Understanding of interaction of γ-rays with matter: Attenuation Coefficient Measurements

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Introduction

The leftover nucleus from a composite system formed by fusion of two heavy ions may remain excited after emission of particles (i.e. neutrons, protons & α), and upon de-excitation it may release gamma photons. These gamma transitions are recorded using high- resolution gamma spectrometers and which are then analysed to comment on the structure of nucleus. [1]
Gamma-ray detection is based on the type of interaction that the gamma photon will undergo to transmit its energy to the electrons of detector medium. Three main processes through which γ—ray interacts with matter are: Photoelectric absorption, Compton scattering and Pair production [2]. Any interaction process that takes place while a γ photon travels through an absorber medium leads to either scattering of photon or its absorption. Therefore, a monochromatic beam of γ photons of intensity say I_0 upon passing through an absorber of thickness t will have intensity I given by:

$$I = I_0 e^{-\mu t} \tag{1}$$

where μ is the linear attenuation coefficient of that absorber and equation is known as Beer-Lambert law. Upon increasing the thickness of absorber medium the intensity of the beam falls exponentially due to the fact that the probability for each mentioned interaction per unit path length are added.
In the present manuscript an attempt has been made to understand the contribution of the interaction processes in attenuation coefficients for different elements such as Al, Cu, Zn, and Pb at various gamma-energies for which an experiment was performed using HPGe Clover detector and ^{133}Ba as radioactive source of γ-rays. The mass attenuation coefficient(μ_m) that includes the density of absorber material has been measured which is defined as ratio of linear attenuation coefficient and density of material.

Experimental Details

The ^{133}Ba source was placed at the target position of INGA array at IUAC and absorbers of Al, Cu, Sn, and Pb of different thickness in form of sheets were used to determine the mass attenuation coefficient. The thickness (g/cm^2) of the absorbers was determined using a weighing balance of high precision and the dimensions using a Vernier Caliper. The data was collected for a

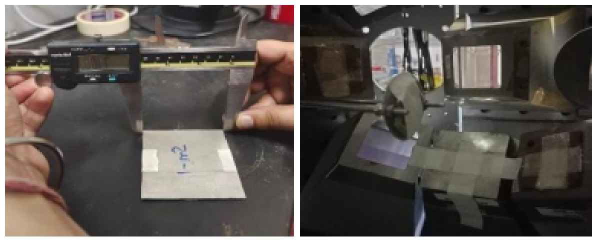

FIG. 1: a) Measurement of dimensions for absorber using Vernier Caliper b) Absorber placed at face of a Clover detector with ^{133}Ba source at target position.

single Clover detector with placing an absorber on the face of it using ROOT [3] based data acquisition system. The unattenuated intensity was also determined, while no absober was there in between the source and detector. The ^{133}Ba radioactive nuclei disintegrates primarily by electron capture to two ^{133}Cs excited levels of 437 keV (85.4%) and 383 keV (14.5%), with three minor branches to the 160 keV, 81 keV excited levels, and the ground state.
Gamma-ray intensity was measured for a variety of absorbers with varying thicknesses and without an absorber to establish I and I_0 for calculating μ. In terms of the mass attenuation coefficient, the attenuation law for γ-rays takes the form:

$$I = I_0 e^{-\frac{\mu}{\rho}\rho t} = I_0 e^{\mu_m \rho t} \tag{2}$$

where the product ρt, is known as the absorber's mass thickness and μ_m as mass attenuation coefficient .

	Element	g/cm^2	81keV	303keV	384keV
Al1	Al	0.5112	-0.0904	-0.0243	-0.0584
Al2		1.0229	-0.1463	-0.0706	-0.0765
Al3		1.5482	-0.2803	-0.1286	-0.1318
Al4		2.0396	-0.3295	-0.1353	-0.1343
Cu1	Cu	0.9518	-0.6541	-0.0355	-0.0487
Cu2		1.3891	-0.9933	-0.0904	-0.0800
Cu3		1.8914	-1.3449	-0.1306	-0.1160
Sn1	Sn	0.6646	-0.6541	-0.0209	-0.0113
Sn2		1.0253	-0.9933	-0.0282	-0.0134
Sn3		1.3154	-1.3449	-0.1009	-0.0744
Pb1	Pb	0.3317	-0.6138	-0.0076	-0.0030
Pb2		0.7298	-1.3615	-0.1291	-0.0669
Pb3		1.0464	-1.9748	-0.2755	-0.1574

TABLE I: Thickness (g/cm^2) and ln (I/I_0) for various absorber materials at different energies

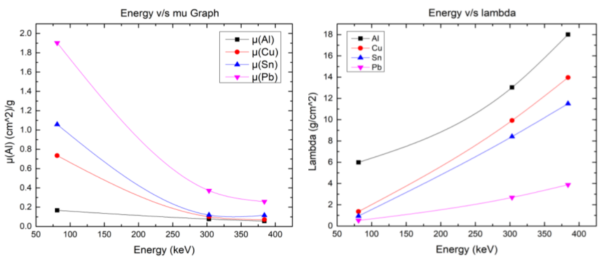

FIG. 2: Plots for (a) Mass attenuation coefficient and (b) Mean free path for Al, Cu, Sn and Pb at different energies

Furthermore, the parameters like half value length (HVL), tenth value length (TVL), and mean free path/penetration length (λ) were also determined, and their relationship with gamma-ray energy was observed upon analysis of collected data using ROOT.

Results and Discussions

The value of μ_m can be determined from the slope of thickness *vs.* $\ln(I/I_0)$ behaviour and it was found that the mass attenuation coefficient (μ_m) for Lead is maximum and for Aluminium is minimum at any energy *i.e.* it increases with increasing Z. When compared to Al, the Pb curve has much higher μ_m value at lower energies, but as the energy increases the drop in the μ_m of Pb is far greater than the fall in the Al, whereas towards far greater energies the μ_m for all metals is approximately same.

Mean free path(λ), on the other hand, is inversely proportional to μ_m and is maximum for Al and minimum for Pb. Because Pb has a larger μ_m than Al and higher Z. Also the HVL and TVL will be smallest for Pb because they are mere multiples of λ. It also means that there will be more interaction in Pb for the same thickness than in Al, Cu, and Zn, resulting in a more drastic reduction in incident intensity of gamma photons. Also, as the energy of gamma rays increases, the value of λ increases, implying that a thicker material is required to stop the higher energies.

In order to determine the attenuation coefficient, HVL, TVL, and γ for composite materials made of Al, Cu, Sn, and Pb as well as their permutations, we will attempt to analyse the experimental data. Along with the previously mentioned parameters, we will also attempt to determine other parameters, such as the effective atomic number (Z_{eff}), exposure buildup factor (EBF), values of the macroscopic removal cross-section (ΣR), and the effective electron density (N_{eff}), that are constitutive elements used in optimization [4, 5] for selecting an appropriate shielding material. The behaviour of μ_m as a function of energy up to 1408 keV would also be clarified by the analysis of data collected using a radioactive source such as ^{152}Eu.

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