Experiment No. (1)

Verification of Inverse Square Law for Gamma-Ray

Apparatus:

- NIM Bin and Power Supply
- High Voltage Power Supply
- Scintillation Detector
- Scintillation Preamplifier
- Linear Amplifier
- Single-Channel Analyzer
- Timer & Counter
- Oscilloscope,
- ^{137}Cs radioactive source
- Connecting Cables.

Purpose:

The student will verify the inverse square relationship between the distance and intensity of radiation.

Theory:

There are many similarities between ordinary light rays and gamma rays. They are both considered to be electromagnetic radiation, and hence they obey the classical equation

$$E = h\nu$$

Where

E ≡ photon energy in Joules.

ν ≡ the frequency of radiation in cycles/s.

h ≡ planks constant (6.624×10^{-34} Joule. s)

Therefore in explaining the inverse square law it is convenient to make the analogy between a light source and gamma-ray source.

Let us assume that we have a light source that emits light photons at a rate N photons/s. it is reasonable to assume that these photons are given off in an isotropic manner, that is, equally in all directions. If we place the light source in center of a clear plastic spherical shell, it is quite easy to measure the number of light photons per second for each cm^2 of the spherical shell. This intensity is given by

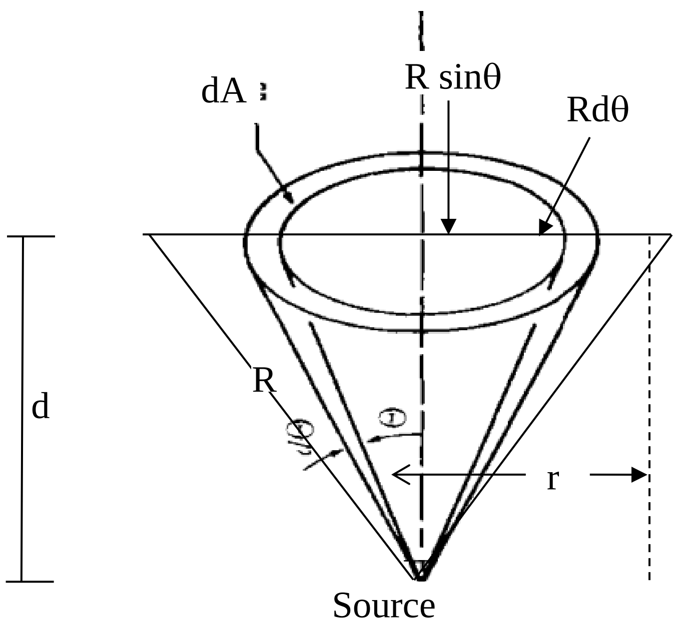
$$n = \frac{N}{A} \text{....................(1)}$$

where N is the total number of photons /s from the source, and A is the total area of the sphere in cm^2. Then equation (1) can be rewritten as:

$$n = \frac{N}{A(= 4\pi r^2)} \text{....................(2)}$$

From eq.(2) we find that (n) is inversely proportional to the square of the distance. This equation is in term of the fraction of solid angle subtended on a point source by the counter entrance window. This is illustrated in the figure below.

The total solid angle subtended by a shell on its center is 4π, if Ω is a solid angle corresponding to a given segment of this shell then



$$n = \frac{N\Omega}{4\pi}$$

If (r) is the radius of detector window or the scintillator crystal face (d) is the vertical distance of source (S) from the detector, we presume that (d>r) which is practically possible.

