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Measurement of atomic number and mass attenuation coefficient in magnesium ferrite

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Abstract. Pure magnesium ferrite sample was prepared by standard ceramic technique and characterized by X-ray diffraction method. XRD pattern revealed that the sample possess single-phase cubic spinel structure. The linear attenuation coefficient (μ), mass attenuation coefficient (μ/ρ), total atomic cross-section (σ_{tot}), total electronic cross-section (σ_{ele}) and the effective atomic number (Z_{eff}) were calculated for pure magnesium ferrite ($MgFe_2O_4$). The values of γ-ray mass attenuation coefficient were obtained using a NaI energy selective scintillation counter with radioactive γ-ray sources having energy 0.36, 0.511, 0.662, 1.17 and 1.28 MeV. The experimentally obtained values of μ/ρ and Z_{eff} agreed fairly well with those obtained theoretically.

Keywords. Absorption; attenuation coefficient; effective atomic number.

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1. Introduction

Mass attenuation and energy absorption coefficients are widely used in the study of interaction of γ-rays with matter. The photoelectric effect, Compton scattering and pair production processes are the predominant interactions between the photons and atoms apart from other types over a wide range of energies. By irradiating the material with γ-rays, ionization of the material takes place and the stored energy of the material increases [1].

Extensive studies have been carried out to determine γ-ray attenuation coefficients for various elements and photon energy [2–4]. Recently, many workers [5–7] have used the mixture rule in order to provide mass attenuation coefficients for multi-element materials. There are reports in the literature, which show effect of gamma radiation on the physical properties of spinel ferrites [1,8].

Ferrites forming a group of semiconducting materials are of great technological importance because of their twin property as a magnetic conductor and an electrical insulator. They can be used in memory cores, high frequency transformers, antenna, recording heads and radar absorbing paints [9]. Extensive work has been carried out on pure and substituted magnesium ferrites with a view to study the electrical, magnetic and micro-structural properties and tailor-make them for suitable applications [10–15], but to our knowledge, no reports are available in the literature on the measurement of mass attenuation coefficient in magnesium ferrite.

The knowledge of photon attenuation coefficient provides an important parameter for characterizing the penetration and diffusion of photon in multi-element materials. The data on attenuation coefficient are useful in various fields such as nuclear science, technology and medical applications. Apart from this, the need of shield to protect against harmful radiation has lead to the studies on attenuation coefficient measurement in different multi-element materials.

Keeping these points in view, attempts have been made to measure the total mass attenuation coefficient, total atomic cross-section, total electronic cross-section and total effective atomic number of magnesium ferrite for samples of different thicknesses in the energy range from 0.360 MeV to 1.28 MeV. The measurement of photon attenuation is performed in a narrow beam geometry configuration. The present paper reports results on mass attenuation coefficient and related parameters of $MgFe_2O_4$.

2. Experimental

The samples of magnesium ferrite have been prepared by standard ceramic technology, using AR grade (99.9% pure) MgO and Fe_2O_3. The details of experimental procedure for the preparation of magnesium ferrite have been described elsewhere [16]. The measurements of γ-ray mass attenuation coefficients were carried out on bulk sample, which was in the form of circular pellets of varying thicknesses, using multichannel analyzer (MCA) in the energy range 0.360 MeV to 1.28 MeV.

Four radioactive sources, namely, ^{137}Cs, ^{133}Ba, ^{60}Co, ^{22}Na are used to find out the values of mass absorption coefficient of γ radiations in magnesium ferrite. All these radioactive sources are obtained from Bhaba Atomic Research Center (BARC), Mumbai, India. The energy range of all the four sources is between 0.360 MeV and 1.28 MeV.

The absorber is taken in the form of a right circular cylinder with a diameter of 15 cm and the thickness is approximately 0.27 to 2.53 cm. The density of the absorber is determined from the dimensions and masses of various pellets.

3. Results and discussion

The room temperature X-ray diffraction patterns were recorded on a Philips X-ray diffractometer (Model PW 3710) using Cu-K_α radiation and is shown in figure 1. X-ray diffraction pattern reflects (2 2 0), (3 1 1), (2 2 2), (4 0 0), (4 2 2), (3 3 3) and (4 4 0) planes belonging to cubic spinel structure. The XRD pattern shows

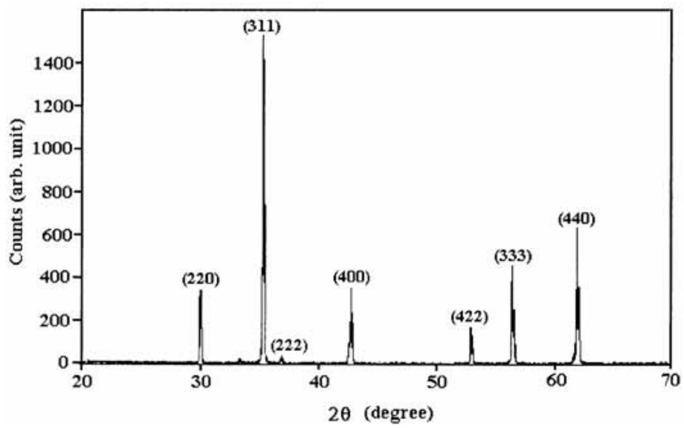

Figure 1. X-ray diffraction pattern of magnesium ferrite.

