Study of Geiger Muller Counter

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We aim to determine the operating voltage of GM counter and hence verifying the inverse square law and calculating the efficiency of counter with gamma and beta source. We used Cs-137 as gamma source and tl-204 as beta source. In the last section, we perform nuclear counting statistics to find various parameters such as mean, variance under differnet time for background and beta source.

Keywords: Plataeu voltage, Dead time, Electron Avalanche, Variance

I. THEORY

Geiger Muller (GM) counters are used to detect the radioactivity. GM tube is filled with inert gas with an anode surrounded by a metal cylinder as cathode. The gas is ionized due to particles entering through window and subsequent electron movement and collision takes place resulting electron avalanche. The electrons are attracted to anode and ionized gas are attracted to cathode. The electrons from the anode flow from the power supply, resulting in counts.

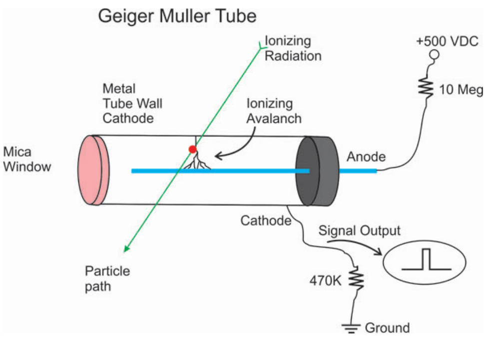

Figure 1: Geiger Muller Tube

Some of the terms used in GM counters are described below. Starting voltage is lowest voltage applied to GM tube before it starts counting. Plateau is section of GM characteristic curve where count rate is independent of applied voltage. The operating voltage is mean of the plateau region. Background radiation is due to cosmic rays and other radioactive sources in the lab. Dead time (T_d) is time interval after initiation of discharge resulting in normal pulse where GM tube is insensitive to further ionizing events. Maximum counting rate is approximately $1/T_d$. Recovery time is minimum time interval between two distinct ionizing events.

Few of the sources for background radiation are the gamma radiation from the environment and cosmic radiation, mesons from cosmic radiation, beta particles from contamination, spontaneous discharge in the detector, electronic noises etc.

II. EXPERIMENT AND ANALYSIS

The radioactive sources Cs-137 and Tl-204 are used as gamma and beta source, respectively throughout the experiment, as shown below.

Figure 2: Sources Cs-137 and Tl-204 used for the experiment

Figure 3: GM counter at lab

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A. Characteristics of GM tube

To study the characteristics of GM tube, we determine the operating voltage with the plot of counts versus voltage. The counts are taken for 30 second time. A plateau is obtained, where the mean of plateau is the operating voltage. We also determine the plateau slope, length from this experiment. The observations are shown in table (I) and (II).

Table I: GM Characteristic Table for Cs-137

HV (V)	Count	BG Count	Corrected Count
307	0	0	0
337	2542	23	2519
367	2802	36	2766
397	2875	34	2841
427	2838	40	2798
457	2870	33	2837
487	2839	39	2800
517	3028	39	2989
547	2940	34	2906
577	2956	38	2918
607	3017	41	2976
637	4563	57	4506
667	5809	67	5742

Table II: GM Characteristic Table for Tl-204

HV (V)	Count	BG Count	Corrected Count
313	0	0	0
343	391	38	353
373	394	41	353
403	455	40	415
433	417	36	381
463	454	46	408
493	420	44	376
523	416	45	371
553	414	42	372
583	387	35	352
613	420	47	373
643	891	69	822