From the definition of solid angle,

$$\Omega = \frac{dA}{R^2}$$

$$d\Omega = \frac{Area\ of\ annular\ ring}{R^2} = \frac{\pi(Rd\theta + R\sin\theta)^2 - \pi R^2 \sin^2\theta}{R^2}$$

Since θ is small, $(d\theta)^2$ can be neglected.

$$d\Omega = 2\pi \sin\theta \, d\theta$$

$$\Omega = 2\pi \int_o^{\propto} \sin\theta \, d\theta = 2\pi\,(1 - \cos\alpha)$$

$$\cos\alpha = \frac{d}{\sqrt{r^2+d^2}}$$

$$\Omega = 2\pi\left(1 - \frac{d}{\sqrt{r^2+d^2}}\right) = 2\pi[1 - (1 + \frac{r^2}{d^2})^{-1/2}]$$

By using binomial theorem $(1+x)^n$ = 1+ nx + n(n-1)/n! x^2+……

$$\Omega = 2\pi[1 - \left(1 - \frac{1}{2}\left(\frac{r^2}{d^2}\right) + \cdots\right)] = 2\pi.(\frac{1}{2}).\frac{r^2}{d^2}$$

$$\Omega = \frac{\pi r^2}{d^2}$$

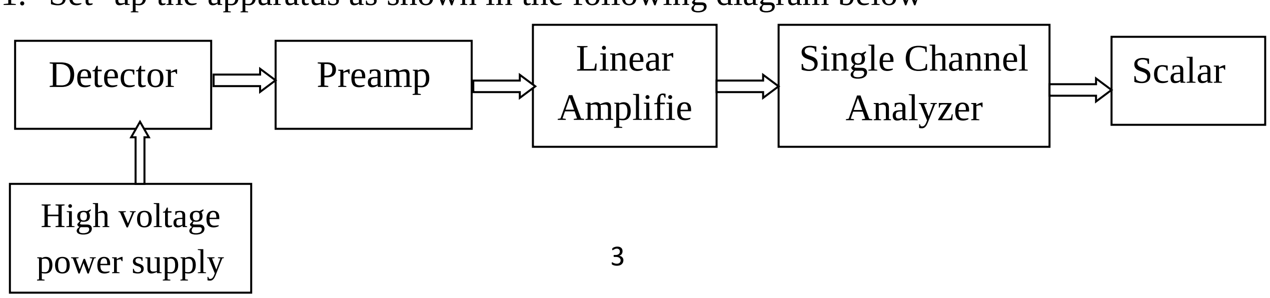
But $= \frac{\Omega}{4\pi}$; where (G) is the geometry factor $G = \frac{r^2}{4d^2}$

$$n = NG = \frac{Nr^2}{4d^2} \ldots\ldots\ldots.(3)$$

Equation (3) is required form of the inverse square law

Procedure:

1. Set- up the apparatus as shown in the following diagram below



2. Place the Cs^{137} source at suitable distance (satisfy $d > r$) from the detector face.
3. Set the scintillation counter voltage at the proper value ($\cong$ 950 V).
4. Count for period of time sufficient to get reasonable statistics.
5. Change the distance between source and counter face in regular step (1 cm) and repeat the counting rate with each change in distance.
6. Find the background count rate (without source) and tabulate data as follows:

d/cm	Count / sec			$n = n_{ave} - n_b$	$1/d^2$ (cm^{-2})
	n_1	n_2	n_{ave}		
4					
4.5					
5					
5.5					
6					
6.5					
7					
7.5					
8					
8.5					
9					
9.5					
10					

8. Plot a graph between n (y-axis) and $1/d^2$ (x-axis), then from the slope evaluate N using eq. (3).
9. Compare the obtained value of N with the current activity of radioactive source Calculated from ($A = A_o e^{-\lambda t}$, A_o = 25 μCi, λ (decay const.) = ln2/($t_{1/2}$=30y) , and t = 41y).

Questions

1. Why it is necessary that the distance between the source and the detector should be greater than the radius of the detector?
2. Give the reason, why the graph between n and $1/d^2$ do not pass through the origin.
3. Is the calculated value of N represents the exact activity of the radioactive source? Explain your answer.

Experiment No. (2)

Deflection of Beta Particles in a Magnetic Field

Apparatus:

Geiger-Müller tube, Holder for Geiger-Müller tube, Holder for radioactive source, strontium-90 (^{90}Sr) beta source, deflecting magnets for plate holder, angular scale and Stopwatch.

