Noise Fundamentals: Johnson Noise

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Abstract

In this lab, a photomultiplier tube with a thallium-doped iodide scintillator was used to observe and plot the emission spectra of four radioactive sources: ^{60}Co, ^{22}Na, ^{137}Cs, and an unknown source. The generated plots displayed the expected various physical phenomena, including Compton Scattering, the Photoelectric effect, pair production, back-scattering, and electron-positron annihilation. The spectrum of the unknown source was used to identify it as another ^{137}Cs source.

1 Introduction

Gamma rays emitted from radioactive elements engage in three main interactions with matter: Compton Scattering, the Photoelectric Effect, and Pair Production. In Compton Scattering, the gamma ray strikes an electron (initially at rest) and scatters a photon at a certain angle with a certain energy. This angle and energy depend on the angle of interaction between the gamma ray and the original electron. The photoelectric effect occurs when an entire gamma ray is absorbed by an atom, which ejects an electron as a result of the interaction. In high-energy gamma ray collisions, pair production occurs. The gamma ray is absorbed completely and a positron-electron pair are ejected from the atom. By building a histogram of energies of emitted particles from different radioactive sources, we can observe these phenomena in real time. In this lab, we examined the gamma-emission spectra of ^{60}Co, ^{22}Na, ^{137}Cs, and an unknown source.

2 Experimental Method

This experiment required a High-Voltage Power Supply, a Tektronix TDS 1001C-EDU Oscilloscope, an NIM ORTEC Amplifier, an NIM ORTEC Multi-Channel Buffer, ORTEC Maestro Multi-Channel Analyzing software on a PC, and various coaxial cables, lead bricks, and the aforementioned radioactive sources. Finally, a Photo-Multiplier tube and scintillator (thallium-doped iodide, optically attached to the PMT) was used. The experiment setup is shown below.

The HV Supply was powered up and began supplying $1200V$ to the PMT, and the oscilloscope was used to read the PMT's signal. This was done using only background radiation first. Then, a ^{137}Cs source was placed as shown in Figure 1, and the oscilloscope's trigger was adjusted to read only when pulses were detected (gamma ray emissions). This signal was amplified and run through the MCB, and finally to the MCA software, again as shown in Figure 1.

To run the experiment, the radioactive source was moved to within 1" of the PMT. In order to maximize precision, the number of bins in ORTEC Maestro was set to 8120, and each source's emissions were recorded for 900 seconds. This experiment resulted in the plots shown below.

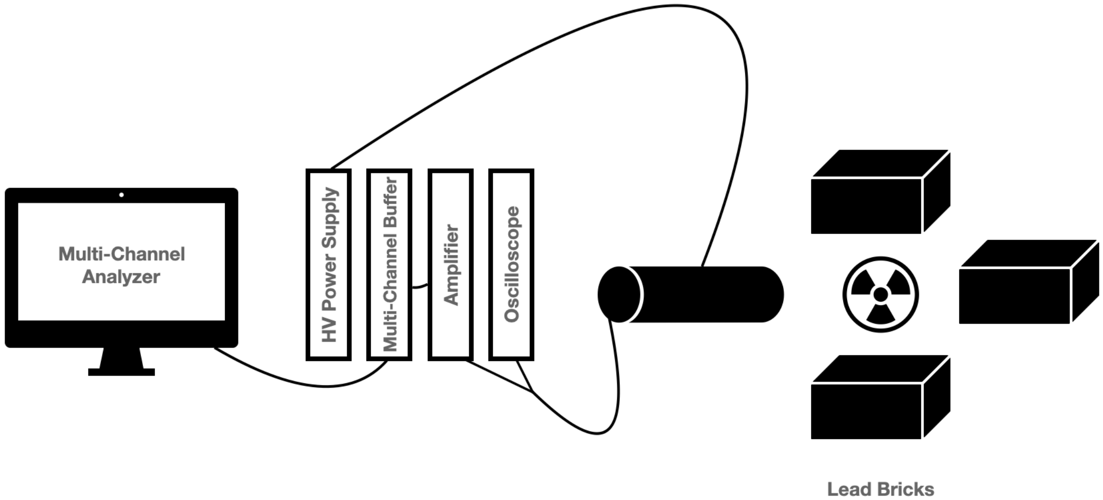

Figure 1: Experiment Setup, showing placement of the cylindrical Photo-Multiplier Tube and radioactive source.

