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Non-Destructive Evaluation of Pb-Sn Alloys by Scattering of 145 Kev Gamma Rays

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The objective of present experiment is to assign effective atomic number (Zeff) to solders (alloys of lead and tin) having different composition of tin. An HPGe semiconductor detector, placed at 70o to the incident beam, detects gamma photons scattered from the sample under investigation. The experiment is performed on various elements with atomic number satisfying, $6 \leq Z \leq 82$, for 145 keV incident photons. The agreement of measured values of Zeff with theory is quite satisfactory.

Key Words: Effective atomic number, Rayleigh and Compton scatterings, Intensity ratio

INTRODUCTION

The composite materials of several interests, for gamma-photon interactions, are assigned a number (equivalent to atomic number in elements) known as "effective atomic number". The quantity "effective atomic number" is quite useful parameter for interpretation of the attenuation of X-ray or γ-radiation by a composite material and medical radiation dosimeter. This number is also very useful to visualize a number of characteristics of a material for technological, nuclear industry, space research programs, engineering and in many fields of scientific applications. Tin-lead solders are commercially available with tin concentrations between 5% and 70% by weight, and solder's tensile and shear strengths depend upon tin concentrations.

Among various nuclear radiation physics techniques used for determination of effective atomic number of composite samples of several interests, the most significant is based upon measurement of Rayleigh to Compton scattered intensity emerging from the sample of composite material in a suitable source-sample-detector arrangement. This technique utilizes strong dependence of Rayleigh to Compton scattered intensity ratio on effective atomic number of scattering medium. This technique has also been tested for some elements with atomic number satisfying, $26 \leq Z \leq 82$ in 59.5 keV for 55° and 115° by İçelli and Erzeneoğlu[1], and İçelli[2]. We have also employed this technique to measure the effective atomic number of composite materials[3] of known composition for 279 keV photons. The agreement of measured values of effective atomic number with the theory is quite satisfactory. In the present experiment, the study of scattering of 145 keV γ-rays from Tin- lead solders is used to assign Z_{eff} values to these solders of varying tin concentration.

EXPERIMENTAL SET-UP

The experimental set-up used in the present measurements is shown in Fig.1. A well-collimated beam of 145 keV gamma rays from of ^{141}Ce source (strength 0.74 GBq) irradiates the sample. The distance of the target under study from the source collimator is kept 100 mm. The gamma photons scattered from the target are detected by an HPGe detector (56.4 mm diameter and 29.5 mm length) placed at scattering angle of 70^{o}.

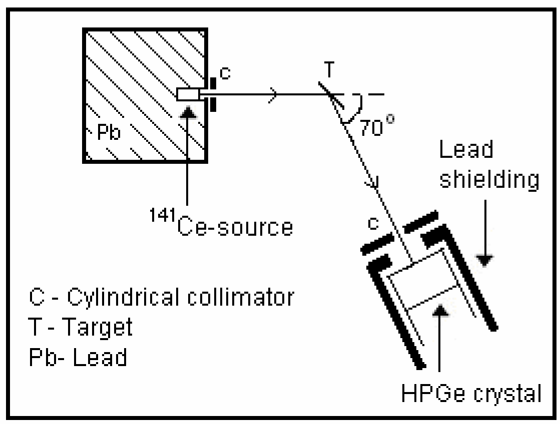

Fig. 1: Experimental set-up of present measurements

The radioactive source and the detector are properly shielded and aligned in such a way that the axes of source and the detector collimators coincide with the centre of the target.The distance between the target under study and the detector collimator opening (radius 4 mm) is kept 100 mm, so the angular spread about the median ray in direction of the gamma detector is $\pm$ 2.9^{o}. The field of view of the HPGe detector is confined to the target only. It has been checked that radiation scattered from the source collimator opening do not reach directly the active volume of the HPGe detector.

