THE ARC SPECTRUM OF PALLADIUM

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Abstract

A practically complete analysis of Pd I is given, based on previous analyses. The electron structures are d^{10}, $d^9 5s$, $6s$, $7s$, $8s$ (part of) $d^8 s^2$ (incomplete) $d^9 5p$, $d^8 sp$ and $d^9 6p$ (parts of), $d^9 5d$, $d^9 6d$ (almost complete).

The presence of an unidentified level k_1 is discussed and it is shown that the only explanation within the Hund theory is that k_1 is a hyperfine structure component of $5d\,^3P_1$. Such an assignment presents very great difficulties.

THE ARC spectrum of palladium has played a considerable part in the development and correction of the Hund theory of atomic spectra. It was partially analyzed by Beals[1] and, later, more completely by McLennan and Smith[2] and by Bechert and Catalan.[3] About the time when McLennan was engaged on the analysis, there appeared Hund's[4] paper, on the correlation between components of terms and the components of the limit terms on which they are built. This circumstance was unfortunate because the accuracy of the theory was quite naturally accepted by McLennan and the naming of the levels of the spectrum was carried out to agree with that theory instead of with the usual criteria, intensities and Zeeman effects. A little later Hund's book[5] was published; and, in it, McLennan's analysis of Pd I appeared as the most conclusive evidence for the theory of limits. That theory has since been proved to be correct in only a few trivial cases.[6] The analysis of Pd I has been only partially corrected in a paper on Ag II by McLennan and McLay[7] and by Shenstone.[8] The present designation of terms was communicated to Gibbs and White and was used by them in their paper[9] on Cd III.

The following analysis is based on the numerical analyses of McLennan and Smith, and Bechert and Catalan. A considerable number of new terms has been found, some of which can be identified as second series members of the d-electron series. The spectrum in the ultraviolet has been measured, and new lines have been found by long exposures throughout the whole visible and ultraviolet.

As much information as possible has been collected in the term table.

[1] Beals, Proc. Roy. Soc. **109A,** 369 (1925).
[2] McLennan and Smith, Proc. Roy. Soc. **112A,** 110 (1926).
[3] Bechert and Catalan, Zeits. f. Physik **35,** 449 (1926).
[4] Hund, Zeits. f. Physik **34,** 296 (1925).
[5] Hund, Linien Spektren und Periodisches System.
[6] Hund, Zeits. f. Physik **52,** 601 (1929).
[7] McLennan and McLay, Trans. Roy. Soc. Can. **22,** 10 (1928).
[8] Shenstone, Nature **121,** 619 (1928).
[9] Gibbs and White, Phys. Rev. **31,** 776 (1928).

Electron configurations, the notation used by Bechert and Catalan, and by McLennan and Smith, the present notation, the level, the level connections, the g-values where known, the Landé g-values, and the Rydberg denominators are given in successive columns. The intervals and g-sums are tabulated separately at the end of the term table.

TABLE I. *Term Table, Pd I.*

Origin.	B. & C.	McL.	S.	Level	Obs. "g"	Landé "g"	Ryd. Den.
$4d^{10}$	$^1S_0$	1^1S_0	a^1S_0	0.0			
$4d^9(^2D_{2\frac{1}{2}})5s$	$^3D_3$	1^3D_3	$5s^3D_3$	6564.0*	1.33	1.33	1.3446
"	$^3D_2$	1^3D_2	$5s^3D_2$	7755.0*	1.17	1.17	1.3579
$4d^9(^2D_{1\frac{1}{2}})5s$	$^3D_1$	1^3D_1	$5s^3D_1$	10093.9*	.50	.50	1.3445
"	$^1D_2$	1^1D_2	$5s^1D_2$	11721.7	1.00	1.00	1.3629
$4d^85s^2$	$^1G_4$	b^3F_4	a^3F_4	25101.1 *			1.2775
"		b^3F_3	a^3F_3	28213.5 *			
"			a^3F_2	29711.0 *			
$4d^9(^2D_{2\frac{1}{2}})5p$	$^3P_2$	1^3P_2	$5p^3P_2$	34068.8*	1.50	1.50	1.8185
"	$^3F_3$	1^1F_3	$5p^3F_3$	35451.3· *	1.08	1.08	1.8576
"	$^3F_4$	1^3F_4	$5p^3F_4$	35927.8· *	1.25	1.25	1.8717
"	$^3P_1$	1^3P_1	$5p^3P_1$	36180.5*·	1.42	1.50	1.8793
"	$^3D_2'$	$1^1D_2'$	$5p^3D_2$	36975.8·· *	1.03	1.17	1.9038
"	$^3D_3'$	1^3F_3	$5p^3D_3$	37393.5·· *	1.33	1.33	1.9171
$4d^85s^2$			a^3P_2	37952.0···			1.2935
$4d^9(^2D_{1\frac{1}{2}})5p$	$^3P_0$	1^3P_0	$5p^3P_0{}^0$	38088.0*··			1.8318
"	$^3F_2$	1^3F_2	$5p^3F_2{}^0$	38811.7 *·	.72	.67	1.8524
"	$^1F_3$	$1^3D_3'$	$5p^1F_3{}^0$	39858.1 ·	1.08	1.00	1.8835
"	$^3D_1'$	1^1P_1	$5p^3D_1{}^0$	40368.6 *	.82	.50	1.8993
"	$^1D_2'$	$1^3D_2'$	$5p^1D_2{}^0$	40771.3	1.14	1.00	1.9120
"	$^1P_1$	$1^3D_1'$	$5p^1P_1{}^0$	40838.7	.76	1.00	1.9141
$4d^9(^2D_{2\frac{1}{2}})6s$	a_3	2^3D_3	$6s^3D_3$	48804.2*			2.4394
"	b_2	2^1D_2	$6s^3D_2$	49019.5*			2.4537
$4d^85s5p$?			z^5D^{70}?	50910.4·	1.47?	1.50	
$4d^9(^2D_{1\frac{1}{2}})6s$	d_1	2^3D_1	$6s^3D_1$	52336.3*			2.4389
			$1_3{}^0$	52457.0	1.26?		
$4d^9(^2D_{1\frac{1}{2}})6s$	e_2	2^3D_2	$6s^1D_2$	52487.7			2.4490
			$z^3F_3{}^0$?	53761.6			
			$2_3{}^0$	54335.9			
$4d^9(^2D_{2\frac{1}{2}})5d$	f_1	a^3S_1	$5d^3S_1$	54574.1			2.9431
			$3_4{}^0$	54600.2?			
			$4_3{}^0$	54673.2	1.29?		
$4d^9(^2D_{2\frac{1}{2}})5d$	$^3G_5$	a^3G_5	$5d^3G_5$	54806.1 *			2.9705
"	$^3G_4$	a^1G_4	$5d^3G_4$	54811.3 *			2.9711
"	h_2	a^3P_2	$5d^3P_2$	54820.6 ·*			2.9722
"	i_1	a^1P_1	$5d^3P_1$	54822.7 ·*			2.9724
?	k_1		k_1	54825.9 ··			
$4d^9(^2D_{2\frac{1}{2}})5d$	l_3	a^3D_3	$5d^3D_3$	54947.7 ··*			2.9875
"	m_2	a^1D_2	$5d^3D_2$	54998.5 ··*			2.9937
"	n_3	a^1F_3	$5d^3F_3$	55012.2 ···*			2.9954
"	o_4	a^3F_4	$5d^3F_4$	55025.2 ···*			2.9970
"	p_0	a^1S_0	$5d^3P_0$	55373.0 ·*··			3.0279
			$6_2{}^0$	55634.1 · ··	.92?		
			$7_2{}^0$	56335.9 · ··			
			$8_4{}^0$	56544.6 · ··	1.06		
$4d^85s5p$?			$y^3D_3{}^0$	56910.9 · ··	1.33	1.33	
			$9_3{}^0$	57255.0 · ··			
			$10_2{}^0$	57565.2 · ··			
			$11_2{}^0$	57926.2?· ··			
$4d^9(^2D_{2\frac{1}{2}})7s$		a^3G_4	$7s^3D_3$	58064.1 ·*··			3.4581
			$12_2{}^0$	58103.7 · ··			
$4d^9(^2D_{2\frac{1}{2}})7s$	q_2	3^1D_2	$7s^3D_2$	58138.3 ·*··			3.4721
$4d^9(^2D_{1\frac{1}{2}})5d$	r_1	a^3P_1	$5d^1P_1$	58195.3 ····			2.9527

