

Geiger Müller Counter (GM Counter)

J. W. Geiger was a student of Sir Ernest Rutherford and developed Geiger tube. Later he came up with an advanced version of the tube with his student W. Müller and the same became popular as GM Counter. This is a gas based detector which uses ionization of gas by radiation as the primary tool to detect radiation. The tube is in the form of cylinder and is filled up with noble gas at certain low pressure. A metallic string which runs through the central axis of the cylindrical shape forms the anode whereas the outer shell serves as cathode. One end of the tube has radiation permeable window (mica or beryllium).

Any radiation incident on the tube window will ionize the noble gas. The electrons thus ejected will get attracted towards the anode whereas the heavy ions will move slowly towards cathode. These charges will further ionize more number of atoms thereby setting up an avalanche of ions and electrons which sets up a discharge current. The current causes the voltage between the anode and cathode to drop which the counter detects as a signal.

Since the detection is based on the avalanche, therefore the output pulses are independent of the energy brought in by the incident radiation. The pulse height remains the same irrespective of the energy of radiation and therefore GM counter can only be used to detect the presence of radiation but not the type of radiation.

As the positive ions arrive at the cathode, they will produce fresh avalanche. As soon as they reach cathode, they would knock capture electrons from the cathode and would become neutralized. But, in the process, it would emit ultraviolet photons which would set secondary Geiger discharge through ejection of photo electrons. This could run the GM set up in to continuous discharge ultimately causing serious damage to the tube. To counter this, the noble gas is in general mixed with halogen or alcohol. The excited noble gas atoms are neutralized by collision with neutral halogen or alcohol molecules, as a result of which they become ionized. This happens because of higher ionization potential of noble gas than that of halogen or alcohol. Reverse process is forbidden. Now the excited halogen or alcohol molecules dissociate at cathode being neutralized by capture of electrons. This process is known as Quenching or Self Quenching or Internal Quenching.

Unlike alcohol based tubes where the alcohol molecules dissociate in to constituent atoms, the halogen based tubes are long lived as the halogen molecules dissociate in to halogen atoms which recombine to form the same molecule.

Contrary to the above process, in early days, external quenching was used. In this method a very resistance was included in the anode circuit. The potential drop being very high across this resistance used to lower the voltage across the counter tube to such a low value so the gas amplification factor becomes insufficient to trigger second discharge. But, introduction of high resistance would increase the RC time factor which resulted in lower count rate.

The figure1 shows the complete experimental set up for the experiment. The tube is mounted on a structure which have different slots to place the source. The tube is connected to the GM Counter Console which hosts the electronics for amplification and counting. It also provides the necessary power



Figure 1: Experimental set up for GM Counter based experiments. Taken from the company manual <http://www.spectrumtechniques.com/resources/instrument-manuals/>

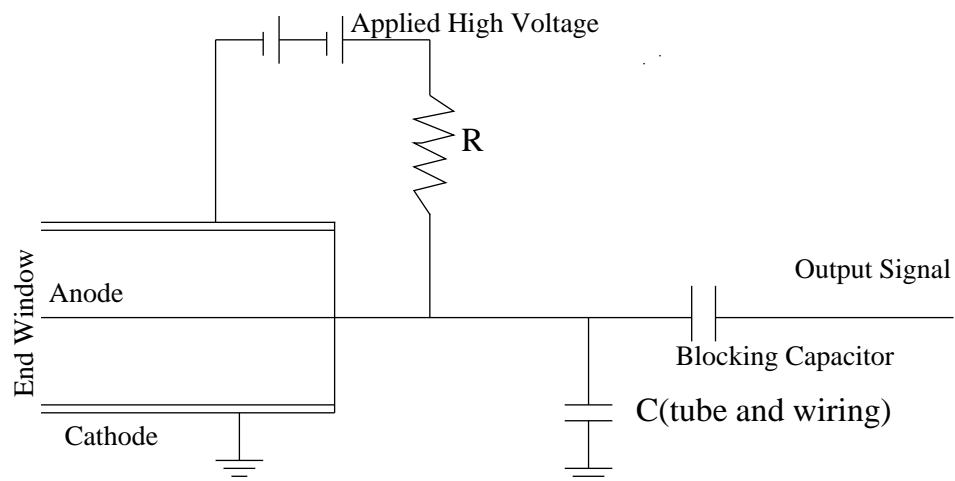


Figure 2: Schematic diagram of GM Counting system.

supply to the tube. For your understanding, a schematic diagram of the set up is given in Fig.2. *By now, you should have wondered how can a single cable be used with GM Tube to provide the power supply as well for the out signal.*

Let us have a look into the schematic diagram. We have learnt in detail about the GM tube operation. The same is depicted in the figure. One can notice a resistance. This is the same resistance, which if increased to a large value would serve the purpose of external quenching. A capacitance has been shown to be connected to the ground. This actually represents all sort of capacitance which can be generated due to the tube, wiring etc. This combination of RC would provide the time constant for the GM set up. This is chosen to be of the order of few microsecond so that only the fast rising components of the signal are preserved. In addition to this, a blocking capacitance is also provided. This serves the purpose of blocking the high voltage and allowing to pass the signal to the subsequent circuitry.

The console can be manually operated as shown in the figure. But, for the present experiment we will be using the computerized interface for all sorts of external control and data acquisition. A demo of how the computer screen would look like is shown in Fig.3. The demo picture is self explanatory. It shows the applied voltage in red block, preset time (time allotted for each count), number of runs (would be required for statistical studies else single run is sufficient), time elapsed (time gradually approaches the preset time and stops) and the counts. The block shown in gray shows the saved files of each run. You can see lots of menus are shown on top of the screen, such as, File, Edit, Set up etc.

1. The File menu can be used to open a file, save a file, print a file and exit from the system.
2. Edit is as usual used for copy and paste.
3. The most useful menu is the Set Up menu. It is used for setting up high voltage through "HV Setting". Here one can also define the steps of increasing voltage and enable the option.
4. Through Preset Menu, the preset time can be set as per the requirement. Here one can also define number of runs through "Runs" command.

