Title

SOME USEFUL TABLES FOR NUCLEAR SPECTROSCOPY IN TRANSMERCURY GROUP OF ELEMENTS: ELECTRON BINDING ENERGIES, X-RAY ENERGIES, AUGER ELECTRON ENERGIES AND FLUORESCENT YIELDS

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TABLE 1: BINDING ENERGIES OF ELECTRONS IN ELEMENTS 80-104
(Prepared with assistance of H. M. Blann)

Gamma ray transition energies are frequently determined by measurement of the energy of conversion electrons. In order to calculate the energy of the transition from such data, it is necessary to know the energies required to remove electrons from the various shells and sub-shells of the atom in which the conversion occurs. We present here a table of electron energies for the elements 80-104. The term critical X-ray absorption energies is also applied to these energy values since the absorption of an X-ray as a function of its energy undergoes a sharp increase as its energy just exceeds the value required to remove an electron from the atom.

HILL, CHURCH, AND MIHELICH[1] correlated data published to 1952 and constructed a useful table of these critical X-ray absorption energies for elements 3 to 100. In our table we have used the HILL, CHURCH, AND MIHELICH values for mercury (80), thallium (81), lead (82), bismuth (83), and thorium (90). Two choices of K-energies are given for the elements above iridium in the HILL, CHURCH, AND MIHELICH tables based on two discrepant values for the K-energy of uranium. Later work by several

1. R. D. Hill, E. L. Church, and J. W. Mihelich, Review. Sci. Inst. 23, 523 (1952); also reprinted as Appendix VI in "Beta and Gamma Spectroscopy," edited by Kai Siegbahn, North Holland Publishing Company, Amsterdam, 1955.

authors[3, 6] has clearly established that the values based on a uranium K-electron energy of 115.591 kev[2] are the more accurate. In our table we have used the values of MERRILL[4, 5] for the L, M, N, and O electron energies of uranium (92), neptunium (93), plutonium (94), and americium (95) with the exception that the N_{VI} and N_{VII} values are taken from HILL, CHURCH, AND MIHELICH.[1] The K-value for plutonium is taken to be 121.76 kev by combining the KL_I binding energy difference reported by EWAN, GEIGER, GRAHAM, AND MACKENZIE[6] with the L_I binding energy of 23.095 reported by MERRILL[4]. All other values in our table were obtained by interpolation or extrapolation of linear plots of the square roots of the appropriate energy values. Uncertainty in the final digit or pair of digits is indicated by raised numerals.

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2. Y. Cauchois, J. Phys. et Radium 13, 113, 1952.

3. J. M. Hollander, W. Smith, and J. W. Mihelich, Phys. Rev. 102, 740 (1956).

4. J. J. Merrill, Ph.D. Thesis, "Precision Measurement of X-Ray Spectra with Application to the L X-Ray Spectra of Uranium, Neptunium, Plutonium, and Americium," California Institute of Technology (1960).

5. J. J. Merrill and J. W. M. Du Mond, "Precision Measurement of the L X-Ray Spectra of Uranium and Plutonium," Phys. Rev. 110, 79 (1958).

6. Ewan, Geiger, Graham, and MacKenzie, Phys. Rev. 116, 950 (1959).

TABLE 1. ELECTRON BINDING ENERGIES FOR ELEMENTS 80 - 104 (IN KEV)

	K	L_I	L_{II}	L_{III}	M_I	M_{II}	M_{III}	M_{IV}	M_V
80 Hg	83.1^{06}	*$14.^{84}$	*14.21	*12.27	*3.56	*3.2^{8}	*2.8^{5}	*2.3^{8}	*2.29
81 Tl	85.5^{17}	15.3^{44}	14.6^{95}	12.6^{53}	3.7^{01}	3.4^{13}	2.9^{51}	2.4^{80}	2.3^{84}
82 Pb	88.0^{01}	15.8^{61}	15.2^{00}	13.0^{33}	3.8^{52}	3.5^{58}	3.0^{67}	2.5^{84}	2.4^{82}
83 Bi	90.5^{21}	16.3^{86}	15.7^{09}	13.4^{17}	4.0^{00}	3.6^{95}	3.1^{77}	2.6^{88}	2.5^{78}
84 Po	*93.2^{1}	*16.9^{3}	*16.2^{3}	*13.8^{1}	*4.1^{5}	*3.8^{4}	*3.29	*2.7^{9}	*2.6^{8}
85 At	*95.8^{4}	*17.4^{8}	*16.7^{8}	*14.2^{1}	*4.3^{1}	*4.0^{0}	*3.41	*2.9^{0}	*2.7^{8}
86 Em	*98.5^{2}	*18.0^{5}	*17.3^{3}	*14.6^{1}	*4.4^{8}	*4.1^{5}	*3.53	*3.0^{1}	*2.8^{8}
87 Fr	*101.2^{3}	*18.6^{3}	*17.8^{9}	*15.0^{2}	*4.6^{4}	*4.3^{1}	*3.66	*3.1^{3}	*$2.^{99}$
88 Ra	*103.9^{8}	*19.2^{3}	*18.4^{7}	*15.4^{4}	*4.8^{1}	*4.4^{7}	*3.78	*3.2^{4}	*3.0^{9}
89 Ac	*106.7^{6}	*19.8^{4}	*19.0^{7}	*15.8^{6}	*4.9^{9}	*4.6^{4}	*3.91	*3.3^{6}	*3.2^{0}
90 Th	109.6^{30}	20.4^{52}	19.6^{73}	16.2^{78}	5.1^{63}	4.8^{10}	4.0^{25}	3.4^{69}	3.3^{10}
91 Pa	*112.6^{0}	*21.1^{1}	*20.2^{9}	*16.71	*5.3^{6}	*5.00	*4.1^{6}	*3.6^{0}	*3.4^{3}
92 U	115.5^{91}	21.75^{7}	20.94^{8}	17.16^{7}	5.54^{9}	5.18^{3}	4.30^{3}	3.72^{8}	3.55^{2}
93 Np	*118.6^{6}	22.41^{4}	21.59^{6}	17.60^{6}	5.72^{4}	5.35^{4}	4.42^{2}	3.84^{7}	3.66^{6}
94 Pu	121.7^{6}	23.09^{5}	22.26^{3}	18.05^{3}	5.91^{4}	5.54^{0}	4.55^{5}	3.96^{9}	3.77^{4}
95 Am	†$124.^{9}$	23.79^{2}	22.94^{3}	18.50^{3}	6.11^{4}	5.73^{0}	4.68^{7}	4.09^{2}	3.88^{6}
96 Cm	†$128.^{1}$	†24.5^{0}	†23.6^{2}	†18.9^{6}	†6.2^{5}	†5.87	†4.8^{6}	†4.2^{2}	†4.0^{0}
97 Bk	†$131.^{3}$	†25.2^{0}	†24.3^{0}	†19.4^{5}	†6.4^{5}	†6.0^{5}	†5.0^{2}	†4.3^{5}	†4.1^{4}
98 Cf	†$134.^{5}$	†25.9^{0}	†25.0^{5}	†19.9^{2}	†6.6^{6}	†6.2^{2}	†5.1^{5}	†4.4^{9}	†4.2^{6}
99 E	†$137.^{8}$	†26.6^{3}	†25.7^{5}	†20.4^{2}	†6.8^{4}	†6.4^{0}	†5.3^{0}	†4.6^{2}	†4.4^{1}
100 Fm	†$141.^{1}$	†27.3^{5}	†26.4^{7}	†20.8^{8}	†7.0^{2}	†6.6^{0}	†5.4^{8}	†4.7^{5}	†4.5^{4}
101 Mv	†$145.^{5}$	†28.1^{1}	†27.2^{1}	†21.3^{4}	†7.2^{4}	†6.7^{8}	†5.6^{2}	†4.8^{8}	†4.6^{7}
102	†$147.^{9}$	†28.8^{4}	†27.9^{8}	†21.8^{5}	†7.4^{2}	†6.9^{7}	†5.7^{8}	†5.0^{4}	†4.8^{0}
103 Lw	†$151.^{4}$	†29.6^{4}	†28.7^{3}	†22.3^{7}	†7.6^{4}	†7.1^{8}	†5.9^{5}	†5.1^{7}	†4.9^{3}
104	†$154.^{9}$	†30.4^{2}	†29.4^{8}	†22.8^{5}	†7.8^{4}	†7.3^{7}	†6.1^{0}	†5.3^{4}	†5.0^{8}

