Measurement of the L_2-L_3 Coster-Kronig transition probability in Tm($Z=69$)

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The L_2-L_3 Coster-Kronig transition probability (f_{23}) in Tm was measured by multiparameter K versus L x-ray coincidence techniques. The Tm x rays were obtained from a radioactive source of ^{169}Yb and were detected with cooled germanium and silicon detectors of high-energy resolution. Corrections were applied for the contribution of $K\alpha_1$ x rays to the $K\alpha_2$ x-ray peak and for the contribution of unresolved $L\eta$ x rays to the $L\alpha_{1,2}$ x-ray peak. The contribution of $K\alpha_1$ x rays to the $K\alpha_2$ x-ray peak was determined solely from the results of the coincidence measurements using a method of data analysis which was previously described elsewhere. The contribution of $L\eta$ x rays to the $L\alpha_{1,2}$ x-ray peak was determined from the coincidence measurements and published values of the $L\eta$ to $L\beta_1$ x-ray intensity ratio. The result obtained for f_{23} is $(13.44\pm0.24)\times10^{-2}$ or $(14.06\pm0.24)\times10^{-2}$ depending on the value of the $L\eta$ to $L\beta_1$ intensity ratio used in applying the correction. Both values are slightly lower than predicted by the latest theoretical calculations confirming a trend of departures from theory recently observed in other medium- and high-Z atoms.

I. INTRODUCTION

In a previous paper,[1] we described the measurement of the L_2-L_3 Coster-Kronig transition probability f_{23} in Pb using multiparameter K versus L x-ray concidence techniques and a new method of data analysis to determine the contribution of $K\alpha_1$ x rays to the $K\alpha_2$ x-ray peak. In the present paper we describe the application of the same method of data acquisition and analysis to the determination of f_{23} in Tm. A preliminary result of this work was reported elsewhere;[2] we provide here a definitive account of the work performed and its final result as well as further elaboration on the method of data analysis employed and on the secondary corrections applied. The notation used in this paper is identical to that used in Ref. 1.

There is only one previous measurement of f_{23} in Tm by Douglas.[3] Douglas used a photoionization source of Tm x rays, K versus L x-ray coincidence techniques and a graphical method to correct for the contribution of $K\alpha_1$ x rays to the $K\alpha_2$ x-ray peak. The result obtained $f_{23}=0.148\pm0.007$ is somewhat higher than the values theoretically predicted by McGuire[4] using nonrelativistic approximate Hartree-Slater calculations and by Chen, Crasemann, and Kostroun[5] who used in their calculations nonrelativistic screened hydrogenic wave functions. The result is, however, in good agreement with calculations by Chen and Crasemann using the Green-Sellin-Zachor independent-particle model[6] and in particular with the latest theoretical calculations by Chen, Crasemann, and Mark[7] which are relativistic using the independent-particle model with Dirac-Hartree-Slater wave functions.

A recent measurement[8] of f_{23} in Yb with a neighboring atomic number, $Z=70$ yielded a value of 0.141 ± 0.007 in excellent agreement with the calculations by Chen *et al.*[7] The same work, however, yielded for Nd, $Z=60$, a value lower the theoretically calculated.

Other experimental work[1,9–14] in the atomic number range $54\leq Z\leq 82$ also yielded for f_{23}, values slightly lower than calculated by Chen *et al.*[7] Much lower values were obtained especially by the recently developed synchrotron photoionization method in the atomic number range $72\leq Z\leq 82$.[15,16]

The basic expression for the determination of f_{23} from measurements of K versus L x-ray coincidences is[17–19]

$$f_{23}=\frac{C_{L\alpha}(K\alpha_2)}{C_{L\alpha}(K\alpha_1)}\frac{n(K\alpha_1)}{n(K\alpha_2)}W(\theta)\ , \quad (1)$$

where $C_{L\alpha}(K\alpha_1)$ and $C_{L\alpha}(K\alpha_2)$ are the number of $L\alpha$ x-ray photons measured in coincidence with $K\alpha_1$ and $K\alpha_2$ x rays, respectively, and $n(K\alpha_1)$ and $n(K\alpha_2)$ are the numbers of $K\alpha_1$ and $K\alpha_2$ x-ray photons in coincidence with which $C_{L\alpha}(K\alpha_1)$ and $C_{L\alpha}(K\alpha_2)$ were measured, respectively. $W(\theta)$ is the value of the angular correlation function for the $K\alpha_1$-$L\alpha$ x-ray cascade at θ, the angle between the directions of propagation of the radiations incident on the K and L x-ray detectors.

