Experiments with G.M. Counter

Lab report

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1. Study of the characteristics of a G.M. Tube
2. Inverse square law: Gamma rays
3. Determination of Beta particle range
4. Production and attenuation of Bremsstrahlung
5. Backscattering of Beta particles

1 Study of the characteristics of a G.M. Tube

1.1 Aim of Experiment

To find out the operating voltage of the G.M. Tube.

1.2 Apparatus used

1. G.M. Detector with MHV to UHF connecting cable.
2. G.M. counting system GC602A
3. Stand for G.M. Detector
4. Cs-137 Gamma source
5. BNC connecting cable

1.3 Theroy

A Geiger counter consists of a Geiger–Müller tube (the sensing element that detects the radiation) and the processing electronics, which display the result. A high voltage is applied to a tube containing low-pressure inert gas like helium, neon, or argon. When high energy particles or gamma radiation hit the gas, they make it conductive by knocking out electrons from the gas atoms. This causes a chain reaction of electron multiplication inside the tube, called the Townsend discharge effect, also known as avalanche, which creates a large pulse of electric current that can be easily detected and displayed by the electronic circuit. The Geiger counter is relatively simple and inexpensive to make because of this large pulse from the tube. In general, a DC voltage ranging from 400 V to 600 V is needed for the tube to work properly. This voltage has to be chosen carefully because if it is too high, the tube will discharge continuously, damaging the instrument and giving wrong results. The electric field will be too weak to produce a current pulse if it is too low. The G.M. tube cannot measure high radiation rates efficiently, has a finite life in high radiation areas, and cannot measure incident radiation energy, so no spectral information can be generated. There is no discrimination between radiation types, such as between alpha and beta particles. The filled gas mixture contains one or more rare gases and a quenching agent. Quenching is the termination of the ionization current pulse in a G.M. tube.

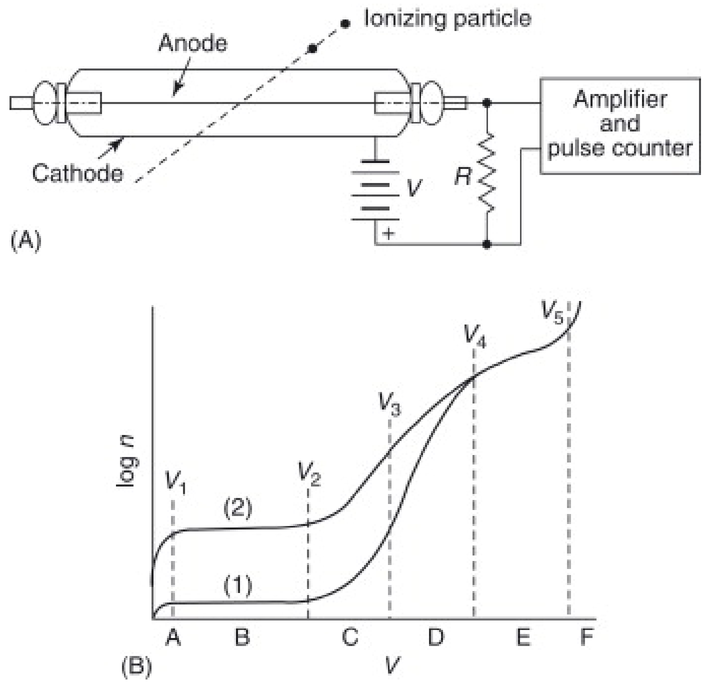

Figure 1: (a) Schematic diagram of a GM counting system. (b) Different regions of operation of gas-filled detectors. 1

1.3.1 Operating charactristics

1. **Starting Voltage (V_s):** This is the lowest voltage applied to the G.M. Tube at which pulses appear across the anode resistor and unit starts counting.

2. **Plateau:** This is the section of the G.M. characteristics curve constructed with counting rate versus applied voltage (with constant irradiation) over which the counting rate is substantially independent of the applied voltage. Unless otherwise stated, the plateau is measured at a counting rate of an approximately 100 counts.

3. **Plateau threshold voltage (V_1):** This is the lowest applied voltage, which corresponds to the start of the plateau for the stated sensitivity of the measuring circuit.

4. **Plateau Length:** This is the range of applied voltage over which the plateau region extends.

5. **Upper threshold voltage (V_2):** This is the higher voltage up to which the plateau extends, beyond which the count rate increases with an increase in applied voltage.

6. **Plateau Slope:** Change in the counting rate expressed in percentage over a plateau length of 100 V, expressed in % per volt

7. **Operating voltage:** This is the supply voltage at which the G.M. Tube should preferably be used. This voltage is normally chosen to be in the middle of the plateau.

8. **Background count:** This is the counting rate measured in the absence of the radiation source. The background count can be due to cosmic rays and any active sources in the experimental room.

