

Atomic radiative and radiationless yields for K and L shells

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Atomic Radiative and Radiationless Yields for K and L Shells

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The available body of information on (a) fluorescence, Auger, and Coster-Kronig yields, (b) radiative and radiationless transition rates, (c) level widths, (d) x-ray and Auger line widths, (e) x-ray and Auger spectra, and (f) Coster-Kronig energies has been used to generate an internally consistent set of values of atomic radiative and radiationless yields for the K shell ($5 \leq Z \leq 110$) and the L subshells ($12 \leq Z \leq 110$). Values of fluorescence yields $\omega_K, \omega_1, \omega_2, \omega_3$, Coster-Kronig yields $f_1, f_{1,2}, f_{1,3}, f'_{1,3}, f_{2,3}$, Auger yields a_K, a_1, a_2, a_3 , and effective fluorescence yields ν_1 and ν_2 are presented in tables and graphs. Estimates of uncertainties are given. Updated and expanded graphs of partial and total widths of K, L_1, L_2 , and L_3 levels are presented as well as a reference list of papers published since about 1972.

Key words: Atomic properties; Auger yield; Coster-Kronig yield; effective fluorescence yield; fluorescence yield; K shell; L shell; non-radiative yield; partial level width; radiative yield.

Contents

	Page		Page
Nomenclature	307	Table 3. Fluorescence Yields for K Shell, $5 \leq Z \leq 110$;	
1. Introduction	308	Fluorescence and Coster-Kronig Yields for	
2. Definitions and Relations	308	L Subshells, $12 \leq Z \leq 110$	315
3. Source Material	309	Table 4. Auger Yields for K Shell, $5 \leq Z \leq 110$,	
4. Partial and Total Atomic Level Widths	309	and L Subshells, $12 \leq Z \leq 110$	319
5. Evaluation Procedure	310	Table 5. Effective Fluorescence Yields for L_1 and L_2	
5.1. Generalizations	310	Subshells, $12 \leq Z \leq 110$	320
5.2. Outline of Procedure	311		
5.3. Details on Individual Selections	312		
6. Estimate of Uncertainties	313		
7. Presentation of Output Data	313	Figure 1. K Shell Partial and Total Widths	309
8. Problem Areas	313	Figure 2. L_1 Subshell Partial and Total Widths	310
9. Acknowledgements	314	Figure 3. L_2 Subshell Partial and Total Widths	311
References	322	Figure 4. L_3 Subshell Partial and Total Widths	312
Appendix	323	Figure 5. K Shell Fluorescence and Auger Yields ..	317

List of Figures

Figure 6. L_1 Subshell Fluorescence, Auger and Coster-Kronig Yields	317
Figure 7. L_2 Subshell Fluorescence, Auger and Coster-Kronig Yields	318
Figure 8. L_3 Subshell Fluorescence and Auger Yields	318
Figure 9. L_1 Subshell Effective Fluorescence Yield..	321
Figure 10. L_2 Subshell Effective Fluorescence Yield.	321

List of Tables

Table 1. Fluorescence, Auger and Coster-Kronig Yields for Light Atoms in Condensed Matter	314
Table 2. Estimated Uncertainties of Adopted Values of Fluorescence and Coster-Kronig Yields..	314

Nomenclature

Previous convention is followed that omits the L shell designation in subscripts, for example, ω_1 instead of ω_{L_1} .

S Transition rate.

S_j ($j = R, A, C$) Transition rates of radiative (R), Auger (A) and Coster-Kronig (C) components.

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Γ	Natural level width.
Γ_j ($j = R, A, C$)	Partial level widths: radiative width (R), Auger width (A), and Coster-Kronig width (C).
ω_i ($i = K, 1, 2, 3$)	Fluorescence or radiative yield of K, L_1, L_2, L_3 levels.
a_i ($i = K, 1, 2, 3$)	Auger yield of K, L_1, L_2, L_3 levels.
$f_1 = f_{1,2} + f_{1,3}$	Coster-Kronig yield of L_1 level.
$f_{i,k}$ ($i, k = 1, 2, 3$)	Coster-Kronig yield for radiationless transitions between L levels i, k .

$f'_{1,3}$	Intrashell radiative yield for transition $L_1 \rightarrow L_3$.
ν_1, ν_2	Effective fluorescence yield of L_1 and L_2 levels.
Z	Atomic number.

Assuming the different decay modes are independent, the total rate S will be given by the sum of the partial rates

$$S = S_R + S_A + S_C \quad (3)$$

and the total level width (natural width) by

$$\Gamma = \Gamma_R + \Gamma_A + \Gamma_C, \quad (4)$$

where subscripts denote the radiative, Auger, and Coster-Kronig branches. Yields for the various processes are defined as follows:

$$\text{Radiative or fluorescence yield} \quad \omega = \Gamma_R/\Gamma \quad (5)$$

$$\text{Auger yield} \quad a = \Gamma_A/\Gamma \quad (6)$$

$$\text{Coster-Kronig yield} \quad f = \Gamma_C/\Gamma \quad (7)$$

The sum of radiative yield ω and radiationless yields a and f is unity:

$$\omega + a + f = 1. \quad (8)$$

Furthermore, the effective L -shell fluorescence yields ν_1 and ν_2 for an initial vacancy in the L_1 and L_2 subshells³ are given, respectively, by

$$\nu_1 = \omega_1 + \omega_2 f_{1,2} + \omega_3 (f_{1,3} + f_{1,2} f_{2,3} + f'_{1,3}) \quad (9)$$

and

$$\nu_2 = \omega_2 + \omega_3 f_{2,3} \quad (10)$$

in terms of the subshell fluorescence and Coster-Kronig yields and the intrashell radiative yield $f'_{1,3}$, which refers to the transition $L_1 \rightarrow L_3$.

The width of an x-ray line is given by

$$\Gamma(X \rightarrow Y) = \Gamma(X) + \Gamma(Y) \quad (11)$$

where X and Y are the levels involved in the transition.

Analogously, the width of an Auger or Coster-Kronig line is given by

$$\Gamma(X \rightarrow YZ) = \Gamma(X) + \Gamma(YZ) \quad (12)$$

where YZ is a double-hole configuration. Widths of eqs (11) and (12), or directly measured level widths Γ , can be correlated with transition rates S (eqs (2) to (4)), and yields (eqs (5) to (7)) only if (a) effects other than lifetime broadening are absent or negligible, and (b) the width of one of the levels involved in a transition is known or is small compared to the other.

* Figures in brackets indicate literature references at the end of this paper.
† These data are compiled in the Appendix.

³ Designation for the L shell is dropped in subscripts.

3. Source Material

The following material was utilized in the evaluation: (a) experimental fluorescence, Auger, and Coster-Kronig yields, (b) theoretical radiative and non-radiative rates, (c) level widths, (d) x-ray and Auger-line widths, (e) x-ray and Auger spectra, and (f) Coster-Kronig energies. Original data of item (a) were taken from the compilations of references 2 and 3, and from later work summarized in the Appendix, but excluding data from those ion-atom collisions that produce highly ionized species. Rates were taken from the graphs of partial level widths displayed in figures 1 to 4. For level widths recent data (Appendix) and compilations [7-9] were consulted, and for x-ray line widths recent evaluations [10,11] formed the major input. Most data on Auger line widths and x-ray spectra are of recent origin as is a comprehensive calculation of Coster-Kronig energies [12]. Source material up to October, 1977 was considered.

4. Partial and Total Atomic Level Widths

Theoretical transition rates, expressed as partial level widths, are displayed in figures 1 to 4 to allow the reader

to interrelate the different categories of source material, to assess the relative importance of the various quantities in different Z regions, and to visualize trends of rates, yields and level widths as a function of Z .

Figures 1 to 4 are updated and expanded versions of the K and L graphs of an earlier presentation [13] of theoretical results. Curves of partial widths Γ_A and Γ_R show averaged results for K shell [14] and L subshells [15] from the same sources used in reference 13; but in averaging, the hydrogenic-type calculations were given much less weight, especially at low Z , than previously [13]. In figures 2 and 3, discontinuities in the Γ_C plots were located in accordance with a recent calculation [12] of Coster-Kronig energies. Partial widths Γ_R were taken solely from relativistic Hartree-Fock calculations [16,17]. Relativistic Hartree-Slater values [18] were used, however, to aid in the interpolation of the relativistic Hartree-Fock values reported in references 16 and 17.

In the evaluation procedure outlined below, theoretical widths of the L subshells were modified to be compatible with experimental data of level and line widths. The resulting semi-empirical values, which contain many of the quantities used as source material (items (b) to (f) of sec. 3), are plotted in the insets of figures 2 and 3 in those regions in which substantial changes occur. In the

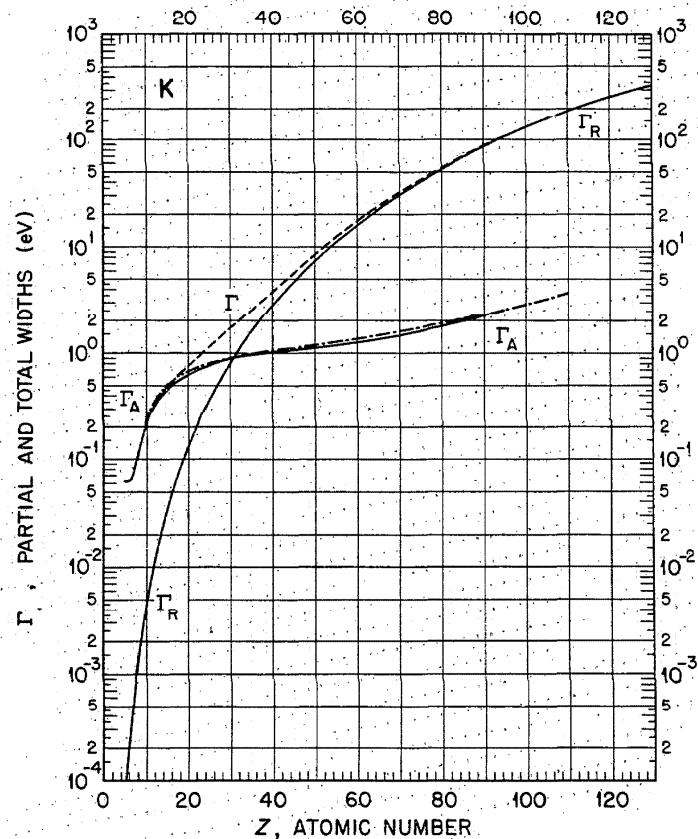


FIGURE 1. Theoretical partial and total atomic level widths for K shell. Γ_A = Auger width; Γ_R = radiative width; Γ = total width. Dot-dash curve represents semi-empirical Γ_A curve obtained from adopted ω_K values and theoretical Γ_R curve: $\omega_K \Gamma_A = (1 - \omega_K) \Gamma_R$.

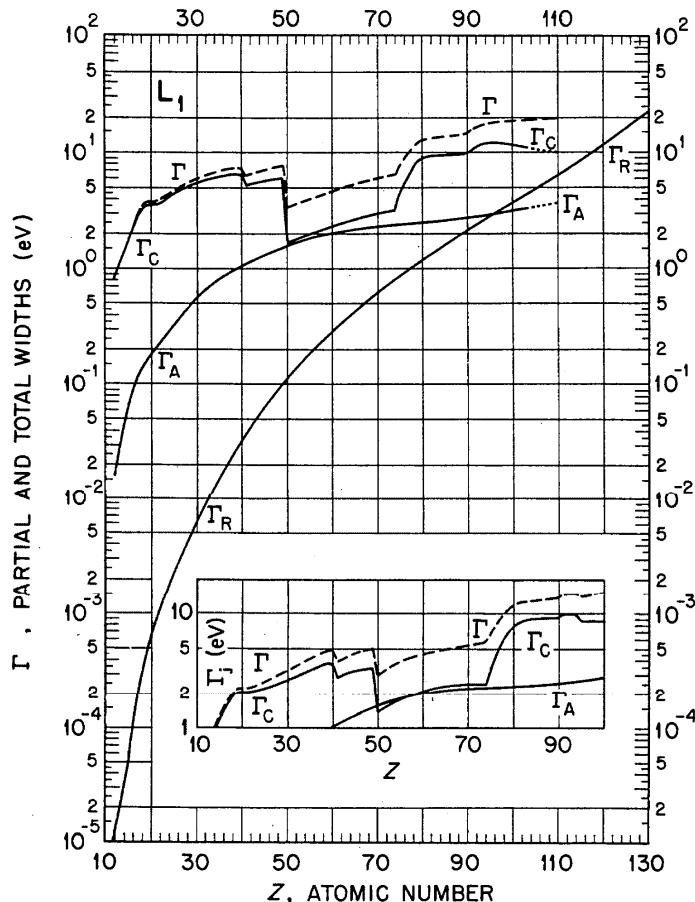


FIGURE 2. Theoretical partial and total atomic level widths for L_1 subshell. Γ_A = Auger width, Γ_C = Coster-Kronig width, Γ_R = radiative width, Γ = total width. Inset shows semi-empirical widths.

remaining regions, in which modifications are small, semi-empirical curves are not distinguished from theoretical curves in the graphic representation of figures 1 to 4.

