Asian Journal of Chemistry Vol. 18, No. 5 (2006), 3275-3278

Determination of Effective Atomic Number using Rayleigh to Compton Scattering of Gamma Rays

M.P. SINGH, B.S. SANDHU* and BHAJAN SINGH
Physics Department, Punjabi University, Patiala-147 002, India

In the present work, Rayleigh to Compton scattering intensity ratio method is used to determine the effective atomic number of binary alloys. The experiment is performed with various elements ($13 \leq Z \leq 79$) using HPGe solid-state detector placed at 50° relative to incident beam of 279 keV gamma photons. The intensity ratio under Rayleigh to Compton scattered peaks is plotted as a function of atomic number and fitted with a curve. From this calibration curve, the effective atomic number of the brass is determined.

Key Words: Effective atomic number, Rayleigh to Compton scattering cross-section ratio, Intensity ratio.

INTRODUCTION

In the intermediate energy range and for the materials normally studied, the dominant mode contributing to γ-beam attenuation is the Compton scattering. Due to dominance of scattering over absorption, there are several advantages to perform a scattering rather than transmission measurement. Firstly, the information achieved is essentially three dimensional rather than two-dimensional. The signal depends upon the composition volume element defined by the overlap of the incident and scattered collimated beams rather than the transmission ray sum integrated along one direction. Imaging is achieved directly by a scan in three dimensions rather than indirectly by reconstruction from two-dimensional scans. The contrast of the localized defects can be very high, especially if the beam widths are less than the defect size. Secondly, the scattering method allows changes in composition to be monitored irrespective of the attenuation of the incident and scattered beams. In general, densitometry can be carried out on the absolute scale. Finally, the scattering method only requires access from one side and this can be a major advantage if the object is a part of a large structure.

Rayleigh to Compton scattering intensity ratio method is generally employed for probing a material, as Rayleigh cross section is proportional to approximately Z^3 and Compton cross section is proportional to Z of the material and the ratio follows approximately Z^2. Numerous attempts[1-4] have been made to use ratio of intensity of elastic to inelastic scattering for the evaluation of samples of industrial and medical interest. While designing an experiment based on this technique, care must be taken to select properly the incident photon energy, scattering angle and material to be probed. The intensity of the elastically and inelastically scattered peaks should be sufficient and the two peaks must be well separated from each other, otherwise the analysis procedure becomes complicated. Because this method involves the ratio of intensity of Rayleigh and Compton scattered peaks, the cross section ratio is independent of the geometrical source-sample-detector arrangement. To determine the effective atomic number of a material, the experiment is first performed on various elements with known atomic numbers using high resolution solid state detector placed at particular scattering angle for an incident photon energy, then a calibration curve is drawn between R/C ratio and atomic number, and from this curve effective atomic number of a material is determined. The present experiment is performed on various elements ($13 \leq Z \leq 79$) and brass using HPGe solid-state detector placed at 50° scattering angle for 279 keV incident photons.

EXPERIMENTAL

The experimental set-up used in the present measurements is shown in Fig. 1.

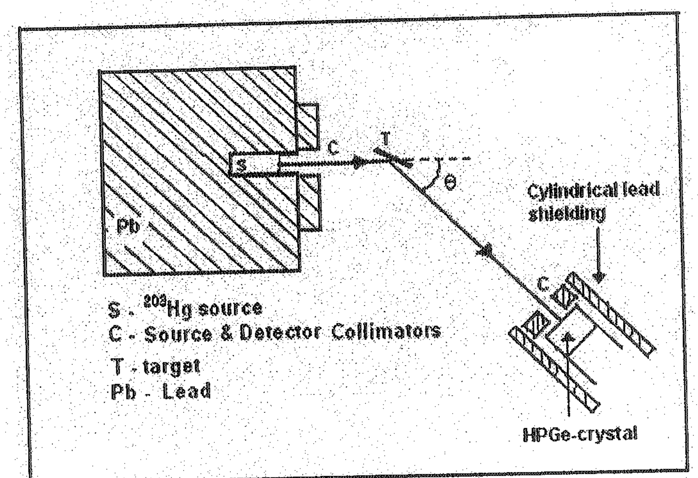

Fig. 1: Experimental set-up

A well-collimated beam of 279 keV gamma rays from of ^{203}Hg source (strength 25 mCi) irradiates the sample. The distance between the front face of the radioactive source and centre of scatterer is 10 cm. Photons scattered from the scatterer are detected by an HPGe solid state detector of dimensions 56.4 mm diameter and 29.5 mm length placed at scattering angle of 50°. The radioactive source and the detector are well shielded with lead bricks and aligned in such a way that the axes of source and the detector collimators coincide with the centre of the scatterer. Detector collimator having diameter 8 mm and thickness 20 mm is placed before the detector at a distance of 120 mm from centre of scatterer. The experimental data are accumulated on a PC based ORTEC Mastreo-32 plug-in MCA. The intensity under the Rayleigh to Compton scattered peaks is recorded with and without the scatterer in the primary incident beam for 10 ks. The difference between two sets of readings gives true Rayleigh to Compton scattered intensity (R/C) ratio.

