The History of Photon and Gamma-rays Measurement and Applications

Photon is gauge boson and one of the elementary particles that serves as the quantum of the electromagnetic force carrier. Gamma-rays are high energy photons. They are generally emitted by radioactive nuclei. In this paper we will discuss the history, measurement, and application of photon and gamma-rays nowadays. The gamma-rays will be detecting and measuring through different detectors. And Energy of gamma-rays will be calculated.

I. INTRODUCTION

Human being's understanding of light has been changing with time. Before the 18th century, people generally only understood the basic properties of light such as refraction and reflection. It was not until Newton (1643-1727) proposed the corpuscular theory of light. And Christiaan Huygens (1629-1695) suggested a wave picture of light. During that time people generally agreed with Newton's theory. Because Newton's status was so great at that time.

And so on until the early 19th century Thomas Young (1773–1829) who, in 1802, conclusively demonstrated the wave nature of light through his doubleslit experiment. With Thomas's experiment, the interpretation that light is a wave has become mainstream.

With James Clerk Maxwell's study in 1865, it was generally accepted that light was an electromagnetic wave.

In 1887, the German physicist Heinrich Rudolf Hertz (1857-1894) first confirmed the existence of electromagnetic waves with his experiment. The same year he discovered that ultraviolet light shining on metal plate could generated electrical sparks. This discovery led to the study of photoelectric effect and photons.[0]

A. Photon

Scientists were studying the photoelectric effect. They found out that the excited electrons are not related to the intensity of the light but the frequency of light, and electrons can be excited only when the light reaches a certain frequency. In 1900, Planck proposed the energy are quantized to explain the question of black body radiation. By 1905 Einstein proposed that the energy of light is also quantized and gave the formula

$$E = hf$$

where h is Planck constant and f is the frequency.

When this theory first came out, people doubt it. Physicist Robert Andrews Milligan tried to prove Einstein was wrong through experiments to measure the Planck constant and found that Einstein was right.

In 1923, American physicist Arthur Compton observed that when gamma-ray interact with matter, the wavelength of light becomes longer due to loss of energy. This experiment convinced physicists at the time that light was somehow particle-like.

Since then, people have accepted the concept of photons. Einstein in 1921, Milligan in 1923, Arthur Holly Compton in 1927 won the Nobel Prize in Physics because of the concept of photon.

B. Gamma-rays

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. MEASURMENT

A. Background

Thanks to Einstein's paper, the energy of a photon is remarkably easy to calculate

$$E = hf = \frac{hc}{\lambda}$$

The photon energy is inversely proportional to the wavelength of the electromagnetic wave. The shorter the wavelength, the more energetic is the photon, the longer the wavelength, the less energetic is the photon.

But to measure the energy of gamma rays, we first need to understand 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

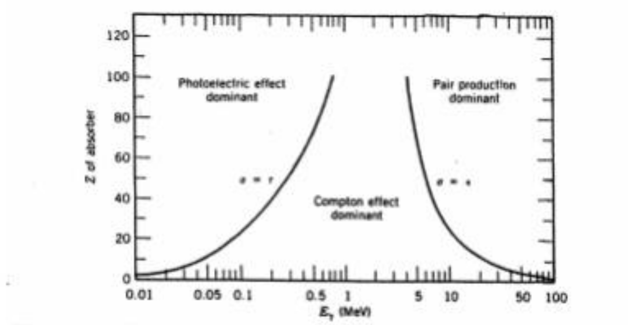

FIG. 1. The three gamma-ray interaction processes and their regions of dominance [1]

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. Detector

We are going to use 2 types of detectors. 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

$$\frac{2\sqrt{N}}{N} = \frac{2}{\sqrt{N}}$$

N is the counts of the electrons

C. Setup

The experiment setup as Figure 2 showed.

