Radiation Measurement with Geiger-Meuller Tubes
Advanced Lab 2023

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Abstract

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Introduction

Intro about 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.[?] In addition to the GM counter, we will be using a ST360 Radiation Counter to count and track radiation detections.

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

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

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

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

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

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

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 X is given by the equation

$$I = I_0 e^{-\mu X}, \tag{8}$$

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

$$1/2 I = I_0 e^{-\mu X_{1/2}}. \tag{9}$$

Solving Equation (9) for μ gives

$$\mu = ln(2)/X_{1/2}. \tag{10}$$

Varying different thickness of lead shielding from 1.625mm to 6.350mm and measuring the resulting count rate, we determine the relationship between attenuation and material thickness.

Data and Results

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Discussion

We have presented the operating voltage and dead time for our Geiger Müller 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 0.0942 ± 0.02 seconds. We
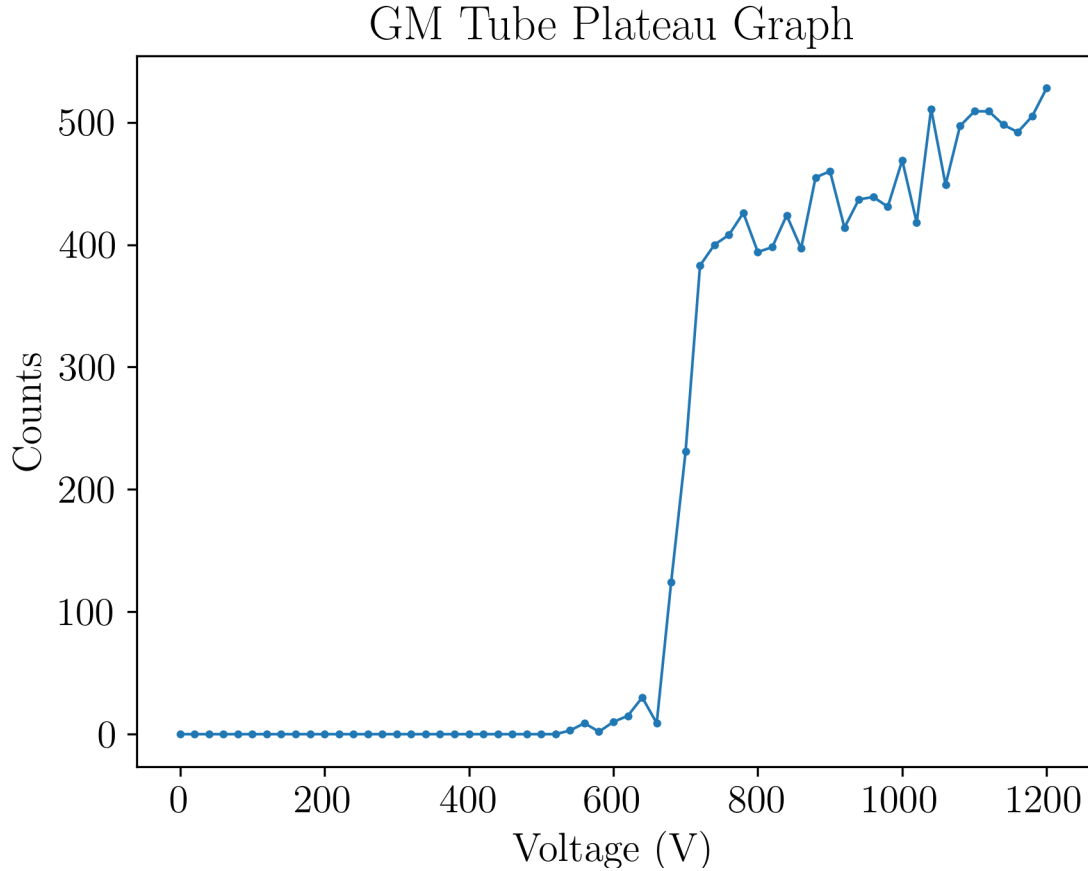
Figure 1: Counts vs. Voltage (V) for the plateau curve experiment, where the operating voltage of the Geiger-Muller tube was increased by 20 V from 0 V to 1200 V.

used two sources (Co-60 & Cs-137) and several methods to calculate the attenuation coefficient of lead shielding for gamma rays. Firstly, we calculated the attenuation coefficient for Co-60 as 8.63 ± 10 mm by taking the mean of the shielded data (attenuation data reference) and plugging it into our equation (attenuation equation reference). Secondly, we calculated the attenuation coefficient for Cs-137 as 9.72 ± 0.6 mm by fitting the data (attenuation data and plot reference). Lastly, we calculated the theoretical attenuation coefficient for Cs-137 as 14.994 mm by the equation (theoretical attenuation equation reference).

