Radiation Measurement with Geiger-Meuller Tubes

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Abstract

When using a Geiger-*Müller* tube to measure radioactivity, there is a dead-time period after the tube detects an event during which no new events can be detected. We measured this dead-time by using the two source method. In addition to dead-time, we also measured the attenuation of gamma radiation through lead. We then compared our shielding coefficient to the known value in the scientific literature.

Introduction

Radioactivity is an important part of modern physics. It is a common physical process that has been harnessed in many forms, from nuclear reactors to smoke alarms. Natural radiation is ubiquitous in nature, from both radioactive isotopes on earth and from cosmic rays originating in space. This natural radiation is called background radiation, and it must be taken into account when doing experiments that involve measuring radiation.[?]

The three main kinds of radiation are alpha, beta, and gamma radiation. Alpha radiation is a helium nucleus, two protons and two neutrons. It has a +2 charge, is relatively heavy, and is easily shielded by paper. Beta radiation comes in two varieties, β^+ and β^-. β^+ radiation occurs when a neutron decays into a proton, an electron, and a neutrino. β^- radiation occurs when a proton decays into a neutron, a positron, and a neutrino. Both beta radiations are charged and can be shielded by thin metal sheets. Finally, gamma radiation is high energy photons, in the MeV range and higher. Gamma radiation is electrically neutral and needs heavy shielding, as it can penetrate lead in high enough concentrations.[?] In our experiment, we will be using Cobalt-60 (Co-60) and Cesium-137 (Cs-137), both of which are gamma sources.

In this experiment, we will be using Geiger-*Müller* tubes to measure radiation. Geiger *Müller* (GM) counters are the most widely used tool for radiation detection because of their accuracy and simple design. A GM counter is able to detect alpha, beta, X-ray, and gamma radiation, giving it high versatility. Their internal construction is a cylindrical tube with a rod running down the center. The tube is filled with a gas, usually neon, argon, or helium, that will be ionized by radiation. A potential is applied between the tube and the inner rod, so that when radiation enters the chamber and ionizes the gas, there is a current flow between the tube and the rod. This current flow is detected by further circuitry and marked as a radiation detection event.[?] After the current flow, there is a brief period where the the GM tube will not distinguish a new event from the original event. This time period is known as the deadtime, and the GM tube will register no new counts during this period. In addition to the GM counter, we will be using a ST360 Radiation Counter to count and track radiation detections.

One other important aspect of radiation relevant to our experiment is radiation shielding. Putting a physical barrier between a detector and a radiation source will reduce the amount of radiation reaching the detector. For a gamma ray source, we expect an decaying exponential relationship between shielding thickness and radiation attentuation. Each material has a half-thickness, denoted $X_(1/2)$, which is the thickness of the material required to drop the radiation intensity in half. So, the radiation intensity will decrease by 50% for each half-thickness worth of shielding. So, the radiation intensity exponentially decays as a function of the shielding thickness.[?]A more complete derivation of the half-thickness, radiation intensity, and shielding can be found in the Methods section of this report.

We will go through a four step process in this lab. First, we will determine the operating voltage of the GM counter, which we will use for the rest of the experiment.

Second, we will measure the background radiation to subtract from our later radiation rate measurements. Third, we will calculate the dead time of the GM counter using the two source method. Finally, we will calculate the shielding coefficient of lead with a gamma ray source and the relationship between the shielding thickness and the radiation attenuation.

Methods

To run the experiment, we first had to determine the operating voltage for high sensitivity for the GM tube. This was done by sweeping the operating voltage from 0V - 1200V in 20V increments for 30 seconds on a Spectrum Techniques ST360 GM tube. This data was then plotted to determine a range in which the operating voltage would be sensitive enough without causing dialectric breakdown and damaging the equipment. As seen in figure [], the operating voltage for high sensitivity is within the 800V-1100V range. Thus, 900V was chosen as it was within this range at a convenient point and agreed with the value provided by the manufacturer.

Once the operating voltage was determined, the background radiation count was measured to account for noise in the count rate. This was done by running the GM counter for 1000 runs at 1s intervals with no radioactive samples. This background count rate was then subtracted from each data set for count rate measured to minimize noise and gain more accurate results.