Other drop-down menus are not required so often. We can discuss those in the lab. **Now in the next menu line, a green rhombus is shown. This is the button to start the counting. Once run is started, the red button just beside the green one will become active. By pressing the Red Button one can stop the run.**

Exercise : *This type of ionization tubes can be operated in various regions according to the applied voltage. We have just seen one of the regions, i.e.; GM region. Now it is a task for you to find out other regions : ionization region and proportional counter region as well as the applications, advantages and disadvantages over the GM region.*

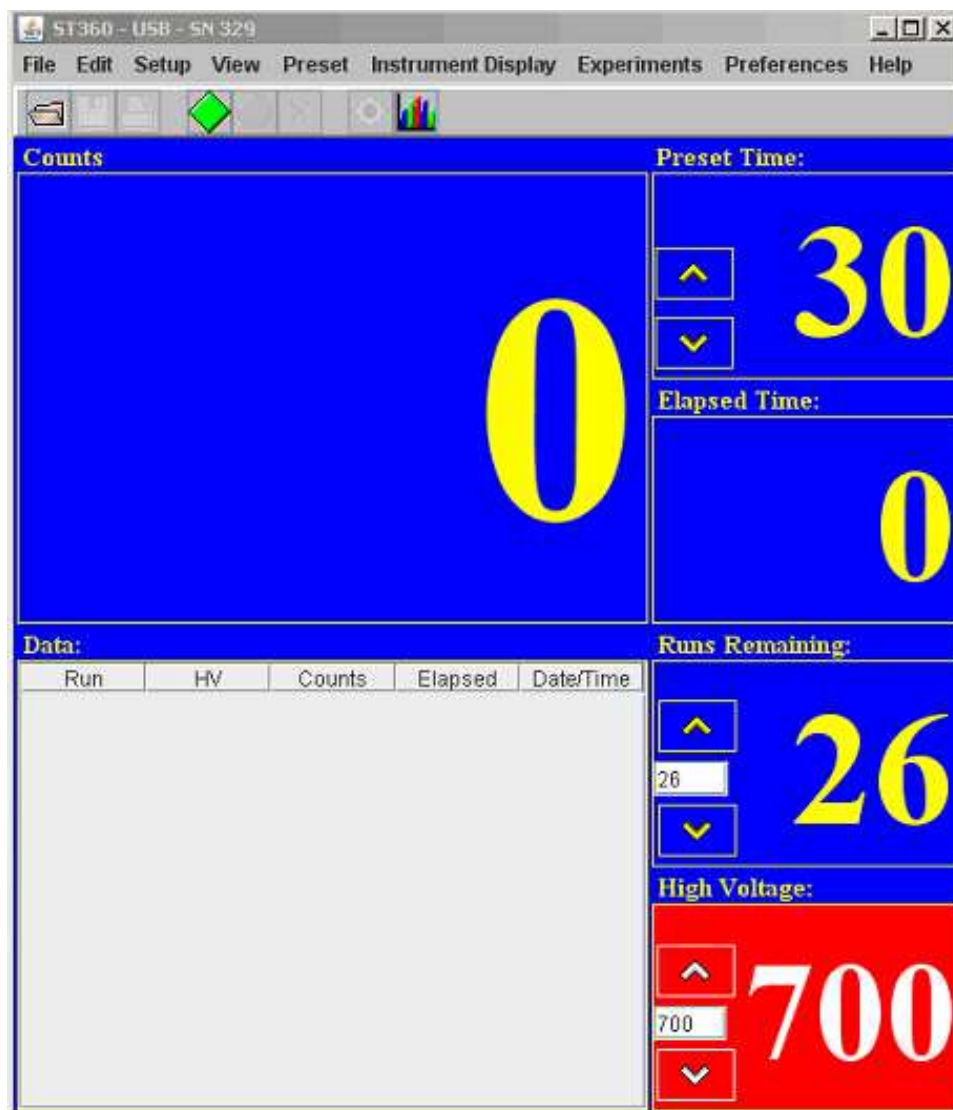


Figure 3: Display of software for GM counting data acquisition. Taken from the company manual <http://www.spectrumtechniques.com/resources/instrument-manuals/>

EXPERIMENT : Operating Plateau for GM Tube

Purpose

The purpose of this experiment is to determine Plateau Characteristics of GM tube and to determine reasonable operating point for the tube.

Underlying Physical Aspects

We have now understood the basic working of GM tube. So, in order to observe the effect of incident radiation on GM tube, we need to increase the voltage between anode and cathode, to a value where the gas amplification sets in. This voltage is called the *Threshold Voltage* or *starting voltage*. Thereafter, the counting rate keeps on increasing till the voltage reaches a *knee value* beyond which the count rate becomes saturated or constant. In this constant region of operation all the primary events are recorded irrespective of the energy. This flat region is called *Plateau of the counter*. If we keep still keep on increasing the voltage, the tube will run in to continuous discharge region which is not desirable. The mid point of the plateau region is taken to be the *Operating Voltage* of the GM tube and once determined, the tube must be operated at this value for subsequent experiments.

Procedure

1. After setting up the GM tube and electronics we can start our experiment. Place the source at a distance of around 6 mm. One can set up a starting voltage say around 650 V with a step voltage of say 20 V. Set the preset time of 30 s.
2. Initially no counts will be registered. Around 750 V, there will be sudden increase in the counts, which would saturate around 800V. Though a small increase in counts will be registered through the experiment.
3. Stop the experiment at around 1200 V or before.
4. As we know that there are background counts in the laboratory. So, whatever counts we have registered, have to be corrected for background counts. One can repeat the steps 1-3, without a source. The process should be repeated twice or thrice and average of the same should be taken to be the background at each voltage. Make sure that no source lies nearby otherwise that might contribute to the background count.
5. Subtract the corresponding background count from each reading and register the correct counts vs voltage in table1.
6. A demo labeled plot of Counts vs Voltage is shown in Fig.4. You should plot Corrected Count Rate vs Voltage.

Inference

- Starting Voltage \pm [We have least measuring voltage value of 1 V. What error should we mention in the result : either the instrumental value or the graphical one ?]

Table 1: Data Table for GM Plateau

| S. No. | Voltage (V) | Counts | Avg. Bkg. Counts | Corrected Counts | Corrected Count rate |
|--------|-------------|--------|------------------|------------------|----------------------|
| 1. | 650 | | | | |
| 2. | 670 | | | | |
| 3. | | | | | |
| 4. | | | | | |
| 5. | | | | | |
| 6. | | | | | |

- Knee Voltage \pm
- Range of Plateau \pm [While calculating error, keep in consideration that the range is calculated as the difference of two voltage values.]
- Operating Voltage \pm
- Percentage slope of Plateau = $\frac{\text{Slope of the plateau region}}{\text{Knee Voltage} * \text{Voltage Difference of Plateau region}} * 100$

Post Lab Questions and Take Home Messages

1. Will the operating voltage remain same if the present tube is replaced by another one ?
2. Will this operating voltage remain constant even after long period of time, say, ten years ?
3. What does the slope of plateau shows ? Why do we have slope, however small it may be ?
4. What will happen if we place the source at the last groove ? We might get the answer in subsequent experiments.
5. For background, we have taken two or three different readings at each voltage and every time we found that we did not get the same reading as previous one. But, the reading varies about certain value. Will it be the same for counts with the sources ? You can check yourself by repeating the counting at operating voltage. And if it varies like the background count, then the data which we have acquired is not correct. What is the remedy to this problem ? Again upcoming experiments may help us to get the answer to our question.

