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L_2-L_3 Coster-Kronig transition probability for $Z=54$

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The total Coster-Kronig transition probability f_{23} for the L_2-L_3 atomic transition was measured utilizing resolved L-K x-ray coincidence techniques for $Z=54$ with radioactive sources of 9.69 day ^{131}Cs. The value of f_{23} is 0.148 ± 0.029.

Significant improvements in the experimental techniques for investigating x-ray emission from single L-vacancy atomic states permit closer testing of the theoretical models employed to calculate L-shell yields. While Krause[1] has published a semiempirical fit based on the available body of experimental values of L-shell yields and level widths, a set of theoretical L-shell yields, based on *ab initio* relativistic calculations are available in the range $18 \leq Z \leq 100$ from the work of Chen, Crasemann, and Mark.[2]

Accurate experimental values of L-subshell yields also are important in many practical applications, ranging from elemental analysis by x-ray emission techniques to basic studies of nuclear and atomic processes leading to emission of x rays and Auger electrons, such as electron capture, internal conversion, and ionization cross section measurements.

The present work extends the measurement of the total L_2-L_3 Coster-Kronig transition probability f_{23}, the probability for shifting a vacancy in the L_2 to the L_3 subshell, to $Z=54$.

The basic physical relationships among the L subshells involved in the determination of f_{23} have been published previously,[3] but are repeated here for clarity. Measurement of f_{23} proceeds from the relationship

$$f_{23}=\frac{C_{L_3X(K\alpha_2)}I_{K\alpha_1}}{C_{L_3X(K\alpha_1)(\theta)}I_{K\alpha_2}}\,, \tag{1}$$

where $C_{L_3X(K\alpha_2)}$ and $C_{L_3X(K\alpha_1)}$ are the total numbers of L x-ray counts gated by $K\alpha_2$ and $K\alpha_1$ x rays, respectively, arising from L_3-X shell transitions, where X represents the $M,N,\ldots$ higher shells, which give rise to the $L_l+L\alpha_{1,2}+L\beta_{2,15}$ components of the L x-ray series. These quantities are corrected for background, nuclear cascading, if present, and chance coincidences, as well as directional correlations in the case of $C_{L_3X(K\alpha_1)}$ and L x-ray coincidences arising from $K\alpha_1$ tail events falling within the $K\alpha_2$ gate in the case of $C_{L_3X(K\alpha_2)}$. The quantities $I_{K\alpha_1}$ and $I_{K\alpha_2}$ are the intensities (counts) of $K\alpha_1$ and and $K\alpha_2$ *singles* events falling within the energy region defined by the $K\alpha_1$ and $K\alpha_2$ coincidence gates, respectively. (Note that $I_{K\alpha_1}$ and $I_{K\alpha_2}$ arise from events falling within the energy region of the *singles* spectrum defined by the $K\alpha_1$ and $K\alpha_2$ gates and are *not* coincidence intensities.)

The radioactive sources used were 9.69 day ^{131}Cs prepared by irradiating 2 g of $^{\mathrm{nat}}$Ba(NO$_3$)$_2$ for 20 h at 10^{13} n/cm^2 sec in the thermal neutron flux of the Georgia Tech Research Reactor. The irradiated sample was retained for 7–10 days to allow the ^{139}Ba activity to die out at which time a radiochemical separation of ^{131}Cs following the decay of 11.5 day ^{131}Ba was carried out. This separation consisted of a series of $\mathrm{BaCl_2{\cdot}H_2O}$ precipitations[4] to give a carrier-free, solids-free source, which was drop evaporated onto a Mylar backing.

The experimental apparatus to acquire three parameter *XXt* coincidence spectra and K x-ray singles spectra has been described in detail elsewhere.[3] The K x-ray detector is a ruggedized ion-implanted planar Ge (HP) with resolution of 230 eV full width at half maximum (FWHM) at 14.4 keV, and the L x-ray detector is a planar Si (Li) with resolution of 240 eV FWHM at 5.9 keV. Both detectors are fitted with 0.125 mm Be windows and were used in 180° coincidence geometry. An example of the K x-ray spectrum is shown in Fig. 1 and the L spectra in Fig. 2.

