Geiger-Muller (GM) Counter-II (Applications of GM counters

Biswaranjan Meher
Integrated M.Sc.
Roll No.-2011050
School of Physical Sciences
National Institute of Science Education and Research, Bhubaneswar
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In the previous experiment, we got good knowledge about the working, construction, and some basic applications of GM counters. In this experiment, we are going to use GM counters in Nuclear physics, specifically in radioactivity, determining the half-life of a source, range and end-point energy of β-particles by carrying out their absorption studies with Aluminium, verifying attenuation of Bremsstrahlung radiation, etc.

I. OBJECTIVES

- Determination of range of β-particles and endpoint energy from different sources.
- To study the backscattering of β rays from Aluminium sheets using GM counter.
- To study the Bremsstrahlung attenuation of β-rays due to different combinations of Aluminium, Copper and Perspex layers using GM counter.
- Determination of the short half-life period of a given source.

II. THEORY

Beta particles are electrons produced in the nucleus as a result of nuclear reactions (i.e. when a neutron disintegrates into a proton and an electron).

$$n \rightarrow p + e^- + \bar{\nu} \tag{1}$$

Because this electron forms in the high-energy nucleus, it has more energy and can ionize and penetrate materials more than alpha particles.

A. Range of β particles and end-point energy

When beta particles strike a material, they are scattered by the nuclei or lose energy due to electron-beta particle collision. We will only look at the number of beta particles that can pass through the absorber in this experiment.
The range of β particles is given by the empirical relation:

$$R_o = (0.52E_o - 0.09)g/cm^2 \tag{2}$$

Where E_o is the endpoint energy of beta rays from a radioactive source in MeV.
The number of *beta* particles that can pass through the material decreases as the thickness and density of the material increase. In this case, we use thick aluminium sheets (0.6mm). We use multiple layers of aluminium to determine the thickness at which the number of beta particles passing through the aluminium absorber is reduced to half that measured without any absorber.
Let $t_{1/2}$ be the thickness for a given source for which the counts decrease by half. Then the ratio of $t_{1/2}$ of two different sources is given as:

$$\frac{t_{1/2}^{(1)}}{t_{1/2}^{(2)}} = \frac{R_1}{R_2} \tag{3}$$

B. Backscattering of β particles

Backscattering is defined as the phenomenon that occurs when radiation or particles are scattered at angles greater than 90° to the original direction of motion.

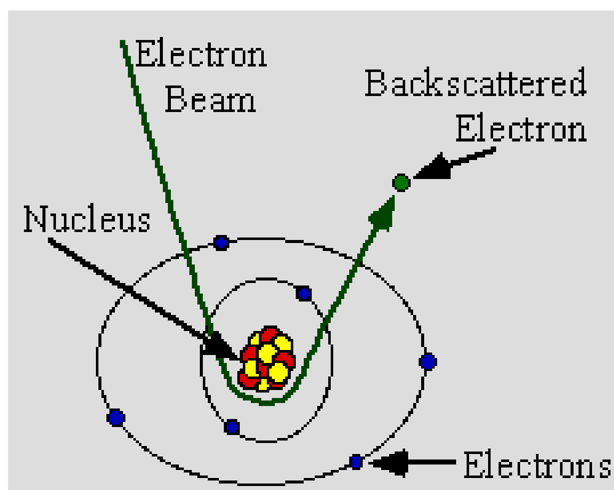

FIG. 1. Backscattering of β particle (electron)

When β particles collide with a surface, they are either absorbed or scattered. The particles scattered by the material are the focus of backscattering (due to Aluminium). When the nuclear charge increases (i.e. depends on Z), the probability of a particle being scattered increases; thus, the higher the atomic number, the greater the scattering angle and thus backscattering.

Backscattering is also affected by the material's thickness (or mass per unit area). The scattering increases with thickness up to a saturation value. It saturates because the scattered beta particles are absorbed by more layers.