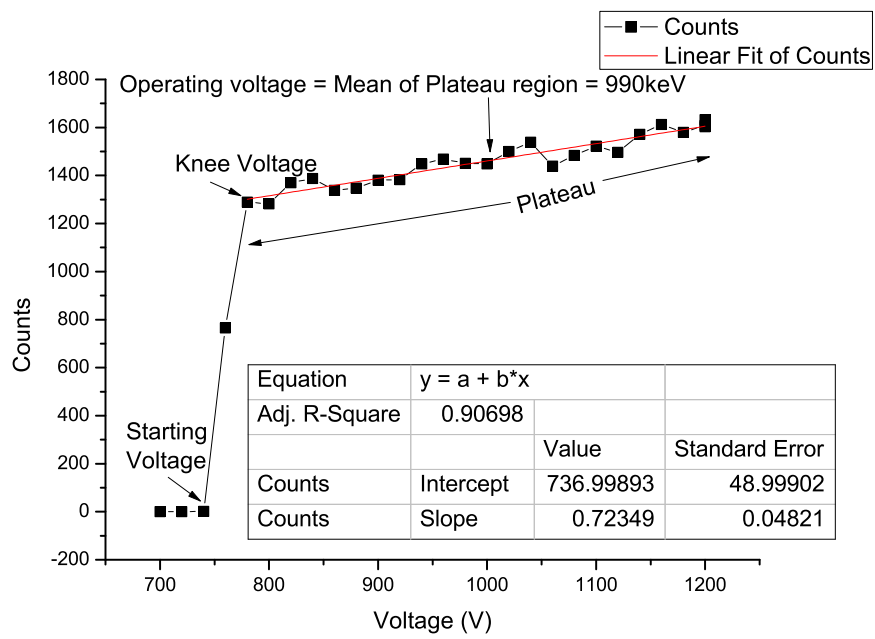


Figure 4: Plateau characteristics of GM Tube with counts recorded for 30 s at each voltage. The source was kept at third groove. Distance between each groove is 2 mm.

EXPERIMENT : Counting Statistics

Purpose

The radiation emission is statistical in nature. Thus, each event is independent of all previous measurements. But, when data acquisition is repeated for large number times, one can make a wise prediction about the deviation of individual counts about what might be the average of counts in the ensemble. The purpose of the present study is to observe for the particular deviation from the average within a give sample size interval.

Underlying Theory

Let us assume we have ensemble of N independent measurements for the same event :

$x_1, x_2, x_3, \dots, x_N$.

Then the total sum of the above data will be

$$\Sigma = \sum_{i=1}^N x_i \quad (1)$$

Experimental mean

$$\bar{x} = \Sigma/N \quad (2)$$

Now, since we have large set of data, it is convenient to describe the parameters in terms of frequency of data.

$$F(x) = \text{number of occurrence of value of } x/N \quad (3)$$

then the mean,

$$\bar{x} = \Sigma = \sum_{x=0}^{\infty} xF(x) \quad (4)$$

Since, the data is random and we have large number of data, it is helpful to look at the variance than the deviation of the individual data from the mean.

$$\sigma^2 = \frac{\sum_{i=1}^N (x_i - \bar{x})^2}{N} \quad (5)$$

Or in terms of frequency

$$\sigma^2 = \sum_{x=0}^{\infty} (x - \bar{x})^2 F(x) \quad (6)$$

Which when expanded

$$\sigma^2 = \bar{x^2} - (\bar{x})^2 \quad (7)$$

Now for random nature of nuclear radiation, Gaussian Distribution holds good when the average is large and the count rate is high. The Gaussian distribution can be shown as :

$$P(x) = \frac{1}{\sqrt{2 * \pi * \bar{x}}} * \exp\left(-\frac{x - \bar{x}}{2\sigma^2}\right); \quad (8)$$

This is normalized such that

$$\sum_{x=0}^N P(x) = 1 \quad (9)$$

That shows that each data has a variance σ around the average value.

Procedure

1. Set the GM tube at the operating voltage. One can keep a comparatively lower value than what you got from the Plateau curve.
2. Now set the number of runs to a high value, say, 150 and preset time at, say, 20 seconds.
3. Acquire the data by taking care of background and tabulate the same as shown in Table 2.
4. Now distribute the data into bins of equal interval and look for the frequency corresponding to the bin.
5. Draw histograms for the data.
6. Join the mid points of the histogram or fit it with Gaussian curve. Two demo plots are shown for your convenience (Fig.5).

Table 2: Data Table for Counting Statistics at Operating voltage

| S. No. | Counts | Avg. Bkg. Counts | Corrected Counts |
|--------|--------|------------------|------------------|
| 1. | | | |
| 2. | | | |
| 3. | | | |
| 4. | | | |
| 5. | | | |
| 6. | | | |

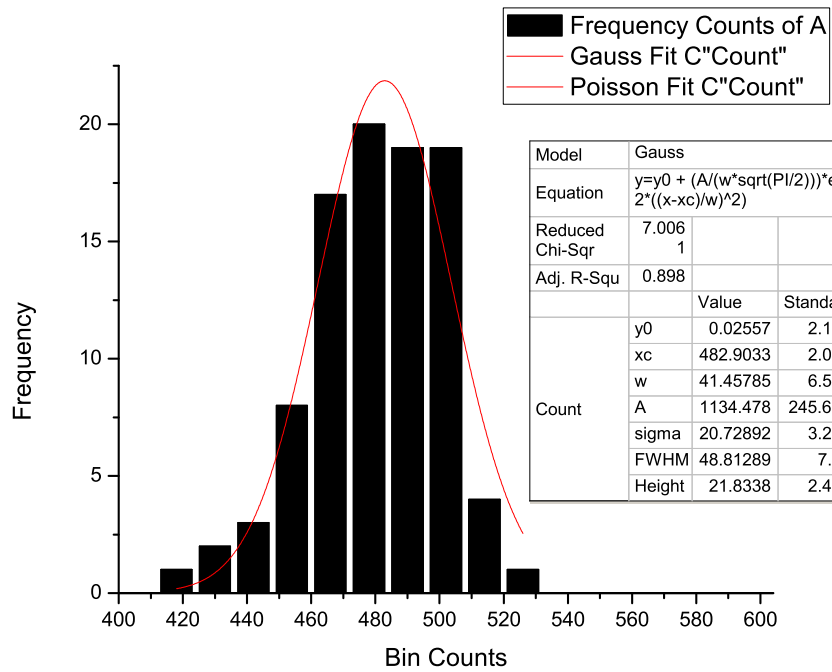
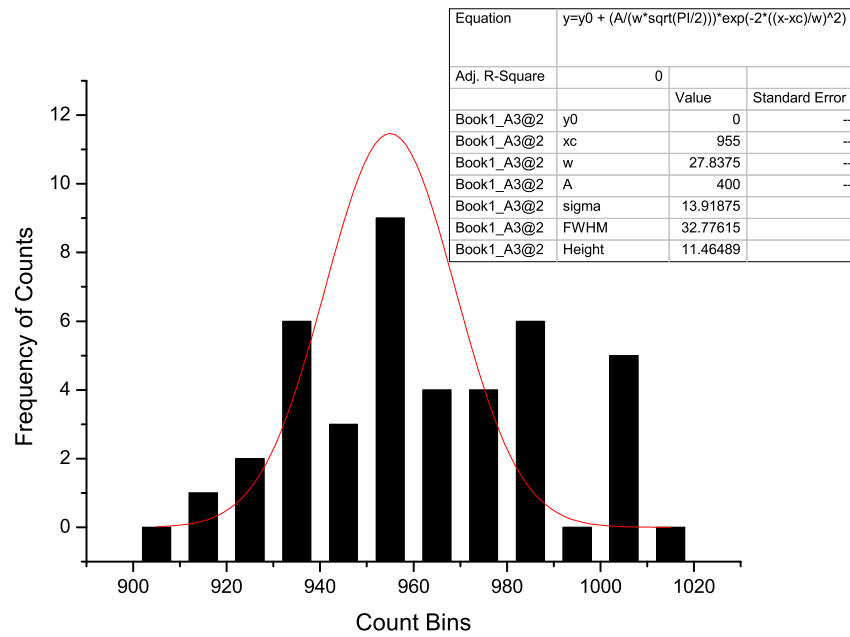


