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Measurements of L1 and L2 Subshell Fluorescence Yields for Dy at 22.6 keV Incident Photon Energy

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The L1 and L2 subshell fluorescence yields have been deduced from the measured cross sections for production of Ll, Lα, Lβ1,4, Lβ3,6, Lβ2,15,9,10,7, Lγ1,5 and Lγ2,3,4 x-rays of Dy66 at 22.6 keV incident photon energy. These measurements were performed using a sealed point (3mm ϕ) radioactive source of Cd109 (20 mCi) as a photon source and Peltier cooled x-ray detector arranged in reflection geometry. The present deduced values of fluorescence yields are compared with the DHS model based theoretical values, the semi-empirical values, and those recommended by Campbell.

INTRODUCTION

Reliable accurate data on the L shell fluorescence and Coster-Kronig yields are required for a variety of applications such as radiation shielding, radiation transport and mass-attenuation calculations, dosimetric computations, and the quantitative elemental analysis using x-ray emission techniques (EDXRF and PIXE).

Three sets of the L_i(i=1-3) subshell fluorescence (ω_i) and Coster Kronig (f_{ij}) yields are available in literature. Puri et al.[1] reported a comprehensive set of the ω_i and f_{ij} yields for all the elements with $25 \leq Z \leq 96$ evaluated using the Dirac-Hartree-Slater (DHS) model based x-ray emission rates[2], and the non-radiative transition rates interpolated from the DHS model based data[3] available for limited elements considering the onset / cut-off[4] of different CK transitions. Krause[5] tabulated a set of semi-empirical fitted values of ω_i and f_{ij} yields for all elements with $12 \leq Z \leq 110$ based on the experimental data available till 1979. Recently, Campbell[6,7] provided a set of recommended values of the ω_i and f_{ij} yields for the elements with $62 \leq Z \leq 96$.

Only a limited number of measurements of the L_i subshell fluorescence yields for the rare-earth elements are available in literature. Xu et al [8] reported the ω_1 and ω_2 yields deduced from the L x-ray spectra of $_{57}$La, $_{60}$Nd, $_{66}$Dy, $_{70}$Yb and $_{71}$Lu elements induced by 2 MeV proton beam. It may be mentioned that the measured fluorescence yields reported by Xu et al [8] strongly depend on the theoretical L_i(i=1-3) subshell Coster-Kronig yields (f_{12}, f_{13} and f_{23}) and the x-ray emission rates.

In the present investigations, the L_1 and L_2 subshell fluorescence yields have been deduced for $_{66}$Dy elements from the L_k(k=l, α, $\beta_{1,4}$, $\beta_{3,6}$, $\beta_{2,15,9,10,7}$, $\gamma_{1,5}$ and $\gamma_{2,3,4}$)

x-ray production (XRP) cross sections measured at 22.6 keV incident photon energy. The deduced fluorescence yields have been compared with the theoretical values[1], semidata[8].

EXPERIMENTAL PROCEDURES

The experimental setup used for present measurements consists of a sealed point (3mm ϕ) radioactive source of Cd^{109} (20 mCi) as a photon source and Peltier cooled x-ray detector (FWHM 155eV at 5.9 keV) arranged in reflection geometry. Spectroscopically pure self-supporting pressed pellet of Dy_2O_3 of thicknesses ~103 mg/cm^2 was used as target. To reduce the statistical error in measurements, three spectra were recorded for time intervals ranging 30-35 hrs.