TABLE I. (*Continued*).

Origin.	B. & C.	McL.	S.	Level	Obs. "g"	Landé "g"	Ryd. Den.
$4d^85s5p$?			$y^3F_4^0$	58316.8 · · · ·	1.25	1.25	
$4d^9(^2D_{1\frac{1}{2}})5d$	$^3G_3$	a^3G_3	$5d^3G_3$	58348 9 *· · ·			2 9710
“	t_4		$5d^1G_4$	58387.8 · · ·			2.9757
			13_3^0	58389.8 · · ·			
“	u_1	a^3D_1	$5d^3D_1$	58408.1 ·*·			2.9781
			14_2^0	58415.1 · ·	.91?		
“	v_2	a^3D_2	$5d^1D_2$	58448.5 · ·			2.9830
“	w_2	a^3F_2	$5d^3F_2$	58555.8 · *			2.9961
“	x_3	a^3F_3	$5d^1F_3$	58561.7 ·			2.9968
“	y_0	a^3P_0	$5d^1S_0$	58681.3 ·			3.0108
			15_3^0	59143.1 ·	1.04?		
			16_1^0	59588.4 ·			
			17_2^0	59731.2 ·			
$4d^9(^2D_{2\frac{1}{2}})6d$			$6d^3S_1$	60225.8? ·			3.9556
“			$6d^3G_5$?	60315.5 *·			3.9809
“			$6d^3G_4$	60318.2 *·			3.9817
“			$6d^3P_2$	60322.0 · · *			3.9829
“			$6d^3P_1$	60323.4 · · *			3.9832
“			$6d^3D_3$	60370.4 · · · *			3.9968
“			$6d^3F_3$	60397.9 · · · · *			4.0050
“			$6d^3D_2$	60397.9 · · · *·			4.0050
“			$6d^3F_4$	60404.0 · · · · *			4.0068
$4d^85s5p$?			$y^3F_3^0$	60722.6 · · · · ·	1.20?	1.08	
			18_1^0	60729.8 · · · · ·			
$4d^9(^2D_{1\frac{1}{2}})7s$	z_1	3^3D_1	$7s^3D_1$	61602.8 ·*· · ·			4.4581
“	a_2'	3^3D_2	$7s^1D_2$	61638.6 · · · ·			4.4649
$4d^9(^2D_{2\frac{1}{2}})8s$			$8s^3D_3$	61736.2 · · · ·			4.4656
			19_3^0	62316.3 · · · ·	1.08		
$4d^9(^2D_{2\frac{1}{2}})9s$			$9s^3D_3$	63571.7?· · · ·			5.4715
$4d^9(^2D_{1\frac{1}{2}})6d$			$6d^3G_3$	63853.0 * · · ·			3.9806
“			$6d^1G_4$	63872.7 · · ·			3.9863
“			$6d^3D_1$	63896.3 ·*·			3.9929
“			$6d^3F_2$	63937.4 · *			4.0050
“			$6d^1F_3$	63939.8 ·			4.0059
$4d^9$			$4d^2D_{2\frac{1}{2}}$	67236.0			
“			$4d^2D_{1\frac{1}{2}}$	70775.0			
$4d^85s^2$			$5s^4F_{4\frac{1}{2}}$	92307.0			
“			$5s^4P_{2\frac{1}{2}}$	103507.5			

Column 1 Electron Configuration.
“ 2 Notation of Bechert and Catalan.
“ 3 Notation of McLennan and Smith.
“ 4 Notation of Shenstone.
Column 5 Numerical Value of Level.
“ 6 "g" Value, observed.
“ 7 "g" Value, Landé.
“ 8 Rydberg Denominator.

Term separations.

d^95s	^3D	1191; 2339.
$6s$		215; 3317.
$7s$		74; 3465.
$5p$	$^3P^0$	2112; 1908.
	D	−418; 3393.
	F	−477; 3360.
$5d$	^3P	2; 550.
$6d$		1; ?
$5d$	D	51; 3410.
$6d$		17; 3498.
$5d$	F	−13; 3544.
$6d$		−6; 3540.
$5d$	G	5; 3538.
$6d$		3; 3535.
d^8s^2	a^3F	3112; 1497.

"g-sums"

Structure	J	Obs.	Lande.
d^95s	3	1.33	1.33
	2	2.17	2.17
	1	.50	.50
d^95p	4	1.25	1.25
	3	3.49	3.41
	2	4.39	4.34
	1	3.00	3.00

Certain levels given by other authors have not been included. They are given in Table II.

