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The Spectra of Cd IV, In V and Sn VI in the Isoelectric Sequence Rh I to Sn VI

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The spectra of Cd IV, In V and Sn VI were photographed in the region 270A to 1800A with a three-meter, normal incidence, vacuum spectrograph, with a highly condensed, high voltage vacuum spark as a source of light. The irregular doublet law and the law of constant second difference were applied in the classification of many of the lines of these three ions. The separation of the $4d^9\ ^2D$ multiplet of the ground state has been found for all three ions. Most of the odd terms arising from the $4d^85p$ electron configuration and some of the even terms arising from the $4d^85s$ electron configuration have been determined. Classifications have been made for one hundred eighty-five lines of Cd IV, forty-three lines of In V and thirty-nine lines of Sn VI, making possible the assignment of fifty-one term values for Cd IV, thirty-two for In V and twenty-five for Sn VI.

THE spectra of Rh I, Pd II and Ag III have been analyzed by Sommers,[1] Shenstone[2] and Gilbert,[3] respectively. With the data on these three spectra in conjunction with the law of constant second difference and the irregular doublet law, the analyzed spectra of this isoelectronic sequence has been extended three more elements, i.e., through Sn VI. The predicted and observed terms for the spectra of

TABLE I. *Predicted and observed terms in* Cd IV, In V *and* Sn VI.

ELECTRON CONFIG.	PREDICTED TERMS	PARENT TERM IN ION	OBSERVED TERMS		
			Cd IV	In V	Sn VI
$4d^9$	^2D		^2D	^2D	^2D
$4d^85s$	^2S	^1S	—	—	—
	^2D	^1D			
	^2G	^1G	^2G		
	2 and ^4P	^3P			
	2 and ^4F	^3F	2 and ^4F		
$4d^85p$	$^2P^\circ$	^1S	—	—	—
	$^2(P^\circ D^\circ F^\circ)$	^1D	$^2(P^\circ D^\circ F^\circ)$	$^2(P^\circ D^\circ F^\circ)$	$^2(P^\circ D^\circ F^\circ)$
	$^2(F^\circ G^\circ H^\circ)$	^1G	$^2(F^\circ H^\circ)$	$^2F^\circ$	$^2F^\circ$
	2 and $^4(S^\circ P^\circ D^\circ)$	^3P	$^2(S^\circ P^\circ D^\circ)$	$^2(S^\circ P^\circ D^\circ)$	$^2(S^\circ P^\circ D^\circ)$
	2 and $^4(D^\circ F^\circ G^\circ)$	^3F	2 and $^4(D^\circ F^\circ G^\circ)$	2 and $^4(D^\circ F^\circ)$ $^4G^\circ$	$^2D^\circ$ 2 and $^4F^\circ$ $^4G^\circ$

TABLE II. *Radiated frequencies with first and second differences. First series members.*

ION	$4d^9\ ^2D_3-4d^8(^3F)5p\ ^2D^\circ_3$			$4d^9\ ^2D_3-4d^8(^3F)5p\ ^4F^\circ_4$		
Rh I	28,737			29,867		
		43,995			41,379	
Pd II	72,732		8365	71,246		11,003
		52,360			52,382	
Ag III	125,092		6850	123,628		6,963
		59,209			59,345	
Cd IV	184,301		6134	182,973		6,197
		65,343			65,542	
In V	249,644		5735	248,515		5,805
		71,076			71,345	
Sn VI	320,720			319,860		

TABLE III. *A comparison of the $4d^9\ ^2D_{3,2}$ splitting with the difference $4d^9\ 5s\ ^3D_3-4d^9\ 5s\ ^3D_1$ of the same element.*

ION	$^2D_{3,2}$(CM^{-1})		Ion	$^3D_{3,1}$(CM^{-1})	
Rh I	2350				
		1190			
Pd II	3540		Pd I	3530	
		1070			1045
Ag III	4610		Ag II	4575	
		1200			1195
Cd IV	5810		Cd III	5770	
		1350			1340
In V	7160		In IV	7110	
		1550			1510
Sn VI	8710		Sn V	8620	

TABLE IV. *Term values in* Cd IV.

TERM SYMBOL		RELATIVE TERM VALUES (CM^{-1})	TERM SYMBOL		RELATIVE TERM VALUES (CM^{-1})
$4d^9$	$^2D_3$	0	$4d^8(^3F)5p$	$^2D^\circ_2$	187,213
	$^2D_2$	5,812		$^2G^\circ_4$	188,147
$4d^8(^3F)5s$	$^4F_5$	108,704		$^2F^\circ_3$	188,296
	$^4F_4$	111,734	$(^3P)5p$	$^4P^\circ_1$	189,404
	$^4F_3$	114,758		$^4P^\circ_2$	190,411
	$^4F_2$	116,125		$^4P^\circ_3$	190,694
	$^2F_4$	118,333	$(^1D)5p$	$^2F^\circ_3$	191,953
	$^2F_3$	120,557		$^2P^\circ_1$	194,212
$(^1G)5s$	$^2G_5$	133,860		$^2F^\circ_4$	194,367
	$^2G_4$	134,010		$^2P^\circ_2$	195,542
$(^3F)5p$	$^4D^\circ_4$	172,387		$^2D^\circ_3$	196,255
	$^4G^\circ_5$	175,319	$(^3P)5p$	$^4D^\circ_1$	196,370
	$^4D^\circ_3$	177,252	$(^1D)5p$	$^2D^\circ_2$(?)	196,485
	$^4G^\circ_6$	179,173	$(^1G)5p$	$^2H^\circ_5$	196,560
	$^4G^\circ_4$	179,375	$(^3P)5p$	$^4D^\circ_4$	197,508
	$^4G^\circ_3$	180,812		$^4D^\circ_2$	198,220
	$^4D^\circ_2$	180,868		$^4D^\circ_3$	198,338
	$^4F^\circ_5$	181,672		$^2D^\circ_3$	199,525
	$^4F^\circ_2$	182,176		$^2D^\circ_2$	200,743
	$^4D^\circ_1$	182,864	$(^1G)5p$	$^2H^\circ_6$	201,293
	$^4F^\circ_4$	182,973	$(^3P)5p$	$^2P^\circ_2$	201,967
	$^2D^\circ_3$	184,301		$^2S^\circ_1$	202,655
	$^2G^\circ_5$	185,366	$(^1G)5p$	$^2F^\circ_4$	202,836
	$^4F^\circ_3$	186,307		$^2F^\circ_3$	204,196
	$^2F^\circ_4$	187,168	$(^3P)5p$	$^4S^\circ_2$	204,294
				$^2P^\circ_1$	206,402

