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MASS ATTENUATION COEFFICIENT, TOTAL ATOMIC CROSS-SECTION AND TOTAL ELECTRONIC CROSS-SECTION OF $Ni_{0.3}Zn_{0.5}Cu_{0.2}Fe_2O_4$ FERRITE

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Abstract: *In this article, we report the structural characterization and the results on mass attenuation coefficient, total atomic cross-section and total electronic cross-section of $Ni_{0.3}Zn_{0.5}Cu_{0.2}Fe_2O_4$ spinel ferrite multi-elemental composite.. The structural characterization of $Ni_{0.3}Zn_{0.5}Cu_{0.2}Fe_2O_4$ ferrite composite was carried out by X-ray diffraction technique. The X-ray analysis confirmed the formation of single phase cubic spinel structure. The mass attenuation coefficient, total atomic cross section and total electronic cross-section of $Ni_{0.3}Zn_{0.5}Cu_{0.2}Fe_2O_4$ spinel ferrite have been obtained using narrow beam technique as a function of varying thickness. The results show that as thickness increases all these parameters decreases. XCOM program was used to obtain the theoretical values of mass attenuation coefficient.*

Keywords: *Ferrite Composite, Mass attenuation coefficient, Total electronic cross-section.*

Introduction

With ever-increasing use of gamma rays in various fields such as industry, medicine, agriculture etc, the study of photon interaction with different composite materials has become a topic of prime importance for radiation physicists. Some parameters of dosimetry interest are the mass attenuation coefficient, effective atomic number, total photon interaction cross-section and total electronic cross-section. These parameters help in basic understanding of photon interaction with composite materials.

Berger and Hubbell have developed a computer program XCOM [1], for calculation of mass attenuation coefficient and photon interaction cross-section in the energy range 1 keV to 100 GeV. The nanosize magnetic materials are extensively investigated for their interesting deviation in magnetic, optical, electric and thermal properties [2]. Over the increasing wide use of magnetic materials in various fields, spinel ferrites with the chemical MFe_2O_4(M is a divalent cation) formula are considered as a composite material in the present study.

Experimental

The sample of $Ni_{0.3}Zn_{0.5}Cu_{0.2}Fe_2O_4$ spinel ferrite composite was prepared by ceramic technique using AR grade (99.9% pure) oxides. The dried mixture is compressed in circular pellet form. The polyvinyl alcohol (PVA) was used as a binder. The pellet was then sintered at 1100 ^{0}C for 24 h and finally cooled slowly to room temperature at the rate of 2 ^{0}C/min and used for further measurements. X-ray diffraction (XRD) pattern was obtained at room temperature using Philips X-ray diffractometer (Model PW 3710) using Cu-Kα radiations (λ = 1.5405 A^0). The pellets of uniform thickness were used to find the linear attenuation coefficient, mass attenuation coefficient and other related parameter for various energies. A narrow beam geometry technique was used to obtain the absorption of gamma radiations

Results and Discussions

X-Ray Diffraction: Fig. I represent X-ray diffraction (XRD) pattern of $Ni_{0.3}Zn_{0.5}Cu_{0.2}Fe_2O_4$ spinel ferrite composite. The XRD pattern shows the reflections belonging to cubic spinel structure. The single phase cubic spinel structure of the present sample has been confirmed by the analysis of XRD pattern.

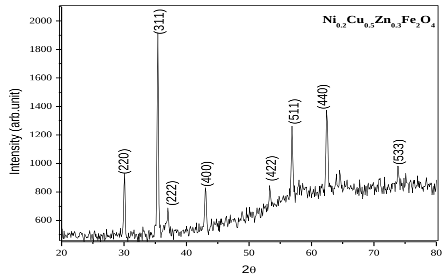

Fig I X-ray diffraction pattern of spinel ferrite composite $Ni_{0.3}Zn_{0.5}Cu_{0.2}Fe_2O_4$.

Mass attenuation coefficient: The mass attenuation coefficient was calculated using the mass-density relation as: $\mu_m=\mu/\rho$ where, μ_m-mass absorption coefficient, ρ - density of the material.

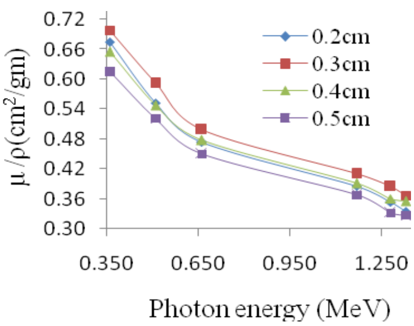

Fig II Plots of photon attenuation coefficient μ/ρ (cm^2/gm) vs photon energy in MeV for $Ni_{0.3}Zn_{0.5}Cu_{0.2}Fe_2O_4$ (0.2 cm to 0.5 cm collimation).