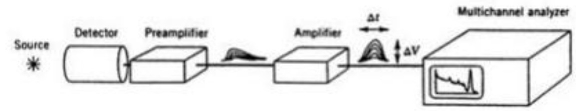

FIG. 2. The setup of the gamma-ray spectroscopy experiment. Gamma-rays enter the detector produce signals, then analyze by multichannel analyzer

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

D. Results and analysis

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:

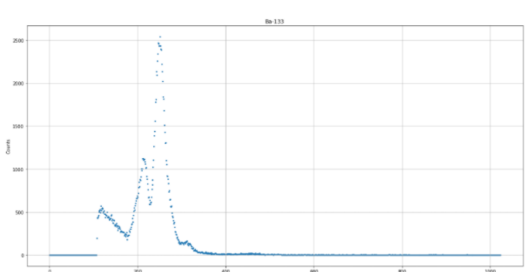

FIG. 3. Gamma-ray spectra plotted as counts vs channel number obtained from radioactive sources Ba133

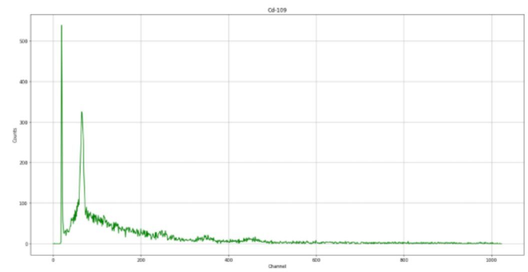

FIG. 4. Gamma-ray spectra plotted as counts vs channel number obtained from radioactive sources Cd109

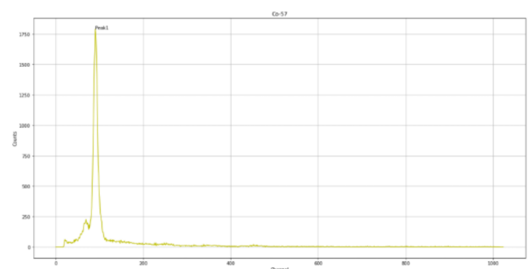

FIG. 5. Gamma-ray spectra plotted as counts vs channel number obtained from radioactive sources Co57

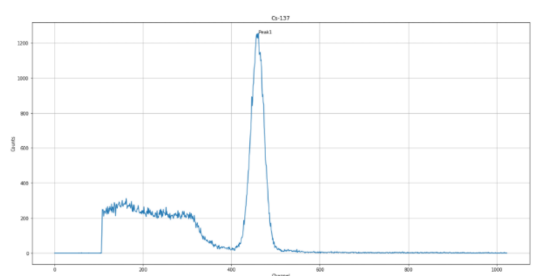

FIG. 7. Gamma-ray spectra plotted as counts vs channel number obtained from radioactive sources Cs137

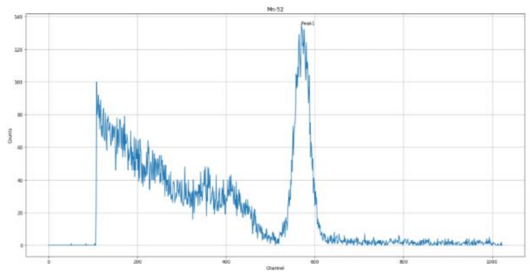

FIG. 8. Gamma-ray spectra plotted as counts vs channel number obtained from radioactive sources Mn52

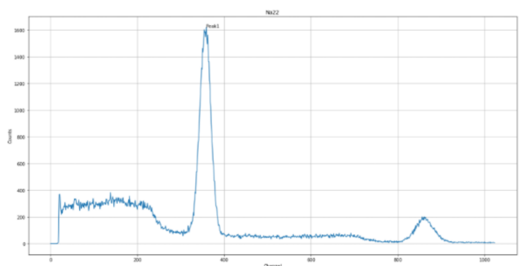

FIG. 9. Gamma-ray spectra plotted as counts vs channel number obtained from radioactive sources Na22

TABLE II. ISOTOPES SPECTRA CHANNEL AND ENERGY

Channel Number	Energy	Channel Number	Energy
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.

