THE SPARK SPECTRUM OF COBALT, Co II

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Abstract

A further examination of the Co II spectrum, based on the previous work of Meggers, has been made. A magnetic analysis shows that Meggers' classification of the terms now called $d^7p\ ^5F^\circ$, $^5D^\circ$ should be interchanged, except for the term $^5F_5^\circ$. Since Meggers' results were obtained from intensity rules, the author's $^5F\ ^5F^\circ$ and $^5F\ ^5D^\circ$ multiplets show irregular intensities. The strongest lines in these multiplets are, respectively, $^5F_n\ ^5F^\circ_{n-1}$ and $^5F_n\ ^5D^\circ_n$. The magnetic analysis also shows that Meggers' terms ^3D should be $d^7s\ ^5P$ and that his ^3P, $^3D^1$, and ^3F should be partly $d^7p\ ^5P^\circ$ and $^5D^\circ$. In addition, the terms $d^7s\ ^3F$, $d^7p\ ^3D^\circ$, $^3F^\circ$, $^3G^\circ$, $^5S^\circ$, $^5P^\circ$, $^5D^\circ$, and the lowest terms $d^8\ ^3F$ have been found. The location of the second member of the $d^7s\ ^5F\ ^3F$ series gives an I. P. of 16.9 volts from d^7s to d^7 and 17.3 volts from d^8 to d^7, in practically exact agreement with the predictions of Dr. H. N. Russell.

Introductory Review

A PREVIOUS analysis of the first spark spectrum of cobalt was made by Meggers.[1] The purpose of the author's work was to extend Meggers' analysis with the aid of the Zeeman effect. The magnetic analysis afforded a change in the interpretation of several of Meggers' levels, and several new levels were found by the usual method of wave-number differences.

Experimental Procedure

The author was fortunate in having the use of unpublished measurements and intensity estimates in the region from λ5000 to λ2000 made by Dr. Meggers of the Bureau of Standards. Further measurements were also made by the author of sharp lines in the range from λ2000 to λ1940 and of diffuse lines from λ3000 to λ2550, the standards being the copper arc and spark lines calculated by Shenstone.[2] Meggers' measurements were corrected to agree with these standards.

A Hilger E1 quartz spectrograph was used with Cramer Contrast and Hilger Schumann plates in taking photographs for wave-length determinations, sheets of very pure cobalt serving as electrodes.

Zeeman effect photographs were taken from λ3700 to λ2190 with the same instrument and an electromagnet, giving a field of about 35,500 gauss with pole pieces 1 cm in diameter and an air gap of about 3 mm. A button of cobalt about 1 mm thick clamped against one of the pole pieces of the magnet served as the anode, and a copper rod with a small tip on the end bent at right angles to the rest of the rod was used as the cathode of an arc, carrying a current of about 1 ampere at 250 volts, in taking most of the

[1] W. F. Meggers, Journ. Wash. Ac. Sci. **18**, 325 (1928).
[2] A. G. Shenstone, Phys. Rev. **28**, 449 (1926); **29**, 380 (1927).