Since calculations of Auger rates have not yet reached the same reliability as calculations of radiative rates, it is interesting in the case of the K shell to compare the theoretical Auger rate [14] with the semi-empirical Auger rate derived from the theoretical radiative rate [16-18] and the accurate, fitted fluorescence yield value's (sec. 5.3). The result is shown in figure 1 and indicates that in the middle-to-high Z range the semi-empirical width (dot-dash curve) rises more slowly than the averaged theoretical prediction of Γ_A (solid curve). Assuming that this finding could be transferred to the L shell (generalization (2) in sec. 5.1.), the Auger widths Γ_A of the L subshells were modified analogously. The Γ_A curves in the insets of figures 2 and 3 incorporate this adjustment and show that a minor downward correction had to be applied at high Z .

5. Evaluation Procedure

In this work, all pertinent data were included in the evaluation process and judiciously weighed to obtain

compatibility among the data of the different, but related properties (eqs (2) to (8), (11) and (12)). To achieve consistency between corresponding yields of individual subshells, strong reliance was placed on the *trends* of total and partial level widths plotted in figures 1 to 4. Stated and presumed accuracies were taken into account, but a least-squares adjustment for *all* data sets followed by a χ^2 test for consistency [19] could not be justified because of the use of theoretical predictions and the scarcity of experimental data in certain Z ranges. If in a given Z range input data of different types could not be mutually reconciled within their error limits, a judgement was made as to which set or sets of data were the most reliable.

The evaluation procedure adopted is outlined in the following sections, both in general terms and in detail.

5.1. Generalizations

The following generalizations were made for K and L shells:

(1) Partial and total level widths increase smoothly with atomic number Z , except at cutoffs and onsets of Coster-Kronig transitions (see figs. 1 to 4).

(2) Radiative and Auger widths of the different levels

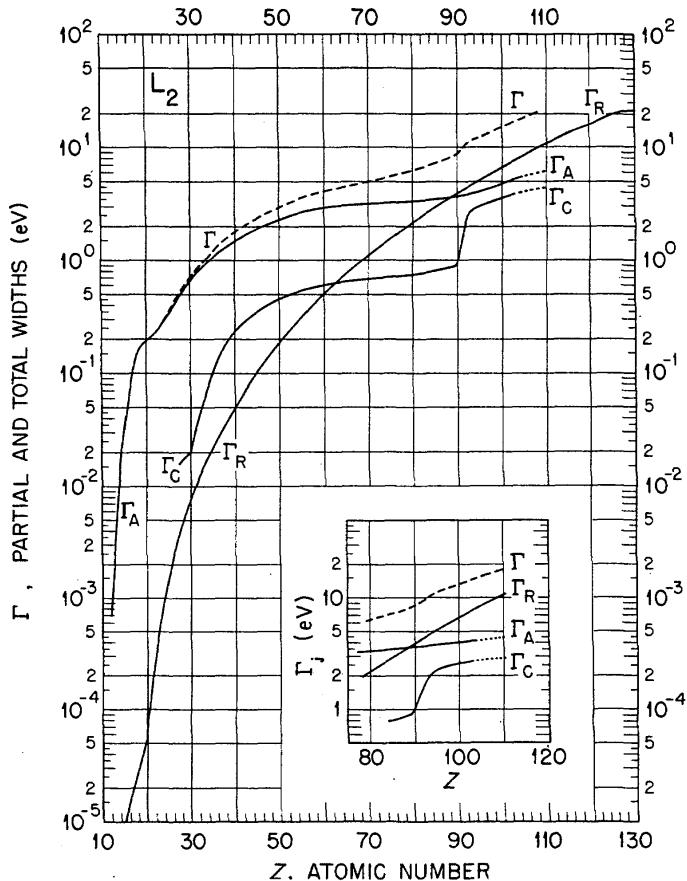


FIGURE 3. Theoretical partial and total atomic level width for L_2 subshell. Γ_A = Auger width, Γ_C = Coster-Kronig width, Γ_R = radiative width, Γ = total width. Inset shows semi-empirical widths.

display similar trends as a function of Z . As a consequence, fluorescence yields ω_K , ω_3 , and ω_2 where Γ_C is small, will vary similarly (compare figs. 1 to 4). This characteristic has been used previously [3] to derive an analytical expression for ω_3 similar to that for ω_K .

(3) Relativistic Hartree-Fock values of the radiative widths [16,17] are considered reliable because of their agreement (a) with measured $K\alpha$ line widths [10,11] of the heavy elements in which the radiative component predominates, and in particular (b) with intensity ratios of x-ray emission lines [20] with final states in different principal shells, such as $K\beta$ and $K\alpha$ lines.

(4) Theory overestimates Coster-Kronig rates Γ_C .

5.2. Outline of Procedure

The evaluation procedure for the L subshells involved seven steps (for K shell see sec 5.3):

(1) Weighted least-squares fits to experimental yield data were made in regions where number and quality of measurements justified the procedure.

(2) Theoretical level widths Γ were modified in accordance with experimental data on level widths, x-ray line widths and Auger line widths (line widths corrected for width of other level(s) involved in transition). Partial

widths Γ_C and sometimes Γ_A were modified correspondingly; in several instances, further information on Γ_C was derived from x-ray spectral data. Only those data on level and line widths were utilized for which absence of non-lifetime broadening [21,22] and reliability of measurements could be presumed. Partial and total level widths were extrapolated to $Z = 110$.

(3) Radiative and radiationless yields were calculated from modified theoretical rates of step (2).

(4) Semi-empirical values from step (3) were compared with experimental yield values, including fitted values from step (1), and the two sets of data were averaged according to the stated or presumed accuracies of all entries. In regions in which few or no measurements have been reported, results from step (3) were weighted more heavily than values obtained by extrapolation of the least-squares fits of step (1).

(5) Results from step (4) were smoothed, separately for each yield, as a function of Z .

(6) Values obtained in step (5) were checked against experimental fluorescence and Coster-Kronig yields and the semi-empirical results from step (3). This was done to assure that the averaging and smoothing steps did not introduce unacceptable slopes and fluctuations in the curves of partial widths (see points (1) and (2) of

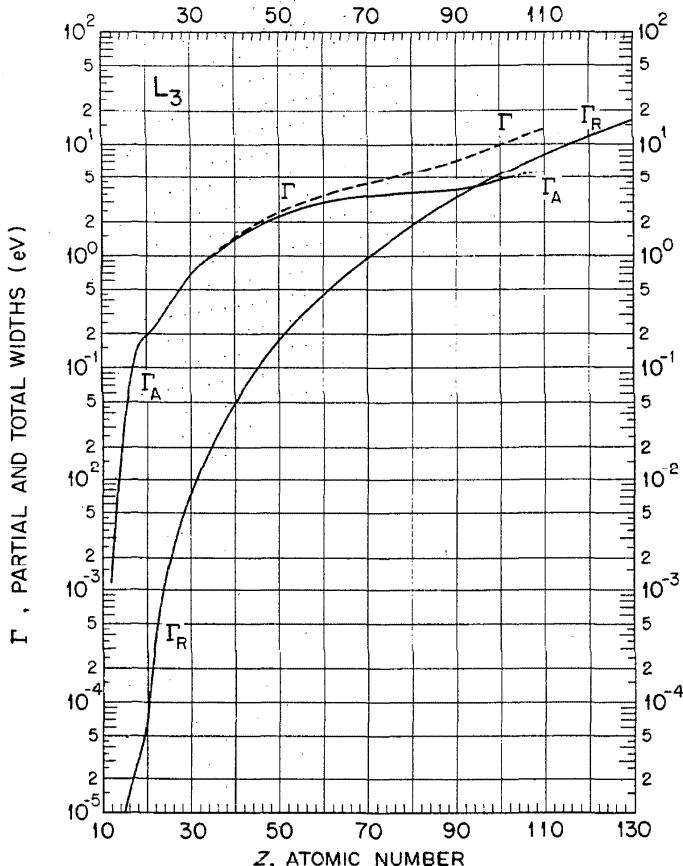


FIGURE 4. Theoretical partial and total atomic level widths for L_3 subshell. Γ_A = Auger width, Γ_R = radiative width, Γ = total width.

generalizations) or excessive deviations from the experimental data. Corrections were made if a need was indicated.

(7) Level widths Γ_i were calculated from the fluorescence yields of step (6) and theoretical radiative transition rates [16-18]. This step was done to assure that (a) the resulting width values of each subshell increased smoothly with Z , except at Coster-Kronig breaks, (point (l) of generalizations), and (b) combinations of Γ_i values were in reasonable agreement with experimental or evaluated widths of $KL_3\alpha_1$ and $KL_2\alpha_2$ x rays and the width difference of the $L_2M_4\beta_1$ and $L_3M_4\alpha_2$ x-ray lines [10,11]. A final smoothing adjustment was made in the fluorescence yield values and the complementary radiationless yields.

5.3. Details Concerning Individual Selections

The more important details in the evaluation are described in the following:

K Shell.

In the range $10 \leq Z \leq 93$, adopted values of ω_K represent the mean, weighted toward recent data (Appendix), between the selections by Bambynek et al. [2]

and by Burhop and Asaad [3]. New data listed in the Appendix were utilized for $93 \leq Z \leq 99$. At low Z , only gas-target determinations were considered, and the datum for neon served as an anchor point. Solid-target data furnished the values given in table 1.

L_3 Subshell.

In the range $55 \leq Z \leq 96$, a least-squares fit was applied to the data compiled in references 2 and 3 and the Appendix. Results were averaged with those from the L_3 graph (fig. 4) on partial and total widths, whereby the width of the $L_3M_5\alpha_1$ line was taken into account [10]. Below $Z \sim 55$, I emphasized the results taken from figure 4 and modified these in accordance with level widths determinations at $Z = 18$ and 30. Note that Γ_A was not allowed to increase as steeply near $Z = 95$ as shown in figure 4.

L_2 Subshell

In the range $60 \leq Z \leq 90$, least-squares-fit values of experimental ω_2 data were retained nearly unaltered, since they agree well with those obtained from the L_2 graph (fig. 3). Experimental $f_{2,3}$ values, especially those of recent origin, were found to agree satisfactorily with

the theoretical values obtained from figure 3. The latter values were adopted. On the basis of this accord the partial widths in figure 3 were trusted to supply reliable ω_2 and $f_{2,3}$ values also for $30 \leq Z \leq 60$. Values below $Z \approx 30$ were obtained from the theoretical partial widths (fig. 3) that were modified in accordance with the experimental widths data at $Z = 18$ and 30 for free atoms. Note that the transition L_2-L_33d is forbidden in free atoms for $Z \leq 30$ [6,12] (as for $Z > 30$), but is allowed in metals for $26 \leq Z \leq 30$ and possibly to $Z = 22$ [23,24]. Estimates of yields for these metals are given in table 1. Adopted values for ω_2 and $f_{2,3}$ following the onset of $L_2-L_3M_5$ transitions at $Z = 91$ were derived from a compromise between the measured values and those from the inset of figure 3. I may point out that reducing Γ_C to about 2.5 eV yields satisfactory agreement with (a) the reported width differences [10] $\Gamma(L_2M_4\beta_1) - \Gamma(L_3M_4\alpha_2)$, (b) the general tendency of the calculations to overestimate Coster-Kronig rates, and (c) the average of all ω_2 values reported.