1.3.2 Formulae used

Operating voltage $= (\frac{V_1+V_2}{2})$

The slope of the plateau is given by slope $= (\frac{N_2-N_1}{N_1}) \times (\frac{100}{V_2-V_1}) \times 100$

Where N_1 is the count rate at starting voltage V_1 and N_2 is the count rate at upper threshold voltage of the plateau V_2.

1.4 Observation

S. No	Voltage (V)	Source count N_s	Background count N_b	Corrected counts $N = (N_s - N_b)$
1	340	0	0	0
2	370	5669	72	5597
3	400	5996	81	5915
4	430	6023	76	5947
5	460	6161	71	6090
6	490	6182	81	6101
7	520	6201	59	6142
8	550	6475	59	6416
9	580	6410	68	6342
10	610	6473	79	6394
11	640	10947	47	10900

Table 1: Data for voltage v/s source count at Preset time = 30 sec

1.5 Graph and calculations

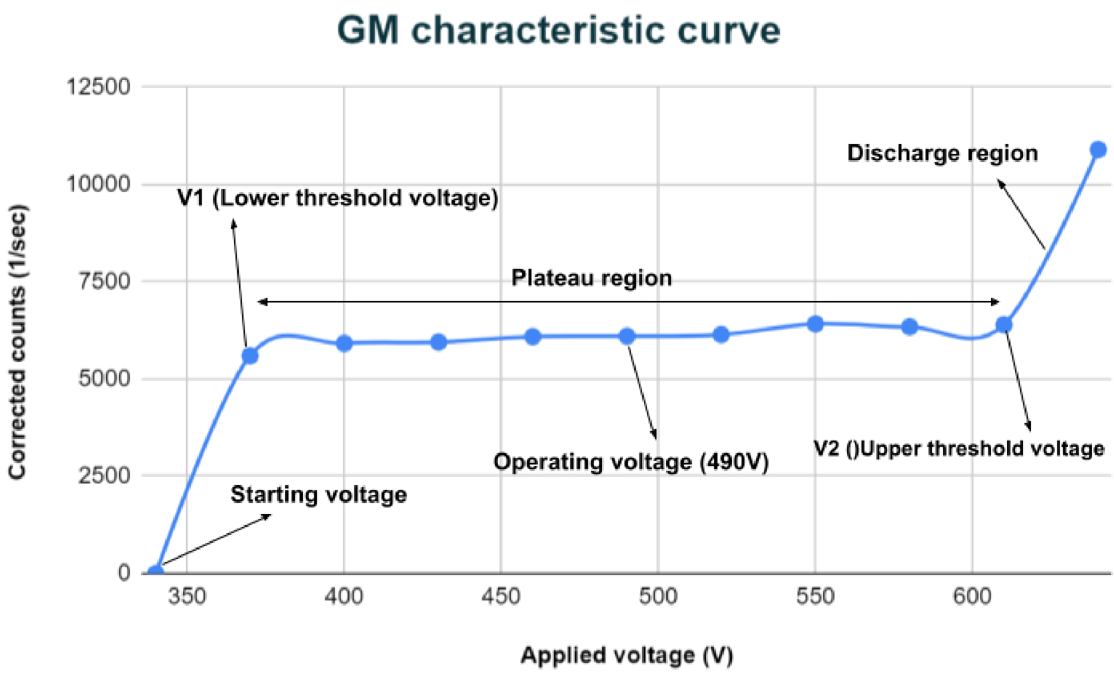

Figure 2: Voltage v/s Number count

From the above data,
V_1 (Lower threshold voltage) = 370 V

V_2 (Upper threshold voltage) = 610 V

Plateau length = $V_2 - V_1$ = 610 V- 370 V = 240 V

Operating voltage = $(\frac{V_1+V_2}{2}) = \frac{370+610}{2} = 490$ V

The slope of the plateau = $(\frac{N_2-N_1}{N_1}) \times (\frac{100}{V_2-V_1}) \times 100$

$= (\frac{6394-5597}{5597}) \times (\frac{100}{610-370}) \times 100 = 5.93\ \%$

Where N_1 is the count rate at the lower threshold voltage V_1 and N_2 is the count rate at upper threshold voltage of the plateau V_2.

1.6 Conclusion

From the plateau, it can be noticed that the midpoint of the characteristics of the GM tube is defined as operating voltage and is used for counting applications. The operating voltage obtained is 490 V. The tube is operated at this operating voltage when used in radiation monitors for measurements in the plateau region. We get a steep increase in count rate which indicates the discharge region, where uncontrolled avalanches start getting triggered. Operating GM tube in that region may result in damage.

1.7 Preacautions

1. Do not let anything touch the window, it's very fragile.
2. Avoid applying a high voltage in the discharge region, as the tube will be damaged.
3. Handle the radioactive sources with utmost care.
4. Reduce the applied voltage gradually and slowly.

