Journal of Physical Chemistry and Functional Materials

Home Page of Journal: https://dergipark.org.tr/jphcfum

Comparison of Energy Resolution and Efficiency of NaI(TI) and HPGe Detector using Gamma-ray Spectroscopy

Hiwa Mohammad Qadr

Department of Physics, College of Science, University of Raparin, Sulaimanyah, Iraq
** Corresponding author: E-mail: hiwa.physics@uor.edu.krd*, ORCID: 0000-0001-5585-3260

ABSTRACT

This paper investigated gamma ray spectra from several radioactive sources, by using thallium activated sodium iodide NaI(TI) and high purity germanium HPGe detectors. The energy dependence of full energy peak efficiency and resolution of NaI(TI) and HPGe by using gamma ray spectroscopy were demonstrated in this work. Spectra were produced for a 137Cs and ^{60}Co source, illustrating the interaction mechanisms that result in partial or complete deposition of incident gamma ray energy in the detector. The result shows that the resolution of HPGe detector is better than NaI(TI) detector. Furthermore, efficiency of NaI(TI) detector is better efficiency than HPGe detector.

ARTICLE INFO

Keywords:
High purity germanium;
Energy resolution;
Efficiency;
FWHM

Received: 27-April-2020,
Accepted: 14-May-2020
ISSN: 2651-3080

1. Introduction

Gamma ray is an electromagnetic radiation and particle which depends on the high energy radiation and short wavelengths within the electromagnetic spectrum (energy of 10 - 5000 keV). This high energy photon can cause harmful when absorbed by living cells. Because of it has the highest penetration power [1-3]. Three main processes of interactions exist between an incident photon and matter in which photon deposits its energy partly or entirely in the matter: photoelectric absorption, Compton scattering and pair production. The possibility of each process depends on the property of the material (atomic number) and the energy of the incident photon [4, 5]. In addition, elastic photon interaction, also known as Rayleigh scattering, is a fourth process which is important at low energy (below 100 keV) [6].

Germanium detectors are widely used for gamma ray spectroscopy. The main advantage of HPGe detector, for gamma ray measurement, is its superior energy resolution. The resolution depends on the number of single carriers which are generated during particle interaction with the detector material [7, 8]. On the other hand, this detector has two main disadvantages. First, the efficiency of it is lower that of NaI(TI) because of their smaller size and lower Z. Detection efficiency of a NaI (TI) detector system depends on different parameters [9]. Second, it is necessary to cool it down to very low temperature by utilized liquid nitrogen. This makes HPGe detector more expensive to purchase and to maintain than NaI(TI) [10].

In this paper, two types of detectors were used, NaI(TI) and HPGe detectors. The main purpose of this work is to understand the characteristic differences between these two detectors in terms of energy calibration, energy resolution and efficiency.

2. Experimental Methods

The output from a gamma ray detector is an amount of electrical charge which is proportional to the amount of gamma ray energy absorbed by the detector. The primary function of the electronic system is basically to collect that charge. A typical simple electronic system for gamma ray spectrometry can be shown in Figure 1. The detector in this work can be scintillator detector as NaI(TI) with its