* Interpolated

† Extrapolated

TABLE 1. ELECTRON BINDING ENERGIES FOR ELEMENTS 80 - 104 (IN KEV) (continued)

		N_I	N_{II}	N_{III}	N_{IV}	N_V	N_{VI}	N_{VII}
80	Hg	* $.7^{99}$	* $.6^{77}$	* $.5^{72}$	* $.3^{76}$	* $.3^{58}$	* $.1^{00}$	* $.0^{96}$
81	Tl	$.8^{42}$	$.7^{17}$	$.6^{05}$	$.4^{03}$	$.3^{81}$	$.1^{18}$	$.1^{14}$
82	Pb	$.8^{93}$	$.7^{60}$	$.6^{42}$	$.4^{37}$	$.4^{14}$	$.1^{43}$	$.1^{36}$
83	Bi	$.9^{38}$	$.8^{05}$	$.6^{76}$	$.4^{64}$	$.4^{40}$	$.1^{62}$	$.1^{56}$
84	Po	* $.9^{90}$	* $.8^{48}$	* $.7^{12}$	* $.4^{93}$	* $.4^{68}$	* $.1^{81}$	* $.1^{76}$
85	At	*1.0^{4}	* $.8^{95}$	* $.7^{48}$	* $.5^{26}$	* $.4^{97}$	* $.2^{02}$	* $.1^{95}$
86	Em	*1.0^{9}	* $.9^{43}$	* $.7^{87}$	* $.5^{58}$	* $.5^{29}$	* $.2^{24}$	* $.2^{17}$
87	Fr	*1.1^{4}	* $.9^{92}$	* $.8^{26}$	* $.5^{91}$	* $.5^{61}$	* $.2^{46}$	* $.2^{40}$
88	Ra	*1.2^{0}	*1.0^{4}	* $.8^{67}$	* $.6^{27}$	* $.5^{93}$	* $.2^{70}$	* $.2^{64}$
89	Ac	*1.2^{5}	*1.1^{0}	* $.9^{08}$	* $.6^{63}$	* $.6^{27}$	* $.2^{96}$	* $.2^{88}$
90	Th	1.3^{06}	1.1^{47}	$.9^{44}$	$.6^{92}$	$.6^{56}$	$.3^{22}$	$.3^{15}$
91	Pa	*1.3^{7}	*1.21	*1.0^{0}	* $.7^{38}$	* $.7^{00}$	* $.3^{53}$	* $.3^{43}$
92	U	1.44^{1}	1.27^{3}	1.04^{5}	$.78^{1}$	$.73^{9}$	$.3^{87}$	$.3^{75}$
93	Np	1.49^{0}	1.31^{8}	1.07^{6}	$.81^{2}$	$.76^{8}$		
94	Pu	1.55^{5}	1.37^{1}	1.11^{4}	$.84^{6}$	$.79^{8}$		
95	Am	1.61^{7}	1.42^{9}	1.15^{4}	$.87^{9}$	$.82^{7}$		
96	Cm	†1.6^{8}	†1.4^{6}	†1.1^{9}	† $.9^{12}$	† $.8^{56}$		
97	Bk	†1.7^{4}	†1.5^{1}	†1.2^{3}	† $.9^{48}$	† $.8^{88}$		
98	Cf	†1.8^{1}	†1.5^{7}	†1.2^{7}	† $.9^{80}$	† $.9^{18}$		
99	E	†1.8^{8}	†1.6^{2}	†1.3^{0}	†1.0^{2}	† $.9^{49}$		
100	Fm	†1.9^{5}	†1.6^{9}	†1.3^{5}	†1.0^{6}	† $.9^{86}$		
101	Mv	†2.0^{2}	†1.7^{4}	†1.3^{8}	†1.0^{9}	†1.0^{2}		
102		†2.0^{7}	†1.8^{0}	†1.4^{2}	†1.1^{3}	†1.0^{5}		
103	Lw	†2.1^{6}	†1.8^{5}	†1.4^{6}	†1.1^{7}	†1.0^{9}		
104		†2.2^{2}	†1.9^{1}	†1.5^{0}	†1.2^{1}	†1.1^{2}		

* Interpolated

† Extrapolated

TABLE 1. ELECTRON BINDING ENERGIES FOR ELEMENTS 80 - 104 (IN KEV) (continued)