RESULTS AND DISCUSSION

In the present measurements, the experimental data are accumulated on a PC based ORTEC Mastreo-32 Multi channel analyzer (MCA). The target-in scattered spectra are recorded for a period of 5 ks by placing each of the targets, known Z and solders of various tin concentrations, in the primary gamma ray beam. The background is recorded after removing the target out of the primary beam to permit the registration of events due to cosmic rays and to any other process independent of the target. The subtraction of background events from the recorded target-in scattered spectra results in events originating from the interaction of primary gamma rays in the given target. A typical observed spectrum from solder when irradiated by 145 keV photons is shown in Fig.2. The Rayleigh and Compton peaks are observed at 145 and 122.2 keV respectively. The spread in observed Compton peak is caused by finite angular aperture of the source and detector collimator opening, and Doppler broadening of Compton peak in addition to inherent energy resolution of the HPGe detector. These observed intensities are corrected for photo-peak efficiency of the HPGe detector, absorption in air present between target and the detector, and self-absorption in the target, which has been described in our earlier measurements[3]. The corrected values of ratio of Rayleigh to Compton scattered intensity, for different targets of known atomic number and thickness, are plotted as a function of atomic number of targets used in the experimental study, and is shown in Fig.3. The solid curve represents the best-fit curve through experimental data points corresponding to the intensity ratio of Rayleigh to Compton scattering.

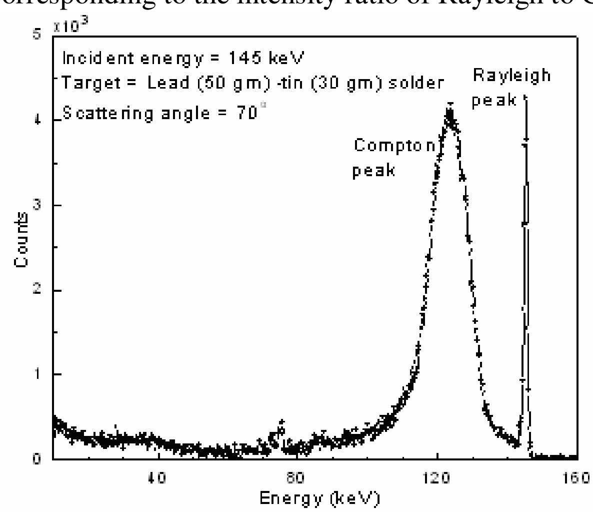

Fig. 2: A typical observed spectra at 70° for 145 keV gamma photons from solder (lead 50 gm and tin 30 gm) for 5 ks time duration

The use of this best-fit curve along with the corrected values of Rayleigh to Compton intensity ratio arising from solders of different tin concentrations provides the Zeff values to the respective solders. The solid curve of Fig. 4 provides theoretical dependence of effective atomic number as function of mass concentration of tin in lead-tin alloy. It is observed that the "effective atomic number" decreases non-linearly with increasing tin concentration in the alloy. Our measured Z_{eff} values, for various concentrations of tin, also decreases with increase in tin concentration, and are nearly in agreement with theory. The observed statistical uncertainties in the measured results lie within the diameter of the data points shown by filled circles. It has been checked that contribution

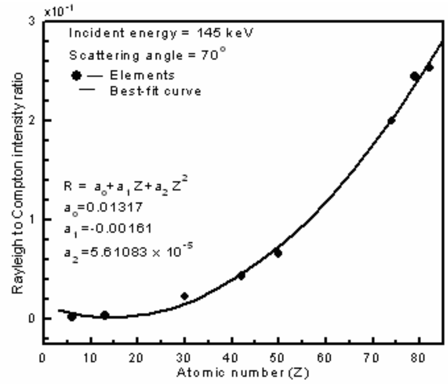

Fig. 3: Experimental variation of intensity ratio as function of atomic number

arising multiple scatterings[4] in the targets under present experimental conditions is negligibly small. The present measurements do not require absolute source strength of radioactive source and solid angles subtended by the source and detector at the target. At low incident photon energies, the probability for Rayleigh scattering is enhanced significantly in comparison to Compton scattering, so there is need to explore this technique at low energy incident photons (59.54 keV) for samples of various interests at different possible scattering angles.

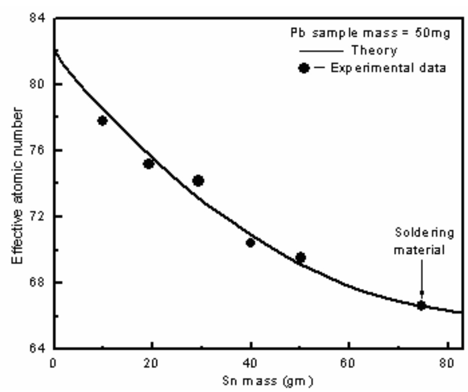

Fig. 4: Effective atomic number as function of mass concentration of tin in lead-tin solder. The experimental measured values (filled circles) support the theory (solid curve)

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