Theory:

Any charged particle moving through a magnetic field will experience a force ***F***. This force is called the "Lorentz force" and will be perpendicular to the directions of both the magnetic field **B** and the velocity **V** of the charged particle and is given by:

$$\vec{F} = q\,\vec{v} \times \vec{B}$$

The exact direction of the force is given by the right hand rule. If θ is the angle between **v** and **B**, we can right for the magnitude of :

$$F = q\,vB\sin\theta$$

Hence, for a magnetic field that is perpendicular to the direction of motion of the charged particles

$$F = q\,vB$$

If the particle has a negative charge, as does a conventional Beta particle, the force will be in the opposite direction from that experienced by the positive charged particle. When the magnetic field remains constant, the charged particle will continue to experience the Lorentz force which will be constant in magnitude but with a direction that is always perpendicular to its velocity vector. This force will change the direction of the charged particle and force it to follow a circular path in the magnetic field. Therefore, if we put a detector that can be rotated in front of the beta source after applying the magnetic field, we should observe that the path of the particles is indeed deflected.

Procedure:

- Connect the apparatus as shown in **Fig.1**.
- Insert the source of radiation in the source holder. Place the source holder in front of the plate holder and slide the source of radiation until its exit opening is in front of the deflecting

magnets, Place the plate holder with the deflecting magnets on the center point of the angular scale.

- Carefully remove the protective cap from the counter tube, start the first measurement by pressing the enter button. Note the first count rate in Table 1 on the Results page.
- Move the counter tube holder to the 10° graduation on the angular scale, making absolutely sure that the distance of the counting tube from the source of radiation does not change and that the axis of the counter tube is exactly aligned along the angle graduation. Start the next measurement and enter the count rate in Table 1.
- Repeat this measurement with all of the angles from +90° to -90° listed in Table 1.
- Remove the deflecting magnets, and then determine the count rates for all listed angles as before.
- On completion of this measurement series, replace the protective cap on the counter tube and replace the source of radiation in the container.
- Plot a graph between the angle (θ) on x-axis and the count rate per 60s on y-axis.

Table 1.

Angle(θ) degrees	**Without magnets N counts /min**	**With magnets N counts /min**
90		
80		
70		
60		
50		
40		
30		
20		
10		
0		
-10		
-20		
-30		
-40		
-50		
-60		
-70		
-80		
-90		

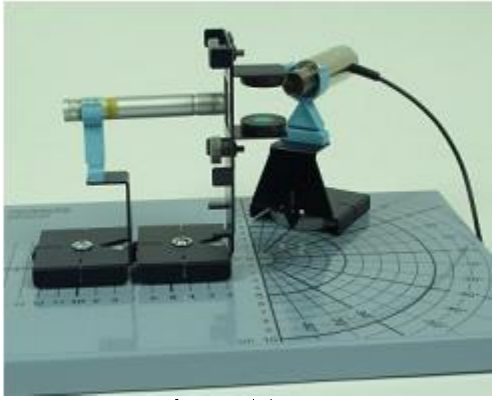


Figure (1).

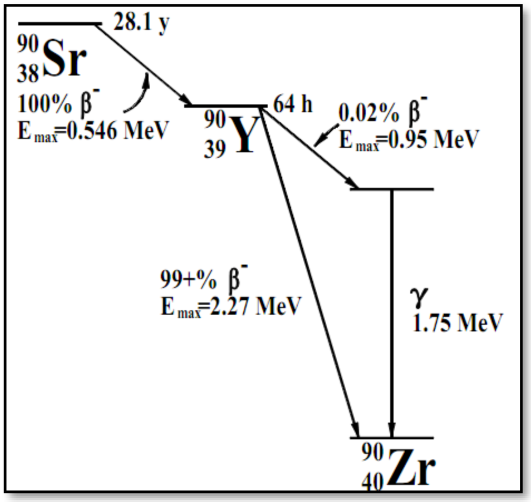


Figure (2). Decay scheme for strontium-

Attention:
The counter tube window of the Geiger-Müller counter is not guarded. The danger that touching the counting tube window can destruct it should be particularly stressed. As a matter of principle, the students should therefore only remove the protective cap shortly before beginning the measurements and replace it directly after they are finished.