		O_I	O_{II}	O_{III}	O_{IV}	O_V
80	Hg	* $.1^{16}$	$.0^{88}$(.063)			
81	Tl	$.1^{26}$	† $.0^{99}$(.072)			
82	Pb	$.1^{48}$	† $.1^{10}$(.087)		(.022)	
83	Bi	$.1^{57}$	$.1^{19}$	.092	(.024)	
84	Po	* $.1^{71}$	* $.1^{35}$	* $.1^{11}$	*(.029)	
85	At	* $.1^{85}$	* $.1^{47}$	* $.1^{18}$	*(.035)	
86	Em	* $.2^{00}$	* $.1^{61}$	* $.1^{25}$	*(.041)	
87	Fr	* $.2^{15}$	* $.1^{75}$	* $.1^{32}$	*(.047)	
88	Ra	* $.2^{32}$	* $.1^{90}$	* $.1^{40}$	*(.054)	
89	Ac	* $.2^{49}$	* $.2^{04}$	* $.1^{48}$	*(.062)	
90	Th	$.2^{66}$	$.2^{12}$	$.1^{56}$	($.0^{69}$)	
91	Pa	* $.2^{94}$	* $.2^{37}$	* .175	(.082)	
92	U	$.32^{2}$	$.26^{0}$	$.19^{5}$	$.10^{6}$	$.09^{7}$
93	Np	$.34^{0}$	$.27^{5}$	$.19^{6}$	$.10^{8}$	$.09^{8}$
94	Pu	$.36^{0}$	$.29^{2}$	$.20^{2}$	$.11^{3}$	$.10^{3}$
95	Am	$.37^{8}$	$.30^{9}$	$.20^{7}$	$.11^{6}$	$.10^{5}$
96	Cm	† $.3^{98}$	† $.3^{13}$			
97	Bk	† $.4^{20}$	† $.3^{31}$			
98	Cf	† $.4^{41}$	† $.3^{53}$			
99	E	† $.4^{62}$				
100	Fm	† $.4^{84}$				
101	Mv	† $.5^{06}$				
102						
103						
104						

* Interpolated
† Extrapolated

TABLE 2. K AND L X-RAY ENERGIES FOR ELEMENTS 81 - 104

Transition	X-ray	Tl	Pb	Bi	Po	At	Em	Fr	Ra
KL_{II}	$K\alpha_2$	70.82	72.80	74.81	76.98	79.06	81.19	83.34	85.51
KL_{III}	$K\alpha_1$	72.86	74.92	77.10	79.40	81.63	83.91	86.21	88.54
KM_{II}	$K\beta_1$	82.10	84.44	86.83	89.37	91.84	94.37	96.92	99.51
KM_{III}	$K\beta_3$	82.57	84.93	86.34	89.92	92.43	94.99	97.57	100.20
KN_{II}	$K\beta_2$	84.80	87.24	89.72	92.36	94.94	97.58	100.18	102.94
KN_{III}	$K\beta_2$	84.91	87.36	89.85	92.50	95.09	97.73	100.34	103.11
L_IM_{II}	$L\beta_4$	11.93	12.30	12.69	13.09	13.48	13.90	14.32	14.76
L_IM_{III}	$L\beta_3$	12.39	12.79	13.21	13.64	14.07	14.52	14.97	15.55
L_IN_{II}	$L\gamma_2$	14.63	15.10	15.58	16.08	16.58	17.11	17.64	18.19
L_IN_{III}	$L\gamma_3$	14.74	15.22	15.71	16.22	16.63	17.27	17.80	18.36
L_IO_{II}	$L\gamma_4$	-	-	16.27	16.80	17.34	17.90	18.46	19.05
L_IO_{III}	$L\gamma_4$	-	-	16.29	16.82	17.36	17.93	18.50	19.09
$L_{II}M_I$	$L\eta$	10.99	11.35	11.71	12.08	12.47	12.85	13.25	13.66
$L_{II}N_I$	$L\gamma_5$	13.85	14.31	14.77	15.24	15.74	16.24	16.75	17.27
$L_{II}O_I$	$L\gamma_8$	14.57	15.05	15.55	16.06	15.59	17.13	17.67	18.24
$L_{II}M_{IV}$	$L\beta_1$	12.22	12.62	13.02	13.44	13.88	14.32	14.76	15.23
$L_{II}N_{IV}$	$L\gamma_1$	14.29	14.76	15.25	15.74	16.25	16.77	17.30	17.84
$L_{II}O_{IV}$	$L\gamma_6$	-	15.18	15.69	16.20	16.75	17.29	17.84	18.42
$L_{III}M_I$	$L\ell$	8.95	9.18	9.42	9.66	9.90	10.13	10.38	10.63
$L_{III}N_I$	$L\beta_6$	11.81	12.14	12.48	12.82	13.17	13.52	13.88	14.24
$L_{III}O_I$	$L\beta_7$	12.53	12.89	13.26	13.64	14.03	14.41	14.81	15.21
$L_{III}M_{IV}$	$L\alpha_2$	10.17	10.45	10.73	11.02	11.31	11.60	11.89	12.20
$L_{III}M_V$	$L\alpha_1$	10.27	10.55	10.84	11.13	11.43	11.73	12.03	12.35
$L_{III}N_{IV}$	$L\beta_{15}$	12.25	12.60	12.95	13.32	13.68	14.05	14.43	14.81
$L_{III}N_V$	$L\beta_2$	12.27	12.62	12.98	13.34	13.71	14.08	14.46	14.85
$L_{III}O_{IV,V}$	$L\beta_5$	-	13.01	13.39	13.78	14.18	14.57	14.97	15.39
L_IM_{IV}	$L\beta_{10}$	12.86	13.28	13.70	14.14	14.58	15.04	15.50	15.99
L_IM_V	$L\beta_9$	12.96	13.38	13.81	14.25	14.70	15.17	15.64	16.14
$L_{III}M_{II}$	Lt	9.24	9.48	9.72	9.97	10.21	10.46	10.71	10.97
$L_{III}M_{III}$	Ls	9.70	9.97	10.24	10.51	10.80	11.08	11.36	11.66

This table prepared with the assistance of H.M. Blann.

