Original Research Article

Effective atomic numbers for some alloys at 662 keV Using gamma rays backscattering technique

ABSTRACT

The gamma backscattering is a useful technique in determining effective atomic number of backscattering material. In gamma backscattering technique there is no direct contact with the detector and material under study. So, in the present work the intensity distribution of backscattered photons was determined both as a function of atomic number of the target and thickness of the target and then find out the effective atomic number of (Pb-Sn, Pb-Zn and Zn-Sn) alloys at 662 keV. These alloys were synthesized in different compositions of Pb, Sn and Zn elements using melt quenching technique with the help of muffle furnace. The intensity distribution of backscattered photons was recorded with the help of GAMMARAD5 (76 mm x 76 mm NaI(Tl) scintillator detector. The experimental results so obtained were compared with the theoretical ones which were computed using atomic to electronic cross-section method with the help of mass attenuation coefficients database of WinXCom. A good agreement has been observed between theoretical and experimental results of the effective atomic numbers for the selected alloys.

Keywords: Backscattering, Effective Atomic Number, Binary Alloys.

1. INTRODUCTION

The backscattering of photons plays important role in radiation shielding. It gives information about the characteristics of the materials i.e. electron density, cross sections and effective atomic number of the alloys. The numbers of backscattered photons increases with increase in target thickness (Udagani, 2013). In backscattering technique the sample can be accessed from the same side, imaging is simple and also the depth information of the sample is possible (Majid and Balamesh, 2005). In the gamma backscattering, the intensity of backscatter gamma photons depends on thickness of the material and the atomic number of the material. The “effective atomic number” introduced by Hine (1952) has a physical meaning and is quite useful parameter for interpretation of attenuation of X-ray or gamma radiation by a composite material. This number is also very useful to visualize a number of characteristics of a material of scientific and biological interest (Singh et al., 2010). The gamma backscattering is strongly dependent on mass numbers of the target atoms and effective atomic number (Z_{eff}) of the selected materials. Hence, it is a useful technique in determining effective atomic number (Z_{eff}) of backscattering materials (Sabharwal et al., 2009). In the present measurements effective atomic number of PbSn, PbZn and ZnSn alloys was calculated by gamma backscattering. An element is mixed with another element of different concentration to enhance mechanical properties such as tensile strength, hardness mould ability etc. In the field of radiation physics, tin and zinc is added to lead to make the alloy machine able and of high density so that it can be used as a good shielding material for gamma rays. In the present work, PbSn, PbZn and ZnSn alloys are taken as these materials are easily available and easy to prepare their alloys in the laboratory as the melting point of lead, zinc and tin is low.

