Theoretical calculation of mass attenuation coefficient and radiation shielding parameters of WO$_3$-TeO$_3$ glasses

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Abstract. In this study, the photon interactions of WO$_3$-TeO$_3$ glass system have been calculated using WinXCom program at energy 1 keV-10$^3$ keV. The mass attenuation coefficient ($\mu_m$) and the partial interactions were presented. The results show that the values of $\mu_m$ increased toward the decrease of gamma ray energies, indicates the dependence of the mass attenuation coefficient values on the photon energy. The partial interactions found that three energy ranges relative to the partial processes photoelectric absorption, Compton scattering and coherent scattering. These glass sample was observed that the photoelectric absorption found to be the main interaction of energy range. The discontinuous of glass sample illustrate that it occur from photoelectric absorption edge of sample element compositions at low photon energies. The coherent scattering found to be significant at low photon energy and rapidly decreases with increasing of photon energy but the Compton scattering, the values was slightly increase with increasing of photon energy.

Keywords: borate glasses; radiation shielding parameter; the mass attenuation coefficient; partial interaction

1. Introduction

Nowadays, glass science and technology is an important material for several fields such as engineering, science, medical, artificial gemstone and applications in medicine. Tellurite-based (TeO$_2$) glasses have been interest to glass scientists due to their many technological applications such as optical memory, gas sensors and optical devices including to application in radiation shielding [1]. WO$_3$-TeO$_3$ glass is particularly interest as this conditional glass network former has a low melting point and can form a glass when combined with alkali metal ions, transition metal ions, and even rare earth ions [2]. WO$_3$ is very interesting material to candidate for gamma shielding materials because the heavy atomic number (74) and high density (7.16 g/cm$^3$). Many characterization and investigation fields of photon interaction have been reported, J. Kaewkhao in 2008 was studies on determination of effective atomic numbers and effective electron densities for Cu/Zn alloy [2]. P. Limkitjaroenporn in 2011 was studies on physical, optical, structural and gamma-ray shielding properties of lead sodium borate glasses [3]. S. Gupta in 2014 was studies on gamma-rays absorption studies of garnet series of gemstones at 1 Kev to 100 GeV: theoretical calculation [4]. Above mentioned, it is seen that the radiation shielding parameters are very
important to study in various fields and is potential useful in development of semi-empirical formulations of high accuracy. Especially the mass attenuation coefficient ($\mu_m$) parameter, it is momentous to determination of these value for radiation shielding materials because of the theoretical data shows probability of interaction and this data can be used for development and characterizations the materials [5]. The mass attenuation coefficient is basic quantity to determining the attenuation of X-rays and gamma rays in matters and required for shield design [6].

This research have been investigation the photon interaction of $40\text{WO}_3:60\text{TeO}_3$ (mol%) glass system theoretical calculation using WinXCom program at energy of $1 \text{ keV}-10^3 \text{ keV}$. The mass attenuation coefficient ($\mu_m$) and the partial interactions were presented.

2. Theoretical calculation

For theoretical calculation, the interaction coefficients (fractions by weight or partial densities) and total attenuation coefficients for any chemical compound or homogeneous mixture of shielding materials are obtained as weighted sums over the corresponding coefficients for elements. The mass attenuation coefficients ($\mu_m / \rho$) can be given by the following weighted summation [7]:

$$\mu / \rho = \sum_i w_i (\mu / \rho)_i,$$

where $\rho$ is the mass density of the sample and $w_i$ and $(\mu / \rho)_i$ are the fraction by weight and mass attenuation coefficient of $i^{th}$ constituent, respectively. The mass attenuation coefficients for total and partial interactions have been obtained from the WinXCom program [7]. Equation 1, this well-known mixture rule is valid with the assumption that the effects of molecular binding and the chemical and crystalline environment are negligible. For a chemical compound, the fraction by weight is given by [7]:

$$w_i = \frac{a_i A_i}{\sum_f a_f A_f},$$

where $a_i$ and $A_i$ are the number of formula units and the atomic weight of the $i^{th}$ element, respectively.

