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Mass attenuation coefficients, effective atomic and electron numbers of Ti and Ni alloys

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ABSTRACT

The total mass attenuation coefficients (μ_m), for Ti, Ni and Ti_xNi_{1-x}($x = 0.7, 0.6, 0.5, 0.4$ and 0.3) alloys were measured at 22.1, 25.0, 59.5 and 88.0 keV photon energies. The samples were irradiated with 10 mCi Cd-109 and 100 mCi Am-241 radioactive point source using transmission arrangement. The γ- and X-rays were counted by a Si(Li) detector with a resolution of 160 eV at 5.9 keV. Total atomic and electronic cross-sections (σ_t and σ_e), effective atomic and electron numbers (Z_{eff} and N_{eff}) were determined experimentally and theoretically using the obtained μ_m values for Ti_xNi_{1-x} alloys. The theoretical μ_m values of each alloy were estimated using mixture rule. The experimental values were compared with the calculated values for all samples.

1. Introduction

The 3d transition metals and their alloys have played an important role in the development of modern technology, and knowledge of their physical parameters such as mass attenuation coefficients, total atomic and electronic cross-sections, effective atomic and electron numbers is very important for understanding their physical properties. Since the mass attenuation coefficients are important in fundamental physics and many applied fields, the accurate values of mass attenuation coefficients for X- and γ-rays in several materials are essential for some fields such as, nuclear, radiation physics, radiation dosimetry, biological, medical, agricultural and industrial. Recently, there are a great number of experimental and theoretical investigations of mass attenuation coefficient (μ_m) (Hubbell, 1982; Berger and Hubbell, 1987; Hubbell and Seltzer, 1995; Wang et al., 1995; Khanna et al., 1996). Hubbell (1982) presented tables of μ_m values for 40 elements and 45 mixtures and compounds over the energy range from 1 keV to 20 MeV. These tables were renewed with tabulation for all elements in the atomic range $1 \leq Z \leq 92$ and 48 additional substances of dosimetric interest by Hubbell and Seltzer (1995) and Berger and Hubbell (1987). Wang et al. (1995) measured systematically the μ_m values in the range of X-ray energies between 1.486 keV and 15.165 keV for SiH_4 and between 8.041 keV and 29.109 keV for Si. Khanna et al. (1996) measured γ-ray attenuation coefficients in some heavy metal oxide borate glasses at 662 keV. Orlic et al. (1999) published μ_m values for photon energies between 100 eV and 1000 MeV. Abdel-Rahman et al. (2000) determined γ-rays attenuation coefficients for perspex, bakelite, paraffin, *Al*, *Cu*, *Pb* and *Hg* at three different γ-ray energies (59.54, 661.6 and 1332.5 keV). The μ_m values for 22 high purity elemental materials (*C*, *Al*, *Ti*, *V*, *Mn*, *Fe*, *Co*, *Ni*, *Cu*, *Zn*, *Zr*, *Nb*, *Mo*, *Rh*, *Pd*, *Ag*, *Cd*, *In*, *Ta*, *Pt*, *Au* and *Pb*) were measured in the X-ray energy obtained by a variable-energy X-ray source range from 13 keV to 50 keV using a high purity germanium detector having thin Be window (Angelonea et al., 2001). Turgut et al. (2002, 2005) measured μ_m values for the elements Co, Mn, Fe and some of their compounds Co_2O_3, $CoCl_2{\cdot}6H_2O$, $CoSO_4$, $CoSO_4{\cdot}7H_2O$, $MnCl_2{\cdot}4H_2O$, $MnCO_3$, $KMnO_4$, $MnCl_2{\cdot}2H_2O$, FeF_3, Fe_2O_3, $FeCl_2{\cdot}4H_2O$, $FeCl_3{\cdot}2NH_4Cl{\cdot}H_2O$ at different energies between 4.508 and 11.210 keV using a secondary excitation method. The μ_m values of n-type *InSe*, *InSe*:*Gd*, *InSe*:*Ho*, *InSe*:*Er* single crystals and of *InSe* single crystals having different Ho concentrations were measured using a Si(Li) detector and energy dispersive X-ray fluorescence system in the energy region 15.746–40.930 keV X-rays (İcelli et al., 2005; Erzeneoglu et al., 2006). The X-ray μ_m values of silver in the 15–50 keV energy range with a level of uncertainty between 0.27% and 0.4% away from the K-edge were evaluated by Tran et al. (2005). The X-ray attenuation coefficients for materials containing elements from hydrogen to calcium were measured using characteristic X- and γ-rays with energies 32–66 keV produced by X-ray fluorescence using a secondary excitation method, and 140 keV obtained