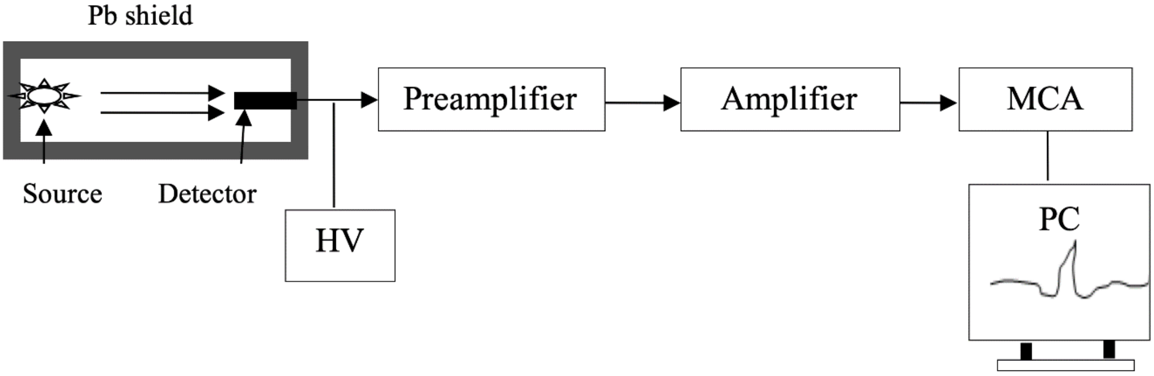

Figure 1. A diagram on experiment connection

corresponding photomultiplier tube or semiconductor detector as HPGe. The high-voltage (HV) power supply provides a positive or negative voltage necessary for the operation of the detector. NaI(TI) and HPGe detectors were operated in positive HV at about 0.5 and 3.5 kV respectively. The main purpose of the preamplifier is to give an optimized coupling between the output of the detector and the rest of counting system and to minimize any sources of noise which may charge the signal. The amplifier converts the very weak signal, in mille volts to a signal that is suitable for measurement by multiplying the signal by factor of thousand or more. The multichannel analyzer (MCA) records and stores pulses according to their height and is a device that scans a stream of high voltage pulses and organizes them into a spectrum [11]. Each storage unit is called channel. The height of the pulse is usually proportional to the energy of the gamma ray that enters into the detector. Each pulse is consecutively stored in a particular channel corresponding to a known energy [2].

3. Results and Discussions

3.1. Energy Calibration and Resolution

It is necessary first to calibrate the system using the ^{60}Co and ^{137}Cs sources provided for 300 seconds. The particle steps for calibration of MCA are provided in the laboratory script. For both sources, the full width half maximum (FWHM) and the photopeak channel are identified. Then, the channel number against the peak energy is plotted in Figure 2. It is clear the relationship between the energy and the channel number is linear for both detectors.

Equation (1) shows the energy resolution, R, which is defined as the detector's ability to resolve little alterations in the energy of incident photons. (FWHM) is the full width at half maximum and it is known as the width of the distribution at half of the level of the peak and where H_0 represents the peak centroid channel number [12, 13].

$$R = \frac{FWHM}{H_0} \times 100\% \quad (1)$$

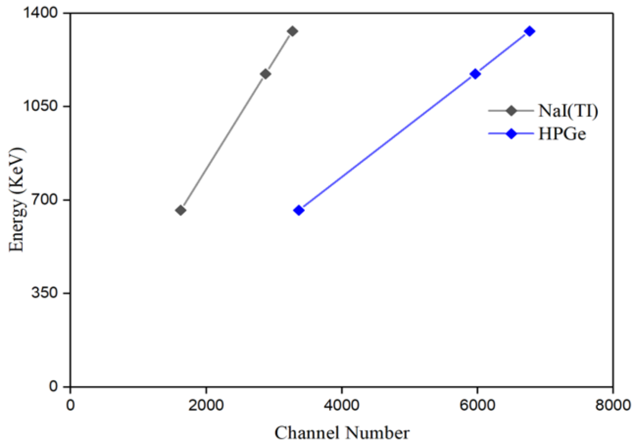

Figure 2. The linear relationship for NaI(TI) and HPGe detectors calibration

A number of gamma radioactive sources were chosen such as (^{137}Cs, ^{60}Co, ^{22}Na) for the NaI(TI) detector and (^{137}Cs, ^{60}Co, ^{152}Eu) for the HPGe detector . With these sources the energy resolution for each detector was determined clearly as a function of gamma-ray energies. By using equation (1), NaI(TI) and HPGe resolution were calculated. The average value of full width at half maximum (FWHM) corresponds to the energy resolution of the NaI(TI) and HPGe detector. From Figure 3, it can be clearly noticed that the energy resolution of the NaI(TI) and HPGe detector decrease as the energy increases. Therefore HPGe detector can be very good energy resolution and is a good instrument for nuclide identification compared to the NaI(TI) detector [14].

