Observation of Nuclear Decay

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Abstract

In this lab, we observed nuclear decay using a Geiger-Müller detector and a sodium-iodide gamma-ray detector. The GM detector was receptive to the ionization of molecules. It was concluded in the first half of the GM detector experiment that the detector was most receptive to ionized molecules between 800 V and 1000 V. Setting the detector back to 800 V and measuring counts for each half of the thallium-204 source yielded a dead time of 3.815e-06 s which led to a corrected count value for R_12 of 1.671e+04 counts. In the second part of the experiment, we analyzed the nuclear decay of barium-137 and cesium-137 and obtained a spectrum plot for each which provided peak energy values that were matched up to x-ray and gamma-ray probabilities in the isotope database. Potential sources of error could have resulted from random error and minor instrumentation discrepancies in data transmission from the detector to the software.

Introduction

Atomic nuclei are denoted by the form:

$$_{Z}^{A}X$$

X is the symbol of the element, A is the combined number of protons and neutrons also known as the nucleon number, and Z is the atomic number.

This lab studies the process of nuclear decay. This occurs when unstable nuclei spontaneously decay, and another nuclear configuration is formed. The original nucleus is called the *parent*, meanwhile the newly formed nucleus is referred to as the *daughter*.

There are three common types of nuclear decay that are likely to occur. These consist of Alpha decay, Beta decay, and Electron Capture.

Alpha decay is when a helium-4 nucleus is emitted.

Beta decay occurs when an electron or a positron is emitted.

Finally, Electron Capture occurs when the inner shell of an electron is tunneled into the nucleus causing a proton to convert to a neutron.

Since nuclear decay occurs spontaneously, a Poisson Distribution is used to determine the probability that the outcome of nuclear decay will be observed. The Poisson Distribution is given by the following equation:

Equation 1: Poisson Distribution

$$P_N = \frac{m^N}{N!} e^{-m}$$

Where P_N is the probability of seeing the outcome N. The average number of trials is *m*. To find the standard deviation of the Poisson Distribution, take the square root of the mean.

Experimental Procedure

The first part of this lab makes use of a Geiger-Müller detector. The Geiger-Müller detector contains a chamber filled with gas and has two metal electrodes set at differing electric potentials. Free electrons are attracted to the positive electrode. Molecules can be ionized when a high-energy particle passes through the chamber causing ions will be attracted to the negative electrode. Specifically, the GM detector detects ionizing particles.

A GM detector is connected to a ST370 Radiation Counter that is then connected to the STX software on the lab computer.

The experiment begins with a starting voltage of 400V and is raised by 50V after each count and voltage measurement is taken until the maximum voltage of 1,200V is reached.

Lastly, a dead time measurement is taken to determine the time it takes for the GM detector to reset to the state of detection. To determine the dead time, the detector is set to an operating voltage within the STX software. Using a sample of Thallium-204 placed in the detector, we measured the number of counts obtained over a period of 300 seconds. Three measurements in total were taken beginning with one half of the Thallium-204 sample, both halves, then the other half that had not been measured. The dead time was determined from the following equation:

Equation 2: Dead-time Tau

$$\tau \approx \frac{R_1 + R_2 - R_{(12)}}{2R_1R_2}$$

The calculated dead time is then used to calculate the corrected count rate using the following equation:

Equation 3: Corrected dead-time

$$R_c = \frac{R_u}{1 - R_u\tau}$$

The second part of this lab utilized a sodium-iodide gamma-ray detector that blocks alpha and beta particles so it can only detect gamma-rays. When a photon emission occurs due to gamma-ray incidence on a NaI crystal, an electrical signal is produced. We begin with a barium-133 source and will analyze its nuclear decay via electron capture to cesium-133.

Using the NaI gamma-ray detector connected to USX software on the lab computer, we set up the Multi-Channel Analyzer (MCA) to take 1,024 measurements lasting for 10 ms and recording the counts for each. To do this, the conversion gain is set to 1024 and the coarse gain is set to 8. The mode is set to MCS Internal, then the dwell time is set to 10 ms. Lastly, the voltage of the detector is set to 1,100 V.