L₁ Subshell

Since the Coster-Kronig rate is the dominant component of the L_1 decay rate, its proper assessment will determine the quality of yield values in regions in which directly measured values are nonexistent or inaccurate. Preselected partial widths plotted in the inset of figure 2 were used to derive, with minor adjustments, the adopted ω_1 and f_1 values. Possible discontinuities were placed at $Z = 40, 41, Z = 49, 50, Z = 74, 75, Z = 90, 91$, and $Z = 104$ in accordance with cutoffs and onsets of Coster-Kronig transitions [12,25], but were ignored between $Z \approx 22$ and $Z \approx 35$ because of lack of precise information on the size of the jumps. The choices made for Γ_C and Γ_A at $Z \geq 76$ gave ω_1 values that agree satisfactorily with experimental data, but f_1 values that are 10–15% lower than the majority of the measured values. Partitioning of f_1 into its $f_{1,2}$ and $f_{1,3}$ components followed the pattern suggested by theory. Intrashell radiative yield values, $f'_{1,3}$, were taken exclusively from Scofield's calculation [16,18], since virtually no experimental data are available. However, the only experiment [26] carried out so far, points to lower values than those calculated.

6. Estimate of Uncertainties

Presumed and stated reliability of input material, number or lack of measurements, and the degree of compatibility of the different relevant data determined the uncertainties assigned to the adopted values. Uncertainties in the various Z ranges are given in table 2.

7. Presentation of Output Data

The values of atomic fluorescence and Coster-Kronig yields that are tabulated in table 3 and plotted in figures 5 to 8 are the values adopted in section 5.2, step (7) of

the evaluation procedure. Note that in this work the intrashell radiative yield $f'_{1,3}$ is contained in the L_1 subshell fluorescence yield ω_1 . The same applies to the $f'_{1,2}$ component of the L_1 intrashell radiative yield; however since $f'_{1,2} \ll f'_{1,3}$ [16,18], the yield $f'_{1,2}$ is not listed separately in table 3.

The adopted values of the Auger yields are presented in table 4 and figures 5 to 8; these values were calculated from eq (8) using the values of fluorescence and Coster-Kronig yields of table 3.

The effective fluorescence yields for ionization in the L_1 and L_2 subshells are given in table 5 and figures 9 and 10; these values were obtained from eqs (9) and (10) using the entries of table 3. The corresponding yield ν_3 for the L_3 subshell is identical with ω_3 ; and it can be seen from tables 3 and 5 that the effective fluorescence yields for the three L subshells differ by less than 10% over most of the periodic table. Level widths were obtained as a set of output data in step (7) of the evaluation procedure (sec 5.2). The values that were calculated with the final, adopted values of the fluorescence yields are reported and discussed in the following paper [27].

As pointed out in sections 5.3 and 8, radiative and radiationless yields depend on the chemical structure in the light elements, in which transitions involve electrons which participate in bonding. However, little is known about the exact dependence of the yields, or transition rates, on the chemical structure for these light elements. It is with this *caveat* that the values for condensed matter listed in table 1 should be used.

Values of ω_K presented in table 1 were obtained from a curve fitted to experimental data ([2,3] and Appendix) for the metals Li, Be, B and Al, and the elemental solids C, P and S. Values of ω_2 and $f_{2,3}$ in table 1 were derived from the atomic radiative and Auger widths obtained in section 5 and experimental data [21,23] pertaining to the Coster-Kronig yield $f_{2,3}$ in the metals Zn and Cu. Theoretical Coster-Kronig rates [15], which were matched at $Z = 29$ to the experimental value, were used for $25 < Z < 29$ and extrapolated to $Z = 22$. No estimates of the yields for any of the L subshells are entered in table 1 for $Z \leq 21$, since virtually no experimental data are available for bound atoms in this range. However, it might be assumed, in analogy to the findings for the K shell, that the fluorescence yields would be smaller for the bound atoms than for the free atoms (table 3).

8. Problem Areas

In general, reduction of the data to single-hole atomic values has remained outside the capabilities of experiment and theory. This is of some concern in determining Coster-Kronig yields and assessing the reliability of the measured values. Investigations on the effect of double vacancies have not yet produced precise guidelines [28]; however, detailed results have become available of the effects of multiple vacancies on the fluorescence yields in several light atoms [29].

Table 1. Fluorescence, Auger and Coster-Kronig yields for light atoms in condensed matter.^a ($9.0 \text{ E-}5 \equiv 9.0 \times 10^{-5}$).

Z	K Shell		L ₂ Subshell				
	Z	ω_K	a_K	Z	ω_2	a_2	$f_{2,3}$
3	9.0 E-5	1.000		22	1.1 E-3 ^b	0.75 ^b	0.25 ^b
4	3.3 E-4	1.000		23	1.8 E-3 ^b	0.71 ^b	0.29 ^b
5	7.0 E-4	1.000		24	2.3 E-3 ^b	0.65 ^b	0.35 ^b
6	1.4 E-3	0.999		25	3.1 E-3 ^b	0.61 ^b	0.39 ^b
7	3.1 E-3	0.997		26	3.6 E-3	0.58	0.42
8	5.8 E-3	0.994		27	4.4 E-3	0.57	0.43
9	9.2 E-3	0.991		28	5.1 E-3	0.54	0.45
10	0.016	0.984		29	5.7 E-3	0.52	0.47
11	0.021	0.979		30	9.5 E-3	0.75	0.24
12	0.028	0.972					
13	0.036	0.964					
14	0.048	0.952					
15	0.061	0.939					

^aK-shell values are based primarily on experimental determinations of ω_K (see Appendix). L₂-shell values take into account the rates of L₂-L₂M_{4,5} Coster-Kronig transitions, which are energetically favored in the indicated range.

^bAssuming the transition 2p_{1/2}-2p_{3/2}3d is allowed also for Z = 22 to 25.

In the range $88 \leq Z \leq 96$, several measured values of both ω_2 and $f_{2,3}$ lie above the adopted values for a given Z. Such data cannot be accommodated within the systematics of the rates detailed in figure 3, as this would require Γ_A to decrease sharply with increasing Z, or Γ_R to increase by 10 to 20%. Either alternative is

difficult to accept. A similar situation pertains to the ω_1 and f_1 yields above $Z \approx 80$. Obviously, accurate measurements and careful considerations of double-hole effects are desirable in these regions.

Larger uncertainties occur for the K shell fluorescence yield below $Z = 10$ and the L shell fluorescence yield below $Z \approx 20$ since the adopted values were derived from data on molecules and from theoretical rates based on calculations in the single-particle model. However, in these regions transition rates may be altered substantially by many-body interactions [30] and chemical effects. The strong influence of many-body effects on Coster-Kronig transitions was recently demonstrated for the M shell [31]; these effects presumably occur also in the L shell, though probably to a lesser degree, and may result in a reduction of Γ_C similar to the semi-empirical reduction made in this work.

9. Acknowledgements

I am indebted to M. Schmorak for a computer search of literature, and especially to C. W. Nestor, Jr. for computer composition of the main tables and graphs. This work was sponsored by the U. S. Department of Energy, Division of Nuclear Sciences, Office of Basic Energy Sciences, under contract W-7405-eng-26 with the Union Carbide Corporation, operator of the Oak Ridge National Laboratory.

Table 2. Estimated uncertainties (in percent) of adopted values for fluorescence and Coster-Kronig yields.

Yield	Range of atomic numbers										
	5-10 ^a	10-20	20-30	30-40	40-50	50-60	60-70	70-80	80-90	90-100	100-110
ω_K	40-10 ^a	10-5	5-3	3	2	2-1	1	1	≤1	≤1	1
ω_1	-	≥30 ^a	30 ^a	30 ^b	30-20 ^b	20-15	15	15 ^b	15	15-20	20
ω_2	-	≥25 ^a	25 ^{a,b}	25	25-10	10	10-5	5	5	10 ^b	10
ω_3	-	≥25 ^a	25 ^a	20	20-10	10-5	5	5-3	3	3-5	5
f_1	-	3 ^a	5 ^a	5	5-10 ^b	15	10	10-5 ^b	5	5-10	15
$f_{1,2}$	-	10 ^a	15 ^a	15	20 ^b	20	15	20 ^b	10	10-50	50-100
$f_{1,3}$	-	5 ^a	10 ^a	10	10 ^b	15	10	10-5 ^b	5	5-10	15
$f_{2,3}$	-	-	≥40 ^a	30-20	20	20	20-15	15	15	15 ^b	20

^aIn these regions, yields for molecules and solids may differ from those for atoms by more than the values quoted.

^bNear-breaks in the yield curves, uncertainties may exceed those listed.

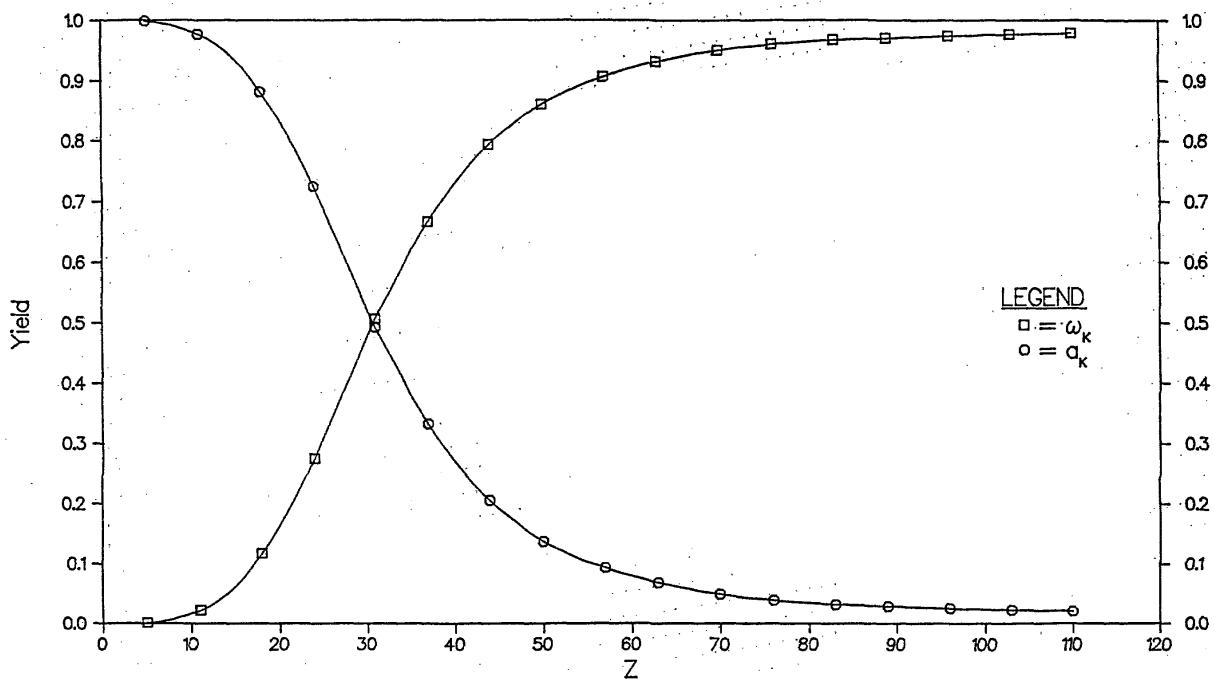
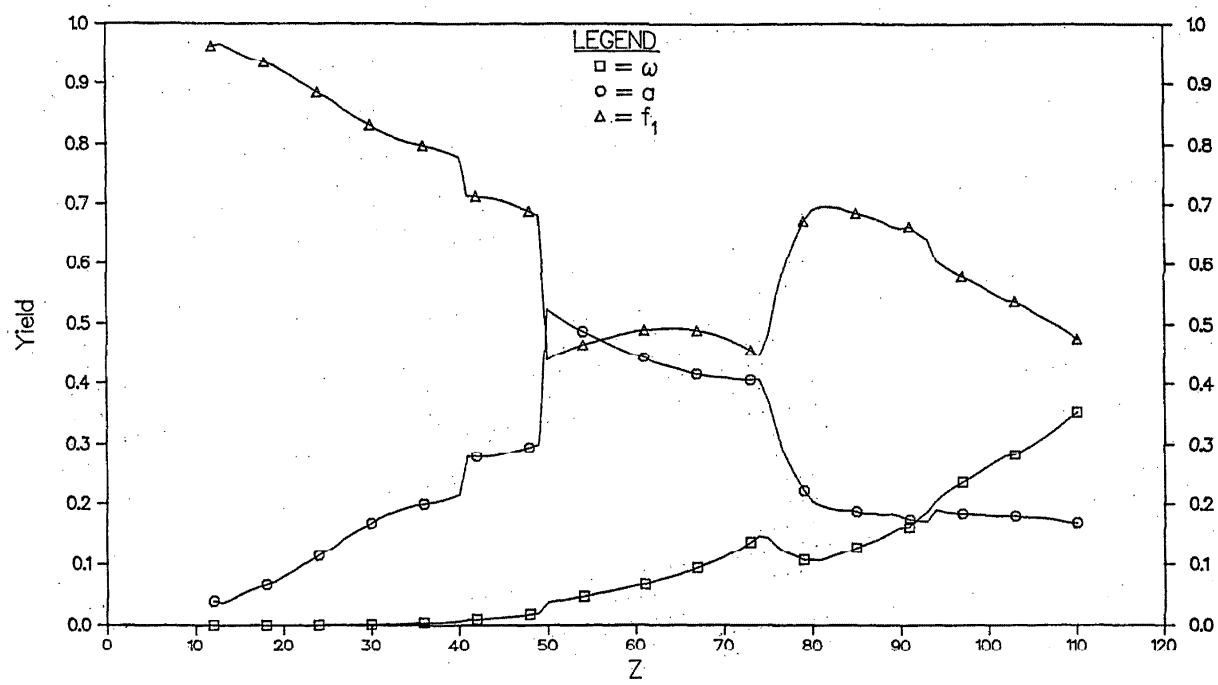
Table 3. Adopted values of fluorescence and Coster-Kronig yields^a

