EXPERIMENT 1

The Geiger Counter

Discussion

In the study of radioactivity there are usually three parameters associated with an unknown source that are necessary to know. These are: 1) What kinds of particles is the source emitting, 2) What are the energies of these particles, and 3) How many particles per unit time is the source emitting. In this experiment, the Geiger-Mueller counter (called GM) will be used to help answer the third question. In subsequent experiments, the other two questions will be studied in great detail.

The GM tube is one of a variety of radiation detectors that take advantage of the fact that charged particles lose energy in a gas by creating electron-ion pairs. In air for example, an alpha particle will ionize from 50,000 to 100,000 molecules per cm of its path. The Geiger tube is simply a metal cylinder that is filled with some kind of counting gas. A thin window at one end of the cylinder allows the radiation to enter the counting region. The ion-pairs that are produced by the radiation are swept out and collected by an electric field that is maintained between a thin wire on the axis of the tube (anode) and the metal cylinder (cathode). The electric field between these two electrodes is high enough that the ions produced by the initial radiation are accelerated and produce secondary ions. This phenomena is called an avalanche.

In this experiment β's, & γ's will be measured with one of these end-window Geiger tubes. In order to detect gammas with these detectors, a two step process must occur. The gamma must first make a photoelectric or Compton interaction in the gas. The recoil electrons from these interactions then produce the ion-pairs that cause the avalanche. In the experiment, it will be seen that the GM tube is quite efficient for detecting beta particles, and the voltage gradient across the tube will be set such that any of these ionizing particles that enter the sensitive region will cause an avalanche. The output pulse is usually greater than one volt. The GM tube does not differentiate between kinds of particles or energies; it simply gives an output pulse when any ionizing particle triggers this avalanche. These output pulses are then recorded in a scaler which acts as an electronic adding machine.

Scope

In this experiment, the properties of the GM tube and some important counting parameters will be studied. These include the GM operating voltage plateau and the resolving time of the GM tube. After these introductory measurements, the GM counter will be used to study absorption, the inverse square law, half-life, and counting statistics.

EXPERIMENT 1.1

Determining the Operating Plateau for the Geiger Tube

Experimental Procedure

Figure 1.1 shows a typical voltage plateau curve for a GM tube. At low voltages, there is no output. As the voltage is increased, a few counts will be recorded at the "starting voltage." As the voltage is further increased, the counting rate will change rapidly until the "knee" or threshold of the plateau is reached. From this point on, the counting rate is fairly constant for approximately 200 volts. This is called the plateau region. Shortly after the plateau region, the tube breaks down and goes into a continuous discharge. The operating voltage for the measurements in this experiment will be 25% of the plateau above the knee or threshold. Halogen quenched geiger tubes, such as the Model PK-2 used in this experiment, are NOT harmed by a continuous discharge. Lower the voltage to the plateau level, and the GM tube will again operate normally.

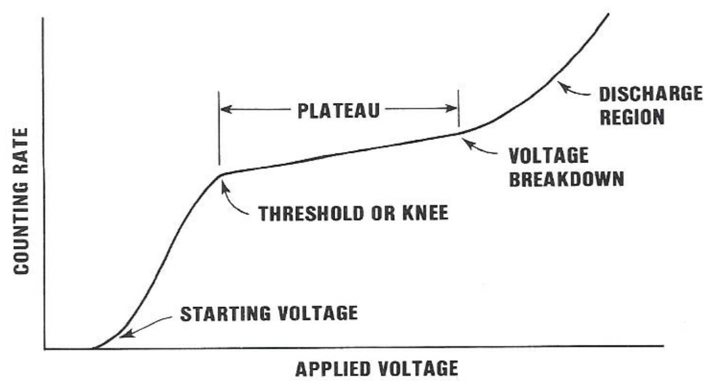

Figure 1.1. Typical Geiger-Mueller Characteristic Curve.