After collecting data for this part, the USX software is calibrated to detect count vs. energy data by setting the detection mode to PHA-PreAmp In. We are investigating the nuclear decay of cesium-137 to barium-137. After obtaining a plot of count vs. energy, the region of interest (ROI) tool within the USX software is used to provide the centroid value for each peak. After obtaining a spectrum for cesium-137 to barium-137 nuclear decay, a barium-133 sample was placed in the detector and we obtained a spectrum for the barium-133 to cesium-133 nuclear decay.

Results

Part I:

Figure 1 is the graphical representation of the counts versus the detector voltage or the gas amplification curve after using the GM detector to detect ionizing particles. From the gas amplification curve, we determined that the appropriate operating voltage for the GM detector is within the range of 800 V – 1000 V.

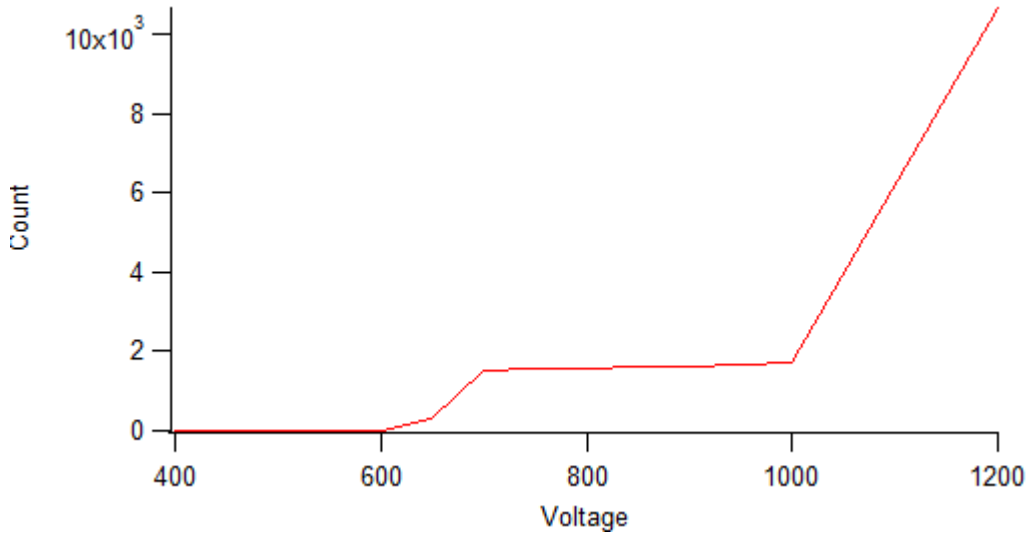

Figure 1: Gas amplification curve plot of total counts vs. detector voltage

Secondly, the detector was set to 800 V within the STX software to find the dead time measurement using the thallium-204 sample and equation 2. The calculated dead time measurement was then corrected using equation 3. Table 1 shows the data collected for each half of the thallium-204 sample along with both halves when the detector was set to 800 V.

Table 1: Dead-time measurement data

	Counts at 800 V
First half of thallium-204 (R1)	8244
Second half of thallium-204 (R2)	7964

Both halves of thallium-204 (R12)	15707

The calculated dead-time using equation 2 was determined to be 3.815e-06 s. Correcting this value using equation 3 yielded 1.671e+04 counts for both halves of the thallium-204 source.