Figure 5: Statistical nature of nuclear radiation. The GM tube was kept at operating voltage. The counts were recorded for 20s for 40 times in the first graph. For the latter, data was recorded for 10s and repeated for 110 times.

Inference

- Find the σ value of the fitting.
- The Full Width at Half Maximum (FWHM) will be 2.35σ .
- Find out the fraction of area under the region bounded by $\bar{x} + \sigma$ and $\bar{x} - \sigma$. It should be around 68.8%. Similarly the region bounded by $\bar{x} + 2\sigma$ and $\bar{x} - 2\sigma$ occupies 95.5% whereas for the 3σ it up to 97.7%.

Post Lab Questions and Take Home Messages

1. Two plots are shown in Fig.5. Can you spot the difference ?
2. What will happen to the distribution when the count rate as well as the average counts reduces appreciable ?
3. Redraw the Plateau Characteristics by incorporating the error value for each count. A demo has been shown in Fig.6, where each count is accompanied with error bar equivalent to $\sqrt{\text{count}}$. If you would have repeated the counts at each voltage and would have reported the mean of those counts at each corresponding voltage then the error bar would have been $\sigma_{mean} = \frac{\sigma}{\text{number of events}}$. Now you need to find the error in Count rate. However, what we have found just now, is the error in count.

$$\sigma_t = \frac{\sigma}{\text{time}} \quad (10)$$

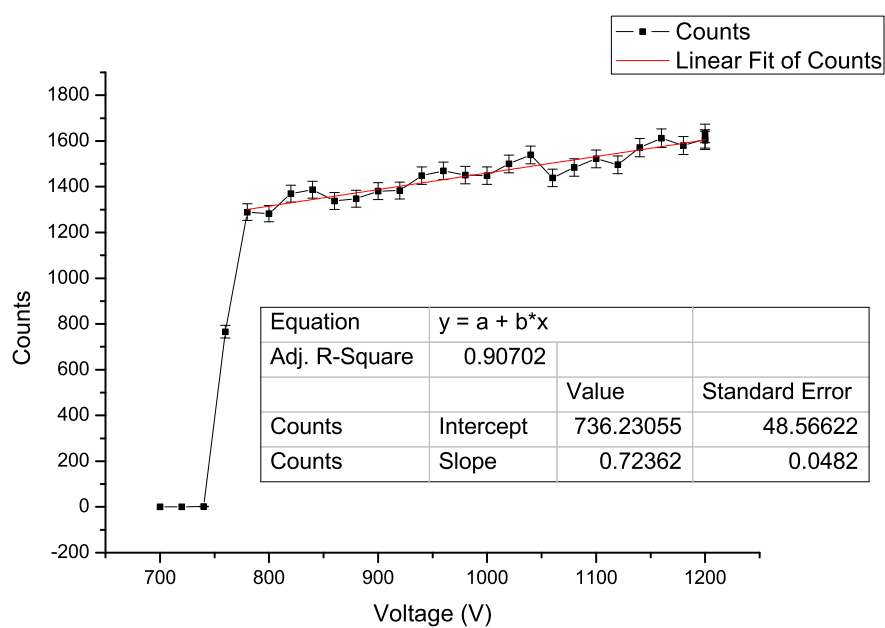


Figure 6: Plateau characteristics of GM tube with counts corrected for error bar.

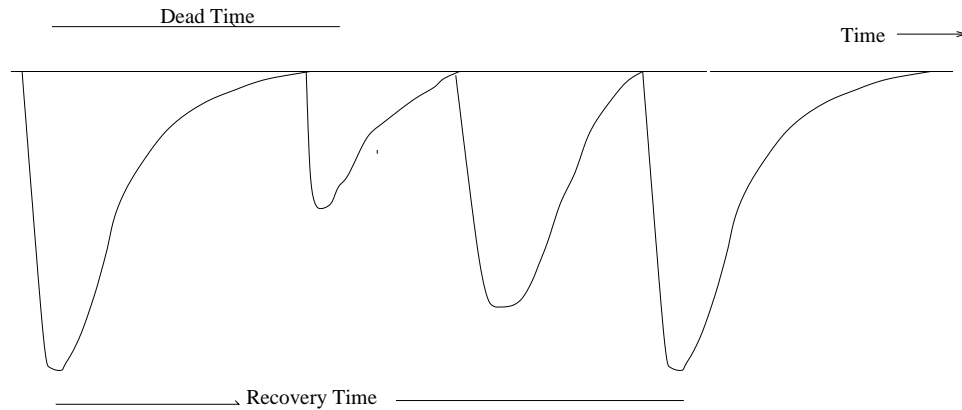


Figure 7: Dead time and Recovery time of GM Tube.

EXPERIMENT : Resolving Time or dead time of GM Counter with two source method

Purpose

To determine the dead time or resolving time of GM counter.

Underlying Physical Aspects

As discussed initially, GM tube consists of noble gases which are ionized by incident radiation generating fast moving electrons and slow moving ions. As the field is high nearby the anode the electrons quickly move towards the anode. But, the ions being heavy move slowly towards the cathode and in turn get accumulated near the central wire thereby forming a space charge sheath which reduces the field near the wire and that ultimately lowers the gas multiplication. Once this process continues for a longer period of time, the Geiger discharge stops and GM becomes unable to register any output pulse. The period for which GM tube remains idle is known as **Dead Time or Resolving Time**.

