Experiments with GM Counter

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1. Verify the inverse square law
2. Determination of beta particle range and maximum energy
3. Study the back-scattering of beta particles
4. Production and attenuation of Bremsstrahlung

2 | Apparatus

- G.M Counting System (GC602A)
- G.M detector stands for G.M detector. Sliding bench for G.M Experiments
- Radioactive source kit
- Aluminum, copper & lead Absorber Set

Principle of Operation of GM counter

The GM counter operates based on the principle of gas ionization and avalanche multiplication. When an ionizing particle enters the detector, it ionizes the gas molecules, producing primary ion pairs (electrons and positive ions).
Under a strong electric field:

- The liberated electrons accelerate toward the anode and cause secondary ionizations, forming *Townsend avalanches.*
- At sufficiently high voltage, these avalanches propagate throughout the gas due to ultraviolet photons emitted during de-excitation, leading to a self-sustained discharge.

This **Geiger discharge** produces a large output pulse that is independent of the initial ionization energy. Thus, the GM counter is a *counting device only* and does not provide energy information about the radiation.

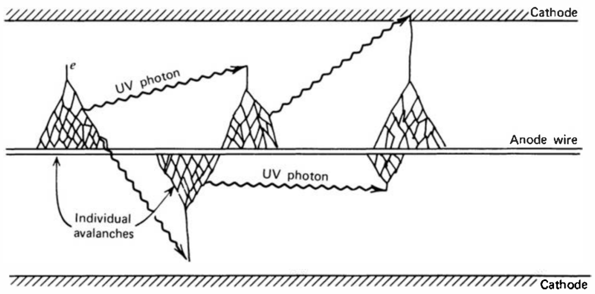


Figure 2.1: The mechanism by which additional avalanches are triggered in a Geiger discharge. [2]

Construction

A typical GM tube consists of:

- **Cathode:** A cylindrical metal or glass tube coated with a conducting layer.
- **Anode:** A fine central wire (approximately 0.1 mm in diameter).
- **Fill Gas:** An inert gas such as argon or neon at low pressure (0.1–1 atm).
- **Quenching Gas:** A small amount (5–10%) of an organic vapor or halogen gas to stop continuous discharge.

- **End Window (optional):** Thin mica or plastic window for detecting low-energy alpha and beta particles.

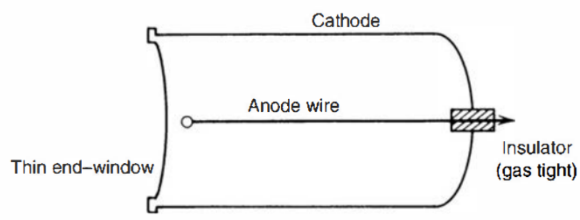


Figure 2.2: A cross section of a typical end window Geiger tube [2]

Quenching Mechanism

After the initiation of a Geiger discharge, it is essential to stop it quickly to restore the tube for subsequent detections. Two quenching methods are employed:

(a) External Quenching

A large series resistor (typically 10^8 Ω) limits the current and drops the voltage below the sustaining level immediately after each pulse. This method is simple but limits the counting rate.

(b) Internal Quenching

The use of a quenching gas prevents continuous discharge.

- **Organic Quench Gases** (e.g., alcohol vapors) absorb energy through molecular dissociation, but they degrade over time.
- **Halogen Quench Gases** (e.g., chlorine or bromine) recombine after dissociation, giving long life and stable operation.

Dead Time and Recovery

After each discharge, a cloud of positive ions around the anode temporarily reduces the electric field strength, making the tube insensitive to further events. This period is known as the **dead time** (typically 50–100μs. The **recovery time** follows, during which the detector gradually regains full sensitivity. At high counting rates, dead-time corrections become necessary.

The Geiger Plateau

When the applied voltage is gradually increased:

1. The counting rate initially increases rapidly.
2. It then reaches a nearly constant region called the **Geiger plateau**.

The plateau should be as flat as possible (slope $< 3\%$ per 100 V) for stable operation. The **operating voltage** is chosen approximately at the midpoint of this plateau.

GC602A G.M. Counting System Summary

Overview

The GC602A is a microcontroller-based integral counting system designed by Nucleonix Systems for beta radiation detection and sample counting. It integrates high-voltage generation, pulse shaping, data acquisition, and display functionalities.

