G.M. 2: Application of GM Counter(Range of Beta Particles, Attenuation of Bremsstrahlung, Back Scattering)

Aritra Mukhopadhyay
National Institute of Science Education and Research
Bhubaneswar, Odisha 751005, India
3rd year, Integrated M.Sc. Physics
Roll No.: 2011030
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Our study focused on the interaction of Tl-304 and Sr-90 sources with different absorber materials. We estimated the range of beta particles for these sources in aluminium absorbers and calculated the endpoint energy for Sr-90 with a 3.6% error margin. We also observed backscattering effects with the aluminium absorber and studied the Bremsstrahlung phenomenon for three different absorbers. Our findings revealed that metal absorbers, such as aluminium, absorb more energy in Bremsstrahlung compared to plastic. The results of our study have important implications in fields such as nuclear medicine and radiation therapy, enabling better shielding materials to be developed and improved safety measures to be implemented to protect workers and the environment from radiation exposure.

- Learn to use a GM counter to conduct absorption studies on β rays and determine the endpoint energy of β rays emitted from the source.
- Investigate the backscattering of Beta particle.
- Production and attenuation of Bremsstrahlung.

I. THEORY

Beta radiation refers to the stream of beta particles (β) emitted from atomic nuclei during the process of beta decay, which is a form of radioactive decay. Beta decay is commonly observed in unstable nuclei that contain an excess of neutrons compared to protons. The beta particles are typically high-energy electrons (β^-) or positrons (β^+) that are ejected from the nucleus. These particles have a much smaller mass than a proton, making up only one-half of one-thousandth of its mass. Despite their small mass, they can achieve high speeds close to the speed of light due to their high energy.

Because of their light mass, beta particles quickly lose energy as they interact with matter. As a result, they have limited ranges in materials, typically only a few millimeters. However, their range in air can be tens of centimeters, depending on their energy. The process of beta decay and the resulting beta radiation have important applications in various fields, including nuclear physics and medical imaging. The ability of beta particles to penetrate materials to a limited depth makes them useful in measuring material thickness and in detecting material defects. In medicine, beta-emitting radioactive isotopes are used for cancer treatment and imaging.

A. Range of β particle

The range of β particle is given by

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

where E_o is the endpoint energy of the beta rays in MeV. 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

$$\frac{t_{1\frac{1}{2}}}{t_{2\frac{1}{2}}} = \frac{\text{Range of beta rays from first source}}{\text{Range of beta rays from second source}} \tag{2}$$

$$\frac{t_{1\frac{1}{2}}}{t_{2\frac{1}{2}}} = \frac{R_1}{R_2} \tag{3}$$

B. Back scattering

When a beta particle, either an electron or a positron, enters a material, it undergoes a series of interactions with the atoms in the material. The attractive electrostatic force between the positively charged nucleus of the atoms and the negatively charged beta particle causes the path of the beta particle to be deflected. The degree of deflection depends on the energy of the beta particle, but the overall effect is a scattering of the particles. Typically, this causes the forward direction of the beta particle to change by a few degrees.

In some cases, however, the angle of deflection can be quite large, and the beta particle can be deflected back in the direction from which it came. This phenomenon is known as backscattering, and it occurs when the angle of deflection is greater than 90 degrees. Backscattering is more likely to occur in materials with high atomic number, as the larger number of positively charged nuclei increases the likelihood of a strong electrostatic interaction with the beta particle.

Backscattering of beta particles has important implications for radiation detection and measurement. For example, when using a detector to measure the amount of beta radiation emitted from a sample, backscattering can cause a portion of the radiation to be reflected back into the sample, leading to an overestimation of the true amount of radiation emitted. To mitigate this effect, detectors are often designed with thin windows or other features that minimize backscattering and allow the beta particles to escape from the sample more easily.

In addition to its impact on radiation detection, backscattering of beta particles also plays a role in the interactions between radiation and matter in a variety of contexts, including medical imaging and radiation therapy. Understanding the principles of backscattering is therefore important for a wide range of applications in the fields of nuclear physics, radiation biology, and radiation protection.