The dead time is of the order of a few hundred microseconds. Thereafter, GM tube once again start registering the incident radiation. However, the pulse height might not rise to the fullest. It takes a little bit longer time for the pulses to grow to its original height. This time span within which the pulses once again regain their original pulse height is called **Recovering Time**. The entire process is pictorially shown in Fig.7. The dead time is inbuilt feature of every detector system. In some cases, dead time might be introduced due to electronics of the system. Dead poses a high threat to the high counting rate events.

There are two models for dead time calculation : *Paralyzable or Extendable* and *Non Paralyzable or Non-Extendable*. This can be understood with the help of figure8. The top figure shows six pulses even though some of them are overlapped. So, we had six original counts. Now in the paralyzable model, if the overlapping pulses are registered, then, the dead time is extended for the subsequent pulses. In the figure, let us say, the dead time is the width of each rectangle. In third and fourth case, since we have overlapping pulses, the dead time will keep on adding up and hence the detector wont register any further pulse. So in this context, Paralyzable Model would only consider three pulses instead of

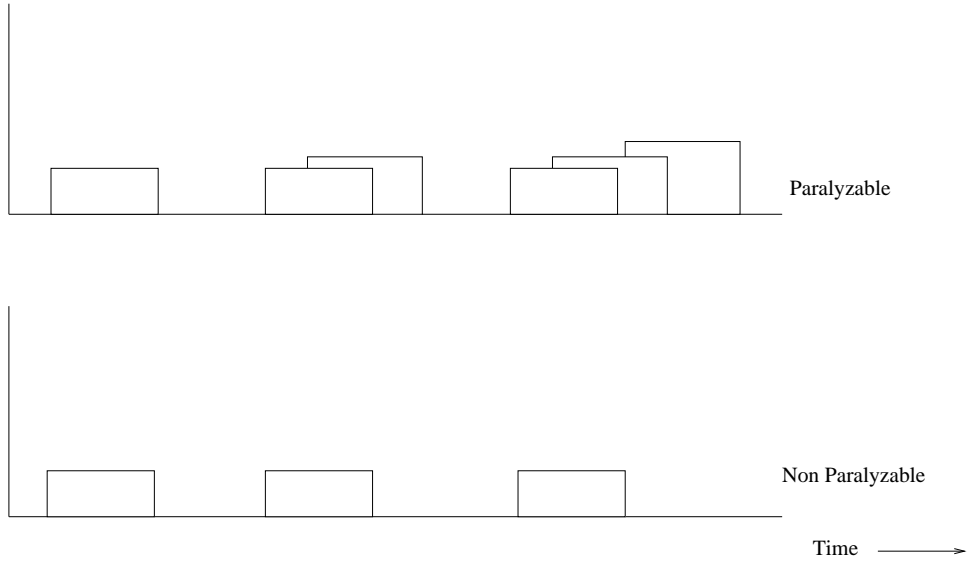


Figure 8: Comparison of paralyzable and non paralyzable models of Dead time.

six. Here if N is the actual rate of arrival of ionizing particles, n is the count rate that counter is able to register and τ be the dead time, then :

$$n = N \exp(-N\tau) \quad (11)$$

This is a transcendental equation and can be solved using graphical method. [Refer to Techniques for Nuclear and Particle Physics experiments by Leo.]

For non-paralyzable model, it only considers the dead time of the first pulse and would register the next pulse if it lies beyond the dead time limit of the first. So for the first two cases it registers two pulses whereas in the third case where three pulses are overlapped, it does not record the second overlapping pulse but did register the third one since it lies outside the dead time limit of the first pulse. Therefore, it would record four pulses. In the context of this model, let us consider N to be the actual rate of arrival of ionizing particles, n be the count rate that counter is able to register and τ be the dead time. Then, number of particles skipped by the counter per unit time is $Nn\tau$ which should be equal to $N - n$. This implies :

$$N = \frac{n}{1 - n\tau} \quad (12)$$

Based upon this notion, let us consider two sources of approximately same strength and determine the count rates (n_1 and n_2 respectively) for individual sources along with the sum of the count rates (n_t when both the sources are placed). If we solve those three individual equations considering higher powers of τ^2 to be negligible, we obtain :

$$N_t - N_b = N_1 - N_b + N_2 - N_b \quad (13)$$

$$N_{12} + N_b = N_1 + N_2 \quad (14)$$

$$\tau = \frac{X(1 - \sqrt{1 - Z})}{Y} \quad (15)$$

$$X = n_1 n_2 - n_b n_{12} \quad (16)$$

$$Y = n_1 n_2 (n_{12} + n_b) - n_b n_{12} (n_1 + n_2) \quad (17)$$

$$Z = \frac{Y(n_1 + n_2 - n_{12} - n_b)}{X^2} \quad (18)$$

If the background counts are not considered, then ;

$$\tau = \frac{n_1 n_2 - \sqrt{[n_1 n_2 (n_{12} - n_1)(n_{12} - n_2)]}}{n_1 n_2 n_{12}} \quad (19)$$

At last, let us consider the limit when our count rate is low so that paralyzable and non-paralyzable model both agree on same dead time value. In that limit, if the relation is solved for two source method we obtain :

$$\tau = \frac{n_1 + n_2 - n_{12}}{2n_1 n_2} \quad (20)$$

if background data is considered then the equation will be :

$$\tau = \frac{n_1 + n_2 - n_{12} - n_b}{2n_1 n_2} \quad (21)$$

The method has been discussed with two oscillator frequencies by Muller (Volume 112, Issues 12, SeptemberOctober 1973, Pages 47-57 Nuclear Instruments and Methods).

We will consider the non paralyzable model in this experiment.

Procedure

1. Here, instead of normal source holder a separate holder is provided which has two slots made in such a way that half area of each circular slot will be seen by the end window of GM Tube. Place the source holder in the third groove of the mount.
2. Take two sources of similar intensity.
3. Place one of the sources in left slot and set the preset time 300 s. You may repeat the counting and take the average as well as calculate the statistical error bar.
4. Repeat the process for the other source but place it in the right slot. One should be extremely careful not to disturb the positioning of the source holder.
5. Now replace the first source in the left slot and register the counts for 300 s.
6. Apply the formula for non paralyzable model and determine the dead time using both the conditions : with background and without background. Also apply the low count rate approximation and calculate the deadtime.

Table 3: Data Table for Dead Time

| Sources | Counts | Avg. Bkg. Counts | Corrected Counts |
|------------------|--------|------------------|------------------|
| Source1 | | | |
| Source2 | | | |
| Combined Sources | | | |

7. Also estimate the error bar for low count rate approximation. One can use the following relation which can be derived by applying error Error Propagation Rule. **Exercise :** Read about Error Propagation Rule from the given references.

$$\frac{\sigma_{\tau}^2}{\tau^2} = \frac{1}{2} \left[\left(\frac{\sigma_{n_1}^2 + \sigma_{n_2}^2 + \sigma_{n_{12}}^2}{(n_1 + n_2 - n_{12})} \right)^2 + \left(\frac{\frac{\sigma_{n_1}^2}{n_1^2} + \frac{\sigma_{n_2}^2}{n_2^2}}{n_1 n_2} \right)^2 \right] \quad (22)$$

Inference

- Dead time of GM set up is (non paralyzable model with background)
Dead time of GM set up is (non paralyzable model without background)
Dead time of GM set up is \pm (non paralyzable model with low count rate approximation)
- Now use the dead time value in the equation for true counts N and determine the value of N . You can compare the value of N with the data you have acquired in the previous experiment. If your count rate was higher than the N obtained, then you tend to loose more amount of valuable data and need to rectify the same.