TABLE 2. K AND L X-RAY ENERGIES FOR ELEMENTS 81-104 (cont'd)

Transition	X-ray	Ac	Th	Pa	U	Np	Pu	Am	Cm
KL_{II}	$K\alpha_2$	87.69	89.96	92.31	94.64	97.06	99.50	102.0	104.5
KL_{III}	$K\alpha_1$	90.90	93.35	95.89	98.43	101.05	103.71	106.4	109.1
KM_{II}	$K\beta_1$	102.12	104.82	107.60	110.41	113.31	116.22	119.2	122.2
KM_{III}	$K\beta_3$	102.85	105.61	108.44	111.29	114.24	117.20	120.2	123.2
KN_{II}	$K\beta_2$	105.66	108.48	111.39	114.32	117.34	120.39	123.5	126.6
KN_{III}	$K\beta_2$	105.85	108.68	111.60	114.55	117.58	120.65	123.8	126.9
L_IM_{II}	$L\beta_4$	15.20	15.64	16.11	16.58	17.06	17.56	18.06	18.63
L_IM_{III}	$L\beta_3$	15.93	16.43	16.95	17.46	17.99	18.54	19.10	19.64
L_IN_{II}	$L\gamma_2$	18.74	19.31	19.90	20.49	21.09	21.73	22.36	23.04
L_IN_{III}	$L\gamma_3$	18.93	19.51	20.11	20.72	21.33	21.99	22.64	23.31
L_IO_{II}	$L\gamma_4$	19.64	20.24	20.87	21.51	22.13	22.81	23.48	24.19
L_IO_{III}	$L\gamma_4$	19.69	20.30	20.93	21.57	22.21	22.90	23.58	-
$L_{II}M_I$	$L\eta$	14.08	14.51	14.93	15.40	15.88	16.35	16.83	17.37
$L_{II}N_I$	$L\gamma_5$	17.82	18.37	18.92	19.51	20.11	20.70	21.32	21.94
$L_{II}O_I$	$L\gamma_8$	18.82	19.41	20.00	20.62	21.26	21.90	22.56	23.22
$L_{II}M_{IV}$	$L\beta_1$	15.71	16.20	16.69	17.22	17.75	18.29	18.85	19.40
$L_{II}N_{IV}$	$L\gamma_1$	18.41	18.98	19.55	20.16	20.79	21.41	22.06	22.71
$L_{II}O_{IV}$	$L\gamma_6$	19.01	19.60	-	20.85	21.49	22.15	22.82	-
$L_{III}M_I$	$L\ell$	10.87	11.12	11.35	11.62	11.89	12.14	12.39	12.71
$L_{III}N_I$	$L\beta_6$	14.61	14.97	15.34	15.73	16.02	16.49	16.88	17.28
$L_{III}O_I$	$L\beta_7$	15.61	16.01	16.42	16.84	17.27	17.69	18.12	18.56
$L_{III}M_{IV}$	$L\alpha_2$	12.50	12.81	13.11	13.44	13.76	14.08	14.41	14.74
$L_{III}M_V$	$L\alpha_1$	12.66	12.97	13.28	13.62	13.94	14.28	14.61	14.96
$L_{III}N_{IV}$	$L\beta_{15}$	15.20	15.59	15.97	16.38	16.80	17.20	17.62	18.05
$L_{III}N_V$	$L\beta_2$	15.23	15.62	16.01	16.43	16.84	17.25	17.67	18.10
$L_{III}O_{IV,V}$	$L\beta_5$	15.80	16.21	16.63	17.07	17.51	17.95	18.39	-
L_IM_{IV}	$L\beta_{10}$	16.48	16.98	17.51	18.03	18.56	19.03	19.70	20.28
L_IM_V	$L\beta_9$	16.64	17.14	17.68	18.21	18.74	19.33	19.90	20.50
$L_{III}M_{II}$	Lt	11.22	11.47	11.71	11.99	12.26	12.51	12.77	13.09
$L_{III}M_{III}$	Ls	11.95	12.25	12.55	12.86	13.19	13.49	13.81	14.10

TABLE 2. K AND L X-RAY ENERGIES FOR ELEMENTS 81-104 (cont'd)

Transition	X-ray	Bk	Cf	E	Fm	Mv	102	103	104
KL_{II}	$K\alpha_2$	107.0	109.5	112.0	114.6	117.3	119.9	122.7	125.4
KL_{III}	$K\alpha_1$	111.9	114.6	117.4	120.2	123.2	126.0	129.0	132.0
KM_{II}	$K\beta_1$	125.2	128.3	131.4	134.5	137.7	140.9	144.2	147.5
KM_{III}	$K\beta_3$	126.3	129.4	132.5	135.6	138.9	142.1	145.4	148.8
KN_{II}	$K\beta_2$	129.8	132.9	136.2	139.4	142.8	146.1	149.6	153.0
KN_{III}	$K\beta_2$	130.1	133.2	136.5	139.7	143.1	146.5	149.9	153.4
L_IM_{II}	$L\beta_4$	19.15	19.68	20.23	20.75	21.33	21.87	22.46	23.05
L_IM_{III}	$L\beta_3$	20.18	20.75	21.33	21.87	22.49	23.06	23.69	24.32
L_IN_{II}	$L\gamma_2$	23.69	24.33	25.01	25.66	26.37	27.04	27.79	28.51
L_IN_{III}	$L\gamma_3$	23.97	24.63	25.33	26.00	26.73	27.42	28.18	28.92
L_IO_{II}	$L\gamma_4$	24.87	25.55	-	-	-	-	-	-
L_IO_{III}	$L\gamma_4$	-	-	-	-	-	-	-	-
$L_{II}M_I$	$L\eta$	17.85	18.39	18.91	19.45	19.97	20.56	21.09	21.64
$L_{II}N_I$	$L\gamma_5$	22.56	23.24	23.87	24.52	25.19	25.91	26.57	27.26
$L_{II}O_I$	$L\gamma_8$	23.88	24.61	25.29	25.99	26.70	-	-	-
$L_{II}M_{IV}$	$L\beta_1$	19.95	20.56	21.13	21.72	22.33	22.94	23.56	24.14
$L_{II}N_{IV}$	$L\gamma_1$	23.35	24.07	24.73	25.41	26.12	26.85	27.56	28.27
$L_{II}O_{IV}$	$L\gamma_6$	-	-	-	-	-	-	-	-
$L_{III}M_I$	$L\ell$	13.00	13.26	13.58	13.86	14.10	14.43	14.73	15.01
$L_{III}N_I$	$L\beta_6$	17.71	18.11	18.54	18.93	19.32	19.78	20.21	20.63
$L_{III}O_I$	$L\beta_7$	19.03	19.48	19.96	20.40	20.83	-	-	-
$L_{III}M_{IV}$	$L\alpha_2$	15.10	15.43	15.80	16.13	16.46	16.81	17.20	17.51
$L_{III}M_V$	$L\alpha_1$	15.31	15.66	16.01	16.34	16.67	17.05	17.44	17.77
$L_{III}N_{IV}$	$L\beta_{15}$	18.50	18.94	19.40	19.82	20.25	20.72	21.20	21.64
$L_{III}N_V$	$L\beta_2$	18.56	19.00	19.47	19.89	20.32	20.80	21.28	21.73
$L_{III}O_{IV,V}$	$L\beta_5$	-	-	-	-	-	-	-	-
L_IM_{IV}	$L\beta_{10}$	20.85	21.41	22.01	22.60	23.23	23.80	24.47	25.08
L_IM_V	$L\beta_9$	21.06	21.64	22.22	22.81	23.44	24.04	24.71	25.34
$L_{III}M_{II}$	Lt	13.40	13.70	14.02	14.28	14.56	14.88	15.19	15.48
$L_{III}M_{III}$	Ls	14.43	14.77	15.12	15.40	15.72	16.07	16.42	16.75

Notes on Table 2:

1. All values computed from electron energies given in Table 1. See footnotes of that table for references to original data. This table prepared by H. M. Blann.