2. EXPERIMENTAL DETAILS

The binary alloys of Zn (Z=30), Sn (Z=50) and Pb (Z=82) were synthesized using melt quench technique in different compositions using muffle furnace. The Zn (melting point: 419.527^{o}C as quoted at www.rsc.org/periodic-table/element/30/zinc), Sn (melting point: 231.928^{o}C as quoted at www.rsc.org/periodic-table/element/50/tin) and Pb (melting point: 327.462^{o}C as quoted at www.rsc.org/periodic-table/element/82/lead) metalloids granules (purity > 99.5%) procured from Nice chemicals (P) Ltd, India, were weighed in required amounts using electronic digital balance (least count: 1 mg and maximum capacity: 500 g) and then heated in alumina crucible at 450 ˚C for 10 minutes in muffle furnace and then poured quickly in cast iron mould of dimensions 2 x 2 x 2 cm^3 at room temperature. The chemical composition and physical properties of the prepared samples were listed in the Table 1 and 2. The experimental work carried out using ^{137}Cs radioactive isotopes by placing a gamma rays detector at an angle of 180^{o} to the incident beam. The backscattered photons were recorded using GAMMARAD5 (scintillator detector) of dimensions 76 mm x 76 mm having energy resolution of 7% at 662 keV coupled with multichannel analyser (MCA) based on Amptek's DP5G Digital Pulse Processor for 600 s. The scintillator detector has been placed in front of ^{137}Cs gamma rays source at a distance of 9.5 cm. In order to calibrate the detector in terms of backscattering of gamma rays, different spectra were recorded using calibration sources ^{57}Co (122 keV), ^{133}Ba (81 keV, 302 keV and 356 keV), ^{137}Cs (662 keV), ^{22}Na (511 keV), ^{60}Co (1173 keV and 1332 keV) placed at the target position. After calibration of the detector a particular incident energy photon ^{137}Cs (662 keV) irradiate on the metals ($_{13}Al$, $_{28}Ni$, $_{50}Sn$ period and $_{82}Pb$) of varying thickness and all the spectra were recorded with increasing thickness of selected metals ($_{13}Al$, $_{28}Ni$, $_{50}Sn$ period and $_{82}Pb$) by placing them behind the sources for the time of 600 s, so as to have sufficient number of counts (more than 10,000) under the area of backscattered peak (which appears at 200.91 keV). The metals (Al, Ni, Sn and Pb) of varying thickness are used as a target placed behind the sources at a distance of 9.5 cm from gamma rays detector. The recorded spectra were analyzed to measure the area under the backscattered photon. The contribution of backscattered photons was obtained after subtracting area under the backscattered photon (with sample) from area under the backscattered photon (without sample). The schematic of experimental set up is shown in the Fig. 1.

3. RESULTS AND DISCUSSION

The numbers of backscattered photons depend upon the atomic number of the target and thickness of the target used in the experiment. So, in present work the intensity distribution of backscattered photons was determined both as a function of atomic number of the target and thickness of the target. To use samples of different thickness the backscattered photons at scattering angle 180^o a typical backscattered peak (with sample) and a backscattered peak (without sample) from the nickel target (thickness 19.0 mm) exposed to 662 keV gamma photons is given in Fig. 2. We obtain the contribution of backscattered photons after subtracting this observed backscattered peak (with sample) from backscattered peak (without sample). For analysis of recorded spectrum, it is necessary to select the area under the peak. From the recorded spectrum the backscattering peak area has been identified for experimental work. For fixed experimental geometry the backscatter peak appears at around 200.91 keV when using the ^{137}Cs radioactive source. With the same experimental geometry the known metals (Al, Ni, Sn and Pb) are placed at 180^o with the ^{137}Cs radioactive source and detector assembly. The area under the peak was recorded. The backscattering sample thickness was increased by placing known metals (Al, Ni, Sn and Pb) one by one behind the previously placed known metals without disturbing the experimental geometry. This procedure is repeated for targets of different metals and different thicknesses to evaluate the intensity of multiply backscattered photons, when exposed to 662 keV gamma photons from ^{137}Cs source. The number of backscattered counts, for different metals (Al, Ni, Sn and Pb) as a function of target thickness is shown in Fig.2 .The numbers of backscattered counts increases with increase in target thickness. A calibration line is drawn between the backscattered counts and the value of atomic number of elemental targets (Al, Ni, Sn and Pb). The solid curves represent the best-fit curves through the experimental data points corresponding to backscattered counts. At 180^{o} scattering angle, the best fitted line is shown in Fig. 3. The numbers of backscattered counts increases due to the fact that an increase in target thickness results in higher number of scattering centres for the interaction of primary gamma rays with target material. The backscattering of gamma photons, is successfully used as an experimental technique for the evaluation of ‘‘effective atomic number’’ of alloys of known composition. The “effective atomic number” of an alloy Z_{eff}, provides conclusive information about the alloy when gamma radiations are incident on it. The number of backscattered counts for 662 keV gamma photons in alloys provide the “effective atomic number” of these alloys using best-fit curves (Figs. 4 - 6) through the experimental data points for pure elements (Al, Ni, Sn and Pb) at scattering angles of 180^{o} . Now each of the target of which the effective atomic number is to be determined is replaced by the elemental target and again the scattered spectra are recorded for the same duration of time at scattering angles of 180^{o}. The backscattered counts mentioned in Table 3 are marked on the calibration line in Fig. 4, 5 and 6 corresponding to the scattering angles 180^{o} and the corresponding atomic number values are interpolated along the X-axis. These values are the effective atomic number of alloys under study. The effective atomic numbers of these samples are also evaluated from known elemental concentration of the constituent elements using ratio of atomic to electronic cross-section method (Singh T. et al. 2007; Sharma R. et al. 2012). The theoretical Z_{eff} values were obtained using mass attenuation coefficient database of WinXCom (Gerward et al.; 2001) agreed with the experimental measured values. The number of backscattered counts for the selected alloy of different target thickness as a function of atomic number is shown in Figs. 4 - 6. It have been observed that the number of backscattered counts decreases with the increase in atomic numbers due to increase in number of scattering centres for the interaction of primary gamma rays with target metals. It has also been observed that the numbers of multiply backscattered counts increases with decrease in atomic numbers. The measured values of multiply backscattered counts using 662 keV gamma photons from targets of selected alloys are given in columns 2 of Table 3. The third and fourth column in the table provides theoretical and experimental values of effective atomic numbers for different composition of alloys. There is a need of experiment and theoretical data for gamma backscattering for alloys of industrial and nuclear interest as there is no experimental data and theoretical data tables available in literature for these materials. Knowledge of gamma backscattering is useful in the calculation of effective atomic number, absorption and also in the field of radiation dosimetry and reactor shielding. The slight deviation of experimental results from the theoretical data may be due to the non-uniformity of target's thickness.