Exp. (3)

Absorption Coefficient for γ - rays

Apparatus

- Geiger-Muller Tube
- Timer & Counter
- ^{137}Cs radioactive source
- Connecting Cables.
- Lead and copper absorber sheets

Purpose

The purpose of the experiment is to measure experimentally the linear and mass absorption coefficient in lead and copper for 662 KeV gamma rays.

Introduction

Gamma rays are highly penetrating radiation and interact in matter primarily by photo electric, Compton, or pair production interaction. In this experiment we will measure the number of gammas that are removed by photo electric or Compton interaction that occur in a lead or copper absorber placed between the source and the detector.

From the Lambert law equation the decrease of intensity of radiation as it passes through an absorber is given by

$$I = I_0 \, e^{-\mu x} \text{ ……………………..(1)}$$

Where

I: intensity after the absorber.

I_0: intensity before the absorber.

μ: linear mass absorption coefficient in cm^{-1}.

x: is the thickness in cm .

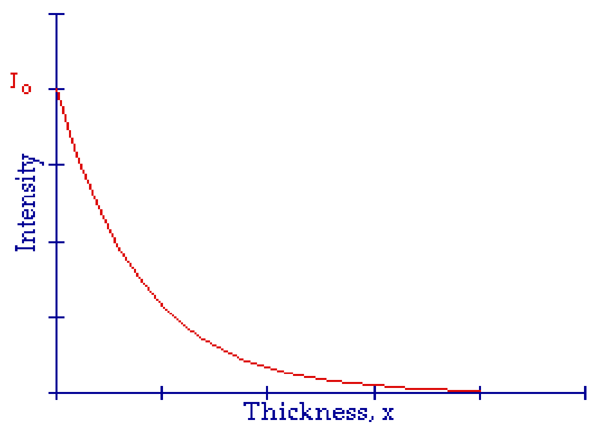


Fig. (1): intensity Vs. thickness for gamma ray energy of 662 KeV.

The half-value layer ($X_{1/2}$) is defined as the thickness of the absorbing material that will reduce the original intensity by one-half. From equation (1)

$$\ln\frac{I}{I_0} = -\mu x \quad \text{… … … … … … …} (2)$$

If $I/I_0 = 1/2$ and $x = X_{1/2}$, the ln (1/2) = - μ ($X_{1/2}$) and hence

$$X_{1/2} = 0.693/\mu \quad \text{………………..}(3)$$

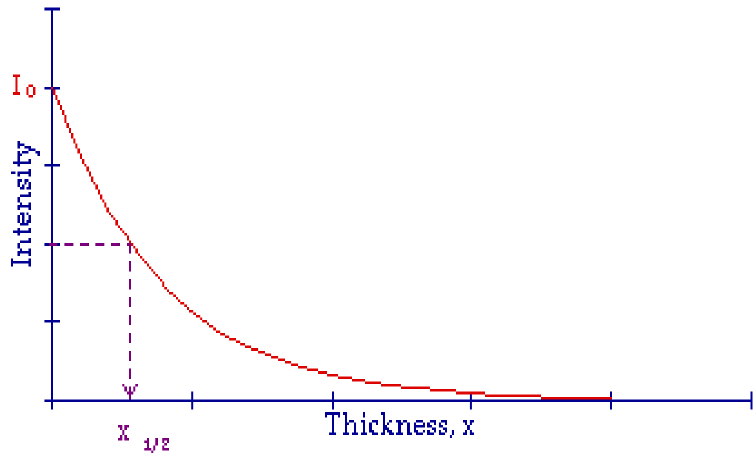


Fig. (2): The Half Value Layer for a range of absorbers.