Part II:

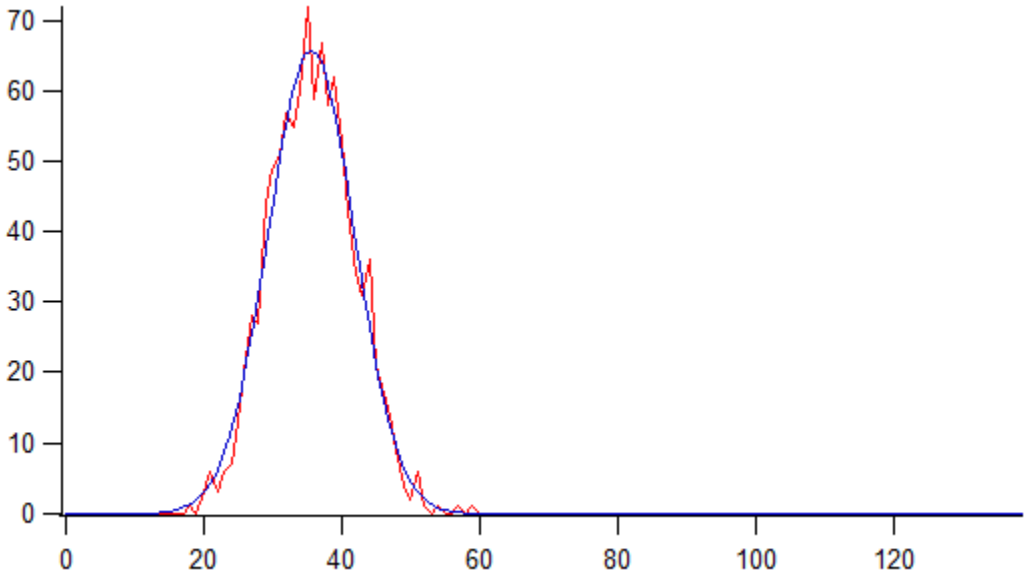

Figure 2: Histogram for Barrium-133

The width value determined from the Gaussian fit is 8.8671 ± 0.112. To calculate the standard deviation, the width value is divided by the square root of two.

$$\sigma = \frac{8.86716}{\sqrt{(2)}} = 6.26998653946$$

The mean determined from the wave used to make the histogram was $\sqrt{m} = 7.31429$.

Figures 3 and 4 show the spectrums obtained from the other half of the part II experiment.

The cesium-137 spectrum contained two peaks that were analyzed using the ROI feature. The centroid values for 32.1 keV and 661.66 keV were determined to be channels 38 and 746 respectively.

