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L X-Rays from the Internal Conversion of the 39.85 keV Transition in ^{208}Tl

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The TI L x-ray spectrum resulting from the internal conversion of the 39.85 keV transition in ^{208}Tl was analyzed with a high resolution Ge(Li) spectrometer. Internal conversion coefficients and fluorescence, Coster-Kronig and Auger yields in the L-subshells are deduced in alternate ways combining results of the present work with theoretical and/or previously reported experimental results.

A partir do estudo do espectro de raios *X*, resultante da conversão interna da transição de 39.85 keV no 208TI foram obtidos os valores dos coeficientes de conversão interna. dos rendimentos de fluorescência e das probabilidades de transições Auger e Coster-Kronig nas subcamadas L do TI. Vários modos alternativos para a obtenção desses parâmetros foram empregados e a consistência dos resultados é discutida.

1. Introduction

The internal conversion of nuclear transitions is a vers commonly used source of vacancies in the inner atomic shells. From the knowledge of the internal conversion coefficient (ICC) in the j-shell, α^j. the number of primary vacancies produced in this shell can be calculated. Then. from the observation of the resultant x-rays and of the ejected Auger and Coster-Kronig (CK) electrons, the yields of the radiative and non-radiative atomic processes can be deduced. Conversely, if the fluorescence and CK yields are known and if the x-rays and unconverted gamma ray intensities are measured. the ICC can be calculated.

The situation is particularly simple when all the x-rays are due to a single

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nuclear transition and the energy of this transition is such that it cannot be converted in shells inner than the one the ICC is under investigation. Let us suppose a nuclear transition that can be internally converted only in the L (or higher)-shells. In this case relations involving the L-subshells ICC's, α_i^L, the fluorescence yields ω_i and CK yields $f_{K_i}(K < i = 1, 2, 3)$ are.

$$\alpha_1^L = \frac{X_1^L}{\omega_1}, \quad \alpha_2^L = \frac{X_2^L}{\omega_2} - \frac{X_1^L}{\omega_1} f_{12}, \quad \alpha_3^L = \frac{X_3^L}{\omega_3} - \frac{X_2^L}{\omega_2} f_{23} - \frac{X_1^L}{\omega_1} f_{13},$$

where $X_i^L = N(X_i^L)/N_\gamma$, N_γ being the intensity of the unconverted gamma rays and $N(X_i^L)$ the number of x-rays resulting from the radiative filling of a vacancy in the L_i-subshell.

Defining the total L x-ray yield by $N(L) = \sum_i N(X_i^L)$ and the total L-ICC by $\alpha^L = \sum_i \alpha_i^L$, the average fluorescence yield will be given by

$$\bar{\omega}_L = N(L)/N_\gamma \alpha^L = X^L/\alpha^L.$$

This average yield is a quantity which depends on the mode of vacancy production since it is a linear combination of the subshell fluorescence yields ω_i^L, each one being weighted with the probability of a vacancy occurring in the subshell.

In this paper, the L-internal conversion of the 39.85 keV transition in ^{208}Tl is examined. This energy is not enough to ionize the K-shell. This nuclear transition results from the de-excitation of the first excited state of ^{208}Tl (probably a 4^+ state) and feeds the ground state (probably a 5' state). It is observed following the alpha decay of ^{212}Bi. The decay scheme of ^{212}Bi was recently studied by two of tlie authors[1] and the ICC of the 39.85 keV transition was determined by using the relative intensities of L-shell conversion electrons given by Siegbahn[2] rather than using the L-shell x-ray data. A value of $\alpha^L = 17.8 \pm 2.0$ was found. A previous determination of the total ICC of this transition was reported by Krause[3] who obtained $\alpha = 22.8 \pm 1.0$ by the norrrialized-peak-to-gamma method. Assuming[4] that $a = 1.33a^L$, one gets $a^L = 17.2$. The $L_1 : L_2 : L_3$ ratios reported by Sevier[5] are $939 \pm 38 : 100 : 8 \pm 3$. The ensemble of these results seems to indicate a pure magnetic dipole character for this transition. The purpose of this paper is twofold. First, the partial ICC's α_i^L will be re-investigated from the analysis of the L x-ray spectrum and. second, the consistency of the currently reported values of the radiative and non-radiative L-shell yields will be checked.

Values for the L-shell fluorescence and CK yields are poorly known in general. However, reliable experimental values for some heavy elements were recently published by several authors, an extensive compilation being presented in a review article by Bambynek et *al.*[6]. Recent measurements in Bi, Ra, Rn, and Np (Refs. 7, 8) have been added by one of the authors. Theoretical calculations[9-11] can also be used as a guide.