If μ_m represents the mass absorption coefficient, it's the ratio of the corresponding linear attenuation coefficient to the density of the attenuator in gm/cm^2, then $\mu_m = \mu/\rho$, where ρ is the density of medium.

$$I = I_0 e^{-\left(\frac{\mu}{\rho}\right)\rho\, x}$$

$$I = I_0 e^{-(\mu_m)\, x'}$$

The density thickness is the product of the density in g/cm^3 times the thickness in cm. $x^- = \rho x$

$$\text{In}\ (I/I_0) = -\mu_m x^-$$

In this experiment we will measure μ and μ_m in lead and copper for 662 KeV gammas from ^{137}Cs. The accepted value of μ_m for lead is 0.105 cm^2/g.

Procedure

1. Connect the electronic equipment and place the radioactive source (^{137}Cs) at some distance far from the detector face.
2. Take counts for one minute without absorber.
3. Place a first sheet between source and detector, and take counts for the same time interval.
4. Place a second, third,…… sheets on the top of the first one and record counts for the same time interval for each case, and continue adding the sheets until the number of counts reach 25% of the number recorded without absorber.
5. Plot a graph between intensity and thickness as shown in Fig.(1).
6. Evaluate $X_{1/2}$, μ and μ_m for each of lead and copper.

Exp.(4)

Foundation of Material Height in Closed Containers

Apparatus

- Geiger-Muller Tube
- Timer & Counter
- ^{241}Am radioactive source
- Connecting Cable
- Material container.

Purpose

The purpose of the experiment is to determine the material height in a closed container.

Introduction

The level of material (foods, dyes, oils,……) in closed containers can be determined by the γ-ray absorption method. The absorption of γ-ray in air is different from its absorption in the container walls and also through the wall + material inside. This difference can be estimated by measuring the no. of γ-ray quanta per unit time through these three different mediums. Fig.(1) shows the experimental setup.

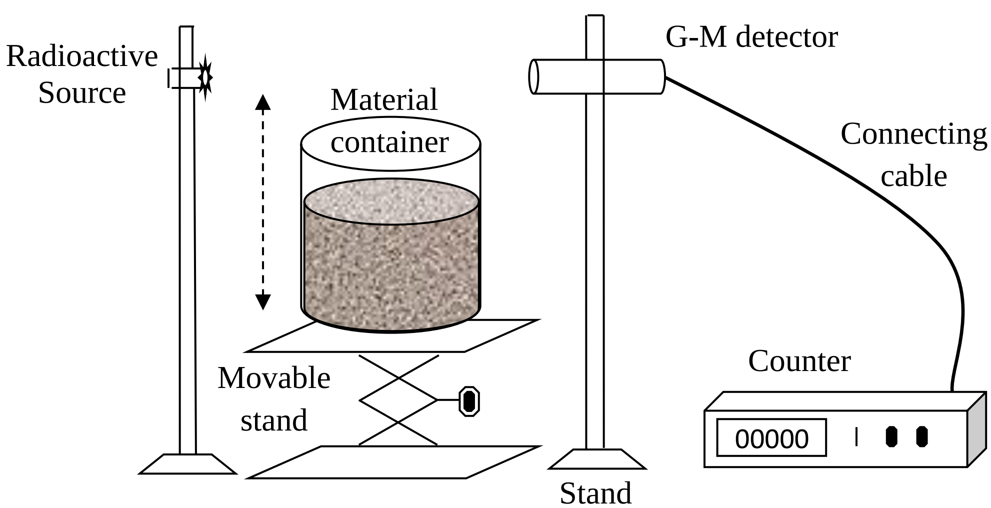


Fig. (1): The experimental setup.

Procedure

1- Set up the apparatus as shown in Fig.(1)
2- Make the ^{241}Am source and the G-M detector in one level.