2 Inverse square law: Gamma rays

2.1 Aim of Experiment

To find out the operating voltage of the G.M. Tube.

2.2 Apparatus used

1. G.M. Detector with MHV to UHF connecting cable.
2. G.M. counting system GC602A
3. Stand for G.M. Detector
4. Cs-137 Gamma source
5. BNC connecting cable

2.3 Theory

Inverse Square Law states that the intensity of radiation is inversely proportional to the square of the distance from the source.The inverse square law equation allows a direct calculation of the intensity of radiation at a predetermined distance from the source. Gravitation, light, sound, and electricity also follow the inverse square law. The mathematical representation of this law is:

$$Intensity \propto \frac{1}{(distance)^2}$$

In the diagram diagram below we can see that as the distance doubles, the area quadruples and thus, the initial radiation amount is spread over that entire area and is therefore reduced, proportionately.

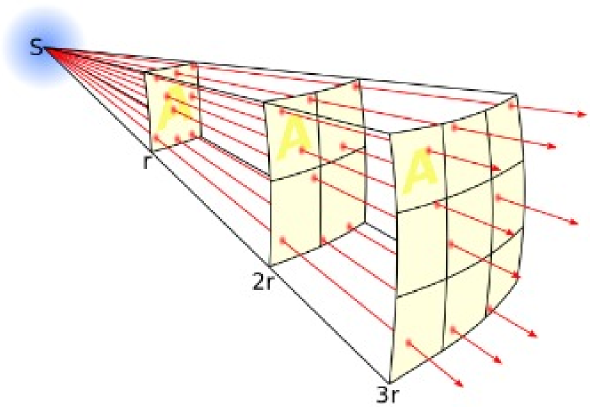

Figure 3: pictorial depiction of the inverse square law

Figure 4: Experimental setup for Inverse square law

2.4 Observation

Average background counts = 80.6
Preset time = 60 sec

Distance (cm)	Counts with bkg	Net count	Net count rate (R)	1/d^2	logd	logR	R.d^2
7	1902	1821.4	30.357	0.020	1.946	3.413	1487.48
8	1494	1413.4	23.557	0.016	2.079	3.159	1507.63
9	1196	1115.4	18.590	0.012	2.197	2.923	1505.79
10	985	904.4	15.073	0.010	2.303	2.713	1507.33
11	799	718.4	11.973	0.008	2.398	2.483	1448.77
12	629	548.4	9.140	0.007	2.485	2.213	1316.16
13	571	490.4	8.173	0.006	2.565	2.101	1381.29
14	485	404.4	6.740	0.005	2.639	1.908	1321.04
15	482	401.4	6.690	0.004	2.708	1.901	1505.25
16	374	293.4	4.890	0.004	2.773	1.587	1251.84