$W(\theta)$ appears in expression (1) to compensate for the anisotropy which exists[20] in the emission of $L\alpha$ x rays relative to the direction of emission of $K\alpha_1$ x rays while relative to the direction of emission of $K\alpha_2$ x rays, $L\alpha$ x rays are emitted isotropically. $W(\theta)$ can be obtained from theory[21] or experiment or can be made to equal 1 by choosing $\theta=125.16°$ (See Ref. 1 for details).

Due to insufficient energy resolution of the available x-ray detectors $K\alpha_1$ and $K\alpha_2$ x rays cannot be fully separated from each other experimentally. Therefore, the quantities $n(K\alpha_1)$, $n(K\alpha_2)$ and $C_{L\alpha}(K\alpha_1)$. $C_{L\alpha}(K\alpha_2)$ as defined above cannot be measured directly. The quantities actually measured, which are denoted by $N(K\alpha_1)$, $N(K\alpha_2)$, $N_{L\alpha}(K\alpha_1)$, and $N_{L\alpha}(K\alpha_2)$, respectively, may each contain contributions due to both $K\alpha_1$ and $K\alpha_2$ x rays.

In high-Z atoms the energy difference between the $K\alpha_1$

and $K\alpha_2$ x rays is larger and as a result the energy resolution of the K x-ray detectors is usually sufficient to ensure that the lower energy $K\alpha_2$ x rays do not contribute to the $K\alpha_1$ photopeak of the measured K x-ray spectrum. In such cases $N(K\alpha_1)$ and consequently $N_{L\alpha}(K\alpha_1)$ can be measured free from contributions due to $K\alpha_2$ x rays. However, $N(K\alpha_2)$, and consequently all quantities derived from L x-ray spectra measured in coincidence with $K\alpha_2$ x rays, e.g., $N_{L\alpha}(K\alpha_2)$, contain contributions due to the higher-energy $K\alpha_1$ x rays.

Assuming that the contribution of $K\alpha_1$ x rays to $N(K\alpha_2)$, denoted by $N^{K\alpha_1}(K\alpha_2)$, is proportional to $N(K\alpha_1)$ and denoting the constant of proportionality by R, i.e., $N^{K\alpha_1}(K\alpha_2)=RN(K\alpha_1)$, it has been shown in Ref. 1 that expression (1) for f_{23} can be rewritten in terms of R and the directly measurable quantities $N(K\alpha_1)$, $N(K\alpha_2)$, $N_{L\alpha}(K\alpha_1)$, and $N_{L\alpha}(K\alpha_2)$ as follows:

$$f_{23}=\frac{[N_{L\alpha}(K\alpha_2)/N_{L\alpha}(K\alpha_1)-R]}{[N(K\alpha_2)/N(K\alpha_1)-R]}W(\theta) . \tag{2}$$

It has also been shown in Ref. 1 that R can be determined from the expression

$$R=\frac{N_{Lx}(\mathrm{BK})N(K\alpha_1)-N(\mathrm{BK})N_{Lx}(K\alpha_1)}{N_{Lx}(K\alpha_2)N(K\alpha_1)-N(K\alpha_2)N_{Lx}(K\alpha_1)} \tag{3}$$

in which all quantities are directly measurable. $N(K\alpha_i)$ and $N_{Lx}(K\alpha_i)$, $i=1,2$ are, respectively, the numbers of $K\alpha_i$ x-ray photons counted within equal energy windows set on the $K\alpha_i$ photopeaks (see Fig. 1) and the numbers of Lx photons (x standing for any peak in the L x-ray spectrum, e.g., $L\alpha$, $L\beta$) measured in coincidence with them. $N(\mathrm{BK})$ in the number of $K\alpha$ x-ray photons counted within an energy window equal in width to the windows set on the $K\alpha_1$ and $K\alpha_2$ photopeaks centered at an energy E_{BK} which is lower then the energy of the $K\alpha_2$ x rays ($E_{K\alpha_2}$) by the same amount that $E_{K\alpha_2}$ is lower than the energy of the $K\alpha_1$ x rays ($E_{K\alpha_1}$). $N_{Lx}(\mathrm{BK})$ is the number of Lx photons (see above) measured in coincidence with $N(\mathrm{BK})$.

