Geiger-Mueller

Introduction

The main objective of this experiment is multiple. On the one hand, we are going to study the behavior of a Geiger-Mueller counter measuring some of its characteristics as the operating voltage or the dead time (or better the resolving time). On the other hand we are going to use the setup to study some characteristics of the radiation as its statistical nature or the absorption coefficients of photons.

Equipment required

- A Geiger-Mueller tube and its support stand
- Module SPETECH ST360 Spectrum : HV generator and counting
- Set of calibrated absorbers
- Radioactive sources: ^{60}Co, ^{204}Tl, radioactive source split disk, ^{116m}In
- A PC with STX software installed

Setup description

The setup, sketched in figure 1, is relatively simple. It consists of a Geiger-Mueller tube placed in a support in which we can place radioactive samples at different heights. The readout electronics, HV supply and connection to the computer is fully integrated in the module SPTECH ST350. Unfortunately it's not possible to have direct access to the electronic chain. User Guide of both the module itself as well as the software can be found in the webpage www.spectrumtechniques.com.

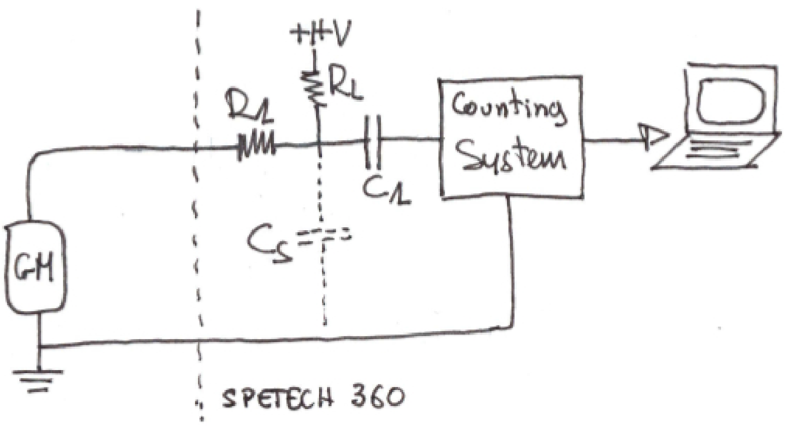

Figure 1: GM experimental setup

IMPORTANT:

- Please do not forget to clear the measurement before you start an experiment and to save your measurements once you have finished.
- In all cases, you should estimate the errors of both direct and derived measurements.

EXPERIMENT 1: Operating Plateau for the Geiger Tube

Description

The purpose of this part is to determine the voltage plateau for the GM tube and to establish an optimal operation point. In Figure 2 it's represented a graph of the counts vs voltage curve. The region between $C1$ and $C2$, corresponding to operation voltages $V1$ and $V2$ contains a "plateau" where the Geiger regime is obtained. If voltage is $V < V1$ we will work in the proportional region, and if $V > V2$ we will work in the discharge region. The optimal operation point is the middle of the "plateau" region.

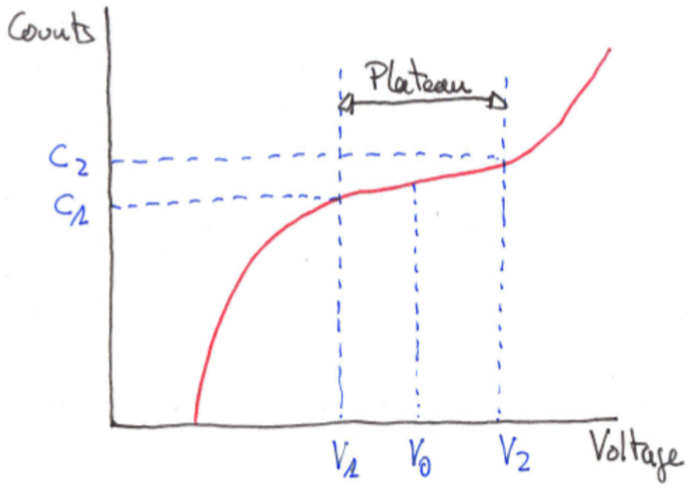

Figure 2: GM: Plateau Curve

Procedure

Estimated time for data taking: 5 minutes

1. Place a ^{60}Co radioactive source in a position close to the window.
2. Go to: Experiments → Plateau
   - High Voltage range: Start: 600 V
     Stop: 1150 V
   - Step Voltage: 25 V
   - Time : 10 seconds
   - Check the case Show Graph Results
3. Start Run. After counting has begun, it will automatically stop when runs equals zero.
4. Save the data to a file. Before saving, a description of the data may be entered into the Description box.

