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Study of attenuation profile of variable thickness metallic absorber plates with G-M Counter

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Abstract

The paper investigates the behavior of gamma radiation as it interacts with different materials through a transmission experiment using a Geiger Muller counter. In this experiment, energetic gamma rays are directed towards a detector after passing through metallic absorber plates of varying thickness. The primary objective is to analyze how the intensity of radiation changes as it passes through different thicknesses of the absorber plates. During the experiment, radiation counts per 30 seconds are meticulously recorded and plotted. These plots are crucial as they allow researchers to determine the half value layer (HVL) of the materials. The HVL represents the thickness of the material required to reduce the intensity of the gamma radiation by half. From the graphical analysis of the radiation counts, researchers are able to calculate two important parameters: the linear attenuation coefficient and the mass attenuation coefficient. These coefficients quantify how effectively a material attenuates or reduces the intensity of gamma radiation. Moreover, the paper explores the relationship between these attenuation coefficients and the density of the materials used as absorbers. Through a comparative study, it is observed that the attenuation coefficients are directly proportional to the density of the absorbing materials. This finding is significant as it underscores the importance of material density in designing effective radiation shielding and monitoring systems.

Overall, the paper contributes valuable insights into radiation detection, shielding, and monitoring applications. By systematically analyzing the attenuation of gamma radiation through different materials, it provides essential data for improving safety protocols in environments where radiation exposure is a concern.

Keywords: Geiger discharge; attenuation coefficient; linear attenuation; mass attenuation; half value length.

1. Introduction

The Geiger Muller (GM) counter is a pivotal tool in radiation research, designed by physicist Hans Geiger and his student Walther Muller in the early 20th century. It serves as a robust, cost-effective detector capable of identifying and measuring various types of ionizing radiation, including gamma and beta particles. This device operates on the principle of gas ionization, where incoming radiation ionizes gas molecules within the counter. A notable feature of the GM counter is its sensitivity to the Geiger discharge or Townsend avalanche, a phenomenon where ionization cascades through the gas medium, amplifying the initial ionization event. This cascade effect enhances the counter's ability to detect even minute quantities of radiation, making it invaluable for tasks such as analyzing radioactive samples. The attenuation refers to the reduction in intensity of gamma radiation as it passes through a material. This phenomenon is crucial in various fields, including medical imaging, environmental monitoring and industrial safety. The attenuation process occurs due to interactions between gamma rays and the atoms of the material they traverse. These interactions can include absorption, where gamma rays are completely absorbed by the material, or scattering, where they change direction without being absorbed. Attenuation can be characterized in two main ways: linear attenuation and mass attenuation. Linear attenuation refers to the reduction in gamma ray intensity per unit thickness of the absorbing material. It is quantified by the linear attenuation coefficient, which measures how effectively a material attenuates gamma rays per unit distance. Mass attenuation considers the reduction in gamma ray intensity per unit mass of the absorbing material. It provides insights into the material's effectiveness in attenuating gamma rays based on its density and atomic composition **[2].**

2. Linear and mass attenuation

When gamma radiation with an intensity $\mathbf{I_0}$ at an instant $\mathbf{t=0}$ is made to pass through an absorber of thickness $\mathbf{T}$, the emerging intensity **I** of the radiation at an instant t is given as-

$$\boldsymbol{I = I_0 e^{-\mu T}}$$

where, $\boldsymbol{\mu}$ is defined as the linear attenuation coefficient.

If the absorber with thickness $\mathbf{T}$ is having a mass m and a density $\boldsymbol{\rho}$ associated with it, then the mass attenuation coefficient $\boldsymbol{\mu_m}$ is given as-

$$\boldsymbol{\mu_m = \frac{\mu}{\rho}}$$

The mass attenuation coefficient $\boldsymbol{\mu_m}$ is defined as a ratio of linear attenuation coefficient and density of the absorbing or scattering material. Also, the mass attenuation coefficient $\boldsymbol{\mu_m}$ can be defined as the ratio of mass *absorptivity* to molar mass **[3].**

