Absorption of Beta and Gamma Rays

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Abstract

An experiment exploring the behavior of beta (β) and gamma (γ) rays using a Geiger counter.

1 Introduction

The study of beta (β) and gamma (γ) radiation and their interaction with matter provides insight into the fundamental principles of nuclear and particle physics; the radioactive decay processes, which is characteristic of nuclei heavier than lead as well as many lighter isotopes, involve the emission of β and γ rays, each with unique properties and interactions with matter.

Beta particles, essentially high-energy electrons, emerge from the nucleus during the decay process with a range of kinetic energies, are influenced by the accompanying emission of an antineutrino. Their interaction with matter primarily involves ionization and energy loss, leading to a definable range in specific materials. This range is a function of their initial energy and the material's properties through which they are passing. Gamma rays are high-energy photons with behaviors similar to particles due to their short wavelengths and high energies. Their interaction with matter, unlike charged particles, does not involve ionization. Rather, they interact through processes like Compton scattering, the photoelectric effect, and, at sufficiently high energies, pair production. These interactions are quantified using the linear absorption coefficient, which varies based on the gamma ray's energy and the atomic structure of the absorbing material.

2 Method

The primary tool for detecting beta and gamma particles in this experiment is a Geiger counter, which is sensitive to ionization caused by high-energy particles. The Geiger counter records the counts of particles passing through or interacting with it. The setup of the Geiger counter is depicted in Figure 1.

To determine the range of beta particles, Thallium-204 is used as a radioactive source. Aluminum foil absorbers of a known thickness are thenb placed in the path of the beta particles, which are emitted from the source. The counts registered by the Geiger counter are then monitored as the thickness of the aluminum absorbers is increased until the counts reach the level of background radiation. This process will determine the maximum range of the beta particles in aluminum.

Cesium-137 is used as the gamma ray source. Lead absorbers of a known thickness are now used to study the absorption of gamma rays. The number of gamma rays passing through successive layers of lead absorbers will be measured using the Geiger counter. The data will be used to

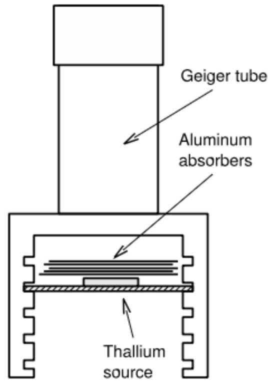

Figure 1: Geiger Counter Setup for Beta Particles

calculate the linear absorption coefficient of gamma rays in lead, based on the exponential decay of the counts with increasing absorber thickness.

Since ambient background radiation can affect the counts recorded by the Geiger counter, it is essential to measure and account for this background radiation. The background count rate is determined prior to the experiments and will be subtracted from the data collected during the beta and gamma ray measurements.

3 Results and Discussion

The background count rate was determined to be 46.6 counts per minute, twice that of the average of 23.3 counts observed over a 30-second interval. This rate is crucial for correcting the experimental data, ensuring that the counts measured are primarily due to the source rather than environmental radiation.

The plateau in the count rate versus voltage graph was observed at approximately 890V, indicating the stable operating range of the Geiger counter. This is illustrated in Figure 2.

The estimated maximum energy of the beta particles, calculated to be 0.119 MeV, significantly deviates from the expected value of 0.765 MeV for Thallium-204. This deviation, was 21.13 standard deviations from the expected value, and suggests potential limitations in the experimental setup or theoretical model used. Factors such as the maximum range estimation from the aluminum absorber thickness, detector efficiency, and the accuracy of the empirical relationship used for energy calculation might have contributed to this discrepancy. One issue that was observed was that the aluminum absorbers didn't always fit in the counter, and needed to be folded at their edges to fit. This may have created some back scatter, impacting final counts. Further investigation and refinement of the experimental methodology is necessary to determine the exact cause of these differences and improve the accuracy of the beta particle energy estimation. This analysis is plotted in Figure 3.