3.2. Efficiency

Efficiency is an important parameter of NaI(TI) and HPGe detector. The efficiency is divided into several parts, (absolute efficiency, intrinsic efficiency, and intrinsic photopeak efficiency) [15] . For any gamma radiation detector, a formal definition of absolute efficiency *(ε)* is given by the following ratio [16]:

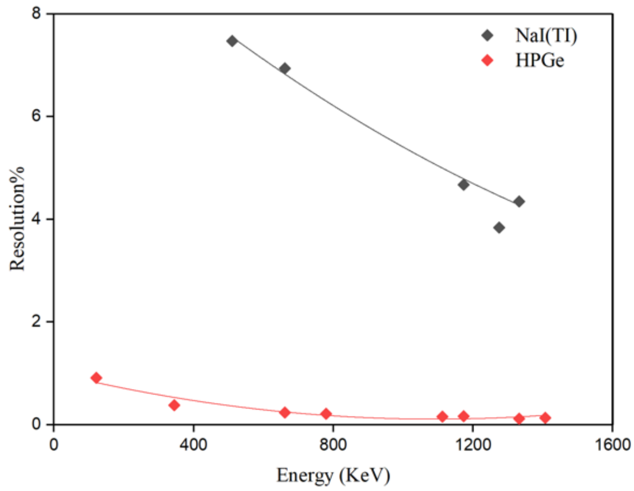

Figure 3. A graph of the energy resolution for the NaI(Tl) and HPGe detector

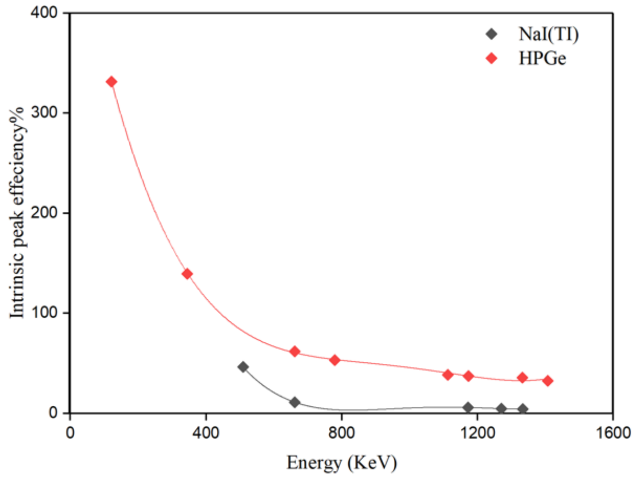

Figure 4. Intrinsic peak efficiency for the NaI(Tl) and HPGe detector

$$\varepsilon = \frac{N_c}{N_s} \qquad (2)$$

where N_c is the number of record pluses and N_s is the number of emitted photons by a source. The most significant parameter in practical gamma ray spectrometry is the intrinsic photopeak efficiency (ε_p) which considers only the full energy peak region of interest in its calculation and is a useful value since it does not consider regions in the spectrum where there may be scattering from surrounding objects or electrical noise. Formula 3 shows intrinsic photopeak efficiency. Where c_p is the number of counts in the photopeak corresponding to energy E_γ per unit time, and N_γ' is the total number of gamma ray emitted by the source per unit time [17].

$$\varepsilon_p = \frac{c_p}{N_\gamma'} \times 100\% \qquad (3)$$

In order to observe the relation between the peak energy and the NaI(TI) and PHGe intrinsic photopeak efficiency the following Figure 4 was plotted. It is shown that intrinsic peak efficiency for both detectors decrease as the energy increases. And efficiency in the HPGe detector is smaller than the NaI(TI) detector. The NaI(TI) detector has better efficiency compared to the HPGe detector. So, the NaI(TI) is used to measure the absolute intensity of a given source of gamma ray. For instance, at 1173.23 keV, the intrinsic photopeak efficiency of ^{60}Co was 24.8% for NaI(TI) detector and 5.87% for HPGe detector.