4. CONCLUSION

Gamma rays backscattering technique provides non-destructive method for successfully assigning effective atomic numbers to the selected alloys. This method has an additional benefit over other experimental techniques: Rayleigh to Compton scattering ratio (Singh M.P. et al. 2010), multiple scattering at different angles (Singh G. et al., 2010) that it works at lower source strength, hence reducing the cost factor in terms of less shielding requirements for the experimental setup. Moreover, it requires less time duration as compared to other experimental techniques.

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Table 1 Chemical composition of prepared alloy samples

Sample No.	**Selected alloys**		**Chemical Composition (Fractional weight)**
1.	Pb-Sn	Pb80Sn20	Pb=0.80, Sn=0.20
		Pb60Sn40	Pb=0.60, Sn=0.40
		Pb40Sn60	Pb=0.40, Sn=0.60
		Pb20Sn80	Pb=0.20, Sn=0.80
2.	Pb-Zn	Pb80Zn20	Pb=0.80, Zn=0.20
		Pb50Zn50	Pb=050, Zn=0.50
		Pb40Zn60	Pb=0.40, Zn=0.60
3.	Zn-Sn	Zn80Sn20	Zn=0.80, Sn=0.20
		Zn60Sn40	Zn=0.60, Sn=0.40
		Zn70Sn30	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.	PbSn	Pb80Sn20	0.750	2.94	27.19	9.25
		Pb60Sn40	0.820	3.46	27.87	8.07
		Pb40Sn60	0.877	3.22	27.07	8.41
		Pb20Sn80	0.870	3.50	24.76	7.08
2.	PbZn	Pb80Zn20	0.540	2.66	19.92	9.62
		Pb50Zn50	0.400	1.55	11.44	7.36
		Pb40Zn60	0.600	2.24	12.00	5.33
3.	ZnSn	Zn80Sn20	0.630	2.07	16.8	6.67
		Zn60Sn40	0.530	1.55	14.33	6.57
		Zn70Sn30	0.600	2.25	12.41	6.85

Table 3 Effective Atomic Numbers for selected alloys at 662 keV gamma photons.