Table 2: Experimental readings

2.5 Graph and calculations

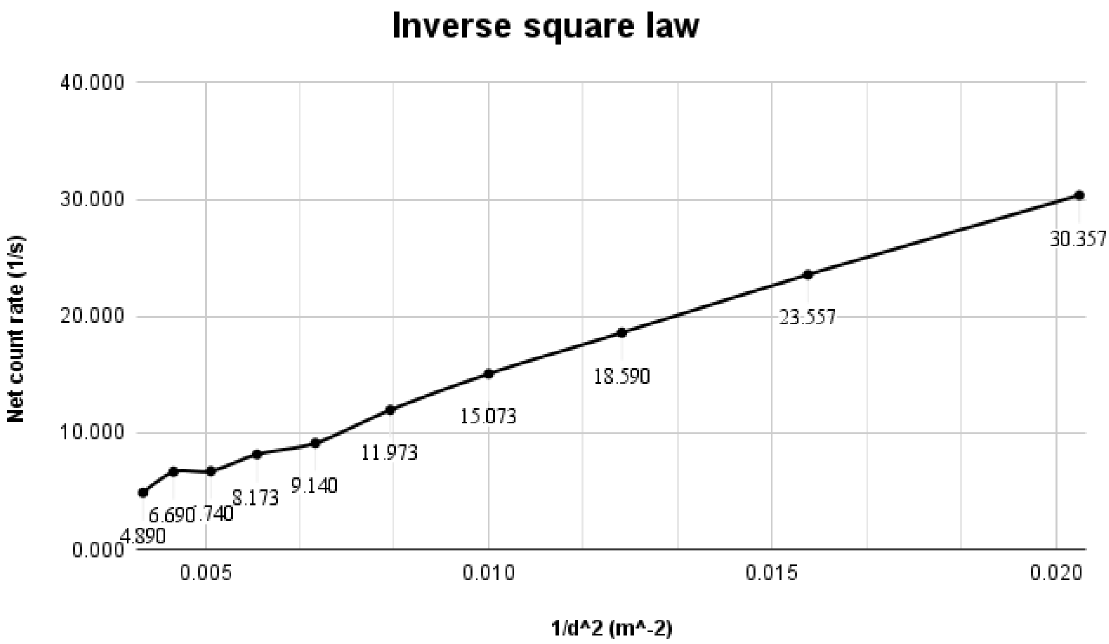

Figure 5: Graph showing particle counts following inverse square law

Figure 6: Count rate varying inversly with square of the distance

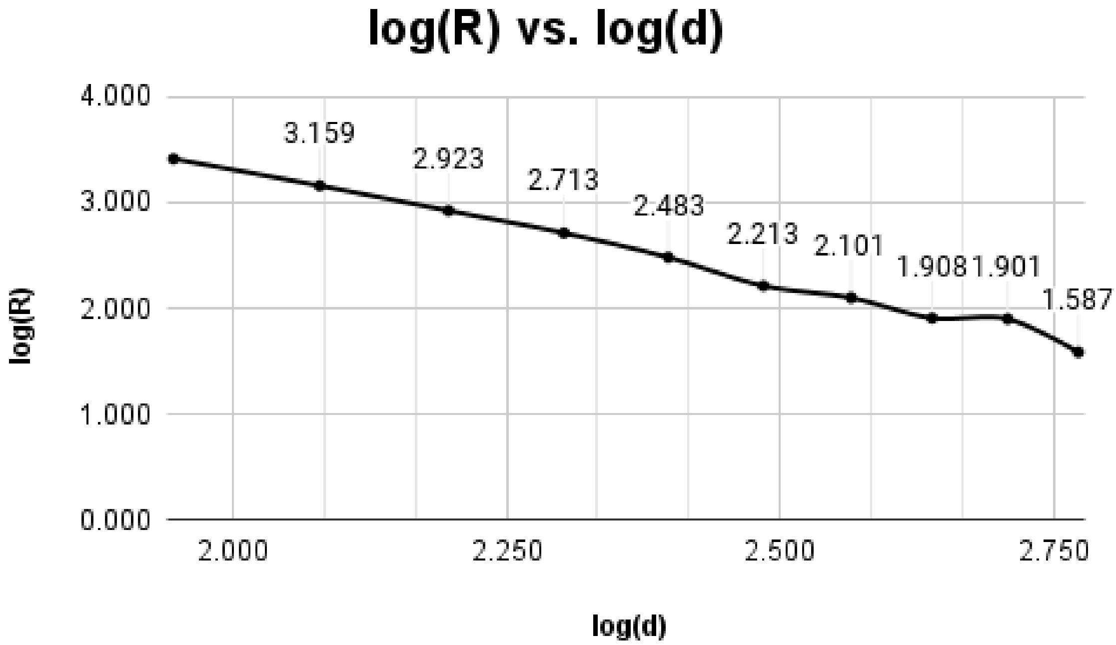

Figure 7: Measuring the gradient of the straight line

Another way of analysing the data is to plot a log-log graph for Net count rate and distance and see whether its coming out to be a straight line or not. The inverse square law is followed if the straight line has a gradient of 2.

$$Gradient = -\frac{log(R_2) - log(R_1)}{log(d_2) - log(d_1)} = -\frac{2.923 - 2.101}{2.197 - 2.565} = 2.233$$

Where $log(R_2)$ and $log(R_1)$ are any two values from the graph and their corresponding $log(d_2)$ and $log(d_1)$.

The inverse square law is followed by all types of radiations emittting out from a point source. The law isn't reliable when the source to measurement point distance is smaller compared to the dimension of the source. The law best works when the distance from the source to the measurement point is at least ten times the largest dimension of the source.

2.6 Conclusion

We can conclude from the above graphs that the radiation emitted from a radioactive point source follows inverse square law over a distance. So, we can calculate the particle fluence and conclude that it remains constant.

3 Determination of Beta particle range

3.1 Aim of Experiment

To study and determination of beta particle range and maximum energy by Half value method.

3.2 Apparatus required

1. GM tube
2. Stand for GM detector
3. Aluminium absorber set
4. GM counting system
5. Radioactive source(Sr 90)

3.3 Theory

The electron energy spectrum of most beta sources is continuous with an intensity maximum at about some average beta energy and minimum intensity at maximum electron energy. The continous spectrum of beta particle indicates that the beta decay is not a two body decay process. Along with a beta particle, a neutral particle is also emitted, neutrino in β -positive decay and anti-neutrino in β -negative. The total beta energy which is emitted during a beta disintegration process is shared by an electron and an anti-neutrino. A typical beta decay reaction by parent Sr-90 is given as

$$^{90}Sr_{38} \longrightarrow ^{9}{}^{0}Y_{39} +^{0} e_{-1} + \bar{\nu}_e$$

High energy electrons loose energy in materials through (a) inelastic collisions with the atoms of the material, ionizing its atoms and (b) through radiative loss due to deacceleration by the nucleus (Bremsstrahlung). Calculating the transmission rate for electrons is very complicated, making it necessary to measure it as a function of material thickness.