TABLE I. *Term table for Co II.*

Configuration	Designation: Author's	Designation: Megger's	Level	g: Obs.	g: Landé	Intervals (Higher J's first)
$3d^8$	a^3F_4		0.0*			
$3d^8$	a^3F_3		950.3*			
$3d^8$	a^3F_2		1597.2*			
$3d^7(^4F)4s$	$4s^5F_5$	$^5F_5'$	3350.5 *	1.39	1.40	
"	$4s^5F_4$	$^5F_4'$	4028.9 *	1.36	1.35	
"	$4s^5F_3$	$^5F_3'$	4560.8 *	1.25	1.25	
"	$4s^5F_2$	$^5F_2'$	4950.0 *	1.00	1.00	
"	$4s^5F_1$	$^5F_1'$	5204.5 *	.00	.00	
"	$4s^3F_4$		9812.7*	1.28	1.25	
"	$4s^3F_3$		10708.1*	1.10	1.08	
"	$4s^3F_2$		11321.5*	0.60	0.67	
$3d^7(^4P)4s$	$4s^5P_3$	$^3D_3$	17771.5 *	1.70	1.67	
"	$4s^5P_2$	$^3D_2$	18031.5 *	1.86	1.83	
"	$4s^5P_1$	$^3D_1$	18338.5 *	2.48	2.50	
$3d^7(^4F)4p$	$4p^5F_5^\circ$	$^5F_5$	45197.8*	1.40	1.40	
"	$4p^5F_4^\circ$	$^5D_4'$	45378.8*	1.38	1.35	
"	$4p^5F_3^\circ$	$^5D_3'$	45972.1*	1.26	1.25	
"	$4pz^5D_4^\circ$	$^5F_4$	46320.8 ·*	1.48	1.50	a^3F 950.3, 646.9
"	$4p^5F_2^\circ$	$^5D_2'$	46452.6*·	1.02	1.00	$4s^5F$ 678.4, 531.9, 389.2, 254.5
"	$4p^5F_1^\circ$	$^5D_1'$	46786.3*·	.00	.00	$4s^3F$ 895.4, 613.4
"	$4pz^5D_3^\circ$	$^5F_3$	47039.0 *	1.51	1.50	$4s^5P$ 260, 307
"	$4p^5G_6^\circ$	$^5G_6'$	47078.2 ·*	1.33	1.33	$4p^5F^\circ$ 181.0, 593.3, 480.5, 333.7
"	$4p^5G_5^\circ$	$^5G_5'$	47345.7 ·*	1.27	1.27	$4p_z{}^5D^\circ$ 718.2, 498.1, 311.4, 146.6
"	$4pz^5D_2^\circ$	$^5F_2$	47537.1 *·	1.52	1.50	$4p^5G^\circ$ 267.5, 461.5, 343.5, 237.4
"	$4p^5G_4^\circ$	$^5G_4'$	47807.2 ·*	1.15	1.15	$4p^3G^\circ$ 792.3, 687.3
"	$4pz^5D_1^\circ$	$^5F_1$	47848.5 *·	1.53	1.50	$4p^3F^\circ$ 684.1, 532.2
"	$4pz^5D_0^\circ$		47995.1 *·	0/0	0/0	$4p^3D^\circ$ 717.4, 454.9
"	$4p^5G_3^\circ$	$^5G_3'$	48150.7 *	0.92	0.92	$4py^5D^\circ$ −147.3, 19.3, 88.4, 109.4
"	$4p^5G_2^\circ$	$^5G_2'$	48388.1 *	0.33	0.33	$4p^5P^\circ$ 22.8, 298.1
"	$4p^3G_5^\circ$		48555.9*	1.20	1.20	$5s^5F$ 572.5, 580.5, 428.6, 280.2
"	$4p^3G_4^\circ$		49348.2*	1.09	1.05	$5s^3F$ 864.6, 593.9
"	$4p^3F_4^\circ$		49697.5·*	1.20	1.25	
"	$4p^3G_3^\circ$		50035.9*·	0.80	0.75	
"	$4p^3F_3^\circ$		50381.6 *	1.08	1.08	
"	$4p^3F_2^\circ$		50913.8 *	0.65	0.67	
"	$4p^3D_3^\circ$		51512.2*	1.32	1.33	
"	$4p^3D_2^\circ$		52229.6*	1.16	1.17	
"	$4p^3D_1^\circ$		52684.5*	0.45	0.50	
$3d^7(^4P)4p$	$4p^5S_2^\circ$		56010.6	1.99	2.00	
"	$4py^5D_3^\circ$	$^3D_3'$	61240.8 *	1.51	1.50	
"	$4py^5D_2^\circ$	$^3D_2'$	61260.1 *	1.51	1.50	
"	$4py^5D_1^\circ$		61348.5 *(?)	—	1.50	
"	$4py^5D_4^\circ$		61388.1 *	1.50	1.50	
"	$4py^5D_0^\circ$		61457.9 *	0/0	0/0	
"	$4p^5P_3^\circ$	$^3P_2$	63344.1*	1.67	1.67	
"	$4p^5P_2^\circ$	$^3F_2$	63366.9*	1.86	1.83	
"	$4p^3P_2^\circ$		63615.7	1.33	1.50	
"	$4p^5P_1^\circ$	$^3P_1$	63665.0*	2.62	2.50	
$3d^7(^4F)5s$	$5s^5F_5$		84012.3 *			
"	$5s^5F_4$		84584.8 *			
"	$5s^5F_3$		85165.3 *			
"	$5s^3F_4$		85479.2*·			
"	$5s^5F_2$		85593.9·*			
"	$5s^5F_1$		85874.1·*			
"	$5s^3F_3$		86343.8*			
"	$5s^3F_2$		86937.7*			