Yield	Experimental Value	Reference
ω_1	0.07 ± 0.02	*a*
ω_2	0.319 ± 0.010	*a*
	0.373 ± 0.025	*b*
ω_3	0.37 ± 0.07	*c*
	0.386 ± 0.053	*d*
	0.306 ± 0.010	*a*
	0.330 ± 0.021	*b*
f_{12}	0.17 ± 0.05	*e**
	0.14 ± 0.03	*a*
f_{13}	0.76 ± 0.10	*f***
	0.57 ± 0.10	*g*
	0.56 ± 0.07	*e**
	0.56 ± 0.05	*a*
f_{23}	0.25 ± 0.13	*e**
	0.169 ± 0.010	*a*
	0.159 ± 0.013	*b*
ν_1	0.280 ± 0.010	*a*
ν_2	0.57 ± 0.10	*c*
	0.450 ± 0.061	*d*
	0.371 ± 0.010	*a*
	0.423 ± 0.024	*b*
$\bar{\omega}_L$	0.50 ± 0.02	*h*
	0.48 ± 0.03	*i*
	0.32	*j*
	0.41 ± 0.04	*k*

*Assumed $f_{12} + f_{13} = 0.73$ and $\omega_3 = 0.32$
**Assumed $f_{23} = 0$

Table I - Experimental values for L-fluorescente and CK yieids for Z = 81 found in the literature. a-Ref. 12, b-Ref. 13, c-Ref. 14, d-Ref. 15, e-Ref. 16, *f*-Ref. 17, g-ReE 18, *h*-Ref. 19, i-Ref. 20, j-Ref. 21, k-Ref. 22.

Direct measurements in Tl are given in Table 1 but it was felt that more realistic values could be obtained by a critical selection of a number of recently measured values of ω_i and f_{ij} in the neighborhood of the element $Z = 81$ and by fitting them with a smooth curve. Three of such graphs are shown in Figs. 1 to 3. When more than one value for a given Z were selected an weighted average was used, the weights being the squared reciprocals of the reported errors. The interpolated points at $Z = 81$ were adopted and they are given in Table 11.

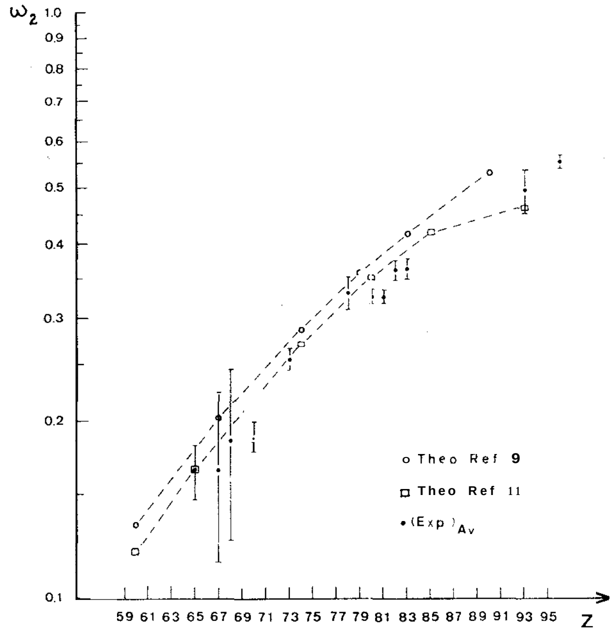

Fig. 1 - Average L_2-subshell fluorescence yield as a function of atomic number

2. Experimental

2.1. General

The ^{212}Pb sources were collected electrostatically from the decay products of thoron that emanated from a ^{228}Th source. A surface-barrier detector was used to count the a- particles from the sources collected on thin gold on formvar foils. Proper choice of the alpha particles energy windows selected the group feeding the first excited state of ^{208}Tl. An x-ray spectrometer was used to observe the unconverted 39.85 keV gamma rays and the L x-rays in coincidence with the 5.051 MeV a-particles. Constant fraction timing was used in both channels and the time window was set at about 200 nsec, the FWTM being 50 nsec. The two detectors were positioned at 180° to each other for all of the coincidence measurements in the present work but the solid angles subtended by both detectors were made as large as possible in order to prevent angular correlation effects.

ω_1	0.095
ω_2	0.32
ω_3	0.32
f_{12}	0.14
f_{13}	0.60
f_{23}	0.16

Table II - Adopted values of L-fluorescence and Coster-Kronig yields for $Z = 81$ (see text for explanation).

The analysis of the L x-ray spectra necessary to distinguish the contributions from each L_i-subshell requires a high quality x-ray spectrometer. A Ge(Li) spectrometer was preferred rather than a Si(Li) one since the detection efficiency of the first system more than compensated the best resolution of the second one. A detailed description of the detection system is presented in the next section.

