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Technical Note

Experimental investigation of effective atomic numbers for some binary alloys

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ABSTRACT

In the present work, the gamma ray backscattering technique was used to determine the effective atomic numbers for certain binary alloys. With the help of a muffle furnace, the binary alloys were synthesized using the melt quenching technique with different compositions of $_{82}$Pb, $_{50}$Sn, and $_{30}$Zn. The intensity distribution of backscattered photons from radioactive isotope ^{22}Na (511 keV) was recorded with the help of GAMMARAD5 [76 mm × 76 mm NaI(Tl) scintillator detector] and analyzed as a function of both atomic number and thickness of the target material. The effective atomic numbers for the same binary alloys were also computed theoretically using the atomic to electronic cross-section method with the help of the mass attenuation coefficient database of WinXCom (2001). Good agreement was observed between theoretical and experimental results for the effective atomic numbers of all the selected alloys.

1. Introduction

The backscattering of gamma ray photons plays an important role in radiation physics. Information regarding the thickness and density of a material can be obtained by the gamma ray back scattering technique. Gamma ray backscattering results correspond to the incident gamma photons, which are scattered at an angle of 180° with respect to the incident direction. The gamma backscattering technique is a nondestructive method of testing a material, in which there is no direct contact with the material under study or with the detector assembly [1]. When the ultrasonic method fails to work, the gamma backscattering method is very useful for estimating the thickness of hot objects and unclean and corroded surfaces [2]. The gamma ray backscattering method can be successfully used to measure corrosion in insulated pipe [3]. The importance of backscattered photons and multiple scattered photons from different types of materials were explored by different researchers [4–10].

The parameter "effective atomic number" for compounds/mixtures is analogous to the "atomic number" of elements. It signifies that, at a given energy, photons will interact with a compound/mixture in a similar way as a single element of atomic number equivalent to that compound/mixture. This number provides the characteristics of the material, knowledge of which is very helpful in numerous applications such as technological, nuclear industry, space research program, and engineering applications. This number plays an important role in the field of nondestructive testing of samples of medical (radiology, nuclear medicines, and radiotherapy), agricultural (characterization of various types of woods and inhomogeneity in different parts of woods), and industrial (to check for void and insertion in the inner part of the material) interest. Hence, its measurement and computation with high accuracy are required.

An alloy is a mixture of two or more elements of different characteristic properties, created to enhance properties such as tensile strength, hardness, resistance to corrosion, etc. An alloy can be a combination of metals with metals or metals with nonmetals to achieve the desired characteristics. Since an alloy can be synthesized from combinations of various known elements in different compositions, these can be classified in numerous ways (on the basis of number of elements, on the basis of elements of major contribution, etc.). Here, binary alloys refer to alloys that are made up of two elements. In the present work, effective atomic numbers for different compositions of Pb–Sn, Pb–Zn, and Zn–Sn alloys were measured by the gamma ray backscattering technique; values were also computed using the electronic to atomic cross-section ratio method.

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Table 1
Chemical composition of prepared alloy samples.

Sample no.	Selected alloys		Chemical composition (fractional weight)
1.	Pb–Sn	$_{80}Pb_{20}Sn$	Pb = 0.80, Sn = 0.20
		$_{60}Pb_{40}Sn$	Pb = 0.60, Sn = 0.40
		$_{40}Pb_{60}Sn$	Pb = 0.40, Sn = 0.60
		$_{20}Pb_{80}Sn$	Pb = 0.20, Sn = 0.80
2.	Pb–Zn	$_{80}Pb_{20}Zn$	Pb = 0.80, Zn = 0.20
		$_{50}Pb_{50}Zn$	Pb = 050, Zn = 0.50
		$_{40}Pb_{60}Zn$	Pb = 0.40, Zn = 0.60
3.	Zn–Sn	$_{80}Zn_{20}Sn$	Zn = 0.80, Sn = 0.20
		$_{60}Zn_{40}Sn$	Zn = 0.60, Sn = 0.40
		$_{70}Zn_{30}Sn$	Zn = 0.70, Sn = 0.30

Table 2
Properties of the prepared alloy samples.

Sample no.	Selected alloys		Thickness (cm)	Volume (cm^3)	Mass (g)	Density (g/cm^3)
1.	Pb–Sn	$_{80}Pb_{20}Sn$	0.75	2.94	27.19	9.25
		$_{60}Pb_{40}Sn$	0.82	3.46	27.87	8.07
		$_{40}Pb_{60}Sn$	0.877	3.22	27.07	8.41
		$_{20}Pb_{80}Sn$	0.87	3.50	24.76	7.08
2.	Pb–Zn	$_{80}Pb_{20}Zn$	0.54	2.66	19.92	9.62
		$_{50}Pb_{50}Zn$	0.40	1.55	11.44	7.36
		$_{40}Pb_{60}Zn$	0.60	2.24	12.0	5.33
3.	Zn–Sn	$_{80}Zn_{20}Sn$	0.63	2.07	16.8	6.67
		$_{60}Zn_{40}Sn$	0.53	1.55	14.33	6.57
		$_{70}Zn_{30}Sn$	0.60	2.25	12.41	6.85