Sample No.	Selected Alloys		No. of backscattered counts	Z_{eff} (Theoretical)	Z_{eff} (Experimental)
1.	Pb-Sn	Pb80Sn20	7258	75.7	76.64
		Pb60Sn40	9436	69.3	70.35
		Pb40Sn60	10374	63.7	63.9
		Pb20Sn80	10835	56.5	56.9
2.	Pb-Zn	Pb80Zn20	9071	72.2	71.8
		Pb50Zn50	10354	57.1	58.07
		Pb40Zn60	10208	49.9	52.5
3.	Zn-Sn	Zn80Sn20	15628	34.3	35.9
		Zn60Sn40	13356	38.4	40.65
		Zn70Sn30	13486	37.0	39.5

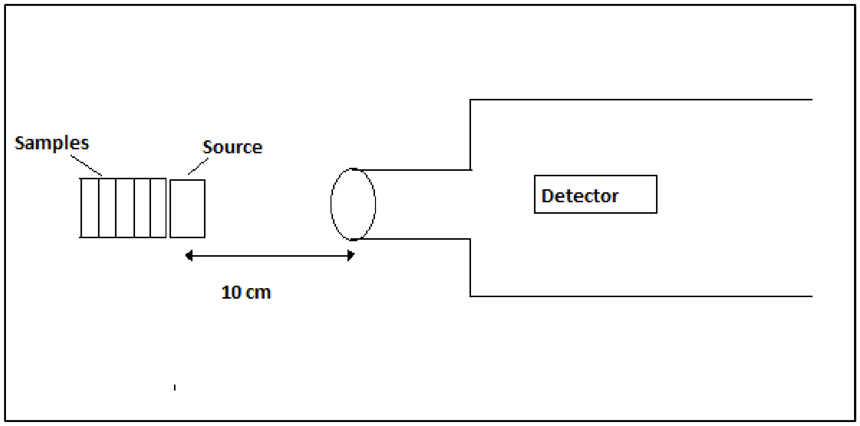

Figure 1 Experimental Setup (Not to scale)

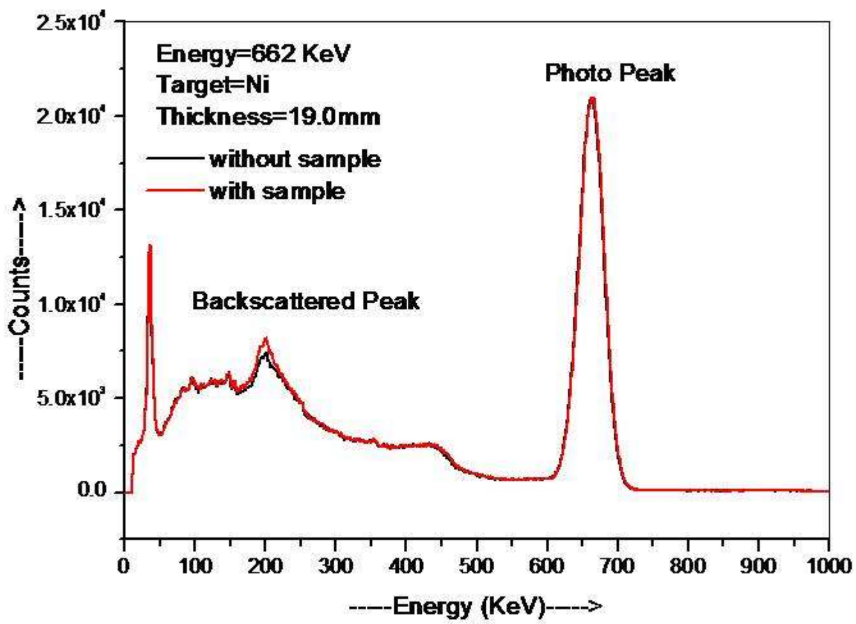

Figure 2: The backscattered peak (200.91 keV) and photo peak (662 keV) with Nickel sample (thickness 19.0 mm) using ^{137}Cs radioactive isotope