The experimental L*k*(*k*=l, α, $\beta_{1,4}$, $\beta_{3,6}$, $\beta_{2,15,9,10,7}$, $\gamma_{1,5}$ and $\gamma_{2,3,4}$) XRP cross sections, σ^x_{Lk}, at incident photon energy E_{inc}(=22.6 keV) have been evaluated using the relation

$$\sigma^x_{Lk} = N_{Lk}/(I_o G\varepsilon\beta_{Lk} m) \qquad (1)$$

where N_{Lk} is the number of counts per unit time under the L*k* photopeak, IoG is the intensity of the incident radiation falling on the area of the target visible to the detector, ε is the detector efficiency, m is the mass thickness (g/cm^2) of the target element under investigation, and β_{Lk} is the self-absorption correction factor which accounts for the absorption of incident and emitted photons in the target. The values of β_{Lk} have been calculated as explained in our earlier paper [9] and were found to be in the range (0.0424-0.0913) for the target under investigation. Each spectrum was analyzed for photo-peak areas (N_{Lk}) using commercial software package "Origin" as explained in our earlier paper [9]. The Lβ and Lγ groups of x-rays have been resolved into components ($L\beta_{1,4}$, $L\beta_{3,6}$ and $L\beta_{2,7,15,9,10}$) and ($L\gamma_{1,5}$, $L\gamma_{2,3}$ and $L\gamma_4$), respectively, by fitting procedures as shown in Fig. 1.

The product, IoGε was determined by measuring the K x-ray yields from targets of $K_2Cr_2O_7$, MnO_2, $Co(NO_3)_2.6H_2O$, $NiCl_2.6H_2O$, CuO, $ZnSO_4.7H_2O$, As_2O_3, Se, $SrCO_3$, MoO_3 in the same experimental setup as used for the L*k* XRP cross section measurements and using Eq. (1), but for the Kα x-rays rather than the L*k* x-rays. The details are given elsewhere[9]. The L_1 and L_2 subshell fluorescence yields have been deduced from the present measured L*k* XRP cross sections as explained in our earlier paper [9].

RESULTS AND DISCUSSION

The present measured L_k(k=l, α, $\beta_{1,4}$, $\beta_{3,6}$, $\beta_{2,15,9,10,7}$, $\gamma_{1,5}$ and $\gamma_{2,3,4}$) XRP cross sections, $\sigma^x_{Lk}(\text{exp})$, for $_{66}$Dy are listed in Table1. The overall error in the present measured cross sections is estimated to be 6-9%. The present measured $\sigma^x_{Lk}(\text{exp})$ values are compared with the three sets of calculated, $\sigma^x_{Lk}(\text{DHS})$,

σ^{x}_{Lk}(Kr.) and σ^{x}_{Lk}(Camp) (k=l, α, $\beta_{1,4}$, $\beta_{3,6}$, $\beta_{2,15,9,10,7}$, $\gamma_{1,5}$ and $\gamma_{2,3,4}$) values in Table 1. The σ^{x}_{Lk}(DHS) values are, on an average, higher than the σ^{x}_{Lk}(Kr.) values by ~11% for the Ll, Lα, L$\beta_{1,4}$, L$\beta_{2,15,9,10,7}$, L$\gamma_{1,5}$ groups of x-rays and by ~4% for the L$\beta_{3,6}$, L$\gamma_{2,3,4}$, groups of x-rays, respectively. The σ^{x}_{Lk}(Camp) are, on an average, higher than the σ^{x}_{Lk}(Kr.) values by ~15% for the L$\beta_{3,6}$, L$\gamma_{2,3,4}$ groups of x-rays, by ~9% for the L$\beta_{1,4}$, and L $\gamma_{1,5}$ groups of x-rays and by ~4% for the Ll, Lα and L$\beta_{2,15,9,10,7}$ groups of x-rays, respectively. The σ^{x}_{Lk}(DHS) values are, on an average, higher than the σ^{x}_{Lk}(Camp) values by ~5% for the Ll, Lα and L$\beta_{2,15,9,10,7}$ groups of x-rays, by ~2-4% for the L$\beta_{1,4}$, and L $\gamma_{1,5}$ groups of x-rays, and are lower than these values by ~9% for the L$\beta_{3,6}$ and L$\gamma_{2,3,4}$ groups of x-rays, respectively. The σ^{x}_{Lk}(exp) values exhibit good agreement with the σ^{x}_{Lk}(DHS) and σ^{x}_{Lk}(Camp) values for all x-ray components except for L$\beta_{3,6}$ where the measured value is higher than DHS value by ~34% and 21%, respectively. The measured values are higher than the σ^{x}_{Lk}(Kr.) values by ~8-36% for different x-ray components. The present deduced ω_1(exp) and ω_2(exp) values are compared with the three sets [1,5,6] of available values and earlier measured values [8] in Table 2 and Table 3, respectively. The three sets of available ω_1 and ω_2 values [1,5,6,7] differ from each other