2.2. Spectrometer Characteristics

2.2.1 – Physical Properties

The Ge(Li) detector was an ORTEC Model 8013-10-300 x-ray spectrometer. The active diameter and sensitive depth of the detector were 100 mm and 5 mm, respectivelly. The detector was housed in a chamber with a 0.13 mm beryllium window and cooled to liquid nitrogen temperature. The detector output was connected to an ORTEC Model 109 FET preamplifier the first stage of which was also cooled with the detector. The thickness of the gold contact on the incident radiation side, as given by the manufacturer, was 100-200 Å. Gold L x-rays may be made to fluoresce by using any convenient source of photons with an energy greater than the Au L, absorption edge. Gamma rays of 14.4 keV from ^{57}Co decay were used to investigate the thickness of this layer. following a technique described by Hansen *et al.*[23]. The thickness of the electrode was found to be 210 ± 25 Å. The possible existence of a Ge entrance window was

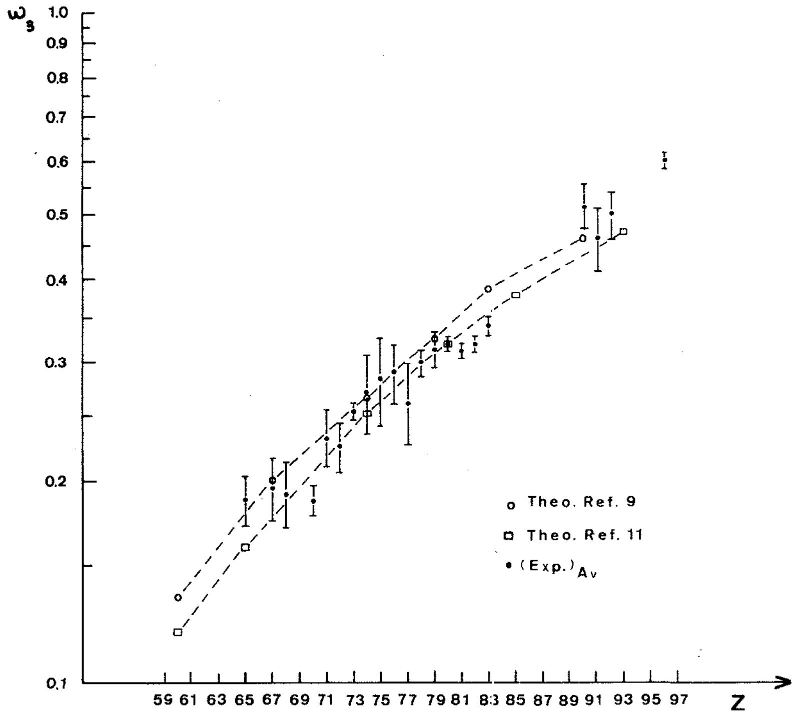

Fig. 2 - Average L,-subshell fluorescence yield as a function of atomic number.

also investigated by trying to observe the germanium K x-rays produced in this dead layer by sources of photons with energies greater than the Ge K absorption edge. With sources of ^{241}Am and ^{57}Co no meaningful increase was observed in the background at 9.88 and 10.98 keV (K_α and K_β Ge x-rays. respectively). An estimate is that the dead layer is thinner than $\simeq$ 2 000 Å.

The detector operated at a negative bias of 1.000 volts. An 451 ORTEC amplifier and a 5401B Hewlett Packard 4096 channel pulse-height analyser completed the detection system.

2.2. Resolution

Many factors contribute to determine the overall system resolution. The squared total full width at half maximum $(FWHM)_t^2$ is given by a quadratic expression, from which it may be possible to extract the intrinsic