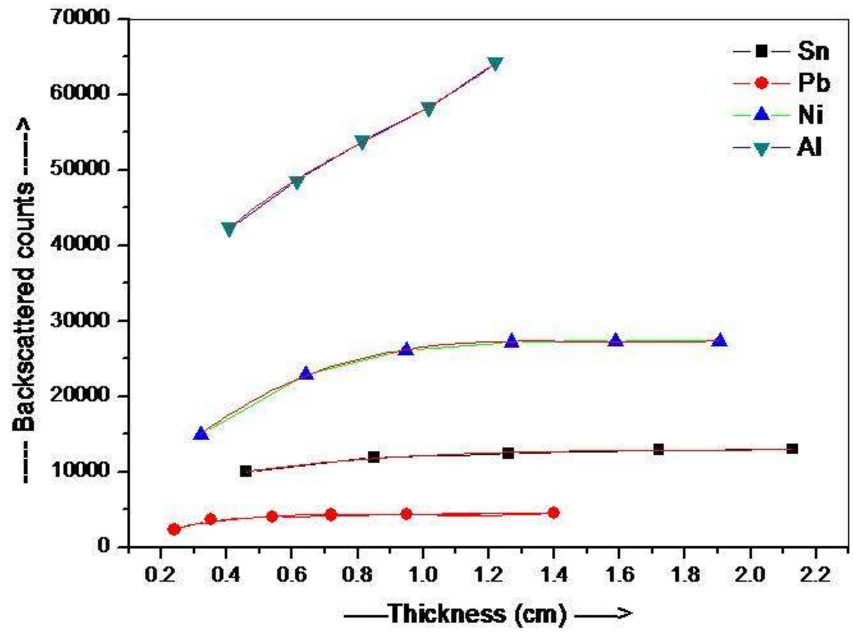

Figure 3: Number of backscattered counts for selected metals ($_{13}$Al, $_{28}$Ni, $_{50}$Sn and $_{82}$Pb) as a function of target thickness

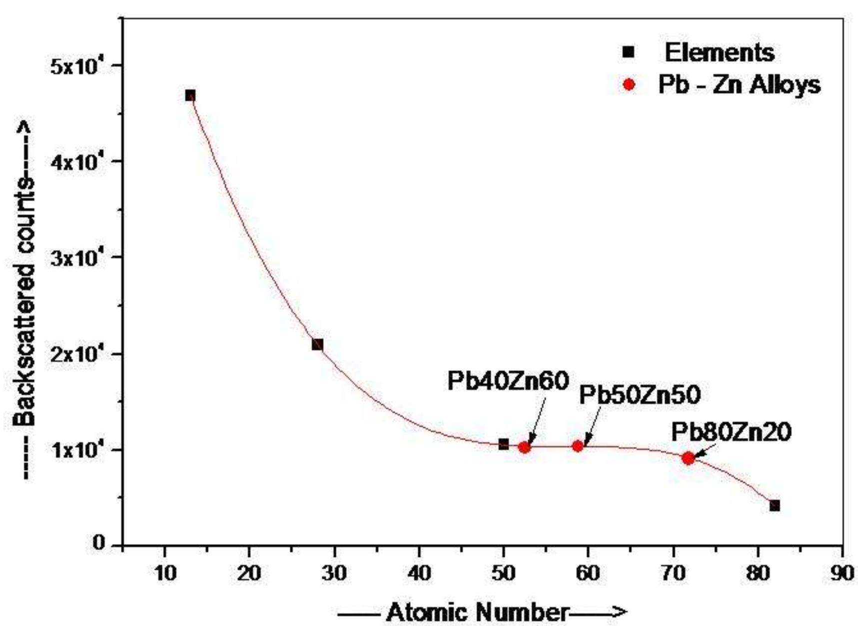

Figure 4 : Variation of backscattered counts with atomic number for Pb-Zn alloys of different compositions at 662 keV gamma photons

