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Investigation of Angular Distribution of K Shell X-rays-A New Approach

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Measurement of differential K shell X ray intensity ratios, $\frac{I(K_\alpha)}{I(K_\beta)}$ for Copper and Gadolinium at 60°-100° has been reported. A new approach has been developed to know quantitatively the isotropy in K shell X-rays. The present results confirm the prediction of the calculations of Flugge *et al.*[1], Scofield[2], Berezhko *et al.*[3] and Cooper and Zare[4] that, after photoionization of inner shells, the vacancy states with J = 1/2 has equal population of magnetic sub states and the subsequent K shell X-ray emission is isotropic.

Key Words: K shell, X-rays, Angular distribution, Isotropy.

INTRODUCTION

Angular distribution of X-rays created by ion atom collisions has been widely studied. However in the case of photon atom collisions contradictory theories are existing. Cooper and Zare[4] predicted that vacancy states produced after photoionisation with $j \geq 1/2$ are unaligned and thus X-rays emitted are isotropic and unpolarized. Flugge *et al.*[1], Scofield[2] and Berezhko *et al.*[3] contradicted the above view and suggested that vacancy states produced after photoionisation of subshell with $j > 1/2$ are aligned and accordingly X-rays emitted are anisotropic and polarized. Thus both theories predicted that vacancies with J = 1/2 are unaligned and consequently X-rays emitted are isotropic.

Recently experiments have been performed by researchers of various laboratories[5-8] using unpolarized radiations to check the theories of Flugge *et al.*[1], Scofield[2], Berezhko *et al.*[3] and Cooper and Zare[4] by using photon atom interactions. From these results no particular conclusion can be drawn, as some of the results favours the calculations of Flugge *et al.*[1], Scofield[2], Berezhko *et al.*[3] and other favours the result of Cooper and Zare[4]. The experiments reported in this direction were the measurements of angular distribution of emission of L X-rays in some high Z elements. The results of Kahlon *et al.*[5], Sharma *et al.*[6] Ertugrul *et al.*[7] and Sabriye Seven *et al.*[8] support the view that vacancy states produced after photoionisation with vacancy $j \geq 3/2$ are aligned and are in agreement with the results of Flugge *et al*[1], Scofield[2] and Berezhko *et al.*[3].

The results of Puri *et al.*[9] support the theory of Cooper and Zare[4] which predicted that vacancy states with $j \geq 1/2$ produced by unpolarized radiations are unaligned and consequently the X-rays emitted are isotropic and unpolarized in nature.

In order to explore the alignment of K shell vacancy states and provide a further check to the theoretical predictions of Cooper and Zare[4], Flugge *et al.*[1], Scofield[2] and Berezhko *et al.*[3], it is worthwhile to study the K shell X-ray intensities related to copper and gadolinium at 60°, 70°, 80°, 90° and 100°. A new method has been developed to investigate the angular distribution of K shell X-rays by measuring the intensity of $\frac{I(K_\alpha)}{I(K_\beta)}$ at different emission angles.

EXPERIMENTAL

The experimental set-up for measurement is described earlier in Kahlon *et al.*[5]. The ^{241}Am source and Gd or Mo targets were mounted on a movable arm which can rotate about an axis through the center of a graduated circular table and move the source and target together with respect to Si(Li) X-ray detector which is kept fixed. 60 keV γ-rays emitted from ^{241}Am source, of strength approximately 100 mCi, are collimated to fall on a 99.99% pure metallic foil of Gd or Mo. The angle of incidence was kept fixed at 70° while the angle of emission was varied to 60°-100° with intervals of 10°. The angular spread in the experimental setup was 2.5°.

When a target T of thickness t gm/cm^2 was irradiated with unpolarized photons from a source of strength S, fluorescent X-rays were emitted from it as a result of interaction of incident photons with the inner shell electrons of the atoms. The target elements under investigation were chosen in such a way that the energy of incident photons from source S be above their K shell threshold energies. Detector used in present setup has resolution of 300 eV at 6 keV and could separate out K_α and K_β X-rays group. It has been found that in addition to the emission of K X-rays there was scattering of 60 keV γ-rays from the target. However, the Si(Li) X-ray spectrometer used in the present measurements clearly separated the K X-ray from the scattered radiation.

