Calculation of Gamma-ray Mass Absorption Coefficients for some Geological Compounds for Energy of 10–150 keV

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Abstract—Information about gamma-ray mass absorption coefficients in different geological compounds with different percentage to their rations is vital for accurate gamma-ray spectroscopy analysis. In this paper, gamma-ray absorption coefficients for energy (10–150 keV) were calculated for Corundum (AL₂O₃), Quartz (SiO₂), Calcite (CaCO₃), Hematite (Fe₂O₃), and Magnetite (Fe₃O₄) compounds with their % mixtures.

Keywords — Mass Absorption Coefficients; Gamma-Ray Spectroscopy; Geology; Mixtures.

1. Introduction

The most important description of the amount of radiation penetration into the material is the Linear Attenuation Coefficient, which is a quantity that depends on the energy of the incident photon and the atomic number of the material. This quantity represents a fraction of the energy lost from the incident photon for every 1 cm penetrated through the material. The unit of linear absorption coefficient µ is cm⁻¹. According to Lambert - Beer’s law [1-6], when a narrow photon beam of single-energy hν₀ and a flux density N₀ (the number of photons per unit area and time) falls on a homogeneous medium and penetrates it a distance (x), the flux density of the transmitted photon beam from this medium is N and is given as:

\[ N(X) = N_0 e^{-\mu x} \]  

(1)

This law shows that the transmitted photons decrease exponentially with the thickness of the absorbent material. It can be stated that, when photon energies are greater than electron binding energies, µ is directly proportional to the physical density of the absorbent material [5, 7]. Therefore, equation (1) can be rewritten as follows:

\[ N = N_0 e^{-\frac{\mu}{\rho} x \rho} \]  

(2)

Where \( \mu/\rho \) is the mass absorption coefficient (cm²/g). This quantity \( \mu/\rho \) is related to the probability (or cross-section) that the beam will interact with matter and contribute in some way. Each interaction somehow contributes to the loss of a number of photons from the incident photon ray even though the scattering of the photon does not lead to its absorption from the photon beam. This probability gives a measure of the mass absorption of the photons that pass through the medium and since there are three basic interactions that occur when the photon interacts with the material, and these interactions are the phenomenon of photoelectric absorption (ph), Compton scattering (C) and Rayleigh scattering (R), the mass absorption coefficient It can be written as follows:

\[ \frac{\mu}{\rho} = \frac{\mu_{ph}}{\rho} + \frac{\mu_{C}}{\rho} + \frac{\mu_{R}}{\rho} \]  

(3)

2. Mass Absorption Coefficient of Mixtures

When the absorbent material is a homogeneous mixture of different types of elements (chemical compound) or a mixture, the mass attenuation coefficient is given as [6]

\[ \mu/\rho = \sum \omega_j \mu_j / \rho_j \]  

(4)

Where \( \omega_j \) represents the weight of the component j, \( \mu_j \) represents the element’s linear attenuation coefficient for element j and \( \rho_j \) is the density of element j.

3. Calculation of the Mass Absorption Coefficient of some Geological Components

The mass absorption coefficients for Corundum (AL₂O₃), Quartz (SiO₂), Calcite (CaCO₃), Hematite (Fe₂O₃), and Magnetite (Fe₃O₄) compounds with their % mixtures were calculated as a function of incident photon energies (10 – 150 keV). Table 1 shows the mass absorption coefficient of a mixture in terms of the energy of the incident photon.

Figure 1 shows the calculated mass absorption coefficients for AL₂O₃, SiO₂ and Fe₃O₄ as a function of incident photon energies. It can be seen from figure 1, that Haematite (density 5.3 g/m/cm³) has higher mass absorption coefficients than Corundum (density 4.02 g/m/cm³).
gm/cm³) and Quartz (density 2.65 gm/cm³) due to differences in density.