Post Lab Questions and Take Home Messages

1. In any case, did you obtain negative dead time? If yes, can you figure out the reason of lapses you committed during the experiment? Of course, whenever, we deal with statistical data, we discourage any relation which involves subtraction of two parameters.
2. Do you think that in the limit of low count rate, i.e.; $\tau \ll \frac{1}{N}$ both the models should fetch same value for dead time? It should come out to be $n = N(1 - N\tau)$ or otherwise $N = n(1 + n\tau)$.

EXPERIMENT : Verification of Inverse Square Law

Purpose

To verify the inverse square law for radiation intensity with the increasing distance from the detector.

Underlying Physical Aspects

The experiment is based on a valid assumption that the sources used in this experiment can be considered to be point source with respect to linear dimension between the source and detector. We already know that if there exists a point source emanating EM waves or radiation the flux that goes out is dependent on the areal surface of sphere. Therefore, the intensity would fall as $1/r^2$ where r is the distance between source and detector.

Let us say, that, the activity of the source is A_0 which is kept at a distance r from the detector. Now, it is to be noted that the point source emits in entire 4π direction of which only a fraction which falls within the solid angle that is subtended by the source on to the detector face (say area is πr_d^2 , is actually measured. Moreover, there are other factors within the detector which might lead to loss of certain counts which fall on the detector window. Let us denote that factor by ε_{int} and term it as intrinsic efficiency.

Therefore, we have :

$$I = \frac{A_0 \pi r_d^2 \varepsilon_{int}}{4\pi r^2} \quad (23)$$

If we talk about efficiency there are two types of efficiency : *absolute efficiency* and *intrinsic efficiency*. Absolute efficiency is also termed as total efficiency and it is given as :

$$\varepsilon_{tot} = \frac{\text{events registered}}{\text{events emitted by the source}} \quad (24)$$

The intrinsic efficiency is given by :

$$\varepsilon_{tot} = \frac{\text{events registered}}{\text{events impinged the detector}} \quad (25)$$

So if we rewrite the intensity term as :

$$\frac{I}{A_0} = \frac{\pi r_d^2 \varepsilon_{int}}{4\pi r^2} \quad (26)$$

or

$$\varepsilon_{abs} = \frac{\pi r_d^2 \varepsilon_{int}}{4\pi r^2} \quad (27)$$

$$\varepsilon_{abs} = \varepsilon_{geom} \varepsilon_{int} \quad (28)$$

Procedure

1. Place the source in the first groove and set the preset time as 30 s. Acquire the data and place the source in the subsequent groove.

2. Again acquire the data for 30s and move on to the next groove. Repeat the process till you reach the last slot.
3. Now, again repeat the whole exercise of steps 1 and 2 while placing the source in slots starting from the lowest one.
4. Take the average of counts for each groove and correct it for background reading.
5. Plot corrected counts vs distance as well as fit the curve of $\ln(\text{corrected counts})$ vs $\ln(\text{distance})$. This should be a curve with negative slope. Note down the slope of the curve. It should come around 2. Demo of both the plots are shown in Fig.9.

Table 4: Data Table for Inverse Square Law Experiment

| Distance | Corrected Count Rate Increasing | Corrected Count Rate Decreasing | Mean Count Rate |
|----------|---------------------------------|---------------------------------|-----------------|
| 1. | | | |
| 2. | | | |
| 3. | | | |
| 4. | | | |
| 5. | | | |
| 6. | | | |
| 7. | | | |
| 8. | | | |
| 9. | | | |
| 10. | | | |

Inference

- The variation of intensity of radiation with the distance as a power of
- Also calculate the product $I * r^2$ for all the distances measured and this should be a constant for a given detector.
- From the value of above constant one can find out the value of intrinsic efficiency also.
- So, now do you think that whatever experiments we have performed till date, in every case each data point should be revised by including the effect of efficiency factor? Redraw the plateau characteristics with efficiency correction. Here you can use 35 mm as tube's diameter and the distance as per source was kept in the third groove.