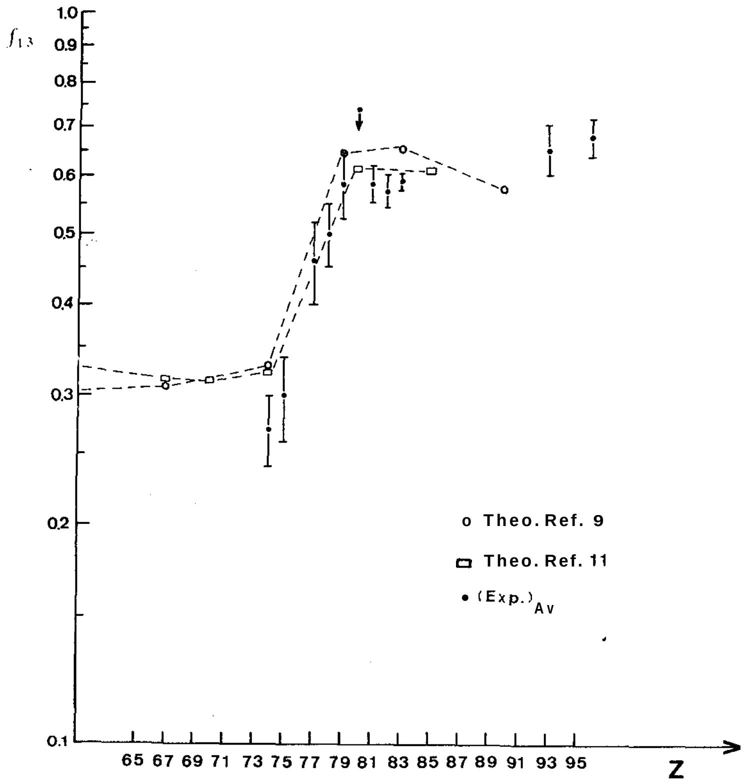

Fig. 3 - Average L, – L,-Coster-Kronig yield as a function of atomic number

detector resolution, $(FWHM)_i$. The electronic resolution, (FWHM), , was minimized by proper choice of the time constants adequate to the counting rate of our source of ^{212}Pb. After subtracting the electronic contribution, as measureú with a precision pulser fed into the input of the preamplifier, the FWHM includes any contribution due to fluctuations in the charge collection in the detector. The quantity $A = [(FWHM)_t^2 - (FWHM)_e^2]^{1/2}$ was reproduced as a function of the photon energy, E, by the expression:

$$\log A \text{ (eV)} = 1.6308 + \frac{1}{2} \log E \text{ (keV)}.$$

From this and supposing that the energy to create an electron-hole pair is 2.98 ± 0.03 eV, we get for the Fanno factor in the interval from 5.9

to 136 keV the value F = 0.111 ± 0.004. This value is slightly lower than some recently published results[24,25,26].

It has been argued[27] that probably the Fanno factor is much lower than some experimentally determined values and that the difference (about a factor of two) comes from the neglecting of the charge collection effect. Zulliger and Aitken suggested[27] that the correct procedure is to examine

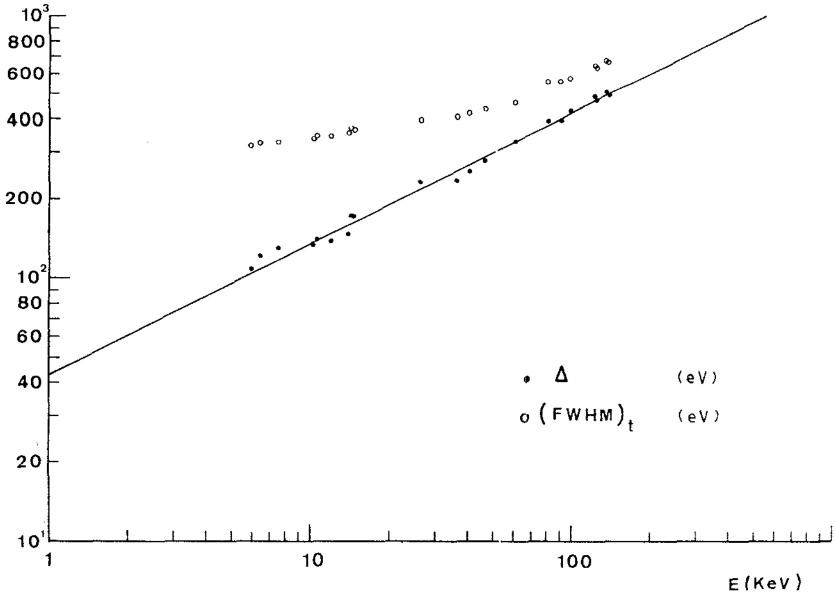

Fig. 4 - Energy dependence of (FWHM), and A. The solid straight line was drawn for F = 0.111.

how the quantity A changes with the applied bias voltage (V) and then to extrapolate the experimental curve to V → x in order to get (FWHM), which is then proportional to $(FE)^{1/2}$. A liriear plot of A^2 vs 1 V has been obtained by some authors[27,28]. In the present work. this linear dependente was found only for very low applied voltages ($|V| < 700$ volts). For V = –800 volts and V = – 1000 volts no appreciable difference was found in the value of A. indicating that probably an asymptotic value is very near and that $A(|V| \to \infty)$ is not very different from $\Delta(|V| = 1000$ volts).

All measurements of A and (FWHM),, reported in Fig. 4. were made at V = – 1000 volts and the value of F must be considered an upper limit in this energy region.

2.2.3. Efficiency

The relative detection efficiency curve of the detector was determined in the interval from 3 to 200 keV. The following sources were used: 'Fe, ^{57}Co, ^{59}Ni, ^{75}As, ^{109}Cd, ^{137}Cs, ^{125}Sb, ^{144}Ce, ^{210}Pb and ^{241}Am corresponding to a total of 36 fully resolved lines or group of lines of well known relative intensities. Each source exhibited at least two of such lines or group of lines. The method was essentially the pair-point method: the relative positions of groups of related points were adjusted graphicaliy until a smooth curve could be drawn through them. Special care was taken with the discontinuity introduced by the K absortion edge in germanium. The K_α/K_β ratio in As and the L_α/L_β ratio in Bi are well suited for this purpose. They were previously measured with a Si(Li) detector with the same Be and Au entrance windows as the Ge(Li) spectrometer. The effects of the gold L edges were not clearly observed experimentally.

