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Araştırma Makalesi / Research Article

Gamma Radiation Reflection Parameters of Ce and Selected Ce Compounds

Ahmet TURŞUCU[1,2*]

Abstract

In this study, the albedo parameters are known as the reflectance capacity of the electromagnetic radiation falling on the target samples; the surface's reflectivity was investigated. For this purpose, in the experimental setup, ^{241}Am as a radioactive source and a semiconductor detector were used to count the scattered photons due to reflecting the gamma rays radiating from the source. The data obtained from the experiment were plotted depending on the atomic number of the target samples. It is understood from this study that the albedo factor parameters of the target samples selected for research decrease with increasing average atomic number.

Keywords: Gamma-Ray Scattering, Albedo Factors, Albedo Number, Albedo Energy, Albedo Dose.

Seryum ve Bazı Seçilmiş Seryum Bileşiklerinde Gama Radyasyonu Yansıtma Parametreleri

Öz

Bu çalışmada albedo parametreleri, hedef numuneler üzerine düşen elektromanyetik radyasyonun yansıtma kapasitesi olarak bilinir; yüzeyin yansıtma özelliği araştırıldı. Bu amaçla deney düzeneğinde radyoaktif kaynak olarak ^{241}Am ve kaynaktan yayılan gama ışınlarını yansıtması nedeniyle saçılan fotonları saymak için yarı iletken dedektör kullanılmıştır. Deneyden elde edilen veriler, hedef numunelerin atom numarasına bağlı olarak çizildi. Sonuç olarak, bu çalışma, seçilen örneklerin albedo faktör parametrelerinin artan ortalama atom numarası ile azaldığını göstermektedir.

Anahtar Kelimeler: Gama Işını Saçılımı, Albedo Faktörleri, Albedo Sayısı, Albedo Enerjisi, Albedo Dozu.

[1]Şırnak University, Department of Electric Electronic Engineering, Şırnak, ahmettursucu@sirnak.edu.tr
[2]Şırnak University, Department of Technology and Research Center, Şırnak

[1]https://orcid.org/0000-0002-4963-697X

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1. Introduction

The electromagnetic radiation emitted by radioactive nuclei is defined as gamma radiation. Suppose an unstable radioactive nucleus has high energy after alpha or beta decay. To reduce this excess energy, gamma decay occurs by the nucleus, which tries to become more stable. During the gamma decay phase, no change in the nucleus is observed in the number of protons or neutrons. In this way, during the gamma decay process during the stabilization phase, three basic interactions occur with its environment. These are Compton scattering, pair production, and photoelectric interaction. Gamma radiation has a high penetrating power due to its high energy value. For this reason, using lead plates to reduce the effect is quite common and effective.

During the stabilization phase of an unstable nucleus, X-rays observed with the release of excess energy in the nucleus are electromagnetic radiation. An example is the withdrawal of electrons from shells close to the nucleus or the capture of an electron from these shells. Due to these events, the gaps formed in the energy levels of the electron cloud are filled by electrons in other energy levels, and after this process, x-rays emerge. X-rays release energy through interactions such as Compton scattering and the photoelectric effect. Two types of scattering are collected. One is consistent (or elastic or Rayleigh) scattering, and the other is inconsistent (or inelastic or Compton). In this study, some calculations were made using the data obtained from both scatterings.