Z	ω_K	ω_1	ω_2	ω_3	f_1	$f_{1,2}$	$f_{1,3}$	$f'_{1,3}$	$f_{2,3}$
5 B	1.7E-03								
6 C	2.8E-03								
7 N	5.2E-03								
8 O	8.3E-03								
9 F	0.013								
10 NE	0.018								
11 NA	0.023								
12 MG	0.030	2.9E-05	1.2E-03	1.2E-03	0.962	0.32	0.64	2.0E-05	
13 AL	0.039	2.6E-05	7.5E-04	7.5E-04	0.965	0.32	0.64	1.6E-05	
14 SI	0.050	3.0E-05	3.7E-04	3.8E-04	0.959	0.32	0.64	1.4E-05	
15 P	0.063	3.9E-05	3.1E-04	3.1E-04	0.951	0.32	0.63	1.2E-05	
16 S	0.078	7.4E-05	2.6E-04	2.6E-04	0.944	0.32	0.62	1.4E-05	
17 CL	0.097	1.2E-04	2.4E-04	2.4E-04	0.939	0.32	0.62	1.4E-05	
18 AR	0.118	1.8E-04	2.2E-04	2.2E-04	0.934	0.31	0.62	1.3E-05	
19 K	0.140	2.4E-04	2.7E-04	2.7E-04	0.929	0.31	0.62	1.2E-05	
20 CA	0.163	3.1E-04	3.3E-04	3.3E-04	0.920	0.31	0.61	1.4E-05	
21 SC	0.188	3.9E-04	8.4E-04	8.4E-04	0.912	0.31	0.60	1.4E-05	
22 TI	0.214	4.7E-04	1.5E-03	1.5E-03	0.902	0.31	0.59	1.5E-05	
23 V	0.243	5.8E-04	2.6E-03	2.6E-03	0.894	0.31	0.58	1.6E-05	
24 CR	0.275	7.1E-04	3.7E-03	3.7E-03	0.885	0.31	0.57	1.8E-05	
25 MN	0.308	8.4E-04	5.0E-03	5.0E-03	0.877	0.30	0.58	1.9E-05	
26 FE	0.340	1.0E-03	6.3E-03	6.3E-03	0.868	0.30	0.57	2.1E-05	
27 CO	0.373	1.2E-03	7.7E-03	7.7E-03	0.856	0.30	0.56	2.3E-05	
28 NI	0.406	1.4E-03	8.6E-03	9.3E-03	0.847	0.30	0.55	2.4E-05	0.028
29 CU	0.440	1.6E-03	0.010	0.011	0.839	0.30	0.54	2.6E-05	0.028
30 ZN	0.474	1.8E-03	0.011	0.012	0.831	0.29	0.54	2.8E-05	0.026
31 GA	0.507	2.1E-03	0.012	0.013	0.822	0.29	0.53	3.0E-05	0.032
32 GE	0.535	2.4E-03	0.013	0.015	0.815	0.28	0.53	3.2E-05	0.050
33 AS	0.562	2.8E-03	0.014	0.016	0.809	0.28	0.53	3.4E-05	0.063
34 SE	0.589	3.2E-03	0.016	0.018	0.804	0.28	0.52	3.6E-05	0.076
35 BR	0.618	3.6E-03	0.018	0.020	0.800	0.28	0.52	3.8E-05	0.088
36 KR	0.643	4.1E-03	0.020	0.022	0.797	0.27	0.52	4.1E-05	0.100
37 RB	0.667	4.6E-03	0.022	0.024	0.794	0.27	0.52	4.4E-05	0.109
38 SR	0.690	5.1E-03	0.024	0.026	0.790	0.27	0.52	4.7E-05	0.117
39 Y	0.710	5.9E-03	0.026	0.028	0.785	0.26	0.52	5.2E-05	0.126
40 ZR	0.730	6.8E-03	0.028	0.031	0.779	0.26	0.52	5.8E-05	0.132
41 NB	0.747	9.4E-03	0.031	0.034	0.713	0.10	0.61	7.8E-05	0.137
42 MO	0.765	0.010	0.034	0.037	0.712	0.10	0.61	8.1E-05	0.141
43 TC	0.780	0.011	0.037	0.040	0.711	0.10	0.61	8.8E-05	0.144
44 RU	0.794	0.012	0.040	0.043	0.709	0.10	0.61	9.6E-05	0.148
45 RH	0.808	0.013	0.043	0.046	0.705	0.10	0.60	1.0E-04	0.150
46 PD	0.820	0.014	0.047	0.049	0.700	0.10	0.60	1.1E-04	0.151
47 AG	0.831	0.016	0.051	0.052	0.694	0.10	0.59	1.2E-04	0.153
48 CD	0.843	0.018	0.056	0.056	0.688	0.10	0.59	1.4E-04	0.155
49 IN	0.853	0.020	0.061	0.060	0.681	0.10	0.59	1.6E-04	0.157
50 SN	0.862	0.037	0.065	0.064	0.439	0.17	0.27	3.0E-04	0.157
51 SB	0.870	0.039	0.069	0.069	0.448	0.17	0.28	3.2E-04	0.156
52 TE	0.877	0.041	0.074	0.074	0.455	0.18	0.28	3.4E-04	0.155
53 I	0.884	0.044	0.079	0.079	0.461	0.18	0.28	3.7E-04	0.154
54 XE	0.891	0.046	0.083	0.085	0.466	0.19	0.28	4.0E-04	0.154
55 CS	0.897	0.049	0.090	0.091	0.470	0.19	0.28	4.3E-04	0.154
56 BA	0.902	0.052	0.096	0.097	0.474	0.19	0.28	4.7E-04	0.153
57 LA	0.907	0.055	0.103	0.104	0.478	0.19	0.29	5.1E-04	0.153
58 CE	0.912	0.058	0.110	0.111	0.482	0.19	0.29	5.5E-04	0.153
59 PR	0.917	0.061	0.117	0.118	0.485	0.19	0.29	6.0E-04	0.153
60 ND	0.921	0.064	0.124	0.125	0.488	0.19	0.30	6.6E-04	0.152
61 PM	0.925	0.066	0.132	0.132	0.490	0.19	0.30	7.2E-04	0.151
62 SM	0.929	0.071	0.140	0.139	0.492	0.19	0.30	7.9E-04	0.150
63 EU	0.932	0.075	0.149	0.147	0.493	0.19	0.30	8.7E-04	0.149
64 GD	0.935	0.079	0.158	0.155	0.493	0.19	0.30	9.6E-04	0.147

Table 3. Adopted values of fluorescence and Coster-Kronig yields^a - continued

Z	ω_K	ω_1	ω_2	ω_3	f_1	$f_{1,2}$	$f_{1,3}$	$f'_{1,3}$	$f_{2,3}$
65 TB	0.938	0.083	0.167	0.164	0.493	0.19	0.30	1.1E-03	0.145
66 DY	0.941	0.089	0.178	0.174	0.492	0.19	0.30	1.2E-03	0.143
67 HO	0.944	0.094	0.189	0.182	0.490	0.19	0.30	1.3E-03	0.142
68 ER	0.947	0.100	0.200	0.192	0.487	0.19	0.30	1.4E-03	0.140
69 TM	0.949	0.106	0.211	0.201	0.483	0.19	0.29	1.6E-03	0.139
70 YB	0.951	0.112	0.222	0.210	0.478	0.19	0.29	1.8E-03	0.138
71 LU	0.953	0.120	0.234	0.220	0.472	0.19	0.28	2.0E-03	0.136
72 HF	0.955	0.128	0.246	0.231	0.465	0.18	0.28	2.3E-03	0.135
73 TA	0.957	0.137	0.258	0.243	0.457	0.18	0.28	2.6E-03	0.134
74 W	0.958	0.147	0.270	0.255	0.447	0.17	0.28	2.8E-03	0.133
75 RE	0.959	0.144	0.283	0.268	0.485	0.16	0.33	3.0E-03	0.130
76 OS	0.961	0.130	0.295	0.281	0.552	0.16	0.39	2.9E-03	0.128
77 IR	0.962	0.120	0.308	0.294	0.603	0.15	0.45	2.8E-03	0.126
78 PT	0.963	0.114	0.321	0.306	0.640	0.14	0.50	2.8E-03	0.124
79 AU	0.964	0.107	0.334	0.320	0.672	0.14	0.53	2.8E-03	0.122
80 HG	0.965	0.107	0.347	0.333	0.690	0.13	0.56	3.0E-03	0.120
81 TL	0.966	0.107	0.360	0.347	0.696	0.13	0.57	3.2E-03	0.118
82 PB	0.967	0.112	0.373	0.360	0.696	0.12	0.58	3.5E-03	0.116
83 BI	0.968	0.117	0.387	0.373	0.694	0.11	0.58	3.8E-03	0.113
84 PO	0.968	0.122	0.401	0.386	0.689	0.11	0.58	4.2E-03	0.111
85 AT	0.969	0.128	0.415	0.399	0.685	0.10	0.59	4.7E-03	0.111
86 RN	0.969	0.134	0.429	0.411	0.682	0.10	0.58	5.2E-03	0.110
87 FR	0.970	0.139	0.443	0.424	0.677	0.10	0.58	5.8E-03	0.109
88 RA	0.970	0.146	0.456	0.437	0.672	0.09	0.58	6.4E-03	0.108
89 AC	0.971	0.153	0.468	0.450	0.664	0.09	0.58	7.1E-03	0.108
90 TB	0.971	0.161	0.479	0.463	0.660	0.09	0.57	7.8E-03	0.108
91 PA	0.972	0.162	0.472	0.476	0.664	0.08	0.58	8.4E-03	0.139
92 U	0.972	0.176	0.467	0.489	0.652	0.08	0.57	9.7E-03	0.167
93 NP	0.973	0.187	0.466	0.502	0.642	0.07	0.57	0.011	0.192
94 PU	0.973	0.205	0.464	0.514	0.605	0.05	0.56	0.013	0.198
95 AM	0.974	0.218	0.471	0.526	0.595	0.05	0.55	0.014	0.203
96 CM	0.974	0.228	0.479	0.539	0.587	0.04	0.55	0.016	0.200
97 BK	0.975	0.236	0.485	0.550	0.580	0.04	0.54	0.017	0.198
98 CF	0.975	0.244	0.490	0.560	0.573	0.03	0.54	0.019	0.197
99 ES	0.975	0.253	0.497	0.570	0.565	0.03	0.54	0.021	0.196
100 FM	0.976	0.263	0.506	0.579	0.556	0.03	0.53	0.023	0.194
101 MD	0.976	0.272	0.515	0.588	0.548	0.02	0.53	0.026	0.191
102 NO	0.976	0.280	0.524	0.596	0.540	0.02	0.52	0.028	0.189
103 LR	0.977	0.282	0.533	0.604	0.538	0.01	0.53	0.030	0.185
104	0.977	0.291	0.544	0.611	0.531	0.01	0.52	0.033	0.181
105	0.977	0.300	0.553	0.618	0.522	0.01	0.51	0.035	0.178
106	0.978	0.310	0.562	0.624	0.513		0.51	0.038	0.174
107	0.978	0.320	0.573	0.630	0.505		0.50	0.042	0.171
108	0.978	0.331	0.584	0.635	0.497		0.50	0.046	0.165
109	0.978	0.343	0.590	0.640	0.488		0.49	0.050	0.163
110	0.979	0.354	0.598	0.644	0.477		0.48	0.054	0.158

^aNote: 1.7E-03 ≡ 1.7 × 10⁻³; designation for L shell is omitted, read for example $\omega_1 = \omega_{L1}$; $f_1 = f_{1,2} + f_{1,3}$; uncertainties are given in table 2.