Key Features

- Microcontroller: AT89S52, 8-bit architecture
- Display: 20×2 alphanumeric LCD for counts, elapsed time, and EHT
- EHT Range: 0–1500V @ 1mA (limited to 800V for safety)
- Count Capacity: Up to 999999 events
- Preset Time: 0–9999 seconds
- Data Storage: Up to 6665 readings in EEPROM
- Interfaces: USB serial port and parallel printer port
- Programmable Labels: BG (Background), ST (Standard), SP (Sample)

System Architecture

- **High Voltage (HV) PCB**: DC–DC converter with oscillator, RF transformer, voltage doubler, filter, and regulator
- **Low Voltage (LV) PCB**: Supplies +5V and +12V for system operation
- **Pulse Shaper Circuit**: Converts GM tube's negative tail pulse to TTL-compatible signal
- **Microcontroller Functions**:
  - Reads counter data every second
  - Displays real-time values on LCD
  - Stores and recalls data from EEPROM
  - Handles keypad interrupts for acquisition control

Operation Notes

- Ensure GM tube is properly connected before powering on
- Adjust EHT using front-panel knob; monitor via LCD
- Use intelligent keypad for programming acquisition modes, preset time, and data storage
- Acquisition modes include preset time, CPS, and CPM
- Data can be stored with or without EHT values

Applications

- Beta sample counting in health physics labs
- Radiation experiments in academic institutions
- Monitoring in nuclear facilities: reactors, reprocessing plants, enrichment units

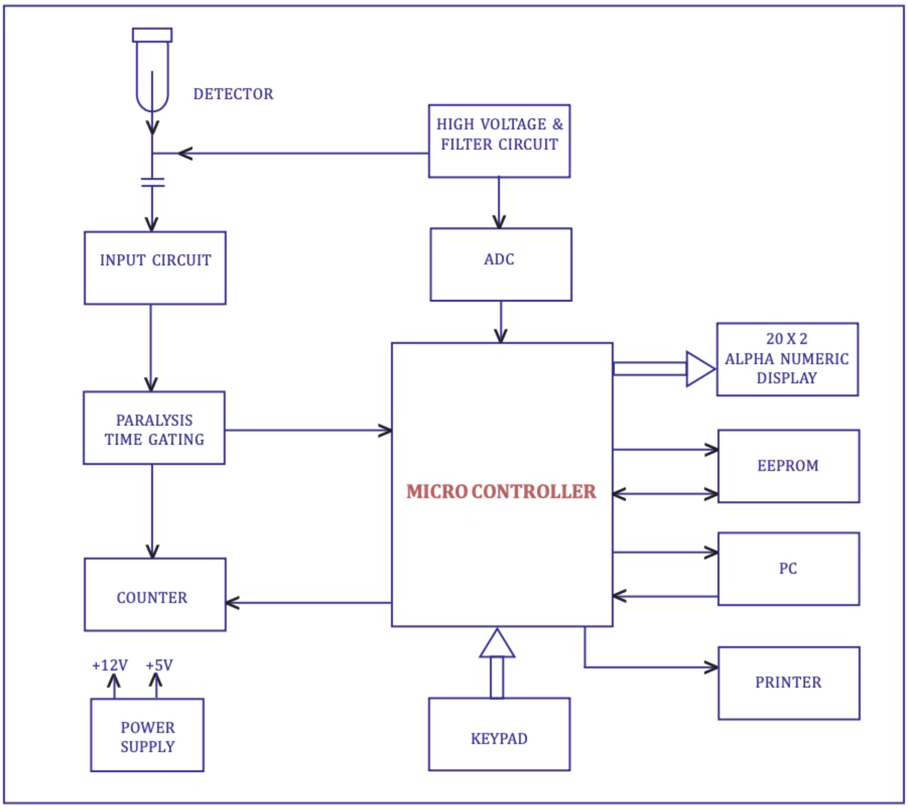


Figure 2.3: Block Diagram of GM counting system [4]

3 | Verification of inverse square law

3.1 | Theory

The Inverse Square Law states that the intensity of radiation from a point source decreases proportionally to the square of the distance from the source. Mathematically:

$$I \propto \frac{1}{d^2}$$

Where:

- I is the intensity (or count rate) of gamma radiation
- d is the distance between the source and the detector

This relationship arises because gamma rays propagate isotopically in three-dimensional space. As the distance increases, the same quantity of radiation spreads over a larger spherical surface area.