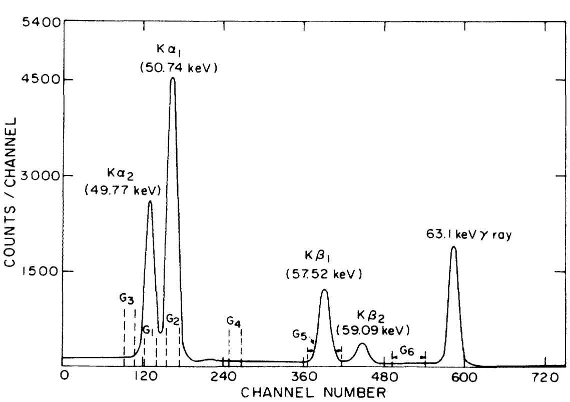

FIG. 1. Spectrum of Tm K x rays and 63.1-keV γ ray obtained from electron-capture decay of ^{169}Yb measured with cooled Ge(HP) spectrometer in random coincidence with L x rays. G_1 to G_6 mark the locations of the windows set on the various parts of the spectrum as described in Sec. III A.

Expressions (2) and (3) were used in the present work to determine f_{23}. The necessary quantities were measured as will be described in the proceeding.

II. EXPERIMENTAL SETUP

A. X-ray source and detectors

The Tm x rays were obtained from a radioactive source of ^{169}Yb which decays to ^{169}Tm by electron capture, predominantly K electron capture, with a half-life of 32 days. The decay proceeds to excited states of ^{169}Tm which deexcite in part by electron internal conversion in the K shell. Both these processes result in vacancies in the K electron shell of Tm thus initiating K-L x-ray cascades in the Tm atom.

Due to the relatively short half-life of ^{169}Yb, two different sources had to be used during the three-month period of experimental data gathering. They were both approximately 2 mm in diameter and 30 μCi initial intensity. They were prepared by drying droplets of ^{169}Yb in HCl solution on 0.25 mil thick mylar film. The radioactive ^{169}Yb stock used in the preparation of the two sources was obtained from two different commercial manufacturers and differed slightly in its specific activity.

The K x rays were detected with a liquid-nitrogen-cooled hyperpure germanium detector Ge(HP) 10 mm in diameter and 5 mm thick with an energy resolution of 480 eV at 122 keV. It was housed in a cryostat with a beryllium entrance window 0.13 mm thick. Throughout the experiment an additional aluminum absorber was placed in front of the beryllium window to absorb internal conversion electrons. The L x rays were detected with a liquid-nitrogen-cooled lithium drifted silicon detector Si(Li) 4 mm in diameter and 3 mm thick with an energy resolution of 180 eV at 5.9 keV. It was housed in a cryostat with a beryllium entrance window 0.050 mm thick.

The relative angle between the two detectors was 135° or 225° randomly changed between experimental runs. Their distances from the source were 4.5 and 2.10 cm for the Ge(HP) and Si(Li) detectors, respectively, in most of the experimental runs.

B. Electronic system

The electronic system used in this experiment was described in detail in Ref. 1. Its core consisted of a computer-based multichannel coincidence system which in each case of coincident detection of radiation by the Ge(HP) and Si(Li) detectors allowed the determination and recording of three parameters: the energies deposited in the two detectors by the respective x-ray photons and the time interval between their detection. This last parameter measured with a time-to-amplitude converter allowed the separation of true coincidence events from random ones.

The three parameters were recorded on magnetic tape in the form of a list which could subsequently (and/or simultaneously) be sorted to build histograms showing the spectrum of any one parameter for arbitrarily set conditions (digital gates) on the other two.