ATTENTION:

Notice that the counts increase rapidly for high voltages ($V > 1100$ V). This indicates that the tube is entering its breakdown region. Do not continue to operate the tube in this region. You may damage the tube

Questions

1. Plot the counts vs voltage graph and determine:
   (a) The voltage $V1$ where the plateau start, and the voltage $V2$ where the plateau ends. What's is the width of plateau?
   (b) Determine the operating voltage in the midpoint.
2. Evaluate the GM tube by measuring the slope of the plateau. It should be less that 10% per 100 V.
$$\text{Slope(in \%)} = \frac{C_2 - C_1}{(C_1 + C_2)/2} \frac{100}{V_2 - V_1} \times 100$$
3. Can you explain the existence of this plateau?

EXPERIMENT 2: Counting Statistics. Background determination

Description

Radioactive decays is an excellent example (if not the paradigm) of a random process. Each measurement of a radioactive activity is independent and repeated individual measurements of the activity vary randomly. However, if a large sample of measurements is taken into account, the deviation from the mean behaves in a predictive way, being small deviations more probable than large deviations. The subjacent process in radioactive decay is well described by a Poisson distribution, where there is only one parameter, the mean (μ):

$$P(n;\mu) = \frac{\mu^n e^{-\mu}}{n!} \quad \rightarrow \quad \begin{array}{r} \text{mean} = \mu \\ \sigma^2 = \mu \end{array}$$

The standard deviation of this distribution is $\sigma = \sqrt{\mu}$ and the best estimator of the mean is simply the arithmetic mean. In case that μ is large enough ($\mu > 20$) the distribution can be approximated with a gaussian where the $\sigma = \sqrt{\mu}$

The purpose of this experiment is to check counting statistics by measuring the statistical fluctuations in two cases:

- Measurement of the background, where count rate is relative small. At the same time we check the Poisson statistics we will estimate the background that we may use later to correct rate measurements
- Measurement of the relatively high rate source. In this case we will see the

Procedure

Estimated time for data taking: 35 minutes

1. Set the operating voltage of the GM tube at the value determined in Experiment 1.
2. Take out all radioactive sources around the GM tube
3. Take 100 independent runs of 10 seconds each
   (a) Preset → Number of Runs = 100
   (b) Preset → Time = 10
   (c) Start run
4. Save data in a file and clear the data

5. Place now a ^{60}Co radioactive source at distance of the source such that the number of counts in 10 seconds is $\sim$100 times of the background count
6. Take 100 independent runs of 10 seconds each.
7. Save data in a file.

Questions

For each measurement

1. Plot the 100 measurements as histograms. Do not forget to draw the errors.
2. Calculate the mean and the sampling variance
3. Perform the χ^2 test to compare the sampling variance and the sigma predicted by the counting statistics. Do they agree?

   Special question.
4. BONUS QUESTION. Fit both histograms to a Poisson and a Gaussian distribution (using minimum square root or maximum likelihood method) and compare the obtained parameters with the mean and sampling variance obtained previously.
   (a) Please comment on the quality of the fit
   (b) Does the curve follow the data?

EXPERIMENT 3: Dead time determination

Description

As we have studied, G-M tubes are very slow detectors. It takes of the order of a microsecond to the detector to develop its full response to the passage of a particle and few hundred microseconds to restore the detector to be fully operational. Besides this dead time, associated only with the detector characteristics, we need to add the time it takes to subsequent events to recover to a sufficient amplitude to cross the discriminator. Indeed the net effect is not only the contribution of the dead time due to the detector but the overall contributions, including, those from the electronics.