The detection of gamma rays is plotted in Figure 4. It was experimentally determined that the linear absorption coefficient (μ) for gamma rays in lead was approximately 1.268 cm^{-1}. Based on the chart in Figure 5, this value corresponds to an estimated gamma ray energy close to 0.75 MeV, which is consistent with the expected energy value of 0.662 MeV for gamma rays emitted by Cesium-137. The standard deviation in the determination of μ, found to be about 0.141, indicates a moderate level of uncertainty in this measurement, suggesting that the experimental MeV is

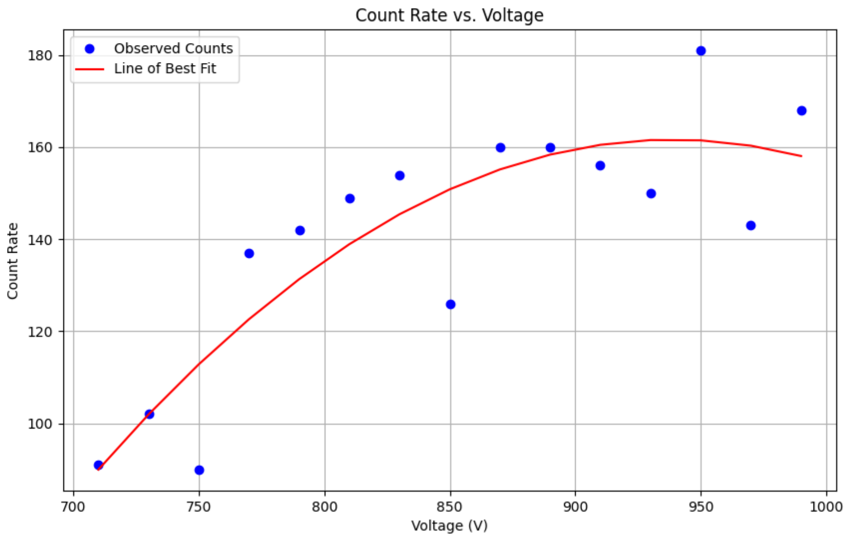

Figure 2: Ambient Radiation Count

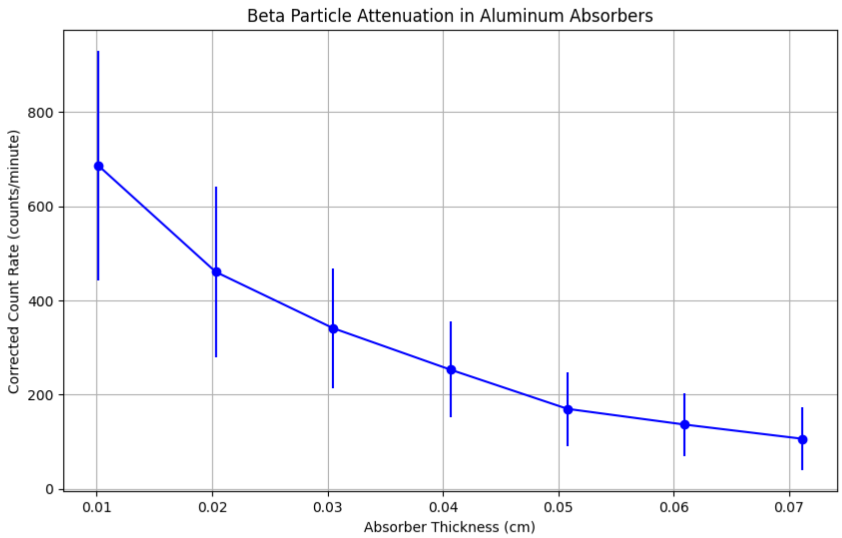

Figure 3: Beta Particle Attenuation through Aluminum

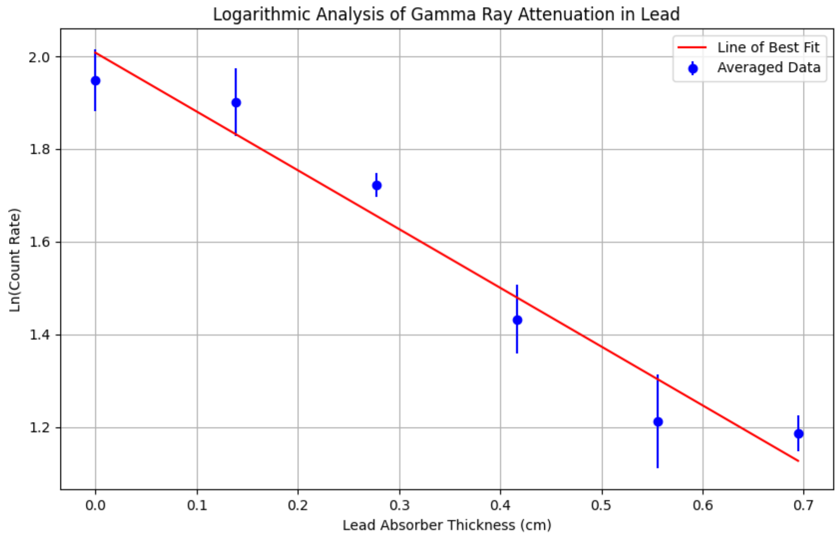

Figure 4: Gamma Particles Attenuation through Lead

well within 1σ variation. This uncertainty could be attributed to factors such as the geometric efficiency of the detection setup, statistical variations in the count rate, and the intrinsic energy distribution of the gamma rays.

It is worthwhile to mention the inherent limitations of the Geiger counter in accurately detecting gamma rays, especially considering their lower ionization probability compared to alpha or beta particles. This limitation might have influenced the precision of our measurements and suggests the potential benefit of using more sensitive detection methods, such as