III. DATA ACQUISITION AND ANALYSIS

A. Acquisition and sorting of basic experimental data

Data were acquired in 41 experimental runs ranging in duration from 3 to 72 h with the majority being approximately 24 h long. In 39 of these runs which were grouped into three series of 11, 13, and 15 runs data was acquired as described in the previous section. In the remaining two runs the Si(Li) detector was shielded by an aluminum absorber 143 mg/cm^2 thick, sufficient to attenuate to a negligible extent the Tm L x rays while being almost transparent to the Tm K x rays and higher-energy radiation from the source. The purpose of these two runs was to determine the contribution to the data of coincidences due to interdetector scattering (see Ref. 1).

In about half of the runs data was acquired in full list mode on tape while histograms sorted according to previously set digital gates were recorded in memory. In the remaining half of the runs only histograms sorted according to previously set digitial gates were acquired in memory. The stability of the system during these runs was carefully monitored to ascertain that there were no significant spectral shifts to affect the validity of the preset digital gates. In each experimental run the following nine spectra S_1 to S_9 were obtained.

(1) S_1 and S_2. Spectra of L x rays in coincidence with $K\alpha_2$ and $K\alpha_1$ x rays, respectively. The $K\alpha_1$ and $K\alpha_2$ x rays were defined by energy windows 540-eV wide centered on the corresponding photopeaks in the spectrum obtained with the Ge(HP) detector. (See Fig. 1, windows G_2 and G_1, respectively.) The condition of true coincidence was defined by a window 250 nsec wide centered on the prompt coincidence peak in the spectrum of pulses from the time-to-amplitude converter. (See Fig. 3.)

(2) S_3. Spectrum of L x rays in coincidence with radiation which deposited in the Ge(HP) detector an amount of energy within a window 540 eV wide, i.e., as wide as the windows set on the $K\alpha_1$ and $K\alpha_2$ photopeaks, centered at the energy E_{BK} which was defined in Sec. I. (See also Fig. 1 window G_3.)

(3) S_4. Spectrum of L x rays in coincidence with radiation which deposited in the Ge(HP) detector an amount of energy within a window 540-eV-wide set above the energy of the $K\alpha_1$ photopeak. (See Fig. 1 window G_4.) This spectrum was used to determine the contribution of coincidences with higher-energy radiations to the three previous spectra.

(4) S_5. Spectrum of L x rays in coincidence with $K\beta$ x rays. The $K\beta$ x rays were defined by the energy window G_5 shown in Fig. 1. This spectrum was used to determine the contribution of "nuclear" or "nonrelated" coincidences to the L x-ray spectra measured in coincidence with $K\alpha_1$ or $K\alpha_2$ x rays. The procedure was explained in detail in Ref. 1. See also previous references.[22,23]

(5) S_6. Spectrum of L x rays in coincidence with radiation which deposited in the Ge(HP) detector an amount of energy within a window set above the $K\beta$ photopeaks. (See Fig. 1 window G_6.) This spectrum was used to determine the contribution of coincidences with higher-energy radiations to spectrum S_5.

(6) S_7. Spectrum of L x rays in *random coincidence* with radiation which deposited in the Ge(HP) detector an amount of energy within a window of 30 keV which included all K x-ray peaks of interest in the present work as well as the 63.1-keV ^{169}Tm γ ray. The condition of random coincidence was defined by two time windows each 1000 nsec wide set on the two sides of the prompt coincidence peak in the spectrum of pulses from the time-to-amplitude converter. As can be seen from Fig. 3 these two time windows are well separated from the prompt coincidence peak in order not to include any true coincidences. This spectrum shown in Fig. 2 was used, with proper normalization, to determine the contribution of random coincidences to all previously mentioned L x-ray spectra.

(7) S_8. Spectrum of K x rays in *random coincidence* with radiation which deposited in the Si(Li) detector an amount of energy within a window of 4–13 keV, i.e., the energy range of the previously measured L x-ray spectra. This spectrum is shown in part in Fig. 1. As has been explained in Ref. 1, Sec. III A, this spectrum and the previous one are derived from the sorting of the same random coincidence events, each spectrum showing the distribution of a different parameter. It should therefore be noted that the two spectra must contain the same number of counts. This fact was monitored throughout the experiment as an indicator to the correct operation of the system.