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[1] L. A. Sommers, Zeits. f. Physik **45**, 147 (1927).
[2] A. G. Shenstone, Phys. Rev. **32**, 30 (1928).
[3] W. P. Gilbert, Phys. Rev. **48**, 338 (1935).

TABLE V. *Classified lines in* Cd IV.

INT.	λ VAC.	ν VAC.	CLASSIFICATION
1	1929.70	51,821	$4d^8(^3F)5s\ ^2F_3-4d^8(^3F)5p\ ^4D^\circ_4$
1	1850.40	54,043	$^2F_4-$ $^4D^\circ_4$
6	1763.67	56,700	$^2F_3-$ $^4D^\circ_3$
0	1735.42	57,623	$^4F_3-$ $^4D^\circ_4$
4	1700.14	58,819	$^2F_3-$ $^4G^\circ_4$
4	1697.07	58,925	$^2F_4-$ $^4D^\circ_3$
6	1659.51	60,259	$^2F_3-$ $^4G^\circ_3$
4	1658.08	60,311	$^2F_3-$ $^4D^\circ_2$
2	1648.58	60,658	$^4F_4-$ $^4D^\circ_4$
4	1638.19	61,042	$^2F_4-$ $^4G^\circ_4$
0	1635.81	61,132	$^4F_2-$ $^4D^\circ_3$
8	1622.87	61,619	$^2F_3-$ $^4F^\circ_2$
4	1602.20	62,414	$^2F_3-$ $^4F^\circ_4$
10	1600.42	62,484	$^2F_4-$ $^4G^\circ_3$
4	1600.13	62,495	$^4F_3-$ $^4D^\circ_3$
10	1598.73	62,550	$(^1G)5s\ ^2G_4-$ $(^1G)5p\ ^2H^\circ_5$
6	1594.86	62,701	$^2G_5-$ $^2H^\circ_5$
6	1578.90	63,335	$(^3F)5s\ ^2F_4-$ $(^3F)5p\ ^4F^\circ_5$
6	1572.69	63,585	$^4F_4-$ $^4G^\circ_5$
10	1570.20	63,686	$^4F_5-$ $^4D^\circ_4$
6	1547.62	64,615	$^4F_3-$ $^4G^\circ_4$
6	1547.01	64,641	$^2F_4-$ $^4F^\circ_4$
6	1545.79	64,691	$^4F_2-$ $^4G^\circ_3$
2	1544.52	64,745	$^4F_2-$ $^4D^\circ_2$
6	1526.15	65,520	$^4F_4-$ $^4D^\circ_3$
2	1520.88	65,750	$^2F_3-$ $^4F^\circ_3$
6	1515.77	65,973	$4d^8(^3F)5s\ ^2F_4-4d^8(^3F)5p\ ^2D^\circ_3$
6	1513.92	66,054	$^4F_2-$ $^4F^\circ_2$
6	1513.75	66,057	$^4F_3-$ $^4G^\circ_3$
6	1512.57	66,113	$^4F_3-$ $^4D^\circ_2$
6b	1501.13	66,616	$^2F_3-$ $^2F^\circ_4$ $^4F_5-$ $^4G^\circ_5$
4	1500.11	66,662	$^2F_3-$ $^2D^\circ_2$
4	1498.39	66,738	$^4F_2-$ $^4D^\circ_1$
10	1491.79	67,034	$^2F_4-$ $^2G^\circ_5$
0	1483.28	67,418	$^4F_3-$ $^4F^\circ_2$
8	1482.95	67,433	$(^1G)5s\ ^2G_5-$ $(^1G)5p\ ^2H^\circ_6$
6	1479.37	67,596	$(^3F)5s\ ^2F_3-$ $(^3F)5p\ ^2G^\circ_4$
6	1478.32	67,644	$^4F_4-$ $^4G^\circ_4$
6	1476.22	67,741	$^2F_3-$ $^2F^\circ_3$
6	1471.08	67,978	$^2F_4-$ $^4F^\circ_3$
8	1466.67	68,182	$^4F_2-$ $^2D^\circ_3$
8	1465.97	68,214	$^4F_3-$ $^4F^\circ_4$
2	1452.90	68,828	$(^1G)5s\ ^2G_4-$ $(^1G)5p\ ^2F^\circ_4$
10	1452.63	68,841	$(^3F)5s\ ^2F_4-$ $(^3F)5p\ ^2F^\circ_4$
6	1449.71	68,979	$(^1G)5s\ ^2G_5-$ $(^1G)5p\ ^2F^\circ_4$
10	1447.54	69,083	$(^3P)5s\ ^4F_4-$ $(^3F)5p\ ^4G^\circ_3$
6	1437.90	69,546	$^4F_3-$ $^2D^\circ_3$
4	1432.23	69,821	$^2F_4-$ $^2G^\circ_4$
4	1431.55	69,854	$^2F_3-$ $(^3P)5p\ ^4P^\circ_2$
8	1429.83	69,938	$^4F_4-$ $(^3F)5p\ ^4F^\circ_5$
6	1429.28	69,965	$^2F_4-$ $^2F^\circ_3$
6	1425.73	70,139	$^2F_3-$ $(^3P)5p\ ^4P^\circ_3$
6	1424.92	70,179	$4d^8(^1G)5s\ ^2G_4-4d^8(^1G)5p\ ^2F^\circ_3$
4	1424.81	70,185	$(^3F)5s\ ^4F_2-$ $(^3F)5p\ ^4F^\circ_5$
16	1418.89	70,478	$^4F_5-$ $^4G^\circ_6$
6	1414.83	70,680	$^4F_5-$ $^4G^\circ_4$
8	1406.58	71,094	$4d^8(^3F)5s\ ^4F_2-4d^8(^3F)5p\ ^2D^\circ_2$
12	1403.68	71,239	$^4F_4-$ $^4F^\circ_4$
6	1400.72	71,392	$^2F_3-$ $(^1D)\ ^2F^\circ_3$
10	1397.65	71,549	$^4F_3-$ $(^3F)\ ^4F^\circ_3$
6	1385.55	72,173	$^4F_2-$ $^2F^\circ_3$
2	1381.88	72,365	$^2F_4-$ $(^3P)\ ^4P^\circ_3$
12	1380.98	72,412	$^4F_3-$ $(^3F)\ ^2F^\circ_4$
16	1370.48	72,967	$^4F_5-$ $^4F^\circ_5$
4	1364.37	73,294	$^4F_2-$ $(^3P)\ ^4P^\circ_1$
