Faint Lines in the L Spectrum of the Elements 73 Ta to 90 Th. I.

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Numerous weak L lines in the x-ray spectra of the heavier elements are reported. The majority are diagram lines attributable to quadrupole radiations. The non-diagram lines are satellites of $L\beta_2$. Measurements were made with a modified Siegbahn-Thoraeus high vacuum spectrometer having a dispersion, with calcite in first order and at $\lambda = 1080$ X.U., of 4.5 X.U./mm.

WITHIN the last decade several investigators[1, 2, 3, 4, 5] have reported faint lines in x-ray spectra which cannot be explained as normal dipole radiations. These lines are of two classes. First, "forbidden" lines which fit into the energy level diagrams but involve transitions violating the dipole selection rules. Second, those lines which as yet have no place in the energy level schemes, known variously as "non-diagram" lines, "satellites" or "spark" lines. This paper is an experimental report on both types of faint lines observed in the region of the $L\beta_2$ line for nine and the $L\gamma_1$ line for four of the heavier elements. Italics in the tables below indicate lines not reported before.

The spectrometer used was of the high vacuum type described by Siegbahn and Thoraeus[6] with slit width of 0.04 mm, slit-crystal distance of 27.15 cm and crystal-plate distance of 105.61 cm. This arrangement gives a large dispersion; at the wave-length of Au β_1 it is about 4.5 X.U./mm with a calcite crystal in first order. Plates were exposed from 10 to 30 hours at 29 kv and 10 to 25 m.a. with the crystal stationary during each exposure.

Wave-length measurements for each element except Pb are relative to Friman's[7] and Wennerlof's[8] values for the β_1, β_2 or γ_1-lines. Idei's[9] value of β_3 for Pb was used as a standard for the β region of that element. The β_1 and β_2-lines, measured as a single line by Friman, were partially resolved in the present work. The error in the wave-lengths given below is estimated to be less than 0.4 X.U.

The "computed" values of ν/R in the tables are from data on the strong lines of the L series by Idei[9] and from the M series measurements of Lindberg.[10]

I. DIAGRAM LINES

Dipole radiation

The dipole selection rules for the quantum numbers l and j allow transitions between energy states for which $\Delta l = \pm 1$; $\Delta j = 0, \pm 1$ except $j = 0$ to $j = 0$. Table I gives the weak lines in the γ region obeying these rules.

Quadrupole radiation

The quadrupole selection rules[11, 12] for l and j are $\Delta l = 0, \pm 1, \pm 2$ except $l = 0$ to $l = 0$; $\Delta j = 0, \pm 1, \pm 2$ except $j = 0$ to $j = 0$ and $j = 1/2$ to $j = 1/2$. Observed lines obeying these quadrupole rules are given in Tables II–XVI.

β_9 and β_{10} are the strongest of the quadrupole lines observed in this work. Richtmyer and Barnes,[13] in this laboratory, find the ratio of

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1 Data reported before 1931 are tabulated in M. Siegbahn, *Spektroskopie der Röntgenstrahlen*, second edition (1931).

2 P. A. Ross, Phys. Rev. **39**, 536 and 748 (1932).

3 S. Kaufman, Phys. Rev. **40**, 116 (1932).

4 E. Carlsson, Zeits. f. Physik **80**, 604; **84**, 119 (1932).

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8 I. Wennerlof, Zeits. f. Physik **41**, 524 (1927).

9 S. Idei, Tohoku Imp. Univ., Sci. Rep. **19**, 559 (1930).

10 E. Lindberg, Nova Acta Reg. Soc. Sc. Upsala **7**, No. 7 (1931).

11 E. Segrè, Rend. Accad. Naz. dei Lincei, **16**, 9 (1932).

12 H. C. Brinkman, Dissertation, Utrecht (1932).

13 Unpublished preliminary data on relative intensities and widths of Au lines. Double crystal spectrometer used.

TABLE I. *Dipole transitions.* Claësson[5] gives ν/R values for W γ_4' 887.8, W γ_4 888.6, Au γ_4' 1052.5, Au γ_4 1052.9.

Transition	Line	λ	ν/R	ν/R (comp.)
$L_{II}O_I$	Pb γ_8	821.7	1109.0	1108.9
	Bi γ_8	*795.6*	*1145.4*	1145.6
L_IO_{II}	W γ_4'	1026.4	887.8	887.4
	Pb γ_4'	*785.3*	*1160.4*	
	Bi γ_4'	760.4	1198.5	1198.4
L_IO_{III}	W γ_4	1025.7	888.5	
	Au γ_4	865.6	1052.8	1053.2
	Pb γ_4	783.9	1162.5	1162.1
	Bi γ_4	759.2	1200.3	
$L_IP_{II,\,III}$	Bi γ_{13}	755.3	1206.5	

TABLE II. $L_{III}N_{II}$ ($\Delta l=0$, $\Delta j=+1$).