TABLE II. *Rejected terms.*

Author	Level	Explanation
McL. & S.	45489.3	Unidentified line
	56519.6	Unidentified line and spark line
	56695.	Unidentified line
	57650.	Unidentified line and spark line
	58028.	Unidentified line
	64701.	Insufficient evidence
B. and C.	49533.6	2 of 3 lines used elsewhere
	51285.0	2 or 3 lines are spark lines
	56168.4	2 or 3 lines used elsewhere

The 6 levels rejected from McLennan and Smith's list are all founded on lines observed by them in the underwater spark or in absorption in palladium vapor. These lines are all either spark lines or lines which have not been identified as palladium lines in any other source.

Of the 3 levels rejected from Bechert and Catalan's list, one is founded on spark lines, and the other two give only three combinations and of those, two in each case are lines otherwise used in the analysis. Those two levels are therefore possible but extremely improbable.

1. *Determination of the term types.* The information from which the term types may be determined consists of intensities of lines and Zeeman effects. For the low multiplets, the intensities[10] give sufficient evidence that Bechert and Catalan's selection of terms was correct. The intensity diagram (Figure 1) demonstrates this result. Beals' Zeeman effect measurements must also be considered. These measurements are not altogether satisfactory since they are in some cases inconsistent. I have remeasured some of the ultra-

	$5s^3D_3$	$^3D_2$	$^3D_1$	$^1D_2$
$5p^3P_2^0$	700R	75	20	50
$^3P_1$		500*r*	75	50
$^3P_0$			200	
$^3D_3$	1000R	300		200
$^3D_2$	50	500R	100	200
$^3D_1$		100	400	200
$^3F_4$	1000R			
$^3F_3$	300r	600R		200
$^3F_2$		20	400r	200
$^1P_1$		10	200	250
$^1D_2$	40	100	300	300
$^1F_3$	50	200		500*r*

Fig. 1. Intensity diagram of low multiplets.

[10] The intensities are Meggers' estimates and are somewhat different from those used in Table III of the paper, Phil. Mag. **8,** 765 (1929).

violet lines, and from all the evidence available have calculated the probable values of the g-factors for a considerable number of terms. They are not to be considered as having an accuracy of better than about 3%. It is worth notice that the g-values would hardly permit of a choice between $5p^3D_1{}^0$ and $5p^1P_1{}^0$ although the evidence of the intensity diagram is reasonably certain.

The terms of prefix $5d$ are all from old levels. Intensities again suffice to determine the types unambiguously except perhaps for the two levels of $J=0$. The lower of the two levels has been chosen as $^3P_0$ because its combinations with triplet terms are considerably stronger than those of the higher level. In Ag II the equivalent levels in my analysis have both been found by Blair (to be published shortly) to be false and a new $^3P_0$ has been found which agrees in position and characteristics with the level chosen in Pd I. No very probable $^1S_0$ has been found in Ag II. The terms of prefix $6d$ were identified partly from intensities and partly from series extrapolation. In some cases they are doubtful levels and are followed by a question sign. In addition there are the terms of prefix $6s$, $7s$, $8s$, $9s$ which will be discussed below; and a large number of unidentified or doubtfully identified high odd levels. The designation of one level as k is carried over from Bechert and Catalan and the level is discussed below.

2. *Structures*. From the atomic number (46) of Pd it can be predicted that the spectrum should have low terms from the structures $4d^{10}$, $4d^95s$, $4d^85s^2$; and, from the general relations amongst similar structures in other spectra, their relative energies can be roughly predicted. Such a prediction is in agreement with the discovery of $^1S_0$ as the lowest term, ^3D, ^1D as the next and ^3F as the next. The relatively high position of the ^3F and, there fore, of all other terms based on $4d^85s$ makes the spectrum very much less complicated than Ni I in which $3d^94s$ and $3d^84s^2$ are of practically equal energy and importance. Except for a^3F and a^3P_2 no terms founded on $4d^85s$ can be definitely identified although a few high odd terms probably do belong to that structure.

3. *Limits*. All terms based on the ion $4d^9$ are prefixed by the symbols which indicate the quantum numbers of the one electron whose change of condition is responsible for the emission of spectral lines. Amongst the even terms it is possible to pick out directly three members of the series ns^3D^1D. A calculation of a Ritz formula then allows the prediction of the position of higher terms. The $8s^3D_3$ and the doubtful $9s^3D_3$ were found in this way. The series was then recalculated using the $6s$, $7s$, $8s$ terms. The limit of this series is $4d^9\ {}^2D_{2\frac{1}{2}}$ of Pd II and the addition of 3529, known from Pd II, yields $4d^9\ {}^2D_{1\frac{1}{2}}$. Those terms are given at the end of the table, together with $4d^85s\ {}^4F_{4\frac{1}{2}}$ and $^4P_{2\frac{1}{2}}$ which were used to calculate the Rydberg denominators of a^3F_4 and a^3P_2. The separation of the ^2D limit is so great (3529) that even the $5p$ terms break up naturally into two groups corresponding to the components of ^2D. This effect is very much more in evidence in the higher terms where we find the groups much closer together and separated by about 3500 wave numbers. In spite of such evidence of practically complete jj coupling, the intensities of the lines indicate at least as close an approach to

LS coupling as occurs amongst the lower levels. The $6d$ group of terms is new and almost complete. Its combinations with the $5p$ group give the diffuse lines in the visible and near ultraviolet previously unassigned. In particular, the two lines λ4020 and λ4098 which are given in the tables as reversed are in reality double lines and belong to this group. Part of one of these lines is unassigned though it would fit well as the prohibited combination $5p^3F_3{}^0-6d^3G_5$. There is therefore some doubt of the naming of $^3G_5$.

The Rydberg denominator of every level whose limit is known is given in the term table. The values of these numbers for the $5d$ and $6d$ terms form confirmation of the accuracy of the calculation of the series limit.

The Ritz formula calculated from the terms $6s$, $7s$ and $8s^3D_3$ is

$$T = 67236 - T^1 = 67236.0 - \frac{R}{(n + 0.47681 - 2.037 \times 10^{-6}T^1)^2}.$$

4. *High odd terms.* The wave-length list was extended as far into the ultraviolet as possible in the hope that the terms from the structure $4d^96p$ could be found and give some evidence concerning the still rather unsatisfactory theory of limits. A large number of levels was found in the proper energy range but in most cases there is insufficient evidence on which to classify them. There are undoubtedly numbers of odd levels of the structure $4d^85s5p$ in that same region and they naturally add to the difficulty. An attempt has been made to classify by means of Zeeman effects, but this also was not very successful. Some possible levels of the latter structure are indicated in the term table, the evidence being mainly Zeeman effect and intensity of combination with the term a^3F. A number of rather strong sharp lines in the region around λ 3000–3200 have been used to form these terms and there remain a few such lines unidentified.