3- Place the counter on stand where the top of container is lower the source and G-M detector level.
4- Record the number of γ- quanta for every 1 minute.
5- Repeat step 4 for each 5 mm increase in the container level until its bottom exceeds the source and G-M detector level.
6- Plot a graph between the position of movable stand and no. of γ-quanta as shown in Fig.(2)

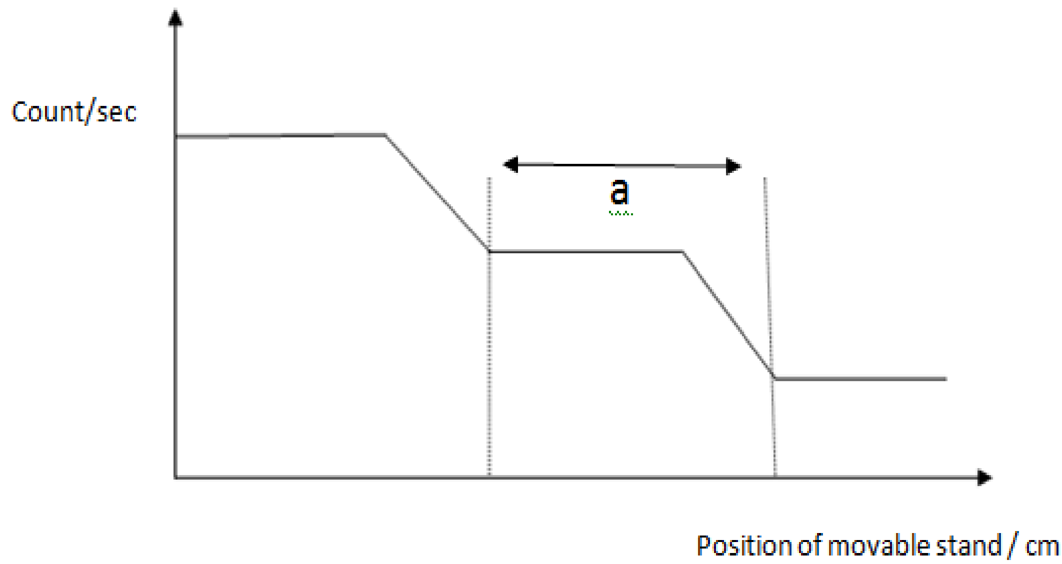


Fig (2): Gamma-quanta rate versus movable stand level.

Questions

1. Why we uses γ-ray instead of α and β rays to perform this experiment?
2. Is it possible to replace the G-M counter by the Scintillation detector?
3. Mention three practical applications of this experiment.

Experiment No. (5)

Determination of Dead Time (Resolving Time) of G.M. counters by Two –Source Method.

Apparatus:

- Geiger-Muller Tube
- Timer & Counter
- ^{241}Am radioactive sources
- Connecting Cables.

Purpose:

To determine the resolving time (dead time) of a Geiger-Muller counter

Theory:

The time following the entry of the ionizing event in the counter during which the later remain insensitive to next event is called the dead time T of the counter. This arises from slow motion of positive ion sheath from the anode. The presence of positive ion cloud in the vicinity of the anode lower the electric field to such value that the pulse of required size will not be formed if another particle, entered the counter soon after the first one and is therefore likely to be missed. After some time the positive ions, however, reach cathode and the counter recovered fully to receive another particle and develop a pulse of normal size. The time of travel of positive ions from the anode to cathode is, in principle, the dead time of the counter, but if the input sensitivity of scalar is higher so that it can also register pulses of less than normal, the dead time corresponding smaller, because in this case the next event need not wait for positive ions to go actually to cathode. As soon as the positive ions reach a point away from the anode such that electric field is recovered to a value (threshold) so as to give rise to pulse of size equal to input acceptance level of scalar, the counter will be able to receive the next event. It is therefore clear that the dead time of counter depends upon the kind of scalar used in the experimental set-up and the voltage applied to the anode.

The resolving time also can be defined as the minimum time required by the set-up to just resolve two successive pulses arising from two successive ionizing events entering the counter. True resolving times span a range from a few microseconds for small tubes to 1000 microseconds for very large detectors. The loss of particles is important, especially when there are high count rates involved and the losses accumulate into large numbers.