It is important to note a few things about the maintenance of certain factors in the setup during experimentation. The amplitude of the MCA changes the energies of the bin widths (so, increasing the amplitude would move the peaks into different bins). Additionally, the number of counts is inversely related to the voltage supplied to the PMT (so, increasing the voltage decreases the total counts). As a result, voltage and amplitude must be kept consistent throughout the experiment for a single calibration factor to be used throughout.

3 Results

We've calculated energies using a calibration factor generated by running the multi-channel analyzer for 1200 seconds with ^{137}Cs 1 inch from the photomultiplier tube. To obtain the factor, we found the maximum frequency bin at the photopeak (which has expected value 0.6617 [1]), and dividing its energy by its bin number. This yields an 'energy per bin' of

$$\frac{0.6617keV}{254} = 2.605\frac{eV}{bin}. \quad (1)$$

This calibration factor was used to calculate the remainder of the energies in the plots based on their bin numbers. The error of our calculated energy values was determined based on the resolution of the MCA - the photopeak could reasonably have been in 12 bins surrounding bin 254 (which happened to have the maximum count). So, the error it

$$12bins \times 2.605\frac{eV}{bin} = 31.26eV \quad (2)$$

4 Discussion & Conclusion

All of the expected energy values given in [1] and [2] for these emission spectra fit within our range of uncertainty for this experiment. The backscatter peaks are all within the uncertainty

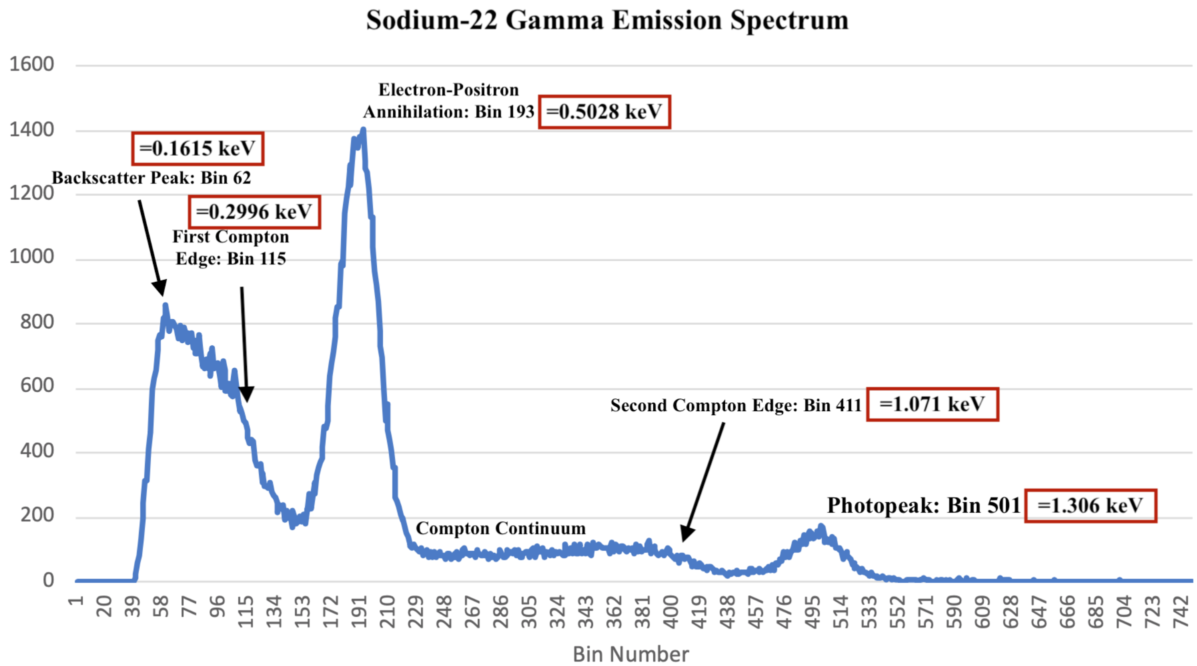

Figure 2: The gamma emission specturm of ^{22}Na.