C. Bremsstrahlung

Bremsstrahlung is a form of electromagnetic radiation that is similar to x-radiation. It is generated when a charged particle experiences a deceleration due to a series of collisions with atomic particles. When a beta particle moves through matter, it may encounter a nucleus and be deflected by it. This deflection causes a reduction in the beta particle's kinetic energy, resulting in the emission of energy in the form of a photon of bremsstrahlung radiation or "braking radiation." The energy of the emitted bremsstrahlung photon is equal to the difference in energy between the initial and final kinetic energies of the beta particle.

The amount of bremsstrahlung radiation emitted by a beta particle depends on several factors, including the kinetic energy of the beta particle, the atomic number of the absorbing material, and the density of the material. As the beta particle approaches a nucleus and is deflected, the magnitude of the deflection and the associated energy loss depend on the proximity and atomic charge of the nucleus. The closer the beta particle is to the nucleus, the greater the energy loss, and the higher the frequency of the emitted bremsstrahlung photons. In addition, the higher the atomic number of the absorbing material, the greater the number of potential nuclei that the beta particle may interact with, leading to an increased probability of bremsstrahlung radiation emission.

II. OBSERVATION AND CALCULATION

A. Beta particle range

sl no.	background
1	84
2	60
3	65
4	74
5	69
avg	70.4

TABLE I: Background counts for 60s

In Table 1 we have taken 5 counts of background for 60 seconds and average of it is 70.4. So:

$$\text{Background rate} = \frac{70.4}{60}\text{counts/second} = 1.1733cps$$

thickness	count	net count
0	1216	204
0.6	853	783
0.12	706	636
0.18	504	434
0.24	420	350
0.3	311	241
0.36	222	152
0.42	199	129
0.48	168	98
0.54	145	75

TABLE II: β praticle counts for Tl^{204} in aluminium absorber

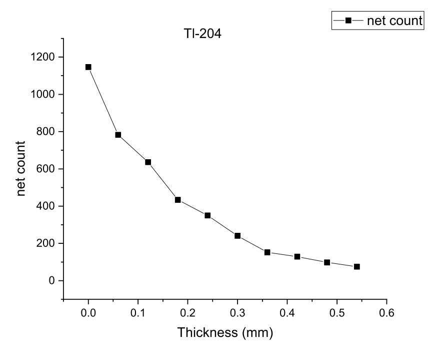

FIG. 1: Absorption of bata particle from Tl^{204}

thickness	count	net count
0	3626	3556
0.6	3418	3348
0.12	2856	2786
0.18	2574	2504
0.24	2291	2221
0.3	2136	2066
0.36	1954	1884
0.42	1836	1766
0.48	1793	1723
0.54	1660	1590

TABLE III: β particle counts for Sr^{90} in aluminium absorber

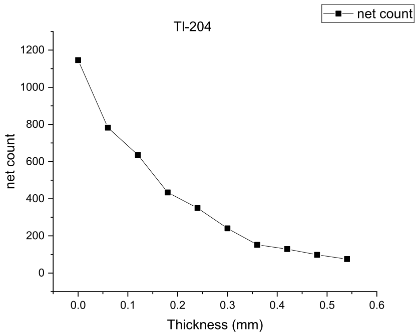

FIG. 2: Absorption of bata particle from Sr^{90}

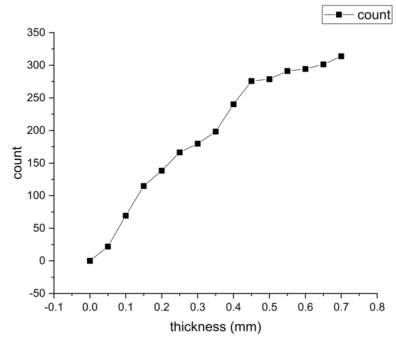

FIG. 3: Backscattering of beta particle from Aluminium

We have endpoint energy of $Tl^{204} = 0.764 MeV$
Range of $Tl^{204} = R_1 = (0.52E_O - 0.09)G/CM^2 = 0.30728 g/cm^2$