Zeeman effect photographs, the exposures of which were fron 5 to 15 minutes. A blast of nitrogen blowing over the arc kept the cobalt from burning away too rapidly and, hence, made the arc run more steadily. Under these conditions, most of the lines appearing on the Zeeman effect plates were cobalt spark lines. However, in the region from λ3700 to λ3000 a spark discharge had to be used as a light source to bring out the spark lines. A few copper lines appeared on the plates. Of these λ3273.97 ($^2S_{\frac{1}{2}}-{}^2P_{\frac{1}{2}}$), λ2441.63 ($^2S_{\frac{1}{2}}-{}^4P_{\frac{1}{2}}$), and λ2181.71 ($^2S_{\frac{1}{2}}-{}^2P_{\frac{1}{2}}$) were used to determine the field. A quartz double image prism separated the parallel and perpendicular components of the patterns.

Term Designation

The Hund theory predicts that the low terms should be ^3F from the structure $3d^8$, and $^{3\&5}F$, $^{3\&5}P$, etc. from the structure $3d^74s$. The middle terms shoud be the $^{3\&5}S^0$, P^0, D^0, F^0, G^0, etc. from $3d^74p$. Many of these terms have been discovered and are given in Table I together with the $^{3\&5}F$ from $3d^75s$. The notation used is that recommended by H. N. Russell, A. G. Shenstone, and L. A. Turner.[3]

Table II. *Resolved Zeeman patterns of Co II.*

λ	$X-Y$	Z.E. Pattern	Remarks
3370.94	$4s^5P_1-4pz^5D_0^\circ$	O(0.00) 2.40 C(0.00) 2.50	Good measurements not expected in this range.
2524.98	$4s^3F_2-4p^3F_2^\circ$	O(0.00) 0.68 C(0.00) 0.67	
2423.61	$4s^5F_1-4p^5F_2^\circ$	O(0.00, 1.10) 0.00, 1.10, 2.20 C(0.00, 1.00) 0.00, 1.00, 2.00	Discrepancy here unexplained.
2417.66	$4s^5F_4-4p^5F_4^\circ$	O(0.00) 1.39 C(0.00) 1.35	
2414.06	$4s^5F_3-4p^5F_3^\circ$	O(0.00) 1.26 C(0.00) 1.25	
2408.76	$4s^5F_2-4p^5F_2^\circ$	O(0.00) 1.01 C(0.00) 1.00	
2404.17	$4s^5F_1-4p^5F_1^\circ$	O(0.00) 0.00 C(0.00) 0.00	
2389.54	$4s^5F_2-4p^5F_1^\circ$	O(0.00, 0.92) 0.00, 0.92, 2.00 C(0.00, 1.00) 0.00, 1.00, 2.00	Discrepancy also unexplained.
2388.90	$4s^5F_5-4p^5F_5^\circ$	O(0.00) 1.39 C(0.00) 1.40	
2361.52	$4s^5F_1-4pz^5D_2^\circ$	O(0.00, 1.50) 0.00, 1.50, 3.00 C(0.00, 1.50) 0.00, 1.50, 3.00	
2344.26	$4s^5F_1-4pz^5D_1^\circ$	O(1.52), 0.00, 1.53 C(1.50), 0.00, 1.50	
2336.23	$4s^5F_1-4pz^5D_0^\circ$	O(0.00) 0.00 C(0.00) 0.00	
2318.41	$4s^5P_1-4py^5D_0^\circ$	O(0.00) 2.48 C(0.00) 2.50	
2220.11	$4s^5P_1-4p^5P_2^\circ$	O(0.00, 0.88) 0.92, 1.86, faint. C(0.00, 0.67) 1.17, 1.83, 2.50	
2207.90	$4s^5P_1-4p^3P_2^\circ$	O(0.00, 1.18) 0.00, 1.33, faint. C(0.00, 1.00) 0.50, 1.50, 2.50	Unsymmetrical in π and σ. 0.50 components in σ unresolved.