The two spectra provide also good representations of the spectra of radiation detected by the two detectors without any coincidence requirements.

(8) S_9. Spectrum of output pulses from the time-to-amplitude converter. This spectrum was collected for monitoring purposes only.

B. Processing of the raw x-ray spectra

The raw spectra S_1, S_2, and S_3 were each corrected for contribution due to random coincidences, coincidences

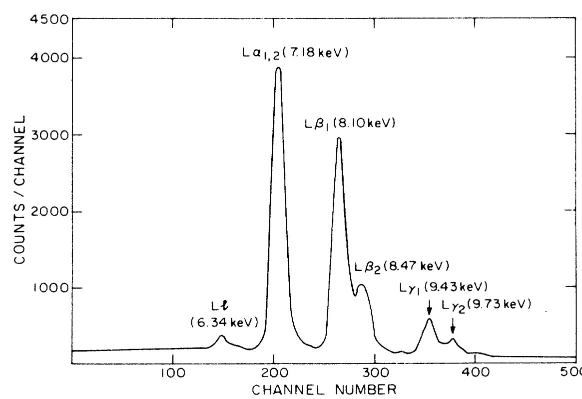

FIG. 2. Spectrum of L x rays of Tm from electron-capture decay of ^{169}Yb measured with cooled Si(Li) spectrometer in random coincidence with K x rays.

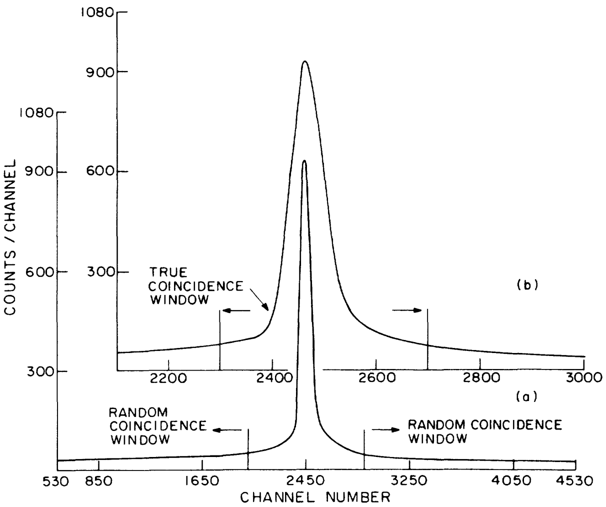

FIG. 3. Spectrum of output pulses from the time-to-amplitude converter. Each channel represents 0.625 nsec. (a) The true coincidence peak is shown on the background due to random coincidence events. The upper boundary of the lower 1-μsec window and the lower boundary of the upper 1-μsec window used to define random coincidence events are marked. (b) Enlarged portion of the spectrum showing the true coincidence peak and the 250-nsec window used to define true coincidence events.

with radiations of higher energy than $K\alpha_1$ x rays, and "nuclear" or "nonrelated" coincidences.

The corrections were applied using the auxiliary spectra S_4 to S_8 and following the procedures described in Ref. 1, Sec. III B. The resulting corrected spectra $S_{Lx}(K\alpha_2)$, $S_{Lx}(K\alpha_1)$, and $S_{Lx}(\mathrm{BK})$, respectively, are shown in Fig. 4.

IV. RESULTS AND DISCUSSION

For each experimental run values of R were calculated using Eq. (3) and the quantities $N_{Lx}(K\alpha_1)$, $N_{Lx}(K\alpha_2)$, and $N_{Lx}(\mathrm{BK})$ for $Lx = L\alpha$ and $Lx = L\beta$. Since in spectrum $S_{Lx}(\mathrm{BK})$ the region around the weak-$L\gamma$ peak was found to be contaminated by coincidences due to interdetector scattering [see Fig. 4(c)] no calculations of R using data from the $L\gamma$ peak were considered.