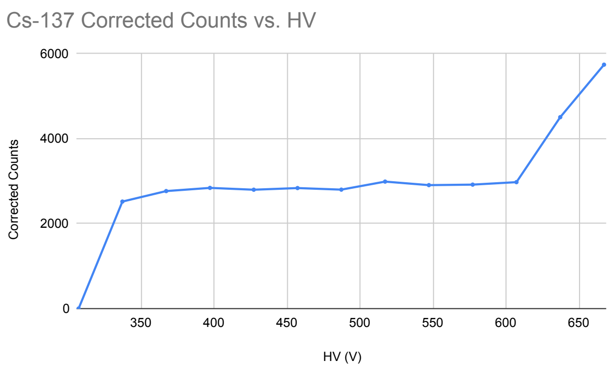

Figure 4: GM characteristic curve for Cs-137

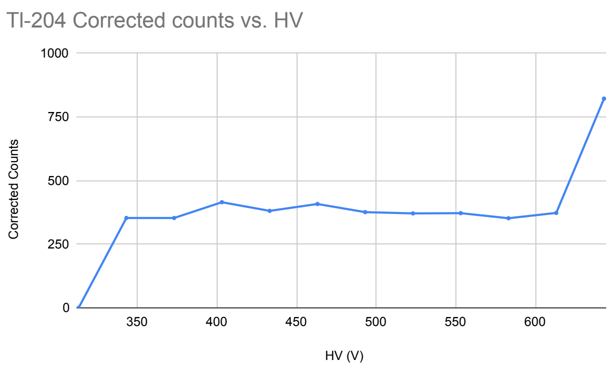

Figure 5: GM characteristic curve for Tl-204

Cs-137

The starting voltage (V_1) is 337 V and Upper threshold voltage (V_2) is 607 V. The Plateau length is $V_2 - V_1 = 270\ V$. The operating voltage is:

$$V_o = (V_1 + V_2)/2 = 472\ V \tag{1}$$

The percentage slope of plateau is given by:

$$Slope\ Percent = \frac{N_2 - N_1}{N_1} . \frac{100}{V_2 - V_1} .100 \tag{2}$$

where N_1, N_2 are count rate of V_1 and V_2.

$$Slope\ Percent = \frac{2976 - 2519}{2519} . \frac{100}{270} .100 = 6.72\% \tag{3}$$

Tl-204

The starting voltage (V_1) is 343 V and Upper threshold voltage (V_2) is 613 V. The Plateau length is $V_2 - V_1 = 270\ V$. The operating voltage is:

$$V_o = (V_1 + V_2)/2 = 478\ V \tag{4}$$

The percentage slope of plateau is given by:

$$Slope\ Percent = \frac{N_2 - N_1}{N_1} . \frac{100}{V_2 - V_1} .100 \tag{5}$$

where N_1, N_2 are count rate of V_1 and V_2.

$$Slope\ Percent = \frac{373 - 353}{353} . \frac{100}{270} .100 = 2.1\% \tag{6}$$

We take operating voltage as mean of both these, i.e 472 V and 478 V giving as 475 V. It is seen that the slope percent less than 10% is desirable. The mid point of GM characteristics is the operating voltage of the counter. For the beta source the efficiency of detector increases.

B. Inverse Square law

The inverse square law states that the intensity of gamma radiation is inversely proportional to the square of the distance of the source.

R is the Net count rate and d is the distance of the source, then:

$$R = C/d^2 \implies log(R) = log(C) - 2log(d) \tag{7}$$

where C is constant.

We can verify the inverse square law by:

1. Plot of $1/d^2$ versus R which should be linear
2. Plot of log(d) versus log(R) where slope should be -2.

as shown in figures (6) , (7) and (8). The observation tables are shown in tables (III) and (IV).

Table III: The mean count is 77.8 with net count rate as 1.3 cps

Background Count
84
67
75
77
86

Table IV: Table for inverse square law dependence of intensity with distance.

Distance d (cm)	Corrected Count (N)	Net Count (R)/s	$C = Rd^2$	$1/d^2 (m^{-2})$	log (R)	log(d)
2	3768.2	62.80	251.21	2500.00	1.797982695	0.3010299957
2.5	3011.2	50.19	313.67	1600.00	1.700588351	0.3979400087
3	2368.2	39.47	355.23	1111.11	1.596267126	0.4771212547
3.5	2025.2	33.75	413.48	816.33	1.528316668	0.5440680444
4	1635.2	27.25	436.05	625.00	1.435419628	0.6020599913
4.5	1465.2	24.42	494.51	493.83	1.38774566	0.6532125138
5	1306.2	21.77	544.25	400.00	1.337858429	0.6989700043
5.5	1008.2	16.80	508.30	330.58	1.225395443	0.7403626895
6	927.2	15.45	556.32	277.78	1.189022173	0.7781512504
6.5	782.2	13.04	550.80	236.69	1.115166561	0.8129133566
7	718.2	11.97	586.53	204.08	1.07809415	0.84509804
7.5	605.2	10.09	567.38	177.78	1.003747669	0.8750612634
8	581.2	9.69	619.95	156.25	0.9861743552	0.903089987
8.5	507.2	8.45	610.75	138.41	0.9270279945	0.9294189257
9	406.2	6.77	548.37	123.46	0.8305886687	0.9542425094
9.5	372.2	6.20	559.85	110.80	0.7926251184	0.9777236053
10	360.2	6.00	600.33	100.00	0.7783924581	1