5. *The level k_1.* The designation k_1 for the level 54825.9 found by Bechert and Catalan has been retained as a distinguishing mark because of the very peculiar nature of that level. It is an even level of $J=1$ or 2 (but almost certainly 1) and it makes 5 exact combinations, all of which are diffuse.[11] It is distant from $5d\ ^3P_1$ only 3.2 wave numbers and all of its combinations occur with those terms with which $5d^3P_1$ combines strongly. There are no other diffuse lines in Meggers' list except λ4631.37, which is triply assigned.

There are three possible origins for the level k_1: (1) A term of the system $4d^9nx$; (2) A term of the system $4d^85s\ nx$; (3) A hyperfine structure component of $5d^3P_1$. The first possibility may be eliminated by the observation that all terms of that structure which could have such an energy have been discovered. The second possibility reduces to a consideration of $4d^85s^2$ only, since all other even configurations yield terms much too high. The configuration d^8s^2 contains only one level of $J=1$. It is a $^3P_1$ level, but an examination of the analogous spectra Ni I, and Pt I and the spectrum Pd II demonstrates that k_1 is about 10,000 wave numbers too far above $^3F_4$ and $^3P_2$. There is

[11] The line λ4816.27 is of the same character as the other k_1 lines on Meggers' plates and has been so labelled in the wave-length list.

a remote possibility that the level is $^1D_2$ but it is at least 5000 wave numbers too high and it does not combine with either $^1F_3$ or $^1D_2$. The third possibility, that k_1 is a hyperfine structure component of $5d^3P_1$, appears to be extremely improbable. There is certainly no expectation that a single level in a whole spectrum should show a structure of 3.2 units and that level one not involving an s-electron at all. If it is hyperfine structure, then the hyperfine structure is wider than the fine structure since $^3P_2-{}^3P_1$ is only 2.2 units.

I believe that the level k_1 is the only level yet found in any spectrum which cannot be logically explained on the Hund theory; but a single exception is sufficient to indicate that there is a factor which is yet to be considered. It would be of great interest to examine the Zeeman effect of a group of lines involving the levels $5d^3P_2$, $^3P_1$ and k_1. The fields produced by an ordinary magnet are sufficient to produce the beginnings of a Paschen-Back effect of the three levels if they have the necessary structural affiliation.

I would like to point out in this connection that the type of analysis which has been carried out since the development of the Hund theory is unlikely to give anything but confirmation since the theory is assumed correct to start with. But that theory has been shown to be incorrect in one part, the prediction of limits, and it is possible that it is either incomplete or incorrect in other details. There is, of course, no doubt of the essential correctness of the theory.

The wave-length table (Table III) contains all the identified lines of Pd I and, in addition, the few remaining unidentified lines of any strength. The intensities are the estimates of Dr. Meggers except for a short range from λ3700 to λ4500 and a number of newly observed lines for which I have made estimates on about the same scale. As usual, Dr. Meggers has been extremely kind in placing at my disposal considerable unpublished data.

TABLE III

λ	I	A	ν	Combination	λ	I	A	ν	Combination
9234.02	1	M	10826.6	$a^3F_4-5p^3F_4^0$	7026.91	1	M	14227.1	$5p^1D_2^0-5d^3D_2$
8761.34	2	M	11410.7	$5p^3D_3^0-6s^3D_3$	7016.44	8	M	14248.3	$5p^3P_0^0-6s^3D_1$
8695.03	1	M	11497.7	$5p^1P_1^0-6s^3D_1$	6917.56	2	M	14452.0	$5p^3D_1^0-5d^3P_2$
8644.38	1	M	11565.0	$5p^1D_2^0-6s^3D_1$	16.56	9	M	14454.1	$5p^3D_1^0-5d^3P_1$
8599.06	2	M	11626.0	$5p^3D_3^0-6s^3D_2$	6914.98	2h	M	14457.4	$5p^3D_1^0-k_1$
8585.28	1	M	11644.6	$a^3F_3-5p^1F_3^0$	6892.52	0	M	14504.5	$a^3P_2-1_3^0$
8581.99	2	M	11649.1	$5p^1P_1^0-6s^1D_2$	78.35	2	M	14534.4	$5p^1P_1^0-5d^3P_0$
8532.67	2	M	11716.5	$5p^1D_2^0-6s^1D_2$	56.89	0	M	14579.9	
8451.93	0	M	11828.4	$5p^3D_2^0-6s^3D_3$	6833.42	8	M	14629.9	$5p^3D_1^0-5d^3D_2$
8353.54	2	M	11967.7	$5p^3D_1^0-6s^3D_1$	6784.52	10	M	14735.4	$5p^3P_2^0-6s^3D_3$
8300.81	5	M	12043.7	$5p^3D_2^0-6s^3D_2$	6774.54	12	M	14757.1	$a^3F_4-5p^1F_3^0$
8132.85	6	M	12292.4	$a^3F_4-5p^3D_3^0$	6739.16	0	M	14834.6	
7961.04	4	M	12557.7	$a^3F_3-5p^1D_2^0$	6712.10	0	M	14894.4	
7915.84	7	M	12629.4	$5p^1F_3^0-5d^1D_2$	6686.79	3	M	14950.7	$5p^3P_2^0-6s^3D_2$
7786.66	7	M	12839.0	$5p^3P_1^0-6s^3D_2$	85.71	2	M	14953.2	$5p^1F_3^0-5d^3G_4$
7763.99	12	M	12876.4	$5p^3F_4^0-6s^3D_3$	81.56	3	M	14962.4	$5p^1F_3^0-5d^3P_2$
7486.93	7	M	13352.9	$5p^3F_3^0-6s^3D_3$	62.86	4	M	15004.6	$5p^3D_1^0-5d^3P_0$
7391.91	8	M	13524.6	$5p^3F_2^0-6s^3D_1$	25.28	4	M	15089.5	$5p^1F_3^0-5d^3D_3$
68.14	15	M	13568.2	$5p^3F_3^0-6s^3D_2$	23.26	4	M	15094.1	$5p^3D_3^0-6s^1D_2$
7310.06	5	M	13676.0	$5p^3F_2^0-6s^1D_2$	6603.03	1	M	15140.4	$5p^1F_3^0-5d^3D_2$
7278.44	2	M	13735.4	$5p^1P_1^0-5d^3S_1$	6599.32	0	M	15148.9	
42.90	2	M	13802.8	$5p^1D_2^0-5d^3S_1$	97.08	1	M	15154.0	$5p^1F_3^0-5d^3F_3$
7228.99	1	M	13829.4	Pb?	6591.44	3	M	15167.0	$5p^1F_3^0-5d^3F_4$
7149.11	6	M	13983.9	$5p^1P_1^0-5d^3P_1$	6508.41	6	M	15360.5	$5p^3D_2^0-6s^3D_1$
*7147.45	1h	M	13987.2	$5p^1P_1^0-k_1$	6465.90	0	M	15461.5	
7115.84	3	M	14049.1	$5p^1D_2^0-5d^3P_2$	6464.68	0	M	15464.4	
7060.29	5	M	14159.8	$5p^1P_1^0-5d^3D_2$	6444.89	2	M	15511.9	$5p^3D_2^0-6s^1D_2$
52.04	2	M	14176.4	$5p^1D_2^0-5d^3D_3$	6342.46	1	M	15762.4	$5p^3F_2^0-5d^3S_1$
37.58	3	M	14205.5	$5p^3D_1^0-5d^3S_1$	6268.23	0	M	15949.1	Cu?