The number of fluorescent K X-rays detected by the detector per unit time under the K ith X-ray peak is

$$N^\theta(Ki) = S_\gamma a_\gamma \omega_1 \frac{\omega_2}{4\pi} \frac{d^\theta \sigma(K_i)}{d\Omega} \frac{N}{M} \omega_K t_K \beta^\theta(K_i) \varepsilon(K_i) \tag{1}$$

where i = α,β. S_γ is the number of photons emitted from the source per unit time; ω_1 is the source-target solid angle, a_γ is the correction factor which takes into account the absorption of gamma rays in the source and the air column between the source and target; t_K is the thickness of target in gm/cm², N/M is the number of atoms per gm of target material; $\beta^{\theta}(K_i)$ is the self absorption correction factor which takes into account the effect of absorption of incident gamma rays and emitted K X-rays in the target at an emission angle θ. $\frac{d^{\theta}\sigma(K_i)}{d\Omega}$ is the differential cross-section for the emission of K_i X-rays at angle θ; $\frac{\omega_2}{4\pi}$ is the target-detector solid angle and ε(Ki) is efficiency of the detector for the detection of the K ith X-ray under the photo peak.

From equation (1), the differential K X-ray emission cross-section at angle θ is given by

$$\frac{d^{\theta}\sigma(K_i)}{d\Omega} = I^{\theta}(Ki) = \frac{N^{\theta}(Ki)}{\frac{N}{M}\omega_K t_K \beta^{\theta}(K_i)\varepsilon(K_i)S_{\gamma}a_{\gamma}\omega_1\frac{\omega_2}{4\pi}} \qquad (2)$$

It is seen from equation (2) that determination of $\frac{d^{\theta}\sigma(K_i)}{d\Omega}$ requires the knowledge of various physical parameters relating to gamma ray source, target and X-ray spectrometer *e.g.* absolute source strength S, the solid angles ω_1 and $\frac{\omega_2}{4\pi}$, the efficiency of the detector $\varepsilon(K_i)$, the self absorption correction factor $\beta^{\theta}(K_i)$, parameters of the target (N/M) and number of K shell fluorescent X-rays detected by the X-ray spectrometer per unit time, is required.

The accuracy of the measurement of differential K X-ray emission cross-section at any angle θ *i.e.*, $\frac{d^{\theta}\sigma(K_i)}{d\Omega}$ wass obviously limited by the uncertainties involved in the determination of these parameters. However, the accuracy of the measurements was improved by measuring the relative K X-ray emission intensities. The ratio of K X-ray intensity ratios measured at emission angle θ is therefore given by

$$\frac{I^{\theta}(K_{\alpha})}{I^{\theta}(K_{\beta})} = \frac{N^{\theta}(K\alpha)}{N^{\theta}(K\beta)}\frac{\beta^{\theta}(K_{\beta})}{\beta^{\theta}(K_{\alpha})}\frac{\varepsilon(K_{\beta})}{\varepsilon(K_{\alpha})}$$

Thus the intensity ratios can be measured at various emission angles θ by determining the ratio of self-absorption correction factors of target $\frac{\beta^{\theta}(K_{\beta})}{\beta^{\theta}(K_{\alpha})}$, area under K_{α} and K_{β} peaks $\frac{N^{\theta}(K\alpha)}{N^{\theta}(K\beta)}$ and efficiency of detector $\frac{\varepsilon(K_{\beta})}{\varepsilon(K_{\alpha})}$. Efficiency ratios $\frac{\varepsilon(K_{\beta})}{\varepsilon(K_{\alpha})}$ are dependent only on energy and are angle independent. Thus variation of K X-ray intensity ratios depends only upon $\frac{N^{\theta}(K\alpha)}{N^{\theta}(K\beta)}$ and $\frac{\beta^{\theta}(K_{\beta})}{\beta^{\theta}(K_{\alpha})}$. The values of $\frac{N^{\theta}(K\alpha)}{N^{\theta}(K\beta)}$ at different angles θ were determined experimentally, while the values of $\frac{\beta^{\theta}(K_{\beta})}{\beta^{\theta}(K_{\alpha})}$ are calculated from the known photon absorption coefficients given by Hubbel *et al.*[10]. The ratios of $\frac{\beta^{\theta}(K_{\beta})}{\beta^{\theta}(K_{\alpha})}$ are calculated by using equation