Operating voltage = 900 V
Dead time = 0.0942 ± 0.02 seconds Reported Background Count Rate = 0.424 ± 0.02 counts per second
Mean attenuation coefficient for Co-60: 8.63 ± 10 mm (calculated by taking the mean of the shielded data)
Attenuation coefficient for Cs-137: 9.72 ± 0.6 mm (calculated by fitting the data)
Theoretical attenuation coefficient foor Cs-137: 14.994 (with our Co-60 source reported to emit between 1.17 MeV and 1.333 MeV, the average between the two was taken and used to calculate the theoretical attenuation coefficient. This mass-attenuation value is 1.25 MeV
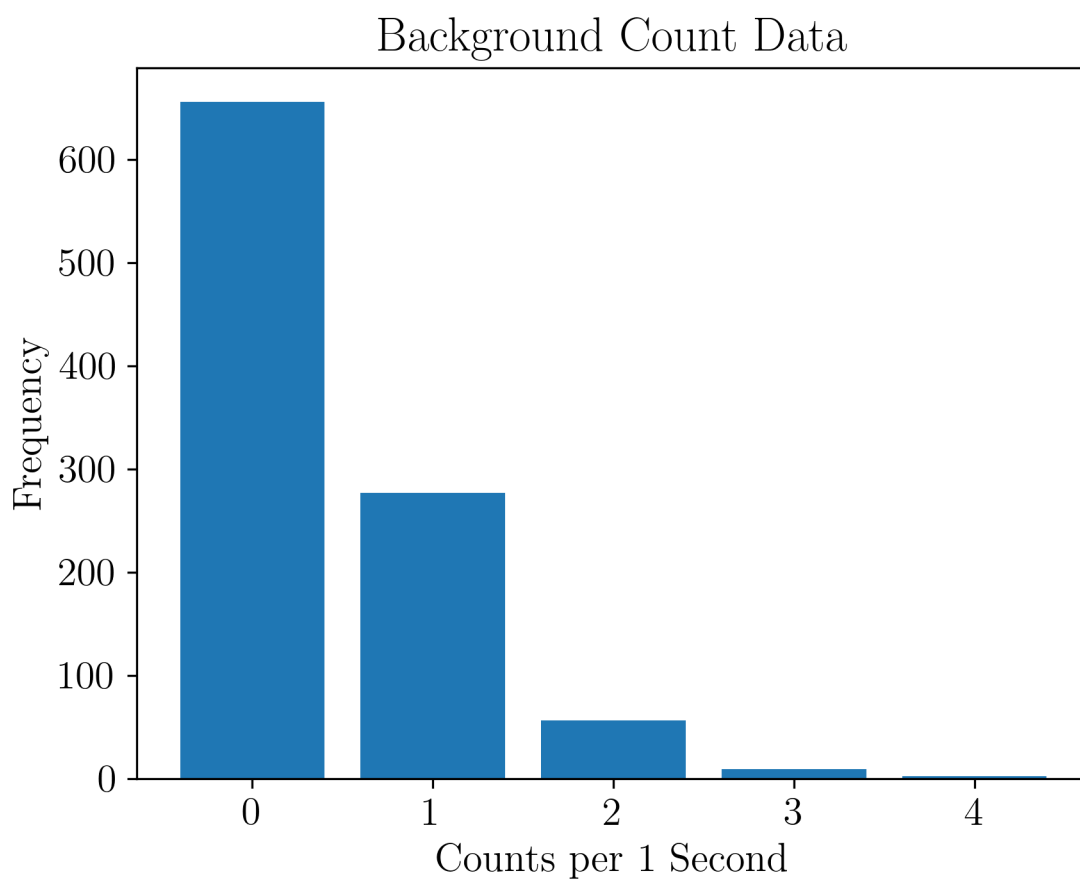
Figure 2: Count distributions over intervals of 1 second for the background measurement.
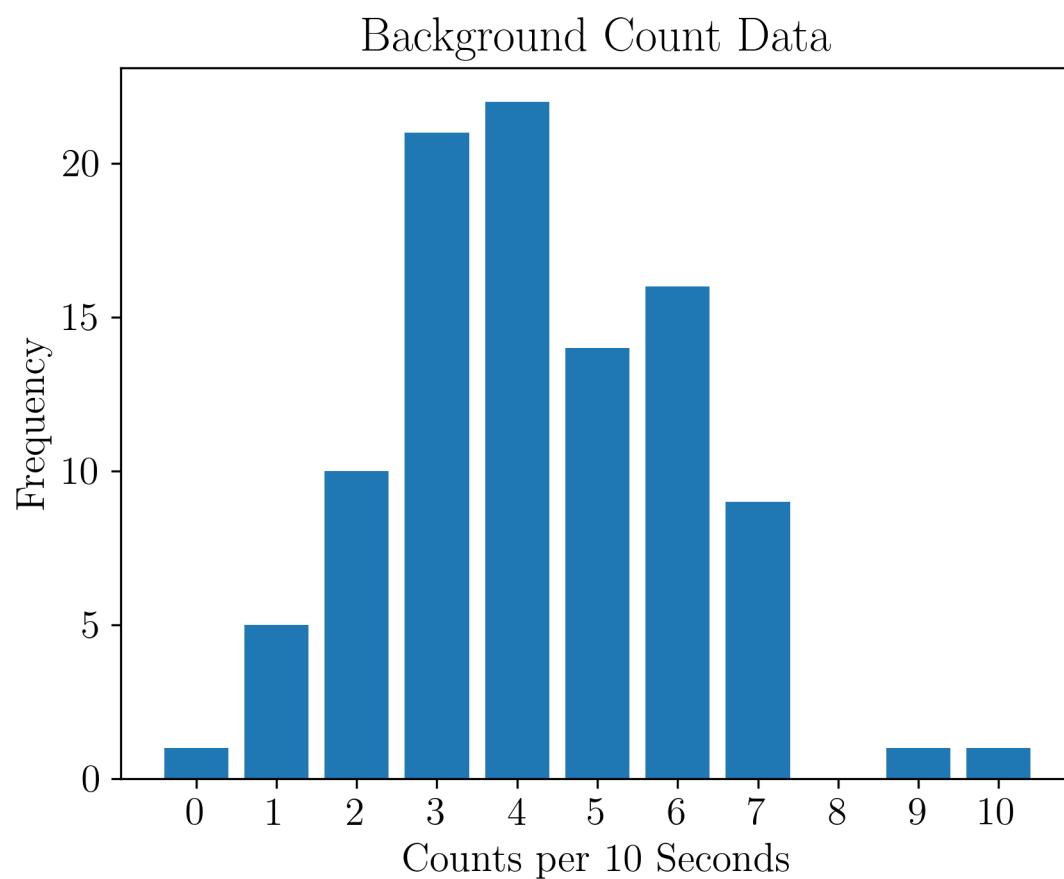
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Figure 3: Count distributions over intervals of 10 seconds for the background measurement.
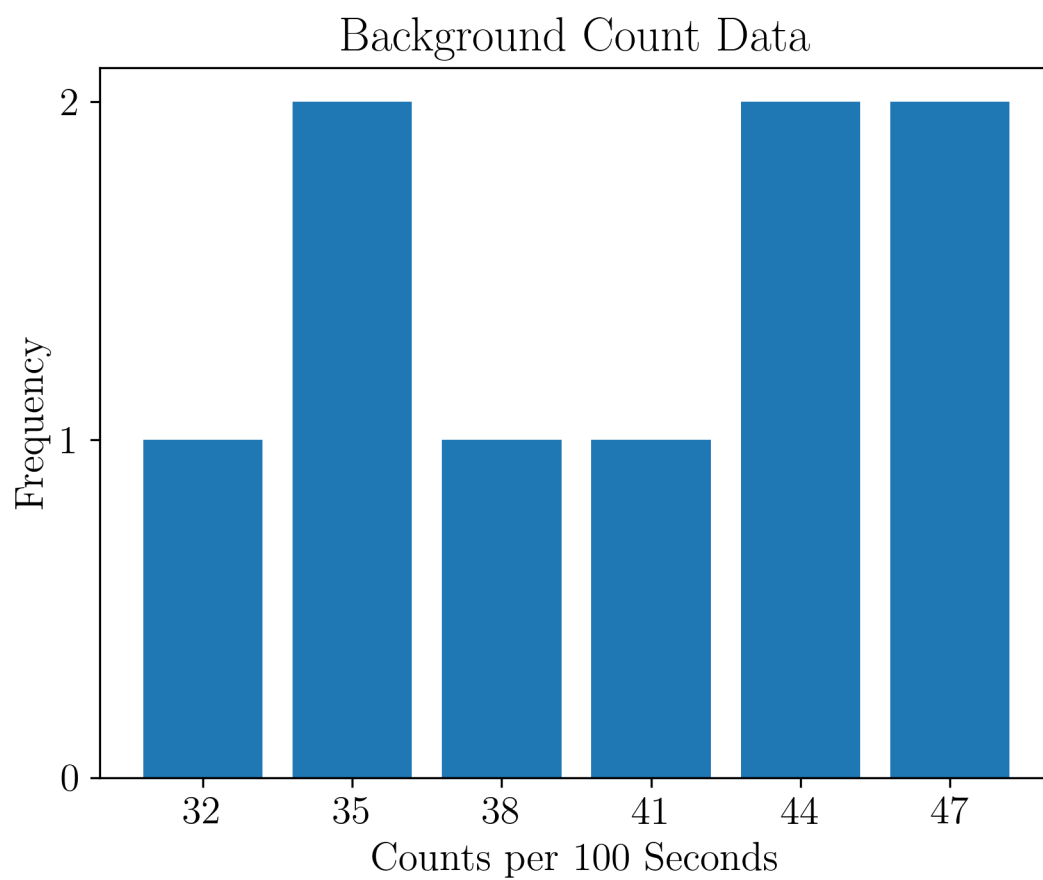
References

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