[3] H. N. Russell, A. G. Shenstone, L. A. Turner, Phys. Rev. **33**, 900 (1929).

Zeeman Effect

Several resolved patterns were obtained on the Zeeman effect photographs. Table II gives both the observed and calculated arrangement of these patterns. However, most of the lines appeared as simple triplets due to the low resolving power of the instrument. Nevertheless, a formula described by Shenstone and Blair[4] allowed the calculation of g-values from the unresolved patterns. The g's calculated from all the resolved and unresolved patterns are consistent with the assumption that all the terms have Landé g-values.

The magnetic analysis readily indicated that Meggers' classification of the ^5F and $^5D'$ terms should be interchanged except for $^5F_5$, his ^3D terms should be $4s^5P$, and his ^3P, $^3D'$, and ^3F should be partly $d^7p^5P^0$ and $^5D^0$.

Since Meggers' results were based on intensity rules, the author's $4s^5F4p^5F^0$ and $4s^5F4p^5D^0$ multiplets show the irregular intensities indicated in Table III. In the case of spectra in which the Russell-Saunders coupling is broken down, there are usually irregular intensities, the g-values depart from Landé values, and the interval rule is not obeyed. In this spectrum, however, the interval rule is obeyed fairly well, and the terms have Landé g-values, yet two of the three principal multiplets show very anomalous intensities.

Table III. *Intensities in the principal multiplets.*

	$4s^5F_5$	$^5F_4$	$^5F_3$	$^5F_2$	$^5F_1$
$4pz^5D_4^\circ$	25	80	10		
$^5D_3^\circ$		40	60	15	
$^5D_2^\circ$			30	30	10
$^5D_1^\circ$				30	25
$^5D_0^\circ$					20
$^5F_5^\circ$	100	10			
$^5F_4^\circ$	100	40	10		
$^5F_3^\circ$		80	40	10	
$^5F_2^\circ$			50	25	10
$^5F_1^\circ$				40	20
$^5G_6^\circ$	100				
$^5G_5^\circ$	8	75			
$^5G_4^\circ$	2	15	50		
$^5G_3^\circ$		3	20	40	
$^5G_2^\circ$			4	15	30

Ionization Potentials

The limits of the $4s^5F$, ^3F series were determined by the application of a Rydberg formula to the two members of these series. However, on account of the inaccuracy of a Rydberg formula, this calculation did not, as is to be expected, give any indication of the four separate limits approached by the eight series.

The limit of the $4s^5F_5$ series gives an ionization potential of 16.9 volts from $3d^74s$ to $3d^7$, and 17.3 volts from $3d^8$ to $3d^7$. Using H. N. Russell's[5]

[4] A. G. Shenstone and H. A. Blair, Phil. Mag. **8**, 765 (1929).

[5] H. N. Russell, Astrophys. J. **66**, 223 (1927).