Another method in reducing the uncertainty for our experiment was calculating the dead time for the GM tube. Dead time is the period of time in which the positive ions take to reach the cathode and the tube becomes insensitive to radiation. Because count rates for radioactive samples are essentially random, we can attempt to correct this random statistical process to determine a true count rate of a substance. Since the decay of radioactive nuclei can be described by a Poisson distribution, we relate the true count rate as[?]

$$r = Re^{-RT}, \tag{1}$$

where r is the measured rate, R is the true count rate, and T is the dead time. If we take an approximation of this true count rate with a second-order Taylor Series approximation we see that

$$r \approx R(1 - RT). \tag{2}$$

Rearranging Equation (2) for true count rate, we have that

$$R \approx \frac{r}{1 - rT} \tag{3}$$

By accounting for the dead time in our experiment, we can calculate the true count rate of a radioactive sample. This is done by implementing the two-source method. When combining two sources, we measure the combined activity, r_3, as[?]

$$r_1 + r_2 = r_3 + b, \tag{4}$$

where r_1 and r_2 are the individual counts and b is the background count. If each count rates are corrected for dead time, the previous equation becomes

$$\frac{r_1}{1-r_1T}+\frac{r_2}{1-r_2T}=\frac{r_3}{1-r_3T}+b. \tag{5}$$

The background count is not corrected because it is already negligible as is. This means we can transform Equation (5) for dead time into a quadratic by

$$r_1r_2r_3T^2-2r_1r_2T+r_1+r_2-r_3=0. \tag{6}$$

Because T is roughly on the order of microseconds, we can also negate the T^2 term and reduces the equation to the final dead time calculation of

$$T=\frac{r_1+r_2-r_3}{2r_1r_2}. \tag{7}$$

To determine dead time through this two-source method in Equation (7), we used one Co-60 source and one Cs-137 source and measured both individual count rates. Then both sources were measured together, roughly stacked on top of each other since we did not have half-sources, for the total count rate. Then the dead time was calculated by the above equation.

Using the true count rate calculated by the measured dead time, we can use this value to understand how gamma ray radiation interacts with different materials. We expect the radiation attenuation through a material to follow an exponential decay as a function of thickness. The intensity I after passing through a lead shield of thickness d is given by the equation?

$$I=I_0e^{-d/d_0)}, \tag{8}$$

where I_0 is the initial intensity and d_0 is the attenuation coefficient. To solve for d_0, we set the final intensity equal to half the initial intensity, which will occur after a thickness $d_{1/2}$, the half thickness:

$$\frac{1}{2}I_0=I_0e^{-d_{1/2}/d_0}. \tag{9}$$

Solving Equation (9) for d_0 gives

$$d_0=$$

Data and Results

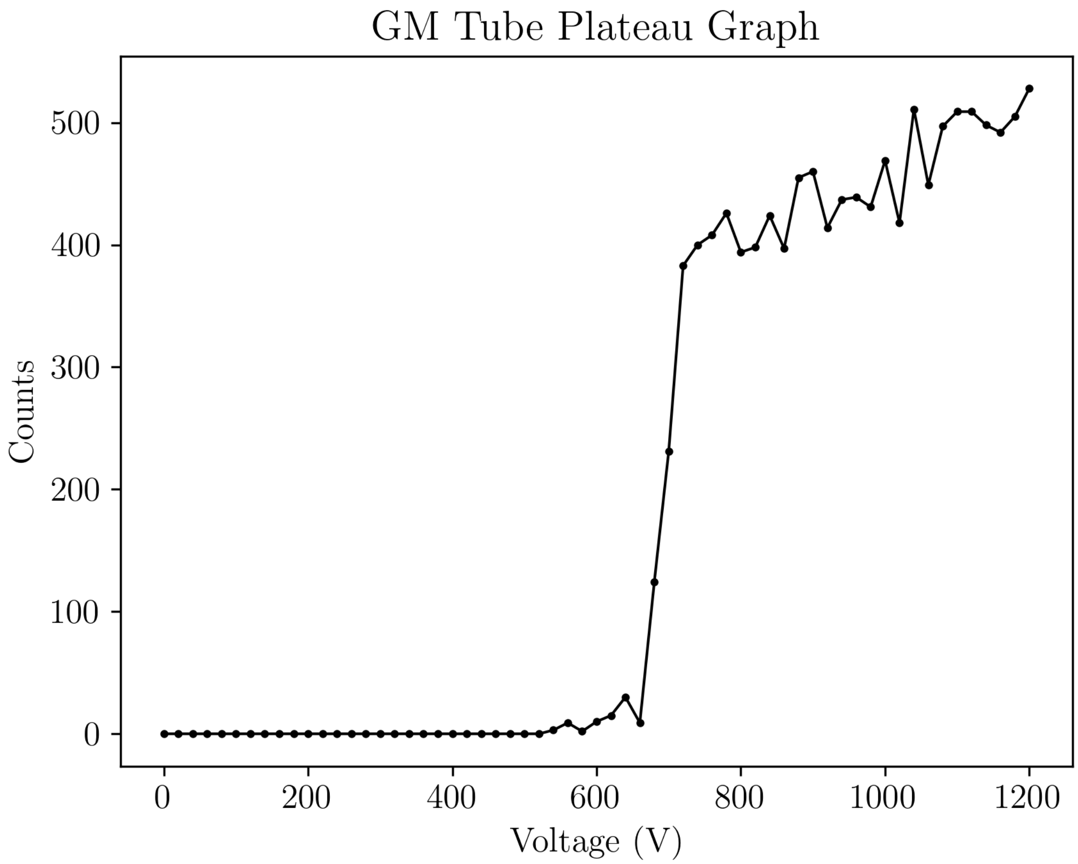

Figure 1: Counts vs. Voltage (V) for the plateau curve experiment, where the operating voltage of the Geiger-Muller tube was increased by 20 V from 0 V to 1200 V.