To verify the inverse square law experimentally:

- Measure the net count rate R at various distances d from the source.
- Subtract background radiation to isolate the contribution from the gamma source.
- Plot R vs d, and alternatively R vs $\frac{1}{d^2}$.

If the law holds, the product Rd^2 should remain approximately constant across measurements. Additionally, a plot of R vs $\frac{1}{d^2}$ should yield a straight line through the origin, confirming the theoretical model.
To further validate the power-law relationship, a log-log plot of log(R) vs log(d) is constructed. The slope of this line should be approximately -2, consistent with the inverse square dependence:

$$\log(R) = \log(k) - 2\log(d)$$

Where k is a proportionality constant.

Assumptions and Limitations

- The source is treated as a point emitter.
- The GM tube has uniform detection efficiency across distances.
- Air attenuation and scattering are negligible over the measured range.
- Background radiation is stable and accurately subtracted.

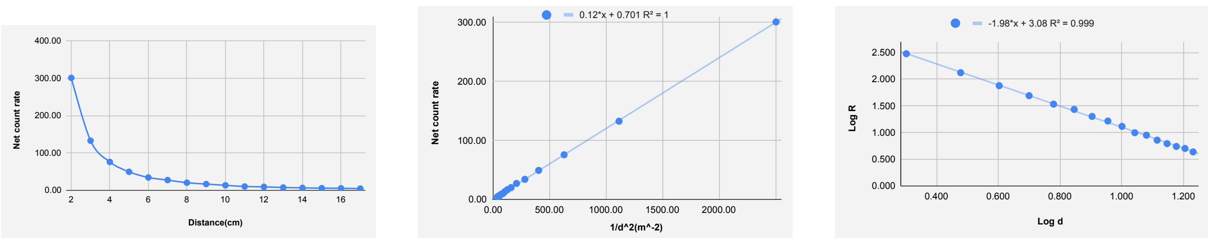
3.2 | Observation

We have used Cs-137 as a gamma source. The average background in 60 sec is = 58. Net Count = Total count - avr bkg count.

Table 3.1: Variation of count rate with distance

Distance (cm)	Counts in 60 s	Net Count Rate	$1/d^2$ (m^{-2})	Log d	Log R	R.d^2
2	18121	301.05	2500.00	0.301	2.479	1204.200
3	8020	132.70	1111.11	0.477	2.123	1194.300
4	4602	75.73	625.00	0.602	1.879	1211.733
5	3013	49.25	400.00	0.699	1.692	1231.250
6	2105	34.12	277.78	0.778	1.533	1228.200
7	1687	27.15	204.08	0.845	1.434	1330.350
8	1262	20.07	156.25	0.903	1.302	1284.267
9	1045	16.45	123.46	0.954	1.216	1332.450
10	842	13.07	100.00	1.000	1.116	1306.667
11	653	9.92	82.64	1.041	0.996	1199.917
12	593	8.92	69.44	1.079	0.950	1284.000
13	490	7.20	59.17	1.114	0.857	1216.800
14	430	6.20	51.02	1.146	0.792	1215.200
15	387	5.48	44.44	1.176	0.739	1233.750
16	360	5.03	39.06	1.204	0.702	1288.533
17	318	4.33	34.60	1.230	0.637	1252.333

Figure 3.1: Verification of Inverse Square Law



3.3 | Applications

In this experiment, a Geiger-Müller (GM) tube is used to detect gamma radiation emitted from a radioactive source. The GM tube operates in the Geiger region, where each ionizing event produces a uniform output pulse, allowing for reliable count rate measurements.

Gamma rays, being highly penetrating electromagnetic radiation, are minimally attenuated by air over short distances. Thus, the observed variation in count rate with distance is predominantly due to geometric spreading, validating the inverse square law.