Post Lab Questions and Take Home Messages

1. Do all types of radiations follow inverse square law?

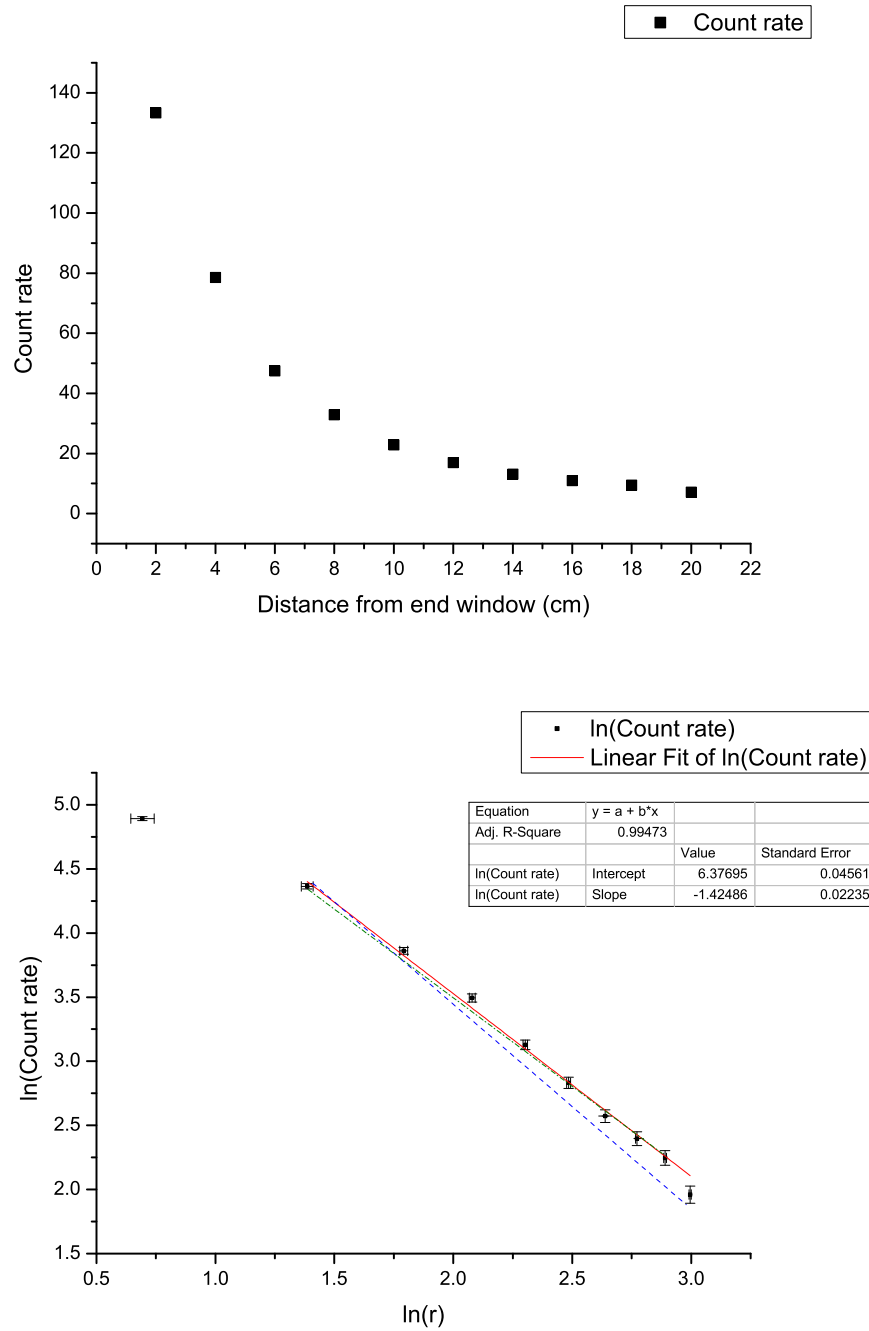


Figure 9: The first plot shows how the Counts vary with the distance of source from the end window of the GM tube. The second plot is simply the logarithmic plot of counts vs distance. The dashed lines show the error fittings with maximum and minimum slope. We hope that the process of graphical error fitting has already been discussed in first year, so details are not discussed here.

2. How would have the risk factor been altered if the nuclear radiation would have followed inverse cubic law?
3. Did you get $I * r^2$ to be constant all throughout ? Or is it totally random ? Or do you see any valid fluctuation and can you somehow correlate the same with efficiency ?
4. In the very first experiment we have asked a question regarding what will happen if the source is placed at last groove. Hopefully, by the end of this experiment you have got the answer.

EXPERIMENT : To distinguish between beta and gamma radiation using GM Tube

Purpose

To use GM counter to differentiate between beta and gamma radiation.

Underlying concept

Initially, we learnt the GM tube is not capable of discriminating between different radiations as for each type of radiation it only generates a output pulse which is independent of incident energy. But, using the property that different materials have different absorbing power for different radiations. Again different radiations have different penetrating power into the materials. For example, gamma radiation has very high penetrating power whereas alpha radiation cannot pass through air even. In general, the intensity I of radiation will be related to the thickness (x) of the material as :

$$I = I_0 \exp(-\mu x) \quad (29)$$

where, I_0 is the original intensity at null thickness. The parameter μ is called the *coefficient of linear absorption*.

If \ln is taken on both sides :

$$\ln(I) = \ln(I_0) + (-\mu x) \quad (30)$$

This is an equation of straight line between $\ln(I)$ and x whose negative slope will give the value of linear absorption coefficient of the medium.

The half value layer of the medium is defined as that thickness $x_{1/2}$ where the intensity in the medium falls by half the value of original one.

$$x_{1/2} = \frac{0.693}{\mu} \quad (31)$$

Procedure

1. Choose a source which emits both β and γ radiations.
2. Place the source in the second groove.
3. Choose an absorbing material, preferably, aluminium and place it in the first groove.
4. Keeping the source at the same place, keep on changing the thickness of the aluminium foil or plate. Initially, for a very thin aluminium foil count rate will be very high. As we keep on increasing the thickness, the count rate would decrease sharply but after a particular thickness of aluminium we will find that the rate of decrease in count rate has reduced appreciably. This means, that now the thickness has become sufficient to stop all the less penetrating β particles and only can allow γ radiation.
5. First of all, plot total corrected count rate as a function of thickness of absorbers.

Table 5: Data Table for Beta range

| S. No. | Corrected Counts | Corrected Count Rate | Thickness (mg/cm ²) | ln(Count Rate) |
|--------|------------------|----------------------|---------------------------------|----------------|
| 1. | | | No medium | |
| 2. | | | | |
| 3. | | | | |
| 4. | | | | |
| 5. | | | | |
| 6. | | | | |
| 7. | | | | |
| 8. | | | | |
| 9. | | | | |
| 10. | | | | |

6. Compute $\log_e I = \log_e I_0 - \mu x$ and plot $\log_e I$ with x . From the plot, two separate regions with two different slopes can be easily observed. The first region is formed due to contribution from both β and γ rays whereas the less steeper region II corresponds to γ radiation only. Determine the equation of straight line in region II. Rearrange the equation by computing exponential on both sides and we will obtain the intensity value of γ ray at particular thicknesses.
7. Now, using the same equation for γ ray, compute the γ intensity for the thickness values where both β and γ rays contribute.
8. If we subtract the γ intensity from the total intensity we are left with only the intensity of β radiation. This is corrected β intensity. The steps mentioned in above points can be written in form of equation :

$$\log_e I = \log_e I_0 - \mu x \quad (32)$$

or, more elaborately;

$$\log_e I_{\beta+\gamma} = \log_e I_{0\beta+\gamma} - \mu_{\beta+\gamma} x \quad (33)$$

We the equation for Region 2 is extrapolated :

$$\log_e I_\gamma = \log_e I_{0\gamma} - \mu_\gamma x \quad (34)$$

$$I_\beta = I_{\beta+\gamma} - I_\gamma \quad (35)$$

$$\log_e I_\beta = \log_e I_{0\beta} - \mu_\beta x \quad (36)$$

9. Now plot a graph between $\log_e(\beta intensity)$ and thickness whose slope will correspond to the linear absorption coefficient for beta particles.
10. A demo table is shown below for the above steps. Three demo plots are shown in Fig.10 and 11.

Table 6: Data Table for Beta range

| S. No. | Total Counts/s in Region 1 | Gamma Count Rate in Region 1 | Total Counts/s - Gamma Counts/s | Thickness (mg/cm ²) |
|--------|-------------------------------|---------------------------------|---------------------------------|---------------------------------|
| 1. | | | | |
| 2. | | | | |
| 3. | | | | |
| 4. | | | | |
| 5. | | | | |

11. Instead of using a source which emits both β and γ radiations, if we use sources which are predominantly β emitter, then subtraction of γ background is not required. It is straightforward to calculate the absorption coefficient of β particles in a particular medium.
12. Perform error calculation.

Inference

- The value of linear absorption coefficient for β particle in aluminium = \pm
- The value of linear absorption coefficient for γ particle in aluminium = \pm
- The value half thickness layer = \pm
- The end point energy of the β particle can be calculated as $E_\beta = 1.84 * Range + 0.212 =$ MeV Range can be determined from the plot where the beta absorption reaches the maximum value and thereafter gamma absorption takes over.