The $\mu / \rho$ have been compared with the author materials such as scintillation crystal and radiation shielding glass.

3. Results and discussions

The photon interactions in formula of $40\text{WO}_3:60\text{TeO}_3$ glass system from WinXcom program at energy range of $1 \text{ keV}-10^3 \text{ keV}$ as shown in Figure 2-5. Figure 2. The photoelectric interaction were decreases with increasing of photon energy and these values found to be the main interaction at energy.
range of 1 keV-300 keV. Furthermore, the glass sample found that at the low energies discontinuities correspond to photoelectric absorption edges of the tungsten (W) and Tellurium (Te) elements. Figure 3. show the coherent scattering interactions were found very small effects on WO$_3$-TeO$_3$ glass system in this energy range. However, these value is not significant for analysis in this glass sample. The incoherent scattering (Compton) interaction found to be the main interaction after energy range of 300 keV as shown in Figure 4.

![Figure 2. Photoelectric absorption of WO$_3$-TeO$_3$ glass](image1)

![Figure 3. Coherent scattering of WO$_3$-TeO$_3$ glass](image2)
Figure 4. Incoherent scattering of WO$_3$-TeO$_3$ glass

Figure 5. Total mass attenuation coefficient of WO$_3$-TeO$_3$ glass

The mass attenuation coefficients of WO$_3$-TeO$_2$ glass were calculated by WinXCom program at energy range of 1 keV-10$^3$ keV as shown in Figure 5. It has been found that the mass attenuation coefficients was decreased with increasing gamma energy reflected to the decreasing photon interaction probability at these energy. Table 1 show the comparative total mass attenuation coefficient of WO$_3$-TeO$_2$ glass with GAGG scintillator (gadolinium aluminium gallium garnet (Gd$_3$Al$_5$Ga$_3$O$_{12}$:GAGG: Ce)), bismuth silicate glass and bismuth borate glass. It is seen that WO$_3$-TeO$_3$ glass sample were shown the highest value when compared with GAGG scintillator, bismuth silicate glass and bismuth borate glass reflected to the possibility of these sample for application in radiation shielding materials [9-10].

Table 1 comparative total mass attenuation coefficient of WO$_3$-TeO$_3$ glass with other materials [9-10].

| Gamma energy (keV) | Total mass attenuation coefficient (cm$^2$/g) |
|--------------------|---------------------------------------------|
|                    | GAGG | Bismuth silicate glass | Bismuth borate glass | WO$_3$: TeO$_3$ glass |
| 662                | 0.0799 | 0.0868 | 0.0855 | 0.09113 |
4. Conclusion

The study of the photon interactions of WO$_3$-TeO$_3$ glass system have been calculated using WinXCom program at energy 1 keV-10$^3$ keV. The results show that the values of $\mu_m$ increased toward the decrease of gamma ray energies, indicates the dependence of the mass attenuation coefficient values on the photon energy. The comparative total mass attenuation coefficient of WO$_3$-TeO$_3$ glass with GAGG scintillator, bismuth silicate glass and bismuth borate glass. It is seen that WO$_3$-TeO$_3$ glass sample shown the highest value when compared with GAGG scintillator, bismuth silicate glass and bismuth borate glass. The partial interactions found that three energy ranges relative to the partial processes photoelectric absorption, Compton scattering and coherent scattering. These glass sample was observed that the photoelectric absorption found to be the main interaction of lower energy range of 1 keV-300 keV. The discontinuous of glass sample illustrate that it occur from photoelectric absorption edge of sample element compositions at low photon energies. The coherent scattering found to be significant at low photon energy and rapidly decreases with increasing of photon energy but the Compton scattering, the values was slightly increase with increasing of photon energy.

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