semiconductor detectors, in future experiments. These methods could offer higher sensitivity and better energy resolution for alpha, beta, and gamma rays, providing a more accurate and detailed analysis of their behavior and interactions.

4 Conclusion

This experiment examined the absorption characteristics of beta and gamma rays in aluminum and lead, respectively. The experimental results for beta particles, using Thallium-204, indicated a significant deviation from the theoretical energy values, likely due to the limitations of the experimental setup or the models used.

In contrast, the experiment with gamma rays, utilizing Cesium-137, yielded a linear absorption coefficient in lead that closely aligns with the theoretical expectations for this isotope. The calculated energy of the gamma rays was approximately 0.75 MeV, falling within the standard deviation of the expected value of 0.662 MeV, suggesting that the methodology for gamma ray detection was reasonably accurate, though the moderate level of uncertainty highlighted by the standard deviation indicates room for improvement. Future experiments would greatly benefit from the use of more sensitive detection methods, such as semiconductor detectors, to enhance precision and reliability in measuring both beta and gamma ray interactions.

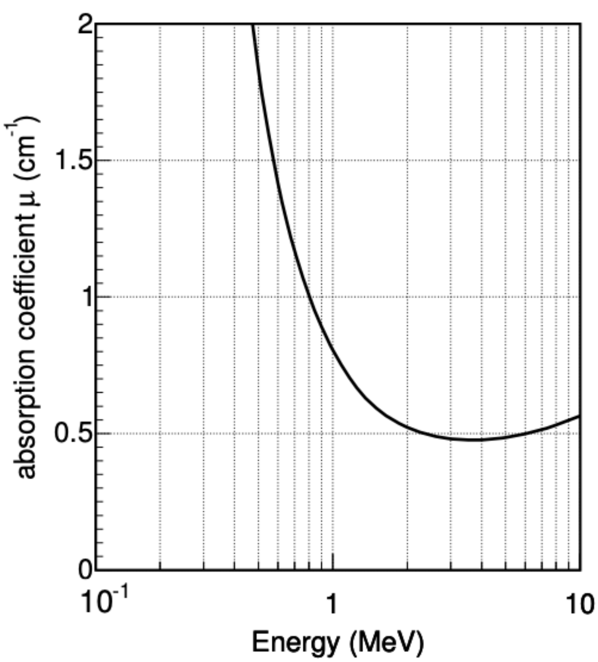

Figure 5: Linear Absorption Coefficient for γ rays in lead, as a fuction of energy.