12	1362.55	73,392	$^4F_3-$ $(^3F)\ ^2G^\circ_4$
4	1359.86	73,537	$^4F_3-$ $^2F^\circ_3$
6	1358.49	73,611	$^2F_4-$ $(^1D)\ ^2F^\circ_3$
10	1358.11	73,632	$^4F_4-$ $(^3F)\ ^2G^\circ_5$
12	1354.78	73,813	$^2F_3-$ $(^1D)\ ^2F^\circ_4$
4	1346.45	74,269	$^4F_5-$ $(^3F)\ ^4F^\circ_4$
8	1346.15	74,286	$^4F_2-$ $(^3P)\ ^4P^\circ_2$
12	1340.97	74,573	$^4F_4-$ $(^3F)\ ^4F^\circ_3$ $^4F_2-$ $(^3P)\ ^4F^\circ_3$
6	1333.53	74,989	$^2F_3-$ $(^3P)\ ^2P^\circ_2$
10	1325.55	75,440	$4d^8(^3F)5s\ ^4F_4-4d^8(^3F)5p\ ^2F^\circ_4$
8	1321.85	75,651	$^4F_3-$ $(^3P)\ ^4P^\circ_2$
4	1318.94	75,818	$^4F_2-$ $(^1D)\ ^2F^\circ_3$(?)
4	1316.99	75,931	$^2F_3-$ $(^1D)\ ^2D^\circ_2$(?)
8	1316.89	75,935	$^4F_3-$ $(^3P)\ ^4P^\circ_3$
4	1315.12	76,039	$^2F_4-$ $(^1D)\ ^2F^\circ_4$
12	1306.07	76,566	$^4F_4-$ $(^3F)\ ^2F^\circ_3$
14	1304.36	76,666	$^4F_5-$ $^2G^\circ_5$
10	1299.46	76,955	$^2F_3-$ $(^3P)\ ^4D^\circ_4$
10	1287.58	77,665	$^2F_3-$ $^4D^\circ_2$
10	1285.63	77,783	$^2F_3-$ $^4D^\circ_3$
4	1283.23	77,928	$^2F_4-$ $(^1D)\ ^2D^\circ_3$
00	1280.50	78,094	$^4F_2-$ $^2P^\circ_1$
8	1274.41	78,468	$^2F_4-$ $(^3F)\ ^4F^\circ_5$
12b	1266.47	78,960	$^4F_4-$ $(^3P)\ ^4P^\circ_3$
2	1266.25	78,973	$^2F_3-$ $(^3P)\ ^2D^\circ_3$
6	1262.98	79,178	$^2F_2-$ $(^3P)\ ^4D^\circ_4$
6	1259.14 (OV)(?)	79,421	$^4F_2-$ $(^1D)\ ^2P^\circ_2$
1	1256.16	79,608	$4d^8(^3F)5s\ ^4F_3-4d^8(^1D)5p\ ^2F^\circ_4$
8	1249.94	78,004	$^2F_4-$ $(^3P)\ ^4D^\circ_3$
2	1247.39 (CIII)(?)	80,195	$^2F_3-$ $^2D^\circ_2$
8	1246.56	80,220	$^4F_4-$ $(^1D)\ ^2F^\circ_3$
10	1246.06	80,253	$^4F_2-$ $(^3P)\ ^4D^\circ_1$
4	1237.87	80,784	$^4F_3-$ $^2P^\circ_2$
0	1231.51	81,201	$^2F_4-$ $^2D^\circ_3$
0	1228.40	81,407	$^2F_3-$ $^2P^\circ_2$
4	1227.07	81,495	$^4F_3-$ $(^1D)\ ^2D^\circ_3$
10	1223.52	81,731	$^4F_3-$ $^2D^\circ_2$
1	1218.04	82,099	$^4F_2-$ $^4D^\circ_2$
8	1215.38	82,279	$^2F_3-$ $(^1G)\ ^2F^\circ_4$
6	1210.24	82,638	$^4F_4-$ $(^1D)\ ^2F^\circ_4$
3	1208.43	82,752	$^4F_3-$ $(^3P)\ ^4D^\circ_4$
10	1198.93	83,408	$^4F_2-$ $^2D^\circ_3$
3	1198.15	83,462	$^4F_1-$ $^2D^\circ_2$
12	1196.47	83,579	$^4F_3-$ $^4D^\circ_3$
10	1195.63	83,638	$^2F_3-$ $(^1G)\ ^2F^\circ_3$
14	1194.13	83,743	$^2F_3-$ $(^3P)\ ^4S^\circ_2$
20	1183.40	84,502	$4d^8(^3F)5s\ ^2F_4-4d^8(^1G)5p\ ^2D^\circ_2$
8	1183.07	84,526	$^4F_4-$ $^2D^\circ_3$
4	1181.66	84,627	$(^3F)\ ^4F_2-$ $(^3P)\ ^2D^\circ_2$
10	1179.73	84,765	$^4F_3-$ $^2D^\circ_3$
14	1167.30	85,668	$^4F_5-$ $^2F^\circ_4$
10	1165.78	85,780	$^4F_4-$ $^4D^\circ_4$
0	1164.89	85,845	$^4F_2-$ $^2P^\circ_2$
20	1164.65	85,863	$^2F_4-$ $(^1G)\ ^2F^\circ_3$
4	1162.87	85,994	$^4F_3-$ $(^3P)\ ^2D^\circ_2$
7	1155.73	86,525	$^4F_2-$ $^2S^\circ_1$
10	1154.64	86,607	$^4F_4-$ $^4D^\circ_3$
2	1146.71	87,206	$^4F_3-$ $^2P^\circ_2$
8	1139.04	87,793	$^4F_4-$ $^2D^\circ_3$
2	1135.46	88,070	$^4F_2-$ $(^1G)\ ^2F^\circ_3$
10	1134.08	88,177	$^4F_2-$ $(^3P)\ ^4S^\circ_2$
12	1126.00	88,810	$^4F_5-$ $^4D^\circ_4$
24	1118.16	89,433	$^4F_3-$ $(^1G)\ ^2F^\circ_3$
2	1116.88	89,535	$^4F_3-$ $(^3P)\ ^4S^\circ_2$
0	1107.76	90,272	$^4F_2-$ $^2P^\circ_1$
6	1097.53	91,114	$4d^8(^3F)5s\ ^4F_4-4d^8(^1G)5p\ ^2F^\circ_4$(?)
2	1081.50	92,464	$^4F_4-$ $^2F^\circ_3$
10	1062.23	94,142	$^4F_5-$ $^2F^\circ_4$
3	583.30	171,438	$4d^9\ ^2D_2-$ $(^3F)\ ^4D^\circ_3$