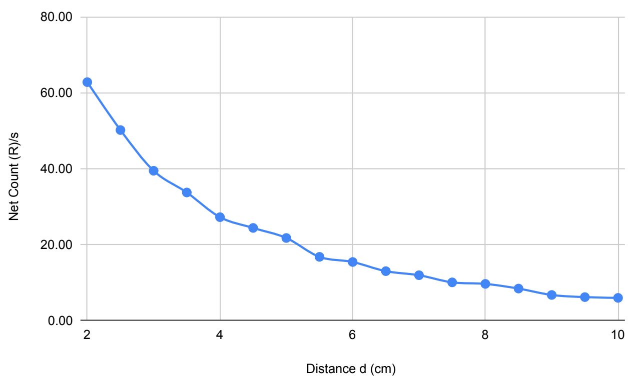

Figure 6: Inverse square law dependence of intensity with distance.

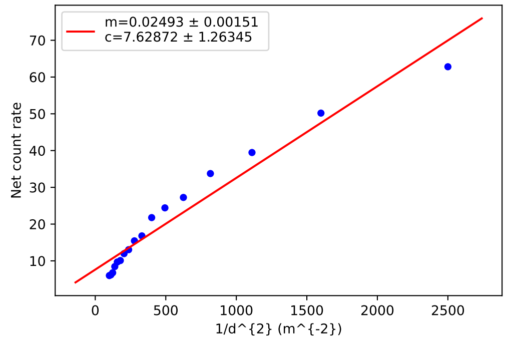

Figure 7: Plot of Net count rate versus $1/d^2$

The slope of figure(7), gives the value of constant C as (0.02493 ± 0.00151) cps/m^2. The actual mean and standard deviation of C from the data is (0.0501 ± 0.0109) cps/m^2.

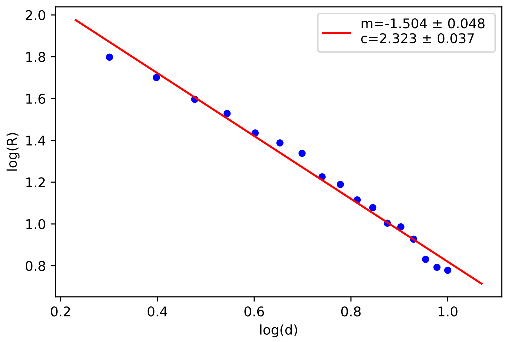

Figure 8: Plot of log(R) and log(d)

From figure (8), we get slope as (-1.504±0.048), we expected slope of -2 for inverse square law dependence.

C. Efficiency

To determine efficiency we need the values of certain parameters which are :

1. D, distance of source to end window
2. d, diameter of end window
3. N_s mean count due to source
4. N_b mean count due to background
5. A, Activity of the sample.

The D is found to be 10 cm and d is 1.5 cm. Note that cps is counts per second and dps is disintegration per second.

1. Cs-137

The activity A of Cs-137 is 86 kBq.

Table V: Background count and count recording for 100 s for Cs-137

Background Count	Count
118	438
132	786
116	718

The $N_b = 122$ and $N_s = 647.3$. Therefore net count rate (N) is

$$N = (N_s - N_b)/100 = 5.253 \ cps \tag{8}$$

The gamma source emits radiation in all the directions. The fraction of radiation entering the GM tube is R:

$$R = \frac{Ad^2}{16D^2} = \frac{86000 * (1.5)^2}{16 * 10^2} = 120.9375 \ dps \tag{9}$$

Therefore, efficiency (E) is

$$E = \frac{N}{R} = 5.253/120.9375 = 4.34\% \tag{10}$$

2. Tl-204

The activity of beta source is 10 kBq. We calculate the intrinsic efficiency where geometry factor is not considered for case of beta source.