2. Some modern reports which present direct experimental information on heavy element X-ray energies include the following.

J. J. Merrill and J. W. M. DuMond, "Precision Measurement of the L X-ray Spectra of Uranium and Plutonium," Phys. Rev. 110, 79 (1958).

J. J. Merrill, "Precision Measurement of X-ray Spectra with Application to the L X-ray Spectra of Uranium, Neptunium, Plutonium and Americium," Ph. D. Thesis, California Institute of Technology, 1960.

Cauchois, Manescu and LeBerquier, Compt. Rend. 239, 1780 (1954).

G. L. Rogosa and W. F. Peed, "L X-ray Energies of Np, Pu, and Am," Phys. Rev. 101, 591 (1956).

H. Claesson, Z. Physik 101, 499 (1936).

Y. Cauchois, "Les Niveaux D'Energie des Atomes Lourds," J. Phys. Rad. 13, 113 (1952).

G. W. Barton, H. P. Robinson, and I. Perlman, "The L X-ray Spectra from Decay of Transuranium Elements," Phys. Rev. 81, 208 (1951).

Jaffe, Passell, Browne, and Perlman, "Gamma and X-Radiation in the Decay of Am^{241}," Phys. Rev. 97, 142 (1955).

P. P. Day, "Electromagnetic Spectrum of Am^{241}," Phys. Rev. 97, 689 (1955).

R. W. Hoff et al., "Radioactive Decay of the Isomers of Americium-242," Phys. Rev. 100, 1403 (1955).

TABLES 3 - 11. AUGER ELECTRON ENERGIES OF THE ELEMENTS 81 - 103

When a radioactive atom decays by orbital electron capture or by the internal conversion process vacancies are produced in the inner atomic shells which are filled again by electrons from outer shells. The energy which results from this process is carried away by an X-ray quantum or is transferred to one of the outer electrons which is ejected from the atom. Such an electron is called an Auger electron.[1, 2, 3] The competition between X-ray and Auger electron emission is similar to the competition between photon and conversion electron emission in a gamma transition. The fraction of the number of primary vacancies of a certain shell leading to the emission of X-rays is called the fluorescence yield, ω. This quantity is discussed in the text accompanying Tables 11-12. The Auger yield, is defined as the number of vacancies leading to the emission of Auger electrons.

A large number of discrete Auger electron lines result from vacancies in a given shell. The designation of these lines is made by a nomenclature which can be illustrated by an example: The KL_IL_{II} electron refers to an electron ejected from the L_{II}-shell by the energy released when an L_I-electron drops into a vacancy in the K-shell. The energy of the Auger electrons cannot be calculated exactly by a simple use of the binding energies of the neutral atom because the electron in the outer orbit of an ionized atom has somewhat more energy than a comparable electron in the neutral atom. In principle this difference in energy can be calculated but the calculation is involved and has not been carried out.

1. A detailed discussion of the Auger process is given by E. H. S. Burhop, "The Auger Effect and Other Radiationless Transitions," Cambridge University Press, London (1952).
2. A brief discussion of Auger electrons from radioactive atoms is given by I. Bergström in Chapter XX, Beta and Gamma Ray Spectroscopy, K. Siegbahn, Editor, North-Holland Publishing Co., Amsterdam, 1955.
3. P. Gray discusses the "Auger Effect in the Heaviest Elements," Phys. Rev. 101, 1306, 1956.

BERGSTROM AND HILL[4] suggest an empirical formula for estimating Auger electron energies for practical purposes. They define an effective incremental charge Δz on the assumption of a linear increase in binding energy with atomic number.

$$\Delta z = \frac{L_q(L_p) - (L_q)_z}{(L_q)_{z+1} - (L_q)_z}$$

Here $L_q(L_p)$ refers to the binding energy of the L_q electron in an atom with an electron missing from the L_p shell and $(L_q)_z$ refers to the normal binding energy for the same electron in a neutral atom of charge z. The Auger electron energy is then given by

$$KL_pL_q = (K-L_p)_z - (L_q)_{z+\Delta z}$$

BERGSTROM AND HILL determined the energies of K Auger lines in mercury and from these energies computed Δz values of 0.55 for the L_I and L_{II} shells and of 0.76 for the L_{III} shell. Other determinations by other authors for heavy elements are summarized in Table 3. There appears to be reasonable agreement between the authors quoted.

Table 4 lists the K-Auger electron energies for the heavy elements calculated according to the prescription of Bergström and Hill. The binding energies of Table 1 were used to evaluate $(K - L_p)_z$ and $(L_q)_z$. The Δz values in the term $(L_q)_{z+\Delta z}$ were chosen in this way.

$$\Delta z = 0.55 \quad \text{for} \quad KL_IL_I$$
$$\Delta z = 0.55 \quad \text{for} \quad KL_pL_{II}$$
$$\Delta z = 0.76 \quad \text{for} \quad KL_pL_{III}$$

4. I. Bergström and R. D. Hill, Arkiv för Fysik 8, 21 (1954).

To avoid ambiguity in the calculation, the convention is made that when the two L-electrons are from different sub-shells the one from the lower shell is written first. For example, the $KL_I L_{III}$ electron must be identical with the $KL_{III} L_I$ electron and the convention prevents the estimation of two slightly different values for the electron energy.

Some $KL_p M_q$ Auger electron energies are also shown in Table 4. MLADJENOVIC and SLATIS[5] report values of 0.59, 0.58, and 0.61 for the M_I, M_{II} and M_{III} subshells in bismuth. In the calculation of the KLM energies in our table we have taken $\Delta z = 0.6$ for all M-subshell electrons.

In Tables 5 through 9 the limited experimental data on the K Auger lines in the heavy elements is compared with the values listed in Table 4.

It is also useful to know the expected intensity pattern for the Auger lines. This knowledge helps in the identification of the lines and in the recognition of gamma transition conversion electron lines which fall in the Auger electron energy range. Experimental data on intensity patterns is summarized in Table 11.