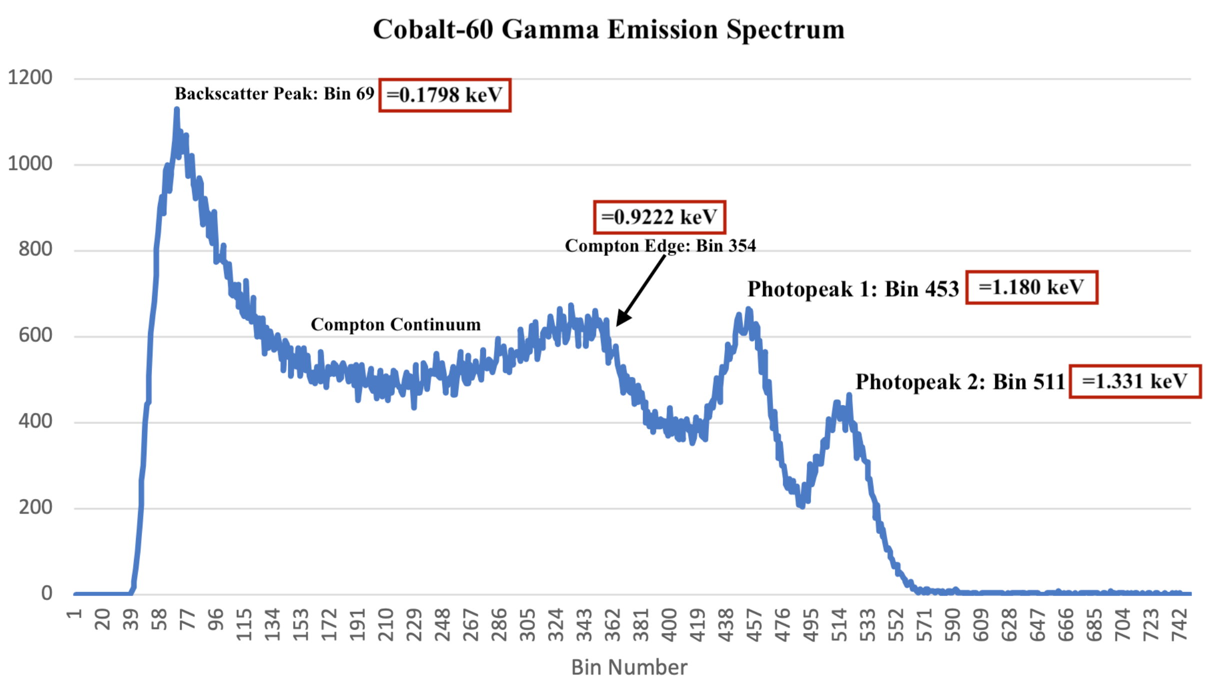

Figure 3: The gamma emission specturm of ^{60}Co.

of the expected value, which makes sense for our setup, which remained unmodified except the radioactive source. The Compton Edges, which we would expect to be at the maximum point