In this experiment, you will perform a more accurate analysis of dead time via a method that uses paired sources. The count rates, or activities, of two sources are measured individually (N_1 and N_2) and then together (N_3). The paired samples form a rectangle into two lengthwise. A first radioactive material is placed on each half making each a "half-source" of approximately equal strength. A blank rectangle is used to duplicate the set-up geometry while using only one source.

We can calculate the dead time of G.M. counter by two-source method if we assume that:

N_{1b} ≡ count rate for the first source with background.

N_{2b} ≡ count rate for the second source with background.

N_{12b} ≡ count rate for the two sources with background.

N_b ≡ background count rate only.

The resolving time is given by,

$$T = \frac{N_1 + N_2 - N_{12}}{2N_1 N_2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

where

$N_1 = N_{1b} - N_b$

$N_2 = N_{2b} - N_b$

$N_{12} = N_{12b} - N_b$

Then the actual or the true counting rate (n) is given as

$$n = \frac{N}{1 - NT}$$

Procedure:

1. Place the first source at 5 cm from the counter window, and record the count rate (N_{1b}) for 3 minute.
2. Put the second source beside the first one and record (N_{12b}) for the same time interval.
3. Replace the first source and determine the count rate (N_{2b}).
4. Find the background count rate (N_b) for 3 minute also.
5. Use eq. (1) to calculate resolving time (T)
6. Find the true counting rate for each case by using eq. (2).
7. Repeat the experiment for another different distance between sources and counter window. Do you expect difference in your result? Explain briefly.

Questions:

1. What is your GM tube's resolving (or dead) time? Does it fall within the accepted 1μs to 100 μs range?
2. Is the percent of correction the same for all your values? Should it be? Why or why not?
3. On what does the resolving time of a counter will depends?

Experiment No. (6)

Operating Plateau for the Geiger Tube

Apparatus:

- SPECTECH ST-350 Counter
- Geiger-Muller Tube
- Shelf stand
- Serial cable
- Radioactive Source (e.g., Cs-137, Sr-90, or Co-60)
- Computer.

Purpose:

To determine the plateau and optimal operating voltage of a Geiger-Müller counter

Theory:

Basically, the Geiger counter consists of two electrodes with a gas at reduced pressure between the electrodes. The outer electrode is usually a cylinder, while the inner (positive) electrode is a thin wire positioned in the center of the cylinder. The voltage between these two electrodes is maintained at such a value that virtually any ionizing particle entering the Geiger tube will cause an electrical avalanche within the tube. The Geiger tube used in this experiment is called an end-window tube because it has a thin window at one end through which the ionizing radiation enters.

The Geiger counter does not differentiate between kinds of particles or energies; it tells only that a certain number of particles (betas and gammas for this experiment) entered the detector during its operation. The voltage pulse from the avalanche is typically >1 V in amplitude. These pulses are large enough that they can be counted in an Timer & Counter without amplification.

All Geiger-Müller (GM) counters do not operate in the exact same way because of differences in their construction. Consequently, each GM counter has a different high voltage that must be applied to obtain optimal performance from the instrument. If a radioactive sample is positioned beneath a tube and the voltage of the GM tube is ramped up (slowly increased by small intervals) from zero, the tube does not start counting right away. The tube must reach the starting voltage where the electron "avalanche" can begin to produce a signal. As the voltage is increased beyond that point, the counting rate increases quickly before it stabilizes. Where the stabilization begins is a region commonly referred to as the knee, or threshold value. Past the knee, increases in the voltage only produce small increases in the count rate. This region is the plateau we are seeking. Determining the optimal operating voltage starts with identifying the plateau first. The end of the plateau is found when increasing the voltage produces a second large rise in count rate. This last region is called the discharge region.