Table VI: Background count and count recording for 100s for Tl-204

Background Count	Count
74	2454
69	2498
89	2493

The $N_b = 77.33$ and $N_s = 2481.67$. Therefore net count rate (N) is

$$N = (N_s - N_b)/60 = 40 \ cps \tag{11}$$

Intrinsic efficiency (E) is calculated as

$$E = \frac{N}{A} = 0.4\% \tag{12}$$

D. Nuclear Counting Statistics

Systematic errors are precise but not accurate whereas random error lacks precision but not accuracy. Random errors are statistical fluctuations during measurement. The following statistical quantities are defined to know about the data and analyse it.

Mean ($\bar{N}$) is the average value of n measurements,

$$\bar{N} = \frac{N_1 + N_2 + ...N_n}{n} \tag{13}$$

The deviation (d) is the difference between actual value and mean.

$$d_i = N_i - \bar{N} \tag{14}$$

Variance (σ^2) is the spread between numbers in data. The standard deviation (σ) is given by square root of variance.

$$\sigma^2 = \frac{1}{n-1}\Sigma_i^n d_i^2 \tag{15}$$

For Poisson distribution, variance is equal to mean, i.e $\sigma^2 = \bar{N} \implies \sigma = \sqrt{\bar{N}}$

The observation table for this part is attached with the report.

The background count was taken 10 readings for 10 s and 100 s. The bar graph of index versus counts is shown in figures (9) and (10).

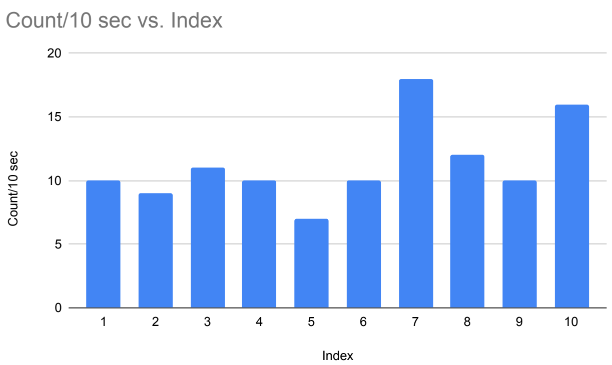

Figure 9: Bar graph of index versus Count for 10 s

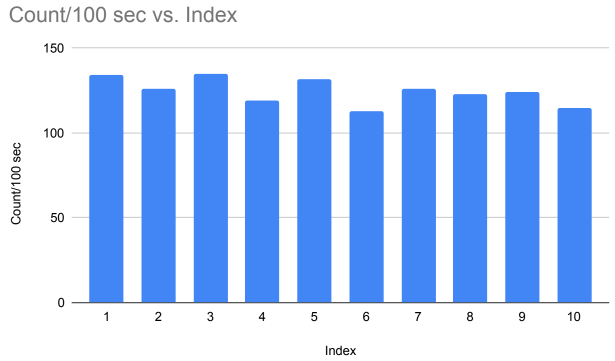

Figure 10: Bar graph of index versus Count for 100 s

The spread in measure values decreases as number of pulses registered increases.

With 100 readings for 100 s, we obtain mean as 58.55 and variance as

$$\sigma^2 = 4774.75/100 = 47.74 \tag{16}$$

Standard deviation σ=6.90. The histogram of this is shown in figure (11).

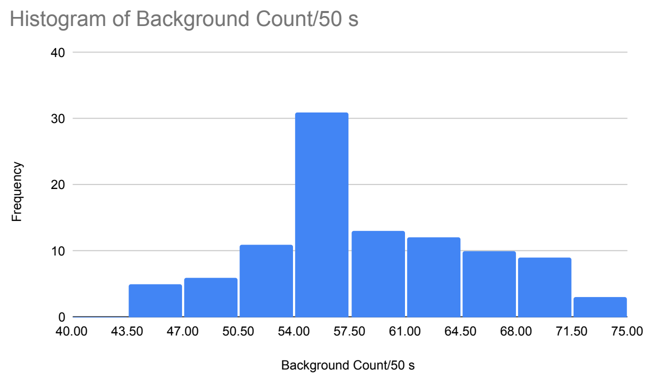

Figure 11: Histogram of Background count in 50 s

To illustrate the no. of counts being high, Poisson distribution follows Gaussian, we take 50 readings of 25 s with beta source.