4 | Determination of beta particle range and maximum energy

4.1 | Theory

Beta particles are high-energy, high-speed electrons (β^-) or positrons (β^+) emitted during the radioactive decay of certain isotopes. Unlike alpha particles, beta particles exhibit a continuous energy spectrum ranging from zero up to a characteristic maximum energy E_0, which is unique to each radionuclide.
As beta particles traverse matter, they lose energy primarily through:

- Ionization and excitation of atoms in the absorber
- Radiative losses (Bremsstrahlung), especially at higher energies
- Elastic scattering, causing deflections and path length variations

Due to these interactions, beta particles have a finite range in a given material, defined as the maximum thickness they can penetrate before being completely absorbed. The range R of beta particles in an absorber (e.g., aluminum) is the thickness at which the particle flux effectively drops to zero. However, experimentally, we determine the half-thickness $t_{1/2}$ the absorber thickness that reduces the net count rate to half its initial value.
This method provides a practical way to estimate the maximum energy E_0 of beta particles using empirical relationships. For beta particles in aluminum, the range R in g/cm^2 is related to the maximum energy E_0(in MeV) by the empirical formula:

$$R = 0.543E_0 - 0.133$$

Where:

- R is the extrapolated range of beta particles
- E_0 is the endpoint energy of the beta spectrum

By measuring $t_{1/2}$ for different sources and comparing their ratios, the range and, hence, the maximum energy of an unknown beta emitter can be deduced.

Comparative Method

For two beta sources (e.g., Tl-204 and Sr-90), the ratio of their half-thicknesses relates directly to the ratio of their ranges:

$$\frac{(t_{1/2})_1}{(t_{1/2})_2} = \frac{R_1}{R_2}$$

Using this, the unknown range R_2 and the corresponding energy E_0 can be determined.

Assumptions

- The beta source emits isotropically.
- The absorber is homogeneous and of known density.
- The GM tube has consistent detection efficiency across measurements.

4.2 Observation

Counting Time: 120 s
Absorber: Aluminium
Background Count: 123
Source: Tl-204

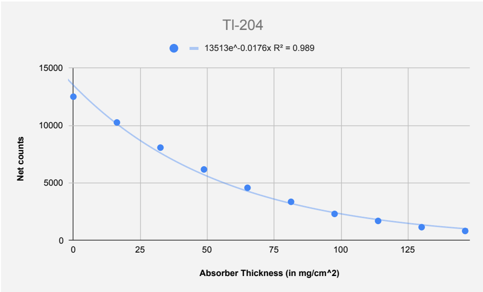
Absorber Thickness (mm)	Absorber Thickness (mg/cm^2)	Counts	Net Counts (Counts - BG)
0	0	12635	12512
0.06	16.26	10392	10269
0.12	32.52	8205	8082
0.18	48.78	6305	6182
0.24	65.04	4709	4586
0.30	81.30	3488	3365
0.36	97.56	2435	2312
0.42	113.82	1824	1701
0.48	130.08	1279	1156
0.54	146.34	950	827

Table 4.1: Absorption of beta particles in Aluminium (Source: Tl-204)

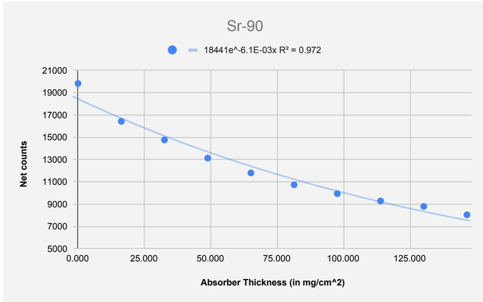
Counting Time: 120 s
Absorber: Aluminium
Background Count: 123
Source: Sr-90

Table 4.2: Absorption of beta particles in Aluminium (Source: Sr-90)

Absorber Thickness (mm)	Absorber Thickness (mg/cm^2)	Counts	Net Counts (Counts - BG)
0	0.000	19949	19826
0.06	16.260	16549	16426
0.12	32.520	14885	14762
0.18	48.780	13255	13132
0.24	65.040	11923	11800
0.30	81.300	10855	10732
0.36	97.560	10059	9936
0.42	113.820	9400	9277
0.48	130.080	8916	8793
0.54	146.340	8166	8043