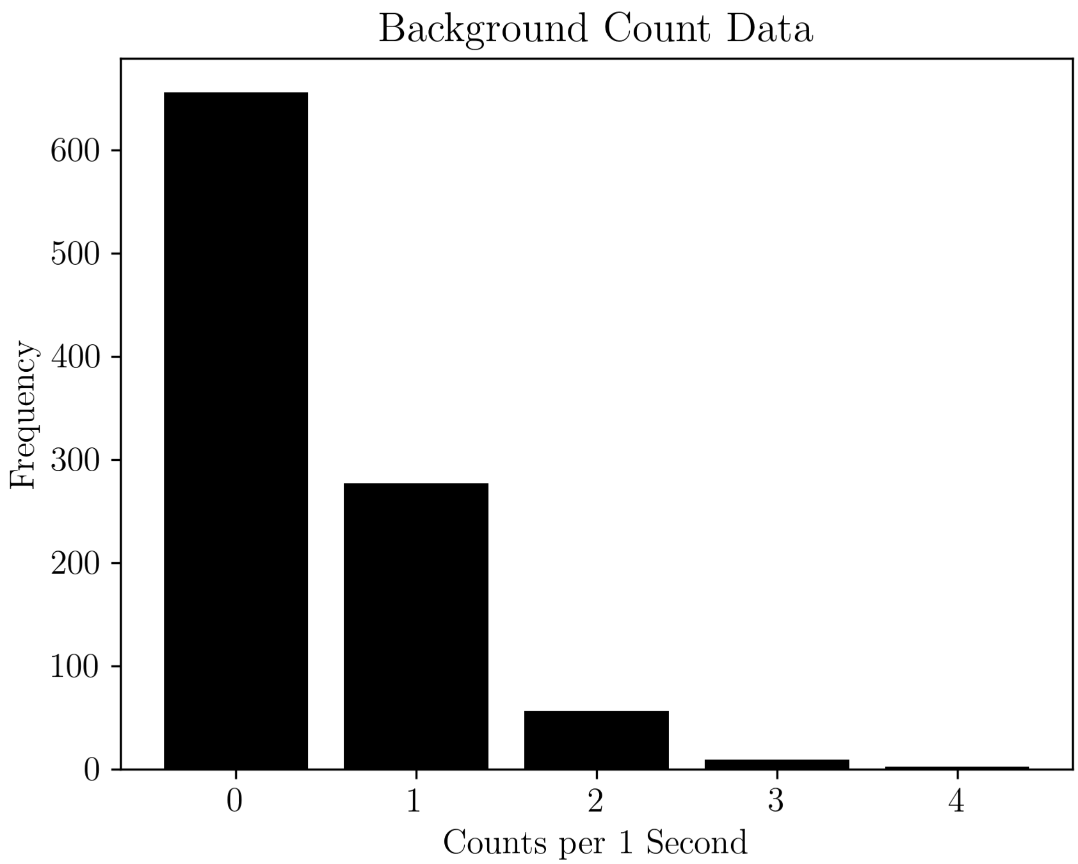

Figure 2: Count distributions over intervals of 1 second for the background measurement.

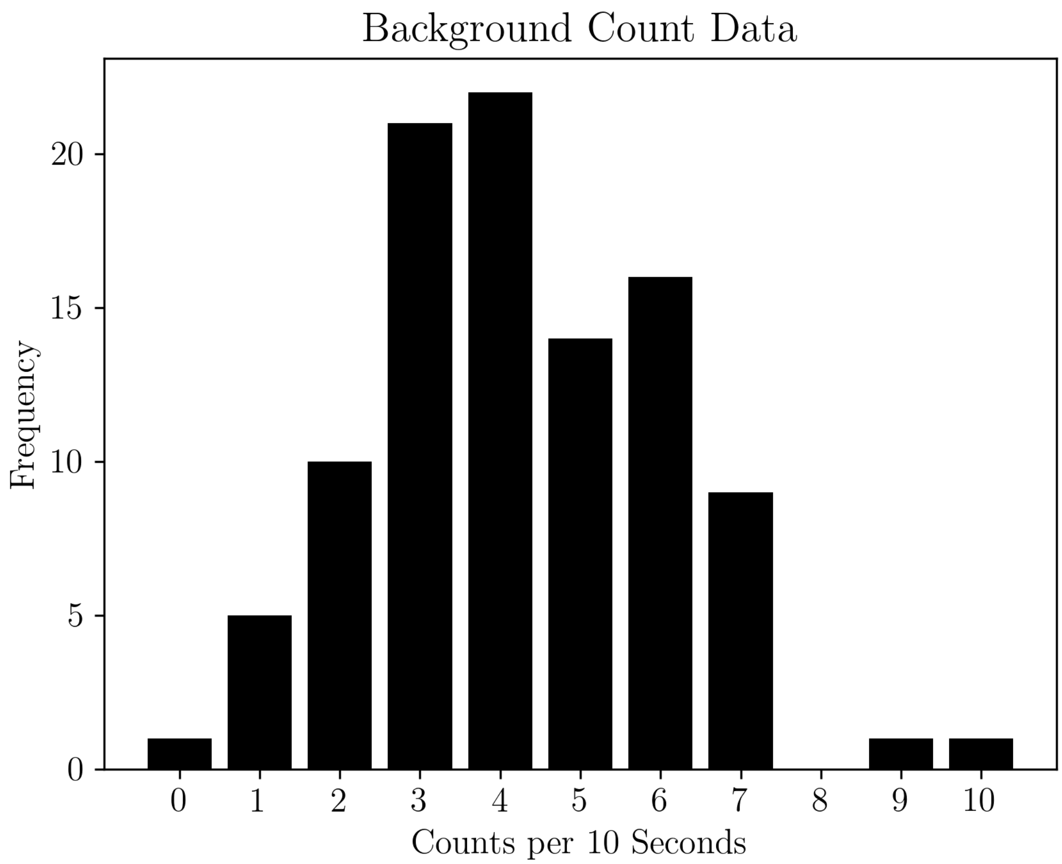

Figure 3: Count distributions over intervals of 10 seconds for the background measurement.