FIGURE 5. K shell fluorescence and Auger yields.FIGURE 6. L_1 subshell fluorescence, Auger, and Coster-Kronig yields.

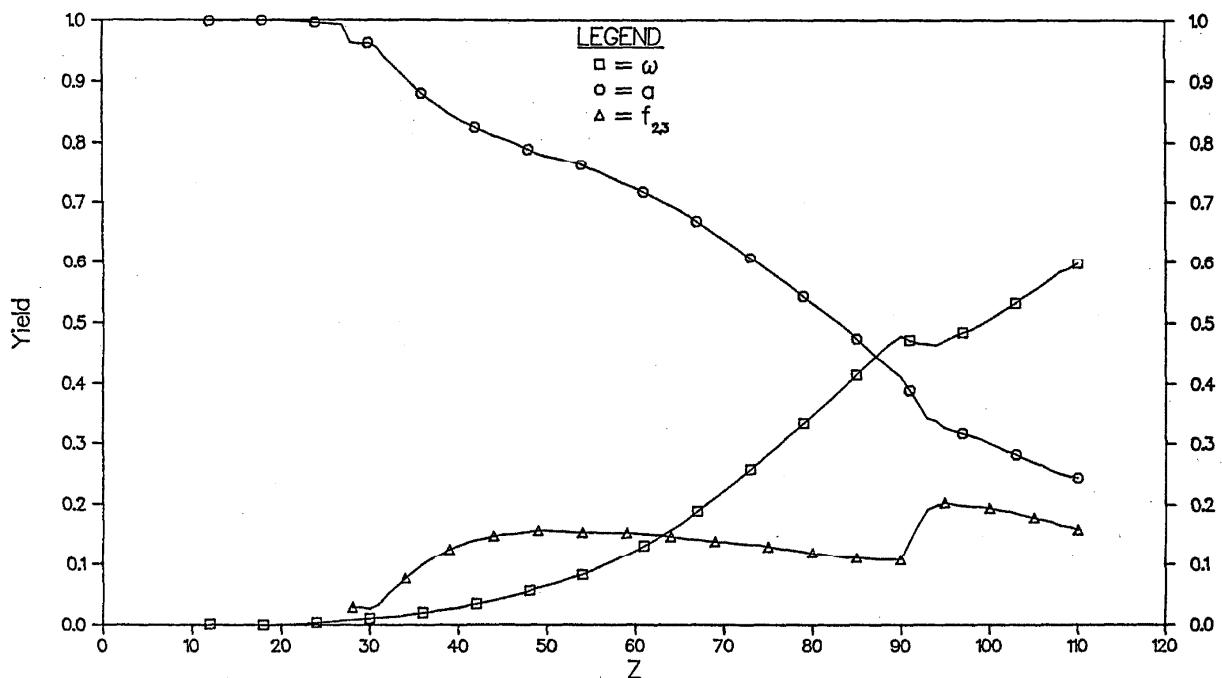
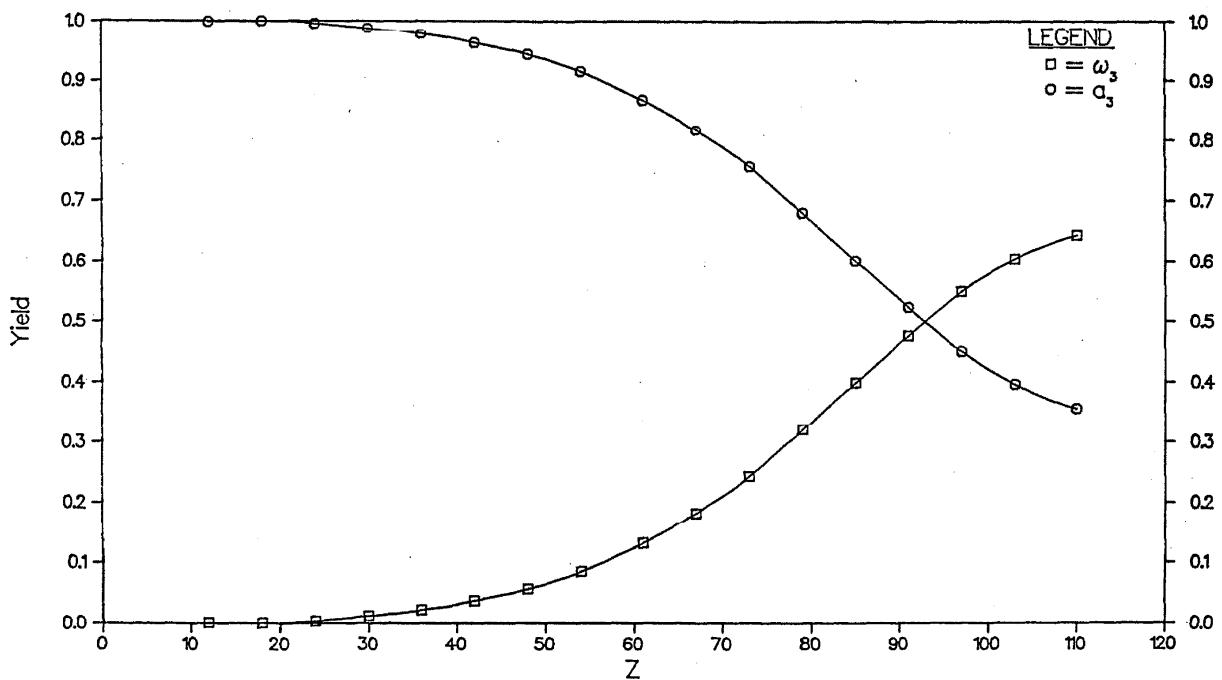
FIGURE 7. L_2 subshell fluorescence, Auger, and Coster-Kronig yields.FIGURE 8. L_3 subshell fluorescence and Auger yields.

Table 4. Auger yields; values calculated from eq(8) with entries from table 3^a

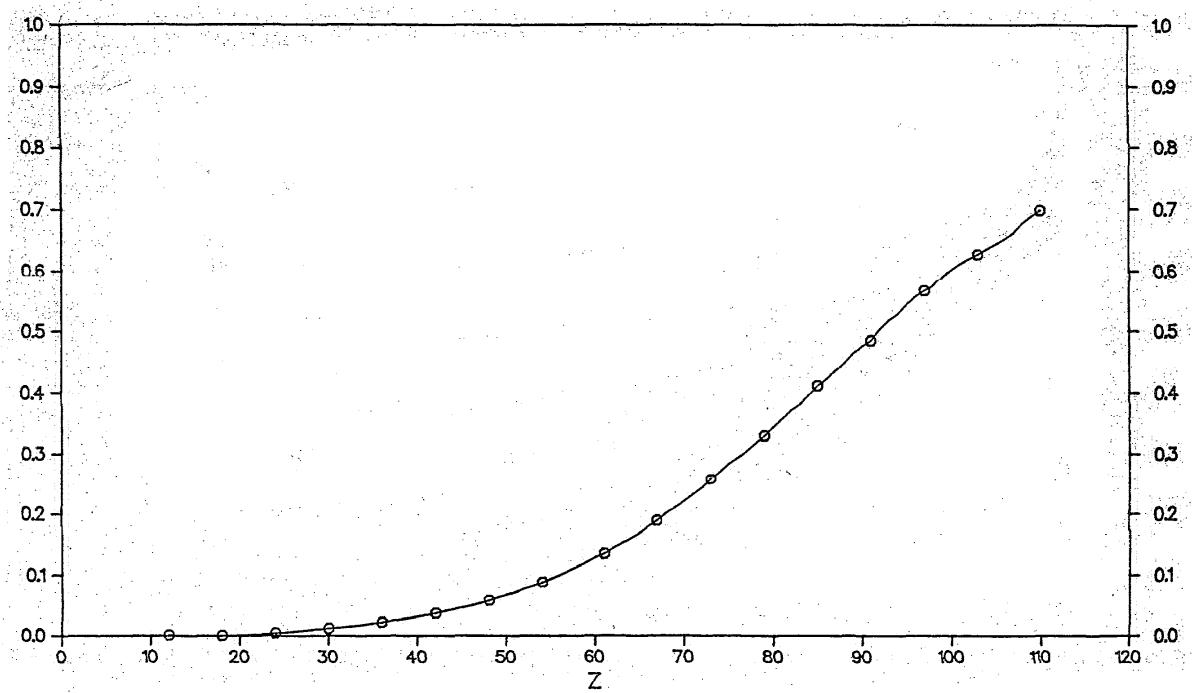
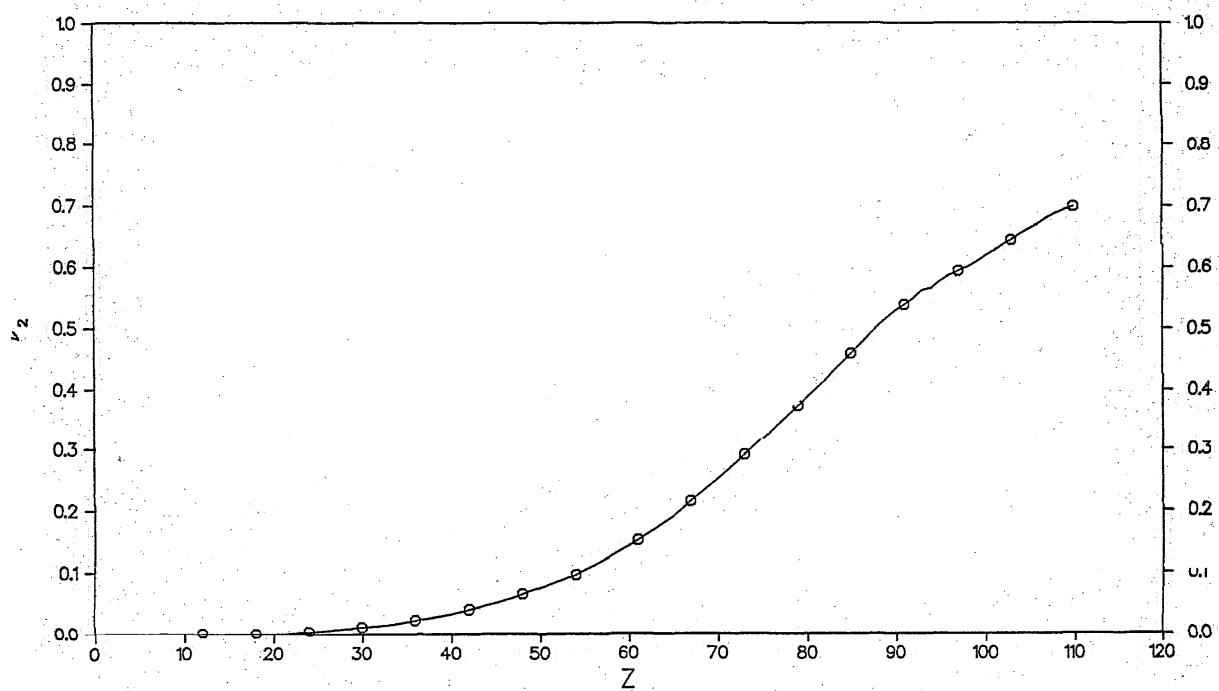
Z	a _K	a ₁	a ₂	a ₃	Z	a _K	a ₁	a ₂	a ₃
5 B	0.998				60 ND	0.079	0.448	0.724	0.875
6 C	0.997				61 PM	0.075	0.444	0.717	0.868
7 N	0.995				62 SM	0.071	0.437	0.710	0.861
8 O	0.992				63 EU	0.068	0.432	0.702	0.853
9 F	0.987				64 GD	0.065	0.428	0.695	0.845
10 NE	0.982				65 TB	0.062	0.424	0.688	0.836
11 NA	0.977				66 DY	0.059	0.419	0.679	0.826
12 MG	0.970	0.038	0.999	0.999	67 HO	0.056	0.416	0.669	0.818
13 AL	0.961	0.035	0.999	0.999	68 ER	0.053	0.413	0.660	0.808
14 SI	0.950	0.041	1.000	1.000	69 TM	0.051	0.411	0.650	0.799
15 P	0.937	0.049	1.000	1.000	70 YB	0.049	0.410	0.640	0.790
16 S	0.922	0.056	1.000	1.000	71 LU	0.047	0.408	0.630	0.780
17 CL	0.903	0.061	1.000	1.000	72 HF	0.045	0.407	0.619	0.769
18 AR	0.882	0.066	1.000	1.000	73 TA	0.043	0.406	0.608	0.757
19 K	0.860	0.071	1.000	1.000	74 W	0.042	0.406	0.597	0.745
20 CA	0.837	0.080	1.000	1.000	75 RE	0.041	0.371	0.587	0.732
21 SC	0.812	0.088	0.999	0.999	76 OS	0.039	0.318	0.577	0.719
22 TI	0.786	0.098	0.999	0.999	77 IR	0.038	0.277	0.566	0.706
23 V	0.757	0.105	0.997	0.997	78 PT	0.037	0.246	0.555	0.694
24 CR	0.725	0.114	0.996	0.996	79 AU	0.036	0.221	0.544	0.680
25 MN	0.692	0.122	0.995	0.995	80 HG	0.035	0.203	0.533	0.667
26 FE	0.660	0.131	0.994	0.994	81 TL	0.034	0.197	0.522	0.653
27 CO	0.627	0.143	0.992	0.992	82 PB	0.033	0.192	0.511	0.640
28 NI	0.594	0.152	0.963	0.991	83 BI	0.032	0.189	0.500	0.627
29 CU	0.560	0.159	0.962	0.989	84 PO	0.032	0.189	0.488	0.614
30 ZN	0.526	0.167	0.963	0.988	85 AT	0.031	0.187	0.474	0.601
31 GA	0.493	0.176	0.956	0.987	86 RN	0.031	0.184	0.461	0.589
32 GE	0.465	0.183	0.937	0.985	87 PR	0.030	0.184	0.448	0.576
33 AS	0.438	0.188	0.923	0.984	88 RA	0.030	0.182	0.436	0.563
34 SE	0.411	0.193	0.908	0.982	89 AC	0.029	0.183	0.424	0.550
35 BR	0.382	0.196	0.894	0.980	90 TH	0.029	0.179	0.413	0.537
36 KR	0.357	0.199	0.880	0.978	91 PA	0.028	0.174	0.389	0.524
37 RB	0.333	0.201	0.869	0.976	92 U	0.028	0.172	0.366	0.511
38 SR	0.310	0.205	0.859	0.974	93 NP	0.027	0.171	0.342	0.498
39 Y	0.290	0.209	0.848	0.972	94 PU	0.027	0.190	0.338	0.486
40 ZR	0.270	0.214	0.840	0.969	95 AM	0.026	0.187	0.326	0.474
41 NB	0.253	0.278	0.832	0.966	96 CM	0.026	0.185	0.321	0.461
42 MO	0.235	0.278	0.825	0.963	97 BK	0.025	0.184	0.317	0.450
43 TC	0.220	0.278	0.819	0.960	98 CP	0.025	0.183	0.313	0.440
44 RU	0.206	0.279	0.812	0.957	99 ES	0.025	0.182	0.307	0.430
45 RH	0.192	0.282	0.807	0.954	100 PM	0.024	0.181	0.300	0.421
46 PD	0.180	0.286	0.802	0.951	101 MD	0.024	0.180	0.294	0.412
47 AG	0.169	0.290	0.796	0.948	102 NO	0.024	0.180	0.287	0.404
48 CD	0.157	0.294	0.789	0.944	103 LR	0.023	0.180	0.282	0.396
49 IN	0.147	0.299	0.782	0.940	104	0.023	0.178	0.275	0.389
50 SN	0.138	0.524	0.778	0.936	105	0.023	0.178	0.269	0.382
51 SB	0.130	0.513	0.775	0.931	106	0.022	0.177	0.264	0.376
52 TE	0.123	0.504	0.771	0.926	107	0.022	0.175	0.256	0.370
53 I	0.116	0.495	0.767	0.921	108	0.022	0.172	0.251	0.365
54 XE	0.109	0.488	0.763	0.915	109	0.022	0.169	0.247	0.360
55 CS	0.103	0.481	0.756	0.909	110	0.021	0.169	0.244	0.356
56 BA	0.098	0.474	0.751	0.903					
57 LA	0.093	0.467	0.744	0.896					
58 CE	0.088	0.460	0.737	0.889					
59 PR	0.083	0.454	0.730	0.882					