(a) The half thickness $t_1 = \frac{\ln 2}{0.0176} = 39.38$ mg/cm^2



(b) The half thickness $t_2 = \frac{\ln 2}{0.0061} = 113.63$ mg/cm^2

Figure 4.1

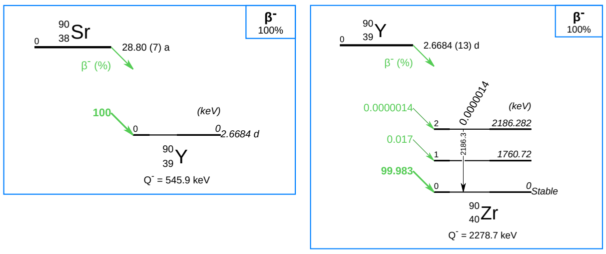


Figure 4.2: Sr-90 being purely beta radiation source of 0.546 MeV and half-life of about 29 years decays into Y-90 of half-life 64 hours. This decay results in a stable substance called Zirconium (Zr-90) [3]

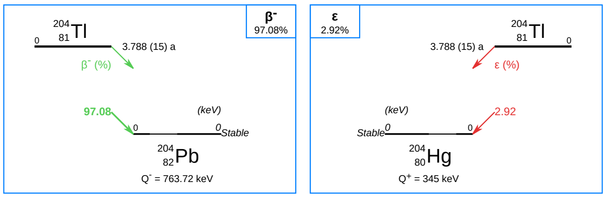


Figure 4.3: Tl-204, with a half life of 3.78 years, decays into Pb-204 and Hg-204 by β^- decay and electron capture respectively. [3]

4.3 | Calculation

The range R of beta particles in a material (in g/cm^2) is empirically related to their endpoint energy E_m (in MeV) by:

$$R = 0.543E_m - 0.133 \tag{4.1}$$

To compare two beta sources, the ratio of absorber thicknesses required to reduce their count rates by half is proportional to the ratio of their ranges:

$$\frac{t_2}{t_1} = \frac{R_2}{R_1} \tag{4.2}$$

Where:

- t_1 and t_2 are the **half-thicknesses** for Tl-204 and Sr-90 respectively
- R_1 and R_2 are the corresponding ranges

For Tl-204:

$$\begin{aligned} E_m &= 0.764 \text{ MeV} \\ R_1 &= 0.543 \times 0.764 - 0.133 \\ &= 0.282 \text{ g/cm}^2 \end{aligned}$$

Given:

- $t_1 = 39.38 \text{ mg/cm}^2$
- $t_2 = 113.63 \text{ mg/cm}^2$

Convert to g/cm^2:

$$\begin{aligned} t_1 &= 0.03938 \text{ g/cm}^2 \\ t_2 &= 0.11363 \text{ g/cm}^2 \end{aligned}$$

Calculate R_2:

$$\begin{aligned} R_2 &= \frac{t_2}{t_1} \times R_1 \\ &= \frac{0.11363}{0.03938} \times 0.282 \\ &= 0.813 \text{ g/cm}^2 \end{aligned}$$

Determine E_m for Sr-90:

$$\begin{aligned} R &= 0.543E_m - 0.133 \\ 0.813 &= 0.543E_m - 0.133 \\ E_m &= \frac{0.813 + 0.133}{0.543} \\ &= 1.74 \text{ MeV} \end{aligned}$$

Result

The endpoint energy of beta particles from Sr-90 is approximately **1.74 MeV**.

4.4 | Applications

- **Radiation Shielding Design**: Understanding beta particle range helps in selecting appropriate absorber materials (e.g., aluminum, plastic) for shielding in medical, industrial, and nuclear environments.
- **Dosimetry and Safety Assessment**: Estimating maximum beta energy aids in calculating dose rates and penetration depths, critical for personnel safety and regulatory compliance in radiation labs.
- **Medical Physics Applications**: Beta-emitting isotopes (e.g., Sr-90, P-32) are used in therapeutic procedures. Knowing their energy and range ensures precise targeting and minimal collateral exposure.

5 | Study the back-scattering of beta particles

5.1 | Theory

Nature of Beta Backscattering

Backscattering refers to the phenomenon where beta particles, upon striking a dense material, are deflected back toward the direction of their origin due to elastic and inelastic collisions with atomic nuclei and

electrons. This effect is prominent when beta particles interact with high atomic number (Z) materials such as aluminum, lead, or copper.
Beta particles are charged and relatively light, making them highly susceptible to scattering. When a beta particle enters a material, it undergoes:

- **Elastic scattering** with nuclei, altering its trajectory without significant energy loss.
- **Inelastic collisions** with electrons, causing ionization and excitation.
- **Backscattering**, where cumulative interactions redirect the particle outward from the material surface.

