Chapter 5

Results And Discussion On Ni_{0.3}Zn_{0.5}Cu_{0.2}Fe_{2}O_{4} Ferrite Composite

5.1 Introduction

With ever-increasing use of gamma rays in various fields such as industry, medicine and agriculture etc, the study of photon interaction with different composite materials has become a topic of prime importance for radiation physicists. Some parameters of dosimetric 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. The mass attenuation coefficient ($\mu/\rho$) is a measure of number of photons interacting (scattered/absorbed) with target material. It is the fundamental tool to derive many other parameters for dosimetric interests such as mass energy absorption coefficient, molecular, atomic and electronic cross-sections, effective atomic number and density of the materials.

Berger and Hubbell have developed a computer program XCOM [1], which is useful for calculation of mass attenuation coefficient and photon interaction cross-section for pure elements and their mixture theoretically in the energy range 1 keV to 100 GeV. Even then, the measurement of mass attenuation coefficient and other parameter is the
subject of large interest for many researchers. The theoretical and experimental values of mass attenuation coefficient may or may not agree with each other because of the experimental procedure and conditions. Several researchers have used different composite materials such as Bakelite, cement high $T_c$ superconductor etc, biologically important materials such as plant leaves, bones, proteins etc, for attenuation coefficient of photon [2-3].

The nanosize magnetic material is exhaustively investigated for their interesting deviation in magnetic, optical, electric and thermal properties compared to that of their bulk counterparts [4]. Among these magnetic materials, soft magnetic materials are used as inductive components in electromagnetic devices viz, transformers of large and small size, telecommunication systems, field sensors in magnetic recording, etc. would determine their suitability of applications in specific electromagnetic devices. For the low magnetic loss, the high resistivity of the material is needed for various applications. In this regard, spinel ferrite is highly suited for their applications as soft magnetic materials because of low coercive field, high resistivity and low production cost [5]. Therefore, spinel ferrites are considered as a composite material in the present study.

The mixed spinel ferrites are useful in many magnetic devices operating in the radio frequency and modified magnetic properties enhanced their ability of applications in magnetic devices. The knowledge of photon attenuation coefficient provides an important parameter for characterizing the penetration and diffusion of photons in multi-elements, materials. The attenuation coefficient, data is useful in
various fields such as nuclear science, shielding technology and medical applications. Apart from this, the need of shield for protect against harmful radiation has lead to the studies on attenuation coefficient measurements in different multi-element materials. Spinel ferrites are multi-elemental materials. Mass attenuation and energy absorption coefficient are widely used in the study of gamma ray interaction with matter. Extensive studies have been carried out to determine gamma ray attenuation coefficient for various elements and photon energy [6-8].

Recently, many researchers [9-11] have used the mixture rule in order to provide mass attenuation coefficients for multi-elements. To our knowledge very few researchers [12] have studied mass attenuation coefficient and effective atomic numbers for their use in shielding purpose, Hubbell [13] provided theoretical values of mass attenuation coefficients for various elements.

For photon interaction, it is not possible to assign a single number to composite materials, the effective atomic number $Z_{\text{effective}}$ is calculated from atomic number of constituent elements and weighted according to different partial interaction process by which the photon interacts and hence it is a energy dependent parameter which signifies that, at a given energy, composite material interact, with photons, in the similar way as a single element of atomic number equivalent to that of composite materials.