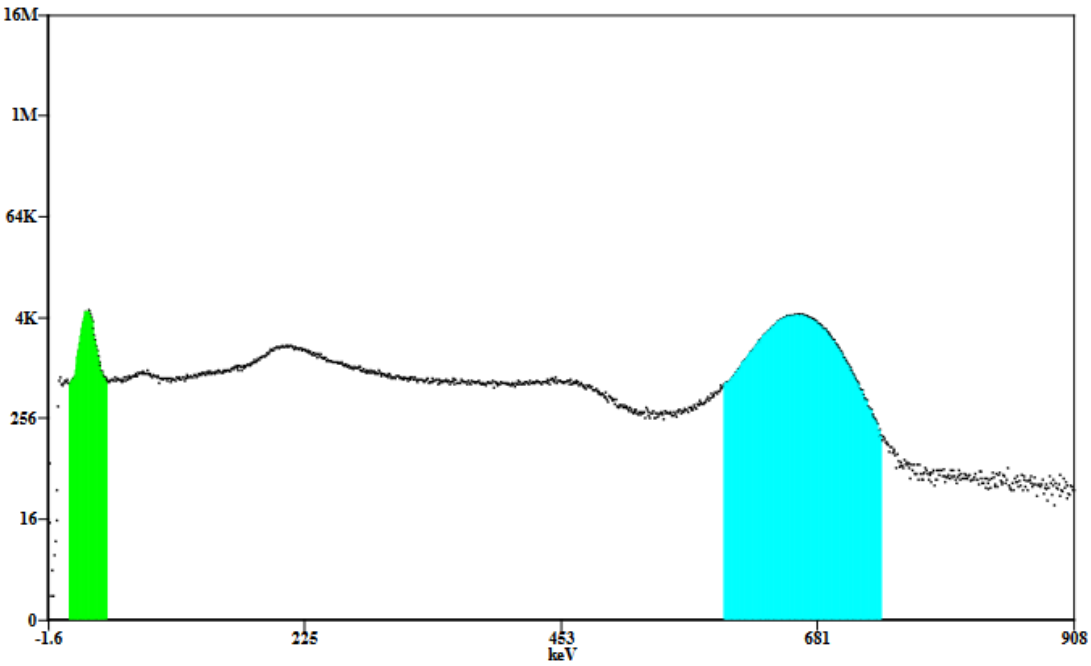

Figure 3: Cesium-137 spectrum

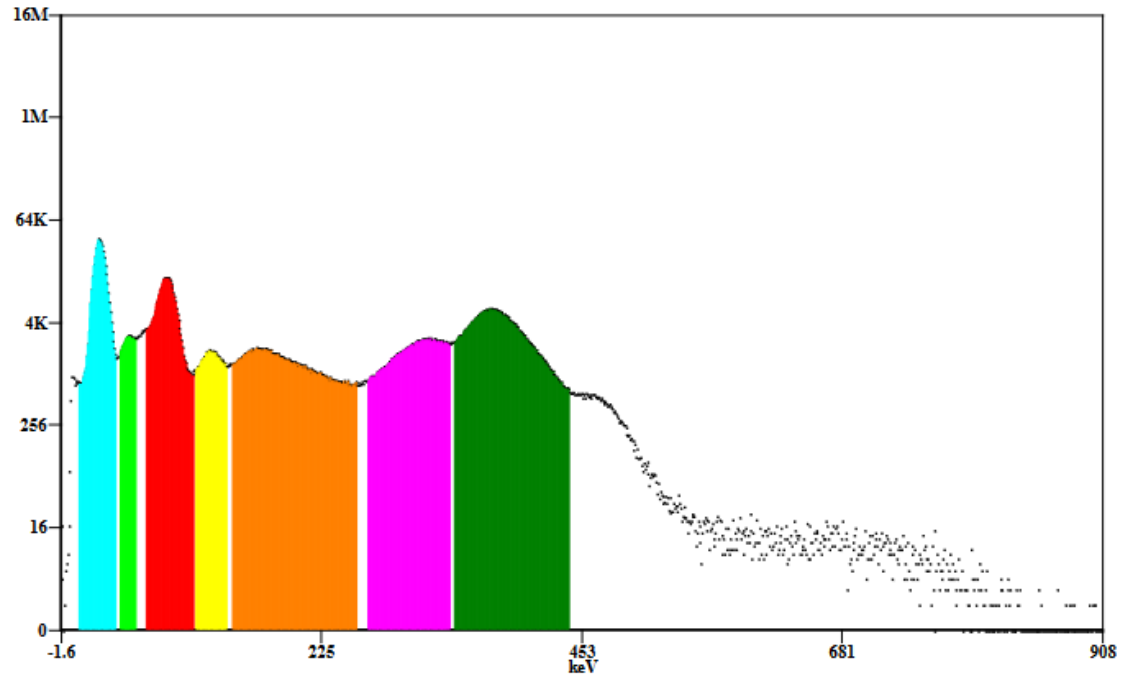

Figure 4: Barrium-133 spectrum

Peak energy (keV)	x-ray probability	gamma-ray probability
31	64.5	2.199
56		2.199
89		34.06
129		0.645
193		0.645
307		18.33
381		8.94

Conclusions

In part I of this experiment, the results from the gas amplification curve showed that the detector is best operated between 800 V and 1,000 V. In operating the detector at 800 V and placing a thallium-204 sample in the detector, a corrected 1.671e+04 count measurement resulted from measuring both halves of the thallium-204 source.

For the first half of part II of the experiment, the values were within 85.72% statistical agreement with each other. This is somewhat agreeable. Random error could account for some uncertainty. Other sources of error could have been minor instrumentation discrepancies in data transmission from the detector to the software on the lab computer.