Experimental Principle

In this experiment, a lead shield is placed between the beta source and the GM detector to block direct radiation. A scatterer (e.g., aluminum foil) is positioned such that beta particles from the source strike it and are backscattered toward the detector.
The GM tube records only the backscattered beta particles. By varying the scatterer thickness, the dependence of backscattering intensity on material thickness is studied.

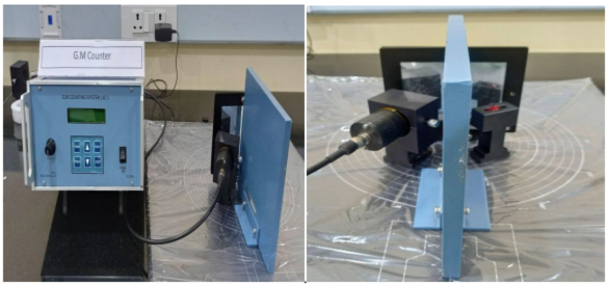


Figure 5.1: Experimental setup [1]

Observational Trends

- **Initial Increase:** As scatterer thickness increases, more beta particles interact, increasing backscattered counts.
- **Saturation:** Beyond a certain thickness, additional layers do not significantly increase backscattering.
- **Material Dependence:** Higher-Z materials produce more backscattering due to stronger Coulomb interactions.

Quantitative Considerations

The backscattered count rate R_b depends on:

- Incident beta energy E
- Atomic number Z and density ρ of the scatterer
- Scatterer thickness t

Assumptions

- The GM detector is shielded from direct beta radiation.
- Background radiation is stable and subtracted accurately.
- The scatterer is homogeneous and uniformly placed.
- The beta source emits isotropically.

5.2 | Observation

Thickness (mm)	Count 1	Count 2	Avr Count	Net count
0	228	228	228	0
0.05	246	241	243.5	15.5
0.1	258	260	259	31
0.15	267	263	265	37
0.2	280	281	280.5	52.5
0.25	293	297	295	67
0.3	305	306	305.5	77.5
0.35	315	318	316.5	88.5
0.4	321	323	322	94
0.45	335	332	333.5	105.5
0.5	341	345	343	115

Table 5.1: Experimental Data: Counts vs Thickness

It can be seen that beyond a certain thickness, additional layers do not significantly increase backscattering.

5.3 | Applications

Understanding backscattering helps in designing protective shields and barriers in hospitals and nuclear medicine departments, where β emitters are used. Backscattered electrons can increase surface dose if not properly accounted for.

6 | Production and attenuation of Bremsstrahlung

6.1 | Theory

Introduction

Bremsstrahlung, derived from the German word for "braking radiation," refers to the electromagnetic radiation emitted when a charged particle—typically a high-energy beta particle—is decelerated or deflected by the electric field of atomic nuclei. This deceleration results in the emission of photons, predominantly in the X-ray or gamma-ray region.
In nuclear instrumentation, Bremsstrahlung is a secondary radiation phenomenon observed when beta particles interact with dense materials. Its intensity and spectral distribution depend on:

- The energy of the incident beta particles
- The atomic number (Z) of the absorber material
- The geometry and thickness of the absorber

Mechanism of Production

When beta particles (e.g., from a ^{90}Sr source) pass through a medium, they undergo Coulomb interactions with nuclei. The probability of Bremsstrahlung emission increases with:

- Higher beta particle energy
- Higher Z of the absorber (e.g., Cu > Al > Perspex)

The emitted Bremsstrahlung photons form a continuous energy spectrum and can penetrate materials more deeply than the original beta particles.

Attenuation of Bremsstrahlung

Attenuation refers to the reduction in intensity of Bremsstrahlung photons as they pass through matter. It follows an exponential decay law:

$$I = I_0 e^{-\mu x} \tag{6.1}$$

Where:

- I is the transmitted intensity
- I_0 is the initial intensity
- μ is the linear attenuation coefficient (dependent on Z and photon energy)
- x is the thickness of the absorber

In this experiment, attenuation is studied by reversing absorber combinations (e.g., Al–Perspex vs. Perspex–Al) and measuring count rates using a GM detector. The difference in counts reflects the directional dependence of Bremsstrahlung production and attenuation.