Element	λ	ν/R	ν/R (comp.)
73 Ta	*1313.5*	*693.8*	693.5
74 W	*1273.9*	*715.4*	715.4
77 Ir	*1162.8*	*783.7*	783.6
78 Pt	*1129.1*	*807.1*	806.9
79 Au	*1097.7*	*830.2*	830.4
82 Pb	*1008.2*	*903.8*	904.0
83 Bi	*980.8*	*929.1*	929.0
90 Th	*817.6*	*1114.6*	1114.5

TABLE III. $L_{III}N_{III}$ ($\Delta l=0$, $\Delta j=0$).

Element	λ	ν/R	ν/R (comp.)
73 Ta	*1306.0*	*697.7*	697.9
74 W	*1264.6*	*720.6*	720.4
77 Ir	*1153.6*	*790.0*	789.8
78 Pt	*1120.1*	*813.5*	813.6
79 Au	*1087.7*	*837.8*	837.8
81 Tl	*1026.3*	*887.9*	887.4
82 Pb	*997.8*	*913.2*	912.7
83 Bi	*970.3*	*939.1*	938.5

TABLE IV. $L_{III}N_{VI}$ ($\Delta l=-2$, $\Delta j=-1$). Also reported by Croffut[14] for W and by Dauvillier[15] for Pt and Au.

Element	λ	ν/R	ν/R (computed)	ν/R, Idei[9]
73 Ta	1255.3	726.0	725.7	725.4
74 W	1216.3	749.2	749.0	749.3
77 Ir	1109.0	821.7	821.3	821.6
78 Pt	1076.3	846.7	846.4	846.2
79 Au	1045.4	871.7	871.5	871.9
81 Tl	986.4	923.9	923.3	923.3
82 Pb	959.2	950.0	949.5	949.8
90 Th	775.2	1175.5	1175.3	1175.5

[14] C. B. Croffut, Phys. Rev. **24**, 9 (1924).

[15] A. Dauvillier, J. de Physique et Radium **3**, 230 (1922).

TABLE V. $L_{III}O_{II,\,III}$ ($\Delta l=0$, $\Delta j=+1$, 0).

Element	λ	ν/R	ν/R (comp.)
73 Ta	*1257.6*	*724.6*	724.3
74 W	*1218.6*	*747.8*	747.9
77 Ir	*1107.3*	*823.0*	
78 Pt	*1073.9*	*848.5*	848.1
79 Au	*1043.4*	*873.3*	873.8
81 Tl	*984.1*	*926.0*	
82 Pb	*956.6*	*952.6*	
	955.8	*953.5*	953.9
83 Bi	*930.0*	*979.9*	979.6
	927.7	*982.3*	
90 Th	*769.8*	*1183.7*	1183.0
	767.5	*1187.3*	

TABLE VI. $L_{III}P_{II,\,III}$ ($\Delta l=0$, $\Delta j=+1$, 0).

Element	λ	ν/R
83 Bi	*922.2*	*988.1*
90 Th	*760.5*	*1198.3*

TABLE VII. $L_{II}M_{III}$ ($\Delta l=0$, $\Delta j=-1$). Reported for Ta, W, Ir and Pt by Dauvillier,[15] for Tl by Idei[9] and for Au by Claësson.[5]

Element	λ	ν/R	ν/R (comp.)
74 W	1335.9	682.1	682.4
78 Pt	1164.7	782.4	782.8
81 Tl	1053.5	865.0	865.0
83 Bi	*987.5*	*922.8*	923.1

TABLE VIII. $L_{II}M_V$ ($\Delta l=-1$, $\Delta j=-2$).

Element	λ	ν/R	ν/R (comp.)
73 Ta	*1316.3*	*692.3*	692.5
74 W	*1270.2*	*717.4*	717.0
77 Ir	*1146.4*	*794.9*	794.4
79 Au	*1072.9*	*849.4*	849.2
82 Pb	*972.5*	*937.0*	936.8
83 Bi	*942.2*	*967.2*	967.2
90 Th	*756.4*	*1204.8*	1205.2

TABLE IX. $L_{II}N_{III}$ ($\Delta l=0$, $\Delta j=-1$). Claësson has reported $L_{II}N_{III}$ for W and Au. He gives for Au $\nu/R=972.1$.

Element	λ	ν/R	ν/R (comp.)
79 Au	938.6	970.9	971.5
82 Pb	*849.9*	*1072.2*	1072.3
83 Bi	*823.3*	*1106.8*	1107.3

TABLE X. $L_{II}N_{VI}$ ($\Delta l=-2$, $\Delta j=-2$). Reported for W by Croffut,[14] for W and Ir by Idei[9] and for W and Au by Claësson.[5] Idei gives ν/R for W 847.5; Claësson gives for W 847.5, for Au 1005.3.