* Previously unpublished line observed by Dr. Meggers of the Bureau of Standards.

TABLE III (*continued*)

λ	I	A	ν	Combination
6244.78	1	M	16009.0	$5p^3F_2^0-5d^3P_2$
43.97	2	M	16011.0	$5p^3F_2^0-5d^3P_1$
03.73	0	M	16114.9	
03.13	0	M	16116.4	
6195.61	2	M	16136.0	$5p^3F_2^0-5d^3D_3$
88.02	6	M	16155.8	$5p^3P_1^0-6s^3D_1$
76.15	5	M	16186.8	$5p^3F_2^0-5d^3D_2$
70.94	5	M	16200.5	$5p^3F_2^0-5d^3F_3$
36.99	1	M	16290.1	
30.59	8	M	16307.2	$5p^3P_1^0-6s^1D_2$
29.45	0	M	16310.2	
01.65	0	M	16384.5	$a^3P_2-2_3^0$
6064.08	1	M	16486.0	$5p^3P_0^0-5d^3S_1$
5995.94	0?	M	16673.3	
78.96	0	M	16720.7	$a^3P_2-4_3^0$
74.03	0	M	16734.5	$5p^3P_0\ -5d^3P_1$
5868.14	2	M	17036.4	$5p^3F_3^0-6s^1D_2$
5782.14	3	M	17289.9	Cu
5778.85	1	M	17299.7	$5p^1P_1\ -7s^3D_2$
59.92	4	M	17356.6	$5p^1P_1\ -5d^1P_1$
39.68	7	M	17417.8	$5p^3D_3^0-5d^3G_4$
37.65	4	M	17423.9	$5p^1D_2^0-5d^1P_1$
36.52	12	M	17427.0	$5p^3D_3^0-5d^3P_2$
30.52	0	M	17445.6	
5698.10	0	S	17544.9	
95.08	20	M	17554.1	$5p^3D_3^0-5d^3D_3$
90.14	8	M	17569.4	$5p^1P_1^0-5d^3D_1$
87.49	3	M	17577.6	$5p^1D_2^0-5d^3G_3$
80.80	2	M	17598.3	$5p^3D_2^0-5d^3S_1$
77.07	1	M	17609.9	$5p^1P_1^0-5d^1D_2$
74.25	3	M	17618.6	$5p^3D_3^0-5d^3F_3$
70.90	0	S	17629.0	V?
70.06	30	M	17631.6	$5p^3D_3^0-5d^3F_4$
68.42	3	M	17636.7	$5p^1D_2^0-5d^3D_1$
55.42	10	M	17677.3	$5p^1D_2^0-5d^1D_2$
42.71	8	M	17717.1	$5p^1P_1^0-5d^3F_2$
21.33	3	M	17784.4	$5p^1D_2^0-5d^3F_2$
19.46	12	M	17790.4	$5p^1D_2^0-5d^1F_3$
08.02	7	M	17826.7	$5p^3D_1^0-5d^1P_1$
03.00	4	M	17842.6	$5p^1P_1^0-5d^1S_0$
02.29	2	M	17844.9	$5p^3D_2^0-5d^3P_2$
01.65	8	M	17846.9	$5p^3D_2^0-5d^3P_1$
5600.62	2h	M	17850.2	$5p^3D_2-k_1$
5562.70	3	M	17971.9	$5p^3D_2^0-5d^3D_3$
47.02	20	M	18022.7	$5p^3D_2^0-5d^3D_2$
42.80	30	M	18036.4	$5p^3D_2^0-5d^3F_3$
41.88	1	M	18039.4	$5p^3D_1^0-5d^3D_1$
29.45	9	M	18080.0	$5p^3D_1^0-5d^1D_2$
5496.85	6	M	18187.2	$5p^3D_1^0-5d^3F_2$
72.67	1	M	18267.5	$5p^3P_2^0-6s^3D_1$
59.16	2	M	18312.8	$5p^3D_1^0-5d^1S_0$
35.16	7	M	18393.6	$5p^3P_1^0-5d^3S_1$
27.69	4	M	18419.0	$5p^3P_2^0-6s^1D_2$
06.59	5	M	18490.9	$5p^1F_3^0-5d^3G_3$
5395.26	25	M	18529.6	$5p^1F_3^0-5d^1G_4$
94.76	6	M	18531.4	
85.44	2	M	18563.4	
77.62	3	M	18590.4	$5p^1F_3^0-5d^1D_2$
63.26	4	M	18640.2	$5p^3P_1^0-5d^3P_2$
62.69	15	M	18642.2	$5p^3P_1^0-5d^3P_1$
61.72	2hv	M	18645.5	$5p^3P_1^0-k_1$
46.79	2	M	18697.6	$5p^1F_3^0-5d^3F_2$
45.10	10	M	18703.5	$5p^1F_3^0-5d^1F_3$
12.57	12	M	18818.1	$5p^3P_1^0-5d^3D_2$
11.50	1	M	18821.9	
5295.61	50	M	18878.5	$5p^3F_4^0-5d^3G_5$
94.15	7	M	18883.5	$5p^3F_4^0-5d^3G_4$
5256.17	10	M	19020.0	$5p^3F_4^0-5d^3D_3$
38.41	2	M	19084.5	$5p^3F_4^0-5d^3F_3$
34.85	20	M	19097.5	$5p^3F_4^0-5d^3F_4$
20.93	0	M	19151.6	Cu
08.93	10	M	19192.5	$5p^3P_1^0-5d^3P_0$
5179.31	0	M	19302.7	$a^3P_2-9_3^0$
63.83	40	M	19360.1	$5p^3F_3^0-5d^3G_4$
61.36	5	M	19369.4	$5p^3F_3^0-5d^3P_2$
57.56	0	M	19383.6	$5p^3F_2^0-5d^1P_1$
27.71	7	M	19496.5	$5p^3F_3^0-5d^3D_3$
17.01	20	M	19537.3	$5p^3F_2^0-5d^3G_3$
14.38	8	M	19547.3	$5p^3F_3^0-5d^3D_2$
10.81	15	M	19560.9	$5p^3F_3^0-5d^3F_3$
07.43	1	M	19573.9	$5p^3F_3^0-5d^3F_4$
01.51	3	M	19596.4	$5p^3F_2^0-5d^3D_1$
5092.53	0	M	19631.1	
63.40	10	M	19744.1	$5p^3F_2^0-5d^3F_2$
09.95	1	S	19954.7	$5p^3D_1^0-6d^3P_{2,1}$
04.99	0h	S	19974.5	$a^3P_2-11_2^0$