There are many studies in the literature using the scattering data of gamma and x-rays. With these studies, different materials used as targets, space explorations, and the development of social radiation protection techniques and technological tools are assisted. Sabharwal et al. (2009) studied the thickness effects on multiple backscattering of 1,12 MeV gamma photons to give an example of these studies. They used alloy samples of different thicknesses, and the numerous backscattering increased with increased sample thicknesses. The saturation thicknesses were the same for albedo parameters and multiple backscattering. This event shows that the albedo parameters were related to the numerous backscattering. Sabharwal et al. (2011) investigated the multiple backscattering properties and energy intensity distribution of various gamma-ray energies (279, 320, 511, and 662 keV) emerging from target samples. Their experimental measurement has been compared with the Monte Carlo simulation calculator. The available measurements were carried out to examine how the gamma photon number and albedo parameters function in the incident gamma photon energy, the atomic number, and the thickness of an irradiated target change. Uzunoğlu *et al.* (2016) have used the scattered photons in determination of saturation thicknesses of targets. In addition, albedo factors were experimentally investigated using a high-resolution, high-purity germanium detector. Yılmaz *et al.* (2017) calculated the albedo factors of elements with atomic numbers ranging from $26 \leq Z \leq 79$. So, the americium-241 isotope was used as excitation radiation, and an HPGe detector with 182 eV resolution for 59.54 keV photon energy was used to collect gamma photons scattered from target samples. Albedo Number, Albedo Dose and Albedo Number were determined due to the calculations made from the scattered photon data obtained in the detector. Yılmaz and Kılıç (2019) studied the albedo factors, which symbolize the radiation reflectivity of the materials by using cream marble, which is one of the eastern Taurus marble varieties, pink marble consisting of sedimentary limestone, white marble, claret red marble, and green marble materials. Akkuş and Yılmaz (2019) determined the albedo parameters of different samples in the mean atomic number range $9.743 \leq Z \leq 83.00$ measured for 662 keV gamma rays by using an HPGe detector at a 180° scattering angle. Yılmaz *et al.* (2020) measured the albedo number, albedo number, and albedo energies experimentally for undoped V_{Ox} thin films and V_{Ox} thin films doped with selenium, boric acid, ammonium borate, and dimethyl borane complexes. In the Experimental Research phase, scattering from thin film materials was performed using gamma photons with 59.54 keV energy, and the scattered photons were counted with a semiconductor HPGe detector. Akkuş (2020) determined the albedo number, albedo energy, and albedo dose using an HPGe detector with gamma photons with 59.54 keV energy. The materials used in the experiment were prepared with bismuth and cellulose powders using the dilution technique of samples with an average atomic number of $9,743 \leq Z \leq 83.00$. This way, the albedo factor study was performed in a more comprehensive average atomic number range. Yılmaz and Akkuş (2021) calculated the albedo number, energy, and dose for some selected scientifically essential materials at 180° scattering geometry. According to the reflection geometry, the scattered gamma rays were counted using ultra-low energy germanium (U-LEGe) detector. The relation between mean atomic number and albedo factor was determined for the low atomic number region.

In this study, in which calculations similar to the studies described above were made, albedo factor calculations were made for some commercially and technologically important cerium compounds. In the study, we obtained the reflected gamma photons from the gamma rays scattered from the ^{241}Am radioactive isotope and counted these photons using a high-resolution semiconductor HPGe detector. The albedo factor parameters obtained from the study were plotted as a function of the average atomic number. As a result of the examination of the graphics, it has been determined that increasing the atomic number causes a decrease in the albedo parameters (probability of reflection).

2. Materials and Methods

2.1. Experimental Arrangement

Photon counts were made using a gamma ray source and a high purity germanium (HPGe) detector in our study, which was carried out using experimental systems established in the laboratory. The experimental arrangement used in the experiment is shown in Figure 1.

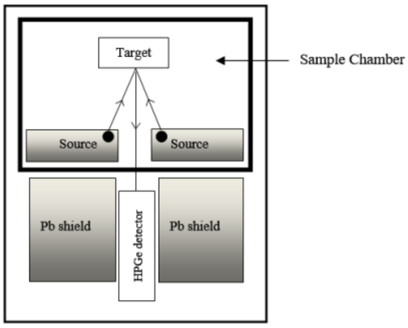

Figure 1. Experimental arrangement.

The healthy operation of the counting system and the sample room prepared to protect the researcher from radiation damage are shown in Figure 2.

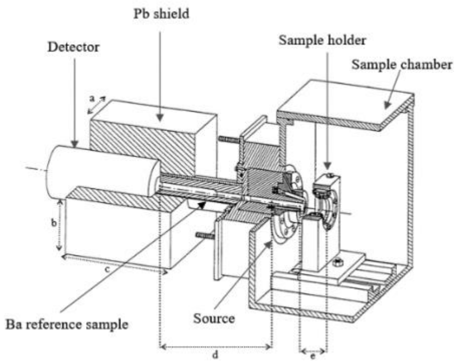

Figure 2. Sample chamber (a=6.5 cm, b=6.3 cm, c=13.5 cm, d=11 cm, e=5 cm).