1. Set up the electronics as shown in Figure 1.2

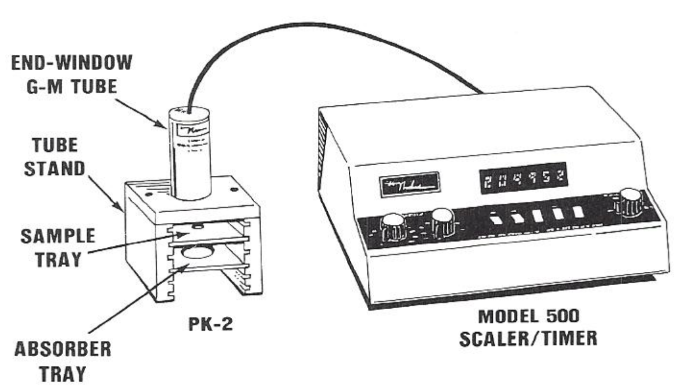

Figure 1.2. Electronics for GM Counting.

EXPERIMENT 1.3

Half-Life Measurement

Discussion

The intensity of a radioactive source changes with time in accordance to the relation:

$$I = I_o e^{-\lambda t} \qquad (3)$$

where λ is the decay constant in reciprocal seconds. I=the intensity at time(t)

I_o = the initial intensity

The half-life, by definition, is the time required for the intensity to fall to one half of its initial value. From eq. (3):

$$\frac{I}{I_o} = 0.5 = e^{-\lambda T_{1/2}} \qquad (4)$$

where $T_{1/2}$ is the half-life. Equation (4) reduces to:

$$\text{Ln } 0.5 = -0.693 = -\lambda T_{1/2} \qquad (5)$$

or

$$T_{1/2} = \frac{.693}{\lambda} \qquad (6)$$

In this experiment the $T_{1/2}$ value will be measured for a short half-life isotope.

Experimental Procedure

1. Set the GM counter at its operating voltage. Take a 300 sec background count and determine the background rate. Obtain the short half-life sample from the instructor. These samples are obtained from a minigenerator or produced with a neutron source by activation. The instructor will usually give a hint as to the value of $T_{1/2}$. This hint will tell how often you must take counts. For example, if the half life is approximately 2 hours, take 5 minute counts every 20 minutes for 3 hours. Other parts of this experiment can be done in between half-life measurements. For each half-life measurement, be sure to place the source at exactly the same distance from the window of the detector. If a minigenerator is used to produce a short $T_{1/2}$ nuclide, place the liquid source in the center of the ringed planchette, and do NOT remove the planchette for the sample tray while obtaining count rate data.

Exercise Subtract the background counting rate from each of the measured rates. Correct each of the rates for resolving time after they have been corrected for background. On semilog paper make a plot of intensity vs elapsed time. This should give a straight line graph similar to figure 1.3. From the graph determine the half-life and λ.

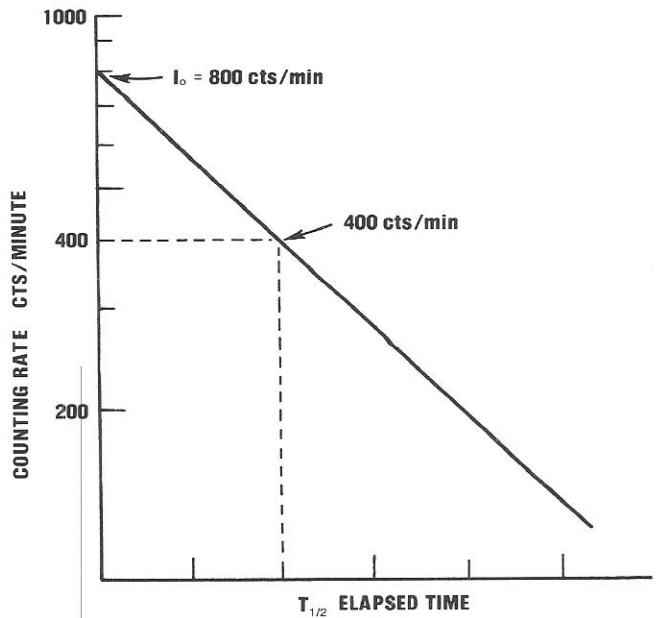

Figure 1.3. Typical Half-Life Curve.