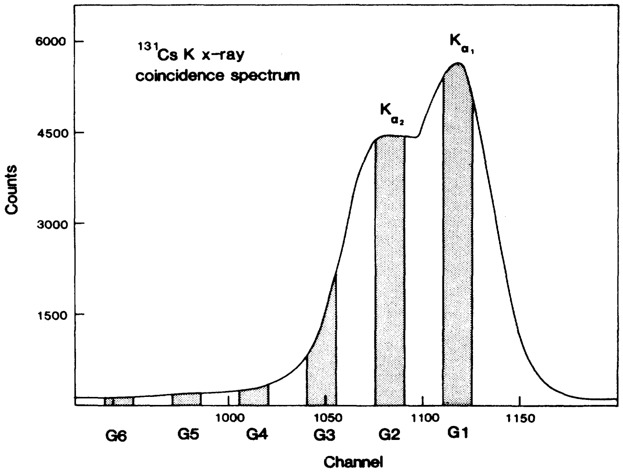
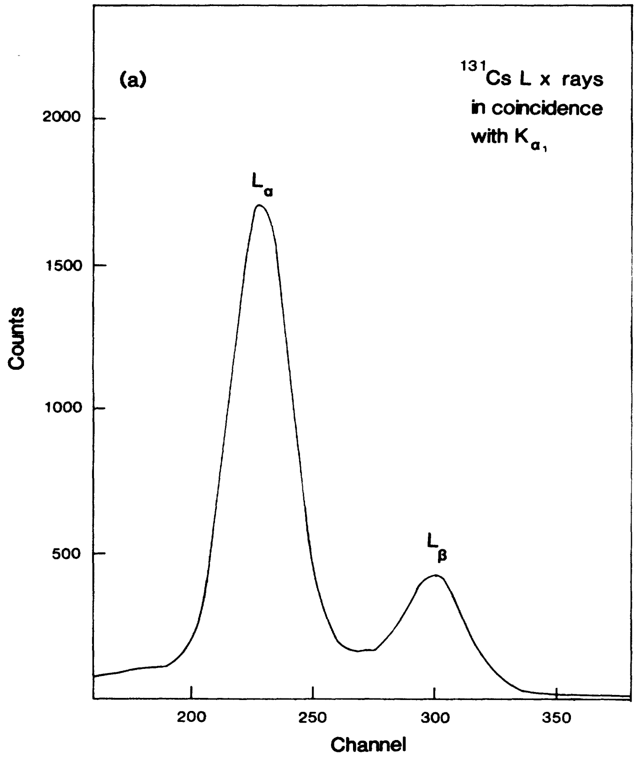


FIG. 1. K x rays from 9.69 day ^{131}Cs decay in coincidence with L x rays. The coincidence gates indicated by the shaded areas are set in the process of data analysis.



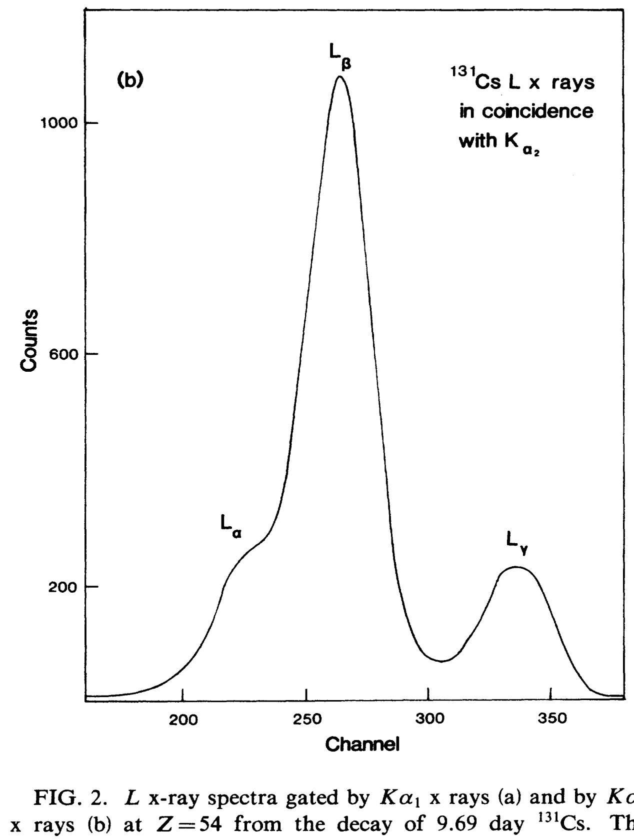


FIG. 2. L x-ray spectra gated by $K\alpha_1$ x rays (a) and by $K\alpha_2$ x rays (b) at $Z=54$ from the decay of 9.69 day ^{131}Cs. The $K\alpha_2$-gated spectrum is corrected for the presence of $K\alpha_1$ tail events (see text).