C. Attenuation of Bremsstrahlung radiation

Bremsstrahlung (or braking radiation) is the phenomenon of electromagnetic radiation production when an electron decelerates or loses energy. To compensate for the kinetic loss, electromagnetic radiation equal to the energy lost by the electron is produced.
When a beta particle collides with an electron or is deflected by an atomic nucleus, it loses energy. Bremsstrahlung has a continuous spectrum that becomes more intense and shifts its peak intensity towards higher frequencies as the energy of the decelerated particles changes.
Bremsstrahlung is also affected by the material's thickness (or mass per unit area). The amount of Bremsstrahlung increases as the atomic number/density of the material increases.

D. Half-life of a radioactive source

For radioactive decay, the number of nuclei decaying in a time t is given by:

$$\frac{dN}{dt} = -\lambda N \tag{4}$$

where λ is the decay constant.
Solving eqn.(4), we get:

$$N = N_o e^{-\lambda t} \tag{5}$$

where N_o= initial number of nuclei.
Now, the half-life of a radioactive source is the duration in which the number of particles reduces to half the initial number of nuclei.

$$t_{1/2} = \frac{ln(2)}{\lambda} \tag{6}$$

III. EXPERIMENTAL SETUP

Components required:

- Sr^{90}**:** Source of β rays.
- Tl^{204}**:** Source of β particles.
- **0.9% NaCl in 0.04 M HCl and isotope generator(containing Cs/Ba-137m):** Sample to determine the short half-life.
- **GM counting system and detector**
- **Aluminium sheets of known thickness**
- **Connecting cables**

