Detection and Measurement of Gamma-rays

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Gamma-rays are high energy photons. They are generally emitted by radioactive nuclei. In Gamma-ray spectroscopy experiment the gamma-rays will be detecting and measuring through different detectors. Energy of gamma-rays will be calculated, and base on energy, unknown gamma decay radioactive material will be identified. Key methods used throughout this experiment is visualization and calibration fit using Matplotlib and NumPy.

I. INTRODUCTION

Gamma-rays also known as gamma radiation. Generated by radioactive decay, lightning, nuclear explosions, supernova explosions, etc. It is an electromagnetic radiation with a wavelength less than 10^{-12} meters. Just like x-rays, gamma rays have strong penetrability. It is discovered by France chemist Paul Ulrich Villard (1860-1934) when he was studying the radioactivity of radium. The frequency of gamma rays is usually greater than 3×10^{19} Hz.

Gamma-Rays generally carry strong energy and have strong penetrability, plus the way they interact with materials. It can easily cause cell mutation or death. Thus, we want to study it, to detect the energy of gamma rays released by different radioactive materials.

II. METHODS

A. Interaction of Gamma Rays with Matter

Gamma rays primarily interact with matter through Photoelectric absorption, Compton scattering, and pair production.[1] Photoelectric absorption mostly happened for low-energy photons, around 100 KeV. In this process, the photon disappears, and its energy transferred to the electrons.

$$E_\gamma = \omega_0 + E_k$$

Compton scattering is when a photon scatters from a target electron, resulting in a reduced energy photon and a scattered electron with energy from photon.[2]

$$E_\gamma = E_{\gamma'} + E_k$$

Pair production is when a photon creates an electron and a positron, but photon disappears in this process. Pair production happens when photon energy higher than 1.022 MeV ($2mc^2$)

$$E_\gamma = 2m_e c^2 + {E_k}^{e^-} + {E_k}^{e^+}$$

Three interaction and there range of energy is shown in figure 1.

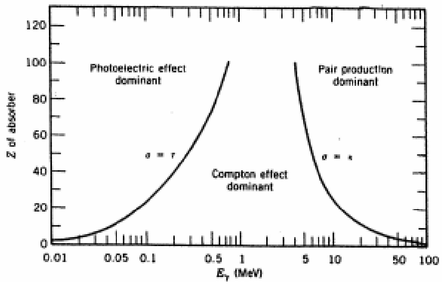

FIG. 1. The three gamma-ray interaction processes and their regions of dominance[1]

Since gamma ray interact with matter through these ways. And as energy decrease, it interacts with matter mainly happen to be photoelectric absorption. Thus, we can use detector to detect the electric single create by gamma ray.

B. Measuring

In this experiment we are going to use 2 type of detector. NaI detector (sodium iodide scintillator detector) and HPGe detector (high-purity germanium semiconductor detector).

NaI detectors are sometimes referred to as NaI(Tl) detectors. [3] When gamma ray enter the detector. The NaI crystal emitted photons are detected by photomultiplier, then photons interact and produce electrons that are detected. The NaI detector is simple, efficient, and reliable.

For the HPGe detector, the ionization electrons are collected by applying an electric field across the semiconductor that have been fabricated as a diode. That's why we also call it HPGe semiconductor detector.

The resolution is related to the number of electrons counts, which is proportional to the gamma ray energy. Base on Poisson statistics, energy resolution is equal to $\frac{2\sqrt{N}}{N} = \frac{2}{\sqrt{N}}$. [3] N is the counts of the electrons.

C. Experimental Setup

The experiment setup as Figure 2 showed

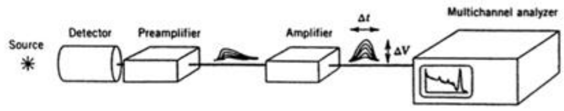

FIG. 2. The setup of the gamma-ray spectroscopy experiment. Gamma-rays enter the detector produce signals, then analyze by multichannel analyzer.

The dataset collect from detector contains signal intensity (counts) and corresponding channel number.

By using Matplotlib from Python, we can visualize the data. matplotlib.pyplot.polt shows the broken line graph. Matplotlib.pyplot,scatter to show the scatter diagram. Code Counts.argmax() → matplotlib.pyplot.text(channel[],counts[]) [4]can show and label the peaks of the graph.

Each peak represents a gamma ray with certain energy and channel number. The channel number have a linear relationship with actual energy. So, after visualizing the data, we find out the corresponding channel and counts. By using Curve fit function, we can establish a calibration equation to figure out the relationship between the channel number and gamma ray energy.

III. RESULTS AND ANALYSIS

A. NaI Detector

The detector will provide channel number and signal intensity for 7 radioactive isotopes. They are Ba133, Cd109, Co57, Co60, CS137, Mn52, and Na22. Visualized graphs are showed from figure 3 to figure 9.