4. Conclusions

This paper has illustrated the general propertied of gamma ray spectra and determining some of the performance characteristics of the NaI(Tl) and HPGe detector. Comparing two detectors, it is clearly seen that the high purity germanium semi-conductor detector has better resolution than the thallium activated sodium iodide scintillation detector.

On other hand, all intrinsic efficiency values decrease as a function of increasing gamma ray energy. It was observe that the NaI(TI) detector is more efficiency than the HPGe detector. Whereas HPGe detector can be used for high energy gamma ray detection with very good resolution.

REFERENCES

[1] G. Gilmore, J. Hemingway, J. Durell, Practical Gamma-ray Spectroscopy, Journal of Physics G-Nuclear and Particle Physics 22(7) (1996) 1117.

[2] G.F. Knoll, Radiation detection and measurement, John Wiley & Sons2010.

[3] H. Qadr, Effect of Ion Irradiation on the Mechanical Properties of High and Low Copper, Atom Indonesia 46(1) (2020) 47-51. 10.17146/aij.2020.923

[4] H.M. Qadr, Calculation for gamma ray buildup factor for aluminium, graphite and lead, International Journal of Nuclear Energy Science and Technology 13(1) (2019) 61-69. 10.1504/IJNEST.2019.099718

[5] S. Kelner, F.A. Aharonian, V. Bugayov, Energy spectra of gamma rays, electrons, and neutrinos produced at proton-proton interactions in the very high energy regime, Physical Review D 74(3) (2006) 034018.

[6] W. Li, A. Belchior, M. Beuve, Y. Chen, S. Di Maria, W. Friedland, B. Gervais, B. Heide, N. Hocine, A. Ipatov, Intercomparison of dose enhancement ratio and secondary electron spectra for gold

nanoparticles irradiated by X-rays calculated using multiple Monte Carlo simulation codes, Physica Medica 69 (2020) 147-163. 10.1016/j.ejmp.2019.12.011

[7] N. Fourches, M. Zielińska, G. Charles, High purity germanium: from gamma-ray detection to dark matter subterranean detectors, Use of Gamma Radiation Techniques in Peaceful Applications, IntechOpen2019.

[8] P. Reiter, γ-ray tracking with AGATA: A new perspective for spectroscopy at radioactive ion beam facilities, Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms 463 (2020) 221-226. 10.1016/j.nimb.2019.05.041

[9] I. Akkurt, K. Gunoglu, S. Arda, Detection efficiency of NaI (Tl) detector in 511–1332 keV energy range, Science and Technology of Nuclear Installations 2014 (2014) 1-5. 10.1155/2014/186798

[10] J.C. Bryan, Introduction to nuclear science, CRC Press2018.

[11] R.S. Peterson, Experimental γ ray spectroscopy and investigations of environmental radioactivity, Spectrum Techniques (1996).

[12] Q. Mohammad, H. Maghdid, Alpha-particle stopping powers in air and argon, Journal of pure and applied physics 5 (2017) 22-28.

[13] M.Q. Hiwa, Stopping power of alpha particles in helium gas, Herald of the Bauman Moscow State Technical University, Series Natural Sciences 2(89) (2020) 117-125. 10.18698/1812-3368-2020-2-117-125

[14] D. Demir, M. Eroğlu, A. Turşucu, Studying of characteristics of the HPGe detector for radioactivity measurements, Journal of Instrumentation 8(10) (2013) P10027.

[15] I. Akkurt, K. Gunoglu, S. Arda, Detection efficiency of NaI (Tl) detector in 511–1332 keV energy range, Science and Technology of Nuclear Installations 2014 (2014).

[16] A.M. Hamad, H.M. Qadr, Gamma-Rays Spectroscopy by Using a Thallium Activated Sodium Iodide NaI (Ti), Eurasian Journal of Science and Engineering 4(1) (2018) 99-111. 10.23918/eajse.v4i1sip99

[17] O.G. Urkiye Akar Tarim, Source-to-detector Distance Dependence of Efficiency and Energy Resolution of a 3"x3" NaI(Tl) Detector, European Journal of Science and Technology (2018) 103-107. 10.31590/ejosat.443565