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Studies on effective atomic numbers, electron densities from mass attenuation coefficients near the K edge in some samarium compounds

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HIGHLIGHTS

- The effective atomic numbers and electron densities determined for some samarium compounds from total mass attenuation coefficients near the K edge.
- The measurements performed using secondary excitation geometry and a Si(Li) detector.
- The experimental results compared with the theoretical calculation.

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ABSTRACT

The effective atomic numbers and electron densities of some samarium compounds were determined using the experimental total mass attenuation coefficient values near the K edge in the X-ray energy range from 36.847 up to 57.142 keV. The measurements, in the region from 36.847 to 57.142 keV, were done in a transmission geometry utilizing the $K\alpha_2$, $K\alpha_1$, $K\beta_1$ and $K\beta_2$ X-rays from different secondary source targets excited by the 59.54 keV gamma-photons from an Am-241 annular source. This paper presents the first measurement of the effective atomic numbers and electron densities for some samarium compounds near the K edge. The results of the study showed that the measured values were in good agreement with the theoretically calculated ones.

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1. Introduction

Samarium, which is a light rare earth element, has a bright silver brightness and is reasonably stable in air. It is found with other rare earth elements in minerals including monazite and bastnaesite. Samarium and/or its compounds have played an important role in the production of permanent magnets. Moreover, they are used in X-ray lasers, precision guided weapons, white-noise production in stealth technology, the absorption of the infrared rays in the optical glasses, and the industries of cinema and electronics.

The mass attenuation coefficient, effective atomic number and electron density are the basic quantities required in determining the penetration of X-ray or γ-photons in a material. A single atomic number is used to represent an element. In composite materials such as, alloys, soil, plastic, biological materials for photon interaction, the atomic number cannot be represented uniquely across the entire energy region, as in the case of elements, by a single number. This number in composite materials is called effective atomic number, and it varies depending on energy (Guru Prasad et al., 1998). The effective atomic number of a material is not constant. The effective atomic number has a physical meaning and allows many characteristic of material to be visualized with a number. The electron density and effective atomic number parameters can be derived from the mass attenuation coefficient at any given energy. The electron density is defined as the numbers of electrons per unit mass. The accurate values of effective atomic number and electron density are required for some of the fields such as nuclear and radiation physics, calculations of absorbed dose in radiotherapy, agricultural and biological industries.

Several investigators have made extensive the effective atomic number and electron density studies in variety of complex materials such as compounds, crystals, alloys, semiconductors, organic

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and inorganic compound. Moreover, in literature, there are only few reports on the effective atomic numbers around the absorption edge, and there are not any reports for samarium compounds around the K shell absorption edge. Gowda et al. (2005) determined the effective atomic numbers and electron densities of some amino acids and sugars using the measured total attenuation cross sections at the energies 30.8, 35.0, 81.0, 145, 276.4, 302.9, 356, 383.9, 661.6, 1173 and 1332.5 keV. Han and Demir (2010) determined the total atomic and electronic cross sections, effective atomic and electron densities for Au and $Au_{99}Be_1$, $Au_{88}Ge_{12}$, $Au_{95}Zn_5$ alloys using the obtained mass attenuation coefficients at 59.5 and 88.0 keV photon energies. Latha et al. (2012) obtained the effective atomic numbers of various combinations of elements with $13 \leq Z \leq 50$ using the mass attenuation values at the 59.5 keV photon energy. Cevik et al. (2008) determined the effective atomic numbers and electron densities for CdSe, CdTe semiconductor utilizing the mass attenuation coefficients at different energies from 9.7 to 87.3 keV using the secondary excitation method. Özdemir and Kurudirek (2009) determined the total mass attenuation coefficients, effective atomic numbers and effective electron densities for 21 different organic and inorganic compounds at 59.54 keV using a narrow beam good geometry set-up. Kaewkhao et al. (2008) determined the mass attenuation coefficients, total interaction cross sections, effective atomic numbers, effective electron densities and photon mean free path of the Cu/Zn alloy on the basis of the mixture rule at 356, 511, 662, 835 and 1275 keV gamma-ray energies. Han and Demir (2009) determined the total mass attenuation coefficients, total atomic and electronic cross sections, effective atomic and electron numbers for Fe_xNi_{1-x}, $Fe_xCr_yNi_{(1-x-y)}$ and Ni_xCr_{1-x} alloys at 22.1, 25.0, 59.5 and 88.0 keV photon energies using transmission arrangement. Some measurements on organic compounds for total mass attenuation coefficients, total photon interaction cross sections, effective atomic numbers and electron densities at the 59.54 keV were performed by Sidhu et al. (2012). They reported that the values of Z_{eff} varies very little with the compound considered as most of the organic compounds used as samples consists of low Z constituent elements. To observe the doping effect and varying concentration of impurities for crystals on effective atomic number, İçelli (2009) determined the effective atomic numbers for InSe and InSe having different holmium concentrations measured in the energy region 15.746 – 40.930 keV using a Si(Li) detector. Polat et al. (2011) measured some photonic energy absorption parameters such as mass attenuation coefficients, molecular, atomic, electronic cross sections, effective atomic numbers and electron densities for some barium compounds around the K absorption edge using a secondary excitation method. Polat and İçelli (2010a) determined the effective atomic numbers of Ag_2O_3, $CsHCO_3$, $Ba(OH)_2$ and La_2O_3 in the X-ray energy range from 25 up to 39 keV using a Si(Li) detector, and they observed that the Z_{eff} was affected from the presence of absorption edge. In order to determine atomic, molecular and electronic cross sections, effective atomic number, electron density and absorption jump factor for some cerium compounds, Polat and İçelli (2010b) measured the mass attenuation coefficients using transmission method in the energy ranging from 39 keV up to 42 keV.