TABLE IV. *Classified lines of Co II.*

λ(Air)	Int.	Auth.	ν(Vac.)	Combination
3621.22	100	M	27607.2	$4s^5P_3-4p^5F^\circ_4$
3578.03	30	M	27940.5	$4s^5P_2-4p^5F^\circ_3$
3555.93	10	M	28114.0	$4s^5P_1-4p^5F^\circ_2$
3545.03	25	M	28200.5	$4s^5P_3-4p^5F^\circ_3$
3517.48	10	M	28421.3	$4s^5P_2-4p^5F^\circ_2$
3514.21	5	M	28447.8	$4s^5P_1-4p^5F^\circ_1$
3501.73	200	M	28549.2	$4s^5P_3-4pz^5D^\circ_4$
3446.40	100	M	29007.5	$4s^5P_2-4pz^5D^\circ_3$
3423.85	75	M	29198.6	$4s^5P_1-4pz^5D^\circ_2$
3415.78	75	M	29267.5	$4s^5P_3-4pz^5D^\circ_3$
3388.18	50	M	29505.8	$4s^5P_2-4pz^5D^\circ_2$
3387.72	60	M	29509.9	$4s^5P_1-4pz^5D^\circ_1$
3370.94	50	M	29656.8	$4s^5P_1-4pz^5D^\circ_0$
3358.59	10	M	29765.9	$4s^5P_3-4pz^5D^\circ_2$
3352.80	30	M	29817.3	$4s^5P_2-4pz^5D^\circ_1$
2943.16	30u	M	33967.2	$4p^3D_3^\circ-5s^3F_4$
2930.45	10u	M	34114.5	$4p^3D_2^\circ-5s^3F_3$
2883.43	1	F	34670.7	$4s^3F_3-4p^5F^\circ_4$
2880.32	3u	F	34708.2	$4p^3D_2^\circ-5s^3F_2$
2870.03	3u	F	34832.7	$4p^3D_3^\circ-5s^3F_3$
2848.36	5u	F	35097.6	$4p^3F_3^\circ-5s^3F_4$
2845.64	2	F	35131.0	$4s^3F_2-4p^5F_2^\circ$
2834.92	2	M	35264.0	$4s^3F_3-4p^5F^\circ_3$
2825.22	8	M	35385.1	$4s^3F_4-4p^5F_5^\circ$
2821.63	5u	F	35430.1	$4p^3F_2^\circ-5s^3F_3$
2818.86	1	M	35464.9	$4s^3F_2-4p^5F_1^0$
2810.85	5	M	35566.0	$4s^3F_4-4p^5F^\circ_4$
2807.17	2	M	35612.6	$4s^3F_3-4pz^5D^\circ_4$
2798.92	2	F	35717.5	$4s^3F_2-4pz^5D^\circ_3$
2796.86	2	F	35744.8	$4s^3F_3-4p^5F^\circ_2$
2793.93	20u	F	35781.3	$4p^3F^\circ_4-5s^3F_4$
2779.82	20u	F	35962.9	$4p^3F^\circ_3-5s^3F_3$
2775.11	20u	F	36024.0	$4p^3F^\circ_2-5s^3F_2$
2766.85	30u	F	36131.6	$4p^3G^\circ_4-5s^3F_4$
2764.75	1	F	36159.1	$4s^3F_4-4p^5F^\circ_3$
2753.38	10u	F	36308.2	$4p^3G^\circ_3-5s^3F_3$
2738.32	1	F	36508.1	$4s^3F_4-4pz^5D^\circ_4$
2736.91	2	M	36526.8	$4s^3F_2-4pz^5D^\circ_1$
2734.68	10u	F	36556.6	$4p^3F^\circ_3-5s^3F_2$
2727.91	20u	F	36647.3	$4p^3F^\circ_4-5s^3F_3$
2714.40	15	M	36829.7	$4s^3F_2-4p^5G^\circ_3$ $4s^3F_3-4pz^5D^\circ_2$
2709.12	10u	F	36901.4	$4p^3G^\circ_3-5s^3F_2$
2707.55	30u	F	36922.8	$4p^3G^\circ_5-5s^3F_4$
2706.72	50u	F	36934.2	$4p^5G^\circ_6-5s^5F_5$
2702.19	20u	F	36996.0	$4p^3G^\circ_4-5s^3F_3$
2697.02	3	M	37067.0	$4s^3F_2-4p^5G^\circ_2$
2694.65	25	M	37099.6	$4s^3F_3-4p^5G^\circ_4$
2686.97	1u	F	37205.6	$4p^5G^\circ_2-5s^5F_2$
2684.50	50u	F	37239.8	$4p^5G^\circ_5-5s^5F_4$
2676.03	20u	F	37357.7	$4p^5G^\circ_4-5s^5F_3$
2669.89	10u	F	37443.6	$4p^5G^\circ_3-5s^5F_2$
2666.82	5u	F	37486.7	$4p^5G^\circ_2-5s^5F_1$
2663.52	60	M	37533.2	$4s^3F_4-4p^5G^\circ_5$
2662.64	2u	F	37545.6	$4pz^5D^\circ_3-5s^5F_4$
2653.68	15	M	37672.3	$4s^5P_1-4p^5S^\circ_2$
2653.16	1	F	37679.6	$4s^3F_3-4p^5G^\circ_2$
2652.36	5u	F	37691.1	$4pz^5D^\circ_4-5s^5F_5$
2639.26	2u	F	37878.1	$4pz^5D^\circ_0-5s^5F_1$
2632.22	30	M	37979.4	$4s^5P_2-4p^5S^\circ_2$
2629.01	0u	F	38025.7	$4pz^5D^\circ_1-5s^5F_1$
2626.89	10u	F	38056.4	$4pz^5D^\circ_2-5s^5F_2$
2622.06	5u	F	38126.5	$4pz^5D^\circ_3-5s^5F_3$