Figure 8: Experimental setup for measurement of beta range

3.4 Observation

Counting time: 180 sec
Background counts: 147

Absorber: Aluminium, density = $2.7 g/cm^3$
Source: Sr-90

Absorber thickness (mm)	Absorber Thickness (mg/cm^2)	Counts	Net Counts
0	0	11848	11701
0.06	16.26	10148	10001
0.12	32.52	8979	8832
0.18	48.78	7887	7740
0.24	65.04	7235	7088
0.3	81.3	6747	6600
0.36	97.56	6210	6063
0.42	113.82	5990	5843
0.48	130.08	5533	5386
0.54	146.34	5164	5017

Table 3: Data for Sr-90

Counting time: 180 sec
Background counts: 147

Absorber: Aluminium, density = $2.7 g/cm^3$
Source: Tl-204

Absorber thickness (mm)	Absorber Thickness (mg/cm^2)	Counts	Net Counts
0	0	6579	6432
0.06	16.26	5023	4876
0.12	32.52	3778	3631
0.18	48.78	2897	2750
0.24	65.04	2138	1991
0.3	81.3	1632	1485
0.36	97.56	1251	1104
0.42	113.82	947	800
0.48	130.08	667	520
0.54	146.34	501	354

Table 4: Data for Tl-204

3.5 Graphs

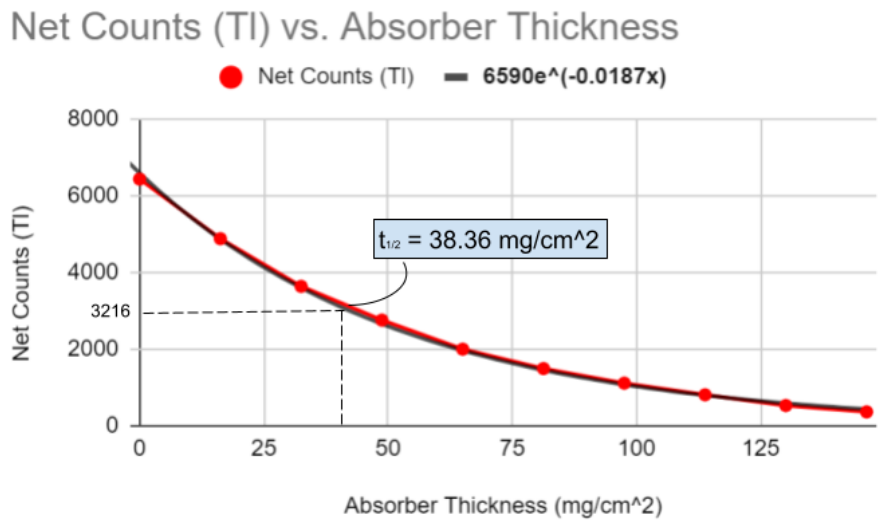

Figure 9: Net counts v/s Absorber thickness for Tl-204

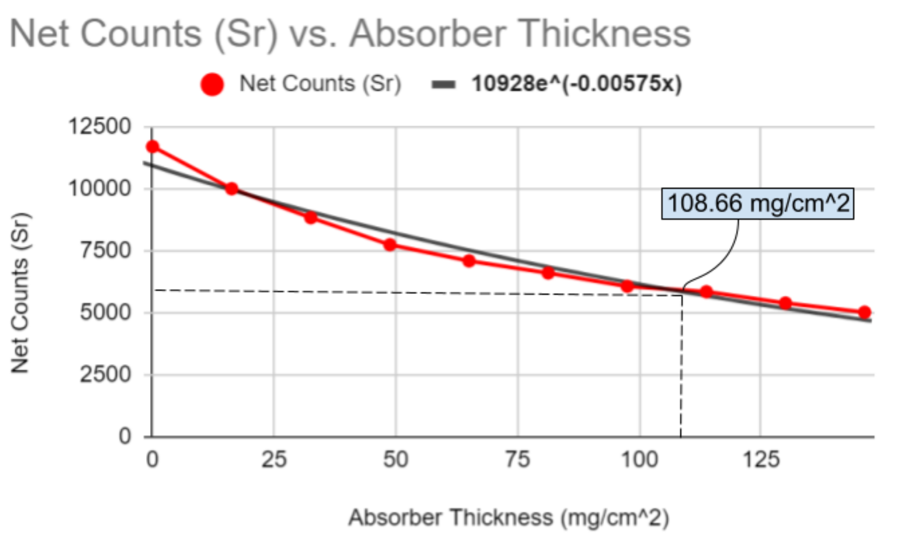

Figure 10: Net counts v/s Absorber thickness for Sr-90

3.6 Analysis and Calculation

In principle,the range of Beta particles is given by the emperical relation

$$R = (0.52E_o - 0.09)g/cm^2 \tag{1}$$

Where E_o is the end point energy of Beta rays from the radioactive source in MeV. We have the ratio of thickness required to reduce the counts of Beta rays from one source to half to the thickness required for the other source is given by

$$\frac{t^1_{1/2}}{t^2_{1/2}} = \frac{R_1}{R_2} \tag{2}$$

Where $R_1\&R_2$ are range of beta rays from two beta sources respectively and $t^1_{1/2}$, $t^2_{1/2}$ represents half value thicknesses of two sources.