Post Lab Questions and Take Home Messages

1. Have you noticed that we have used a different unit to measure the thickness of absorbers ? In general thickness is given in catalogue but you should atleast measure the thickness of one thick absorber plate and convert it into the given units.
2. What do you understand about the penetrating properties of different types of radiations?
3. Can you correlate the absorption coefficient with the atomic number of the absorbing material ?
4. Do you know any relation which related absorption coefficient with that of energy of incident radiation ?

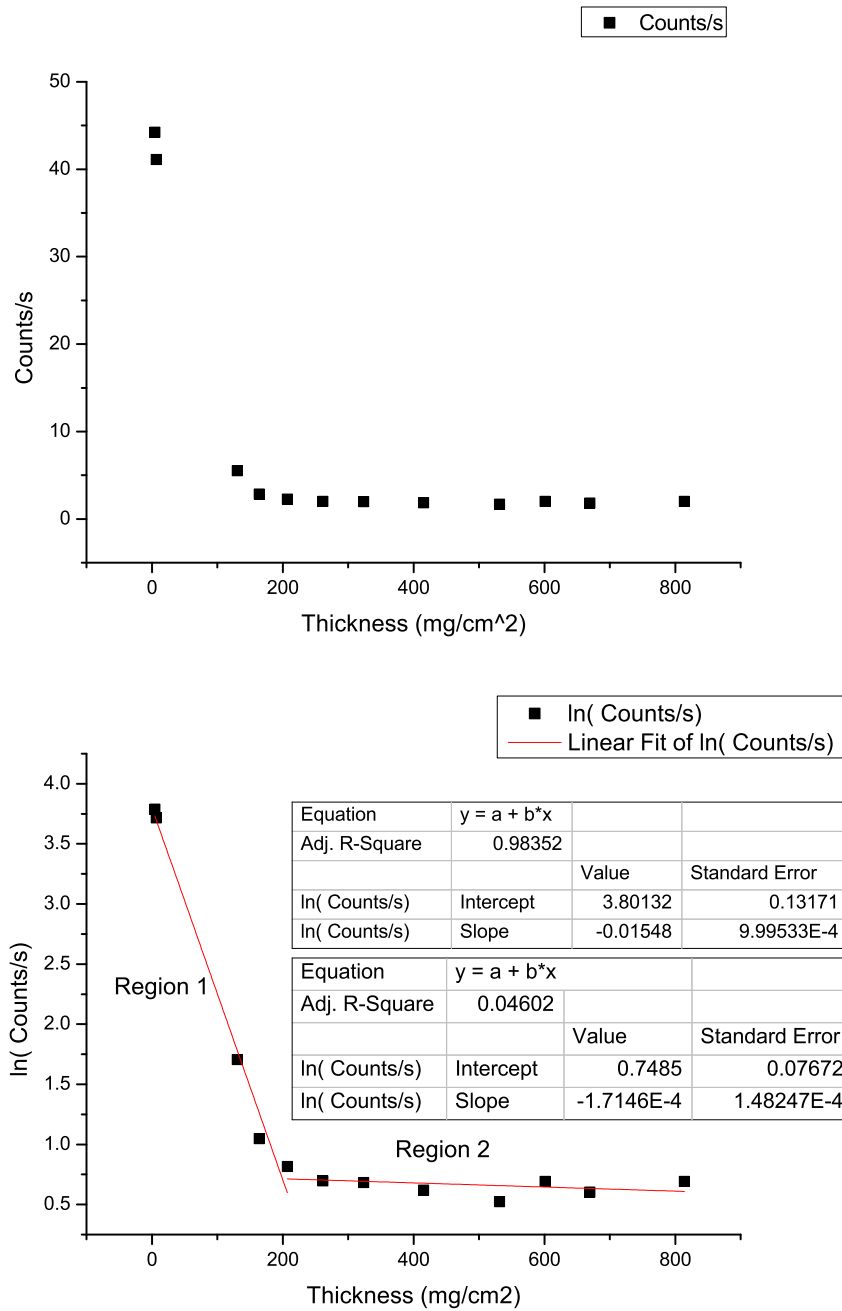


Figure 10: The first figure shows the composite decay of beta and gamma radiation through material medium. Second plot shows the $\ln(\text{count rate})$ vs thickness for composite decay. The preset time was set at 100s and the ^{137}Cs was kept at third source whereas the absorbers were placed at second groove.

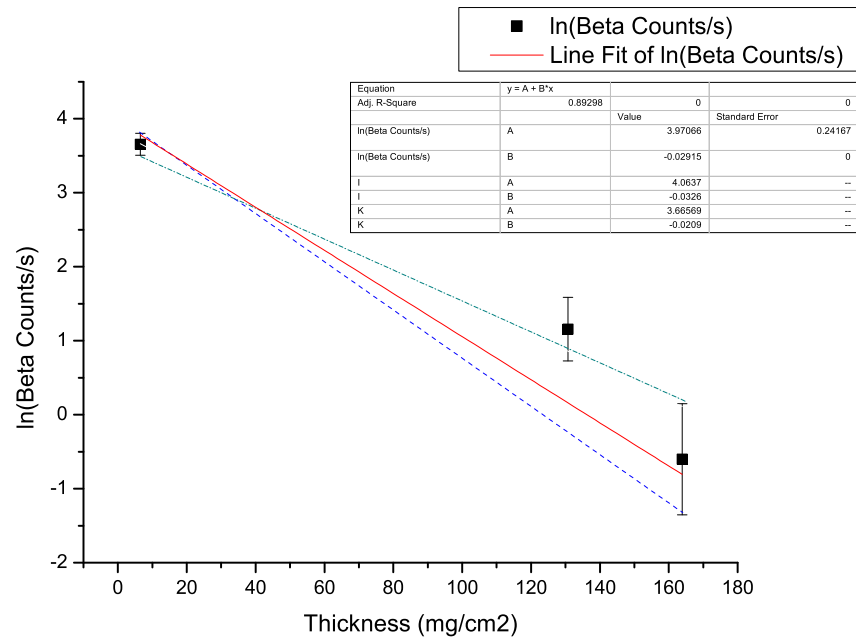


Figure 11: Plot of $\ln(\text{count rate})$ of β corrected for γ background, plotted w.r.t. thickness of aluminium absorbers. The preset time was set at 100s and the ^{137}Cs was kept at third source whereas the absorbers were placed at second groove.

5. You must have seen that in the lab, the radioactive sources are being stored in lead chambers. Do you find any correlation of this experiment with the method of storage of radioactive sources ?
6. If you are interested, you can read about how Co treatment is carried out for cancer patients. Doctors use the concept of absorption of radiation by material medium to protect the healthy organs from irradiation during cancer treatment of the patient.