EXPERIMENT 1.4

Linear Absorption Coefficient

Discussion

When gamma rays pass through matter, the intensity (I) after having gone through X thickness of the material is given by:

$$I = I_o e^{-\mu X} \qquad (7)$$

where

I_o = the measured intensity without an absorber
μ = linear absorption coefficient

From equation (7) we can write:

$$\mu = \frac{.693}{X_{1/2}} \qquad (8)$$

where

$X_{1/2}$ = the half value thickness

This experiment is quite similar to the half life experiment. The fall off in intensity of gammas as they pass through absorbers of increasing thickness will be measured. From the data, a plot of Intensity vs Absorber thickness will be made on semilog paper and the $X_{1/2}$ and μ values calculated from the data.

Exercise A On linear graph paper, plot the corrected intensity vs distance. From the 3 cm data point, obtain the constant K as follows:

$$I = \frac{K}{R^2} \quad (9)$$

Exercise B On the same curve, plot eq. (9) with the other values of R. Use the value of K that was found above. What we have done is normalize the data to the 3 cm measurement. How do the two curves compare?

EXPERIMENT 1.6

Statistical Variation of Data

Discussion

There is no way to predict when a person will have an automobile accident that does $1000 worth of damage to his car. However, if a very large number of drivers are considered it is possible for an insurance company to predict with reasonable accuracy, how many accidents, costing $1000, will occur this year. Insurance companies use large computers to store mounds of statistical data so they can accurately predict these probabilities from random events.

The radioactive decay of a nucleus is also a random event. There is no way to determine when a particular nucleus will decay. However, as we have seen, the half-life can accurately be determined. If two identical counts are taken in sequence on a long lived radioisotope, the counts will almost always differ. If a large number of these individual counts are taken, the average count N can be determined. From this data, a predictable deviation of each count from this average can be calculated. The standard deviation

$$\sigma = \sqrt{\bar{N}}$$

For this experiment, 35 independent measurements will be taken on the long lived isotope $^{137}Cs(T_{1/2} = 30y)$ and with this data, the predictable behavior of the measurements will be shown.

Experimental Procedure

1. Set the operating voltage of the GM counter to its recommended value. Place the ^{137}Cs source at a distance such that 2000 counts can be obtained in 0.5 min.

2. Take 35 sequential 0.5 minute counts and record these uncorrected events (N) in a Table similar to Table 1.3.

Table 1.3 Counting Statistics Data Table

Run No.	N	$N-\bar{N}$	$\frac{N-\bar{N}}{\sigma}$	$\frac{N-\bar{N}}{\sigma}$ (Rounded)
1				
2				
3				
4				
5				
6				
7				
8				

Exercise A Calculate the average of these 35 counts $\bar{N}$. Tabulate $N-\bar{N}$ in the table. Note, the number $N-\bar{N}$ can be positive or negative. If you will add up all of the $(N-\bar{N})$ in the table, the answer should be zero. If it is not, a mistake has been made. Calculate σ which is $\sqrt{\bar{N}}$. This is called the standard deviation. Sixty-eight (68) percent of the observed data should lie within the range $\bar{N} + \sigma$ to $\bar{N} - \sigma$.

In the above case, 24 of these measurements should fall within this range. Does the data fit?

Exercise B Calculate $\frac{N-\bar{N}}{\sigma}$ and tabulate it in the data table. Now round off the value for each entry to the nearest 0.5. For example, if $\frac{N-\bar{N}}{\sigma} = +1.11$, the rounded off figure would be +1 . etc. Plot the frequency of rounded off events versus σ and a normal distribution curve should be seen.

Figure 1.5 shows a normal distribution curve that should be similar to your calculations.