Table 1. The values of linear attenuation coefficient (μ) and mass attenuation coefficient (μ/ρ) of gamma radiations in $MgFe_2O_4$ in the energy range 0.36 MeV to 1.28 MeV.

Energy (MeV)	μ (cm^{-1})	μ/ρ (cm^2/g) Theor.	μ/ρ (cm^2/g) Exp.	Percentage error
0.360	0.3248	0.0981	0.0998	1.715
0.511	0.2562	0.0821	0.0773	5.780
0.662	0.2429	0.0745	0.0729	2.123
1.170	0.1736	0.0546	0.0524	4.029
1.280	0.1629	0.0531	0.0520	2.041

sharp Bragg peaks. The analysis of XRD pattern reveals that the sample possesses single-phase cubic spinel structure.

From the mass and volume of the absorber (i.e. $MgFe_2O_4$), density for each pellet was calculated. Using the values of density (ρ) and linear attenuation coefficient (μ), the values of mass attenuation coefficient (μ/ρ) for different energies were calculated. The values of linear attenuation coefficient (μ) and mass attenuation coefficient (μ/ρ) are listed in table 1.

For materials composed of multi-elements, the total mass attenuation coefficient (μ/ρ) is related to the μ/ρ values of each constituent element by the following mixture rule [17]:

$$\mu/\rho = \sum w_i(\mu/\rho)_i, \tag{1}$$

where w_i is the fraction by weight of the ith atomic constituent. The $(\mu/\rho)_i$ values of each constituent of $MgFe_2O_4$ are taken from Hubble's table for elemental media. The observed and theoretical values are reported in table 1. It can be seen from table 1 that the observed and theoretical values of μ/ρ agree fairly well with each other.

Table 2. The values of total atomic cross-section ($\sigma_{\rm tot}$), the total electronic cross-section ($\sigma_{\rm ele}$) and the effective atomic number ($Z_{\rm eff}$) for magnesium ferrite.

Energy (MeV)	$\sigma_{\rm tot}$ (b/atom)		$\sigma_{\rm ele}$		$Z_{\rm eff}$	
	Expt	Theor.	Expt	Theor.	Expt	Theor.
0.360	4.734	4.654	0.346	0.340	13.70	13.70
0.511	3.667	3.895	0.268	0.284	13.70	13.70
0.662	3.458	3.534	0.252	0.258	13.70	13.70
1.170	2.486	2.590	0.180	0.189	13.70	13.70
1.280	2.467	2.519	0.181	0.184	13.70	13.70

From the measured values of mass attenuation coefficient (μ/ρ), the total atomic cross-section ($\sigma_{\rm tot}$) for magnesium ferrite has been obtained using the following relation [18]:

$$\sigma_{\rm tot} = \frac{10^{24}(\mu/\rho)A}{N_{\rm A}}(\text{b/atom}), \tag{2}$$

where A is the atomic mass and $N_{\rm A}$ is the Avogadro's number.

The values of $\sigma_{\rm tot}$ are given in table 2. The theoretical values of $\sigma_{\rm tot}$ were also calculated by taking the theoretical values of μ/ρ and are given in table 2. The experimental and theoretical values of $\sigma_{\rm tot}$ are compared and it is found that they are in good agreement with each other.

The total electronic cross-section ($\sigma_{\rm ele}$) for the individual element was calculated using the following formula [19]:

$$\sigma_{\rm ele} = \frac{1}{N_{\rm A}}\sum \frac{f_i A_i}{Z_i}(\mu/\rho), \tag{3}$$

where f_i denotes the fractional abundance of the element i with respect to the number of atoms such that $f_1 + f_2 + f_3 + \cdots + f_i = 1$, Z_i is the atomic number of ith element. The total atomic cross-section and the electronic cross-section are related to the effective atomic number ($Z_{\rm eff}$) of the compound through the following relation [20,21]:

$$Z_{\rm eff} = \frac{\sigma_{\rm tot}}{\sigma_{\rm ele}}. \tag{4}$$

The experimental values of $\sigma_{\rm tot}$, $\sigma_{\rm ele}$ and $Z_{\rm eff}$ were calculated using equations (2), (3) and (4) respectively and are presented in table 2. The theoretical values for $\sigma_{\rm tot}$, $\sigma_{\rm ele}$ and $Z_{\rm eff}$ were also obtained and are listed in table 2. A comparison is made between experimental and theoretical values of $\sigma_{\rm tot}$, $\sigma_{\rm ele}$ and $Z_{\rm eff}$ and it can be concluded that the theoretical and experimental values are in good agreement with each other within the experimental errors. The plots of theoretical and experimental values of $\sigma_{\rm tot}$ are shown in figure 2.