Large dead times from G-M tubes distort the measured counting rate for counting rates above few thousand events per minute. In this cases, it's necessary to make a dead-time correction to get the correct counting rates. The purpose of this experiment is to measure the dead time with the two sources method. The measured dead time will be used to correct counting rates in the subsequent experiments.

G-M dead time is well described by a non-paralyzable dead time model. In this model the true rate (n) is related with the measured rate (m) and the dead time (τ) as

$$n = \frac{m}{1 - m\tau} \qquad\qquad m = \frac{n}{1 + n\tau}$$

A useful way to express the dead time is the percent dead time loss:

$$\text{Percent Dead Time} = \frac{n - m}{n} \times 100\% = T\tau \times 100\% = \frac{n\tau}{1 + n\tau}$$

In order to better measure the dead time we should be sure that the counting rates are such that the effect of dead time is sizable. As the dead times we want to measure are of the order of 100 μm, to obtain dead times corrections in the order of 10% to 20%, the measured counting rates should be in the range of 1000-2000 counts/s

In the two sources method we are going to use a radioactive source that has been sectioned in two halves. We are going to perform three rate measurements: R_{12}, rate generated by the two sources, R_1, rate of only source 1 and R_2, rate of only source 2.

Dead time correction can be computed as:

- n_1, n_2, n_{12}, n_b true counting rates
- m_1, m_2, m_{12}, m_b observed rates

$$n_{12} - n_b = (n_1 - n_b) + (n_2 - n_b)$$

$$n_{12} + n_b = n_1 + n_2$$

Assuming non-paralyzable model $n = \frac{m}{1-m\tau}$

$$\frac{m_{12}}{1 - m_{12}\tau} + \frac{m_b}{1 - m_b\tau} = \frac{m_1}{1 - m_1\tau} + \frac{m_2}{1 - m_2\tau}$$

Solving this equation gives

$$\tau = \frac{X(1 - \sqrt{1 - Z})}{Y} \qquad \begin{array}{l} X = m_1 m_2 - m_b m_{12} \\ Y = m_1 m_2 (m_{12} + m_b) - m_b m_{12} (m_1 + m_2) \\ Z = \frac{Y(m_1 + m_2 - m_{12} - m_b)}{X^2} \end{array}$$

In case we neglect the background the solution becomes:

$$\tau = \frac{R_1R_2 - [R_1R_2(R_{12} - R_1)(R_{12} - R_2)]^{\frac{1}{2}}}{R_1R_2R_{12}}$$

An approximation that is sometimes employed is:

$$\tau \simeq \frac{R_1 + R_2 - R_{12}}{2R_1R_2}$$

Dead time correction should be applied whenever the percent dead time exceeds 1%.

Procedure

Estimated time for data taking: 10 minutes

1. Take out all radioactive sources around the GM tube and perform a measurement for 1 minute. This measurement is M_b
2. Place the split radioactive source in the sample holder at a distance such that the counting rate is between 1000 and 2000 counts/s. The source is a beta source, please note the the beta sources have a sense. Beta particles are heavily attenuated in one of the sides of the source
3. Measure the counts for 1 minute. This measurement is M_{12}
4. Take one of the halves and place in its place the blank half disk.
5. Measure the counts for 1 minutes. This measurement is M_1
6. Take out the halve still in place and place the blank half disk in its place. Replace the half removed previously
7. Measure the counts for 1 minute. This measurement is M_2

Questions

1. Calculate the errors of the previous measurements as well as the errors on the measured rates.
2. Compute and compare the dead time corrections as described in the three previous formulas. Express dead time both in absolute value (in μs) as well as in percent dead time. Are they compatible?
3. Figure out a method to compute the error on the dead time

EXPERIMENT 4: Measurement of the Linear Absorption Coefficient

Description

One of the main characteristics of gamma radiation is their exponential attenuation when passing through matter:

$$I(x) = I_0 e^{-\mu x}$$

where I_0 is the initial intensity and μ the so called linear absorption coefficient. In principle, μ depends of the material, but this dependence can be easily removed if we use surface density units for the distance ($s = x\rho$). In this case the previous expression becomes:

$$\mu x = \frac{\mu}{\rho} x\rho = \mu_\rho s$$

$$I = I_0 e^{\mu_\rho s} \quad \ln I = \ln I_0 + \mu_\rho s$$

The coefficient μ_ρ is call the mass attenuation coefficient.