The values of R calculated using data from the $L\alpha$ peak, which will be denoted by $R_{L\alpha}$ were found to be systematically lower than those obtained using data from the $L\beta$ peak which will be denoted by $R_{L\beta}$.

Thus, the weighted average values of $R_{L\alpha}$ and $R_{L\beta}$ in the three series of experiments were

$$R_{L\alpha} = (1.49 \pm 0.17) \times 10^{-2} ,$$

$$R_{L\beta} = (2.35 \pm 0.09) \times 10^{-2} ,$$

$$R_{L\alpha} = (1.73 \pm 0.12) \times 10^{-2} ,$$

$$R_{L\beta} = (2.55 \pm 0.07) \times 10^{-2} ,$$

$$R_{L\alpha} = (1.66 \pm 0.15) \times 10^{-2} ,$$

$$R_{L\beta} = (2.33 \pm 0.08) \times 10^{-2} .$$

The value of $R_{L\alpha}$ is very sensitive to foreign contributions to $N(\mathrm{BK})$, i.e., contributions from other than $K\alpha_1$ or $K\alpha_2$ x rays. Such contributions could result from the imperfect removal from $N(\mathrm{BK})$ of the background due to higher-energy radiations.

Since the effect of such contributions to $N(\mathrm{BK})$ on $R_{L\beta}$, though much smaller, is in opposite direction to their effect on $R_{L\alpha}$, they could explain the observed discrepancy. As a check on the plausibility of this explanation we also calculated R for each experimental run from the shape of the 63.1 keV $^{169}\mathrm{Tm}$ γ-ray peak which appears in the spectra measured with the Ge(HP) detector (see Fig. 1). The weighted average values of R thus calculated were found to be $(1.88 \pm 0.06) \times 10^{-2}$, $(2.17 \pm 0.03) \times 10^{-2}$, and $(2.18 \pm 0.04) \times 10^{-2}$ for the three experimen-

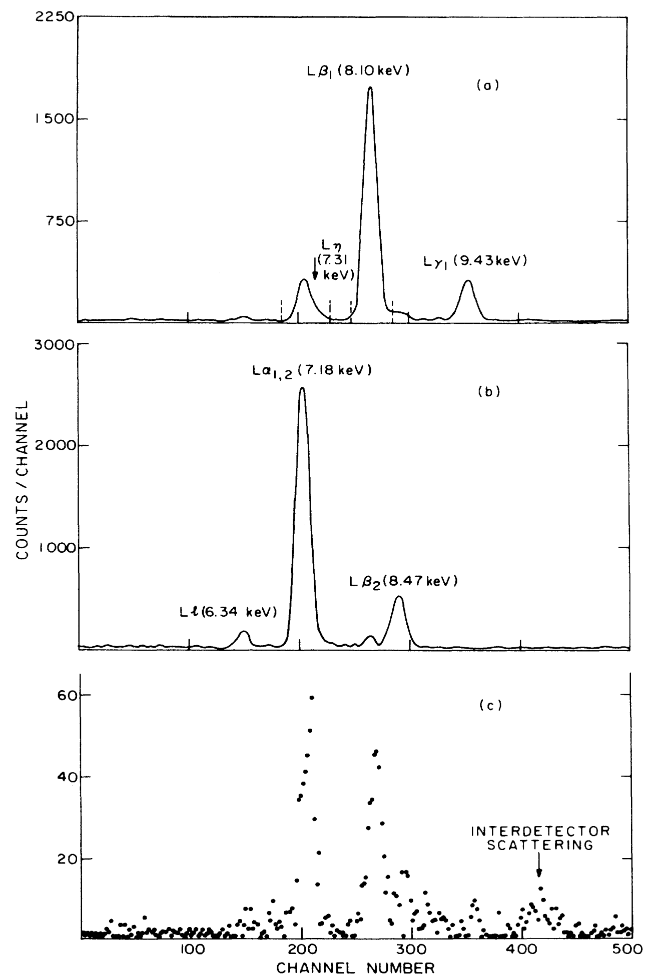

FIG. 4. (a) $S_{Lx}(K\alpha_2)$, (b) $S_{Lx}(K\alpha_1)$, (c) $S_{Lx}(\mathrm{BK})$ are spectra of L x rays in coincidence with radiation which deposited in the germanium detector energy within windows set on the $K\alpha_2$ and $K\alpha_1$ photopeaks and below the K x-ray peaks (BK), respectively. The spectra are shown following the implementation of all the corrections mentioned in Sec. III B. The dashed lines (a) mark the portions of the spectrum assigned in the data analysis to the $L\alpha$ and $L\beta_1$ peaks.

tal series, respectively.