TABLE IV. *Continued.*

λ(Air)	Int.	Auth.	ν(Vac.)	Combination
2614.37	20	M	38238.7	$4s^5P_3-4p^5S_2^\circ$
2612.63	10u	F	38264.1	$4pz^5D_4^\circ-5s^5F_4$
2592.90	2u	F	38555.3	$4pz^5D_{[illegible]}^\circ-5s^5F_2$
2582.37	4u	F	38612.5	$4p^5F_3^\circ-5s^5F_4$
2580.93	5u	F	38634.0	$4p^5F_4^\circ-5s^5F_5$
2587.23	60	M	38639.8	$4s^3F_3-4p^3G_4^\circ$
2582.27	50	M	38714.0	$4s^3F_2-4p^3G_3^\circ$
2580.35	100	M	38742.8	$4s^3F_4-4p^3G_5^\circ$
2575.61	5u	F	38814.1	$4p^5F_5^\circ-5s^5F_5$
2564.04	75	M	38989.3	$4s^3F_3-4p^3F_4^\circ$
2559.41	40	M	39059.8	$4s^3F_2-4p^3F_3^\circ$
2554.09	2u	F	39141.1	$4p^5F_2^\circ-5s^5F_2$
2550.69	5u	F	39193.3	$4p^5F_3^\circ-5s^5F_3$
2549.90	5u	F	39205.4	$4p^5F_4^\circ-5s^5F_4$
2541.95	50	M	39328.1	$4s^3F_3-4p^3G_3^\circ$
2528.61	50	M	39535.5	$4s^3F_4-4p^3G_4^\circ$
2524.98	80	M	39592.4	$4s^3F_2-4p^3F_2^\circ$
2519.82	60	M	39673.4	$4s^3F_3-4p^3F_3^\circ$
2506.47	70	M	39884.7	$4s^3F_4-4p^3F_4^\circ$
2487.43	4	M	40190.0	$4s^3F_2-4p^3D_3^\circ$
2486.45	35	M	40205.8	$4s^3F_3-4p^3F_2^\circ$
2485.36	10	M	40223.5	$4s^3F_4-4p^3G_3^\circ$
2464.20	35	M	40568.8	$4s^3F_4-4p^3F_3^\circ$
2450.01	35	M	40803.8	$4s^3F_3-4p^3D_3^\circ$
2449.15	10	M	40818.1	$4s^5F_3-4p^5F_4^\circ$
2443.77	40	M	40908.0	$4s^3F_2-4p^3D_2^\circ$
2436.98	10	M	41021.9	$4s^5F_2-4p^5F_3^\circ$
2428.29	10	M	41168.7	$4s^5F_4-4p^5F_5^\circ$
2423.61	10	M	41248.2	$4s^5F_1-4p^5F_2^\circ$
2417.66	40	M	41349.7	$4s^5F_4-4p^5F_4^\circ$
2416.90	30	M	41362.7	$4s^3F_2-4p_3D_1^\circ$
