AN EXTENSION OF THE Cd I-LIKE ISOELECTRONIC SEQUENCE TO Sb IV AND Te V*

By R. C. Gibbs and Alice M. Vieweg
Cornell University, Ithaca

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Abstract

Sn III.—New lines, in addition to those classified by Green and Loring, have been identified in this spectrum, in particular, second members of series.

Sb IV.—Lines have been identified arising from transitions $5s5p$ to $5s^2$; and from $5p^2$, $5s5d$, and $5s6s$ to $5s5p$. Some second members have also been found.

Te V.—The Cd I-like isoelectronic sequence has been extended through this element, by the classification of lines resulting from transitions between the same electronic configurations as for Sb IV.

The spectra of tin, antimony and tellurium used in this report were photographed with a vacuum spectrograph, which has been previously described.[1] For this work a grating of speculum metal with about 15,000 lines to the inch, and a radius of curvature of 150 cm was used. The dispersion obtained was about 11.3A per mm. In general, four exposures were taken on each plate; (1) a short exposure from a vacuum spark of the metal being studied, (2) a long exposure of the same element, (3) a longer exposure

Table I. *Doubly ionized tin*, Sn, III.

λ	ν	Int.	Designation	Multiplet No.	λ	ν	Int.	Designation	Multiplet No.
*2665.60	37503.9	1	$5^3D_3-4^3F_3$	9					
*2658.64	37602.0	10	$5^3D_3-4^3F_4$	9	*1251.43	79908	50	$5^1S_0-5^1P_1$	8
*2646.18	37779.1	2	$5^3D_2-4^3F_2$	9	*1243.70	80405	20	$5^3P_2-6^3S_1$	1
*2643.60	37816.0	6	$5^3D_2-4^3F_3$	9	*1218.23	82086	3	$5^3P_2-5^3D_1$	2
*2631.87	37984.5	4	$5^3D_1-4^3F_2$	9	*1215.14	82295	15	$5^3P_2-5^3D_2$	2
?2109.89	47395.8	1	$5^1P_1-5^3P_0'$	15	*1210.55	82607	30	$5^3P_2-5^3D_3$	2
2070.68	48293.3	10	$5^1P_1-5^1D_2$	17	*1184.33	84436	20	$5^3P_1-6^3S_1$	1
1991.68	50208.9	000	$5^1P_1-5^3P_1'$	15	*1161.62	86087	20	$5^3P_0-6^3S_1$	1
1829.61	54656.5	000	$5^1P_1-5^3P_2'$	15	*1161.09	86126	20	$5^3P_1-5^3D_1$	2
*1811.90	55191	20	$5^1S_0-5^3P_1$	7	*1158.37	86328	20	$5^3P_1-5^3D_2$	2
*1674.47	59720	2	$5^1P_1-6^3S_1$	4	*1139.35	87769	20	$5^3P_0-5^3D_1$	2
*1628.51	61406	3	$5^1P_1-5^3D_1$	6					
*1623.13	61609	4	$5^1P_1-5^3D_2$	6	910.92	109779	4	$5^1P_1-6^1D_2$	12
*1570.41	63677	12	$5^1P_1-5^1D_2$	5	784.68	127440	6	$5^3P_2-7^3S_1$	10
1449.73	68978	25	$5^3P_2-5^1D_2$	16	776.58	128770	00	$5^3P_2-6^3D_2$	11
*1410.68	70888	30	$5^3P_2-5^3P_1'$	3	775.79	128901	5	$5^3P_2-6^3D_3$	11
1386.74	72112	20	$5^3P_1-5^3P_0'$	3	760.54	131486	3	$5^3P_1-7^3S_1$	10
1369.71	73008	12	$5^3P_1-5^1D_2$	16	753.47	132719	0	$5^3P_1-6^3D_1$	11
*1334.74	74921	30	$5^3P_1-5^3P_1'$	3	753.01	132800	4	$5^3P_1-6^3D_2$	11
*1327.40	75335	30	$5^3P_2-5^3P_2'$	3	744.24	134365	0	$5^3P_0-6^3D_1$	11
*1306.01	76569	15	$5^3P_0-5^3P_1'$	3	*624.00	160256	00	$5^1S_0-6^3P_1$	13
*1259.97	79367	20	$5^3P_1-5^3P_2'$	3	*614.60	162707	3	$5^1S_0-6^1P_1$	14

* Wave-lengths and classification by Green and Loring.

* A brief report describing some of the results presented in this paper was made at the Pomona Meeting of the American Physical Society, June, 1928.

