤ، حيث تتفاعل أشعة كاما الواردة مع بلورة NaI، مما يجعلها تنبعث منها ومضات من الضوء (الوميض). يتم بعد ذلك تحويل هذه الومضات إلى إشارات كهربائية لتحليلها. تعتبر كاشفات NaI(Tl) فعالة في اكتشاف أشعة كاما ذات طاقات تتراوح من بضعة كيلو إلكترون فولت إلى عدة ميكا إلكترون فولت. ويتكون الكاشف من بلورة NaI المطعمة بالثاليوم (Tl)، مما يعزز عملية الوميض. تقترن البلورة بأنبوب مضاعف ضوئي (PMT) يحول الضوء إلى إشارة كهربائية. تتميز كاشفات NaI(Tl) بحساسية عالية لأشعة كاما، مما يجعلها مناسبة لمجموعة واسعة من التطبيقات، بدءًا من التصوير الطبي وحتى المراقبة البيئية. تقدم دقة طاقة جيدة، مما يعني أنها تستطيع التمييز بين أشعة كاما ذات الطاقات المختلفة. وهذا مهم لتحديد نظائر محددة تنبعث منها إشعاعات كاما.

الكلمات المفتاحية: جهاز الوميض، كاشف الوميض، الإشعاع المؤين، الإشعاع غير المؤين،

جمهورية العراق

وزارة التعليم العالي والبحث العلمي
جامعة بابل - كلية العلوم
قسم الفيزياء

مشروع بحث التخرج

الكشف عن اشعة گاما بإستخدام كاشف يوديد الصوديوم المطعم بالثاليوم NaI(Tl)

للطالبة

بنين حسين كاظم عبد الله

بكلوريوس علوم فيزياء

العام الدراسي 2023-2024

بإشراف

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