λ	I	A	ν	Combination
4991.62	2	S	20028.0	$5p^3D_1^0-6d^3D_2$
71.95	9	M	20107.3	$5p^3P_0^0-5d^1P_1$
62.05	0h	S	20151.4	$a^3P_2-12_2^0$
29.99	3	M	20278.4	
24.20	2	M	20302.2	
4919.87	8	M	20320.1	$5p^3P_0^0-5d^3D_1$
4875.43	20	M	20505.3	$5p^3P_2-5d^3S_1$
36.44	4	M	20670.6	$5p^3D_3^0-7s^3D_3$
19.15	2	M	20744.8	$5p^3D_3^0-7s^3D_2$
17.51	30	M	20751.8	$5p^3P_2^0-5d^3P_2$
17.02	9	M	20754.0	$5p^3P_2^0-5d^3P_1$
16.27	1h	M	20757.2	$5p^3P_2^0-k_1$
14.65	1	M	20764.2	$5p^1P_1^0-7s^3D_1$
06.37	1	M	20799.9	$5p^1P_1^0-7s^1D_2$
4799.02	1	M	20831.8	$5p^1D_2^0-7s^3D_1$
90.85	2	M	20867.3	$5p^1D_2\ -7s^1D_2$
88.18	20	M	20879.0	$5p^3P_2^0-5d^3D_3$
76.56	4	M	20929.7	$5p^3P_2^0-5d^3D_2$
73.37	0	S	20943.7	$5p^3P_2^0-5d^3F_3$
71.37	0	M	20952.5	
93.52	0	S	20955.7	$5p^3D_3^0-5d^3G_3$
61.88	3	M	20994.3	$5p^3D_3^0-5d^1G_4$
24.01	6	M	21162.5	$5p^3D_3^0-5d^3F_2$ $5p^3D_2^0-7s^3D_2$
22.75	1	M	21168.2	$5p^3D_3^0-5d^1F_3$
08.06	2	M	21234.3	$5p^3D_1^0-7s^3D_1$
4700.12	1	M	21270.1	$5p^3D_1^0-7s^1D_2$
4677.46	8	M	21373.2	$5p^3D_2^0-5d^3G_3$
4664.54	0	M	21432.4	$5p^3D_2^0-5d^3D_1$
32.63	3	M	21580.0	$5p^3D_2^0-5d^3F_2$
31.37	2h	M	21585.9	$5p^3D_2^0-5d^1F_3$ $5p^3F_2^0-6d^3F_3(^3D_2)$
4589.99	4	M	21780.5	$5p^1F_3^0-7s^1D_2$
59.83	1	M	21924.5	
52.91	4	M	21957.8	$5p^3P_1^0-7s^3D_2$
41.13	10	M	22014.8	$5p^3P_1^0-5d^1P_1$
23.33	1	M	22106.3	
16.20	10	M	22136.3	$5p^3F_4^0-7s^3D_3$
4497.66	3	M	22227.6	$5p^3P_1^0-5d^3D_1$
89.46	15	E	22268.2	$5p\ P_1^0-5d^1D_2$
73.59	50	E	22347.2	$5s^1D_2-5p^3P_2^0$
58.62	1h	K	22422.2	$5p^3F_4^0-5d^3G_3$
43.04	5	E	22500.8	$5p^3P_1^0-5d^1S_0$
21.03	3	E	22612.8	$5p^3F_3^0-7s^3D_3$
06.55	8	E	22687.1	$5p^3F_3^0-7s^3D_2$
4388.62	5	E	22779.8	$a^3P_2-18_1^0$?
86.48	3	E	22790.9	$5p^3F_2^0-7s^3D_1$
79.58	2	E	22826.8	$5p^3F_2^0-7s^1D_2$
60.23	8h	E	22928.1	$5p^3D_3^0-6d^3P_2$
58.58	8	E	22936.8	$5p^3F_3^0-5d^1G_4$
51.00	10h	E	22976.8	$5p^3D_3^0-6d^3D_3$
4344.66	20h	E	23010.3	$5p^3D_3^0-6d^3F_4$
28.04	2h	E	23098.7	$5p^1P_1^0-6d^3F_2$
26.97	1h	S	23104.4	$5p^3F_3^0-5d^3F_2$
23.04	2h	E	23125.4	$5p^1D_2^0-6d^3D_1$
14.96	6h	E	23168.7	$5p^1D_2^0-6d^1F_3$
4281.89	3h	E	23347.6	$5p^3D_2^0-6d^3P_{2,1}$
68.26	30hd	E	23422.2	$5p^3D_2^0-6d^3F_3(^3D_2)$
51.49	1	E	23514.6	$5p^3P_0^0-7s^3D_1$
49.0	1h	E	23528.3	$5p^3D_1^0-6d^3D_1$
41.7	1h	E	23568.8	$5p^3D_1^0-6d^3F_2$
12.95	200	E	23729.7	$5s^1D_2\ -5p^3F_3^0$
4169.86	20	E	23974.8	$5s^3D_1-5p^3P_2^0$
66.31	10d	S	23995.3	$5p^3P_2^0-7s^3D_3$ $5p^1F_3^0-6d^3G_3$
62.84	3h	S	24015.3	$5p^1F_3^0-6d^1G_4$
56.98	3	S	24049.2	$a^3F_2-z^3F_3^0$
52.12	3h	S	24077.3	
51.36	3h	S	24081.7	$5p^1F_3^0-6d^1F_3$
40.83	5h	S	24142.9	$5p^3P_1^0-6d^3P_{2,1}$
28.37	3h	S	24215.8	$5p^3P_1^0-6d^3D_2$
23.64	5	S	24243.6	$a^3F_3-1_3^0$
4106.85	1h	S	24342.7	$5p^3D_3^0-8s^3D_3$
4099.27	20h	S	24387.7	$5p^3F_4^0-6d^3G_5$
98.87	10h	S	24390.1	$5p^3F_4^0-6d^3G_4$
4090.05	2h	S	24442.7	$5p^3F_4^0-6d^3D_3$
87.37	50	E	24458.7	$5s^1D_2-5p\ P_1^0$
84.35	5h	S	24476.8	$5p^3F_4^0-6d^3F_4$
82.72	1h	S	24486.6	$5p^3P_2^0-5d^3F_2$
81.68	3h	S	24492.8	$5p^3P_2^0-5d^1F_3$
20.66	5h	S	24864.5	
20.20	15h	S	24867.4	$5p^3F_3^0-6d^3G_4$
11.74	0h	S	24919.8	$5p^3F_3^0-6d^3D_3$
4007.5	3h	E	24946.2	$5p^3F_3^0-6d^3F_3(^3D_2)$
4004.93	1h	S	24962.2	$a^3F_2-4_3^0$
3992.3	3h	E	25041.2	$5p^3F_2^0-6d^3G_3$