TABLE V.—*Continued.*

INT.	λ VAC.	ν VAC.	CLASSIFICATION
3	580.09	172,387	$^2D_3-\quad {}^4D^\circ_4$
3	571.43	175,000	$^2D_2-\quad {}^4G^\circ_3$
6	571.25	175,055	$^2D_2-\quad {}^4D^\circ_4$
18	567.03	176,358	$^2D_2-\quad {}^4F^\circ_2$
3	564.80	177,054	$^2D_2-\quad {}^4P^\circ_1$
11	564.17	177,252	$^2D_3-\quad {}^4D^\circ_3$
14	560.25	178,492	$^2D_2-\quad {}^2D^\circ_3$
9	557.49	179,375	$^2D_3-\quad {}^4G^\circ_4$
18	554.04	180,493	$^2D_2-\quad {}^4F^\circ_3$
17	553.06	180,812	$^2D_3-\quad {}^4G^\circ_3$
10	552.89	180,868	$^2D_3-\quad {}^4D^\circ_2$
11	551.26	181,403	$^2D_2-\quad {}^2D^\circ_2$
10	548.92	182,176	$^2D_3-\quad {}^4F^\circ_2$
11	548.00	182,482	$^2D_2-\quad {}^2F^\circ_3$
25	546.53	182,973	$^2D_3-\quad {}^4F^\circ_4$
9	544.68	183,594	$^2D_2-4d^8(^3P)5p\ {}^4P^\circ_1$
25	542.59	184,301	$^2D_3-\quad (^3F)\ {}^2D^\circ_3$
18	541.73	184,594	$^2D_2-\quad (^3P)\ {}^4P^\circ_2$
17	540.89	184,881	$^2D_2-\quad {}^4P^\circ_3$
14	537.22	186,144	$^2D_2-\quad (^1D)\ {}^2F^\circ_3$
17	536.75	186,307	$^2D_3-\quad (^3F)\ {}^4F^\circ_3$
17	534.28	187,168	$^2D_3-\quad {}^2F^\circ_4$
18	531.50	188,147	$^2D_3-\quad {}^2G^\circ_4$
18	531.08	188,296	$^2D_3-\quad {}^2F^\circ_3$
14	530.78	188,402	$^2D_2-\quad (^1D)\ {}^2P^\circ_1$
18	527.06	189,732	$^2D_2-\quad {}^2P^\circ_2$
14	525.18	190,411	$^2D_3-\quad (^3P)\ {}^4P^\circ_2$
17	525.09	190,444	$^2D_2-\quad (^1D)\ {}^2D^\circ_3$
14	524.77	190,560	$^2D_2-\quad (^3P)\ {}^4D^\circ_1?$
14	524.46	190,672	$^2D_2-\quad (^1D)\ {}^2D^\circ_2?$
14	524.40	190,694	$^2D_3-\quad (^3P)\ {}^4P^\circ_3$
9	520.96	191,953	$^2D_3-\quad (^1D)\ {}^2F^\circ_3$
14	519.41	192,526	$^2D_2-\quad (^3P)\ {}^4D^\circ_3$
1	516.22	193,716	$^2D_2-\quad (^3P)\ {}^2D^\circ_3$
17	514.49	194,367	$^2D_3-4d^8(^1D)5p\ {}^2F^\circ_4$
17	512.99	194,936	$^2D_2-\quad (^3P)\ {}^2D^\circ_2$
17	511.40	195,542	$^2D_3-\quad (^1D)\ {}^2P^\circ_2$
3	509.80	196,155	$^2D_2-\quad (^3P)\ {}^2P^\circ_2$
17	509.54	196,255	$^2D_3-\quad (^1D)\ {}^2D^\circ_3$
17	508.01	196,847	$^2D_2-\quad (^3P)\ {}^2S^\circ_1$
19	506.31	197,508	$^2D_3-\quad (^3P)\ {}^4D^\circ_4$
17	504.49	198,220	$^2D_3-\quad {}^4D^\circ_2$
11	504.19	198,338	$^2D_3-\quad {}^4D^\circ_3$
