Experiment # 8: Counting Statistics and Beta Attenuation

References: Lecture Notes
Evans, The Atomic Nucleus
Knoll, Radiation Detection and Measurement
Tsouliyannis, Measurement and Detection of Radiation

Objective: The objective of this experiment is to introduce the operating characteristics of the GM detector, the statistical nature of nuclear pulse counting, and the characteristics of the attenuation of beta particles.

Introduction: In the first portion of this experiment the operating characteristics of the GM detector are introduced by developing a voltage plateau curve. This curve will be used to select the operating voltage for use in the experiment. The voltage selected should fall near the center of the plateau; this point is chosen so small fluctuations in voltage will not affect the count rate.

Once the operating voltage is determined, the next step is to calculate the detector's resolving time. The resolving time, also called the dead time, is the length of time after one pulse is recorded that the detector is unable to detect another pulse. This occurs because the GM detector discharges with each detected event and takes a finite time for the positive ions to migrate to the anode and for the voltage to return to a level where one event ends and another pulse can be detected.

There are two different methods which can be used to estimate the resolving time. In the first method an oscilloscope is connected to the output terminal at the back of the Ludlum counter and the resulting pulse width is measured. This width is the resolving time for the GM detector. The other more complicated technique is the two source method. In this method two Co-60 sources, one labeled A and the other B, are used. Source A is placed under the detector and is counted for one minute. Source B is then placed next to source A. It is very important that the original geometry of source A not be disturbed while inserting source B into the detector. With both sources in the scalar, perform a one minute count. Next remove Source A without disturbing source B. Then perform a one minute count of source B alone. After removing source B perform a one minute background count. The resolving time can then be found using

\[ T_{\text{Resolve}} = \frac{N_A + N_B - N_{AB} - B}{N^2_{AB} - N^2_A - N^2_B} \]

where
- \( N_A \) = Counts from source A alone
- \( N_B \) = Counts from source B alone
\[ N_{AB} = \text{Counts from sources A and B together} \]
\[ B = \text{Counts from background}. \]

The statistical nature of the data can be checked by taking several measurements of identical times and applying the Chi-squared test. This test is used to determine if the data conforms to the Poisson statistical model. Probabilities between 0.05 and 0.95 are considered to fit the model, a value of 0.5 implies a perfect fit. If values outside of these limits are found, then the data should be considered suspect and the electronics checked to ensure that true pulses are being counted and not some spurious signal.

In the final portion of the experiment the characteristics of beta attenuation are observed. Because we know that beta radiation is attenuated exponentially as it passes through a medium, it can be shown that

\[ I(x) = I(0) e^{-\mu x} \quad (2) \]

where \( I(0) \) is the intensity of the unshielded beam and \( I(x) \) is the intensity after passing through thickness \( x \) of shielding. If the count rate is plotted versus the absorber thickness (mg/cm\(^2\)) on semi-log paper then the slope of the resulting line is \( \mu / \rho \) for the material. If there are gamma rays present, the slope of this line will not be a true indication of \( \mu / \rho \). Since only gamma rays will penetrate the thicker absorbers, it is possible to fit a straight line to the data points from these absorbers and extrapolate back to the thinner absorbers. If the contribution of the gamma rays at these thicknesses are then subtracted from the total count rate, the resulting data points will be due to beta radiation only. The slope of a straight line through these “beta only” counts will yield \( \mu / \rho \) for the material.

Once the mass attenuation coefficient is determined the maximum beta energy can be found using

\[ E_{\text{max}} = \left( \frac{17}{\mu / \rho} \right)^{1/14} \quad (3) \]

where \( E_{\text{max}} \) is in MeV and \( \mu / \rho \) is in cm\(^2\)/g.

**Equipment:**

The equipment is to be set up as depicted in Figure 1 below. In addition to the electronics, the following will be required:

- Sr-90 beta source
- Two Co-60 sources for determining resolving time
- Calibrated aluminum absorbers
**Procedure:**

1. Before any data can be collected, a GM detector plateau curve must be generated and the operating voltage selected. Before switching the counter on, check to be sure that the voltage is turned to its minimum setting. GM detectors are very sensitive and can be permanently damaged by excessively high voltages. Place the Sr-90 source in the source holder and slide it under the detector. With the counter on and operating, gradually increase the operating voltage of the GM detector until the scalar begins counting. The voltage at which counts are first detected is the threshold voltage. This represents the beginning of the plateau curve as shown in Figure 2. Continue to slowly increase the voltage until you note a rapid increase in the counting rate. This rapid rise in counts is indicative of the discharge region. Once this is reached note the voltage and **DO NOT EXCEED IT.** Lower the voltage to the threshold value.

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**Figure 1** Electronic Equipment Arrangement

**Figure 2** Typical Voltage Plateau Curve
To generate the plateau curve, measure the counting rate at about ten points between the threshold voltage and the discharge region. Construct a plot of the counting rate vs. voltage. The operating voltage should be selected in the middle of the plateau. Set this voltage for the GM detector and use it throughout the remainder of this experiment. Include the plateau in the final report.

2. Determine the dead time for the GM detector using the oscilloscope and the two source method as described above. Explain any discrepancies in the two values.

3. Determine if the measured data supports the hypothesis of Poisson statistics. With the Sr-90 source in place, take ten one-minute counts. Use an appropriate statistical test to show that the data conforms to Poisson statistics.

4. With the Sr-90 source in the counter, place the aluminum absorbers, one at a time, between the detector and the source and measure the count rate. Once this has been accomplished for each of the aluminum absorbers, remove the source and measure the background. Use the resulting data to determine the attenuation coefficient for the absorber and the maximum beta energy. Think about how to carry out the counting so that counter drift can be identified if it is present. In the set of absorbers there is a mounting ring with no absorber on it. Why?

Write-Up: You should write up this experiment to present the work you have done and your conclusions regarding the operating performance of the GM tube and the energy of the Sr-90 beta particle. Be sure to include graphical and tabular presentations of your results (all results should have an uncertainty associated with them, i.e., ± or error bars). Also, carry out proper statistical analysis on your data to ensure that the detector is functioning properly. Unless otherwise specified, you should take three measurements for each counting arrangement, i.e., three measurements for each of the aluminum beta absorbers used, and use an average value for your computations. Be sure to include the uncertainty in these results.

Include a section describing any discrepancies you have with data you find elsewhere and discuss possible causes for these discrepancies.

Include a section describing changes that could improve the educational quality of this experiment or make it easier to perform.