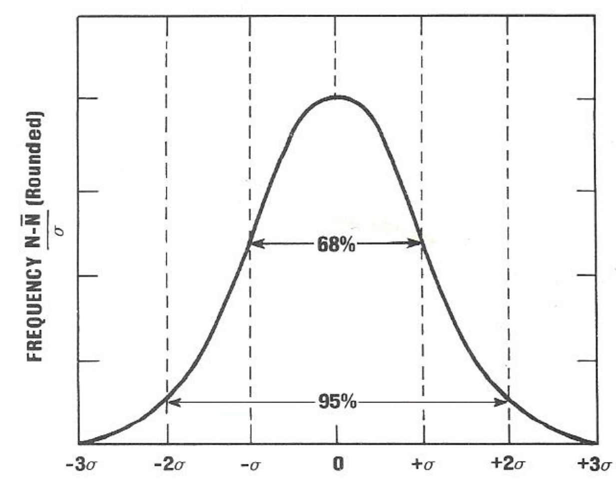

Figure 1.5. Typical Gaussian, Generated from an Extensive Set of Data.

2. Place the ^{204}Tl beta source on the second shelf of the GM stand. Set the timer on "manual" so that the voltage on the tube can be slowly raised and the student can observe all of the features of figure 1.1. Slowly raise the voltage until the starting voltage is reached. Record this value. Continue to increase the voltage until the counting rate levels off. This is the knee of the plateau. Record this value. Continue increasing the voltage until the voltage breakdown region is reached. Record this value. This concludes the visual inspection of the curve.

3. Now we will take data so that the plateau curve can be plotted and the operating voltage for the GM tube established. Go back to the value of the starting voltage and take 60 sec. counts in 50V increments until the breakdown point is reached. Fill in Table 1.1.

Table 1.1 Data for Constructing a Plateau Curve

Run No.	Voltage	Counts	Time Sec	Counting Rate Cts/s
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				

Exercise A Plot a curve of counting rate versus voltage and determine the position of the knee and the voltage breakdown region. Record the operating point, which is 25% of the Plateau, starting from the knee.

Exercise B The plateau region rises with a gentle slope. Calculate the value of the slope. It should be slightly less than 10%.

EXPERIMENT 1.2

Resolving Time Corrections

Discussion

In the earlier discussion it was mentioned that the Beta particle enters the GM tube through the window and loses its energy by creating electron-ion pairs. The electrons that are produced in the resulting avalanche are accelerated to the anode and collected in a short period of time. The positive ions, however, are more massive and make their way slowly to the cylindrical cathode. If their average transient time is called Δt_1, the GM tube is busy, so to speak, during Δt_1. If another ionizing particle enters the GM tube during Δt_1, it will not be counted. This time Δt_1, is called the "dead time" of the tube. In this experiment the resolving time of the GM tube will be determined and the correction factor which can account for these lost events will be shown.

Experimental Procedure

1. Set the GM counter at its operating voltage. Obtain the split source from the instructor. This source is designed such that each half of the source can be counted separately without too many losses, but when both parts are counted at the same time, substantial losses occur. Count the first half of the source on shelf one for 60 sec. Calculate the counting rate and call this rate R_a. Repeat the exact measurement for the second half of the source and call this rate R_b. Now count both halves together for 60 sec. and call this rate R_{a+b}.

Exercise Calculate the resolving time of the GM tube which is given by:

$$T_R = \frac{R_a + R_b - R_{a+b}}{2\, R_a\, R_b} \qquad (1)$$

The true counting rate R_1 can be calculated from the observed counting rate (R_2) by the following:

$$R_1 = \frac{R_2}{1 - R_2\, T_R} \text{ counts/sec} \qquad (2)$$

Note: Because of the solid state electronics used in the circuitry of modern instrumentation such as the scaler, the resolving time of these instruments is normally one microsecond or less. Therefore, only the resolving time of the GM tube affects the true count rate.

For the rest of the data taken in the experiment with the GM tube, eq. (2) should be used to correct the resulting counting rate. Also, the radioactive sources should be moved away and a 60 sec background taken. This background rate should be subtracted from all measurements.