14	504.09	198,377	$^2D_2-\quad (^1G)\ {}^2F^\circ_3$
3	503.81	198,488	$^2D_2-\quad (^3P)\ {}^4S^\circ_2$
1	501.19	199,525	$^2D_3-\quad {}^2D^\circ_3$
17	498.53	200,590	$^2D_2-\quad {}^2P^\circ_1$
17	498.15	200,743	$^2D_3-\quad {}^2D^\circ_2$
17	495.13	201,967	$^2D_3-\quad {}^2P^\circ_1$
17	493.00	202,840	$^2D_3-\quad (^1G)\ {}^2F^\circ_4$
2	489.76	204,182	$^2D_3-\quad {}^2F^\circ_3$
10	489.49	204,294	$^2D_3-\quad (^3P)\ {}^4S^\circ_2$

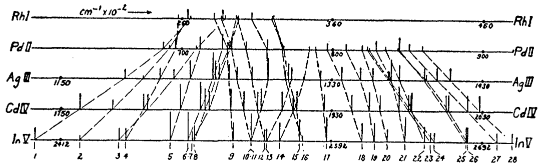
these ionized atoms are shown in Table I. In Table II are listed the frequencies of the two strong transitions $4d^9\ {}^2D_3-4d^8(^3F)5p\,{}^2D^\circ_3$, and $4d^9\ {}^2D_3-4d^8(^3F)5p\,{}^4F^\circ_4$ with first and second differences. The data in the second difference column show an approach toward a constant value for increasing ionization. The displaced frequency diagram for $4d^9-4d^85p$ transition is shown in Fig. 1.

The data in Table III give a comparison of the over-all separation of the triplet levels of the $4d^95s$ electron configuration with the doublet separation of the normal $4d^9\ {}^2D$ state of the ion, indicating the existence of nearly pure *jj*-coupling between the $4d^9$ ion and the $5s$ electron for the ionized atoms isoelectronic with Pd I.

TABLE VI. *Term values in* In V.

TERM SYMBOL	RELATIVE TERM VALUES (CM⁻¹)	TERM SYMBOL	RELATIVE TERM VALUES (CM⁻¹)
$4d^9\ {}^2D_3$	0	$(^1D)5p\ {}^2F^\circ_4$	261,260
$^2D_2$	7,165	$^2P^\circ_2$	262,082
$4d^8(^3F)5p\ {}^4D^\circ_4$	236,317	$^2D_3$	262,971
$^4D^\circ_3$	241,051	$(^1D)5p\ {}^2D^\circ_2$(?)	263,555
$^4G^\circ_4$	243,315	$(^3P)5p\ {}^4D^\circ_4$	264,124
$^4G^\circ_3$	245,128	$^4D^\circ_2$	265,908
$^4D^\circ_2$	246,145	$^4D^\circ_3$	266,071
$^4F^\circ_2$	246,713	$^2D^\circ_2$	268,226
$^4F^\circ_4$	248,515	$^2D^\circ_3$	268,894
$^2D^\circ_3$	249,644	$(^3P)5p\ {}^2P^\circ_2$	270,197
$^2D^\circ_2$	252,648	$^2S^\circ_1$	270,850
$^4F^\circ_3$	252,691	$(^1G)5p\ {}^2F^\circ_4$	271,245
$^2F^\circ_4$	253,878	$^2F^\circ_3$	272,565
$(^3P)5p\ {}^4P^\circ_3$	257,129	$(^3P)5p\ {}^4S^\circ_2$	273,867
$^4P^\circ_2$	257,294	$^2P^\circ_1$	275,305
$(^1D)5p\ {}^2F^\circ_3$	258,598		
$^2P^\circ_1$	261,220		