TABLE I. NaI DETECTOR ISOTOPES SPECTRA

Isotope	Peaks	Channel#	Counts	Energy [KeV]
Ba133 [Fig3]	2	214 251	1112 2541	303 356
Cd109 [Fig4]	1	65	325	88.03
Co57 [Fig5]	1	90	1792	122.06
Co60 [Fig6]	2	796 900	321	1171.64 1331.77
Cs137 [Fig7]	1	461	221	661.6
Mn52 [Fig8]	1	570	135	834.84
Na22 [Fig9]	2	359 882	1620 201	511 1274.5

Actual visualized graphs:

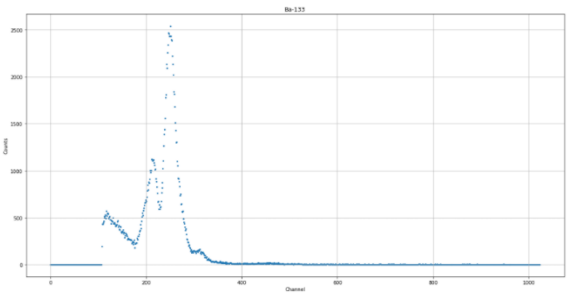

FIG. 3. Gamma-ray spectra plotted as counts vs channel number obtained from radioactive sources Ba133

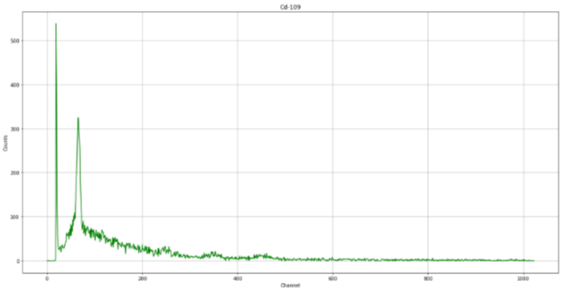

FIG. 4. Gamma-ray spectra plotted as counts vs channel number obtained from radioactive sources Cd109

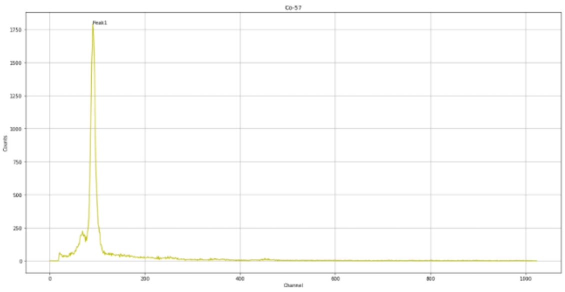

FIG. 5. Gamma-ray spectra plotted as counts vs channel number obtained from radioactive sources Co57

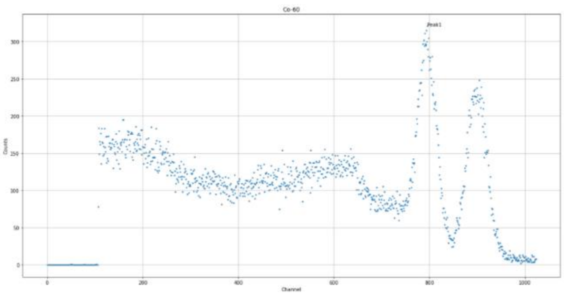

FIG. 6. Gamma-ray spectra plotted as counts vs channel number obtained from radioactive sources Co60

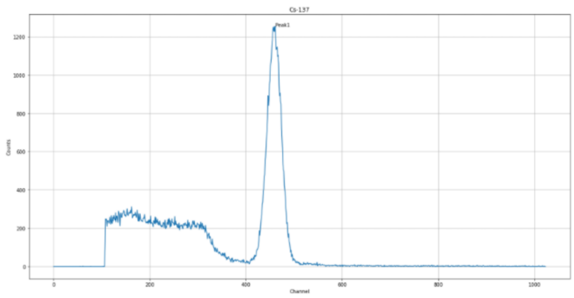

FIG. 7. Gamma-ray spectra plotted as counts vs channel number obtained from radioactive sources Cs137

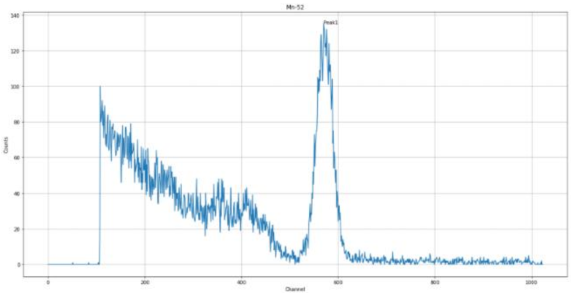

FIG. 8. Gamma-ray spectra plotted as counts vs channel number obtained from radioactive sources Mn52