Table 1: The calculated mass absorption coefficients for different compounds as a function of incident photon energies

| Energy (keV) | Corundum AL₂O₃ | Quartz SiO₂ | Calcite CaCO₃ | Hematite Fe₂O₃ | Magnetite Fe₃O₄ | Total mass absorption coefficient (cm²/g) |
|-------------|-----------------|-------------|---------------|----------------|----------------|-----------------------------------------|
| 10          | 39.53           | 25.98       | 61.25         | 272.38         | 407.93         |                                          |
| 15          | 11.89           | 7.80        | 19.11         | 87.97          | 131.77         |                                          |
| 20          | 05.20           | 3.39        | 8.28          | 40.26          | 60.30          |                                          |
| 30          | 01.82           | 1.17        | 2.65          | 12.88          | 19.28          |                                          |
| 40          | 00.99           | 0.63        | 1.26          | 5.79           | 8.66           |                                          |
| 50          | 00.70           | 0.43        | 0.77          | 3.16           | 4.72           |                                          |
| 60          | 00.56           | 0.34        | 0.54          | 1.99           | 2.97           |                                          |
| 80          | 00.44           | 0.26        | 0.36          | 1.03           | 1.53           |                                          |
| 100         | 00.38           | 0.23        | 0.28          | 0.67           | 1.00           |                                          |
| 150         | 00.32           | 0.19        | 0.21          | 0.39           | 0.57           |                                          |

Fig. 1: shows mass absorption coefficients for AL₂O₃, SiO₂ and Fe₂O₄ in the energy range (10 – 150 keV).

Table 2 shows the calculations of the mass absorption coefficients of two mixtures in fixed proportions in terms of the energy of the incident photon.

Table 2: Calculations of the mass absorption coefficients of two mixtures in terms of the energy of the incident photon

| Energy (keV) | CaCO₃ 50% AL₂O₃ 50% | SiO₂ 50% AL₂O₃ 50% |
|--------------|----------------------|---------------------|
| 10           | 50.39                | 32.75               |
| 15           | 15.50                | 9.85                |
| 20           | 6.74                 | 4.29                |
| 30           | 2.23                 | 1.49                |
| 40           | 1.13                 | 0.81                |
| 50           | 0.73                 | 0.56                |
| 60           | 0.55                 | 0.45                |
| 80           | 0.40                 | 0.35                |
| 100          | 0.33                 | 0.30                |
| 150          | 0.27                 | 0.25                |

Fig. 2: The mass absorption coefficient of two mixtures in the photon energy range (10 – 150 keV)

Table 3 shows the mass absorption coefficient of three compounds with different ratios in terms of the energy of the incident photon.

Table 3 shows the mass absorption coefficients of three compounds (SiO₂ 20 %, CaCO₃ 60 % and Al₂O₃ 20 %) as a function of incident photon.

Fig. 3 shows the projection of the calculated mass absorption coefficients of three compounds (SiO₂ 20 %, CaCO₃ 60 % and Al₂O₃ 20 %) as a function of incident photon.
photon energies. This curve shows higher values of mass absorption coefficients for the mixture which made up of light and relatively higher atomic numbers.

Table 3: Calculated mass absorption coefficient of three compounds with different ratios as a function of incident photon energies

| Energy (keV) | SiO₂ 20 % | CaCO₃ 60 % | Al₂O₃ 20 % |
|-------------|-----------|------------|------------|
|             | Mass absorption coefficients of three mixtures (cm²/g) |
| 10          | 49.85748552 |
| 15          | 15.41015454 |
| 20          | 6.689505311 |
| 30          | 2.192178901 |
| 40          | 1.085724707 |
| 50          | 0.689576363 |
| 60          | 0.510042313 |
| 80          | 0.358827563 |
| 100         | 0.296490347 |
| 150         | 0.234766092 |

Fig. 3: shows the curve of mass absorption coefficient of three compounds with different proportions as a function of incident photon energies (10-150 keV).

5. Conclusion

In x-ray and gamma-ray spectroscopy analysis, it is always required appropriate correction for data matrix of geological materials. However, there are many corrections to be taken into account. Such corrections depend on the type of analysis required. One such important correction is mass absorption coefficients. Since the mass absorption coefficients for materials cannot be measured experimentally due to the fact that there are many different scattering processes involved. Therefore, seeking a theoretical method for calculation of mass absorption coefficients of materials appears to be the only method that is available. This paper deals with estimation of mass absorption coefficients for some geological compounds and their mixtures for incident photon energies (10-150 keV). As seen from the above figures, the mass absorption coefficients curves show exponential decrease as a function of increasing photon energy. This last point has many theoretical and practical applications in different research desplines.

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