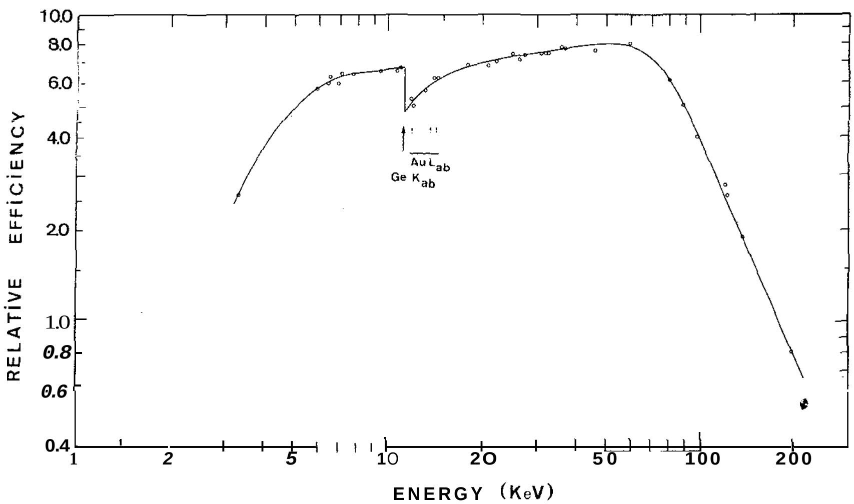

Fig. 5 - Experimental photo-peak detection efficiency vs energy for the Ge(Li) spectrometer.

The resulting efficiency curve is shown in Fig. 5. A maximum at about 60 keV was observed, preceded by a smooth decrease of the detection efficiency with decreasing energy up to the discontinuity and followed by a fast decrease with increasing energy. The first effect is a consequence of the escape of the Ge K x-rays and was checked by observing the ratio of the escape-peak to the full-energy peak as a function of the energy in the interval 11.7 – 59.5 keV (see Fig. 6). The experimental points correspond to the following sources: ^{75}Se, ^{234}Pa, ^{241}Am, ^{137}Cs, ^{125}Sb, ^{144}Ce,

^{210}Pb and ^{212}Pb. The point at 11.7 keV (the K_β peak of As) corresponds to a lower limit since its GeK_β escape (only 600 eV) was not observed.

In calculating the relative intensities of the L x-ray lines of Tl, corrections due to other absorbers (like source backings) were considered.

2.2.4. Tail to Peak Ratios

In order to get well defined line shapes necessary to analyze the complex peaks present in the L x-ray spectrum of Tl. it is important to know, beside the FWHM of the Gaussian-shaped full eriergy peaks, the flat low energy tail. This tail is probably due to slow or incomplete collection of charge from certain regions of the detector. This problem was extensively investigated by Hansen *et al.*[23]. The way the tail to peak ratio changes in the interval from 6 to 16 keV was determined for the selected bias voltage

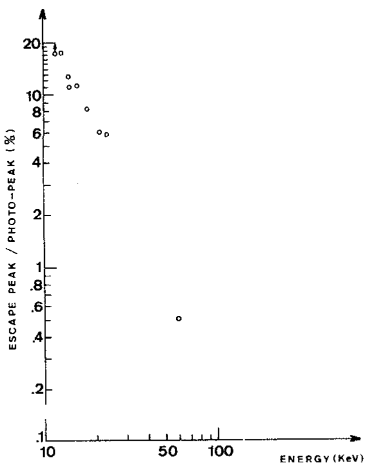

Fig. 6 - The ratio of the Ge K x-ray escape peaks to photo-peak intensities vs energy

and amplifier time constants. Sources like ^{55}Fe, ^{59}Ni, and ^{71}Ge which decays by pure electron capture to the ground state were the best suited for this purpose. The correct determination of the background level due to these tails and due to Compton scattered events from higher energy gamma rays present in the ^{212}Pb sources is essential for the accurate intensity measurements of the weak lines of the L x-ray spectrum. Intensities of the L,, $L_{\beta 6}$ and $L_{\gamma 5}$ lines are particularly affected by any indeterminancy in the background level under the expected peak.

3. Results and Discussion

The basic assumption in analysing the L x-ray spectrum obtained in coincidence with the 6.051 MeV alpha particle group is that, after subtraction of chance coincidences, all the x-rays are due to the internal conversion of the 39.85 keV transition. A coincidence spectrum is shown in Fig. 7.

