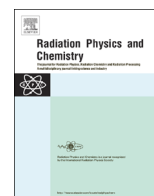




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Radiation Physics and Chemistry

journal homepage: www.elsevier.com/locate/radphyschem

Total photon attenuation coefficients in some rare earth elements using selective excitation method

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HIGHLIGHTS

- Total mass attenuation coefficients were measured for La, Nd, Sm, Gd and Dy.
- Measured energy is 30–53 keV.
- Accurate knowledge of attenuation coefficients is useful for shielding purpose.
- Deviations at energies above K edge support the EXAFS effect.

ARTICLE INFO

Article history:

Received 24 December 2013

Accepted 16 June 2014

Available online 24 June 2014

Keywords:

Mass attenuation coefficients

Selective excitation method

Rare earth elements

Mixture rule

K edge

Extended X-ray Absorption Fine Structure

ABSTRACT

The total mass attenuation coefficients were measured in the elements La, Nd, Sm, Gd and Dy belonging to rare earth region in the energy range 30–55 keV by employing the selective excitation method. This method facilitates selection of excitation energies near the K edge. The present experimental results were compared with the theoretical values due to Chantler and XCOM.

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1. Introduction

Accurate measurement of total mass attenuation coefficients is of great importance for basic studies of atomic, nuclear, molecular, radiation and medical physics. The accurate knowledge of attenuation coefficients is useful for shielding purpose. The impact of computerized tomography (CT) in diagnostic medicine is another interesting area that demands accurate knowledge of attenuation coefficients in biological matrices so that the differentiation of tissues in the reconstruction of images by the axial tomographic technique can be improved.

These total mass attenuation coefficients have long been used for non-destructive analysis of elemental concentrations of various types of samples such as archaeological, biological, medical, geological, industrial, and environmental samples. These are also important for developing more reliable theoretical models for describing the fundamental inner shell ionization processes. Moreover, comparison of measured total mass attenuation coefficients with theoretical

values provides a check on the validity of various physical parameters such as fluorescence yields, jump ratios and X-ray emission rates.

Umesh et al. (1992) have determined the total attenuation coefficients in elements Ce, Pr, La, Nd, Sm, Gd, Dy, Ho and Er at 323 keV using a ^{51}Cr radioactive source. The difference between the total attenuation coefficients of NaNO_3 and NaNO_2 yielded the attenuation coefficient of oxygen and using this experimental value they deduced total attenuation coefficients of Ce, Pr, Na, Nd, Sm, Gd, Dy, Ho and Er from the attenuation coefficients of the respective oxides assuming the validity of the sum rule.

Jahagirdar et al. (1996) measured total mass attenuation coefficients in some rare earth elements in the range $58 \leq Z \leq 66$ at energies 123.6 keV and 145.4 keV using ^{57}Co and ^{141}Ce isotopes respectively. A NaI(Tl) spectrometer system was employed in their measurements. They employed compounds and derived the total mass attenuation coefficients of some elements. Their results are in good agreement with theoretical predictions, suggesting the validity of the sum rule.

Mallikarjuna et al. (2002) measured the total mass attenuation cross sections around the K edge of some rare earth elements. They compared their experimental values to those of Chantler (1995) and XCOM (2001).

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Kerur et al. (1994) measured the X-ray attenuation coefficients for several elements and compounds using a proportional counter system. They used ^{55}Fe and ^{65}Zn radioactive isotopes. They measured the attenuation coefficients at K_{α} average energies of 5.989 keV and 8.041 keV. Their results indicate the non-validity of mixture rule above the edge and also below the edge. Their results show both negative and positive deviations near the edge. They attributed the oscillatory percentage deviations as contributions due to EXAFS and the effect of chemical environment.

Kerur et al. (2006) also measured the L X-ray mass attenuation coefficients for some rare earth compounds at average energies of 5.947 and 8.118 keV. They reported large deviations between experimental and theoretical values at energies close to L-absorption edge. Thus they concluded that mixture rule breaks down close to absorption edge. According to them, the percentage deviations for the rare earth compounds of Sm, Eu, Gd, Tb and Dy may be attributed to the presence of 'ups' and 'trough' in the fine structure. They observed that the percentage difference increased on approaching the near edge as expected from EXAFS studies.

A thorough survey of the literature (Abdullahi et al., 2008; Kerur et al., 2006; Ramachandran et al., 2006; Tartari et al., 1998; Roy et al., 1997) showed that the total mass attenuation coefficients have been determined in the rare earth elements only at certain limited energies.

In the present work by employing selective excitation method the total mass attenuation coefficients were measured in some rare earth elements La, Nd, Sm, Gd and Dy at several energies where no other experimental data is available for all energies employed in the present work.