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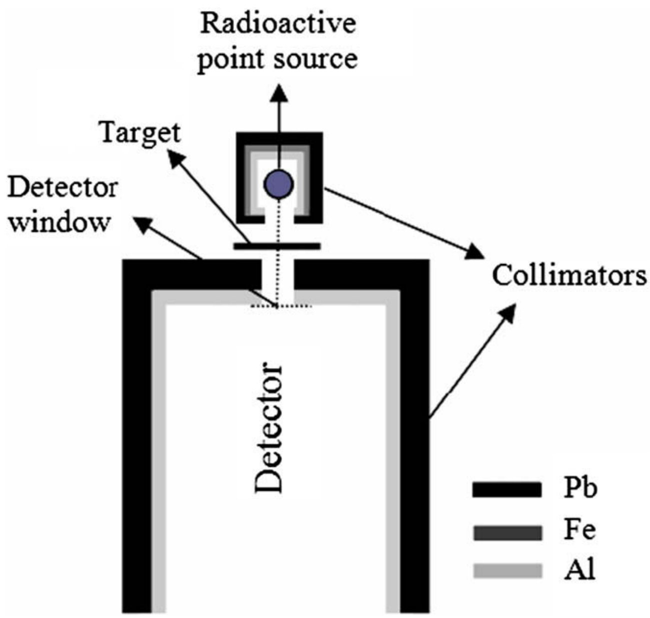

Fig. 1. Experimental setup.

from an unsealed Tc source, respectively (Midgley, 2005). Rettschlag et al. (2007) determined plutonium photon μ_m values by using a collimated-beam transmission method in the energy range from 60 keV to 2615 keV.

The scattering and absorption of γ- and X-rays are related to the density and atomic number of an element. As for composite materials, they are also related to effective atomic number (Z_{eff}). As partial interaction cross-section is dependent on the composite material of elements, a single atomic number being a characteristic of element cannot describe the atomic number of composite material in the entire energy range. This new number for composite materials is called to be the effective atomic number (Z_{eff}) and varies with the energy. The Z_{eff} is a convenient parameter for representing the attenuation of X-rays in a complex medium and particularly for the calculation of the dose in radiation therapy (Jackson and Hawkes, 1981). Some works to determine the Z_{eff} values of composite materials have been reported in the literature. Cevik et al. (2006) and Cevik and Baltas (2007) have measured thicknesses, μ_m and Z_{eff} values for *CuInSe*$_2$ semiconductor; and μ_m values and electron densities for *BiPbSrCaCuO* superconductor at different energies. Baltas et al. (2005, 2007) have measured μ_m and Z_{eff} values for *YBaCuO* and *BiPbSrCaCuO* superconductors at 511 keV, 661 keV and 1274 keV energies and for *MgB*$_2$ superconductor at some energy between 14.1 keV and 29.7 keV. Kumar and Reddy (1997) have calculated Z_{eff} values for different materials of dosimetric interest for total photon interaction in the energy region 1 keV–20 MeV. Effective atomic numbers for photon energy absorption (Z_{PEAeff}) and effective atomic numbers for photon interaction (Z_{PIeff}) of some low-Z substances of dosimetric interest in the energy region of 1 keV–20 MeV have been calculated (Shivaramu et al., 2001). Photon attenuation coefficients in certain tissue equivalent compounds, perspex, polyethylene, polycarbonate and teflon are also measured at energies 13.37, 17.44, 22.10, 32.06 and 44.23 keV; and the Z_{eff} values for total photon interaction for these compounds are derived from the measured coefficients (Parthasaradhi et al., 1992).