The values of linear attenuation coefficient (μ) obtained experimentally for varying energy are given in table I. The calculated values of mass attenuation coefficient from the above relation are listed in table I for 0.2 cm collimeter diameter. Fig.II represents variation of mass attenuation coefficient with different energy and for different collimeter size. It is observed from Fig.II that, mass attenuation decreases as energy increases. This relation is true for varying collimator size. Due to increase in collimeter size linear attenuation coefficient decreases because of scattering.

The values of total mass attenuation coefficient as a function of photon energy and collimator size were calculated from the Hubbell's mixture rule. The total mass attenuation coefficient for the different materials and energies are determined by the transmission.

This process is described by the following equation:

$$I = I_o e^{-\mu t} \quad \text{.............. (I)}$$

where I_o- photon intensity with energy E, without attenuation, I - photon intensity with energy E, after attenuation, $\mu_m = \mu/\rho$ (cm^2/gm) i.e. mass attenuation coefficient and t (gm/cm^2) sample mass thickness (mass per unit area).

The total mass attenuation values for materials that are composed of multi elements is the sum of $(\mu_m)_i$, values of each constituents element by the following mixture rule [3]:

$$\mu_m = \sum wi(\mu_m)_i \quad \text{.............. (II)}$$

where, w_i is the weight fraction of i^{th} element and $(\mu_m)_i$ is mass attenuation coefficient of the i^{th} element. For a material composed of multi-elements, the fraction by weight is given by:

$$w_i = \frac{n_i A_i}{\sum n_i A_i} \quad \text{............ (III)}$$

where, A_i is the atomic weight of the i^{th} element and n_i is the number of formula units [4]. The theoretically obtained values of mass attenuation coefficient are given in Table I. A comparison of theoretical and experimental values shows good agreement. There is small variation of 4 to 9 % in theoretical and experimental values of total mass attenuation. It is observed that, the deviation in experimental and theoretical values of mass attenuation coefficient increases with increase in energy. As energy increases attenuation coefficient decreases and therefore mass attenuation coefficient also decreases. Similar observations for mass attenuation coefficient are reported in the literature [5].

Total electronic cross-section: The total electronic cross-section for $Ni_{0.3}Zn_{0.5}Cu_{0.2}Fe_2O_4$ composite spinel ferrite was calculated by using the following relation:

$$\sigma_{ele} = \frac{1}{N_A} \sum \frac{f_i A_i \times \mu}{Z_i \times \rho} \quad \text{...................... (IV)}$$

where, f_i – denotes the fractional abundance of i^{th} element with respect to number of atoms such that, $f_1 + f_2 + f_3 + \ldots + f_i$, Z_i – atomic number of i^{th} element.

The values of atomic mass of $Ni_{0.3}Zn_{0.5}Cu_{0.2}Fe_2O_4$ composite spinel ferrites was used to calculate the total electronic cross-section (σ_{ele}) and are listed in table I. Similar behaviour was observed for varying diameter of collimator. The variation of total electronic cross-section as a function of energy is shown in Table I.

From Table I, it is observed that the total electronic cross-section decreases with increasing photon energy as expected.

Table: I Experimentally measured values of linear attenuation coefficient (μ), mass attenuation coefficient (μ/ρ), total photon interaction cross-section (σ_{total}), total electronic cross-section (σ_{ele} for collimated photon beam of 0.2 cm diameter in the energy range (0.360 MeV-1.33 MeV) for $Ni_{0.3}Zn_{0.5}Cu_{0.2}Fe_2O_4$

Energy MeV	μ cm^{-1}	μ/ρ cm^2/gm		% Devi	σ_{total} barn/atom	σ_{ele}
		Th.	Ex.			
0.360	2.74	0.7	0.6	4.0	38.21	2.36
0.511	2.24	0.5	0.5	3.7	31.24	1.93
0.662	1.92	0.5	0.4	5.0	26.82	1.65
1.170	1.56	0.4	0.3	6.0	21.82	1.34
1.280	1.44	0.3	0.3	7.0	20.07	1.24
1.330	1.36	0.3	0.3	8.7	18.99	1.17

Conclusions

Spinel ferrite composite ($Ni_{0.2}Zn_{0.5}Cu_{0.3}Fe_2O_4$) was successfully synthesized by standard ceramic technique. Single phase formation of $Ni_{0.2}Zn_{0.5}Cu_{0.3}Fe_2O_4$ composite was confirmed by XRD. The linear attenuation coefficient, mass attenuation coefficient and total photon interaction cross-section decreases exponentially with increase in photon energy. The total electronic cross-section deceases significantly with increase in photon energy. The theoretical and experimental value of mass attenuation coefficient agrees closely with each other. However, the best agreement in the values of theoretical and experimental mass attenuation coefficient was observed for 0.2 cm collimator diameter

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