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[1] Gibbs and White, Phys. Rev. 31, 776 (1928).

of the metal using an inductance in series with the spark, and (4) the spectrum given by aluminum, for standards. In the case of tellurium the metal was consumed so rapidly that it was found necessary to use one of its alloys. An alloy of aluminum and tellurium proved to be very satisfactory, and little difficulty was encountered in distinguishing the lines contributed by each of the metals in the alloy.

TABLE II. *Triply ionized antimony*, Sb IV.

λ	ν	Int.	Designation	Multiplet No.	λ	ν	Int.	Designation	Multiplet No.
*2113.14	47323	3	$5^3D_3-4^3F_3$	9	†940.28	106351	6	$5^3P_2-5^3D_1$	2
*2106.00	47483	10	$5^3D_3-4^3F_4$	9	†937.17	106704	15	$5^3P_2-5^3D_2$	2
*2092.26	47795	2	$5^3D_2-4^3F_2$	9	†932.32	107259	25	$5^3P_2-5^3D_3$	2
*2088.53	47880	10	$5^3D_2-4^3F_3$	9	†891.17	112212	20	$5^3P_1-5^3D_1$	2
*2076.99	48146	5	$5^3D_1-4^3F_2$	9	†888.40	112562	25	$5^3P_1-5^3D_2$	2
1666.93	59991	15	$5^1P_1-5^1D_2$	17	†873.56	114474	20	$5^3P_0-5^3D_1$	2
1654.93	60426	00	$5^1P_1-5^3P_1'$	15	†861.60	116063	25	$5^3P_2-6^3S_1$	1
1499.24	66700	25	$5^1S_0-5^3P_1$	7	†820.21	121920	25	$5^3P_1-6^3S_1$	1
?1480.05	67565	15	$5^1P_1-5^3P_2'$	15	†805.24	124187	15	$5^3P_0-6^3S_1$	1
?1205.18	82975	15	$5^1P_1-5^3D_1$	6					
1200.32	83311	00	$5^1P_1-5^3D_2'$	6	626.54	159606	2	$5^1P_1-6^1D_2$	12
1199.10	83396	25	$5^3P_2-5^1D_2'$	16	548.68	182255	0	$5^3P_2-6^3D_2$	11
†1192.92	83828	25	$5^3P_2-5^3P_1'$	3	547.90	182515	4	$5^3P_2-6^3D_3$	11
1171.38	85370	20	$5^3P_1-5^3P_0'$	3	539.90	185219	6	$5^3P_2-7^3S_1$	10
?1151.49	86844	40	$5^1P_1-5^1D_2'$	5	532.04	187956	00	$5^3P_1-6^3D_1$	11
1120.38	89255	8	$5^3P_1-5^1D_2'$	16	531.54	188132	1	$5^3P_1-6^3D_2$	11
†1115.05	89682	25	$5^3P_1-5^3P_1'$	3	523.38	191064	3	$5^3P_1-7^3S_1$	10
1099.33	90964	30	$5^3P_2-5^3P_2'$	3	517.24	193334	00	$5^3P_0-7^3S_1$	10
†1087.64	91942	8	$5^3P_0-5^3P_1'$	3	463.47	215763	0	$5^1S_0-6^3P_1$	13
†1042.21	95950	75	$5^1S_0-5^1P_1$	8	456.50	219058	1	$5^1S_0-6^1P_1$	14
1032.88	96817	30	$5^3P_1-5^3P_2'$	3					

* Identifications by Green and Lang. † Independent identifications by Green and Lang and by the authors.

The spectra obtained when using an inductance in series with the spark proved to be of considerable value. Lines belonging to various states of ionization were differently affected in intensity and form. In general the addition of series inductance gave lines which were relatively stronger in intensity for lower states of ionization and weaker for higher states. It thus became possible to ascribe a fairly definite type of line to a particular state of ionization.

TABLE III. *Quadruply ionized tellurium*, Te V.