Since values of R associated with γ-ray peaks are expected[24] to be slightly lower than those associated with K x-ray peaks due to the non-negligible natural line width of the latter, these results indicate that the correct values of R in our experiment are close to the calculated $R_{L\beta}$ values consistent with our assumption. Accordingly, a two-step procedure was adopted for the calculation of f_{23}.

First, for each experimental run f_{23} was calculated using Eq. (2) with the value of $R_{L\beta}$ obtained from Eq. (3). The values of $N_{L\alpha}(K\alpha_2)$ used in Eq. (2) were corrected for contributions due to the weak $L\eta$ line which appears in coincidence with $K\alpha_2$ x rays and which at an energy of 7.31 keV is unresolvable from the $L\alpha_{1,2}$ peak at 7.18 keV. The magnitude of the contribution of $L\eta$ x rays to $N_{L\alpha}(K\alpha_2)$ was determined from $N_{L\beta_1}(K\alpha_2)$ the number of $L\beta_1$ x rays measured in coincidence with $K\alpha_2$ x rays in the same experimental run and the intensity ratio of $L\eta$ to $L\beta_1$ x rays. Differences in the efficiency of detection or the absorption in the source of $L\eta$ x rays versus $L\beta_1$ x rays were not taken into account at this stage but will be corrected for later.

Unfortunately, there is no accepted value for the intensity ratio of $L\eta$ to $L\beta_1$ x rays, the measured value, by Salem *et al.*[25] being 0.0211 and the calculated value by Scofield[26] being 0.0269. Therefore the calculations of f_{23} hereby described were performed for both values of the $L\eta$ to $L\beta_1$ intensity ratio. From the values of f_{23} obtained in the 39 experimental runs, weighted averages were calculated, one for each of the three series of experiments.

Each weighted average value of f_{23} was then corrected for the imperfect removal from N(BK) of the background due to higher-energy radiations. The correction was performed as follows.

Assuming that the difference between the weighted averages values of $R_{L\alpha}$ and $R_{L\beta}$ in each experiment series are due to foreign contributions to N(BK) and taking as the correct value of R the quantity $R_{L\beta}+\Delta R$, it can be shown using Eq. (3) that

$$\Delta R = \frac{R_{L\alpha}-R_{L\beta}}{\dfrac{[N_{L\beta}(K\alpha_2)/N_{L\beta}(K\alpha_1)]-[N(K\alpha_2)/N(K\alpha_1)]}{[N(K\alpha_2)/N(K\alpha_1)]-[N_{L\alpha}(K\alpha_2)/N_{L\alpha}(K\alpha_1)]}+1} . \tag{4}$$

For each series of experiments ΔR was calculated using for all quantities and ratios appearing in Eq. (4) their weighted average values for the given experimental series.

The values of ΔR for the three series, respectively, were calculated to be -0.139×10^{-2}, -0.141×10^{-2}, and -0.114×10^{-2} resulting in corrected values of R for the three series of $(2.21\pm0.09)\times10^{-2}$, $(2.22\pm0.09)\times10^{-2}$, and $(2.41\pm0.08)\times10^{-2}$, respectively. The weighted average values of f_{23} for the three series were then corrected for these slight changes in R.

Of course, the correction term ΔR could have been calculated using Eq. (4) for each individual experimental run rather than for each experiment series as was done here, and then, using Eq. (2), f_{23} could have been calculated using the corrected value of R.

If however, as would be expected, the data obtained in the individual experimental runs comprising a given series are not very different, the difference in values of f_{23} obtained by these two different approaches should be negligible, as indeed it was in the present work when this matter was checked for all three experiment series.