- Thickness od Al absorber to reduce the count rate to Tl^{204} by half, $T_{1\frac{1}{2}} = 2.71 g/cm^3 \times 0.15 mm = 0.04065 g/cm^2$
- Thickness od Al absorber to reduce the count rate to Sr^{90} by half, $T_{1\frac{1}{2}} = 2.71 g/cm^3 \times 0.42 mm = 0.11382 g/cm^2$

from equation(3):

$$\frac{t_{1\frac{1}{2}}}{t_{2\frac{1}{2}}} = \frac{R_1}{R_2}$$

$$R_2 = 0.86038 g/cm^2$$

$$E_{sr} = \frac{R_2 + 0.09}{0.52} = 1.827 MeV$$

B. Backscattering

thickness	count1	count2	avg	net count
0.00	236.5	241	238.75	0
0.05	271.5	250	260.75	22
0.10	314	302	308	69.25
0.15	350	357	353.5	114.75
0.20	379	375	377	138.25
0.25	402.5	408	405.25	166.5
0.30	417	420	418.5	179.75
0.35	444	430	437	198.25
0.40	488	470	479	240.25
0.45	524	505	514.5	275.75
0.50	520	515	517.5	278.75
0.55	528	532	530	291.25
0.60	530	536	533	294.25
0.65	538	542	540	301.25
0.70	550	555	552.5	313.75

TABLE IV: Back scattering data

C. Bremsstrahlung

for Al and perspex			
Sl. No.	**Absorber**	**Count**	**Corrected Count**
1	No Absorber	5880	5810
2	Al Facing	603	533
3	Perspex Facing	521	451

for Al and copper			
Sl. No.	**Absorber**	**Count**	**Corrected Count**
1	No Absorber	5880	5810
2	Al Facing	450	380
3	Copper Facing	501	431

for Copper and Perspex			
Sl. No.	**Absorber**	**Count**	**Corrected Count**
1	No Absorber	5880	5810
2	Perspex Facing	448	378
3	Copper Facing	532	462

TABLE V: Bremsstrahlung data

III. ERROR

The calculated error in the endpoint energy of Sr^{90} is 0.036, which is obtained using the formula:

$$\frac{\delta E}{E} = \frac{\delta R}{R} = \sqrt{(\frac{\delta t_1}{t_1}^2) + (\frac{\delta t_2}{t_2})^2}$$

The thickness of the aluminum sheet is insignificant in causing the error in the endpoint energy calculation, and other sources of error such as voltage fluctuations, non-uniform sheet thickness, or the presence of other radioactive sources nearby may have contributed to random errors. In summary, the measured endpoint energy of Sr^{90} is lower than the expected value of $2.276; MeV$, and the error in the measurement is relatively small.

IV. CONCLUSION

The experimental results for the endpoint energies and ranges of Tl^{204} and Sr^{90} were consistent with the theoretical values, although there was a minor difference. The count rate versus thickness graph obtained for the samples followed an exponential decay pattern, allowing us to calculate the half-thickness value.

We also obtained the expected graph for backscattering, with an initial increase in count rate that eventually reaches saturation.

By studying the attenuation of Bremsstrahlung radiation by Cu, Al, and Perspex, we found that more attenuation occurs when Perspex is facing the source. Conversely, we observed higher Bremsstrahlung counts when metals are facing the source. Among the metals, Cu gave more counts than Al, in line with the theory that the amount of Bremsstrahlung increases with the atomic number of the absorbing material.

To determine the half-life of the Cs/Ba^{137m} isotope generator, we recorded a 5-minute video of the GM counter and measured the counts every 10 seconds. Using the first data point as N_0, we obtained a graph of log(counts) versus time that followed a straight line with a negative slope, consistent with the theory.

There are various factors that might have contributed to the minor differences in values obtained and shapes of graphs plotted during the experiment. Some possible sources of errors are:

- The background radiation detected by the GM counter, which may lead to an overestimation of the sample's activity.
- The absorption of radiation in the air between the sample and the GM counter.
- The beta particles from the sample might have been absorbed by the GM tube's window.
- The "dead time" of the GM counter, which is the time during which it cannot detect another event, might have led to a reduction in the count rate and an overestimation of the sample's activity.
- Electronic noise produced by the components of the GM counter might have led to an increase in the count rate and an overestimation of the sample's activity.
- Fluctuations in the GM counter's operating voltage might have led to changes in the count rate and an overestimation or underestimation of the sample's activity.

[1] SPS, Lab manual, Website (2022), `https://www.niser.ac.in/sps/sites/default/files/basic_page/p341_2023/GM-2.pdf`.