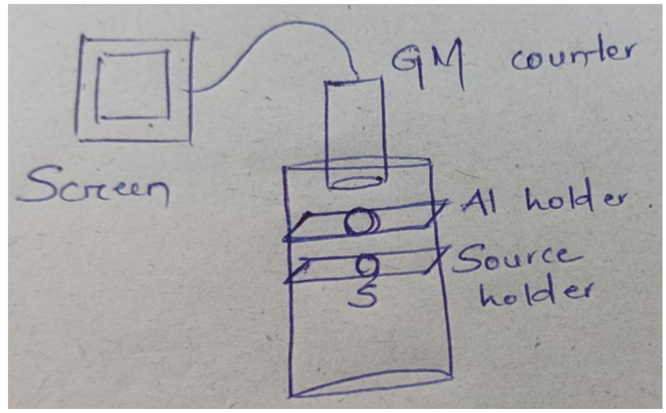

FIG. 2. Experimental setup for range of β particles

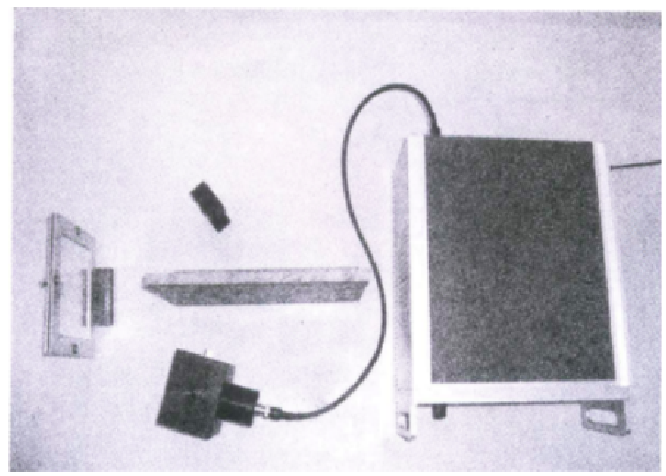

FIG. 3. Experimental setup for backscattering

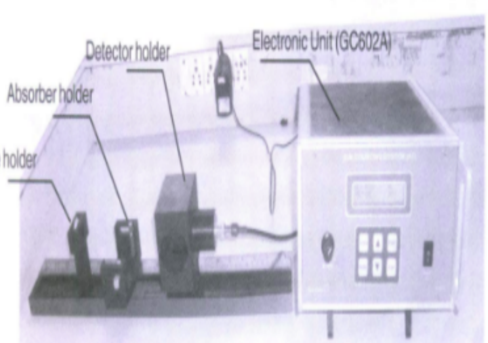

FIG. 4. Experimental setup for attenuation of Bremsstrahlung radiation

IV. OBSERVATIONS AND CALCULATIONS

Table 1: Range of β particles for source 1

Source : Tl^{204} Background - 250			
Absorber Thickness (mm)	Absorber Thickness (mg/cm^2)	Counts	Net Count
0	0	9342	9092
0.06	16.2	7153	6903
0.12	32.4	5441	5191
0.18	48.6	4118	3868
0.24	64.8	3088	2838
0.3	81	2265	2015
0.36	97.2	1710	1460
0.42	113.4	1218	968
0.48	129.6	947	697
0.54	145.8	723	473

Plot 1: Counts vs thickness of Al for Tl^{204}

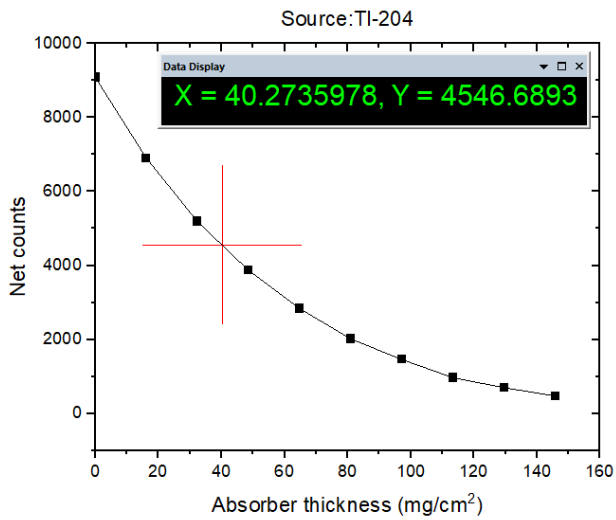

FIG. 5. Net Counts vs thickness of Al for Tl^{204}

Table 2: Range of β particles for source 2

Source - Sr-90 Background - 139			
Absorber Thickness (mm)	Absorber Thickness (mg/cm^2)	Counts	Net Count
0	0	5374	5235
0.06	16.2	4910	4771
0.12	32.4	4118	3979
0.18	48.6	3818	3679
0.24	64.8	3339	3200
0.3	81	3143	3004
0.36	97.2	3036	2897
0.42	113.4	2792	2653
0.48	129.6	2673	2534
0.54	145.8	2487	2348

Plot 2: Counts vs thickness of Al for Sr^{90}

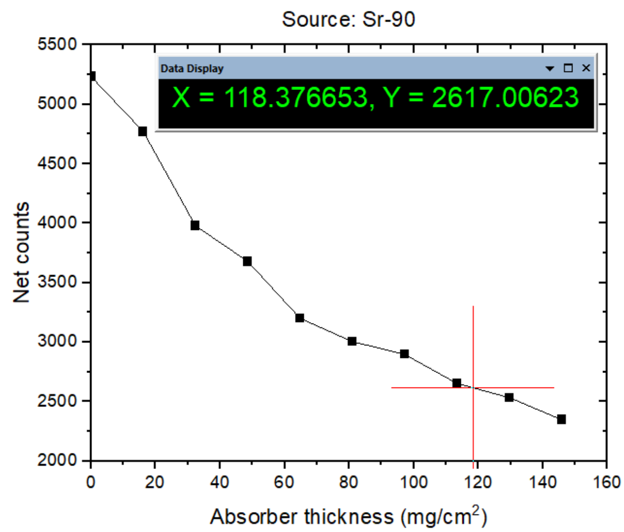

FIG. 6. Net Counts vs thickness of Al for Sr^{90}

From FIG.5, we get the half counts at:

$$t_{1/2}^{Tl} = 40.2736 mg/cm^2$$

From FIG.6, we get the half counts at:

$$t_{1/2}^{Sr} = 118.3766 mg/cm^2$$

We know the endpoint energy of Tl-204 = 0.764 MeV.
From eqn.(2),
Range of Tl-204,$R_1 = 0.30728 g/cm^2$
From eqn.(3),

$$R_2 = R_1 \times \frac{t_{1/2}^{(2)}}{t_{1/2}^{(1)}}$$

$$R_2 = 0.30728 \times \frac{118.3766 \times 10^{-3}}{40.2736 \times 10^{-3}}$$

$$R_2 = 0.9032 g/cm^2$$

Endpoint energy of Sr-90:

$$E_2 = \frac{R_2 + 0.09}{0.52} = 1.91 MeV$$

Error:
Since the only error here is the least count error, the error propagation would be very less for both range and endpoint energy.

Table 3: Backscattering of β particles

Source: Sr-90 Material: Al			
Sl. No.	Thickness (mm)	Counts	Net counts
1	0	249	–
2	0.06	276	27
3	0.12	318	69
4	0.18	339	90
5	0.24	354	105
6	0.3	376	127
7	0.36	393	144
8	0.42	408	159
9	0.48	416	167
10	0.54	418	169

Plot 3: Net counts vs thickness

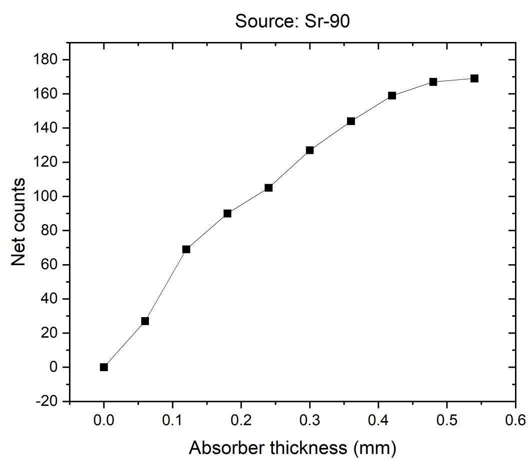

FIG. 7. Plot of net counts vs absorber thickness (in mm)

We can clearly observe that the net counts increase with the increasing thickness of the absorber and attains a saturated value.

Table 4: Attenuation of Bremsstrahlung radiation

For Al(0.7 mm) and Perspex (1.8 mm)			
S.No.	Absorber position	Counts	Net counts
1	–	7903	7517
2	perspex facing S	735	349
3	Al facing S	729	343

For Cu(0.3 mm) and Perspex (1.8 mm)			
S.No.	Absorber position	Counts	Net counts
1	–	7903	7517
2	perspex facing S	713	327
3	Cu facing S	706	320

For Al(0.7 mm) and Cu (0.3 mm)			
S.No.	Absorber position	Counts	Net counts
1	–	7903	7517
2	Cu facing S	545	156
3	Al facing S	602	216

We can observe that the count rate depends on the order in which the absorbent materials are arranged.

Table 5: Short half-life of a radioactive source

Sl.No.	Time elapsed (s)	Counts	Net counts	Net counts/s	log(N)
1	10	2378	2367	236.7	2.374
2	20	4749	2360	236	2.373
3	30	6988	2228	222.8	2.348
4	40	9051	2052	205.2	2.312
5	50	11030	1968	196.8	2.294
6	60	12939	1898	189.8	2.278
7	70	14670	1720	172	2.236
8	80	16409	1728	172.8	2.238
9	90	18070	1650	165	2.217
10	100	19602	1521	152.1	2.182
11	110	21049	1436	143.6	2.157
12	120	22423	1363	136.3	2.134
13	130	23744	1310	131	2.117
14	140	25058	1303	130.3	2.115
15	150	26224	1155	115.5	2.063
16	160	27347	1112	111.2	2.046
17	170	28463	1105	110.5	2.043
18	180	29489	1015	101.5	2.006
19	190	30454	954	95.4	1.98
20	200	31386	921	92.1	1.964
21	210	32245	848	84.8	1.928
22	220	33107	851	85.1	1.93
23	230	33942	824	82.4	1.916
24	240	34695	742	74.2	1.87
25	250	35473	767	76.7	1.885
26	260	36164	680	68	1.833
27	270	36835	660	66	1.82
28	280	37473	627	62.7	1.797
29	290	38140	656	65.6	1.817
30	300	38668	517	51.7	1.713