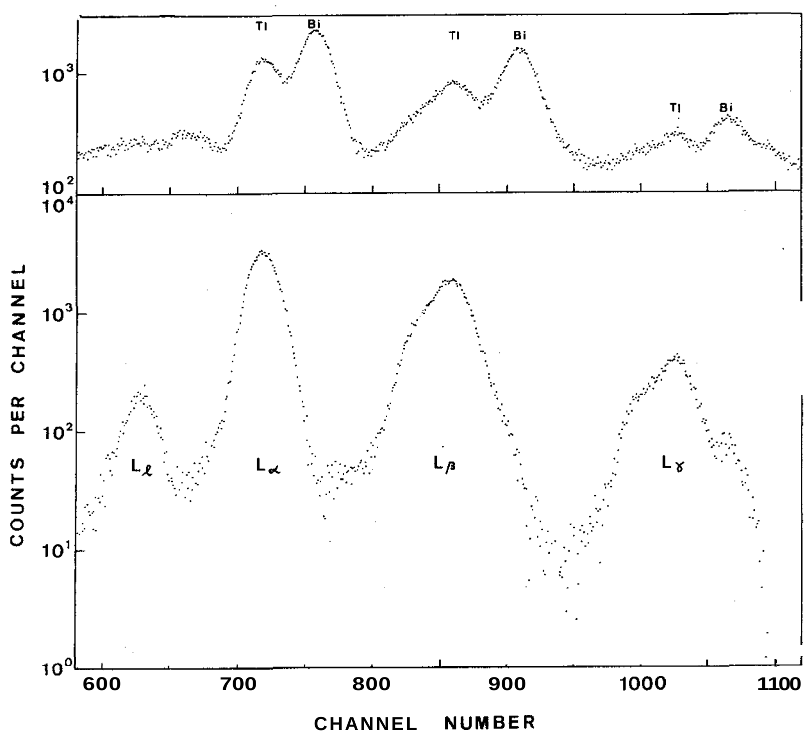

Fig. 7 - Direct (upper part of the figure) and coincidence spectra obtained with the ^{212}Pb source.

Three independent runs were analyzed and the spectrum shown is not the one with best statistics, it corresponds to an accumulation time of 10 hours. For comparison, a direct spectrum is shown in the upper part of the figure.

After subtracting the chance coincidences the ratio of Tl L x-rays to Tl K x-rays was found to be **280 ± 30** thus justifying the neglect of internal conversion of any other transition in ^{208}Tl. In the directabsorptionthe measured X^L/X^K ratio was 42.0 ± 2.3.

The L,, L, and L, lines have energies lower than the Ge K absorption edge. The intensity of the L, line is the most seriously affected by any indeterminacy introduced in the subtraction of t1e chance coincidences since its energy is very near the L, line of Bi present in the source. The measured intensities of the resolved L x-rays lines cf Tl are presented in Table III. They are arbitrarily normalized by making the intensity of the L, line equal to 1000.

Line	Energy (keV)	Relative Intensity	
L_3M_1 (l)	8.953	50.5 ± 2.3	
$L_3M_{4,5}$ ($\alpha_{2,1}$)	10.265	1 000	
L_2M_1 (η)	10.995	8.9 ± 1.8	
L_3N_1 (β_6)	11.810	17.2 ± 2.1	
L_1M_2 (β_4)	11.931	240 ± 20	
L_2M_4 (β_1)	12.215	≃ 350	580 ± 32
$L_3N_{4,5}$ ($\beta_{15,2}$)	12.268	≃ 230	
L_1M_3 (β_3)	12.391	202 ± 19	
$L_3N_{6,7}$ (u), L_3O_1 (β_7)	12.53	3.7 ± 0.5	32.0 ± 2.1
$L_3O_{4,5}$ (β_5)	12.64	28.3 ± 2.6	
$L_1M_{4,5}$ ($\beta_{10,9}$)	12.92	14.8 ± 1.9	
L_2N_1 (γ_5)	13.850	3.9 ± 0.9	
L_2N_4 (γ_1)	14.292	78.9 ± 5.2	
L_1N_2 (γ_2), L_2O_4 (γ_6)	14.625, 14.682	65.1 ± 4.7	128.0 ± 6.6
L_1N_3 (γ_3)	14.737	62.9 ± 4.7	
$L_1O_{2,3}$ (γ_4)	15.26	22.2 ± 1.2	27.1 ± 1.1
L_1P	15.34	4.9 ± 0.5	

Table III - Relative intensities of Tl L x-rays arising from the internal conversion of the 39.85 keV transition.