The spectrograms of cadmium, indium and tin were taken with a three-meter normal incidence vacuum spectrograph. The electrodes used for obtaining the spectra of cadmium and tin were cast from the pure molten metals while those for indium were made by packing an alloy of indium and aluminum into aluminum shells. All elec-



1. $^2D_2-(^3F)^2F^\circ_2$
2. $^2D_2-\quad {}^2D^\circ_3$
3. $^2D_3-\quad {}^4G^\circ_3$
4. $^2D_2-\quad {}^4F^\circ_3$
5. $^2D_3-\quad {}^4F^\circ_4$
6. $^2D_3-\quad {}^2D^\circ_3$
7. $^2D_2-(^3P)^4P^\circ_3$
8. $^2D_2-\quad {}^4P^\circ_2$
9. $^2D_3-(^3F)^4F^\circ_3$
10. $^2D_3-\quad {}^2F^\circ_4$
11. $^2D_3-(^3F)^2F^\circ_3$
12. $^2D_3-\quad {}^2G^\circ_4$
13. $^2D_2-(^1D)^2P^\circ_2$
14. $^2D_2-\quad {}^2D^\circ_3$
15. $^2D_3-(^3P)^4P^\circ_3$
16. $^2D_3-\quad {}^4P^\circ_2$
17. $^2D_2-\quad {}^4D^\circ_3$
18. $^2D_3-(^1D)^2F^\circ_4$
19. $^2D_3-(^1D)^2P^\circ_2$
20. $^2D_3-\quad {}^2D^\circ_3$
21. $^2D_3-(^3P)^4D^\circ_4$
22. $^2D_2-(^1G)^2F^\circ_2$
23. $^2D_3-(^3P)^4D^\circ_2$
24. $^2D_3-(^3P)^4D^\circ_3$
25. $^2D_2-\quad {}^2P^\circ_1$
26. $^2D_3-\quad {}^2D^\circ_2$
27. $^2D_3-\quad {}^2P^\circ_2$
28. $^2D_3-(^1G)^2F^\circ_4$

FIG. 1. Displaced frequency diagram, law of constant second differences for $4d-5p$ electron transition.

TABLE VII. *Classified lines in* In V.

INT.	λ VAC.	ν VAC.	CLASSIFICATION
2	423.16	236,317	$4d^9\ {}^2D_3-4d^8({}^3F)5p\ {}^4D^\circ_4$
0	420.16	238,005	${}^2D_2-\ ({}^3F)\ {}^4G^\circ_3$
2	418.45	238,977	${}^2D_2-\ ({}^3F)\ {}^4D^\circ_2$
9	417.43	239,561	${}^2D_2-\ ({}^3F)\ {}^4F^\circ_2$
0	414.85	241,051	${}^2D_3-\ ({}^3F)\ {}^4D^\circ_3$
0	412.41	242,477	${}^2D_2-\ ({}^3F)\ {}^2D^\circ_3$
9	407.95	245,128	${}^2D_3-\ \ {}^4G^\circ_3$
3	407.36	245,483	${}^2D_2-\ ({}^3F)\ {}^2D^\circ_2$
9	407.28	245,531	${}^2D_2-\ \ {}^4F^\circ_3$
3	405.33	246,713	$\left\{\begin{array}{l}{}^2D_2-\ ({}^3F)\ {}^2F^\circ_3\\{}^2D_2-\ ({}^3F)\ {}^4F^\circ_2\end{array}\right\}$
25	402.39	248,515	${}^2D_3-\ ({}^3F)\ {}^4F^\circ_4$
25	400.57	249,644	${}^2D_3-\ ({}^3F)\ {}^2D^\circ_3$
9	400.05	249,969	${}^2D_2-\ ({}^3P)\ {}^4P^\circ_3$
10	399.79	250,131	${}^2D_2-\ ({}^3P)\ {}^4P^\circ_2$
3	397.73	251,427	${}^2D_2-\ ({}^1D)\ {}^2F^\circ_3$
11	395.74	252,691	${}^2D_3-\ ({}^3F)\ {}^4F^\circ_3$
25	393.89	253,878	$\left\{\begin{array}{l}{}^2D_3-\ ({}^3F)\ {}^2F^\circ_3\\{}^2D_3-\ ({}^3F)\ {}^2F^\circ_4\end{array}\right\}$
1	393.60	254,065	${}^2D_2-\ ({}^1D)\ {}^2P^\circ_1$
9	392.46	254,803	${}^2D_3-\ ({}^3F)\ {}^2G^\circ_4$
9	392.29	254,914	${}^2D_2-\ ({}^1D)\ {}^2P^\circ_2$
11	390.92	255,807	$4d^9\ {}^2D_2-4d^8({}^1D)5p\ {}^2D^\circ_3$
11	390.03	256,391	${}^2D_2-\ ({}^1D)\ {}^2D^\circ_2$(?)
14	388.91	257,129	${}^2D_3-\ ({}^3P)\ {}^4P^\circ_3$
3	388.66	257,294	${}^2D_3-\ ({}^3P)\ {}^4P^\circ_2$
10	386.70	258,598	${}^2D_3-\ ({}^1D)\ {}^2F^\circ_3$
17	386.21 (CIII)(?)	258,927	${}^2D_2-\ ({}^3P)\ {}^4D^\circ_3$
10	383.05	261,063	${}^2D_2-\ ({}^3P)\ {}^2D^\circ_2$
11	382.76	261,260	${}^2D_3-\ ({}^1D)\ {}^2F^\circ_4$
9	382.14	261,684	${}^2D_2-\ ({}^3P)\ {}^2D^\circ_3$
11	381.56	262,082	${}^2D_3-\ ({}^1D)\ {}^2P^\circ_2$
9	380.27	262,971	${}^2D_3-\ ({}^1D)\ {}^2D^\circ_3$
3	379.24	263,685	${}^2D_2-\ ({}^3P)\ {}^2S^\circ_1$
17	378.61	264,124	${}^2D_3-\ ({}^3P)\ {}^4D^\circ_4$
10	376.79	265,400	${}^2D_2-\ ({}^1G)\ {}^2F^\circ_3$
6	376.07	265,908	${}^2D_3-\ ({}^3P)\ {}^4D^\circ_2$
6	375.84	266,071	${}^2D_3-\ ({}^3P)\ {}^4D^\circ_3$
2	374.95	266,702	${}^2D_2-\ ({}^3P)\ {}^4S^\circ_2$
10	372.94	268,140	${}^2D_2-\ ({}^3P)\ {}^2P^\circ_1$
10	372.82	268,226	${}^2D_3-\ ({}^3P)\ {}^2D^\circ_2$
6	370.10	270,197	${}^2D_3-\ ({}^3P)\ {}^2P^\circ_2$
6	368.67	271,245	${}^2D_3-\ ({}^1G)\ {}^2F^\circ_4$