Since TI-204 is a known standard source, which emits Beta Rays with end-point energy 0.764 MeV. Substituting this end-point energy, in equation(1) above, we can find out the Range (R_1) of TI-204 Beta rays in Aluminium Absorber.

For Thallium-204,
End point energy of TI-204 = 0.764 MeV.
Range of TI-204 would be,

$$R_1 = (0.52 \times 0.764 - 0.09) = 0.30728\ gm/cm^2$$

by plotting the net counts vs. thickness, we get thickness of Al absorber required to reduce the count rate of Tl-204 by half

$$t^1_{1/2} = 38.36\ mg/cm^2$$

Similarly, we get the thickness of Al absorber required to reduce the count rate of Sr-90 by half

$$t^2_{1/2} = 108.66\ mg/cm^2$$

from equation (2)

$$R_2 = R_1 \times \frac{t^2_{1/2}}{t^1_{1/2}} = 0.30728 \times \frac{108.66}{38.36} = 0.870\ gm/cm^2$$

End point energy of Sr-90 would then be from equation (1)

$$E_2 = \frac{R_2 + 0.09}{0.52} = \frac{0.870 + 0.09}{0.52} = 1.846\ MeV$$

3.7 Error analysis

The actual end point energy of the beta particles from Sr-90/Yt-90 source is 2.27 MeV.

$$Relative\ error = \frac{Evaluated\ value - Actual\ value}{Actual\ value} \times 100$$

$$Relative\ error = \frac{1.846 - 2.27}{2.27} \times 100 = -18.68\ \%$$

3.8 Result

- We have calculated range of beta rays from sources Sr-90 and TI-204 and ranges are found to be $0.870 gm/cm^3$ and $0.30728\ gm/cm^3$ respectively.
- The endpoint energy of beta rays from Sr-90 source is calculated from energy range emperical relation which is found to be 1.846 MeV with a relative error of 18.68 %.

4 Production and attenuation of Bremsstrahlung

4.1 Aim of Experiment

To study the production and attenuation of bremsrahlung due to beta particles.

4.2 Apparatus required

1. GM tube
2. Stand for GM detector
3. Al (0.7mm), Cu (0.3mm) Perspex (1.8mm) absorber set
4. GM counting system
5. Radioactive source(Sr 90)
6. Sliding Bench
7. Source Holder

4.3 Theory

Beta partcles (positrons and electrons) interact with matter via collisional interaction and radiative interaction. Radiative interaction corresponds to the situation when beta particle directly interact with nucleus of target material. In this process beta particle undergo either acceleration or decceleration. When beta particles are accelerated or decelerated, they must radiate energy, and the deceleration radiation is known as the bremsstrahlung or braking radiation.External bremsstrahlung (EB) is a continuous electromagnetic radiation emitted when an electron or a beta particle is deflected in the Coulomb field of the nucleus. In a thick target, most of the incident electrons are slowed down in the first few layers of the target and produce bremsstrahlung. The production and attenuation of EB take place simultaneously up to the range of the particle but beyond this range only attenuation of EB takes place.Bremsstrahlung has a continuous spectrum which becomes more intense and whose intensity shifts toward higher frequencies as the change of the energy of the accelerated particles increases.

Beta -particle emitting substances sometimes exhibit a weak radiation with continuous spectrum that is due to Bremsstrahlung. In this context, Bremsstrahlung is a type of "sec ondary radiation", in that it is produced as a result of stopping (or slowing) the primary radiation (Beta particles).The amount of Bremsstrahlung increases as the atomic number/density of the absorbing material goes up. If the mass per unit area (thickness X density) of the plates used as absorbers is such that the beta particles are completely absorbed, then for materials of higher atomic number/density, correspondingly higher bremsstrahlung count rates are obtained.