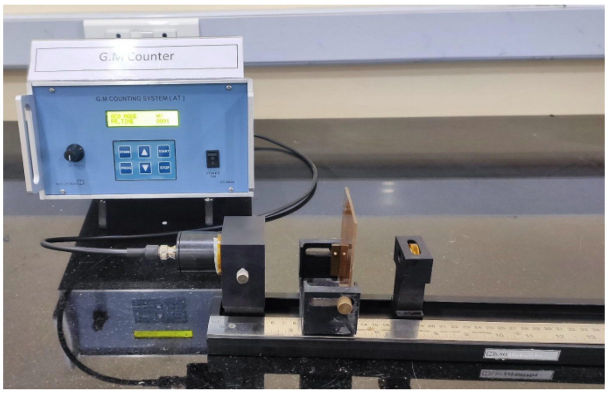


Figure 6.1: Experiment setup for production and attenuation of Bremsstrahlung

Experimental Rationale

By comparing count rates for different absorber orientations:

- When high-Z material faces the source, more Bremsstrahlung is produced and attenuated before reaching the detector.
- When low-Z material faces the source, less Bremsstrahlung is produced, and more photons reach the detector.

This directional asymmetry confirms that Bremsstrahlung is produced predominantly in high-Z materials and attenuated according to their photon absorption properties.

6.2 Observation

Source = Sr-90
Preset time = 300

Distance between source and detector = 6cm
Avr. BG Count= 306

Absorber position	Count	Net count
Without Absorber	8180	7874
Perspex facing source	525	219
Al facing source	561	255

Table 6.1: Al(0.7 mm), Perspex(1.8 mm)

Absorber position	Count	Net count
Without Absorber	8180	7874
Cu facing source	499	193
Perspex facing source	424	118

Table 6.2: Perspex(1.8 mm), Cu(0.3 mm)

Absorber position	Count	Net count
Without Absorber	8180	7874
Al facing source	415	109
Cu facing source	466	160

Table 6.3: Al(0.7 mm), Cu(0.3 mm)

6.3 | Applications

- Helps design effective radiation shielding using high-Z materials like Cu and Al.
- Aids in minimizing secondary radiation exposure in medical and nuclear settings.
- Supports safe handling of beta sources by understanding Bremsstrahlung production.
- Useful in calibrating GM counters for photon detection and attenuation studies.
- Demonstrates directional dependence of radiation for optimized shielding layouts.

7 | Conclusion

The series of experiments conducted using the GC602A G.M. Counting System successfully demonstrated key principles of radiation detection and interaction:

- **Inverse Square Law:** The count rate of gamma radiation was shown to decrease proportionally to the square of the distance from the source, validating the geometric dispersion of radiation in space.
- **Beta Particle Range and Energy:** By analyzing absorption curves for Tl-204 and Sr-90, the half-thickness method enabled estimation of maximum beta energies. The endpoint energy for Sr-90 was calculated to be approximately 1.74 MeV, consistent with literature values.
- **Backscattering of Beta Particles:** The experiment confirmed that beta backscattering increases with absorber thickness and atomic number, with saturation observed beyond a certain material depth.
- **Bremsstrahlung Production and Attenuation:** High-Z materials like copper and aluminum were shown to produce significant Bremsstrahlung when exposed to beta radiation. The directional dependence of absorber placement affected photon attenuation, reinforcing the importance of shielding geometry.

Overall, the experiments provided hands-on validation of theoretical models in radiation physics and highlighted the operational capabilities of GM counters in medical and nuclear applications.

8 | References

[1] *Lab Report, CMRP, NISER.*

[2] Glenn F. Knoll. *Radiation Detection and Measurement.* John Wiley & Sons, Hoboken, NJ, USA, 4 edition, 2010.

[3] Laboratoire National Henri Becquerel. Nucléide-lara: Decay data for alpha and gamma spectrometry. http://www.lnhb.fr/Laraweb/, 2022. Accessed: 2025-10-08.

[4] Nucleonix Systems Pvt. Ltd. *GC602A Instruction Manual: G.M Counting System.* Nucleonix Systems Pvt. Ltd., Plot No. 162 A & B, Phase II, I.D.A. Cherlapally, Hyderabad - 500 051, India, 2015. Version VER_20170626.