^aDesignation for L shell is omitted, read for example $a_1 \equiv a_{L_1}$.

Table 5. Effective fluorescence yields for the L₁ and L₂ subshells; values calculated from eqs (9) and (10) with entries from table 3^a

Z	ν_1	ν_2	Z	ν_1	ν_2	Z	ν_1	ν_2
10 NE			50 SN	0.067	0.075	90 TH	0.476	0.529
11 NA			51 SB	0.072	0.080	91 PA	0.485	0.538
12 MG 1.2E-03	1.2E-03		52 TE	0.077	0.085	92 U	0.503	0.549
13 AL 7.5E-04	7.5E-04		53 I	0.083	0.091	93 NP	0.518	0.562
14 SI 3.9E-04	3.7E-04		54 XE	0.088	0.096	94 PU	0.528	0.566
15 P 3.3E-04	3.1E-04		55 CS	0.094	0.104	95 AM	0.544	0.578
16 S 3.2E-04	2.6E-04		56 BA	0.100	0.111	96 CM	0.557	0.587
17 CL 3.5E-04	2.4E-04		57 LA	0.108	0.119	97 BK	0.566	0.594
18 AR 3.8E-04	2.2E-04		58 CE	0.114	0.127	98 CF	0.575	0.600
19 K 4.9E-04	2.7E-04		59 PR	0.121	0.135	99 ES	0.591	0.609
20 CA 6.1E-04	3.3E-04		60 ND	0.129	0.143	100 FM	0.602	0.618
21 SC 1.2E-03	8.4E-04		61 PM	0.135	0.152	101 MD	0.611	0.627
22 TI 1.8E-03	1.5E-03		62 SM	0.143	0.161	102 NO	0.619	0.637
23 V 2.9E-03	2.6E-03		63 EU	0.152	0.171	103 LR	0.627	0.645
24 CR 4.0E-03	3.7E-03		64 GD	0.160	0.181	104	0.635	0.655
25 MN 5.2E-03	5.0E-03		65 TB	0.169	0.191	105	0.643	0.663
26 PE 6.5E-03	6.3E-03		66 DY	0.180	0.203	106	0.652	0.671
27 CO 7.8E-03	7.7E-03		67 HO	0.190	0.215	107	0.661	0.681
28 NI 9.2E-03	8.9E-03		68 ER	0.201	0.227	108	0.678	0.689
29 CU 0.011	0.010		69 TM	0.210	0.239	109	0.689	0.694
30 ZN 0.012	0.011		70 YB	0.221	0.251	110	0.698	0.700
31 GA 0.013	0.012		71 LU	0.232	0.264			
32 GE 0.014	0.014		72 HF	0.243	0.277			
33 AS 0.015	0.015		73 TA	0.258	0.291			
34 SE 0.017	0.017		74 W	0.271	0.304			
35 BR 0.020	0.020		75 RE	0.284	0.318			
36 KR 0.022	0.022		76 OS	0.293	0.331			
37 RB 0.024	0.025		77 IR	0.305	0.345			
38 SR 0.026	0.027		78 PT	0.318	0.359			
39 Y 0.028	0.030		79 AU	0.330	0.373			
40 ZR 0.031	0.032		80 HG	0.345	0.387			
41 NB 0.034	0.036		81 TL	0.358	0.401			
42 MO 0.036	0.039		82 PB	0.372	0.415			
43 TC 0.040	0.043		83 BT	0.382	0.429			
44 RU 0.043	0.046		84 PO	0.396	0.444			
45 RH 0.046	0.050		85 AT	0.411	0.459			
46 PD 0.049	0.054		86 RN	0.422	0.474			
47 AG 0.053	0.059		87 FR	0.436	0.489			
48 CD 0.058	0.065		88 RA	0.448	0.503			
49 IN 0.062	0.070		89 AC	0.464	0.517			

^aNote: 1.2E-03 ≡ 1.2 × 10⁻³.

FIGURE 9. L_1 subshell effective fluorescence yield.FIGURE 10. L_2 subshell effective fluorescence yield.

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APPENDIX. Reference list

Listing comprises work subsequent to the reviews by Bambynek, et al. (1972), Burhop and Assad (1972) and Sevier (1972). Cut-off date October 1977.

Z Element	Data reported	Notes Expt.: Experiment Th.: Theory	Reference
3 Li	$\omega_K = 1.06(53) E-4$	Expt.; solid target	K. Feser, <i>Phys. Rev. Lett.</i> 29 , 901 (1972).
6 C	$\omega_K = 1.3(4) E-3$		
3 Li	$\Gamma(K) = 0.02 \text{ eV}$	Th.; many-body; from Auger rate	A. J. Glick and A. L. Hagen, <i>Phys. Rev. B15</i> , 1950 (1977)
11 Na	$\Gamma(L_{2,3}) = 0.02 \text{ eV}$		
4 Be	$\omega_K = 2.15 E-5$ $\omega_K - \text{partial}$	Th.; many-body	H. P. Kelly, <i>Phys. Rev. A9</i> , 1582 (1974).
4 Be	$\omega_K - \text{partial}$	Th.; many-body	F. Bely-Dubau, J. Dubau, and D. Petrini, <i>J. Phys. B10</i> , 1613 (1977)
4 Be	$\omega_K = 3.6(1.1) E-4$	Expt.; solid target	K. Feser, <i>Phys. Rev. Lett.</i> 28 , 1013 (1972).
5 B	$\omega_K = 5.7(1.7) E-4$		
4 Be	$\omega_K = 3.0(6) E-4$	Expt.; solid target	C. E. Dick and A. C. Lucas, <i>Phys. Rev. A2</i> , 580 (1970).
5 B	$\omega_K = 7.1(2.8) E-4$		
6 C	$\omega_K = 1.13(22) E-3$		
6 C	$\omega_K = 3.5(4) E-3$	Expt.; solid target	W. Hink and H. Paschke, <i>Phys. Rev. A4</i> , 507 (1971)
6 C	$\omega_K = 2.46(35) E-3$	Expt.; solid-gas combination	G. Bissinger, J. M. Joyce, and H. Kugel, <i>Phys. Rev. A14</i> , 1375 (1976).
6 C	$\omega_K = 2.2(2) E-3$	Expt.; solid-gas combination	A. Langenberg and J. Van Eck, <i>Phys. Rev. Lett.</i> 31 , 71 (1973)
6 C	$\omega_K = 1.5(7) E-3$	Expt.; CH ₄ ; gas target	L. H. Toburen, <i>Phys. Rev. A5</i> , 2482 (1972).
6 C	$\omega_K = 2.43(41) E-3$	Expt.; CH ₄	A. Langenberg and J. Van Eck, <i>J. Phys. B9</i> , 2421 (1976).
7 N	$\omega_K = 5.07(56) E-3$	N ₂	
10 Ne	$\omega_K = 0.018(2)$		
6 C	$\omega_K = 2.69(39) E-3$	Expt.; CH ₄	H. Tawara, K. G. Harrison, and F. J. de Heer, <i>Physica</i> 63 , 351 (1973)
7 N	$\omega_K = 4.73(68) E-3$	N ₂	
10 Ne	$\omega_K = 0.0155(22)$		
18 Ar	$\omega_K = 0.122(21)$		
10 Ne	$\Gamma_A = 0.22 \text{ eV}$	Th; many-body	H. P. Kelly, <i>Phys. Rev. A11</i> , 556 (1975).
10 Ne	$\omega_K - \text{partial}$	Th.	C. P. Bhalla, <i>Phys. Rev. A12</i> , 122 (1975).
10 Ne	$\omega_K = 0.016$	Th.; variation of ω_K with hole configurations	C. P. Bhalla, N. O. Folland, and M. A. Hein, <i>Phys. Rev. A8</i> , 649 (1973); C. P. Bhalla, <i>J. Phys. B8</i> , 1200; 2787; 2792 (1975).
10 Ne	$\omega_K = 0.0159$	Th.; Auger and radiative rates for KL ⁱ hole configurations with i = 0 to 6.	M. H. Chen and B. Crasemann, <i>Phys. Rev. A12</i> , 959 (1975).
10 Ne	$\omega_K = 0.018$	Expt.	N. Stolterfoht, D. Schneider, D. Burch, B. Aagard, E. Bøving, and B. Fastrup, <i>Phys. Rev. A12</i> , 1313 (1975).
10 Ne	$\omega_K = 0.017$	Expt.; variation of ω_K with hole configuration	D. Schneider, Diss.; Freie Univ. Berlin (1975); N. Stolterfoht, D. Schneider, and D. Burch, <i>Proc. IVth Int. Conf. on Atomic Physics</i> , Heidelberg (1974), p. 643.
10 Ne	$\Gamma(K) = 0.23(2) \text{ eV}$	Expt.; photoelectron	U. Gelius, <i>J. Electron Spectrosc.</i> 5 , 1985 (1974).
10 Ne	$\Gamma(K) = 0.21(2) \text{ eV}$	Expt.; Auger	N. Stolterfoht, <i>4th Conf. Application of Small Accelerators</i> . Publ. Nr. 76CH117-9 NTS; Denton, Texas, Oct. 1976.
10 Ne	$\Gamma(K) = 0.27(5) \text{ eV}$	Expt.; x-ray lines	H. Ågren, J. Nordgren, L. Selander, C. Nordling, and K. Siegbahn, <i>Physica Scripta</i> (to be published, 1977/78).
11 Na	$\Gamma(K) = 0.27 \text{ eV}$ $\Gamma(L_1) = 0.4 \text{ eV}$	Th.; Auger lines; free atom	H. Hillig, B. Cleff, W. Mehlhorn, and W. Schmitz, <i>Z. Physik</i> 268 , 225 (1974).
12 Mg	$\Gamma(K) = 0.30(5) \text{ eV}$ $\Gamma(L_1) = 0.7 \text{ eV}$	Expt.; Auger lines; free atom	B. Breuckmann and V. Schmidt, <i>Z. Physik</i> 268 , 235 (1974).
13 Al	$\Gamma(K) = 0.36(5)$	Expt.; x-ray lines; solid target	C. Senemaud, <i>Compt. Rend. (Paris)</i> , B265, 403 (1971); Thesis, Univ. Paris VI (1969).
14 Si	$\Gamma(L_1) = 0.6(1) \text{ eV}$	Expt.; x-ray lines; solid target	E. Zöpf, <i>Phys. Lett.</i> 48A , 105 (1974).
15 P	$\omega_K = 0.056(3)$	Expt.	A. Konstantinov and T. E. Sazonova, <i>Atlanta Conf. Proc.</i> (1973)*, p.158.
16 S	$\omega_K = 0.077(4)$		
15 P	$\omega_K = 0.061(3)$	Expt.	A. Molik, <i>Atlanta Conf. Proc.</i> (1973)*, p. 116.
16 S	$\omega_K = 0.082(3)$		