The sample chamber shown in Figure 2 is lined with a lead layer and is structurally conical. With the conical-designed sample chamber, the effects caused by backscattering are minimized, and monochromatic gamma rays reach the target material. Gamma photons scattered from the target material were detected with the HPGe detector. Gamma photons are directed to the target with a scattering angle of 168 degrees to maximize the efficiency obtained from the system. In this way, it is ensured that unwanted gamma ray values are not detected.

2.2. Calculation of Albedo Factors

The analysis system includes a multi-channel analyzer combined with the Genie-2000 program that controls the multi-channel analyzer. The Genie-2000 program determines the photopic peaks and areas to be considered in the calculations. In calculating the photopeak areas detected with the help of this program, the Origin 7.5 program comes into play. The photopeak areas consist of sample-directed and backscattered photons and are represented in the formula as N_i and N_{bs}, respectively. [Sabharwal *et al.* (2009)]. The components that make up these photo peaks are used in the calculation of the albedo number with the formula below,

$$A_N = \left[\frac{N_{bs}/\varepsilon(E_{bs})}{(N_i/\varepsilon(E_i))(1/d\Omega)(1/2)}\right] \quad (1)$$

The equation used to determine the albedo number is given above. The terms $\varepsilon(E_{bs})$ and $\varepsilon(E_i)$ in the equation represent the photopic efficiencies for the HPGe detector of the photons scattered from and arriving at the material, respectively. Another important term in the equation used to calculate the albedo number is the solid angle ($d\Omega$), defined as the angle supported by the detector by the collimator aperture in the middle of the target. A factor of 1/2 is included in the denominator since only half of the photons emitted from the radioactive source can reach the target material.
Albedo number calculations were used to obtain the albedo energy parameter and related equations given by the following formula,

$$A_E = \left[\frac{E_{bs}}{E_i}\right] A_N \quad (2)$$

E_{bs} and E_i denote the material emitted and incident photon energies, respectively. At this point, the last of the albedo parameters, the albedo dose, is directly proportional to the previously calculated albedo energy and is calculated using the equation given in the equation below,

$$A_D = \left[\frac{\sigma_a(E_{bs})}{\sigma_a(E_s)}\right] A_E \quad (3)$$

Equation (3), above mentioned, contains terms that are represented by the energy absorption coefficients of air for backscattered and incident gamma photons, respectively. The absorption coefficients were obtained from the XCOM Photon Cross-Section Database [Sabharwal et al. (2011)]. Also, the air is one of the components of absorption and is composed of different elements in varying proportions, which are taken from Table 1.

Table 1. Table of gaseous composition of dry air.

Constituent	Chemical symbol	Mole percent
Nitrogen	N_2	78.084
Oxygen	O_2	20.947
Argon	Ar	0.934
Carbon dioxide	CO_2	0.0350
Neon	Ne	0.001818
Helium	He	0.000524
Methane	CH_4	0.00017
Krypton	Kr	0.000114
Hydrogen	H_2	0.000053
Nitrous oxide	N_2O	0.000031
Xenon	Xe	0.0000087
Ozone	O_3	0.00000001

3. Findings and Discussion

Cerium is one of the most common elements in commercial use. In particular, cerium oxide (ceria) is a widely used commercial compound. Seria has replaced other metal oxides used in high-quality optical surfaces. It is one of the sought-after components in lighting systems, especially alloys. It is an essential ingredient in iron alloys. It is widely used to increase the high-temperature oxidation resistance of superalloys. In industrial-scale electrosynthesis applications, cerium is added to methane sulfonic acid solutions as a reversible oxidant. Some of its compounds are used in organic chemistry, as an oxidizer in electronic components, and as a primary standard in quantitative analysis.

An essential component of phosphors used in television screens and fluorescent lamps, cerium prevents polymer formation in pigments exposed to sunlight. Misch metal (flint) containing 50 percent cerium is used as an oxidation inhibitor in various alloys and as an oxygen remover in vacuum tubes. Its +4 valence compounds are good oxidizing agents. Cerium salts are used in photography and the textile industry. Nanoparticles of cerium oxide are an ideal additive for diesel fuel to help it burn more and reduce exhaust emissions. Cerium oxide additive improves engine performance by removing soot in the engine. Cerium oxide is also used to polish glass surfaces. Cerium sulfide is a non-toxic compound with rich red color and is used as a pigment. These pigments can be used in toys and kitchenware.