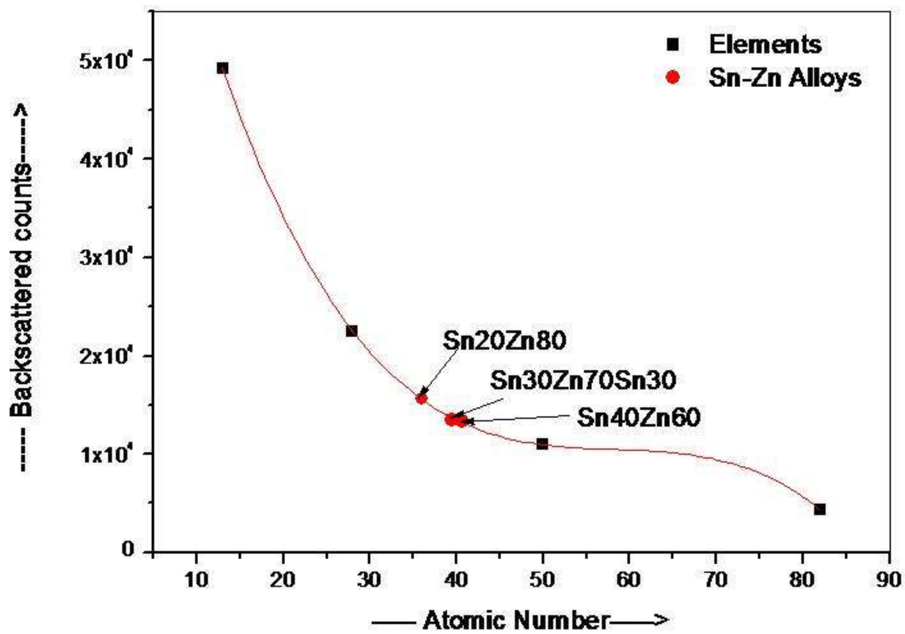

Figure 5: Variation of backscattered counts with atomic number for Zn-Sn alloys of different compositions at 662 keV gamma photons

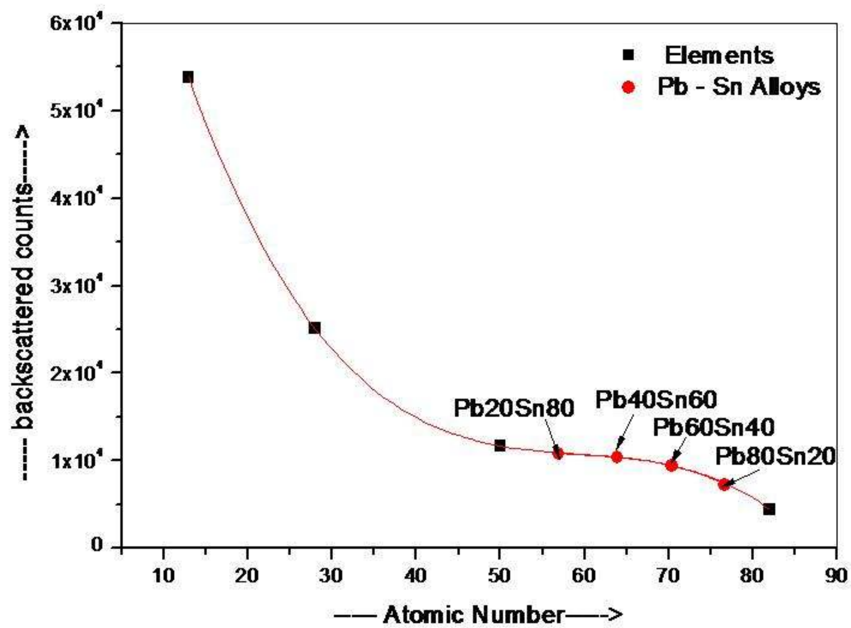

Figure 6: Variation of back Scatter counts with atomic number for Pb-Sn alloys of different compositions at 662 keV gamma photons