Very few measurements of L Auger electrons have been reported for heavy elements. Sujkowski and Slatis[6] report measurements of the L-Auger electrons of thallium and bismuth. Albridge[7] reports some work on the L-Auger spectrum of uranium.

5. M. Mladjenovic and H. Slatis, Arkiv f. Fysik 9, 41 (1954).

6. Z. Sujkowski and H. Slatis, Arkiv f. Fysik 14, 101 (1958).

7. R. G. Albridge, Jr., University of California Radiation Laboratory Report UCRL-8642, April 1960.

TABLE 3. $\Delta 2$ VALUES FOR CALCULATION OF AUGER ELECTRON ENERGIES

Element	Auger Line	$\Delta 2$	Authors
80	KL_IL_I	0.55	Bergstrom and Hill
	KL_IL_{II}	0.55	Arkiv f. Fysik 8, 21 (1954).
	KL_IL_{III}	0.76	
83	KL_IL_I	0.52	Mladjenovic and Slatis
	KL_IL_{II}	0.52	Arkiv f. Fysik 9, 41 (1955).
	KL_IL_{III}	0.76	
83	KL_IL_I	0.53	Zhernovoi et al.
	KL_IL_{II}	0.58	Soviet Physics JETP 5, 563
	KL_IL_{III}	0.80	(1957).
92	KL_IL_I	0.58	R. G. Albridge
	KL_IL_{II}	0.54	UCRL-8642, 1960
	KL_IL_{III}	0.84	

TABLE 4. K-AUGER ELECTRON ENERGIES (IN KEV) FOR ELEMENTS 80-103

(Table prepared by James A. Harris)

Part I. Auger Electrons of Type KL_pL_q

Atomic No.	Element	KL_IL_I	KL_IL_{II}	KL_IL_{III}	$KL_{II}L_{II}$	$KL_{II}L_{III}$	$KL_{III}L_{III}$
80	Hg	53.15	53.79	55.71	54.42	56.34	58.28
81	Tl	54.55	55.20	57.23	55.85	57.88	59.92
82	Pb	55.99	56.66	58.82	57.32	59.48	61.64
83	Bi	57.45	58.14	60.42	58.81	61.10	63.39
84	Po	59.04	59.75	62.17	60.45	62.87	65.29
85	At	60.57	61.28	63.85	61.98	64.55	67.12
86	Rn	62.10	62.83	65.55	63.55	66.27	68.99
87	Fr	64.30	64.39	67.26	65.13	68.00	70.87
88	Ra	65.19	65.95	68.99	66.71	69.75	72.78
89	Ac	66.75	67.52	70.74	68.29	71.51	74.72
90	Th	68.37	69.16	72.57	69.94	73.35	76.74
91	Pa	70.02	70.84	74.43	71.66	75.25	78.83
92	U	71.71	72.53	76.33	73.34	77.14	80.92
93	Np	73.46	74.28	78.30	75.10	79.12	83.11
94	Pu	75.19	76.03	80.27	76.86	81.10	85.31
95	Am	76.9	77.8	82.3	78.6	83.1	87.5
96	Cm	78.7	79.6	84.3	80.5	85.2	89.8
97	Bk	80.5	81.4	86.3	82.3	87.2	92.0
98	Cf	82.3	83.2	88.3	84.0	89.1	94.3
99	E	84.1	85.0	90.4	85.9	91.3	96.6
100	Fm	86.0	86.9	92.5	87.8	93.4	99.0
101	Mv	87.9	88.8	94.7	89.7	95.5	101.4
102		89.8	90.7	96.8	91.5	97.7	103.8
103	Lw	91.7	92.6	99.0	93.5	99.9	106.3

TABLE 4. K-AUGER ELECTRON ENERGIES (IN KEV) FOR ELEMENTS 80-103

Part II. Auger Electrons of Type KL_IM_q

Atomic No.	Element	KL_IM_I	KL_IM_{II}	KL_IM_{III}	KL_IM_{IV}	KL_IM_V
80	Hg	64.21	64.91	65.36	65.83	65.92
81	Tl	66.53	66.81	67.26	67.73	67.83
82	Pb	68.20	68.50	69.01	69.49	69.60
83	Bi	70.05	70.35	70.89	71.39	71.50
84	Po	72.03	72.34	72.92	73.42	75.51
85	At	73.95	74.27	74.88	75.39	75.52
86	Rn	75.89	76.22	76.86	77.39	77.53
87	Fr	77.86	78.19	78.87	79.40	79.55
88	Ra	79.83	80.18	80.89	81.44	81.59
89	Ac	81.83	82.18	82.94	83.49	83.65
90	Th	83.90	84.26	85.07	85.63	85.80
91	Pa	86.02	86.57	87.38	87.94	88.11
92	U	88.18	88.55	89.46	90.03	90.21
93	Np	90.42	90.79	91.75	92.33	92.53
94	Pu	92.63	93.01	94.02	94.62	94.82
95	Am	94.9	95.3	96.3	96.9	97.2
96	Cm	97.2	97.6	98.6	99.3	99.5
97	Bk	99.5	99.5	101.0	101.7	101.9
98	Cf	101.8	102.3	103.4	104.0	104.2
99	E	104.2	104.6	105.8	106.5	106.7
100	Fm	106.6	107.0	108.2	108.9	109.1
101	Mv	109.0	109.7	110.8	111.6	111.8
102		111.5	112.0	113.2	113.9	114.2
103	Lw	114.0	114.5	115.7	116.5	116.7

TABLE 4. K-AUGER ELECTRON ENERGIES (IN KEV) FOR ELEMENTS 80-103

Part III. Auger Electrons of Type $KL_{II}M_q$

Atomic No.	Element	$KL_{II}M_I$	$KL_{II}M_{II}$	$KL_{II}M_{III}$	$KL_{II}M_{IV}$	$KL_{II}M_V$
80	Hg	65.25	65.54	65.99	66.46	66.55
81	Tl	67.18	67.46	67.91	68.38	68.48
82	Pb	68.86	69.16	69.67	70.16	70.26
83	Bi	70.72	71.03	71.57	72.06	72.17
84	Po	72.72	73.04	73.62	74.12	74.24
85	At	74.65	74.97	75.58	76.09	76.22
86	Rn	76.61	76.94	77.58	78.11	78.24
87	Fr	78.60	78.93	79.61	80.14	80.29
88	Ra	80.59	80.94	81.65	82.20	82.35
89	Ac	82.60	82.95	83.71	84.26	84.42
90	Th	84.68	85.04	85.85	86.41	86.58
91	Pa	86.84	87.39	88.20	88.76	88.93
92	U	88.99	89.36	90.27	90.84	91.02
93	Np	91.23	91.60	92.56	93.14	93.33
94	Pu	93.47	93.85	94.86	95.46	95.66
95	Am	95.8	96.2	97.2	97.8	98.0
96	Cm	98.1	98.5	99.5	100.2	100.4
97	Bk	100.4	100.9	101.0	101.7	101.9
98	Cf	102.7	103.1	104.2	104.9	105.1
99	E	105.1	105.5	106.6	107.4	107.6
100	Fm	107.5	107.9	109.1	109.8	110.0
101	Mv	109.9	110.6	111.7	112.5	112.7
102		112.4	112.8	114.0	114.8	115.0
103	Lw	114.9	115.4	116.6	117.4	117.6