In the present work, we report our results on linear, mass attenuation coefficient, total atomic cross-section, total electronic cross-section and effective atomic number of $\text{Ni}_{0.3}\text{Zn}_{0.5}\text{Cu}_{0.2}\text{Fe}_2\text{O}_4$ ferrite composite. The results are verified by Hubble’s mixture rule formula.
5.2 Experimental details

The sample of Ni$_{0.3}$Zn$_{0.5}$Cu$_{0.2}$Fe$_2$O$_4$ ferrite composite system was prepared by standard ceramic technique using AR grade (99.9 % pure) oxides of corresponding metals. The constituent oxides of the respective ferrite were, weighted and mixed thoroughly. The mixture was well grinded for 3 hours using agate mortar and pestle. The homogeneous mixture is then pressed into a circular pellet of 10 mm diameter and about 2 mm thickness using a hydraulic press. The sample in the pellet form was pre-sintered at 950 $^\circ$C for 12 hour in a programmable furnace. The samples are then slowly cooled to room temperature at the rate 2 $^\circ$C per minute. The pre-sintered pellets were again crushed and reground to improve the homogeneity for 2 hours. 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 $^\circ$C for 24 hour and finally cooled slow to room temperature at the rate of 2 $^\circ$C per minute. The final product obtained in the form of pellet is hard, flat and crack free. The bulk density of prepared spinel ferrite composite Ni$_{0.3}$Zn$_{0.5}$Cu$_{0.2}$Fe$_2$O$_4$ is obtained by using mass volume relation is 4.070 gm cm$^{-3}$, and the molecular weight of the prepared sample is 238.66. At room temperature, X-ray diffraction (XRD) patterns of sample were obtained by using Philips X-ray diffractometer (Model PW 3710) using Cu-Kα radiations ($\lambda = 1.5405$ Å$^0$). The sample is taken in the form of right circular cylindrical pellets of uniform thickness. These pellets of uniform thicknesses were used to find the linear attenuation coefficient, mass attenuation coefficient of gamma radiation and related parameter for various energies. A narrow beam geometry technique was used to obtain the absorption of gamma
radiations. All observations were taken on similar assembly as discussed in previous chapter (chapter-3).

5.3 Results and discussion

5.3.1 X-ray diffraction

The single phase cubic spinel structure of the spinel ferrite composite with the chemical formula Ni$_{0.3}$Zn$_{0.5}$Cu$_{0.2}$Fe$_2$O$_4$ has been confirmed by the powder X-ray diffraction technique (XRD). The XRD pattern was recorded on Philips X-ray diffractometer (Model-3710). The X-ray diffraction patterns were recorded using Cu-K$_\alpha$ range, at room temperature. The XRD pattern was recorded in the 2$\theta$ range of 20$^0$ to 80$^0$ with scanning rate 1$^0$ per minute. All the peaks in the recorded X-ray diffraction pattern are sharp intensive and diffraction patterns reflects (220), (311), (222), (400), (422), (511), (440) and (533) planes belonging to cubic spinel structure. Fig 5.1 represents X-ray diffraction pattern of Ni$_{0.3}$Zn$_{0.5}$Cu$_{0.2}$Fe$_2$O$_4$ of spinel ferrite composite.

5.3.2 Linear attenuation coefficient

The prepared Ni$_{0.3}$Zn$_{0.5}$Cu$_{0.2}$Fe$_2$O$_4$ spinel ferrite sample in the form of circular pellets of uniform thickness has been used as an absorber. A narrow beam technique has been used to determine the linear attenuation coefficient for different energies in the present investigation. The thickness of the absorber was varied by staging the absorber. The linear attenuation coefficient ($\mu$) for Ni$_{0.3}$Zn$_{0.5}$Cu$_{0.2}$Fe$_2$O$_4$ for various energies 0.360 MeV to 1.33 MeV were calculated using the following relation,

$$I = I_0e^{-\mu t}$$ \hspace{1cm} 5.1

where, t- thickness of absorber
The values of $I_o$ and $I$ were obtained for different thickness of absorbers using a scintillation counter. The variation of $\ln (I_o/I)$ with thickness has been studied for various energies. The linear attenuation coefficient values were obtained from the slope of $\ln (I_o/I)$ versus $t$ for different collimator diameter 0.2 cm to 0.5 cm in the steps of 0.1 cm and the measured value of linear attenuation coefficient are shown in tables 5.1, 5.2, 5.3 and 5.4 and the exponential plots of linear attenuation coefficient ($\mu$) versus photon energy are shown in Fig 5.2. Similar results were reported in the literature [14].