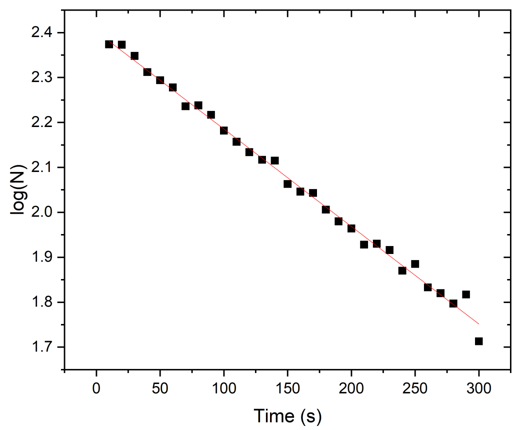

FIG. 8. log(N) vs t

Equation	y = a + b*x
Plot	log(N)
Weight	No Weighting
Intercept	2.40275 ± 0.00569
Slope	-0.00217 ± 3.20488E-5
Residual Sum of Squares	0.00646
Pearson's r	-0.99696
R-Square (COD)	0.99394
Adj. R-Square	0.99372

FIG. 9. Parameters of FIG.8

Using the above parameters (since we have taken base 10), we have

$$\frac{\lambda}{2.303} = 0.00217$$

$$\lambda = 0.00499751 s^{-1}$$

$$t^{1/2} = \frac{ln(2)}{\lambda} = 138.7s$$

Error:

$$\frac{\delta t^{1/2}}{t^{1/2}} = \frac{\delta slope}{slope}$$

$$\frac{\delta t^{1/2}}{t^{1/2}} = \frac{3.20488 \times 10^{-5}}{0.00217} = 0.01477$$

$$\delta t^{1/2} = 2.048s$$

V. RESULTS

- Range of β particles for Sr-90:

$$R_{Sr} = 0.9032 g/cm^2$$

  Endpoint energy of β particles for Sr-90:

$$E_{Sr} = 1.91 MeV$$

- We can observe that the net counts increase with the increasing thickness of the absorber and attaining a saturated value.
- We observed the attenuation of Bremsstrahlung.
- Half-life of a given liquid source:

$$t^{1/2} = (138.7 \pm 2.048)s$$

VI. CONCLUSIONS AND DISCUSSIONS

- The number of beta particles absorbed by the Aluminum sheet increases with an increase in the thickness of the aluminum layer which is in accordance with theory.
- The number of beta particles backscattered reaches a saturation value, as more increase in thickness of the material only absorbs the scattered beta particles and thus no increase in backscattering after a certain value. The saturation thickness is at 0.5mm which is less than the theoretical value of 0.74mm because the aluminum layers used are not one single block but rather multiple layers thus increasing the chance of a beta particle being absorbed.
- For Bremsstrahlung radiation we observed that it depends on the manner in which absorbers are arranged. If firstly the sheet is metal then a higher count rate was measured because Bremsstrahlung is generated in Aluminum but is absorbed to a very less extent in perspex, whereas if the first medium is perspex then low radiation is produced which is further absorbed in Aluminium.
- Materials having less Z/ρ ratio cause less Bremsstrahlung when the radiation is incident on that side, as they have lower nuclear charge and thus the lesser ability to deflect the beta particles.

VII. SOURCES OF ERRORS

- Handling of the GM counter: due to its fragile nature as it contains inert gases.
- Systemic or Instrumental errors associated with the detector.
- Measurement or human errors.
- Errors due to various radiation present in the background.