λ	ν	Int.	Designation	Multiplet No.	λ	ν	Int.	Designation	Multiplet No.
1549.28	64546	2	$5^1P_1-5^3P_0'$	15	895.20	111707	60	$5^1S_0-5^1P_1$	8
1406.56	71095	10	$5^1P_1-5^1D_2$	17	872.81	114572	4	$5^3P_1-5^3P_2'$	3
1281.67	78023	25	$5^1S_0-5^3P_1'$	7	771.55	129609	000	$5^3P_2-5^3D_1$	2
1236.31	80886	3	$5^1P_1-5^3P_2'$	15	768.43	130135	4	$5^3P_2-5^3D_2$	2
1037.08	96424	8	$5^3P_2-5^3P_1'$	3	763.41	130991	15	$5^3P_2-5^3D_3$	2
1033.04	96802	12	$5^3P_2-5^1D_2$	16	726.82	137586	6	$5^3P_1-5^3D_1$	2
1018.07	98225	10	$5^3P_1-5^3P_0'$	3	724.04	138114	10	$5^3P_1-5^3D_2$	2
957.89	104396	5	$5^3P_1-5^3P_1'$	3	711.73	140503	5	$5^3P_0-5^3D_1$	2
954.47	104770	10	$5^3P_1-5^1D_2$	16	645.85	154835	2	$5^3P_2-6^3S_1$	1
938.14	106594	7	$5^3P_2-5^3P_2'$	3	614.20	162813	0	$5^3P_1-6^3S_1$	1
931.90	107308	4	$5^3P_0-5^3P_1'$	3	603.40	165728	000	$5^3P_0-6^3S_1$	1
?910.86	109786	8	$5^1P_1-5^1D_2$	5					

The neutral unexcited atoms of antimony and tellurium contain five ($5s^25p^3$) and six ($5s^25p^4$) valence electrons respectively. The removal of three electrons ($5p^3$) from antimony and four ($5p^4$) from tellurium places these elements as the fourth and fifth members in the sequence of isoelectronic systems starting with cadmium: Cd I, In II, Sn III, Sb IV, Te V. Guided by transitions already established for cadmium,[2] indium,[3] and tin[4] from $^3P_{012}$, $^1P_1(5s5p)$ to $^1S_0(5s^2)$ and from $^3S_1$, $^1S_0(5s6s)$; $^3D_{123}$, $^1D_2(5s5d)$; and $^3P'_{012}$, $^1S_0$, $^1D_2(5p^2)$ to $^3P_{012}$, $^1P_1(5s5p)$, it has been possible by an almost linear extrapolation of the classified lines to locate many of the corresponding lines in the spectra of Sb IV and Te V. This type of extrapolation is illustrated in Fig. 1, where relative intensities and increase of term separations may also be noted.

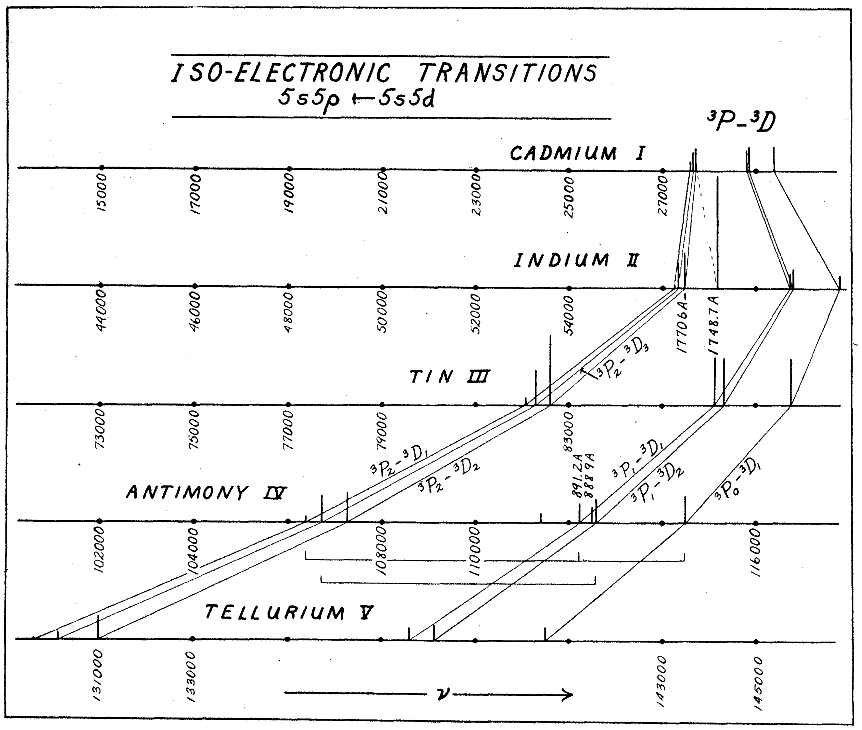

Fig. 1.