Procedure (Creating a Plateau Chart)

I. Running the unit as stand-alone

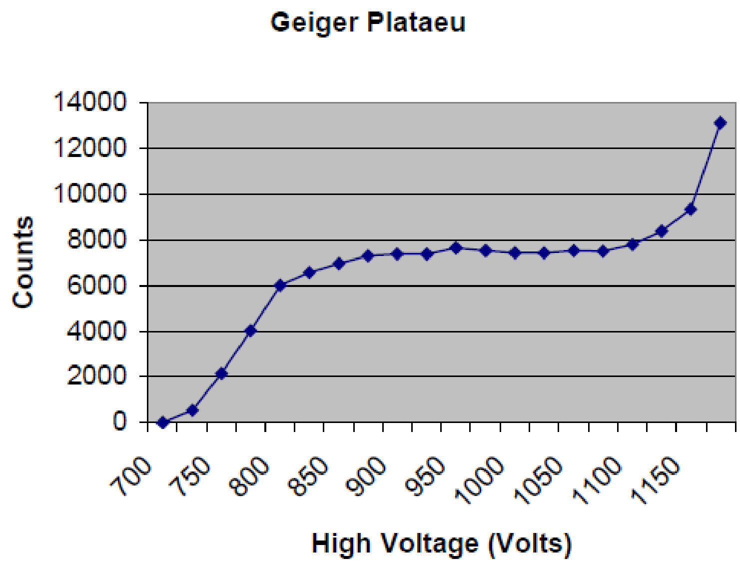
1. Place the radioactive source in a fixed position close to the window or in the well of the detector.
2. Put the ST360 into *Count* mode and slowly increase the high voltage until the first bar of the ACTIVITY bargraph lights.
3. Set the Preset Time to 10 seconds and press *COUNT*.
4. When the preset time expires, record the counts and the high voltage setting.
5. Increase the voltage by 20 volts and count data again.

6. When the preset time expires, record the counts and the high voltage setting again.
7. Repeat steps 5 and 6 until the high voltage reaches its upper limit (this is determined by the upper operating voltage limit of the detector).
8. Create an X-Y graph of the data, with “Y” being the Counts, and “X” being the voltage, and plot the chart.

II. Using the ST360 Software

1. Place the radioactive source in a fixed position close to the window or in the well of the detector.
2. Put the unit in COUNT mode and slowly increase the high voltage until the first segment of the activity bargraph lights. This is the *starting* voltage.
2. Determine the upper operating voltage limit of the detector. This is the *ending* voltage.
3. Subtract the *starting* voltage from the *ending* voltage. Divide the result by the high voltage step size (20 volts in this case). This will yield the number of *runs*.
4. Select *High Voltage Setting* in the *Setup* menu and set the High Voltage to the *starting* voltage and the *Step Voltage* to 20. Also, turn the *Step Voltage Enable ON*.
5. Select Preset Time in the Preset menu and set it to 10 seconds.
6. Select Runs in the Preset menu and set it to the number calculated in step 3.
7. After counting has begun, it will automatically stop when *runs* equals zero.
8. Save the data to a file. Before saving, a description of the data may be entered into the *Description* box.
9. Open the saved file version with a *.tsv* extension into a spreadsheet program such as *Microsoft Excel*.

The following chart shows a typical detector plateau.



10. One way to check to see if your operating voltage is on the plateau is to find the slope of the plateau with your voltage included. If the slope for a GM plateau is less than 10% per 100 volt, then you have a "good" plateau. Determine where your plateau begins and ends, and confirm it is a good plateau.

The equation for slope is

$$Slope(\%) = \frac{(R_2 - R_1)/R_1}{V_2 - V_1} X100,$$

where R_1 and R_2 are the activities for the beginning and end points, respectively. V_1 and V_2 and the voltages for the beginning and end points, respectively.

Questions

1. Where within the plateau one should select the counter operating voltage?
2. On what factors do the operating voltage of the counter will depends?
3. How does electric potential effect a GM tube's operation?
4. Will the value of the operating voltage be the same for this tube ten years from now?