5.3.3 Mass attenuation coefficient

The mass attenuation coefficient was calculated by measuring the sample density using mass-volume relation. The mass attenuation coefficient was calculated using the relation:

$$\mu_m = \mu/\rho$$  \hspace{1cm} 5.2

where, $\mu_m$ - mass absorption coefficient

$\rho$ – density of the material

The calculated values of mass attenuation coefficient from the above relation are listed in tables 5.1, 5.2, 5.3 and 5.4. The variation of mass attenuation coefficients for Ni$_{0.5}$Zn$_{0.5}$Cu$_{0.2}$Fe$_2$O$_4$ is shown in Fig 5.3 for all collimator diameters. From Fig 5.3, it is observed that, the mass attenuation coefficient ($\mu_m$) decreases with increasing photon energies.

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:
\[ I = I_0 e^{-\mu \cdot t} \]

where \( I_0 \) - photon intensity with energy \( E \), without attenuation

\( I \) - photon with energy \( E \), intensity after attenuation

\( \mu_m = \frac{\mu}{\rho} \) (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 [15]:

\[ \mu_m = \sum w_i \left( (\mu_m)_i \right) \]

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:

\[ w_i = \frac{n_i A_i}{\sum n_j A_j} \]

where, \( A_i \) is the atomic weight of the \( i^{th} \) element and \( n_i \) is the number of formula units [16].

The theoretically obtained values of mass attenuation coefficient are given in tables 5.1, 5.2, 5.3 and 5.4. A comparison of theoretical and experimental values shows good agreement. There is small variation of 1 to 12 % in theoretical and experimental values of total mass attenuation for different collimator sizes. It is observed that, the deviation in experimental and theoretical values of mass attenuation coefficient increases with collimator diameter (0.2 cm to 0.5 cm). Similar observations of mass attenuation coefficient are reported in the literature [17].
5.3.4 Total photon interaction cross-section

The values of mass attenuation coefficient were used to calculate the total photon interaction cross-section ($\sigma_{\text{tot}}$) for the prepared Ni$_{0.3}$Zn$_{0.5}$Cu$_{0.2}$Fe$_2$O$_4$ composite material. Following relation was used to calculate the total photon interaction cross-section:

$$\sigma_{\text{tot}} = \frac{\mu_m \times A \times 10^{24}}{N_A} \quad \text{(barn/atom)}$$  \hspace{1cm} (5.6)

where, $\mu_m$ - mass absorption coefficient

A - Atomic weight of sample

$N_A$ - Avogadro’s number

The values of total photon interaction cross-section for Ni$_{0.3}$Zn$_{0.5}$Cu$_{0.2}$Fe$_2$O$_4$ composite spinel ferrite with varying collimator diameter are given in tables 5.1, 5.2, 5.3 and 5.4, and the variation of total photon interaction versus photon energy for collimator diameter 0.2 cm to 0.5 cm is shown in Fig 5.4. It is evident from figure 5.4 that as photon energy increases, the total photon interaction cross-section decreases.

5.3.5 Total electronic cross-section

The total electronic cross-section for Ni$_{0.3}$Zn$_{0.5}$Cu$_{0.2}$Fe$_2$O$_4$ composite spinel ferrite was calculated by using the following relation [18]:

$$\sigma_{\text{ele}} = \frac{1}{N_A} \sum \frac{f_i A_i \times \mu_i}{Z_i x \rho} \quad \text{5.7}$$

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$_2$O$_4$ composite spinel ferrite was used to calculate the total electronic cross-section ($\sigma_{\text{ele}}$) and are listed in tables 5.1, 5.2, 5.3 and 5.4 for varying diameter of collimator.
The variation of total electronic cross-section as a function of energy is shown in Fig 5.5.

From Fig 5.5, it is observed that the total electronic cross-section decreases with increasing photon energy as expected.