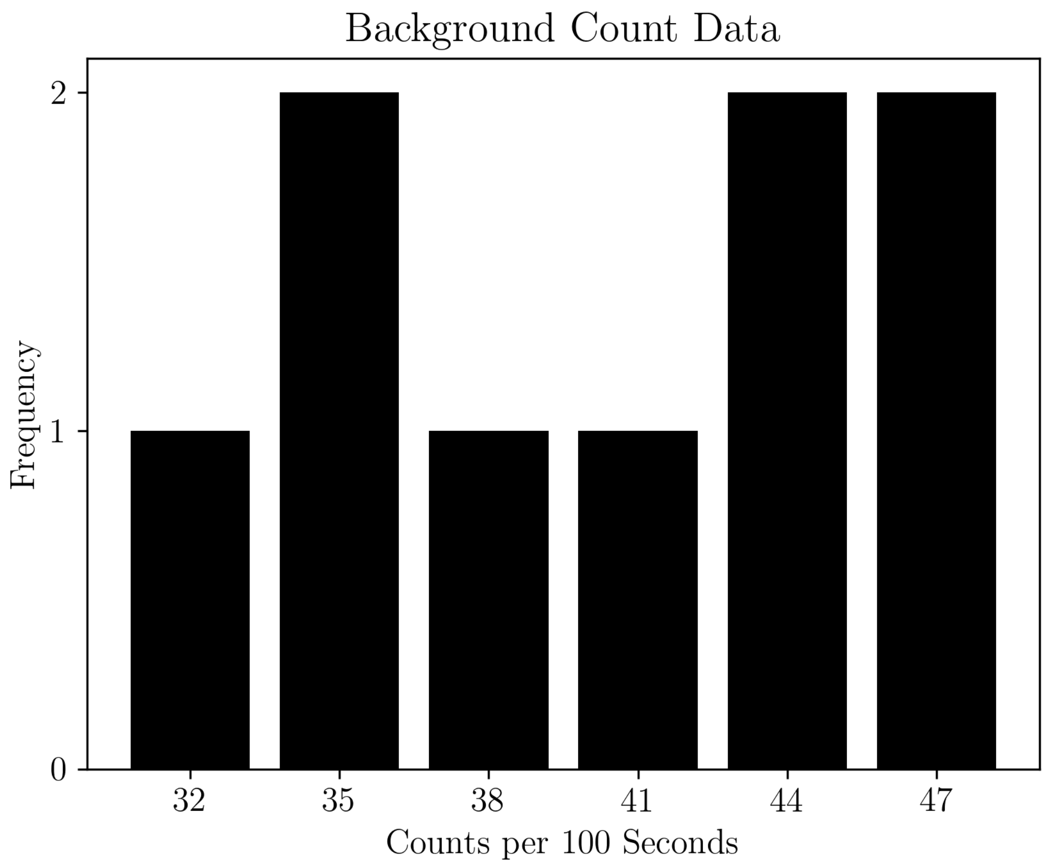

Figure 4: Count distributions over intervals of 100 seconds for the background measurement.

Table 1: Count and count rate data for the ^{60}Co shielding experiment

d (mm)	Total Counts	Total Counts Std.	Count Rate (Bq)	Count Rate Std. (Bq)
0.0000	29669	172	19.779	0.116
1.6256	22194	149	14.796	0.101
3.1750	20293	142	13.529	0.095
6.3500	17420	132	11.613	0.090