2. Experimental details

The experimental setup used in the present investigation is based on the narrow-beam geometry. The radioactive source emitting X-rays and gamma rays used in the present investigation was obtained from Radio Chemical Center, Amersham. The experimental arrangement consists of an HPGe detector, whose FWHM is 700 eV at 22 keV energy, Canberra model GX 1018. The signal from the detector was amplified and processed in a PC-based multi-channel pulse height analyzer. The geometry used for the determination of total mass attenuation coefficients is shown in Fig. 1

For the present investigations, a modified narrow beam geometry consisting of 3 slits was designed and fabricated. Each slit has a diameter of 38 mm and by itself it is a sandwich of 3 slits of lead, copper and aluminum. This graded arrangement is popular in the literature to bring down the secondary X-rays generated in the slits to a non-interfering energy level of 1.5 keV (K X-rays of aluminum)

The slit towards the source has a central hole of 3 mm diameter. The slit towards the absorber has a central hole of 6 mm diameter and the slit towards the detector has a central hole of 8 mm diameter. The exciter was inclined at an angle of 45° to the source.

A thick, rigid PVC tube with inner diameter of 38 mm, outer diameter of 45 mm and length of about 250 mm is bisected longitudinally along the axis, to achieve axial symmetry along a length of 250 mm. The slits are fixed in the open channel of the PVC tube to form a good geometry for present investigations. This geometry is fixed to a lead shield cap of 6 mm thickness, inner diameter of 90 mm and outer diameter of 110 mm.

The sample is held at an angle of 45° with respect to the source and the angular orientation between the incident gamma ray and the emitted characteristic X-ray is 90° . This geometry is selected to avoid the interference of Compton scattered peak with the X-ray peaks of interest.

A very long-lived intense radioactive source ^{241}Am with 100 mCi is used as the primary source to obtain the characteristic X-rays of required energies for the present investigations from elements or their chemical compounds. The secondary X-rays, thus obtained, are employed in the place of radioactive sources in the modified narrow beam geometry setup. This enables selection of the primary photon beam energy near the K-absorption edges. Employing the characteristic X-rays thus produced in the range 30–53 keV the total photon attenuation coefficients were measured accurately in the oxides of the five elements Lanthanum, Neodymium, Samarium, Gadolinium and Dysprosium.

Table 1 furnishes the photon energies of several exciters and Barium source with 5 mCi employed in the present investigations. The average energy of $K_{\alpha 1}$ and $K_{\alpha 2}$ line is taken as energy of K_{α} line. The Barium source is attached to the first slit (shown in Fig. 1) which has 3 mm diameter.

In order to ensure that no photon from the primary source reached the detector directly a series of spectra were recorded for 10,000 s. Spectrum is recorded with geometry in position and the primary source removed. This shows constant average background of less than 5 counts per channel in the entire energy region 30–60 keV. Later another spectrum was recorded with shielded source in position without exciter. No appreciable count rate above the statistical error was observed. From the experimentally determined mass absorption coefficient, the elemental mass attenuation coefficients were obtained by subtracting the contribution of oxygen.

The required thickness for each absorber under investigation for a transmission between 1% and 10% is estimated with the help of the tabulations of Storm and Israel (1970). The absorbers were prepared by using the filter paper technique adopted by Kerur et al. (1993). The circular disks of 17 mm diameter used as absorbers were cut from Wattmann no. 1 filter paper and their weight W_1 is determined accurately with a microbalance. The uniformity of thickness is ensured by determining the attenuations at different positions. The disk is dipped in the solute and is dried in an electrical oven. The weight of the foil W_2 is also determined. These foils are stored in a desiccator to keep them dry. The mass of the deposit is obtained as $(W_2 - W_1)$.

After ascertaining the suitability of the experimental setup, the K X-ray spectra of different compounds selected in the present work were recorded at different energies. These spectra were recorded for sufficiently long time to obtain good statistical accuracy with and without absorbers. After recording the spectra of different compounds the areas under the K_{α} and K_{β} X-ray peaks were estimated using QXAS (Quantitative X-ray Analysis System) software package.

2.1. Derivation of total mass attenuation coefficient

The net counts under K_{α} and K_{β} peaks of the interested absorbers were extracted after subtraction of the background, with and without the absorber. Knowing the absorber thickness, the attenuation coefficient was calculated from the equation

$$I = I_0 e^{-\left(\frac{\mu}{\rho}\right)\rho x} \quad (1)$$

where μ is the linear attenuation coefficient (cm^{-1}), ρ is the density of the sample (g cm^{-3}), x is the thickness of the absorber (cm), I_0 is the count value without the sample and I is the count value of the radiation penetrating through the sample.

The mass attenuation coefficients measured as above correspond to those of the mixtures of the rare earth oxides. In order to extract the mass attenuation coefficients of the rare earth elements the mixture rule was used. The rule gives the attenuation coefficient of any substance as the sum of the appropriately

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