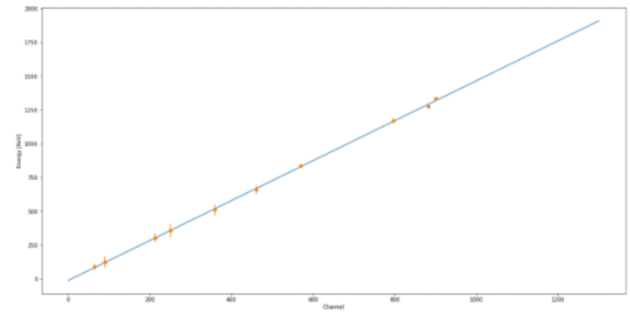

FIG. 10. Gamma-ray energy plotted as energy vs channel number. Error is from intensity count

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

$$Energy\ =\ 1.479 \times\ channel\ number -\ 13.365 \quad (1)$$

HPGe Detector

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

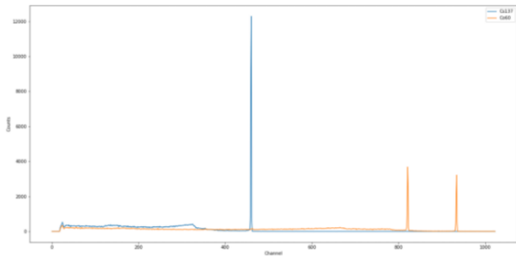

FIG. 11. Gamma-ray spectra plotted as counts vs channel number obtained from radioactive sources Co60 and Cs137. The tall blue peak is from Cs 137 and two orange peaks are from Co6

TABLE III. HPGe DETECTOR ISOTOPES SPECTRA

Channel Number	Energy	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

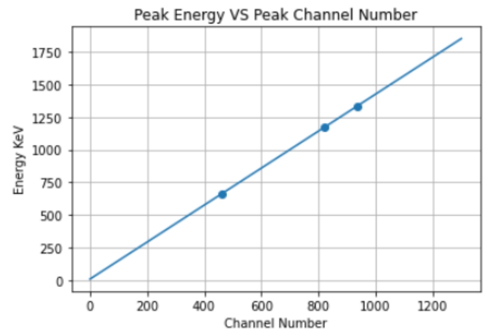

FIG. 12. Gamma-ray energy plotted as energy vs channel number from HPGe detector data

Now we get a more accurate equation:

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

Test the Calibration Equation

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

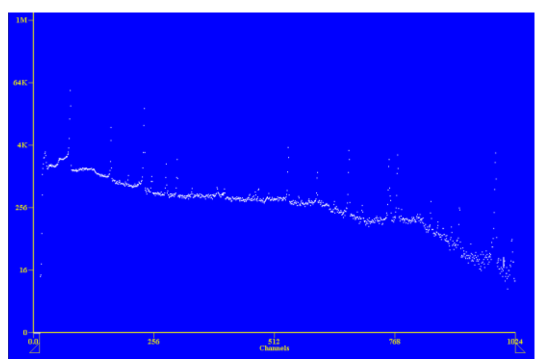

FIG. 13. radioactive isotope Eu152 Gamma-ray spectra plotted as counts vs channel number

Use the equation we got from previous section. 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[4] [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	
744	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.

III. APPLICATION

A. Photoelectric Effect

Since the discovery of the photoelectric effect, our technology has developed rapidly.

First of all, we can manufacture various detection instruments through the principle of photoelectric effect, such as photosensitive elements and photomultipliers. Just like the NaI and HPGe detectors the previous measurement section, neither can leave the important photomultiplier.

With the support of these experimental instruments, we can explore the most cutting-edge knowledge.

At the same time, another major application of the photoelectric effect is the manufacture of solar cells. It enables us to directly convert light into electricity, so that we can generate a steady stream of energy as long as there is light no matter on earth, in space, or on other planets. Let people have the abilities to explore the sea of stars.[5]

B Gamma-ray

Gamma rays could help us probe unseen structures in the universe. In medical filed, gamma-ray can be used as radiation therapy. By sending certain dose of gamma-ray can kill and eliminate the cancer cells. Gamma-rays can also be used for disinfection and incineration.[6]

IV. CONCLUSION

Throughout the research history on photons and gamma-rays, it is not difficult to find out that through scientific experiments and theoretical research. Our understanding of the world is constantly updating.

New discoveries keep appearing, and these discoveries keep pushing us to understand the world more thoroughly.

As we apply the technology from the new discoveries, our life has become more and more convenient, and many things have changed from impossible to possible.

A. Acknowledgments

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Reference

[0] *A Very Brief History of Light*

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[1]-[3] *Notes Detecting Nuclear Radiation*

[4] *Recommended Nuclear Decay Data*

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