Procedure

Estimated time for data taking: 35 minutes

1. Set the G-M tube at the operating voltage determined in Experiment 1.
2. Place a ^{60}Co source in the G-M stand,but taking care to leave at least two free slots between the source and the G-M tube
3. Take the box with the 20 calibrated absorbers. Place the thinner in one of the free slots and take a 30 seconds measurement.
4. Repeat the previous steps with all the absorbers.
5. In case you want to have intermediate values combine two absorbers
6. Save data to a file and clear the measurements

7. Repeat the procedure but this time with the ^{204}Tl beta source.
8. Save data to a file

Questions

For the ^{60}Co measurements:

1. Draw a graph with the number of events (or rate) versus the surface density units. Comment qualitatively the graph obtained.

2. Fit an straight line using the points leading to an attenuation less than 25%. From this fit give an estimation of the mass attenuation coefficient.

For the ^{204}Tl measurements

1. Draw a graph with the number of events (or rate) versus the surface density units. Comment qualitatively the graph obtained.
2. Can you estimate the range of beta particles from this plot? How does this measurement compares with the range provided by ESTAR?

In both cases, please do not forget to well estimate and quote the errors.

EXPERIMENT 5: Half-Life determination

Description

The purpose of this experiment is to determine the half-life of a relatively short half-life isotope. We know that the activity (A) or the number of decays in a time period T (N) follow an exponential decay:

$$A(t) = A_0 e^{-\lambda t} \rightarrow A(t)T = A_0 T e^{-\lambda t} \rightarrow N(t) = N_0 e^{-\lambda t}$$

where A_0 is the activity at t=0, as well as N_0 is the number of decays in a period T for t=0.

The decay constant (λ) is related with the half-life ($T_{1/2}$) as:

$$\lambda = \frac{\ln 2}{T_{1/2}} = \frac{0.693}{T_{1/2}}$$

We can introduce this in the previous equation:

$$N(t) = N_0 e^{-\frac{0.693t}{T_{1/2}}}$$

and taking logarithms we obtain:

$$\ln N(t) = \ln N_0 - \frac{0.693}{T_{1/2}} t$$

Thus plotting the counts measurement versus time on semilog paper will yield a straight line. The decay constant and the half-life can be obtained from the slope of that line.

Procedure

Estimated time for data taking: 12 hours

1. Set the G-M tube at the operating voltage determined in Experiment 1.
2. Ask the the short live source to the assistant and place it as close as possible of the G-M tube.
3. In the control program set the parameters of the "Half-life experiment":
   - Number of runs: 720
   - Time: 60 s
4. The experiment will take few hours to finish. Leave the experiment running and tomorrow the assistant will send you the file with the results by email.

Questions

1. The isotope we are going to use ^{116m}In is generated by bombarding an Indium foil with neutrons generated from an americium-beryllium source. The whole reaction that produce it is:
$$^{115}In + n \rightarrow ^{116m} In \rightarrow ^{116*} Sn + e^- + \nu_e$$
Find all characteristics of this decay in the data sources provided during the lectures: energy of the beta, lifetime, etc...

2. Plot the measurements versus time (with errors) and comment it qualitatively.

3. Make an estimation of the background rate and compare it with the rate obtained in Experiment 2. Should the background be subtracted from the raw data? Associate an error to this measurement.

4. Discuss if the dead time correction should be done.

5. Make an estimation of the half-time of the ^{116m}In.

6. BONUS QUESTION. Fit the spectrum obtained to an exponential+flat background
   (a) Please comment on the quality of the fit
   (b) Compare the errors with the one obtained previously.