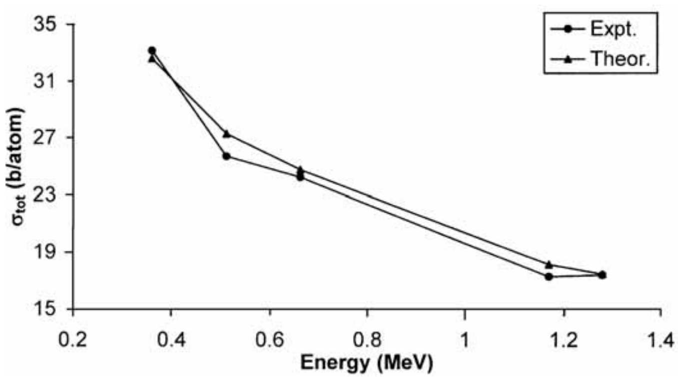

Figure 2. Variation of experimental and theoretical values of total atomic cross-section ($\sigma_{\rm tot}$) for magnesium ferrite.

4. Conclusions

Analysis of XRD pattern revealed the formation of single-phase cubic spinel structure. Hubbel's mixture rule is applicable to find the mass absorption coefficient and related parameters for $MgFe_2O_4$.

The data on mass attenuation coefficient and related parameters of $MgFe_2O_4$ should be helpful in dosimetry and technological applications. However, it would be desirable to measure mass attenuation coefficient for still higher energies but due to non-availability of higher energy sources to us data has not been taken.

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References

[1] F S Terra, *Mod. Phys. Lett.* **B8(28)**, 1781 (1997)
[2] Charlotte Meaker Davison and R D Evans *Phys. Rev.* **81**, 404 (1951)
[3] A L Conner, H F Atwater and E H Plassm, *Ann. Phys. Rev.* **A1**, 539 (1970)
[4] B Goswami and N Chaudhari, *Phys. Rev.* **A7**, 1912 (1973)
[5] M T Teli and L M Chaudhari, *Radiat. Phys. Chem.* **47**, 531 (1996)
[6] G A Battiston, S Degetto, R Gerbasi, G Sbrignadello and L Tositti, *Nucl. Instrum. Methods* **B28**, 438 (1987)
[7] R H Millar and J R Greening, *J. Phys.* **B7**, 2332 (1974)
[8] O H Hemeda, M El-Saadawy *J. Magn. Magn. Mater.* **256**, 63 (2003)
[9] S Krupanicha, *The physics of ferrites and magnetic oxide related to them* (Russian translation) Moscow Min 1st ed. (1976)
[10] M A Ahmed, G Aba-Ekkafut and M Rashad *J. Magn. Magn. Mater.* **233**, 194 (2001)

[11] K B Modi, H H Joshi and R G Kulkarni, *J. Mater. Sci.* **31**, 0001 (1996)
[12] L G Venuitert, *Proc. IRE* 1294 (1956)
[13] C G Whinfrey, D W Eckort and A Touber, *J. Am. Chem. Soc.* **82**, 2695 (1960)
[14] N N Jani, Bimal S Trivedi, H H Joshi and R G Kulkarni, *Ind. J. Pure and Appl. Phys.* **33**, Tulyass, pp. 419–423
[15] Venkatesh Rao and R V Keer, *Pramana – J. Phys.* **19**, 103 (1982)
[16] V B Kawade, G K Bichile and K M Jadhav, *Mat. Lett.* **42**, 33 (2000)
[17] J H Hubbell and S M Seltaer, *NISTIR* 5632 (May 1995)
[18] Wang Da-Chun, Luo Ping-An and Yang Hua, *Nucl. Instrum. Methods* **B95**, 161 (1995)
[19] K Singh, H Singh, V Sharma, R Nathuram, A Khanna, R Kumar, S S Bhatti and H S Sahota, *Nucl. Instrum. Methods* **B194**, 1 (2002)
[20] K Singh, R Kaur and V Kumar, *Radiat. Phys. Chem.* **47**, 535 (1996)
[21] El-Katab and A S Abdul Hamid, *Int. J. Appl. Radiat. Isot.* **42**, 303 (1991)