Element	λ	ν/R	ν/R (comp.)
74 W	1075.1	847.6	847.6
79 Au	906.7	1005.0	1005.2

TABLE XI. $L_{II}O_{III}$ ($\Delta l=0$, $\Delta j=-1$). Claësson gives ν/R for W 846.0, for Au 1007.0.

Element	λ	ν/R	ν/R (comp.)
74 W	1076.7	846.4	
79 Au	904.5	1007.5	1007.5
82 Pb	*818.5*	*1113.4*	1113.5
83 Bi	*792.3*	*1150.2*	

TABLE XII. L_IM_{IV} (β_{10}) ($\Delta l=-2$, $\Delta j=-1$).

Element	λ	ν/R	ν/R (computed)	ν/R, Idei[9]
73 Ta	1251.1	728.4	728.3	728.7
74 W	1209.7	753.3	753.3	753.4
77 Ir	1094.3	832.7	832.5	832.4
78 Pt	*1059.4*	*860.2*	860.0	
79 Au	1025.9	888.2	888.5	888.2
81 Tl	961.6	947.7	947.4	947.7
83 Bi	903.3	1008.8	1009.1	1008.6

TABLE XIII. L_IM_V (β_9) ($\Delta l=-2$, $\Delta j=-2$).

Element	λ	ν/R	ν/R (computed)	ν/R, Idei[9]
73 Ta	1243.9	732.6	732.6	732.6
74 W	1202.2	758.0	757.9	758.0
77 Ir	1087.2	838.2	838.1	838.0
78 Pt	1051.9	866.3	865.8	865.9
79 Au	1018.7	894.6	894.9	894.4
83 Bi	896.4	1016.6	1017.1	1017.0

TABLE XIV. L_IN_{IV} ($\Delta l=-2$, $\Delta j=-1$). L_IN_{IV} has been observed for W by Croffut,[14] for Pb and Bi by Eddy and Turner,[16] and for Au and W by Claësson. The last named gives for W 872.3, for Au 1031.5.

Element	λ	ν/R	ν/R (comp.)
74 W	1044.4	872.5	872.1
79 Au	884.0	1030.9	1031.3
82 Pb	802.0	1136.2	1136.2
83 Bi	777.0	1172.8	1172.9

[16] C. E. Eddy and A. H. Turner, Proc. Roy. Soc. **A114**, 605 (1927).

TABLE XV. L_IN_V ($\Delta l=-2$, $\Delta j=-2$). This transition has been found by Dauvillier[15] for W, Ir, Pt and Au; by Idei[9] for W, Ir, Au, Pb and Th; by Claësson[5] for W and Au. Claësson gives ν/R for W 873.2, for Au 1033.1.

Element	λ	ν/R	ν/R (comp.)
74 W	1043.5	873.3	873.2
79 Au	882.6	1032.5	1032.7
82 Pb	800.6	1138.2	1137.6
83 Bi	*775.6*	*1175.0*	1174.6

TABLE XVI. $L_IO_{IV,\,V}$ ($\Delta l=-2$, $\Delta j=-1,\ -2$). Claësson[5] has reported these lines resolved for W and Au. His measurements for W are $\lambda=1022.8$ and $\lambda=1022.4$; for Au, $\lambda=862.0$ and $\lambda=861.7$.

Element	λ	ν/R
74 W	1023.0	890.7
79 Au	862.2	1056.9
82 Pb	*780.9*	*1167.0*
83 Bi	*756.4*	*1204.8*

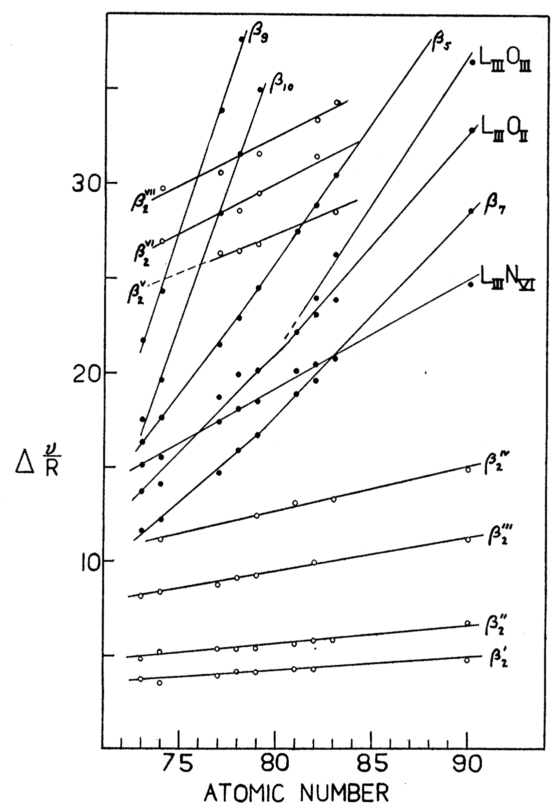

FIG. 1. ν/R from β_2 for lines on short wave-length side of β_2 as a function of atomic number. Diagram lines indicated by solid circles; non-diagram lines by open circles.