APPENDIX. Reference list - continued

Listing comprises work subsequent to the reviews by Bambynek, *et al.* (1972), Burhop and Assad (1972) and Sevier (1972). Cut-off date October 1977.

Z Element	Data reported	Notes Expt.: Experiment Th.: Theory	Reference
17 Cl	$\omega_K = 0.095(4)$ $\omega_K = 0.103(3)$ $\omega_K = 0.121(3)$		
18 Ar	$\Gamma(K) = 0.6(1)$ eV	Expt.; H_2S , referred to Ar $\Gamma(K) = 0.67$ eV	O. Keski-Rahkonen and M. O. Krause, <i>Phys. Rev. A15</i> , 959 (1977).
17 Cl	$\omega_{2,3} = 6.0(2.6) \times 10^{-4}$ $\omega_{2,3} = 4.9(2.4) \times 10^{-4}$	Expt.; HCl Cl_2	Th. P. Hoogkamer, F. W. Saris and F. J. de Heer, <i>J. Phys. B8</i> , L105 (1975).
18 Ar	$\omega_{2,3} = 4.2(1.2) \times 10^{-4}$		F. W. Saris and C. P. Bhalla, <i>J. Phys. B7</i> , L115 (1974).
18 Ar	$\omega_{2,3}$	Th.; variation with hole configuration	A. Langenberg, F. J. de Heer, and J. Van Eck, <i>J. Phys. B8</i> , 2079 (1975). N. Stolterfoht, F. J. de Heer, and J. Van Eck, <i>Phys. Rev. Lett.</i> , 30, 1159 (1973).
18 Ar	$\omega_{2,3} = 2.3(9) \times 10^{-4}$	Expt.; values of $\omega_{2,3}$ for different hole configurations	N. Stolterfoht, D. Schneider and P. Ziem, <i>Phys. Rev. A10</i> , 81 (1974).
18 Ar	$f_1 = 0.96(1)$	Expt.; Auger and Coster-Kronig spectra	F. P. Larkins, <i>J. Phys. B4</i> , L29 (1971).
18 Ar	$\omega_K = 0.130$ $\omega_{2,3} = 1.9 \times 10^{-4}$	Th.; variation with hole configuration	R. L. Cocke, R. R. Randall, S. L. Varghese, and B. Curnette, <i>Phys. Rev. A14</i> , 2026 (1976).
18 Ar	$\omega_K = 0.12$	Expt.; 30 MeV Cl^{+6} projectiles	C. P. Bhalla, <i>Phys. Rev. A8</i> , 2877 (1973).
18 Ar	$\omega_K = 0.120$	Th.; variation with hole configuration	M. H. Chen and B. Crasemann, <i>Phys. Rev. A10</i> , 2232 (1974).
18 Ar	$\omega_{2,3} = 1.48 \times 10^{-4}$	Th.; variation with hole configuration	M. O. Krause, <i>Phys. Rev. Lett.</i> 34, 633 (1975).
18 Ar	$\Gamma(K) = 0.77(10)$	Expt.; Auger; assuming $\Gamma(L_2 L_3) = 0.23$ eV	L. Asplund, P. Keilfle, B. Blomster, H. Siegbahn and K. Siegbahn, <i>Physica Scripta</i> (to be published 1977/78).
18 Ar	$\Gamma(K) = 0.69$ eV	Expt.; Auger; assuming $\Gamma(L_2 L_3) = 0.23$ eV	J. Nordgren, H. Ågren, C. Nordling and K. Siegbahn, <i>Physica Scripta</i> (to be published 1977/78).
18 Ar	$\Gamma(L_{2,3}) = 0.12$ eV $\Gamma(L_1) = 1.3$ eV	Expt.; x-ray lines	D. Ridder, J. Dieringer and N. Stolterfoht, <i>J. Phys. B9</i> , L307 (1976).
18 Ar	$\Gamma(L_{2,3}) = 0.10(2)$ eV	Expt.; Auger	T. Kondow, T. Kawai, K. Kunimori, T. Onishi, and K. Tamura, <i>J. Phys. B6</i> , L156 (1973).
18 Ar	$\Gamma(L_{2,3}) = 0.10(2)$	Expt.; Auger	P. L. Lee and S. I. Salem, <i>Phys. Rev. A10</i> , 2027 (1974).
23-32	$\Gamma(K\alpha_1)$ and $\Gamma(K\alpha_2)$ $\omega_2; \omega_3$	Expt. Semi-empirical	A. A. Konstantinov, T. E. Sazonova, and A. Konstantinov, <i>Atlanta Conf. Proc.</i> (1973)*, p. 144.
24 Cr	$\omega_K = 0.267(4)$	Expt.	A. Mukerji and L. Chin, <i>Atlanta Conf. Proc.</i> (1973)*, p. 164
24 Cr	$\omega_K = 0.284(10)$	Expt.	
25 Fe	$\omega_K = 0.358(18)$		
30 Zn	$\omega_K = 0.442(11)$		
25 Mn	$\omega_K = 0.322(5)$	Expt.	Lj. Dobrilović, Dj. Bek-Uzarov, M. Simović, K. Burai, and A. Milojević, <i>Atlanta Conf. Proc.</i> (1973)*, p. 128.
26-94	$\omega_2; f_{2,3}$	Th.	M. H. Chen and B. Crasemann, <i>Atlanta Conf. Proc.</i> (1973)*, p. 43.
27 Co	$L_{2,3}$ Auger spectra	Expt.; $L_3 3d3d/L_2 3d3d$ intensity ratios in solids	J. A. D. Matthew, J. D. Nuttall, and T. E. Gallon, <i>J. Phys. C9</i> , 883 (1976).
28 Ni			
29 Cu			
30 Zn			
29 Cu	$\Gamma(L_2) = 0.98(4)$ eV $\Gamma(L_3) = 0.54(3)$ eV	Expt.; Auger and photo-electron; solid target	Lo I. Yin, I. Adler, M. H. Chen and B. Crasemann, <i>Phys. Rev. A7</i> , 897 (1973).
30 Zn	$\Gamma(L_2) = 0.84(4)$ eV $\Gamma(L_3) = 0.66(3)$ eV		
29-31	$\Gamma(L_{2,3}); \Gamma_{CK}, \omega_3$	Th.; variation with Coster-Kronig transition cut-offs	E. Antonides, E. C. Janse, and G. A. Sawatzki, <i>Phys. Rev. B15</i> , 1669 and 4569 (1977).
29-32	Γ (Auger lines) Γ (photolines)	Expt.; Coster-Kronig transition cut-offs; Auger satellites	P. Weightman, J. F. McGilp and C. E. Johnson, <i>J. Phys. C9</i> , L585 (1976).
30 Zn	$\Gamma(L_2) = 0.47(5)$ eV $\Gamma(L_3) = 0.33(5)$ eV	Expt.; photo-electron; solid target	

APPENDIX. Reference list - continued

listing comprises work subsequent to the reviews by Bambynek, *et al.* (1972), Burhop and Assad (1972) and Sevier (1972). Cut-off date October 1977.

Z Element	Data reported	Notes Expt.; Experiment Th.; Theory	Reference
30 Zn	$\Gamma(L_2) - \Gamma(L_3) = 0.19$ eV $\Gamma(L_2) - \Gamma(L_3) = 0.04$ eV	Expt.; Auger spectra, solid metallic target dto.; ZnO	E. Antonides and G. A. Sawatzky, <i>J. Phys. C9</i> , L547 (1976).
30 Zn	$\Gamma(L_2) = \Gamma(L_3)$	Expt.; photo-electron; solid target	L. Ley, S. P. Kowalczyk, F. R. McFeely, R. A. Pollak, and D. A. Shirley, <i>Phys. Rev. B8</i> , 2392 (1973).
30 Zn	$\Gamma(L_2) = \Gamma(L_3)$	Expt.; photo-electron; free atom	M. S. Banna, D. C. Frost, C. A. McDowell, and B. Walbank, <i>J. Chem. Phys.</i> (1978).
30 Zn	$\Gamma(L_{2,3}) = 0.50(15)$ eV $\Gamma(L_2) = \Gamma(L_3)$	Expt.; Auger; free atom	S. Aksela, J. Väyrynen, and H. Aksela, <i>Phys. Rev. Lett.</i> 33 , 999 (1974).
31 Ga	$\omega_K = 0.529(2)$	Expt.	A. Molijk, <i>Atlanta Conf. Proc.</i> (1973)*, p. 116.
32 Ge	$\omega_K = 0.570(3)$		
33 As	$\omega_K = 0.588(6)$		
32 Ge	$\omega_K = 0.561(15)$	Expt.	W. Hartl and J. W. Hammer, <i>Z. Physik</i> A279 , 135 (1976).
33 As	$\omega_K = 0.589(27)$	Expt.; AsH ₃	W. M. Chew, J. C. McGeorge, and R. W. Fink, <i>Atlanta Conf. Proc.</i> (1973)*, p. 197
25-43	ω_K	Comparison between Expt. and Th.	
36 Kr	$\Gamma(L_2) = 1.3$ eV $\Gamma(L_3) = 1.2$ eV	Expt.; x-ray absorption	F. Wuilleumier, <i>J. Phys. (Paris)</i> 32 , C4-88 (1971);
37-56	L x-ray spectra	Expt.; Coster-Kronig transition cut-offs near Z = 40 and 50	B. L. Doyle and S. M. Shafrroth in <i>2nd Int. Conf. on Inner Shell Ionization Phenomena</i> , Abstract, Freiburg (1976), p. 211; and to be published (1978).
40 Zr	$\Gamma(L_1) = 4(1)$ eV $\Gamma(L_2) = 1.9(3)$ eV $\Gamma(L_3) = 1.6(3)$ eV	Expt.; semi-empirical deduced from x-ray line widths and spectral features	M. O. Krause, F. Wuilleumier, and C. W. Nestor, Jr., <i>Phys. Rev. A6</i> , 871 (1972).
41 Nb	$\Gamma(L\beta_3) = 10.5(5)$ eV $\Gamma(L\beta_4) = 11-13$ eV $\Gamma(L\gamma_1) = 7$ eV	Expt.; x-ray lines	M. K. Bahl and A. S. Košter, <i>J. Phys. C</i> 8 , 1776 (1975).
47 Ag	$\Gamma(L_1) \approx 3.9$ eV	Semi-empirical; deduced from x-ray spectrum	M. H. Chen, B. Crasemann, M. Aayagi and H. Mark, <i>Phys. Rev. A15</i> , 2312 (1977).
47 Ag	$\omega_K = 0.834(17)$	Expt.	B. Fischer and K. W. Hoffman, <i>Z. Physik</i> A277 , 317 (1976).
51 Sb	$\omega_K = 0.868(14)$		
47 Ag	$\omega_1 = 0.034(3)$ $\omega_2 = 0.051(5)$ $\omega_3 = 0.035(4)$	Expt.	B. Budick and S. Derman, <i>Phys. Rev. Lett.</i> 29 , 1055 (1972).
52 Te	$\omega_1 = 0.062(6)$ $\omega_2 = 0.071(7)$ $\omega_3 = 0.056(6)$		
50 Sn	$\omega_K = 0.857(10)$	Expt.	M. Hribar, A. Kodre, J. Pahor, and V. Stare, <i>Z. Physik A</i> 275 , 323 (1975).
50-100	$\omega_3; \omega_2; f_{2,3}$	Compilation and comparison between Expt. and Th.	J. C. McGeorge, <i>Atlanta Conf. Proc.</i> (1973)*, p. 175
51 Sb	$\omega_K = 0.873(10)$	Expt.	M. Hribar, A. Kodre, and J. Pahor, <i>Z. Physik</i> A272 , 413 (1975).
54 Xe	$\omega_K = 0.889(10)$	Expt.	M. Hribar, A. Kodre, and J. Pahor, <i>Z. Physik</i> A280 , 227 (1977)
54 Xe	$\omega_3 = 0.099(2)$ $v_1 = 0.09(3)$ $v_2 = 0.106(7)$	Expt.	M. Hribar, A. Kodre, and J. Pahor, <i>Physica</i> 92C , 143 (1977).
37 La	$\omega_2 = 0.112(9)$ $\omega_3 = 0.092(8)$ $f_{2,3} = 0.21(2)$	Expt.	D. G. Douglas, <i>Can. J. Phys.</i> 51 , 1519 (1973).
58-74	$\Gamma(L$ x rays)	Expt.	S. I. Salem and P. L. Lee, <i>Phys. Rev. A10</i> , 2033 (1974).
63 Eu	$\omega_1 = 0.06(2)$ $f_{1,2} = 0.26(10)$ $f_{1,3} = 0.27(3)$ $v_1 = 0.138(7)$	Expt.	V. R. Veluri and P. V. Rao, <i>Z. Physik</i> A280 , 317 (1977).
63 Eu	$f_{2,3} = 0.172(15)$	Expt.	M. R. Zalutsky and E. S. Macias, <i>Phys. Rev. A11</i> , 71 (1975).