The $(L_{,} + L_\alpha)/(L_\eta + L_\beta)/L_\gamma$ ratios were found to be 96.1 ± 6.8/100/21.8 ± ± 1.9 in close agreement with the same ratios found from the internal conversion of the 46.5 keV magnetic dipole transition[7] in ^{210}Bi. For electric quadrupole transitions in Ra and Rn[8], the $(L_{,} + L_\alpha)/(L_\eta + L_\beta)$ ratio is substantially different from the values obtained in both M1 transitions. namely 0.77 in the E2 transitions against 0.96 in the M1 transitions. The L_γ/L_β ratios seem to be insensitive to the: multipolarity of the converted transition. This result is connected with the large value of the f_{13} CK yield.

The analysis of the L x-ray spectra was made following techniques described elsewhere[7,8] and was made easier by the fact that the energies of the single lines contributing to each complex x-ray peak are known accurately from the tables of Bearden and Burr[2"]. Hand analysis was used in all the cases. The L, and L, peaks do not present any difficulty since they are due to the filling of vacancies in the L, subshell. The L, peak is composed of transitions arising from the filling of vacancies in both L, and L, subshells. In this group the greatest difficulty is due to the presence of the L„ line (L_2O_4) between the L„ and L„ lines (L_1N_2 and L_1N_3). The contribution of the L„ line to the L, group of x-rays was estimated from the measured L„ intensity and the $L_{\gamma6}/L_{\gamma1}$ theoretical ratio[30]. The L, group is by far the most complex. As in the L x-ray spectrum of Bi[7,31], the complete separation of the L„ line from the L„„ doublet is impossible with Ge(Li) or Si(Li) spectrometers.

A suplementary check for the analysis of the L x-ray spectrum is the determination of the quantities s_i, defined by Rao *et al.*[32]. which represent. for each subshell L,, the ratios of x-ray transitions originating from higher shells (N + O + ...) to transitions originating from *M* shells. We found $s_1 = 0.313 \pm 0.025$. $s_2 = 0.268 \pm 0.024$ and $s_3 = 0.266 \pm 0.020$. The value of s_1 is essentially the theoretical value of Scofield[30] but s_2 and s_3 are definitely larger than the theoretical branching ratios. despite the large experimental errors. That $(s_2)_{exp}$ exceeds $(s_2)_{theo}$ by 10 to 20% is a well established fact[32,6,8]. The present values of the branching ratios s_2 and s_3 can be directly compared with those of Ref. 28 obtained from the internal conversion of the ^{203}Tl 279.1 keV transition (E2 + M1) following the beta-decay of ^{203}Hg. The agreement is within experimental errors but the values obtained now are consistently greater by 10%. In both works it was found that $s_2 \simeq s_3$.

Tl subshell	X_i^L	α_i^L	
		Experimental	Theoretical[33]
L_1	1.707 ± 0.185	17.97 ± 2.10	17.12
L_2	1.293 ± 0.138	1.52 ± 0.24	1.72
L_3	3.800 ± 0.280	0.45 ± 0.30	0.16
L (Total)	6.80 ± 0.20	19.94 ± 2.15	19.00

Table IV - Number of L x-rays per unconverted gamma-ray and the resulting internal conversion coefficients of the 39.85 keV transition.

The $N(L)/N_\gamma$ ratio was found to be 6.80 ± 0.20 and the X_i^L partial ratios are given in Table IV with the resulting values of α_i^L calculated with data of Table 11. The large error in α_3^L reflects the fact that it corresponds to a small difference between large numbers.

These results combined with previous data[1,3,5] seem to indicate a pure magnetic dipole for this transition. From the nuclear shell model point of view the ground and first excited states are probably due to the coupling of a $s_{1/2}$ proton hole state with a $g_{9/2}$ neutron state. The interpretation of this pure M1 transition as a simple spin flipping process is a natural one.

The average $\bar{\omega}_L$ yield obtained from this experiment was 0.341 ± 0.044.

Another approach would be, instead of calculating the ICC's starting from experimentally determined radiative and non-radiative yields, to accept the theoretical[33] values of the L subshelis ICC's and to adopt three of the ω_i and f_{ij} values, thereby calculating the other six yields. In Tabie V, ω_2, f_{12} and f_{23} are the adopted yields and the results are presented together with the most probable values found for Bi[7].

Yield	Tl Z = 81	Bi Z = 83
ω_1	0.10	0.12
f_{12}	0.12	0.10
f_{13}	0.60(*)	0.63
a_1	0.16	0.15
ω_2	0.342(*)	0.37
f_{23}	0.15(*)	0.15
a_2	0.51	0.48
ω_3	0.345	0.32
a_3	0.655	0.68
v_2	0.395	0.42

(*) Adopted

Table V - L-fluorescente, Coster-Kronig and Auger yields for Z = 81 calculated from the theoretical L-subshells ICC's. The "most probable" valu:s[7] found for $Z = 83$ are presented for comparison.

