Determination of Mass Attenuation Coefficient of PVC and Iron Oxide (Fe_2O_3) Alloy

Wrood K. Abood [1], Zeena J. Raheem [1], Reyam R. Mohammed [2]

[1] Department of Physics, College of Education, Al-Iraqia University, Baghdad, IRAQ
[2] College of Education, Al-Iraqia University, Baghdad, IRAQ

Abstract
The Compton Effect is studied with the measurement of a γ-ray energy spectrum using a scintillator, photomultiplier tube, and multichannel analyzer. The gamma rays interact with the detector, producing all three primary interaction processes, so that every phenomenon that is being studied in a sample is also taking place in the detector itself along with several other effects that mask the process of interest. The linear and mass attenuation coefficients are studied for the elements (pvc) and alloys (Fe_2O_3) at different photon energies using a continuous spectrum from the 137 Cs source via standard collimated beam shielding. That the materials with high photon absorption cross-section may be used for changing the shape of the radiation spectrum. The increase in their thickness decreases the mass attenuation coefficient. The measurements were carried out using a 3"×3" NaI (Tl) detector system and an 8 mCi Cs-137 source.

Keywords*:* Mass attenuation; Iron oxide; Mass attenuation coefficient; NaI(Tl) detector
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1. Introduction

Nowadays the measurement of X-ray differential scattering cross-sections becomes a useful study in radiation attenuation, transport, and energy deposition and also plays an important role in medical physics, reactor shielding, and industrial radiography, in addition to X-ray crystallography. While the coherent (Rayleigh) scattering accounts for only a small fraction of the total cross section, which contributes at most 10% in heavy elements, just below the K-edge energy. Also, the incoherent (Compton) scattering accounts for the rest of the total cross section, where, for the low Z materials, this process dominates over most of the energy range [1,2]. Gamma-ray dosimetry is a non-destructive method for determining the density.The principle of gamma-ray tomography measurement is based on the absorption of gamma radiation in the tested material. The scanning is performed using a small radioactive source and a sensitive electronic detector [3]. The source and detector are kept external to the pipe and positioned on opposite sides at a fixed distance apart.In the literature, a variety of experimental data relevant to the measurement of the mass attenuation coefficients of different samples are available.The aim of the present work is measuring and calculating the mass attenuation coefficient of photons in these material of PVC and (Fe_2O_3) alloy

2. Theory

A photon makes its way through matter; there is no way to predict precisely either how far it will travel before engaging in an interaction or the type of interaction it will engage in. In clinical applications we are generally not concerned with the fate of an individual photon, but rather with the collective interaction of the large number of photons [4]. In most instances we are interested in the overall rate at which photons interact as they make their way through a specific material. The interactions, either photoelectric or Compton, remove some of the photons from the beam in a process known as attenuation. Under specific conditions, a certain percentage of the photons will interact, or be attenuated, in a 1-unit thickness of material [5]. When monoenergetic gamma rays are collimated1 into a narrow beam and allowed to strike a detector after passing through an absorber of variable thickness, the result should be simple exponential attenuation of the gamma rays. Each of the interaction process removes the gamma ray photon from the beam either by absorption or by scattering away from the detector direction, and can be characterized by a fixed probability of occurrence per unit path length in the absorber. The sum of these probabilities is simply the probability per unit path length that the gamma ray photon is removed from the beam [6]:

$$\mu = \tau_{(photoelectric)} + \sigma_{(compton)} + k_{(pair)} \quad (1)$$

where μ is called "the linear attenuation coefficient". The number of transmitted photons I is then given in terms of the number without an absorber (I_o) as :

$$\frac{I}{Io} = e^{-\mu x} \quad (2)$$

where x is thickness of absorber

The gamma ray photons can also be characterized by their mean free path λ, defined as the average distance traveled in the absorber before an interaction take place. Its value can be obtained from

$$\lambda = \frac{\int_0^\infty x e^{-\mu x} dx}{\int_0^\infty e^{-\mu x} dx} = \frac{1}{\mu} \qquad (3)$$

and is simply the reciprocal of the linear attenuation coefficient. Typical values of λ range from a few mm to tens of cm in solids for common gamma ray energies .

The use of the linear attenuation coefficient is limited by the fact that it varies with the density of the absorber, even though the absorber material is the same [7]. Therefore the mass attenuation coefficient is much more widely used and is defined as:

$$mass\ attenuation\ coefficient = \frac{\mu}{\rho} \qquad (4)$$

where ρ represents the density of the medium. For a given gamma ray energy the mass attenuation coefficient does not change with the physical state of a given absorber. For example it is the same for water whether present in liquid or vapor form. The mass attenuation coefficient of a compound or mixture of elements can be calculated from:

$$\left(\frac{\mu}{\rho}\right) compound = \sum_i w_i \left(\frac{\mu}{\rho}\right)_i \qquad (5)$$

where the w_i factors represent the weight fraction of element i in the compound or mixture

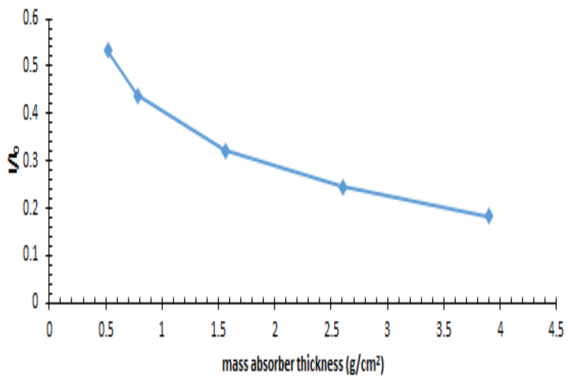
As the radiation interacts with matter, its intensity will decrease. It is important to know, how radiation intensity decreases as it passes through a substance. The degree of attenuation is dependent on the absorber material and the energy of the radiation For all the absorbing materials, the attenuation of gamma radiations is exponential in character. Two important physical spectroscopic parameters used for measuring the extent of attenuation of gamma ray as it passes through a given absorber are linear attenuation coefficient and mass attenuation coefficien [7].