TABLE III (*continued*)

λ	I	A	ν	Combination
3985.48	0h	S	25084.0	$5p^3F_2^0-6d^3D_1$
78.88	1h	S	25125.6	$5p^3F_2^0-6d^3F_2$
58.64	200	E	25254.1	$5s^1D_2-5p^3D_2^0$
26.93	0	S	25458.0	$5p^3P_1^0-7s^1D_2$
13.07	1	S	25548.2	$a^3F_3-z^3F_3^0$
3894.18	200	E	25672.1	$5s^1D_2-5p^3D_3^0$
73.57	1h	S	25808.7	$5p^3P_0^0-6d^3D_1$
				$a^3F_4-z^5D_3^0$
				$5p^3F_4^0-8S^3D_3$
3832.30	75	E	26086.6	$5s^3D_1-5p^3P_1^0$
27.15	3	S	26121.9	$a^3F_3-2_3^0$
21.99	5h	S	26157.0	$5p^3P_2^0-6d^3S_1$?
18.89	1	S	26178.2	$5p^3F_4^0-9s^3D_3$?
3807.87	5h	S	26254.0	$5p^3P_2^0-6d^3P_{2,1}$
3800.96	1	S	26301.7	$5p^3P_2^0-6d^3D_3$
3799.16	75	E	26314.2	$5s^3D_2-5p^3P_2^0$
78.28	1	S	26459.6	$a^3F_3-4_3^0$
54.85	1	S	26624.7	$a^3F_2-7_2^0$
18.91	100	E	26882.0	$5s^3D_1-5p^3D_2^0$
3690.34	200	E	27090.1	$5s^1D_2-5p^3F_2^0$
54.41	2	E	27356.4	$a^3F_4-1_3^0$
45.97	2	E	27419.8	$a^3F_3-6_2^0$
34.70	700R	E	27504.8	$5s^3D_3-5p^3P_2^0$
13.39	0	S	27667.0	$5p^3P_2^0-8s^3D_3$
3609.56	600R	M	27696.3	$5s^3D_2-5p^3F_3^0$
3596.66	4	S	27795.7	
89.16	2	S	27853.7	$a^3F_2-10_2^0$
84.11	2	S	27893.0	
81.06	1	S	27916.8	
77.56	1	S	27944.1	$5p^3F_4^0-6d^1G_4$
71.16	200	M	27994.1	$5s^3D_1-5p^3P_0^0$
66.63	5	M	28029.7	
53.10	500r	M	28136.4	$5s^1D_2-5p^1F_3^0$
43.25	1	S	28214.6?	$a^3F_2-11_2^0$
28.72	5	M	28330.8	$a^3F_3-8_4^0$
21.14	2	S	28391.8	$a^3F_2-12_2^0$
16.95	500r	M	28425.6	$5s^3D_2-5p^3P_1^0$
3489.79	200r	M	28646.9	$5s^1D_2-5p^3D_1^0$
3488.15	1	M	28660.3	$a^3F_4-z^3F_3^0$
81.17	400r	M	28717.8	$5s^3D_1-5p^3F_2^0$
60.76	300r	M	28887.2	$5s^3D_3-5p^3F_3^0$
42.40	3	M	29041.2	$a^3F_3-9_3^0$
41.40	300	M	29049.6	$5s^1D_2-5p^1D_2^0$
33.44	250	M	29117.0	$5s^1D_2-5p^1P_1^0$
21.24	500	M	29220.8	$5s^3D_2-5p^3D_2^0$
19.66	6	M	29234.3	$a^3F_4-2_3^0$
3406.04	3	M	29351.2	$a^3F_3-10_2^0$
3404.60	1000R	M	29363.6	$5s^3D_3-5p^3F_4^0$
3396.79	4	M	29431.1	$a^3F_2-15_3^0$
89.05	3	M	29498.4	$a^3F_4-3_4^0$
80.69	20	M	29571.3	$a^3F_4-4_3^0$
73.02	300	M	29638.5	$5s^3D_2-5p^3D_3^0$
46.12	0	K	29876.8	$a^3F_2-16_1^0$
21.00	5	M	30102.8	$a^3F_3-y^3F_4^0$
12.99	5	M	30175.6	$a^3F_3-13_3^0$
11.04	3	M	30193.3	
10.14	2	K	30201.5	$a^3F_3-14_2^0$
3307.08	2	S	30229.5	
3302.15	400	M	30274.6	$5s^3D_1-5p^3D_1^0$
3287.26	50	M	30411.7	$5s^3D_3-5\ ^3D_2^0$
58.80	300	M	30677.3	$5s^3D_1-5p^1D_2^0$
3251.66	200	M	30744.7	$5s^3D_1-5p^1P_1^0$
42.72	1000R	M	30829.4	$5s^3D_3-5p^3D_3^0$
32.33	5	S	30928.5	$a^3F_3-15_3^0$
18.98	20	M	31056.8	$5s^3D_2-5p^3F_2^0$
3179.41	8	S	31443.3	$a^3F_4-8_4^0$
3171.93	1	S	31517.5	$a^3F_3-17_2^0$
3142.82	50	M	31809.4	$a^3F_4-y^3D_3^0$
3114.05	200	M	32103.2	$5s^3D_2-5p^1$[illegible]$_3^0$
3109.19	5	M	32153.4	$a^3F_4-9_3^0$
3075.17	10	M	32509.1	$a^3F_3-y^3F_3^0$
3066.09	3	M	32605.4	$a^3F_2-19_3^0$