4. Conclusions and Recommendations

The present study was conducted in the low-energy region, where the backscattering probability is more dominant than in other openings. Also, the energy loss fraction in these regions is much smaller than in other high-energy areas. This ensures that most of the energies of the photons directed to the target are transferred to the scattered photons.

As a result of this study, it was determined that the albedo factor increased with increasing atomic number. In addition, it was observed that the Compton scattering effect and shift in scattering centers caused a decrease in albedo factors at similar photon energy and scattering angle (Figure 3-5). In addition, with increasing atomic number, the photoelectric cross section increased; on the contrary, Compton scattering caused a decrease in the test section. It is essential to repeat similar experiments in different compounds and scattering systems to test the results in the broader area and confirm their reliability.

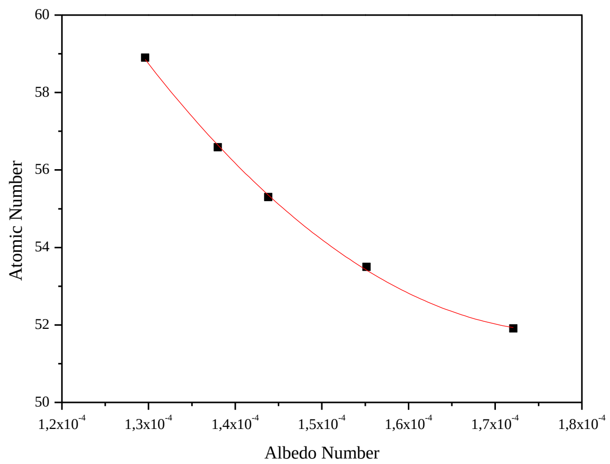

Figure 3. Albedo Numbers vs Atomic Number.

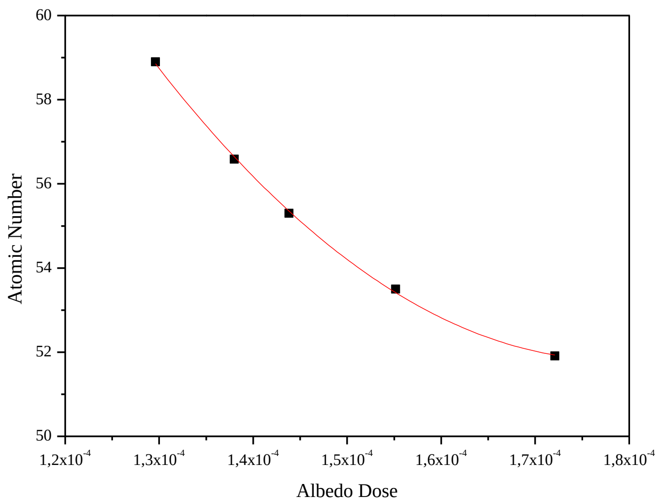

Figure 4. Albedo Dose vs Atomic Number.

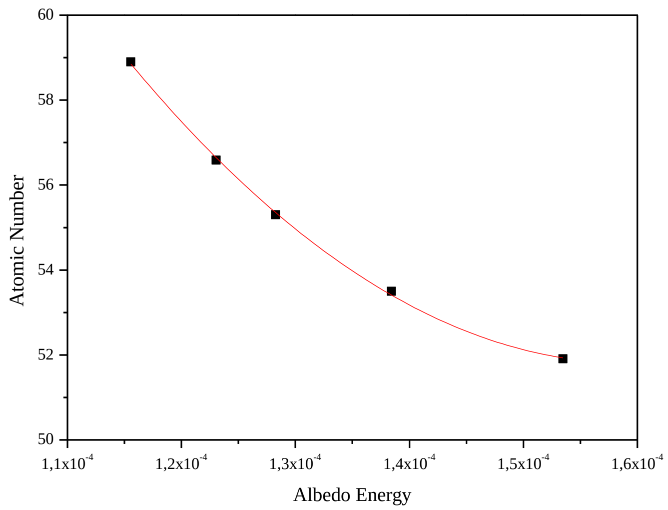

Figure 5. Albedo Energy vs Atomic Number.

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Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

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