3. Materials and Methods

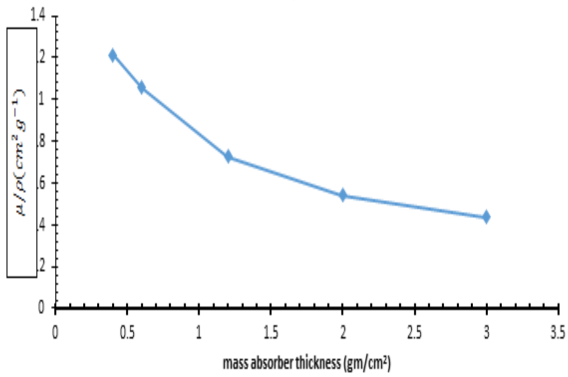
The gamma detector used in this work was a ("3×3") inch NaI (Tl) scintillation detector. The system is portable and can be used in laboratories and fieldwork. It has a fully integrated multichannel analyzer (MCA) tube base that contains a high-voltage power supply and preamplifier, all supplied by Canberra Industries USA. The source was cylindrical 137 Cs, 0.8 cm in diameter, whose activity was 8 mCi, giving collimated gamma rays at the exit of the lead collimator of the same dimension. Samples are located 15 cm after the radioactive source, and the measurement time was 15 minutes.

4. Results and Discussion

In the present work, the different elements are taken to measure and calculate mass attenuation coefficients and cross-sections. From the measured values of I_o and I, Eq. (2), the ratios I/I_o are plotted against mass absorber thickness for the element (pvc) as shown in Fig. (1) and alloys (Fe_2O_3), as shown in Fig. (2). The experimental values of μ/ρ of the continuous energy gamma-ray source for various elements are evaluated using Eq. (4) and depicted in figures (1) and (2). Inspection of these curves reveals that the μ/ρ decreases with increasing the mass absorber thickness. This result may be attributed to the increase in the number of small-angle scattering and multiple scattering photons that reach the detector. This is unlike the mass attenuation of monoenergetic gamma rays, which is independent of mass absorber thickness [8,9]. This confirms that the attenuation of continuous energy gamma rays in an absorber does not conform to a single exponential law (Eq. 2), unlike the absorption of monoenergetic gamma rays. Rather, it is a combination of a large number of exponential terms. This is due to the continuous nature of the spectrum, which undergoes a change in its shape on passing through different mass absorber thicknesses.



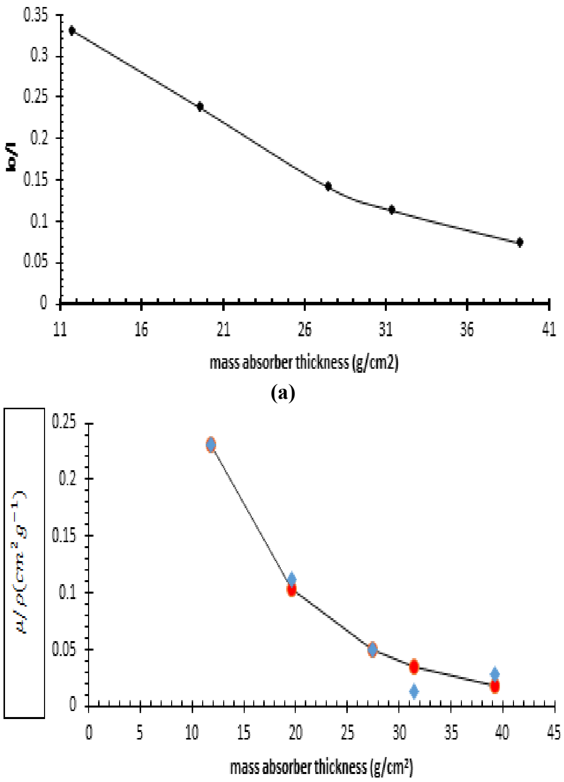
(a)



(b)

Fig. (1) (a) transmitted to incident continuous gamma-ray intensity, and (b) mass attenuation coefficient vs. mass absorber thickness for pvc

At a particular mass thickness of each sample, the value of *μ/ρ* increases with the increase of *the Z value* of the absorber. The reason is that all three processes of absorption of gamma rays in matter increase as the atomic number *Z* increases.



(b)

Fig. (2) (a) transmitted to incident continuous gamma-ray intensity, and (b) mass attenuation coefficient vs. mass absorber thickness for Fe_2O_3

5. Conclusions

This result may be attributed to the increase in the number of small-angle scattering and multiple scattering photons that reach the detector. This is unlike the mass attenuation of mono-energetic gamma-ray which is independent of mass absorber thickness. This confirms that the attenuation of continuous energy gamma-ray in an absorber does not conform to a single exponential la , unlike the absorption of mono-energetic gamma-ray. Rather, it is a combination of a large number of exponential terms. This is due to the continuous nature spectrum, which undergoes a change in its shape on passing through different mass absorber thicknesses. At a particular mass thickness of each sample the value of the mass attenuation coefficients (μ/ρ) of pvc meteral decreases with the increase of *the Z value* of the absorber. The reason is that all three processes of absorption of gamma-rays in matter increase as the atomic number *Z* increases.

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