In this study, the effective atomic numbers and electron densities of some samarium compounds were determined using the experimental total mass attenuation coefficient values near the K edge in the X-ray energy range from 36.847 keV up to 57.142 keV. The measurements were made using a Si(Li) detector and secondary excitation method. To the best of our knowledge, the effective atomic number and electron density values for some samarium compounds have been measured near the K edge for the first time.

2. Theory

In the composite materials, the interaction of gamma or X-rays with the material is related to the effective atomic number, the electron density values of composite materials and the energy of incident photons. In this study, the total atomic ($\sigma_{t,a}$) and molecular ($\sigma_{t,m}$) cross sections were obtained using the measured mass attenuation coefficients (μ/ρ), and the electronic cross sections ($\sigma_{t,e}$) were theoretically calculated. Then, the effective atomic numbers were determined using the total atomic and electronic cross sections, and the effective atomic numbers (Z_{eff}) values were used to calculate the electron densities (N_E). The effective atomic numbers and the electron densities were determined for some Sm compounds in the energy range from 36.847 to 57.142 keV from the experimental values of total mass attenuation coefficients.

The total mass attenuation coefficient (μ/ρ) can be determined using the Beer–Lambert law,

$$\mu/\rho = \frac{1}{\rho x} ln\left(\frac{I_0}{I}\right) \tag{1}$$

where μ/ρ is the total mass attenuation coefficient, ρ is the density of matter, x is the thickness of matter, I_0 and I are the incident photons and transmitted photons intensities, respectively. For any mixture, chemical compound or alloy the mass attenuation coefficient is determined by,

$$(\mu/\rho)_{comp} = \sum_i W_i (\mu/\rho)_i \tag{2}$$

here W_i is the weight fraction, and $(\mu/\rho)_i$ is the mass attenuation coefficient of the ith constituent element. For a chemical compound, the fraction by weight is given by,

$$W_i = \frac{n_i A_i}{\sum_j n_j A_j} \tag{3}$$

in the equation, A_i is the atomic weight of the ith element, and n_i is the number of atoms of ith constituent element in the compound.

Some absorption parameters such as molecular, atomic cross sections, effective atomic number and electron density can be calculated using the mass attenuation coefficient. The molecular cross section for material can be determined using following equation (Singh et al., 2007),

$$\sigma_{t,m} = \frac{1}{N}(\mu/\rho)_{comp} \sum_i (n_i A_i) \quad (\text{cm}^2\text{molecule}^{-1}) \tag{4}$$

here N is the Avogadro number, n_i is the number of atoms of the ith element in a compound, A_i is the atomic weight of the ith element in a compound and $(\mu/\rho)_{comp}$ is the total mass attenuation coefficient. The total atomic cross section can be determined from the molecular cross section (Singh et al., 2007),

$$\sigma_{t,a} = \sigma_{t,m} \frac{1}{\sum_i n_i} (\text{cm}^2\text{atom}^{-1}) \tag{5}$$

The total electronic cross section for the element is determined by the following formula (Singh et al., 2007),

$$\sigma_{t,e} = \frac{1}{N} \sum_i \frac{f_i A_i}{Z_i} (\mu/\rho)_i (\text{cm}^2\text{electrons}^{-1}) \tag{6}$$

where N is the Avogadro number, f_i is the fractional abundance of the ith element with respect to number of atoms, A_i is the atomic weight for the ith element, Z_i is the atomic number for the ith element and $(\mu/\rho)_i$ is the total mass attenuation coefficient of the ith element in a compound.

The effective atomic number (Z_{eff}) is related to the total atomic and electronic cross section through the following equation (Singh

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