In the present work, the total mass attenuation coefficients (μ_m) for Ti, Ni metals and alloys at 22.1, 25.0, 59.5 and 88.0 keV photon energies are measured experimentally and calculated theoretically. Total atomic and electronic cross-sections (σ_t and σ_e), the effective atomic and electron numbers (Z_{eff} and N_{eff}) for these materials have been calculated using the measured μ_m values. Also, the variations of investigated parameters versus photon energy were graphically

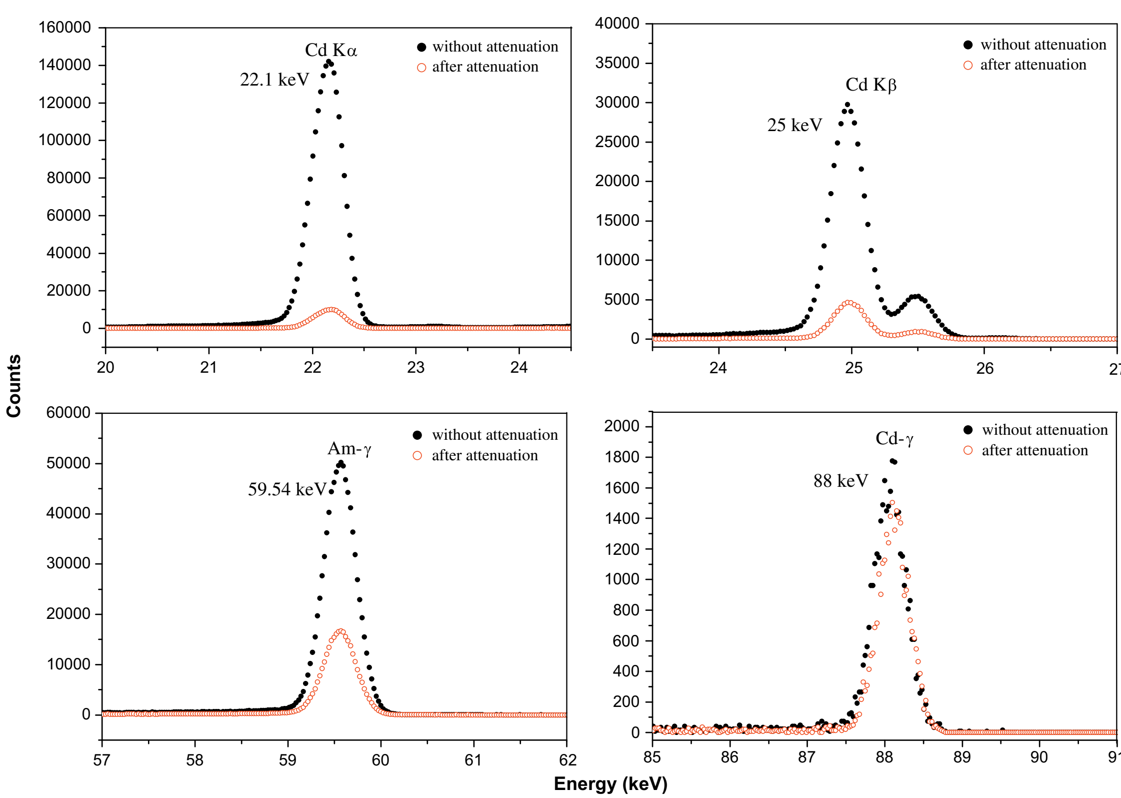

Fig. 2. Typical spectrum of X- and γ-rays without attenuation and attenuated by $Ti_{0.7}Ni_{0.3}$ alloy.