RESULTS AND DISCUSSION

The measured values of Rayleigh to Compton scattered intensity ratio (R/C), corrected for detector efficiency and self-absorption in the target, is plotted as a function of atomic number of elemental targets used in the experiment and is shown in Fig. 2.

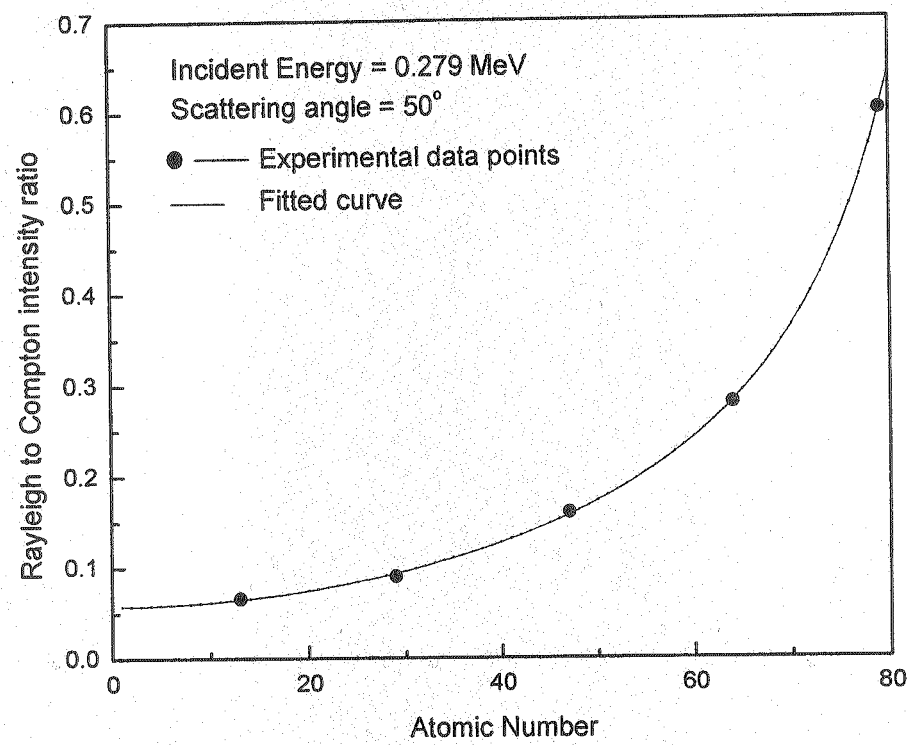

Fig.2: Variation of R/C as a function of atomic number

The experimental data points are best fitted with a function (solid line) follows approximately square law. The R/C ratio of the unknown sample is determined from the experimental spectrum by noting the area under the Rayleigh and Compton scattered peaks. This ratio is then extrapolated to the corresponding atomic number on the calibration plot. The value of effective atomic number for brass comes to be 29. Theoretically, the effective atomic number of the material is determined by mixture rule and by another formula given below

$$Z_{eff} = \sqrt[2.94]{f_1 \times (Z_1)^{2.94} + f_2 \times (Z_2)^{2.94}} \qquad (1)$$

Where f_n is the fraction of total number of electrons associated with each element and Z_n is atomic number of each element. The theoretically calculated value of effective atomic number from the constituent elements of the sample using mixture rule and the formula given above is 29.2. Our experimental value is in agreement with the theoretical value within experimental error. There are no data available in literature for comparison with the present results. The present measurements also do not require absolute source strength of ^{203}Hg radioactive source and solid angles subtended by the source and detector at the target. The present measurements are the preliminary one by our group with stated objective and confirm the usability of this experimental technique to measure the effective atomic number of homogeneous mixtures and compounds of known elemental composition. The experiment is in progress for the binary elements, like bronze, soldering material and other composite samples of medical and industrial interest.

ACKNOWLEGEMENTS

One of the authors (MPS) is thankful to University Grants Commission, New Delhi, India for the award of Teacher Fellowship under Faculty Improvement Program of tenth plan.

REFERENCES

1. P. Puumalainen, P. Sikanen and H. Olkkonen, *Nucl. Instr. Methods*, **163**, 261 (1979).
2. R. Cesareo, *Nucl. Instr. Methdos*, **179**, 545. (1981).
3. S. Manninen and S. Koikkalainen, *Appl. Rad. Isotopes*, **35**, 965 (1984).
4. P. Duvauchelle, G. Peix and D. Babot, *NDT and E International*, **33**, 23 (2000).