In the experiments to follow, this background rate will be referred to as $\frac{\Sigma - B}{t}$.

Experimental Procedure

1. Set the voltage of the GM tube at its operating value. Obtain a 5 minute background count and determine the background counting rate. Obtain the ^{137}Cs source from the instructor and place it on shelf 3.

2. Take a two minute count, calculate the counting rate, subtract the background and record this I_o value in your data table. Remove the thinnest lead absorber from the kit and place it between the source and the window of the detector. Determine the corrected counting rate for this absorber. Repeat for enough absorbers to reduce the initial intensity to 20% of its original value.

Exercise On semilog paper, make a plot of corrected intensity vs absorber thickness. Figure 1.4 shows a typical absorption curve that was made for this experiment. How does the measured value of μ compare with the accepted value of $0.105 \frac{cm^2}{g}$ for the 0.662 MeV gammas from ^{137}Cs in lead?

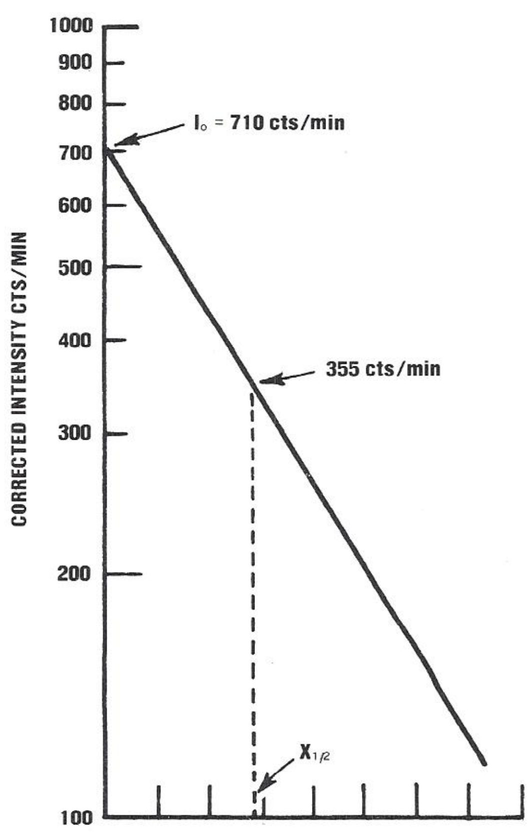

Figure 1.4. Typical Data for the Linear Absorption Coefficient Measurement.

EXPERIMENT 1.5

The Inverse Square Law

Discussion

Most radioactive sources are isotropic in nature. This means that gammas (for a gamma source) are given off equally in all directions. There are some sources, however, where there is a correlation of one gamma relative to the other that is not isotropic. It will be seen in a later experiment that this angular correlation will allow us to predict some properties of the nuclear states that are involved in the decay of these isotopes. In the case of an isotropic source, it is a well known fact that the intensity of the source falls off as $1/R^2$. In this experiment, this $1/R^2$ relationship for a ^{137}Cs source will be verified.

Experimental Procedure

1. Set the voltage of the GM counter at its operating value. Determine the background counting rate.

2. For this experiment, use a ^{137}Cs source. The betas from the source must be attenuated out, since air absorption of the betas will modify the results. This can be done by placing a thin piece ($^1/_{16}$") of almost any material between the source and the window. Place the ^{137}Cs source 1 cm from the window and count for a long enough period of time to get good statistics. Record this uncorrected counting rate in Table 1.2.

Table 1.2 Data for $1/R^2$ Determination

Run No.	Distance	Counting Rate Uncorrected	Back-ground Rate	Counting Rate Correction for Background & Resolving Time
1	1 cm			
2	2 cm			
3	3 cm			
4	4 cm			
5	5 cm			
6	6 cm			
7	7 cm			
8	8 cm			

3. Move the source to the 2 cm position and count for a period of time long enough to get reasonable statistics. Record the uncorrected counting rate in Table 1.2. Continue for the other distances in the table. It should be obvious that the counting time will have to be increased for the longer distances, to get good statistics.

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