TABLE I. Quantities used to evaluate f_{23}.

Quantity	Value	% error
$C_{L_3X(K\alpha_2)}$	5.12×10^3	9.6
$C_{L_3X(K\alpha_1)}(\theta)$	4.98×10^4	2.4
$I_{K\alpha_1}$	3.20×10^8	0.2
$I_{K\alpha_2}$	1.88×10^8	0.2

A TAC window of ~70 nsec FWHM was used, in order to achieve a significant reduction in tailing in the K and L x-ray spectra. This narrow time resolution results in a coincidence efficiency of ~70%, assuming the coincidence efficiency to be 100% for a 200 nsec wide TAC window.

The data were evaluated according to the procedure given in Sec. II of Ref. 3 and the quantities needed for determining f_{23} from Eq. (1) are listed in Table I with numerical results and percent errors. The method used to determine the contribution of the $K\alpha_1$ tail to the $K\alpha_2$ intensity is that of Gnade *et al.*[5] The placement of the gates is indicated by the shaded areas in Fig. 1. The comparison of the composition of the $K\alpha_2$ gate obtained by this method and by a singles line shape fit are summarized in Table II. The contribution of the $K\alpha_1$ tail events determined by the gating method amounts to 18.2% of the $K\alpha_2$ gate events, whereas by fitting a singles line shape, the contribution would be 20.0%. These percentages are consistent with previous observations.[5,6]

The percent errors listed in Table I are essentially statistical, except for $C_{L_3X(K\alpha_2)}$ which is dominated by the presence of systematic uncertainty which arises from the correction for $K\alpha_1$ tail events in the $K\alpha_2$ coincidence gate. The only other correction arises from the unresolved L_η x rays which fall in the $L\alpha$ x-ray peak, for which the method of McGeorge *et al.*[7] is applied using the theoretical values of Scofield[8] for the ratios L_η/L_2 and L_α/L_3. No correction for nuclear cascading is required, since the EC decay of ^{131}Cs proceeds only to the ground state of ^{131}Xe.

A value for the Coster-Kronig transition probability $f_{23}=0.148\pm0.029$ is obtained for $Z=54$. This value is consistent, within the quoted uncertainty, with the value of 0.174 from the relativistic calculations of Chen,

TABLE II. Comparison of the composition of the $K\alpha_2$ gate obtained by the gating method and by a singles line shape fit.

$I_{K\alpha_2}$ gate	Gating method (counts)	Singles line shape fit (counts)
$K\alpha_2$ events	54 521	53 274
$K\alpha_1$ events	12 113	13 360

Crasemann, and Mark.[2]

No attempt was made to obtain the L-subshell fluorescence yields, ω_2 and ω_3, since the systematic error arising in the L x-ray detection efficiency in conjunction with the systematic error arising from the tailing correction results in an overall uncertainty too large to permit a meaningful comparison of these subshell fluorescence yields with theory.

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[1] M. O. Krause, J. Phys. Chem. Ref. Data **8**, 307 (1979).

[2] M. H. Chen, B. Crasemann, and H. Mark, Phys. Rev. A **24**, 177 (1981).

[3] B. E. Gnade, R. A. Braga, and R. W. Fink, Phys. Rev. C **21**, 2025 (1980); **23**, 580(E) (1981).

[4] R. W. Fink and B. L. Robinson, Phys. Rev. **98**, 1293 (1955).

[5] B. E. Gnade, R. A. Braga, W. R. Western, J. L. Wood, and R. W. Fink, Nucl. Instrum. Methods **164**, 163 (1979).

[6] M. Tan, R. A. Braga, R. W. Fink, and P. V. Rao (unpublished).

[7] J. C. McGeorge, S. Mohan, and R. W. Fink, Phys. Rev. A **4**, 1317 (1971).

[8] J. H. Scofield, Phys. Rev. **179**, 9 (1969).