When the experimental value of α^L of Ref. 1 (obtained independentiy from assumptions concerning ω_i and f_{ij}) is taken together with the $L_1 : L_2 : L_3$ ratios of Sevier[5], essentially the same results are obtained nameiy: $\omega_1 = 0.11$, $f_{12} = 0.13$ and $\omega_3 = 0.35$).

With the theoretical value of α^L and the measured X_i^L ratios. one gets $\bar{\omega}_L = 0.358 \pm 0.011$.

Theoretically. for $74 \leq Z \leq 90$, ω_2 exceeds ω_3 by about 10%. The present results combined with those of Refs. 7 and 8. show that ω_2 is still essentially equal to ω_3 even at Z = 81. and it exceeds ω_3 a little in the interval 83 I Z I 93. On the other hand, the present values of ω_1 and f_{12} are consistently larger and smaller. respectively. than previousiy reported values in $Z = 81$.

The results of the present work can be checkedfurther by using the high resolution electron Auger data obtained by Burde and Cohen[19] and by Sujkowski and Melin[16]. From these works. the quantities A_i^L. defined as the fraction of electron Auger intensities resulting from non-radiative Auger filling of vacancies in the L, subshells per total L-shell vacancies, can be extracted. These quantities depend on the mode of vacancy production. However the quantities a,. analogously to the ω_i, do not depend on the ionization process since they correspond to the L, Auger intensities per one vacancy in the L, subshell.

In Ref. 16. the observed L Auger electron spectrum of thallium corresponds to the electron capture decay of ^{203}Pb. From the distribution of the primary vacancies in the L subshells of ^{203}Tl per desintegration of ^{203}Pb, as given in Table I of Ref. 16, and from the reported values of the A_i^L, the values of the radiative and non-radiative yields in Tl can be obtained with the same assumptions made in Table V. These values are: a, = 0.16 (this result does not depend on the above assumptions). a, = 0.51 (this result is a direct consequence of the assumptions), $f_{12} = 0.06$, o, = 0.15, a, = 0.71 and o, = 0.29. The good agreement found for the L, Auger yield is remarkable since in the experiment of Sujkowski and Melin the value of a_1 is obtained directly from the measurements without any additional hypotesis. The most relevant discrepancies concern the values of ω_1, f_{12} and o,. The small value obtained for f_{12} and the relatively high value obtained for o, are obviously related. A higher value for A_2^L and consequently a lower for A_3^L would improve the situation and, at the same time, would render a more reasonable value for o,. For instance with $A_2^L = 0.427$, one gets $f_{12} = 0.12$, o, = 0.12 and $\omega_3 = 0.32$. The errors given in Ref. 16 are 22% for A, and 14% for A, so the above discrepancies are not meaningful.

For a long time, it was currentiy assumed that $f_{23} = 0$ Coincidence experiments showing the presence of the L, and L, peaks in coincidence with the $K_{\alpha 2}$ x-rays clearly demonstrated the importance of Coster-Kronig transfer of vacancies from the L, to the L, subshell. However. the value $f_{23} = 0.25 \pm 0.13$ found by Sujkowski and Melin seems too high. They were led to this value by the same fact responsible for the above disagreements, i.e.. a too high A_3^L/A_2^L ratio.

In Ref. 19. the L Auger spectrum of thallium corresponds to the internal conversion of the 39.85 keV transition under investigation. From Tabie II of Ref. 19, one gets $A_1^L = 0.167$. $A_2^L = 0.135$ and $A_3^L = 0.340$. The original values were re-normalized in order to correspond to our measured value of $\bar{\omega}_L$. With the presently measured values of the X_i^L ratios and adopting the theoretical. ICC's, one further assumption is needed. The choice was $f_{23} = 0.15$, as done in Refs. 7 and 27. The resulting values are **o,** = 0.10. a, = 0.185, $\omega_3 = 0.37$, $a_3 = 0.63$, $f_{12} = 0.165$, $f_{13} = 0.55$, $\omega_2 = 0.285$ and v, = 0.340. General agreement with the results presented in Tabie V is quite satisfactory, the main difference beirig the ratio ω_3/ω_2 that is now completely discordant with what is known from the systematics in this region of the periodic table. The resulting value of v,. that reflects the smallness of to,. is also in disagreement with the systematics. If one looks for the possible source of disagreement it is found that now the ratio A_3^L/A_2^L seems somewhat low. However, again, a small modification compatible with the large experimental errors would improve substantially the situation. Given the enormous difficulties in interpreting the L Auger spectra, these problems are not surprising. As stated in Ref. 16. "a study at much higher resolution would be required to remove some ambiguities in the interpretation of the lines". Limitations of the same kind are present in the analysis of the L x-rays spectra with the available Si(Li). Ge(Li) or intrinsic Ge spectrometers. Accuracy better than 7% in any fluorescence or non-radiative yield requires considerable experimental efforts.

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