3. Experimental module

The experimental setup allows researchers to measure and analyze the exponential attenuation profile of gamma rays. The attenuation observed is a result of multiple interactions between gamma rays and the absorber material, such as the photoelectric effect, Compton scattering, pair production, and other scattering phenomena. Here, a radioactive gamma source is positioned 4 cm away from the end window of a Geiger-Muller (GM) tube. This setup allows for the study of gamma radiation absorption, scattering, and transmission characteristics through different materials. To analyze these properties, metallic absorber plates made of lead and iron are placed between the source and the GM tube. The absorber plates vary in thickness, which affects the amount of gamma radiation that passes through or interacts with the material. The GM tube is used to measure the intensity of gamma radiation that reaches it from the source through the absorber plates. By recording these readings over a preset time of 30 seconds for each thickness of lead and iron plates, researchers can observe how gamma radiation behaves as it passes through these materials. Lead and iron are chosen as absorber materials because they have different atomic numbers and densities, which influence their interaction with gamma radiation. Lead, with its higher atomic number and density compared to iron, typically attenuates (absorbs) gamma radiation more effectively. Through systematic measurement and analysis of the data obtained, researchers can characterize the absorption, scattering, and transmission properties of gamma radiation for lead and iron. This information is crucial for various applications such as radiation shielding, medical imaging, and industrial radiography, where understanding how different materials interact with gamma rays is essential for safety and efficiency.While the lead absorber plates were pre-prepared with varying thicknesses and ready for use, the iron absorber plates were fabricated by cutting them from large iron sheets using a sheet metal cutting machine provided by Sunshine Hydraulic India Private Limited. The use of iron absorber plates in this manner suggests a deliberate choice to investigate or compare the absorption properties of iron with those of lead in relation to the experimental setup involving the radioactive gamma source [4].

The experiment involves placing absorber plates made of lead and iron with variable thicknesses in front of a gamma radiation source. These plates are designed to absorb gamma rays, thereby reducing the intensity of radiation that passes through them. During the experiment, the intensity of gamma radiation transmitted through each plate is measured and recorded over duration of 30 seconds. The purpose of using plates of different thicknesses is to observe how the thickness of the absorber affects the amount of radiation that can penetrate through [Table 1].

Table 1. Measurement of thickness of Iron sheet using vernier caliper

LEAST COUNTS OF VERNIER CALIPER = 0.01 mm			
S.No.	**Main scale readings**	**Vernier scale readings**	**Total readings**
1.	0 mm	5	0.05 mm
2.	0 mm	4	0.04 mm
3.	0 mm	6	0.06 mm

The lead and iron absorber plates with variable thickness are placed in front of the gamma source and the intensity of radiation transmitted through these plates are recorded for a time period of 30 seconds

[Table 2]. Lead and iron are chosen as absorber materials because they are known for their high density, which makes them effective in attenuating gamma radiation. By varying the thickness of these plates, researchers can study the relationship between thickness and radiation absorption, providing valuable data for understanding the interaction of gamma rays with matter.

Table 2. Measurement of thickness of Iron sheet using vernier calliper

No.	**LEAD ABSORBER PLATES**		**IRON ABSORBER PLATES**	
	Thickness of Lead absorber plates (mm)	**Counts in 30 secs (Lead absorber plates)**	**Thickness of Iron absorber plates (mm)**	**Counts in 30 secs (Iron absorber plates)**
1.	0 mm	500	0 mm	350
2.	0.018 mm	270	0.05 mm	175
3.	0.036 mm	160	0.10 mm	100
4.	0.054 mm	120	0.15 mm	75
5.	0.072 mm	100	0.20 mm	60
6.	0.085 mm	90	0.25 mm	55

The results obtained from these measurements contribute to optimizing shielding materials and techniques to enhance safety and efficiency in various applications involving gamma radiation **[5].**

4. Attenuation profile analysis

The graphical analysis of attenuation characteristics set forth the term half value length (HVL) or air kerma rate (AKR). The HVL is defined as the thickness of the absorbing material for which the intensity of radiation incident of the material gets reduced to half of its maximum value. This is also known as air kerma rate (AKR) **[6].**

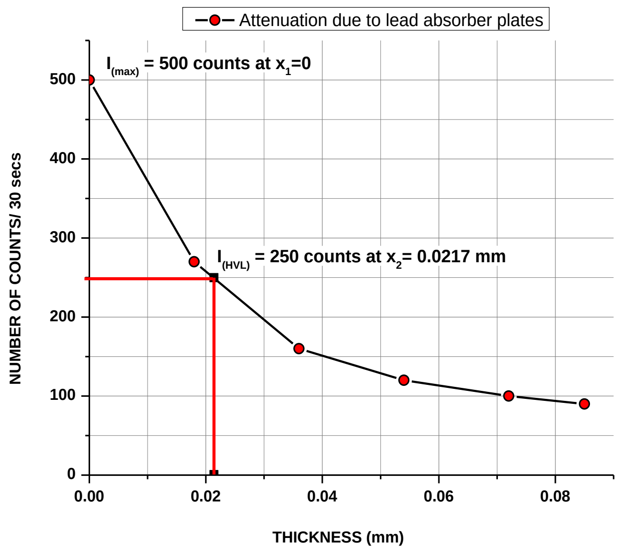

Fig 1. Plot of number of radiation counts per 30 secs with respect to thickness of lead absorber plates

The graph of radiation counts in 30 seconds for each thickness is plotted and studied in order to analyze the attenuation characteristics of gamma radiation with respect to metals. The maximum intensity of gamma radiation gets reduced to its half value for a particular thickness. This value of thickness is known as half value layer (HVL) denoted as $x_{(1/2)}$ or x_2. Here, the attenuation is done in such a way that the radiation gets reduced to half of its maximum value. Besides HVL or AKR, the attenuation behavior can also be studied by studying the exposure rate and quarter value layer (QVL). This means that if I_0 is the maximum at the time of initial incidence then it slowly reduces exponentially with thickness **[7].**

