Determination of K-XRF cross-sections and study of other related inner shell phenomena

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Introduction

The study of interaction of gamma rays with matter which eventually deals with the study of atomic inner shell parameters like photoelectric cross-sections, scattering cross-sections, XRF cross-sections and XRF yield has become increasingly important owing to their wide range of applications in the field of agriculture, medicine, industry, material sciences, elemental analyses etc., [1].

Many investigators have determined K-XRF yields for various elements but few have tried in determining the K-XRF cross-sections [2-5]. But the experimentally determined values are in lower energy range. In the present work, an attempt is being made to determine the K-XRF cross-section in the energy range 511keV-1.33MeV.

Theory

When gamma radiation of intensity $\mathbf{I_0}$ is passed through a medium of thickness **t**, the beam gets attenuated to a intensity $\mathbf{I = I_0\, e^{-\mu t}}$, where $\boldsymbol{\mu}$ is the linear attenuation coefficient. If $\boldsymbol{\rho}$ is the density of the medium, then mass attenuation coefficient is given by

$$\frac{\mu}{\rho} = \frac{1}{t}\ln\frac{I_0}{I}$$

The mass attenuation coefficient $\frac{\mu}{\rho}$ is related to the total interaction cross-section σ_t given by

$$\sigma_t = \left(\frac{\mu}{\rho}\right)\frac{A}{N_A}$$

where, **A** is the mass number of medium or the absorber and $\mathbf{N_A}$ is the Avagadro number.

Here an indirect method is adopted to calculate photoelectric cross-section. The total interaction cross-section when excitation energy is around 1 MeV is

$$\sigma_{total} = \sigma_{photo} + \sigma_{coh} + \sigma_{incoh} + \sigma_{pp}$$

By subtraction technique photoelectric cross-section of the absorber is calculated by the equation below.

$$\sigma_{photo} = \sigma_{total} - (\sigma_{coh} + \sigma_{incoh} + \sigma_{pp})$$

Once we have the σ_{photo} value we can easily calculate the K-XRF cross-section using the relation $\sigma_k = \sigma_{photo} * \omega_k$ where σ_k is K-XRF cross-section and ω_k is K-XRF yield.

Experimental Details

A good geometry setup similar to the one explained in [6] is used in the present work. NaI (Tl) scintillation detector coupled with 1K MCA from GSPEC is used. The detector is calibrated and linearity of the detector is studied. In this work we have used Co^{60}, Cs^{137} and Na^{22} emitting gamma radiations of energy 1.17MeV and 1.33MeV, 662 keV and 511keV and 1.28MeV respectively. Thin absorber foils of 99% purity of Cu, Mo, Ta, Au and Pb are used. Gamma radiation spectra are recorded with and without the absorbers. Counting is done for reasonably large time interval so that around 10^4 counts are recorded under the photo peak. This is to minimize the error due to counting statistics. The area under the photo peak is evaluated. Using the spectra thus obtained the mass attenuation coefficient is calculated and other values are derived from the mass coefficient value using the relations mentioned in the previous section. Fluorescence yield values are taken from [7] for calculation purpose.

Results and Discussions

The values of mass attenuation coefficients for gamma rays of energies mentioned above for the elements Cu, Mo, Ta, Au and Pb were found to be in good agreement with the values obtained by the previous investigators.

The total cross-sections are derived from the mass attenuation coefficients. The derived total cross-section values are compared with the theoretical WinXCOM values of total cross-sections and other experimental values. The sample graph shows the variation of total cross-sections with atomic number Z of the elements. The variation is linear in lower Z region since incoherent scattering dominates in the energy range considered here for low Z elements. The partial processes like coherent scattering and photoelectric effect have different Z^n variation than the incoherent scattering and these processes contribute significantly to the non-linearity observed in the high Z region of the plot.

It can be seen from **Table.1**that the photoelectric cross-sections obtained show a decreasing trend with excitation energy while they increase with Z value. From the slope of the plot $\ln(\sigma_{photo})$ vs. ln(Z) value of n is found which ranges between 4 and 5. The theoretical values of coherent scattering, incoherent scattering and pair production cross-section are obtained from the WinXCOM program.

K-XRF cross-sections are calculated from the photoelectric cross-section values and tabulated in **Table.2**. Error associated with the determined values is estimated to be less than 5%. From the plot showing the variation of σ_k versus Z for various gamma radiation energies we can say that fluorescence cross-sections increase with Z. As gamma radiation energy increases the fluorescence cross-sections decreases.

Conclusion

Variation of total interaction cross-section with atomic number Z is linear in the lower Z (Z<40) region and non-linear in the higher Z region (Z>40). The photoelectric cross sections found to vary as Z^n where n is found to vary between 4 and 5 which is in close agreement with the theoretical value. The photoelectric cross sections found decreasing with increase in the excitation energy. The K-XRF cross-sections determined in this work are for high excitation energy. It is found that the K-XRF cross-sections increase with increase in atomic number but decreases with increase in excitation energy.

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