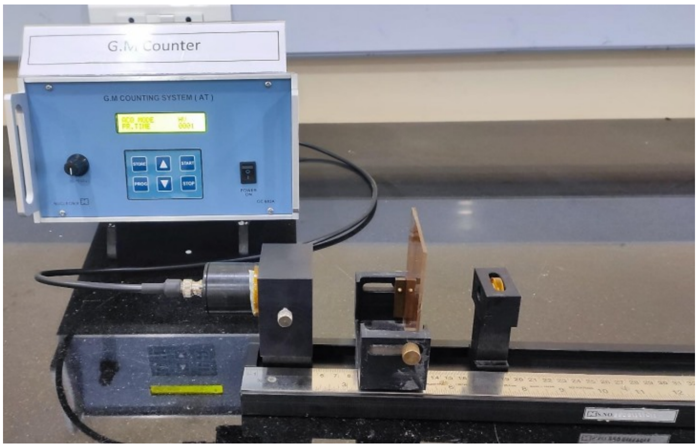

Figure 11: Experiment setup for production and attenuation of Bremsstrahlung

4.4 Observation

Source: Sr-90 Distance between source and detector: 6cm
Activity: 0.1 μCi Preset Time: 300 sec
Avg. Background count: 495.33

We have conducted the experiment with following three combinations of materials

1. Al (0.7mm) & Perspex (1.8mm)
2. Perspex (1.8mm) & Cu (0.3mm)
3. Al (0.7mm) & Cu (0.3mm)

We tabulated the net counts corresponding to different combination of materials.Where net counts refers to the counts minus the background counts i.e. shown as below

Al Perspex		
Absorber position	**Counts**	**Net Counts**
Without absorber	10056	9560.67
Perspex facing source	696	200.67
Al facing source	728	232.67

Table 5: Readings for Al Perspex

Cu Perspex		
Absorber position	**Counts**	**Net Counts**
Without absorber	10056	9560.67
Perspex facing source	641	145.67
Cu facing source	748	252.67

Table 6: Readings for Cu Perspex

Al Cu		
Absorber position	**Counts**	**Net Counts**
Without absorber	10056	9560.67
Cu facing source	655	159.67
Al facing source	613	117.67

Table 7: Readings for Al Cu

4.5 Results and Conclusion

We found that the production of bremstrahlung from absober material depends greatly on the atomic density or atomic no. of the material. High atomic no. material produces more bremstrahlung, as material serves more targets for the collison of beta particle which subsequently leads to radiative loss in form of bremstrahlung.

The count rate of produced bremsstrahlung varies depending on the sequence in which absorbent materials are positioned. When the metal sheet is initially directed towards the source, a higher count rate is observed due to the generation of bremsstrahlung in the aluminum, with minimal absorption in the subsequent "Perspex" sheet. Conversely, if the beta rays first encounter the plastic sheet, the resulting low-energy bremsstrahlung is significantly absorbed by the subsequent metal sheet. These findings are applicable to different material combinations as well.

4.6 Practical implications

The shielding of Beta sources is done by taking the above observations into account. The shielding container has layers of different materials, with lower Z material on the inner side, gradually increasing the Z value towards the outer layer and highest Z material on the outermost side. The high energy beta particles produce relatively lesser bremsstrahlung photons by interacting with lower Z material on the inner shielding layer (as compared to higher Z material) and those bremsstrahlung photons end up interacting with the higher Z metals on the outer layers by the means of photoelectric effect, compton effect and pair production and an effective shielding is achieved. The shielding calculations can be done by taking into account the range and energy of beta particles released by that particular source.

5 Backscattering of Beta particles

5.1 Aim of Experiment

To study the backscattering of beta particles from a scatter

5.2 Apparatus required

1. Electronic Unit GC601A / GC602A.
2. Wide end window GM Detector (GM125)
3. Absorber stand for Back scattering of Beta
4. Absorber set (Beta particle scattering experiment)
5. Beta source (Sr-90)
6. Lead Block for Isolation

5.3 Theory

When Beta Particles interact with matter, two potential outcomes are absorption and scattering. Scattering occurs when Beta particles collide with electrons within the material, causing changes in their speed and trajectory. when deflection angles surpass 90°,The probability of backscattering increases with the atomic number (Z) of the substance. A higher Z increases the chances of large-angle scattering, often without substantial energy loss. The backscattering factor is approximately proportional to the square root of the atomic number.

Material thickness (expressed as mass per unit area or actual thickness) influences the backscattering factor but only up to a certain point of saturation. Maximum backscattering occurs when the material's mass per unit area is less than half the Beta particle's range in that material. Excessive thicknesses cause the absorption of scattered electrons. This saturation value is consistently below 200 mg/cm^2 for all materials, corresponding to approximately < 0.74 mm for Aluminum and <0.17 mm for Lead.