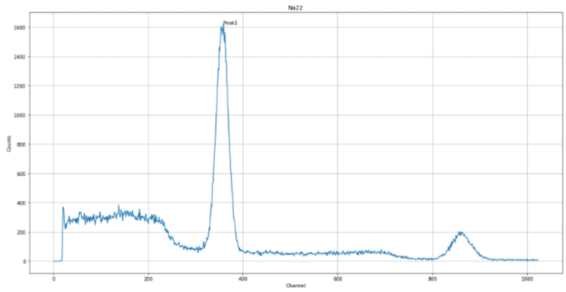

FIG. 9. Gamma-ray spectra plotted as counts vs channel number obtained from radioactive sources Na22

TABLE II. ISOTOPES SPECTRA CHANNEL AND ENERGY

Channel Number	Energy [KeV]	Channel Number	Energy [KeV]
65	88.03	461	661.6
90	122.06	570	834.84
241	303	796	1171.64
251	356	882	1274.5
359	511	900	1331.77

The relationship between channel number and actual energy is in a linear relation. By plotting the energy vs channel, we were able to perform a curve fit as figure 10.

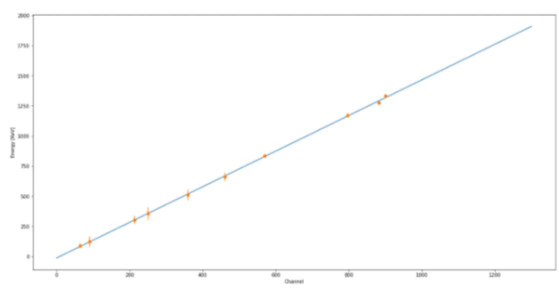

FIG. 10. Gamma-ray energy plotted as energy vs channel number. Error is from intensity counts

From curve fit we got the following equation to describe the relationship between gamma-ray energy and detector channel number:

$$Energy = 1.4795 \times channel\ number - 13.365 \quad (1)$$

B. HPGe Detector

High-purity germanium semiconductor detector has batter resolution with sharp peaks. By measuring isotopes Co60 and Cs137 again. We got figure 11.

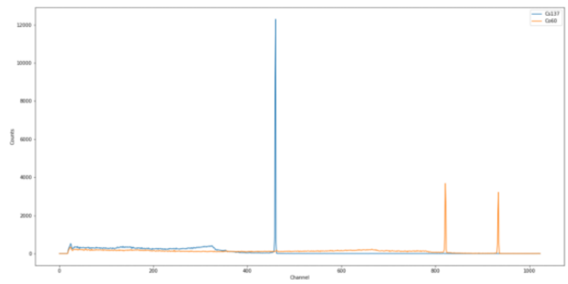

FIG. 11. Gamma-ray spectra plotted as counts vs channel number obtained from radioactive sources Co60 and Cs137. The tall blue peak is from Cs 137 and two orange peaks are from Co60

TABLE III. HPGe DETECTOR ISOTOPES SPECTRA

Channel Number	Energy [KeV]	Counts
460	661.66	12290
821	1173.2	3681
934	1332.50	3217

Plotting the energy vs channel and do the curve fit same as figure 10. We got the result as figure 12.

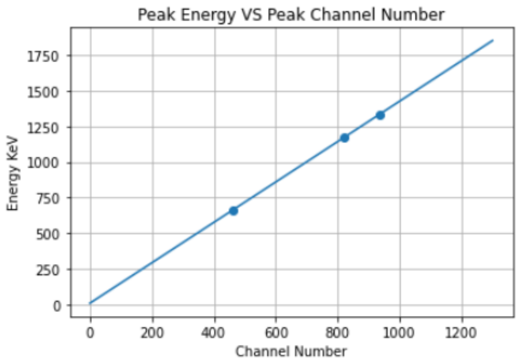

FIG. 12. Gamma-ray energy plotted as energy vs channel number from HPGe detector data

Now we get a more accurate equation:

$$E = 1.41572337 \times \mathit{channel\ number} + 10.52424694 \quad (2)$$

C. Test the Calibration Equation

To test the calibration equation, we use the Eu152. The peaks of Eu152 from spectra looks like figure 13.