Lang[3] selected for the transition $^3P_2-{}^3D_3$ in In II the very intense line at $\nu=57185$, $\lambda=1748.71$A, although he had previously used this same line for the transition $^2S_1-{}^2P_1$ in In III.[5] (Fig. 1.) The less intense line at $\nu=56475$, $\lambda=1770.6$A, reported by Carroll,[6] appears to fit into the frequency diagram much better than the one connected by the dotted line at 57185. In the case of Sb V Lang[5] has used for the transition $^2P_2(5p)-{}^2D_3(5d)$ the line at 891.17A, (Fig. 1). This line, however, fits well into the scheme for Sb IV. Moreover, the exposure showing the effect of inductance, reproduced in Fig. 1 B of the

[2] Fowler, Report on Series in Line Spectra, 1922.
[3] Lang, Phys. Rev. **30,** 762 (1927).
[4] Green and Loring, Phys. Rev. **30,** 574 (1927).
[5] Lang, Proc. Nat. Acad. Sci. **13,** 341 (1927).
[6] Carroll, Phil. Trans. Roy. Soc. **A225,** 408 (1926).

succeeding article, indicates that this line is of the same type as others belonging to Sb IV. Possibly the line at 888.97A may be used for the above transition in Sb V instead of the line at 891.17A. At least the character of the former line, when photographed with series inductance, is similar to that of other lines belonging to the spectrum of quadruply ionized antimony. By thus identifying the line 891.17A as arising from the transition $^3P_1(5s5p)-^3D_1(5s5d)$ in the spectrum of Sb IV, not only does the frequency of this transition pro-

TABLE IV. *Term values.*

Configuration (Limit)	Term	Term Values Sn III	Sb IV	Te V	Multiplet Number
$5s^2$ / $5s$	$^1S_0$	247302	356156	486244	7, 8, 13, 14
$5s5p$ / $5s$	$^3P_0$	193758	291721	411135	1, 2, 3, 10, 11
	$^3P_1$	192111	289456	408221	1, 2, 3, 7, 10, 11, 16
	$^3P_2$	188077	283596	400247	1, 2, 3, 10, 11, 16
	$^1P_1$	167394	260204	374537	4, 5, 6, 8, 12, 15, 17
$5p^2$ / $5p$	$^3P_0'$	120000	204086	309996	3, 15
	$^1D_2$	119106	200200	303447	16, 17
	$^3P_1'$	117190	199774	303825	3, 15
	$^3P_2'$	112741	192639	293652	3, 15
	$^1S_0$				
$5s6s$ / $5s$	$^3S_1$	107672	167534	245407	1, 4
	$^1S_0$				
$5s5d$ / $5s$	$^3D_1$	105989	177244	270632	2, 6, 9
	$^3D_2$	105783	176894	270107	2, 6, 9
	$^3D_3$	105470	176337	269255	2, 9
	$^1D_2$	103717	173360	264751	5
$5s6p$ / $5s$	$^3P_0$				
	$^3P_1$	87097	140393		13
	$^3P_2$				
	$^1P_1$	84581	137098		14
$5s4f$ / $5s$	$^3F_2$	68004	129099		9
	$^3F_3$	67967	129014		9
	$^3F_4$	67868	128854		9
	$^1F_3$				
$5s7s$ / $5s$	$^3S_1$	60625	98385		10
	$^1S_0$				
$5s6d$ / $5s$	$^3D_1$	59394	101500		11
	$^3D_2$	59311	101330		11
	$^3D_3$	59175	101081		11
	$^1D_2$	57615	100585		12

gress more smoothly through the elements of this isoelectronic system but the increase in the $^3D_{1,2}$ separation is much more regular.

Second members of some of the series in the spectra of Sn III and Sb IV have been identified. Their classification has made possible the determination of some of the approximate term values for these elements directly, while radiated frequencies enable us to estimate other term values. The plate for tin gives evidence of very faint lines in the vicinity of 665A, where one would expect third members of some of these same series to appear. Since these lines could not be accurately measured they have not been included in this report. Our plates on tellurium did not bring out the second members of any of the series.

The lines in cadmium at 2239.9A, 2267.5A, and 2329.3A, taken from Fowler's[2] list of unclassified lines in the arc spectrum of that element, have been identified as ${}^3P_{012}-{}^3P_1'$.