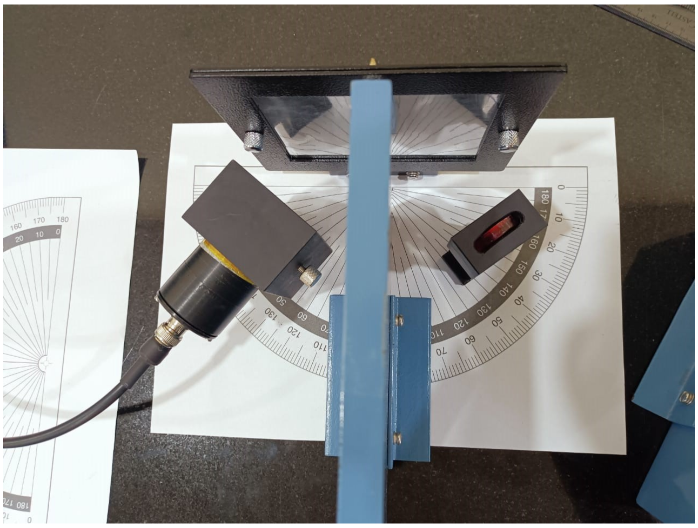

Figure 12: Experimental setup for backscattering experiment

5.4 Observation

Source: Sr-90
Activity: 0.1 μCi
Preset time: 200 seconds

Sl no	Material	Thickness (mm)	Counts		Avg	Net counts
			1	2		
1	Al	0	214	221	217.5	-
2	Al	0.05	274	313	293.5	76
3	Al	0.1	339	307	323	105.5
4	Al	0.15	353	306	329.5	112
5	Al	0.2	339	342	340.5	123
6	Al	0.25	360	353	356.5	139
7	Al	0.3	346	418	382	164.5
8	Al	0.35	379	410	394.5	177
9	Al	0.4	380	396	388	170.5
10	Al	0.45	403	412	407.5	190
11	Al	0.5	379	374	376.5	159
12	Al	0.55	374	372	373	155.5
13	Al	0.6	406	347	376.5	159

Table 8: Readings for backscattering of Beta particles

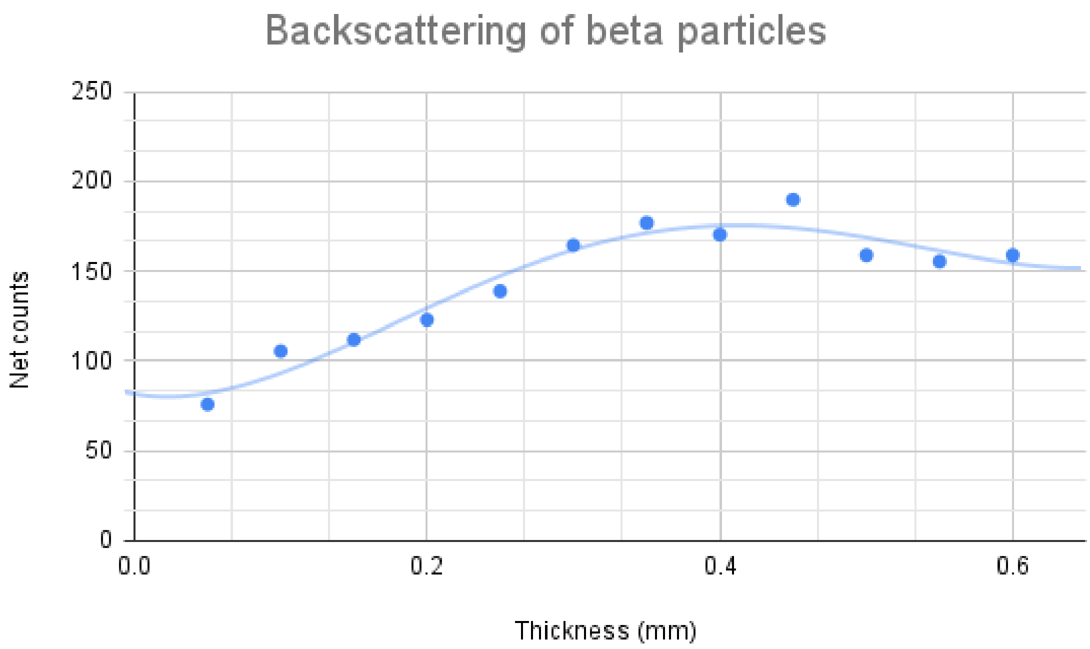

Figure 13: Net counts v/s Thickness using aluminium scatterrer for Sr-90

It is evident from the above graph that the number of beta particles getting backscattered initially increases with increasing thickness but when we keep on increasing the thickness further, the number counts starts saturating primarily because the beta particles which are backscattering much deeper into the thick sheet don't reach the detector and get absorbed midway.

5.5 Conclusion

Based on the experimental findings, it can be deduced that the counts attributed to backscattering rise until a specific thickness of the scattering material is reached, and then they remain relatively stable beyond that thickness. The thickness of the scatterer at which the counts peak is referred to as the Saturation thickness.

References

[1] *CMRP Lab Manual (semester 1 and 3)*

[2] https://en.wikipedia.org/wiki/Inverse-square_law

[3] *Radiation detection and measurement by G.F. Knoll*