TABLE 4. K-AUGER ELECTRON ENERGIES (IN KEV) FOR ELEMENTS 80-103

Part IV. Auger Electrons of Type $KL_{III}M_q$

Atomic No.	Element	$KL_{III}M_I$	$KL_{III}M_{II}$	$KL_{III}M_{III}$	$KL_{III}M_{IV}$	$KL_{III}M_V$
80	Hg	64.62	64.91	65.36	65.83	65.92
81	Tl	69.22	69.50	69.95	70.42	70.52
82	Pb	71.03	71.33	71.84	72.32	72.43
83	Bi	73.01	73.32	73.86	74.35	74.46
84	Po	75.15	75.46	76.04	76.54	76.66
85	At	77.22	77.54	78.15	78.66	78.79
86	Rn	79.33	79.66	80.30	80.83	80.96
87	Fr	81.47	81.80	82.48	83.01	83.16
88	Ra	83.62	83.97	84.68	85.23	85.38
89	Ac	85.81	86.16	86.92	87.47	87.63
90	Th	88.07	88.43	89.24	89.80	89.97
91	Pa	90.42	90.97	91.78	92.34	92.51
92	U	92.77	93.14	94.05	94.62	94.80
93	Np	95.22	95.59	96.55	97.13	97.32
94	Pu	97.68	98.06	99.07	99.67	99.86
95	Am	100.2	100.6	101.6	102.2	102.4
96	Cm	102.3	103.2	104.2	104.8	105.1
97	Bk	105.3	105.7	106.7	107.4	107.6
98	Cf	107.8	108.2	109.3	110.0	110.2
99	E	110.4	110.9	112.0	112.7	112.9
100	Fm	113.1	113.5	114.7	115.4	115.6
101	Mv	115.8	116.5	117.6	118.3	118.5
102		118.5	119.0	120.2	120.9	121.2
103	Lw	121.3	121.7	123.0	123.8	124.0

TABLE 5. COMPARISON OF EXPERIMENTAL DATA ON AUGER ELECTRONS IN MERCURY WITH VALUES GIVEN IN TABLE 4.

Auger Line	Energy (kev)	Relative Intensity	Energy (kev)
KL_IL_I	53.18	1	53.15
KL_IL_{II}	53.79	1.2	53.79
$KL_{II}L_{II}$	54.32	~0.2	54.42
KL_IL_{III}	55.71	0.7	55.71
$KL_{II}L_{III}$	56.35	1.4	56.34
$KL_{III}L_{III}$	58.27	0.6	58.28

Bergstrom and R. D. Hill, Arkiv f. Fysik 8, 21 (1954).

TABLE 6. COMPARISON OF EXPERIMENTAL VALUES OF AUGER ELECTRONS IN BISMUTH WITH TABLE 4 VALUES.

	Source of Data				
Auger Line	Mladjenovic and Slatis		Zhernovoi et. al.		
	Energy (Kev)	Relative Intensity	Energy (Kev)	Relative Intensity	Table 4
KL_IL_I	57.466	1.0	57.458	1.0	57.45
KL_IL_{II}	58.186	1.8	58.147	1.72	58.14
$KL_{II}L_{II}$			58.783	0.17	58.81
KL_IL_{III}	60.417	1.1	60.423	0.91	60.42
$KL_{II}L_{III}$	61.090	1.6	61.070	1.64	61.10
$KL_{III}L_{III}$	63.404	0.8	63.367	0.69	63.39
KL_IM_I	70.020	0.4			70.05
KL_IM_{II}	70.391	0.5			70.35
$KL_{II}M_I$	70.761	0.8			70.72
$KL_{II}M_{III}$	71.553	0.7			71.57
$KL_{III}M_{II}$	73.301	0.7			73.32
$KL_{III}M_{III}$	73.873	1.0			73.86

M. Mladjenovic and H. Slatis, Arkiv f. Fysik 8, 65 (1954).

A.I. Zhernovoi et. al., Soviet Physics Jet P 5, 563 (1957).

TABLE 7. COMPARISON OF EXPERIMENTAL VALUES OF K AUGER ELECTRONS IN POLONIUM WITH VALUES GIVEN IN TABLE 4.

	Energy	
Auger Lines	Hoff	Table 4
KL_IL_I	58.85	59.04
KL_IL_{II}	59.56	59.75
KL_IL_{III}	62.00	62.17
$KL_{II}L_{II}$	60.18	60.45
$KL_{II}L_{III}$	62.63	62.87
$KL_{III}L_{III}$	65.12	65.29

R. Hoff, Unpublished information

TABLE 8. COMPARISON OF EXPERIMENTAL VALUES OF K AUGER ELECTRONS IN PROTACTINIUM WITH VALUES GIVEN IN TABLE 4

	Hollander et al.		Table 4
Auger Line	Energy (Kev)	Relative Intensity	Energy (Kev)
KL_IL_I	70.05	1.0	70.02
KL_IL_{II}	70.87	2.0	70.84
KL_IL_{III}	74.45	0.87	74.43
$KL_{II}L_{III}$	75.21	1.1	75.25
$KL_{III}L_{III}$	78.78	--	78.83
KL_IM_I	85.88	0.1	86.02
KL_IM_{II}	86.29	0.1	86.57

Hollander, Stephens, Asaro and Perlman "Energy Levels of Pa^{231}" paper in publication 1961.