APPENDIX. Reference list - continued

Listing comprises work subsequent to the reviews by Bambynek, *et al.* (1972), Burhop and Assad (1972) and Sevier (1972). Cut-off date October 1977.

Z Element	Data reported	Notes Expt.: Experiment Th.: Theory	Reference
64 Gd	$\omega_2 = 0.182(8)$ $\omega_3 = 0.187(6)$ $f_{2,3} = 0.223(11)$	Expt.	D. G. Douglas, <i>Can. J. Phys.</i> 50, 1697 (1972).
67 Ho	$f_{2,3} = 0.143(10)$	Expt.	D. G. Douglas, <i>Can. J. Phys.</i> 54, 1124 (1976).
69 Tm	$f_{2,3} = 0.148(7)$		
70 Yb	$\omega_1 = 0.126(10);$ $f_{1,2} = 0.16(3);$ $f_{1,3} = 0.297(20)$	Expt.	L. A. McNelles, J. L. Campbell, J. S. Geiger, R. L. Graham, and L. S. Merritt, <i>Can. J. Phys.</i> 53, 1349 (1975).
63 Eu	$f_{2,3} = 0.129(19)$	Expt.; compilation of previous data for $f_{2,3}$	V. R. Veluri, R. E. Wood, J. M. Palms and V. P. Rao, <i>J. Phys.</i> B7, 1486 (1974).
65 Tb	$f_{2,3} = 0.130(11)$		
73 Ta	$f_{2,3} = 0.125(8)$		
80 Hg	$f_{2,3} = 0.134(11)$		
	$f_{2,3} = 0.128(8)$		
81 Tl	$f_{2,3} = 0.113(11)$ $\omega_2 = 0.239(7);$ $f_{2,3} = 0.130(10);$ $\nu_1 = 0.235(8)$ $\omega_3 = 0.220(7);$ $\nu_2 = 0.267(8)$	Expt.	
73 Ta	$\omega_3 = 0.235(18);$ $\nu_1 = 0.271(25)$	Expt.; on yields in L double-hole configuration.	J. L. Campbell, L. A. McNelles, J. S. Geiger, L. S. Merritt and R. L. Graham, <i>Can. J. Phys.</i> 55, 868 (1977).
74 W	$\omega_1 = 0.106(23)$ $f_{1,2} = 0.260(63)$	Expt.	L. Saigueiro, M. T. Ramos, M. L. Escrivao, M. C. Martins, and J. G. Ferreira, <i>J. Phys.</i> B7, 342 (1974).
75 Re	$\omega_1 = 0.095(20)$ $f_{1,2} = 0.286(70)$		
77 Ir	$\omega_1 = 0.096(20)$ $f_{1,2} = 0.157(35)$		
79 Au	$\omega_1 = 0.098(20)$ $f_{1,2} = 0.207(51)$		
90 Th	$\omega_1 = 0.108(22)$ $f_{1,2} = 0.086(20)$		
76 Os	$\omega_2 = 0.300(22)$ $\omega_3 = 0.301(20)$ $f_{2,3} = 0.106(23)$	Expt.	S. Mohan, W. D. Schmidt-Ott, J. C. McGeorge and R. W. Fink, <i>Atlanta Conf. Proc.</i> (1973)*, p. 244.
78 Pt	$\omega_2 = 0.318(22)$ $\omega_3 = 0.309(20)$ $f_{2,3} = 0.126(21)$		
78 Pt	$\omega_K = 0.967(8)$	Expt.	J. S. Hansen, J. C. McGeorge, R. W. Fink, R. E. Wood, P. V. Rao, and J. M. Palms, <i>Z. Physik</i> 249, 373 (1972).
82 Pb	$\omega_K = 0.972(8)$		
92 U	$\omega_K = 0.970(5)$		
80 Hg	$f_{2,3} = 0.123(12)$	Expt.	D. W. Nix and R. W. Fink, <i>Z. Physik</i> A273, 305 (1975).
81 Tl	$f_{2,3} = 0.109(11)$		
82 Pb	$f_{2,3} = 0.105(11)$		
92 U	$f_{2,3} = 0.146(18)$		
63-96	$f_{2,3}$	Selected best values	
82 Pb	$f_{2,3} = 0.156(10)$	Expt.	R. E. Wood, J. M. Palms, P. V. Rao, <i>Phys. Rev.</i> A5, 11 (1972).
83 Bi	$\omega_2 = 0.35(3)$ $f_{2,3} = 0.18(7)$ $a_2 = 0.46(8)$ $\omega_3 = 0.33(2)$ $a_3 = 0.67(2)$ $\nu_2 = 0.41(3)$	Expt.	A. Maio, J. P. Ribeiro, A. Barroso, and F. B. Gil, <i>J. Phys.</i> B8, 1216 (1975).
83 Bi	$\omega_1 = 0.118(11)$	Expt.	M. Weksler and A. G. de Pinho, <i>Rev. Bras. de Fisica</i> , 3, 291 (1973).
93 Np	$\omega_1 = 0.196(20)$ $f_{1,3} = 0.014(3)$		
86 Rn	$\omega_2 = 0.459(25)$ $\omega_3 = 0.384(20)$ $f_{2,3} = 0.105(11)$ $\nu_2 = 0.498(28)$	Expt.	J. C. McGeorge, D. W. Nix and R. W. Fink, <i>J. Phys.</i> B6, 573 (1973).

APPENDIX. Reference list - continued

Listing comprises work subsequent to the reviews by Bambynek, *et al.* (1972), Burhop and Assad (1972) and Sevier (1972). Cut-off date October 1977.

Z Element	Data reported	Notes Expt.: Experiment Th.: Theory	Reference
88 Ra	$\omega_2 = 0.493(30)$ $\omega_3 = 0.408(27)$ $f_{2,3} = 0.053(26)$ $\nu_2 = 0.516(36)$		
94 Pu	$\omega_2 = 0.513(22)$ $\omega_3 = 0.509(29)$ $f_{2,3} = 0.226(16)$ $\nu_2 = 0.627(36)$		
96 Cm	$f_{2,3} = 0.188(10)$		
88 Ra	$\omega_2 = 0.415(27)$ $f_{2,3} = 0.01(7)$ $a_2 = 0.571(84)$	Expt.	F. B. Gil, A. Barroso, J. C. Soares, and J. G. Ferreira, <i>Phys. Rev. A5</i> , 536 (1972).
92 U	$\omega_2 = 0.423(23)$ $f_{2,3} = 0.07(5)$ $a_2 = 0.522(56)$		
88 Ra	$\omega_2 = 0.498(27)$ $\omega_3 = 0.438(22)$ $f_{2,3} = 0.102(6)$	Expt.	J. L. Campbell, L. A. McNelles, J. S. Geiger, R. L. Graham and J. S. Merritt, <i>Can. J. Phys. 52</i> , 488 (1974).
94 Pu	$\omega_2 = 0.485(26)$ $\omega_3 = 0.484(17)$ $f_{2,3} = 0.229(4)$		
90 Th	$\omega_2 = 0.44(3)$	Expt.	J. G. Ferreira, J. C. Soares, A. Barroso, and F. B. Gil, <i>J. Phys. A4</i> , 679 (1971).
92 U	$\omega_2 = 0.560(33)$ $f_{2,3} = 0.147(10)$ $\omega_3 = 0.481(29)$ $\nu_1 = 0.54(4)$ $\nu_2 = 0.630(36)$	Expt.	J. C. McGeorge, D. W. Nix, and R. W. Fink, <i>Z. Physik</i> , 255, 335 (1972)
92 U	$f_{2,3} \approx 0.14$	Expt.; test of onset of Coster-Kronig transitions near $Z = 92$	K. R. Baker, F. Tolea, R. W. Fink, and J. J. Pinajian, <i>Z. Physik</i> 270, 9 (1974).
94 Pu	$f_{2,3} = 0.24$		
94 Pu	$\omega_2 = 0.42(2)$ $f_{2,3} = 0.21(8)$ $a_2 = 0.37(8)$	Expt.	J. Byrne, R. J. D. Beattie, S. Benda, and J. Collingwood, <i>J. Phys. B3</i> , 1166 (1970).
93 Np	$\omega_K = 0.971(5)$	Expt.	I. Ahmad, R. K. Sjoblom, <i>US-ERDA CONF-760539</i> (1976), p. 249
94 Pu	$\omega_K = 0.973(5)$		
96 Cm	$\omega_K = 0.972(7)$		
98 Cf	$\omega_K = 0.972(5)$		
99 Es	$\omega_K = 0.971(5)$		
94 Pu	$f_{2,3} = 0.233(15)$	Expt.	M. R. Zalutsky and E. S. Macias, <i>Phys. Rev. A11</i> , 71 (1975).
96 Cm	$f_{2,3} = 0.226(17)$		
95 Am	$f_{1,2} = 0.16(3)$	Expt. (preliminary); data are averages for indicated elements	M. S. Freedman and F. T. Porter, <i>Atlanta Conf. Proc. (1973)*</i> , p. 680.
98 Cf	$f_{1,3} = 0.63(7)$		
100 Fm	$f_{2,3} = 0.18(4)$		
96 Cm	$\omega_1 = 0.25(6)$ $f_{1,2} \leq 0.10$ $f_{1,3} = 0.69(8)$ $f_{1,3} = 0.015(4)$	Expt.	J. C. McGeorge and R. W. Fink, <i>Z. Physik</i> , 250, 293 (1972).
96 Cm	$f_{2,3} = 0.209(22)$	Expt.	D. W. Nix and R. W. Fink, <i>Z. Physik</i> A278, 234 (1976).
98 Cf	$\omega_K = 0.976(5)$	Expt.	M. S. Freedman, I. Ahmad, F. T. Porter, R. K. Sjoblom, R. F. Barnes, J. Lerner, and P. R. Fields, <i>Phys. Rev. C15</i> , 760 (1977).

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