TABLE XVII. β_2^{I}.

Element	λ	ν/R	$(\nu/R)^{\frac{1}{2}}$
73 Ta	1275.2	714.6	26.732
74 W	1236.1	737.2	27.152
77 Ir	1127.5	808.3	28.430
78 Pt	1094.2	832.8	28.858
79 Au	1062.9	857.4	29.281
81 Tl	1003.4	908.2	30.136
82 Pb	975.9	933.8	30.558
90 Th	788.6	1155.6	33.994

TABLE XVIII. β_2^{II}.

Element	λ	ν/R	$(\nu/R)^{\frac{1}{2}}$
73 Ta	1273.3	715.7	26.752
74 W	1233.2	738.9	27.183
77 Ir	1125.4	809.7	28.456
78 Pt	1092.6	834.0	28.879
79 Au	1061.3	858.7	29.303
81 Tl	1001.9	909.5	30.158
82 Pb	974.3	935.3	30.583
83 Bi	947.4	961.8	31.013
90 Th	787.3	1157.5	34.022

TABLE XIX. β_2^{III}.

Element	λ	ν/R	$(\nu/R)^{\frac{1}{2}}$
73 Ta	*1267.4*	*719.0*	*26.815*
74 W	*1228.0*	*742.1*	*27.241*
77 Ir	*1120.8*	*813.1*	*28.515*
78 Pt	*1087.8*	*837.8*	*28.944*
79 Au	*1056.6*	*862.5*	*29.368*
82 Pb	*970.0*	*939.5*	*30.651*
90 Th	*784.3*	*1161.9*	*34.087*

intensities of Au β_5 to Au β_9 and Au β_{10} to be 10 and 16, respectively.

TABLE XX. β_2^{IV}.

Element	λ	ν/R	$(\nu/R)^{\frac{1}{2}}$
74 W	*1223.5*	*744.8*	*27.292*
79 Au	*1052.7*	*865.7*	*29.422*
81 Tl	*993.8*	*917.0*	*30.281*
83 Bi	*940.1*	*969.3*	*31.134*
90 Th	*781.8*	*1165.7*	*34.142*

TABLE XXI. β_2^{V}.

Element	λ	ν/R	$(\nu/R)^{\frac{1}{2}}$
77 Ir	*1097.0*	*830.7*	*28.821*
78 Pt	*1065.7*	*855.1*	*29.242*
79 Au	*1035.4*	*880.1*	*29.666*
83 Bi	*925.6*	*984.6*	*31.378*

TABLE XXII. β_2^{VI}. Claësson[5] reports for Au, $\lambda = 1032.3$ and $\lambda = 1031.3$.

Element	λ	ν/R	$(\nu/R)^{\frac{1}{2}}$
74 W	*1198.0*	*760.6*	*27.580*
78 Pt	*1063.1*	*857.2*	*29.278*
79 Au	1032.3	882.7	29.711
82 Pb	*948.3*	*961.0*	*30.999*

TABLE XXIII. β_2^{VII}.

Element	λ	ν/R	$(\nu/R)^{\frac{1}{2}}$
74 W	*1193.7*	*763.4*	*27.630*
77 Ir	*1091.5*	*834.9*	*28.895*
79 Au	*1029.9*	*884.8*	*29.746*
82 Pb	*946.4*	*962.9*	*31.031*
83 Bi	*920.1*	*990.4*	*31.470*

II. NON-DIAGRAM LINES

The non-diagram lines in Tables XVII–XXIII are those observed on the short wave-length side of the β_2-line. The measurements of the strong satellites β_2^{I} and β_2^{II} are believed to be superior to those reported before.[1, 17]

The assignment of these lines as satellites of β_2 appears from Fig. 1 in which the ν/R differences between β_2 and the lines on the short wave-length side of β_2 are plotted as a function of the atomic number. The diagram lines, besides fitting the energy level schemes, have slopes independent of that of β_2 whereas the slopes of the satellite curves ($\beta_2^{I}-\beta_2^{VII}$) increase regularly with respect to the slope of β_2.

The work is being continued in regions of the x-ray spectra not included in the present report. It is a pleasure to acknowledge the advice and criticism which Professor F. K. Richtmyer has offered in the course of this research.

[17] F. K. Richtmyer and S. Kaufman, Phys. Rev. **44**, 605 (1933).