VIII. REFERENCES

- NISER Lab Manual
- https://www.imagesco.com/nuclear-science/geiger-counter/experiment-3.html
- https://www.sciencedirect.com/topics/chemistry/bremsstrahlung#:~:text=Bremsstrahlung%20(or%20%E2%80%9Cbraking%20radiation%E2%80%9D,and%20the%20nuclei%20of%20atoms.

Background			**Table-1 :** Source - **Tl-204 ;** Background - **250**			
S.No.	**Count**		**Absorber Thickness. (mm)**	**Absorber Thickness (mg/cm^2)**	**Counts**	**Net Count**
1	83		0	0	9342	9092
2	75		0.06	16.2	7153	6903
3	75		0.12	32.4	5441	5191
4	91		0.18	48.6	4118	3868
5	93		0.24	64.8	3088	2838
Average	83.4		0.3	81	2265	2015
Rate	1.39		0.36	97.2	1710	1460
			0.42	113.4	1218	968
			0.48	129.6	947	697
			0.54	145.8	723	473
			Table-2 : Source - **Sr-90 ;** Background - **139**			
			Absorber Thickness. (mm)	**Absorber Thickness (mg/cm^2)**	**Counts**	**Net Count**
			0	0	5374	5235
			0.06	16.2	4910	4771
			0.12	32.4	4118	3979
			0.18	48.6	3818	3679
			0.24	64.8	3339	3200
			0.3	81	3143	3004
			0.36	97.2	3036	2897
			0.42	113.4	2792	2653
			0.48	129.6	2673	2534
			0.54	145.8	2487	2348

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Background	
S.No.	Count
1	75
2	66
3	69
4	83
5	93
Average	77.2
Rate	1.286666667

For Al(0.7 mm) and Perspex (1.8 mm)			
S.No.	Absorber position	Counts	Net counts
1	--	7903	7517
2	perspex facing S	735	349
3	Al facing S	729	343
For Cu(0.3 mm) and Perspex (1.8 mm)			
S.No.	Absorber position	Counts	Net counts
1	--	7903	7517
2	perspex facing S	713	327
3	Cu facing S	706	320
For Al(0.7 mm) and Cu (0.3 mm)			
S.No.	Absorber position	Counts	Net counts
1	--	7903	7517
2	Cu facing S	545	156
3	Al facing S	602	216

Sl.No.	Time elapsed(s)	Counts	Net counts	Net counts/s	log(N)
1	10	2378	2367	236.7	2.374
2	20	4749	2360	236	2.373
3	30	6988	2228	222.8	2.348
4	40	9051	2052	205.2	2.312
5	50	11030	1968	196.8	2.294
6	60	12939	1898	189.8	2.278
7	70	14670	1720	172	2.236
8	80	16409	1728	172.8	2.238
9	90	18070	1650	165	2.217
10	100	19602	1521	152.1	2.182
11	110	21049	1436	143.6	2.157
12	120	22423	1363	136.3	2.134
13	130	23744	1310	131	2.117
14	140	25058	1303	130.3	2.115
15	150	26224	1155	115.5	2.063
16	160	27347	1112	111.2	2.046
17	170	28463	1105	110.5	2.043
18	180	29489	1015	101.5	2.006
19	190	30454	954	95.4	1.98
20	200	31386	921	92.1	1.964
21	210	32245	848	84.8	1.928
22	220	33107	851	85.1	1.93
23	230	33942	824	82.4	1.916
24	240	34695	742	74.2	1.87
25	250	35473	767	76.7	1.885
26	260	36164	680	68	1.833
27	270	36835	660	66	1.82
28	280	37473	627	62.7	1.797
29	290	38140	656	65.6	1.817
30	300	38668	517	51.7	1.713

Background	
Sl.No.	Counts
1	70
2	72
3	59
4	56
5	72
Average	65.8

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Source: Sr-90 Material: Al			
Sl.No.	Thickness (mm)	Counts	Net counts
1	0	249	--
2	0.06	276	27
3	0.12	318	69
4	0.18	339	90
5	0.24	354	105
6	0.3	376	127
7	0.36	393	144
8	0.42	408	159
9	0.48	416	167
10	0.54	418	169

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