Table 1: The present measured and three sets of calculated L_k(k=l, α, $\beta_{1,4}$, $\beta_{3,6}$, $\beta_{2,15,9,10,7}$, $\gamma_{1,5}$ and $\gamma_{2,3,4}$) XRP cross sections (σ^{x}_{Lk}; barns/atom) for $_{66}$Dy.

	σ^{x}_{Lk}(exp)	σ^{x}_{Lk}(DHS)	σ^{x}_{Lk}(Kr.)	σ^{x}_{Lk}(Camp)
X-ray (subshell)		**$_{66}$Dy**		
Ll (L_3)	24.8 (14)	24.55	22.5	23.09
*Lα (L_3)	609 (36)	595.1	544.5	560.4
L$\beta_{1,4}$ (L_2, L_1)	444 (27)	450.8	403.1	447.3
L$\beta_{3,6}$ (L_1, L_3)	135 (12)	100.9	98.40	110.1
L$\beta_{2,7,15,9,10}$ (L_3, L_1)	109 (7)	108.6	99.81	102.8
Lβ (L1, L_2, L_3)	687 (41)	657.1	601.3	660.2
L$\gamma_{1,5}$ (L_2)	71.4 (45)	74.22	65.28	72.25
L$\gamma_{2,3,4}$ (L_1)	47.3 (34)	47.06	46.02	51.71
Lγ (L_1, L_2)	119 (9)	121.3	111.3	123.9

*-- All values include the cross sections for Lη x-ray line.

Table 2: The L_1 subshell fluorescence yields (ω_1) for $_{66}$Dy.

Z	**ω_1(exp)**	**ω_1(DHS)**	**ω_1(Kr.)**	**ω_1(Camp.)**	**Others work**
66	0.116(9)	0.091	0.089	0.100	0.109(13)[8]

Table 3: The L_2 subshell fluorescence yields (ω_2) for $_{66}$Dy.

Z	ω_2(exp)	ω_2(DHS)	ω_2(Kr.)	ω_1(Camp.)	Others work
66	0.187(16)^ 0.192(16)*	0.197	0.178	0.197	0.190(19)[8]

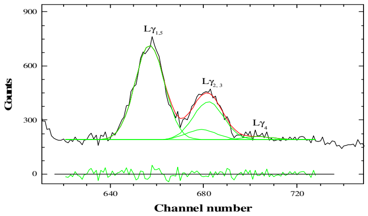

Figure 1(a): A plot of the fitted Lγ x-ray components ($L\gamma_{1,5}$, $L\gamma_{2,3}$, $L\gamma_4$) of $_{66}$Dy along with the residue.

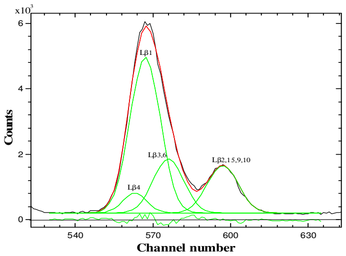

Figure 1(b): A plot of the fitted Lβ x-ray components ($L\beta_1$, $L\beta_4$, $L\beta_{3,6}$, $L\beta_{2,15,9,10,7}$) of $_{66}$Dy along with the residue.

by ~3-11%. The present deduced ω_l value is higher by 16%, 24% and 30% than the Campbell's value [6,7], the DHS value[1] and that of Krause's [5] value, respectively, and agree well with the earlier measured[8] value. The present deduced ω_2(exp) values are found to be in general agreement with the available three sets of values and exhibited excellent agreement with the earlier measured[8] value.

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