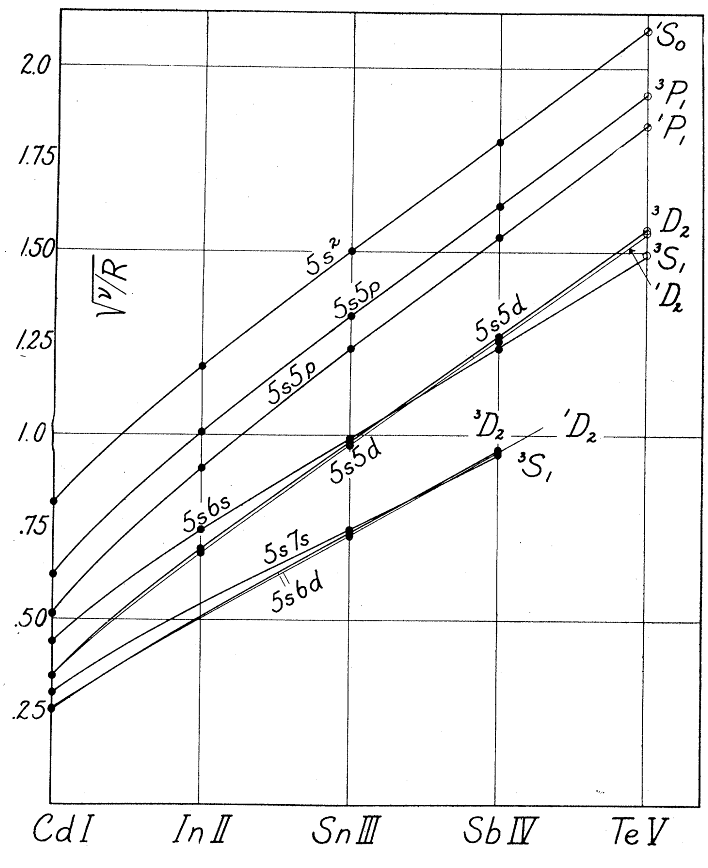

Fig. 2. Moseley diagram.

In the Moseley diagram, Fig. 2, the points for tellurium have been obtained merely by an extension of the curves given by the previous four elements. Evaluation of these points has given the term values for tellurium as recorded in Table IV.

The issue of Nature for August 18, 1928 contains a brief report by Green and Lang on the spectrum of trebly ionized antimony. A further report by them appeared in the September issue of the Proceedings of the National Academy of Sciences. At that time we had not definitely chosen the 5^3D-4^3F

multiplet. However, further investigation has shown these to be the only characteristic lines in the general region where one should expect to find this multiplet. For the sake of completeness, we have, therefore, included these lines in this report, as well as others chosen both by Green and Lang[7] and by ourselves. Their choice of three lines in the $5^3P-5^3P'$ multiplet, at 1145.86A, 1120.43A and 1051.33A, of $5^1S_0-5^3P_1$ at 1513.3A, of $5^1P_1-6^3S_0$ at 1086.5A and of $5^1P_1-5^3D_1$ at 1214.8A differs from ours. Aided by our observations of the influence of inductance on the quality of lines we may say that with the exception of the line at 1120.4A, the lines enumerated do not appear to belong to that class which is typical of Sb IV.

TABLE V. *Term separations.*

	$5s5p$		$(5p)^2$		$5s5d$		$5s6d$		$5s4f$	
	$^3P_2$ $^3P_1$	$^3P_0$	$^3P_2'$ $^3P_1'$	$^3P_0'$	$^3D_3$ $^3D_2$	$^3D_1$	$^3D_3$ $^3D_2$	$^3D_1$	$^3F_4$ $^3F_3$	$^3F_2$
Sn III	4034	1647	4446	2809	313	206	131	81	99	37
Sb IV	5860	2265	7135	4312	557	350	260	176	160	85
Te V	7977	2914	10173	6171	856	527	—	—	—	—

The line at 1120.43A has been identified as one of a pair of lines belonging to the transition $5^3P_{12}-5^1D_2$. Both these lines are identical in character with those of the $^3P-^3P'$ multiplet and appear in the same region with them. In Sn III and Te V similar pairs of lines are found. A corresponding identification in Sn III makes use of the line at 1369.76A, previously identified[4] as $^3P_1-^3P_0'$. However, this line is unquestionably associated with the $^3P_{12}$ interval, and in its stead we have chosen the line at 1386.76A for the transition $^3P_1-^3P_0'$.

In the accompanying tables some lines have been marked as questionable. This indicates either that the intensity appears abnormal, or that there is some doubt about the type of line produced by the inductance. In some cases these irregularities may merely mean the presence of two lines of different types or intensity, which the apparatus available has failed to resolve.

[7] Green and Lang, Proc. Nat. Acad. Sci. **14**, 707 (1928).