$$\beta = \frac{1-\exp[-(\frac{\mu_i}{\cos\theta_1}+\frac{\mu_e}{\cos\theta_2})t_K]}{(\frac{\mu_i}{\cos\theta_1}+\frac{\mu_e}{\cos\theta_2})t_K}$$

where μ_i and μ_e are photon absorption coefficients at incident gamma ray and emitted K X-ray energies respectively.

It has been seen that ratios of value of self-absorption correction factor $\frac{\beta^{\theta}(K_{\beta})}{\beta^{\theta}(K_{\alpha})}$ is not varying with angle and is shown in table I.

In view of above it is found that the variation of ratio of K X-ray intensity ratios $\frac{I^{\theta}(K_{\alpha})}{I^{\theta}(K_{\beta})}$ measured at emission angle θ depends only upon $\frac{N^{\theta}(K\alpha)}{N^{\theta}(K\beta)}$. To measure the ratio of counting rates $\frac{N^{\theta}(K\alpha)}{N^{\theta}(K\beta)}$ targets of Gd and Mo were irradiated with 59.97 keV unpolarized photons in the experimental setup and emitted K shell X-rays were detected at different emission angles by rotating the source target assembly. The experiment with each target was run for long time in order to have statistical accuracy < 1% for K_{α} and K_{β} peaks.

RESULTS and DISCUSSION

The measured values of K shell intensity ratios, $\frac{I^{\theta}(K_{\alpha})}{I^{\theta}(K_{\beta})}$, for Gd and Mo at angles, 60°, 70°, 80° ,90° and 100° are shown in table 1. No experimental data were available for comparison with present results. The errors in the present measurements were ≈ 1.5% and were due to uncertainty in counting statistics only. It has been seen that K shell X-rays intensity ratios were not varying with angle and therefore K shell vacancy states were unaligned and x ray emission is isotropic in nature. These results favours the predictions of Cooper and Zare[4], Flugge *et al.*[1], Scofield[2] and Berezhko *et al.*[3] that after photoionization the vacancy states for J = 1/2 are not aligned and X-ray emission is therefore isotropic.

The present method has never been reported before and is useful in quantitatively prediction of isotropy of K shell X-rays. In present method variation of intensity ratios depends only upon $\frac{N^{\theta}(K\alpha)}{N^{\theta}(K\beta)}$ and therefore uncertainly involved in the experiment is decreased considerably.

TABLE-1

VARIATION OF SELF-ABSORPTION CORRECTION FACTOR AND COUNTING RATES WITH EMISSION ANGLE (THE TERMS IN BRACKETS ARE ERRORS)

Emission angle (θ)	Gd		Mo	
	$\frac{\beta^{\theta}(K_{\beta})}{\beta^{\theta}(K_{\alpha})}$	$\frac{N^{\theta}(K\alpha)}{N^{\theta}(K\beta)}$	$\frac{\beta^{\theta}(K_{\beta})}{\beta^{\theta}(K_{\alpha})}$	$\frac{N^{\theta}(K\alpha)}{N^{\theta}(K\beta)}$
60°	0.98	3.31(0.05)	0.94	5.09(0.07)
70°	0.98	3.38(0.05)	0.94	4.62(0.07)
80°	0.98	3.37(0.05)	0.94	4.66(0.07)
90°	0.98	3.33(0.05)	0.94	5.12(0.07)
100°	0.98	3.39(0.05)	0.93	4.78(0.07)

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