TABLE VIII. *Term values in* Sn VI.

TERM SYMBOL	RELATIVE TERM VALUES (CM^{-1})
$4d^9\ {}^2D_3$	0
${}^2D_2$	8,715
$4d^8({}^3F)5p\ {}^4G^\circ_3$	315,060
${}^4F^\circ_2$	317,581
${}^4F^\circ_4$	319,857
${}^2D^\circ_3$	320,718
${}^4F^\circ_3$	324,925
${}^2F^\circ_3$	326,712
$({}^3P)5p\ {}^4P^\circ_3$	329,131
${}^4P^\circ_2$	330,098
$({}^1D)5p\ {}^2F^\circ_3$	331,356
${}^2F^\circ_4$	333,868
$({}^1D)5p\ {}^2P^\circ_1$	334,183
${}^2P^\circ_2$	334,348
${}^2D^\circ_3$	335,638
${}^2D^\circ_2$	336,530
$({}^3P)5p\ {}^4D^\circ_4$	336,678
${}^4D^\circ_2$	339,443
${}^2D^\circ_2$	341,729
${}^2D^\circ_3$	342,861
${}^2P^\circ_2$	344,400
${}^2S^\circ_1$	344,883
$({}^1G)5p\ {}^2F^\circ_4$	345,770
${}^2F^\circ_3$	347,021
$({}^3P)5p\ {}^2P^\circ_1$	350,245

trodes had a hard pencil lead inserted as a core. The power for the vacuum spark was supplied from a bank of condensers (3 mf capacity) which were charged through a kenotron to a peak potential of 25 kv. The primary of the transformer was operated at 110 volts and 10 amperes.

Prior to the analysis given here L. Bloch and E. Bloch[4] had photographed and measured many of the lines of Cd IV using a high frequency electrodeless discharge as a source. Classifications for some of the stronger lines were suggested by them, none of which turned out to be correct.

TABLE IX. *Classified lines in* Sn VI.

INT.	λ VAC.	ν VAC.	CLASSIFICATION
4	326.43	306,344	$4d^9\ {}^2D_3-4d^8({}^3F)5p\ {}^4G^\circ_3$
1	323.82	308,814	${}^2D_2-\ \ {}^4F^\circ_2$
0	321.15	311,381	${}^2D_2-\ \ {}^2D^\circ_3$
18	317.40	315,060	${}^2D_3-\ \ {}^4G^\circ_3$
16	316.23	316,226	${}^2D_2-\ \ {}^4F^\circ_3$
1	314.88	317,581	${}^2D_3-\ \ {}^4F^\circ_2$
12	312.64	319,857	${}^2D_3-\ \ {}^4F^\circ_4$
10	312.41	320,092	${}^2D_2-\ ({}^3P)5p\ {}^4P^\circ_1$
15	312.10	320,410	${}^2D_2-\ \ {}^4P^\circ_3$
17	311.80	320,718	${}^2D_3-\ ({}^3F)5p\ {}^2D^\circ_3$
16	311.15	321,388	${}^2D_2-\ ({}^3P)5p\ {}^4P^\circ_2$
5	309.94	322,643	${}^2D_2-\ ({}^1D)5p\ {}^2F^\circ_3$
17	307.77	324,920	${}^2D_3-\ ({}^3F)5p\ {}^4F^\circ_3$
15	307.43	325,277	${}^2D_3-\ ({}^3F)5p\ {}^2F^\circ_3$
3	307.25	325,468	${}^2D_2-\ ({}^1D)5p\ {}^2P^\circ_1$
15	307.12	325,606	${}^2D_2-\ \ {}^2P^\circ_2$
10	306.08	326,712	${}^2D_3-\ ({}^3F)5p\ {}^2F^\circ_4$
12	305.87	326,936	${}^2D_2-\ ({}^1D)5p\ {}^2D^\circ_3$
13	305.51	327,322	${}^2D_3-\ ({}^3F)5p\ {}^2G^\circ_4$
15	305.05	327,815	${}^2D_2-\ ({}^1D)5p\ {}^2D^\circ_2$
15	303.83	329,131	$4d^9\ {}^2D_3-4d^8({}^3P)5p\ {}^4P^\circ_3$
3	302.94	330,098	${}^2D_3-\ \ {}^4P^\circ_2$
10	302.33	330,764	${}^2D_2-\ \ {}^4D^\circ_2$
9	302.00	331,126	${}^2D_2-\ \ {}^4D^\circ_3$
10	301.79	331,356	${}^2D_3-\ ({}^1D)5p\ {}^2F^\circ_3$
10	300.34	332,956	${}^2D_2-\ ({}^3P)5p\ {}^2D^\circ_2$
12	299.52	333,868	${}^2D_3-\ ({}^1D)5p\ {}^2F^\circ_4$
8	299.27	334,146	${}^2D_2-\ ({}^3P)5p\ {}^2D^\circ_3$
8	299.09	334,348	${}^2D_3-\ ({}^1D)5p\ {}^2P^\circ_2$
5	297.94	335,638	${}^2D_3-\ \ {}^2D^\circ_3$
4	297.47	336,168	${}^2D_2-\ ({}^3P)5p\ {}^2S^\circ_1$
10	297.02	336,678	${}^2D_3-\ \ {}^4D^\circ_4$
10	295.59	338,306	${}^2D_2-\ ({}^1G)5p\ {}^2F^\circ_3$
5	294.60	339,443	${}^2D_3-\ ({}^3P)5p\ {}^4D^\circ_2$
5	294.24	339,859	${}^2D_3-\ \ {}^4D^\circ_3$
1	292.80	341,530	${}^2D_2-\ \ {}^2P^\circ_1$
1	292.63	341,729	${}^2D_3-\ \ {}^2D^\circ_2$
10	290.36	344,400	${}^2D_3-\ \ {}^2P^\circ_2$
2	289.21	345,770	${}^2D_3-\ ({}^1G)5p\ {}^2F^\circ_4$