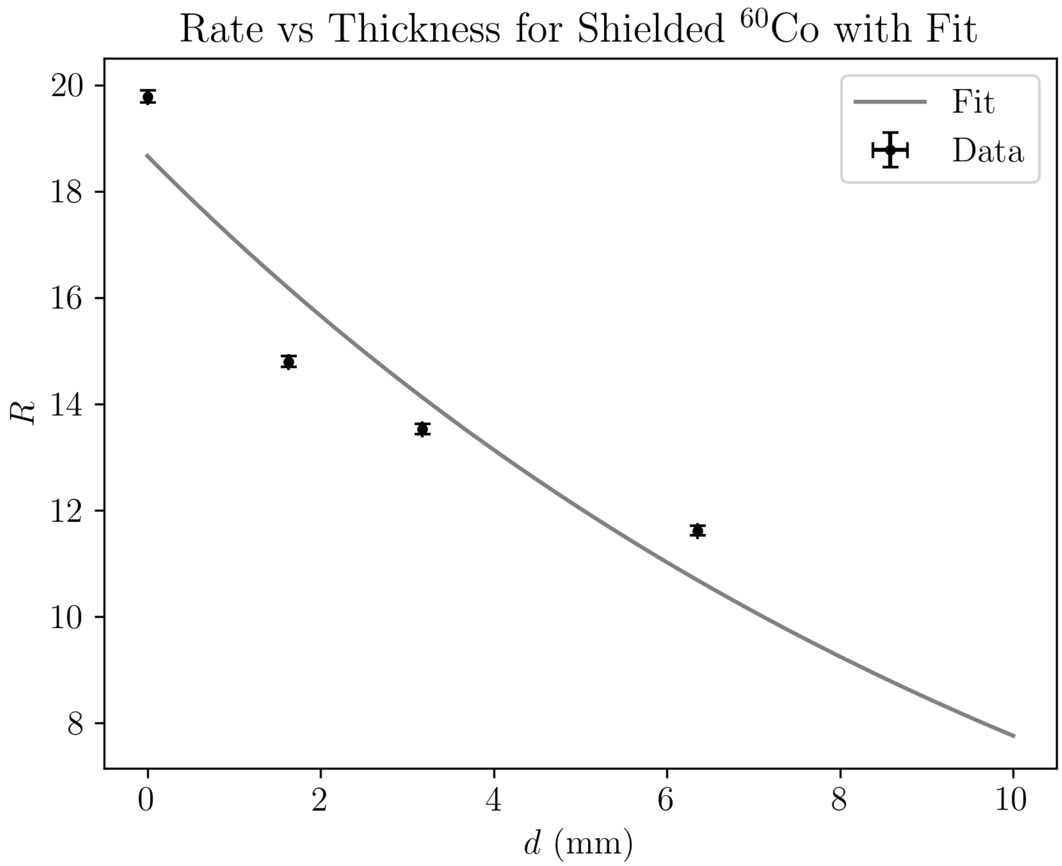

Figure 5: Rate (Bq) vs shielding thickness (mm) for the shielding experiment using ^{60}Co. Fitted using the equation $R = R_0 e^{-d/d_0})$, resulting in $R_0 = 18.663 \pm 0.3245$ Bq and $d_0 = 11.387 \pm 0.801$ mm.

Discussion

We have presented the operating voltage and dead time for our GM tubes, as well as the shielding coefficient for lead with gamma sources. More specifically, we presented the operating voltage as 900 Volts and the dead time as 0.074 ± 0.007 seconds. We have presented our results of the attenuation coefficient for Cs-137 as 11.4 ± 0.8 mm. This result was obtained by fitting the data on a Count Rate vs. Thickness for Lead-Shielded Co-60. The data used in this analysis was obtained through 5 runs at 300 seconds of lead-shielded Co-60 at different thicknesses. Looking at the range of radiation energy emitted by our source, between 1.17 and 1.333 MeV, we chose to use a theoretical calculation of the attenuation coefficient for lead from the NIST website.[?] The attenuation coefficient of lead from a radiation source which emits 1.25 MeV of energy is reported as 14.994 mm. Comparing the result we obtained through data collection and analysis with the reported value from NIST, it shows that these values are not statistically similar with the theoretical value more than one standard deviation larger than the value we found through analysis. In our analysis of the data for lead-shielded Co-60 counts, we took into account both the background counts and the dead time of our GM counters. Also, in our analysis of lead-shielded Co-60 count data, we obtained an attenuation coefficient of 11 ± 30 mm. This value was obtained by taking the mean of calculated attenuation coefficients for 5 runs at 300s of lead-shielded Co-60 at different thicknesses. However, this calculated value carried a relative uncertainty greater than one. Therefore, we decided that it was insignificant in our analysis.

Although radiation count detection carries random uncertainty with it, this random uncertainty was taken into account through use of calculating the true count rate by a second-order Taylor Series approximation. Along with this random source of uncertainty, there were two systematic sources of uncertainty. The first source of systematic uncertainty came from our use of the two-source method to determine the dead time of our GM counter. In doing so, the respective sources were on separate shelves, one on top of the other, in our GM counter. The top source and shelf may have shielded some radiation from the bottom source, effectively lowering the measured count rate from the two sources from their true count rate. The other systematic source of uncertainty came from the assuming that the background count rate was the same with or without lead shielding. In our experiment, we measured the background count rate without lead shielding, effectively obtaining a higher background count rate than the true background count rate for the lead-shielded runs.