TABLE 9. COMPARISON OF EXPERIMENTAL VALUES OF K-AUGER ELECTRONS IN URANIUM WITH VALUES GIVEN IN TABLE 4

	R. G. Albridge UCRL-8642		Table 3
Auger Line	Energy (Kev)	Relative Intensity	Energy (Kev)
KL_IL_I	71.69	1.0	71.71
KL_IL_{II}	72.54	2.6	72.53
KL_IL_{III}	76.29	1.0	76.33
$KL_{II}L_{III}$	77.13	1.5	77.14
KL_IM_I	87.96		88.18
KL_IM_{II}	88.33		88.55
KL_IM_{IV+V} $KL_{II}M_{III}$	90.02		90.03+ 90.21 90.27
$KL_{III}M_{I,II}$	92.95		92.77 + 93.14
KM_IM_{III} ?	105.6		--

TABLE 10. COMPARISON OF EXPERIMENTAL DATA ON AUGER ELECTRONS IN PLUTONIUM WITH VALUE GIVEN IN TABLE 4

Auger Line	Ewan et.al. Energy (Kev)	Relative Intensity	Table 4 Energy (Kev)
KL_IL_I	75.18	1.0	75.19
KL_IL_{II}	76.05	1.86	76.03
$KL_{II}L_{II}$	76.78	0.11	76.86
KL_IL_{III}	80.24	0.60	80.27
KL_IL_{III}	80.40	0.05	
$KL_{II}L_{III}$	81.06	1.11	81.10
$KL_{III}L_{III}$	85.30	0.40	85.31

Ewan, Geiger, Graham and Mackenzie
Can. J. Physics 37, 174 (1959).

TABLE 11. RELATIVE INTENSITY OF AUGER ELECTRON LINES: EXPERIMENTAL VALUES FOR HEAVY ELEMENTS.

Auger Line	Z=75 Ref 1	Z=79 Ref 2	Z=80 Ref 3	Z=80 Ref 9	Z=82 Ref 10	Z=83 Ref 4	Z=84 Ref 5	Z=91 Ref 6	Z=92 Ref 7	Z=94 Ref 8
KL_IL_I	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
KL_IL_{II}	1.4	1.7	1.2	1.68	1.62	1.8	1.9	2	2.6	1.86
KL_IL_{III}	1.1	1.2	0.7	0.85	0.87	1.1	1.6	0.9	1.0	0.6
$KL_{II}L_{II}$	0.1	0.3	0.2	0.14	0.15	0.2				0.11
$KL_{II}L_{III}$	2.0	1.4	1.4	1.84	1.80	1.6	0.9	1.1	1.5	1.11
$KL_{III}L_{III}$	0.95	0.8	0.6	.76	0.75	0.8	0.6			0.40
KL_IM_I	0.44					0.4	0.6	0.1		
KL_IM_{II}	0.30					0.5		0.1		
KL_IM_{III}, $KL_{II}M_I$	0,62					0.8	1.4			
$KL_{II}M_{III}$	0.38					0.7				
$KL_{II}M_{IV}$	0.32					0.1				
$KL_{III}M_I$	0.32					0.21				
$KL_{III}M_{II}$	0.59					0.7				
$KL_{III}M_{III}$	0.60					1.0				

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TABLE 12 - 13. FLUORESCENT YIELDS OF ELEMENTS ABOVE Z=80

The fluorescent yield is defined as the number of X-ray photons emitted per electron vacancy produced. The vacancy in the electron shell may be the result of a radioactive decay process or the result of bombardment of an atom with external radiation.

The K-fluorescence yield, ω_K, is a strong function of Z if the whole periodic system is considered. Summaries of the Z-dependence are presented by Broyles, Thomas and Haynes[1], by Gray[2] and by Roos[3]. In the heavy element group of elements considered here the K-fluorescence yield is nearly constant at a value of 0.96. Recent experimental values are summarized in Table 12.

In the case of L-shell fluorescent yields there exists the possibility of primary vacancies in the L_I, L_{II} or L_{III} shells with characteristic fluorescent yields for each shell. In only a few cases have these individual fluorescent yields been determined. It is more usual to report a mean value of ω_L. It is quite possible that the mean values reported by two experimentalists for the same element will differ if the processes giving rise to the primary electron vacancies produce a different proportion of $L_I L_{II}$ and L_{III} holes. Hence in Table 13, which lists literature values of mean L-fluorescent yields, the specific experiment is given.

The data on L-shell fluorescent yields have been discussed in review articles by Robinson and Fink[4].

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TABLE 12. FLUORESCENT YIELD DETERMINATION FOR Z > 80

Element	Atomic Number	K-fluorescence Yield	Reference
Lead	82	0.96	a, d
Bismuth	83	0.96	b
Polonium	84	0.94	c
Uranium	92	0.97	c
Neptunium	93	0.94	e

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e. Hoffman and Dropesky, Phys. Rev. 109, 1288 (1958).

TABLE 13. MEASUREMENTS OF MEAN L-SHELL FLUORESCENT YIELDS FOR ELEMENTS ABOVE Z = 80

Element	Case Investigated	ω_L	Reference
Thallium	Tl^{208} from α-decay Bi^{212}	0.50±0.02	Burde and Cohen, Phys. Rev. 104, 1085 (1956).
Thallium	Tl^{208} from α-decay Bi^{212}	0.36	Kinsey, Can. J. Res. 26A, 421 (1948).
Thallium	Tl^{208} from α-decay Bi^{212}	0.32±0.02	Winkenbach, Z. Physik 152, 387 (1958).
Thallium	Theoretical calc.	0.29	Kinsey, Can. J. Res. 26A, 404 (1948).
Lead	Fluorescent excitation with Mo K X-rays	0.40	Lay, Z. Physik 91, 533 (1934).
Lead	Fluorescent excitation of Pb with Cd^{109} K X-rays	0.39	Patronis et al., Phys. Rev. 105, 681 (1957).
Bismuth	Bi^{212} from decay of Pb^{212}	0.51±0.03	Burde and Cohen, Phys. Rev. 104, 1085 (1956).
Bismuth	Bi^{210} from α-decay RaD	0.41	Kinsey, Can. J. Res., 26A, 421 (1948).
Bismuth	Bi^{210} from α-decay RaD	0.38±0.02	Fink, Phys. Rev. 106, 271 (1957).
Bismuth	Bi^{212} from decay of Pb^{212}	0.40±.02	Winkenbach, Z. Physik 152, 387 (1958).
Bismuth	Fluorescent excitation of Bi with Mo K X-rays	0.40	Lay, Z. Physik 91, 533 (1934).
Radium	Ra^{220} from α-decay of Th^{230}		Booth et al., Phys. Rev. 102, 800 (1957).
Thorium	Theoretical calc.	0.4	Kinsey, Can. J. Res. 26A, 404, (1948).
Uranium	Fluorescent excitation of U with Mo K X-rays	0.45	Lay, Z. Physik 91, 533 (1934).
Uranium	Theoretical calc.	0.42	Kinsey, Can. J. Physics 26A, 404 (1948).

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