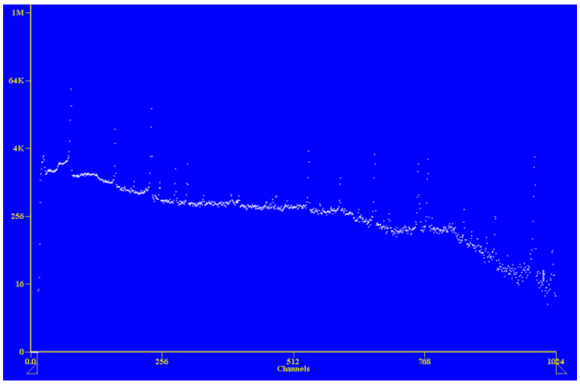

FIG. 13. radioactive isotope Eu152 Gamma-ray spectra plotted as counts vs channel number

Use the equation we got from section B. We can calculate each corresponding energy from the peaks. The table below shows the calculated result compare with results from other institution.

TABLE IV. HPGe DETECTOR ISOTOPES SPECTRA

Channel Number	Calculated Energy [KeV]	Results From [7] [KeV]	Differ. %
78	120.95	121.78	0.682
165	244.12	244.70	0.237
		295.94	
235	343.22	344.28	0.308
282	409.76	411.12	0.331
305	442.32	443.96	0.370
		678.0	
		688.67	
541	776.43	778.90	0.317
603	864.21	867.37	0.364
670	959.06	964.08	0.521
		1005.3	
756	1080.81	1085.9	0.469
		1089.7	
774	1106.30	1112.1	0.522
845	1206.81		
905	1291.75	1299.1	0.566
		1408.0	
		1457.6	

The test results from calibration equation met expectation.

D. Attenuation Coefficient

Attenuation coefficient depends on the initial intensity and the thickness of the material. Here is the equation to describe linear attenuation coefficient:

$$\boldsymbol{I_x = I_0 \cdot e^{-\mu x}} \quad (3)$$

Where I_x is the intensity at depth x cm. I_0 is the initial intensity. From this equation (3) we can get:

$$\boldsymbol{\mu = \frac{\ln\left(\frac{I_0}{I_x}\right)}{x}} \quad (4)$$

In our experiment we can plot the data and use curve fit to find out the attenuation coefficient. We have the intensity and distance data testing on Al and Pb. Figure 14 shows the attenuation of gamma-ray through Al, and figure 15 shows attenuation through Pb.

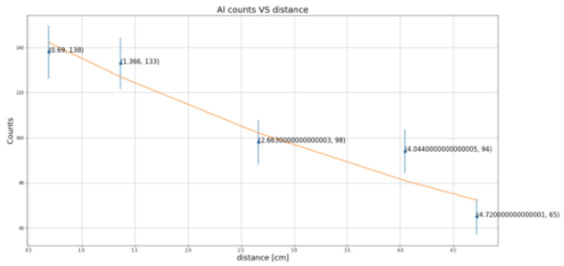

FIG. 14. Gamma-rays counts vs distance through Al. Counts drop as distance increase

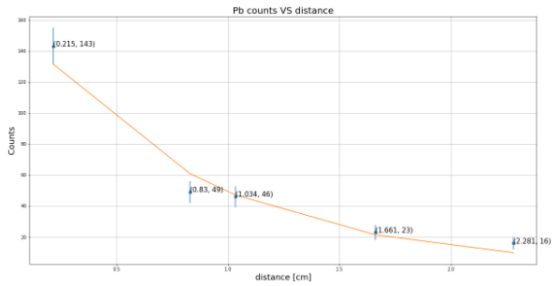

FIG. 15. Gamma-rays counts vs distance through Pb. Counts drop as distance increase

The linear attenuation coefficient for Al is $0.1679 cm^{-1}$, for Pb is $1.2546 cm^{-1}$. Error bar for counts is equal to $\pm\ \sqrt{Counts}$.

IV. DISCUSSION

Throughout this experiment we have used both NaI detector and HPGe detector. The most important part in analysis this dataset is finding the peaks of the “gaussian distribution” like graph. The result accuracy depends on the peak location. In this experiment, result rely on the number of counts. The more counts the more accurate result will be. The analyses also show more counts mean less uncertainty. To be accurate, HPGe detector will be a good choice, increase measure time, and test more samples will help calibration equation became more accurate.

When we use Eu152 as a check for the equation. We found 12 gamma rays’ energy. However, compare with actual energy measure by other institution, there are 18 of them. I think by increasing the measurement time we could identify other peaks and be able to calculate the corresponding energy.

V. CONCLUSION

At the end of this study, we were able to detect and measure gamma-rays using different detector. We were able to calculate gamma decay energy and identify gamma decay radioactive material.

The Calibration fit results and other measurements differed from 0.237% - 0.682%.

Attenuation coefficient for Al and Pb is $0.1679 cm^{-1}$ and $1.2546 cm^{-1}$.

A. Acknowledgments

Truly appreciate Professor Norman Birge and Professor Xianglin Ke for their passion and patience in instruction throughout all time.

References

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