As already mentioned in the preceding in calculating the contribution of $L\eta$ x rays to $N_{L\alpha}(K\alpha_2)$ it was assumed that this contribution is proportional to $N_{L\beta_1}(K\alpha_2)$ and further assumed that $L\eta$ and $L\beta_1$ x rays emitted from the source have an equal probability of being detected. This latter assumption may, however, be subject to substantial error since the difference in the energies of the $L\eta$ x rays (7.31 keV) and $L\beta_1$ x rays (8.10 keV) may cause a significant difference in their absorption in the source and in the intervening media between source and detector.

In order to check this possiblity we calculated from our measurement the ratio $N_{L\beta}(K\alpha_1)/N_{L\alpha}(K\alpha_1)$ and compared it to the theoretically expected value which is 0.183 (Ref. 26) close to the experimentally determined value[27] and to the very recently measured value of 0.182 ± 0.006 in Yb.[28] It should be noted that the $L\alpha$ x rays are close in energy to the $L\eta$ x rays and that most of the $L\beta$ x rays contributing to $N_{L\beta}(K\alpha_1)$ are $L\beta_2$ x rays with an energy of 8.47 keV, very close to the energy of $L\beta_1$ x rays. The best values for the ratio $N_{L\beta}(K\alpha_1)/N_{L\alpha}(K\alpha_1)$ obtained from our three series of experiments were, respectively, 0.216 ± 0.004, 0.222 ± 0.003, and 0.213 ± 0.004 in relatively good agreement with one another and higher than the expected value of 0.183.

These results indicate that there indeed has been differential absorption of $L\beta$ x rays versus $L\alpha$ x rays. They also enable us to calculate by interpolation the differential absorption of $L\eta$ x rays versus $L\beta_1$ x rays and to make the necessary correction in the calculation of the contribution of $L\eta$ x rays to $N_{L\alpha}(K\alpha_2)$. Upon applying this final correction, the values obtained for f_{23} were as follows.

Assuming that the intensity ratio of $L\eta$ to $L\beta_1$ x rays is 0.0269 as calculated by Scofield[26] the results for f_{23} are $(13.59\pm0.45)\times10^{-2}$, $(13.67\pm0.38)\times10^{-2}$, and $(13.02\pm0.43)\times10^{-2}$ for the three series of experiments, respectively, with a weighted average value of $(13.44\pm0.24)\times10^{-2}$. This value is slightly lower than that measured by Douglas[3] who likewise used Scofield's theoretically calculated x-ray intensity ratios to correct for the contribution of $L\eta$ x-rays and also lower than the value of 0.146 expected[29] according to the latest theoretical calculations.

Assuming that the intensity ratio of $L\eta$ to β_1 x rays is 0.0211 as reported by Salem and Schultz[25] the results for f_{23} are $(14.23\pm0.45)\times10^{-2}$, $(14.28\pm0.38)\times10^{-2}$, and $(13.64\pm0.43)\times10^{-2}$ with a weighted average value of $(14.06\pm0.24)\times10^{-2}$. This value is also lower than theoretically predicted but not very signficantly so.

V. CONCLUSION

The L_2-L_3 Coster-Kronig transition probability f_{23} in Tm was measured by K versus L x-ray coincidences using a previously described[1] coincidence method to determine and correct for the contribution of $K\alpha_1$ x rays to the $K\alpha_2$ x-ray peak. Due to the limited energy resolution of the Si(Li) L x-ray detector, $L\eta$ x rays were not separated from $L\alpha_{1,2}$ x rays and consequently their contribution to the $L\alpha$ peak which significantly affects the resulting value of f_{23} was calculated and corrected for using known values of $L\eta$ to $L\beta_1$ x-ray intensity ratio.

Using the theoretical value[26] for the $L\eta/L\beta_1$ ratio, the value obtained for f_{23} is approximately 8% lower than predicted by the latest theoretical calculations[7] confirming a trend of deviations from theory observed over a wide range of atomic numbers $54 \leq Z \leq 82$.[1,9-16] Using the experimental value[25] for the $L\eta/L\beta_1$ ratio, the value obtained for f_{23} is also somewhat lower than theoretically predicted[7] but by a much less significant amount.

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