3065.30	100	M	32613.8	$5s^3D_2-5p^3D_1^0$
3028.76	3	M	33007.2	
3027.92	100	M	33016.4	$5s^3D_2-5p^1D_2^0$
3021.74	10	M	33083.9	$5s^3D_2-5p^1P_1^0$
3009.77	20	M	33215.5	$a^3F_4-y^3F_4^0$
3002.66	50	M	33294.1	$5s^3D_3-5p^1F_3^0$
2936.77	2	S	34041.1	$a^3F_4-15_3^0$
2931.47	4	M	34102.6	$a^3F_3-19_3^0$
2922.50	40	M	34207.3	$5s^3D_3-5p^1D_2^0$
2875.75	2	M	34763.4	
2806.45	1	M	35621.7	$a^3F_4-y^3F_3^0$
2763.08	100R	M	36180.8	$a^1S_0-5p^3P_1^0$
2686.29	3	M	37215.0	$a^3F_4-19_3^0$
2605.08	4	M	38375.1	
2476.43	50R	M	40368.5	$a^1S_0-5p^3D_1^0$
2447.95	10R	M	40838.1	$a^1S_0-5p^1P_1^0$
2360.51	5	M	42350.8	
2327.49	5	S	42951.5	$5s^1D_2-4_3^0$
2216.48	6	S	43155.5	$5s^3D_2-z^5D_3^0$
2276.54	2	M	43912 7	$5s^1D_2-6_2^0$
2254.28	15	M	44346.3	$5s^3D_3-z^5D_3^0$
2240.76	4	M	44613.8	$5s^1D_2-7_2^0$
2236.38	8	M	44701.2	$5s^3D_2-1_3^0$
2225.28	10	M	44924.1	
2195.49	6	M	45533.5	$5s^1D_2-9_3^0$
2178.26	10	M	45893.7	$5s^3D_3-1_3^0$
2174.67	4	M	45969.6	
2172.92	10	M	46006.6	$5s^3D_2-z^3F_3^0$
2151.00	5	S	46475.3	
2142.11	10	S	46668.1	$5s^1D_2-13_3^0$
2130.69	3d	S	46918.2	$5s^3D_2-4_3^0$
2123.76	2	S	47071.4	
2118.09	6	S	47197.4	$5s^3D_3-z^3F_3^0$
2108.09	4	S	47421.1	$5s^1D_2-15_3^0$
2105.87	10	S	47471.3	$5s^3D_1-10_2^0$
2092.61	7	S	47771.9	$5s^3D_3^0-2_3$
2089.97	2	S	47832.3	$5s^3D_1-11_2^0$
2088.47	8	S	47856.7	$5s^3D_1-16_1^0$
2087.93	10	S	47879.3	$5s^3D_2-6_2^0$
2082.24	10	S	48009.7	[6] $5s^3D_1-12_2^0$
				$5s^1D_2-17_2^0$
2081.10	10	S	48036.2	$5s^3D_3-3_4^0$
2079.35	0	S	48076.5	
2077.93	4	S	48109.4	$5s^3D_3-4_3^0$
2076.47	3	S	48143.2	
2068.78	8	S	48322.2	$5s^3D_1-14_2^0$
2061.98	2	S	48481.5	
2057.76	2	S	48580.9	$5s^3D_2-7_2^0$
2057.42	2	S	48588.9	
2042.98	3	S	48932.3	
2040.19	0	S	48992.2	
2039.81	1	S	49008.3	$5s^1D_2-18_1^0$
2019.75	4	S	49495.0	$5s^3D_1-16_1^0$
2019.53	4	S	49500.4	$5s^3D_2-9_3^0$
2013.96	3	S	49637.4	$5s^3D_1-17_2^0$
2006.96	10	S	49810.5	$5s^3D_2-10_2^0$
λ (vac)				
2000.72	2	S	49982.0	$5s^3D_3-8_4^0$
1993.18	3	S	50171.2	$5s^3D_2-11_2^0$
1986.14	2	S	50348.7	$5s^3D_2-12_2^0$
				$5s^3D_3-y^3D_3^0$
1976.48	5	S	50594.9	$5s^1D_2-19_3^0$
1974.88	3	S	50635.9	$5s^3D_2-13_3^0$
1973.94	3	S	50660.1	$5s^3D_2-14_2^0$
1972.74	8	S	50690.8	$5s^3D_3-9_3^0$
1968.33	5	S	50804.4	
1963.71	2	S	50924.0	
1945.98	2	S	51388.1	$5s^3D_2-15_3^0$

For convenience in visualizing the energy relations in the spectrum, a diagram of electron configurations is given in Fig. 2.

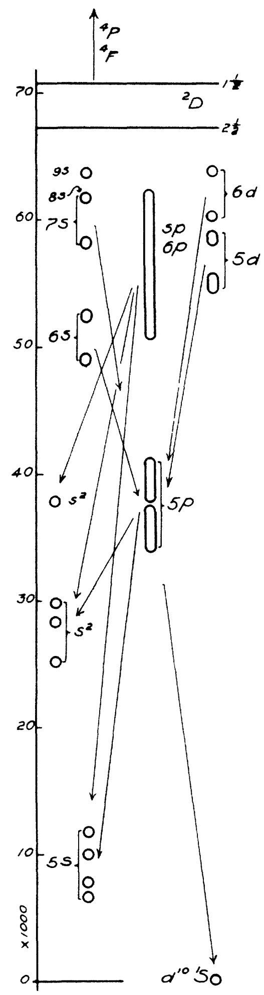

Fig. 2. Diagram of the energies of the electron configurations of Pd I. The last electron only is given except for structures based on 8 *d* electrons for which the characteristics of two electrons are given.