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[4] L. Bloch and E. Bloch, Ann. de physique **5–6**, 332 (1936).

They did obtain, however, the correct value for the $4d^9\,{}^2D_{3,2}$ splitting of the ground state, namely 5810 cm^{-1}.

The term values of Cd IV, In V and Sn VI are listed relative to the $4d^9\,{}^2D_3$ level of the ground state of each ion and are to be found in Tables IV, VI and VIII. The estimated intensities of all classified lines are given in Tables V, VII and IX along with the wave-lengths and corresponding frequencies reduced to vacuum.

The writer is very much indebted to Professor H. E. White for suggesting the problem and for his valuable advice during the course of the investigation.

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Finite Self-Energies in Radiation Theory. Part I

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According to Dirac, electric particles display a finite radius $r_0=2e^2/3mc^2$ as the result of the damping term $(2e^2/3mc^3)d^3x/dt^3$ in the equation of motion. If the finite radius is due to radiative damping, the same must necessarily be true for the finite self-energy that is inversely proportional to the radius. An infinitely large self-energy and an infinitely small radius (Coulomb's law e^2/r) results from *Fermi's* Fourier representation of classical electrodynamics. A certain change is necessary, but the change is to produce at once a finite self-energy and a finite radius r_0. Now, an electric particle vibrating in a field of frequency ν suffers a reduction R_ν of its vibrational energy due to radiative damping, the energy reduction factor being $R_\nu=1/[1+(\nu/\nu_0)^2]$ where $\nu_0=3mc^3/4\pi e^2$. In view of the uncertainty of position due to damping we propose that the Fourier terms in the expression for the *energy* in Fermi's classical radiation theory be reduced by the same factor R_ν with Doppler effect for particles in motion. The result of this reduction is that Dirac's finite radius r_0 now occurs in a modified Coulomb energy $(e^2/r)[1-\exp(-r/r_0)]$, and the finite self-energy of a single particle becomes $e^2/2r_0=(3/4)mc^2$. Whereas the force between charged particles of finite mass remains finite for $r=0$, the force on an ideal test charge of infinite mass becomes infinite for $r=0$. This is analogous to the difference between the field E and the displacement D in Born's unitary field theory. Of interest for nuclear reactions are the electrostatic forces between particles of different masses m and M. The results are related to Sommerfeld's fine-structure constant and to the theory of mesons.

1. INTRODUCTION

ELECTRIC particles can be treated from the unitary or dualistic point of view. In the unitary theory a particle is but a spherically symmetric solution of certain modified field equations, without singularity at $r=0$. Born-Infeld's new field equations yield a finite maximum field $e/r_0{}^2$ at $r=0$. The electronic radius r_0 can be adjusted so that the total field energy is $\kappa\cdot mc^2$; the fraction κ can be chosen at will. This adjustable parameter is a disadvantage since we cannot know beforehand what fraction of the total mass is of electromagnetic origin. We prefer the dualistic point of view in which particles of various masses m are taken for granted, and the field produced by them, the "radius" and the self-energy, are to be expressed in terms of e and m.

One general point is common to all theories of electric particles. The smaller the radius, the larger the mass, the product r_0mc^2 being proportional to the square of the universal charge. However, the accepted (dualistic) radiation theory leads to an infinitely large self-energy and to an infinitely small radius, as expressed in Coulomb's energy $e^2/r=\infty$ for $r=0$. *If there are any reasons for having a finite radius then the same reasons must also be responsible for the finite self-energy.*

A radius dependent on the charge and mass occurs in Thomson's formula for the scattering cross section of an electric particle as the result of *radiative damping*. A similar radius occurs in Dirac's re-examination of the classical Lorentz theory.[1] Due to the damping term

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[1] P. A. M. Dirac, Proc. Roy. Soc. **A167**, 148 (1938).