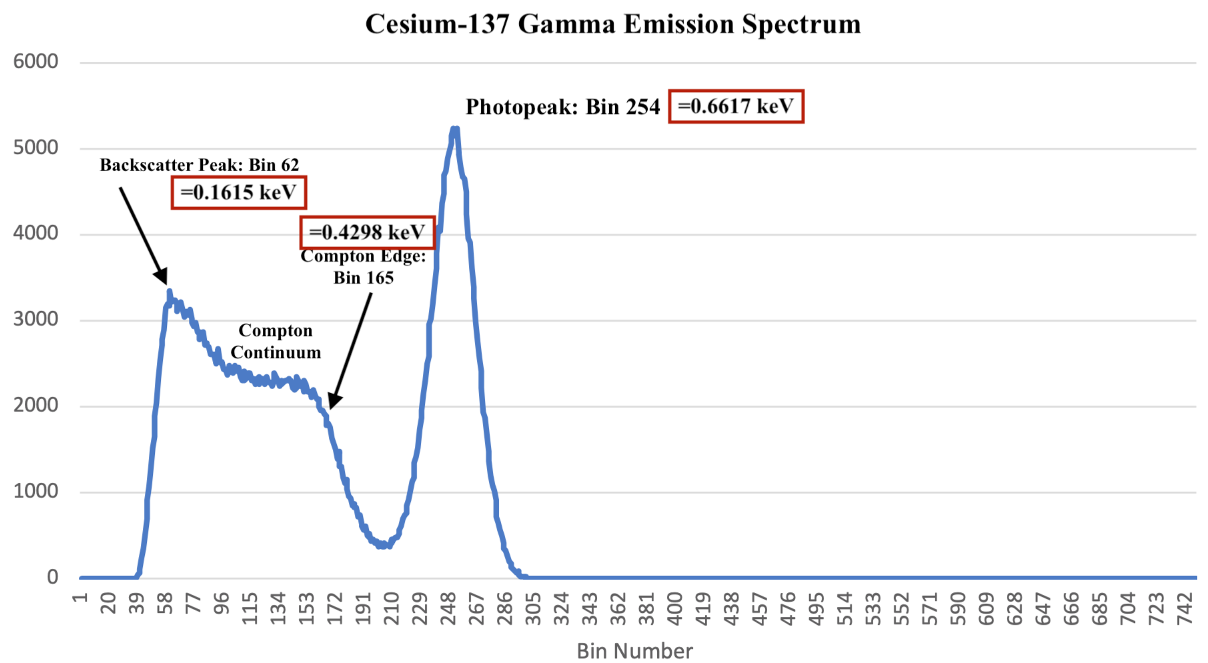

Figure 4: The gamma emission specturm of ^{137}Cs.

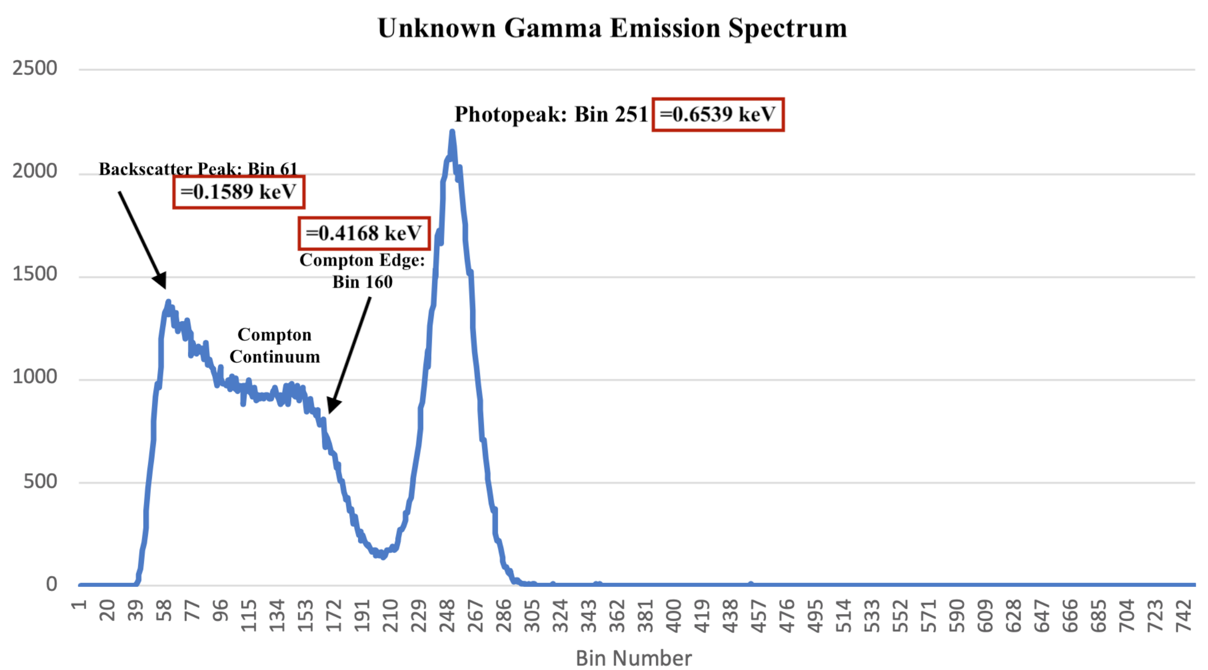

Figure 5: The gamma emission specturm of the Unknown source.

before the "fall-off," have been selected between the midpoint and the knee of the negative slope following the Compton Continuum, as suggested in [3]. Additionally, they follow our expectation of falling around 200 eV before their associated peaks in each plot. The Sodium-22 plot contains a unique feature, the Electron-Positron Annihilation Peak, since its decay involves the emission of a $+\beta$ particle instead of a $-\beta$ particle, as is the case in the remaining plots. Additionally, Cobalt-60 displays two photopeaks, as expected. Finally, we identified the unknown source as a second source of ^{137}Cs due to its nearly identical plot and energy levels.

5 References

[1] PhysicsOpenLab, Gamma Spectroscopy of Radioisotopes, 2016.
[2] Nuclear Power for Everybody, Noise Fundamentals, Cobalt-60 Spectrum, 2021.
[3] William R. Leo, Techniques for Nuclear and Particle Physics Experiments, Springer-Verlag Berlin Heidelberg, 1994, pp. 307.