2. Materials and methods

The melt-quench technique has been employed to synthesize some binary alloys of $_{82}Pb$, $_{50}Sn$, and $_{30}Zn$ in different compositions, as shown in Table 1, using a muffle furnace. High purity (> 99.5%) metallic granules of Zn (melting point: 419°C), Sn (melting point: 231°C), and Pb (melting point: 327°C) were procured from Nice Chemicals (P) Ltd, Cochin, Kerala, India. These metallic granules were weighed in required quantities using an electronic digital balance (least count: 1 mg and maximum capacity: 500 g); then, the mixture was heated in an alumina crucible at 450°C for 10 min in a muffle furnace. The melt was then quickly poured into a cast iron mold of inner dimensions 2 × 2 × 2 cm^3 at room temperature. The physical properties of the prepared alloy samples are listed in Table 2.

Next, to measure the effective atomic numbers of the synthesized binary alloys in terms of back scattered photons, an experimental setup was designed and is shown in Fig. 1. It consists of radioactive isotopes ^{22}Na (photon energy = 511 keV, half-life = 2.6 years, strength = 1.2 μCi; procured from BRIT, Mumbai, India), GAMMARAD5 [NaI(Tl) scintillator detector of dimensions 76 mm × 76 mm and energy resolution is 7% at 662 keV, which is coupled with a multichannel analyzer; procured from Amptek Inc., Bedford, MA 01730, USA], and lead housing/collimators (which are used to minimize the noise or unwanted signal). The scintillator detector was placed in front of the ^{22}Na gamma ray source at a distance of 9.5 cm.

Before initializing the investigation, the detector was calibrated for energy scale. The pulse height spectra were recorded for different calibrating sources of ^{57}Co (122 keV), ^{133}Ba (81 keV, 302 keV, and 356 keV), ^{22}Na (511 keV), ^{137}Cs (662 keV), and ^{60}Co (1,173 keV and 1,332 keV). After calibration of the detector for energy scale (converting channel number into energy value along the x-axis), an attempt was made to calibrate the geometry to determine the thickness and atomic number of the interacting material. For this reason, the back scattered photon spectra of ^{22}Na (511 keV) from different thicknesses of certain metals ($_{28}Ni$, $_{47}Ag$, $_{50}Sn$, and $_{82}Pb$) behind the source were recorded. The thickness of $_{28}Ni$ was increased by placing the Ni metal sheets one by one behind the previously placed Ni metallic sheet, without disturbing the experimental geometry. In this way, at a fixed energy (511 keV) and fixed atomic number (Z = 28), the dependence of the thickness on the backscattered count was analyzed. This procedure was repeated with samples of other metals (Ag, Sn, and Pb). All the spectra were recorded for a time period of 600 s, so as to yield a sufficient number of counts under the backscattered peak; hence, the associated statistical error is within the limit of ± 5%. The contributions of backscattered photons from particular samples were obtained by subtracting the backscattered photon spectrum obtained without the sample from the same spectrum obtained with the sample. Finally, the backscattered photon spectra for the synthesized alloys were recorded for the same time duration.

3. Results

After analyzing the recorded spectra, it was observed that the backscattered peak and the photo peak appear at 170 keV and 511 keV, respectively. Spectra recorded without and with a silver sheet (thickness 9.5 mm) at a scattering angle of 180° are shown in Fig. 2.

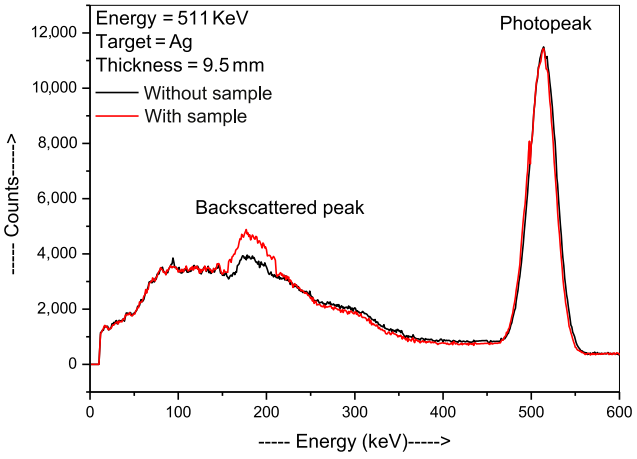

Fig. 2. Recorded spectra for ^{22}Na radioactive isotope with and without sample.

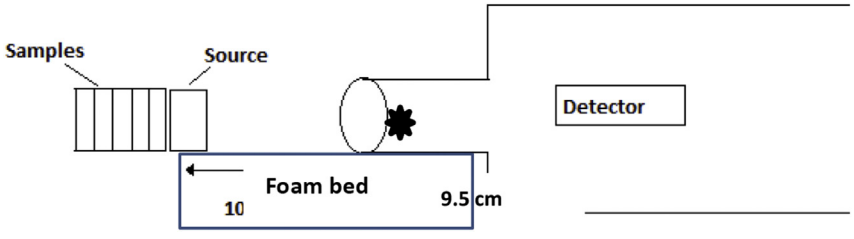

Fig. 1. Experimental setup (not to scale).