Effective atomic numbers of some polymers and other materials for photoelectric process at 59.54 keV

N. Govinda Nayak\textsuperscript{a}\textsuperscript{,*}, M.G. Vijaya\textsuperscript{a}, K. Siddappa\textsuperscript{b}

\textsuperscript{a}Department of Studies in Physics, Mangalore University, Mangalagangothri, Mangalore 574 199, India
\textsuperscript{b}Bangalore University, Bangalore 560 056, India

Abstract

Effective atomic numbers ($Z_{\text{eff}}$) of three polymers, an alloy, a compound and an element have been determined for photoelectric process at 59.54 keV from the accurately measured total attenuation coefficients, for $\gamma$-ray attenuation. Possible conclusions are drawn on electron binding effects and K-edge effects.

Keywords: Effective atomic numbers; K-edge effects

1. Introduction

Studies on $\gamma$-ray interaction in polymers have assumed great importance with the increasing use of these composite materials in many fields of science and technology, nuclear industry and space research programs. In such applications the concept of effective numbers ($Z_{\text{eff}}$) is introduced to describe the properties of these composite materials in terms of an equivalent element. A simple and commonly employed method of obtaining $Z_{\text{eff}}$ of a material consisting of different elements in definite proportions is based on the determination of total attenuation cross section for $\gamma$-ray interaction by the transmission method and finding out an equivalent element which has the same cross section. Very few experimental results on $Z_{\text{eff}}$ were reported for polymers and such other composite materials for the photoelectric process at $\gamma$-ray energy below 100 keV. In the present work we have reported accurate values of $Z_{\text{eff}}$ for three polymers, an alloy, a compound and an element at 59.54 keV.

2. Experimental details

In the present work, values of $Z_{\text{eff}}$ for the photoelectric process were determined from the accurately measured mass attenuation coefficient ($\mu/\rho$) by transmission method employing a good geometry setup (Siddappa et al., 1986; Ashok et al., 1991) by allowing 59.54 keV $\gamma$-rays from $^{241}$Am (300 mCi) source to undergo attenuation in our composite samples. The target polymers were in the form of uniformly thin ($\mu < 1$) high purity (better than 99.99\%) foils with thickness ranging from 0.13 to 0.34 g/cm$^2$. A NaI (TI) scintillation detector (7.62 × 7.62 cm$^2$) mounted on a 6956KL (EMI) photomultiplier was used to detect the attenuated $\gamma$-rays and the spectra were recorded in a PC-based 4K analyzer. The values of $Z_{\text{eff}}$ for our composite samples were evaluated from the accurately determined photoelectric cross sections using the semiempirical relations (Siddappa et al., 1986; Ashok et al., 1991).

3. Results and discussion

Our results of the attenuation cross sections and effective atomic numbers ($Z_{\text{eff}}$) for the composite materials at 59.54 keV have been compared with the semiempirical results and the literature values and are shown in Tables 1 and 2.
Table 1 shows that the measured photoelectric cross sections for NaOH and Polyboron are in very good agreement with the theoretical values. However, for the other samples, the measured values are not in good agreement with the theoretical values. This may be due to the fact that the samples, Plumber Solder, Light Lead-1 and Light Lead-2, contain Pb as one of the constituent elements whose binding energy of K-shell electron is comparable to the energy of the incident gamma ray. Further, the properties of the polymers are related to the chemical nature, the distribution of chain lengths and the amount of additives such as fillers. These factors influence the polymeric properties such as hardness, chemical resistance, etc. (Raymond and Charles, 1988). These could have a direct or indirect bearing on the total processes of γ ray interaction in these materials. In the sample Polyboron, the additives may be of low Z elements and hence the measured photoelectric cross sections agree with the theoretical values. However, in the other two samples, Light Lead-1 and Light Lead-2, the additives may be of high Z elements and also because of the presence of Pb itself, we could observe pronounced deviation from the theory.

Table 2 shows that $Z_{\text{eff}}$ for Polyboron, NaOH and Pb agree with the semiempirical results within the error limits. The results of $Z_{\text{eff}}$ for Plumber Solder (at lower
K-edge) differ considerably from the semiempirical values whereas the results at both lower and upper K-edges do agree with the experimental values reported in the literature (Siddappa et al., 1986). The results of $Z_{\text{eff}}$ for Light Lead-1 and Light Lead-2 at lower K-edges show conspicuous deviations from the semiempirical values whereas at the upper K-edge, the results do agree with the semiempirical values within the error limits. These observations clearly suggest the possible electron binding effects and K-edge effects. Since there are no earlier reports for these polymers and for the compound NaOH, our results of $(\mu/\rho)$ and $Z_{\text{eff}}$ constitute the first measurement for 59.54 keV $\gamma$ rays.

4. Conclusions

- The mixture rule can be used with confidence to evaluate $(\mu/\rho)$ in polymers also, as in the case of compounds and alloys.
- The hygroscopic nature of the compound seems to affect $(\mu/\rho)$ for $\gamma$ ray interaction in compounds.
- At lower $\gamma$ energy (10 keV $\leq E_\gamma \leq$ 100 keV) the measured photoelectric cross sections agree with the theoretical values for polymers having low Z elements as its constituents.
- More extensive studies at this energy and other energies of $\gamma$ rays are needed to throw more light on electron binding effects and K-edge effects.

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References