According to mathematical convention,

$$I = I_0 e^{-\mu T}$$

$$I/Io = 0.5$$

for half value layer $x_{(1/2)}$

$$\ln 0.5 = -\mu_L \; x_{1/2}$$

$$-0.693 = -\mu_L \; x_{1/2}$$

$$0.693 = \mu_L \; x_{1/2}$$

$$\mu_L = 0.693/x_{1/2}$$

or, linear attenuation coefficient,

$$\mu_L = 0.693 / \text{half value layer} \quad [8]$$

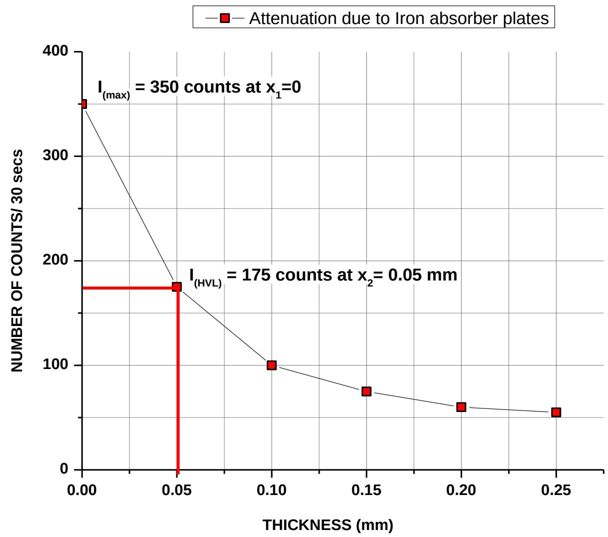

Fig 2. Plot of number of radiation counts per 30 secs with respect to thickness of Iron absorber plates

The number of radiation counts/ 30 secs is plotted against the variable thickness of lead and iron absorber plates [Fig 1, 2]. From the exponential curves, HVL is obtained in order to compute the attenuation coefficients. Using the value of density (ρ) and Half value layer (HVL) $x_{1/2}$, linear attenuation coefficient (μ_L) and Mass attenuation coefficient (μ_M) are calculated [Table 3].

Table 3. Linear and mass attenuation coefficient estimation

S.No	Material	Density (ρ)	Half value layer (HVL) $x_{1/2}$	Linear attenuation coefficient (μ_L)	Mass attenuation coefficient (μ_M)
1.	Lead absorber plates	11.34 gm/cm^3	0.0217 mm	319.35 / cm	28.16 cm^2/gm
2.	Iron absorber plates	7.8 gm/cm^3	0.05 mm	138.6 / cm	17.76 cm^2/gm

The information presented in Table 3 clearly indicates a significant trend: denser metals exhibit higher values of both linear and mass attenuation coefficients. This observation suggests a direct proportional relationship between the density of materials and their respective attenuation coefficients. In other words, as the density of a material increases, so do its linear and mass attenuation coefficients. This relationship is crucial in understanding how materials interact with radiation, as denser materials are more effective at attenuating or reducing the intensity of radiation passing through them. Therefore, the data from Table 3 underscores the importance of density as a fundamental factor influencing the attenuation properties of materials in various applications, such as medical imaging, industrial radiography, and radiation shielding **[9].**

5. Conclusion

In conclusion, the advancements in radiation detection technology, exemplified by devices like the Geiger Muller counter, have significantly enhanced our ability to study and manage ionizing radiation. Understanding the attenuation characteristics of gamma rays through different materials is crucial for optimizing radiation shielding, medical treatments, and industrial safety protocols. The study of linear and mass attenuation coefficients provides essential data for designing effective radiation protection measures and improving our understanding of radiation-matter interactions. Key findings of the research include observations related to linear and mass attenuation of gamma radiation, which were found to depend significantly on the density of the absorber plates. Materials with higher densities, such as lead, exhibited higher attenuation (reduction in radiation intensity) compared to lower density materials like iron. This relationship is explained by the increased likelihood of interactions between gamma radiation and atoms in higher density materials, leading to more effective absorption and attenuation of the radiation. To understand it better an analogy to the dynamics of a spaceship navigating through a meteor cloud of varying densities can be drawn. In a less dense cloud, the spaceship encounters fewer collisions with meteor particles and thus travels more easily, akin to how gamma radiation passes with less obstruction through lower density absorber plates. By understanding how different materials attenuate gamma radiation based on their density characteristics, researchers and engineers can design more effective radiation shielding materials. These materials can then be applied in various contexts where radiation protection is critical, such as in medical facilities, nuclear power plants, and space exploration. Overall, the research contributes to advancing our understanding of gamma radiation attenuation and highlights its practical applications in radiation protection and shielding technology.

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