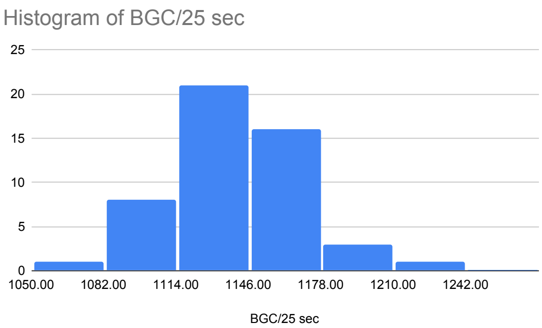

Figure 12: Histogram of count in 25 s with beta source

The mean is 1136.76 with summation of $N_i - \bar{N}$=0.28≈0. The standard deviation is 33.716. It is seen that the histogram of rounded off values is an Gaussian distribution as shown in figure (13) and (14)

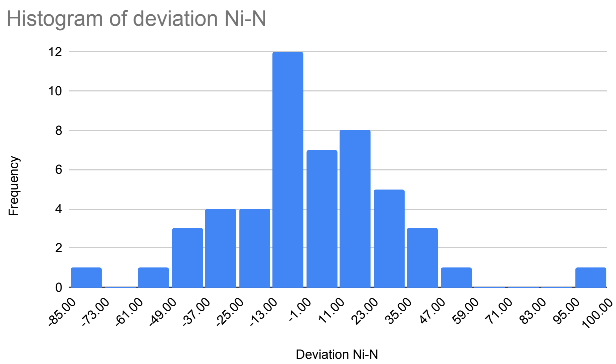

Figure 13: Histogram of Deviation from the mean

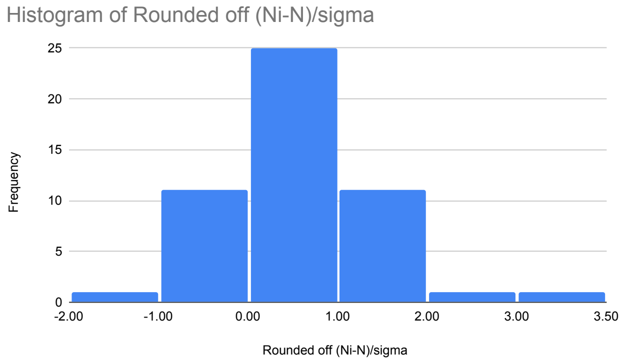

Figure 14: Histogram of rounded off Deviation/standard deviation

III. CONCLUSION

This experiment helped us to familiarize with the basic instrument of nuclear physics lab GM counter. The GM characteristic curve is plateau shaped. The mean of the starting voltage and upper threshold voltage is operating voltage of the counter. We determined the Operating voltage of GM counter as 475 V with slope of plateau as 6.72% for Cs-137 and 2.1% for Tl-204. We also verified the inverse square law. We obtained slope from R versus $1/d^2$ as (0.02493 ± 0.00151) cps/m^2 and the value from data is (0.0501 ± 0.0109) cps/m^2. We obtained slope as (-1.504±0.048) while it was expected to be -2 from the plot of log(R) versus log(d) . The efficiency of for gamma source is 4.34% and beta source is 0.4%. We also calculated various statistical parameters in the last section. It was seen that mean value is nearly same as variance, which is Poisson distribution. The distribution around the mean value closely resembles to Gaussian. Some of the errors may have contributed to the experiment. This included the systematic error in the GM counter as the timer lagged than the original timer. Moreover the value could be made precise by increasing number of readings.

IV. REFERENCES

1. `https://www.imagesco.com/geiger/geiger-counter-tube.html`
2. `https://www.niser.ac.in/sps/sites/default/files/basic_page/p341_2023/GM-1.pdf`