5.3.6 Effective atomic number

The effective atomic number parameter has a physical meaning and allows many characteristics of material to be visualized with a number. Several attempts have been made to determine the effective atomic number ($Z_{\text{eff}}$) for partial and total gamma ray interaction in composite material [19-22]. In account to make use of fact that, scattering and attenuation of gamma radiation are related to the density and effective atomic number of the material. The total atomic cross-section and electronic cross-section are related to the effective atomic number $Z_{\text{eff}}$ of the compound through following relation; our results are in analogous with those reports in the literature:

$$Z_{\text{eff}} = \frac{\sigma_{\text{tot}}}{\sigma_{\text{ele}}} \quad 5.8$$

Using the values of $\sigma_{\text{tot}}$ and $\sigma_{\text{ele}}$, the values of effective atomic number were calculated for various energy and collimator diameter for Ni$_{0.3}$Zn$_{0.5}$Cu$_{0.2}$Fe$_2$O$_4$ spinel ferrite composite. The values of effective atomic number for collimators of various diameters are listed in tables 5.1, 5.2, 5.3 and 5.4. The values of effective atomic number $Z_{\text{effective}}$ of Ni$_{0.3}$Zn$_{0.5}$Cu$_{0.2}$Fe$_2$O$_4$ composite spinel ferrite were graphically shown in Fig 5.6 as a function of photon energy. From Fig 5.6, it is observed that $Z_{\text{eff}}$ remains almost constant in the energy range 0.360 MeV to 1.33 MeV, perhaps in lower energy region we may obtain variation in $Z_{\text{eff}}$ values.
The variation of $Z_{\text{eff}}$ depends on the composition of composite and their properties, and range of atomic number of the elements from which the compound is composed. Fig 5.6 indicates that $Z_{\text{eff}}$ is directly proportional to the atomic number of the elements.

### 5.4 Conclusion

In this work, spinel ferrite composite of great importance, was successfully synthesized by standard ceramic technique. Single phase formation of $\text{Ni}_{0.2}\text{Zn}_{0.5}\text{Cu}_{0.3}\text{Fe}_{2}\text{O}_4$ composite was confirmed by X-ray diffraction technique. 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 decrease significantly with increase in photon energy while effective atomic number remains almost constant for the entire energy studied. The effect of collimator diameter shows that as collimator diameter increases from 0.2 cm to 0.5 cm, linear attenuation coefficient, mass attenuation coefficient, total photon interaction cross-section, and total electronic cross-section all increases. The theoretical and experimental value of mass attenuation coefficient agrees closely with each other. The deviation in these two values increases with collimator diameter. However, the best agreement in the values of theoretical and experimental mass attenuation coefficient was observed for 0.2 cm collimator diameter. The effective atomic number remains almost same for all the photon energy ranging from 0.360 MeV to 1.33 MeV.

The mass attenuation coefficient of the prepared spinel ferrite composite is high compared to other composite materials. Therefore, this spinel ferrite composite can be used for shielding purpose.
REFERENCES


Fig 5.1 X-ray diffraction patterns of spinel ferrite composite

\[ \text{Ni}_{0.3} \text{Zn}_{0.5} \text{Cu}_{0.2} \text{Fe}_2 \text{O}_4 \].
Table 5.1

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}) and effective atomic number (Z_{eff}) for collimated photon beam of 0.2cm diameter in the energy range (0.360 MeV-1.33 MeV) for Ni_{0.3}Zn_{0.5}Cu_{0.2}Fe_{2}O_{4} ferrite composite.

<table>
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<th>Energy (MeV)</th>
<th>µ (cm^{-1})</th>
<th>µ/ρ (cm^{2}/gm)</th>
<th>Percent. Devi.</th>
<th>σ_{total} (barn/atom)</th>
<th>σ_{ele}</th>
<th>Z_{eff}</th>
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<td>Theo.</td>
<td>Expt.</td>
<td></td>
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<td>1.280</td>
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Table 5.2

Experimentally measured values of linear attenuation coefficient ($\mu$), mass attenuation coefficient ($\mu/\rho$), total photon interaction cross-section ($\sigma_{\text{total}}$), total electronic cross-section ($\sigma_{\text{ele}}$) and effective atomic number ($Z_{\text{eff}}$) for collimated photon beam of 0.3 cm diameter in the energy range (0.360 MeV-1.33 MeV) for Ni$_{0.3}$Zn$_{0.5}$Cu$_{0.2}$Fe$_2$O$_4$ ferrite composite.

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<th>Energy (MeV)</th>
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<th>$\mu/\rho$ (cm$^2$/gm)</th>
<th>Percent Devi.</th>
<th>$\sigma_{\text{total}}$ (barn/atom)</th>
<th>$\sigma_{\text{ele}}$</th>
<th>$Z_{\text{eff}}$</th>
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Table 5.3

Experimentally measured values of linear attenuation coefficient ($\mu$), mass attenuation coefficient ($\mu/\rho$), total photon interaction cross-section ($\sigma_{\text{total}}$), total electronic cross-section ($\sigma_{\text{ele}}$) and effective atomic number ($Z_{\text{eff}}$) for collimated photon beam of 0.4 cm diameter in the energy range (0.360 MeV-1.33 MeV) for Ni$_{0.3}$Zn$_{0.5}$Cu$_{0.2}$Fe$_{2}$O$_{4}$ ferrite composite.

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<th>Energy (MeV)</th>
<th>$\mu$ (cm$^{-1}$)</th>
<th>$\mu/\rho$ (cm$^2$/gm)</th>
<th>Percent Devi.</th>
<th>$\sigma_{\text{total}}$ (barn/atom)</th>
<th>$\sigma_{\text{ele}}$</th>
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Table 5.4

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}) and effective atomic number (Z_{eff}) for collimated photon beam of 0.5 cm diameter in the energy range (0.360 MeV-1.33 MeV) for Ni_{0.3}Zn_{0.5}Cu_{0.2}Fe_{2}O_{4} ferrite composite.

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<th>Energy (MeV)</th>
<th>μ (cm^{-1})</th>
<th>μ/ρ (cm²/gm)</th>
<th>Percent. Devi.</th>
<th>σ_{total} (barn/atom)</th>
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Fig 5.2 Plots of photon attenuation coefficient $\mu$ (cm$^{-1}$) v/s photon energy in MeV for Ni$_{0.3}$Zn$_{0.5}$Cu$_{0.2}$Fe$_2$O$_4$ ferrite composite (0.2 cm to 0.5 cm collimation).
Fig 5.3 Plots of photon attenuation coefficient $\mu/\rho$ (cm$^2$/gm) vs photon energy in MeV for Ni$_{0.3}$Zn$_{0.5}$Cu$_{0.2}$Fe$_2$O$_4$ ferrite composite (0.2 cm to 0.5 cm collimation).
Fig 5.4 Plots of photon attenuation coefficient $\sigma_{\text{total}}$ (barn/atom) vs photon energy MeV for Ni$_{0.3}$Zn$_{0.5}$Cu$_{0.2}$Fe$_2$O$_4$ ferrite composite (0.2 cm to 0.5 cm collimation).
**Fig 5.5** Plots of photon attenuation coefficient $\sigma_{\text{ele}}$ vs photon energy in MeV for Ni$_{0.3}$Zn$_{0.3}$Cu$_{0.2}$Fe$_2$O$_4$ ferrite composite (0.2 cm to 0.5 cm collimation).
Fig 5.6 Plots of photon attenuation coefficient $Z_{\text{effective}}$ vs photon energy MeV for Ni$_{0.3}$Zn$_{0.5}$Cu$_{0.2}$Fe$_{2}$O$_{4}$ ferrite composite (0.2 cm to 0.5 cm collimation).