2414.06	40	M	41411.4	$4s^5F_3-4p^5F_3^\circ$
2408.76	25	M	41502.5	$4s^5F_2-4p^5F_2^\circ$
2407.67	20	M	41521.3	$4s^3F_3-4p^3D_2^\circ$
2404.17	20	M	41581.7	$4s^5F_1-4p^5F_1^\circ$
2397.38	60	M	41699.5	$4s^3F_4-4p^3D_3^\circ$
2393.91	10	M	41759.9	$4s^5F_3-4pz^5D_4^\circ$
2389.54	40	M	41836.3	$4s^5F_2-4p^5F_1^\circ$
2388.90	100	M	41847.5	$4s^5F_5-4p^5F_5^\circ$
2386.37	50	M	41891.9	$4s^5F_3-4p^5F_2^\circ$
2383.45	80	M	41943.2	$4s^5F_4-4p^5F_3^\circ$
2378.62	100	M	42028.3	$4s^5F_5-4p^5F_4^\circ$
2375.19	15	M	42089.0	$4s^5F_2-4pz^5D_3^\circ$
2363.79	80	M	42292.0	$4s^5F_4-4pz^5D_4^\circ$
2361.53	10	M*	42332.5	$4s^5F_1-4pz^5D_2^\circ$
2353.43	60	M*	42478.0	$4s^5F_3-4pz^5D_3^\circ$
2347.41	30	M*	42587.1	$4s^5F_2-4pz^5D_2^\circ$
2344.26	25	M*	42644.0	$4s^5F_1-4pz^5D_1^\circ$
2336.24	20	M*	42790.6	$4s^5F_1-4pz^5D_0^\circ$
2330.37	30	M*	42898.5	$4s^5F_2-4pz^5D_1^\circ$
2329.12	10	M*	42921.4	$4s^5P_1-4py^5D_2^\circ$
2326.49	25	M*	42970.0	$4s^5F_5-4pz^5D_4^\circ$
2326.13	20	M*	42976.5	$4s^5F_3-4pz^5D_2^\circ$
2324.32	40	M*	43010.2	{$4s^5F_4-4pz^5D_3^\circ$
				{$4s^5P_1-4py^5D_1^\circ$
2318.43	8	M*	43119.4	$4s^5P_1-4py^5D_0^\circ$
2314.99	30	M*	43183.5	$4s^5F_1-4p^5G_2^\circ$
2314.05	40	M*	43200.9	$4s^5F_2-4p^5G_3^\circ$
2313.60	8	M*	43209.4	$4s^5P_2-4py^5D_3^\circ$
2312.55	10	M*	43228.9	$4s^5P_2-4py^5D_2^\circ$
2311.62	50	M*	43246.5	$4s^5F_3-4p^5G_4^\circ$
2307.86	75	M*	43316.9	{$4s^5P_2-4py^5D_1^\circ$
				{$4s^5F_4-4p^5G_5^\circ$

TABLE IV. *Continued.*

λ(Air)	Int.	Auth.	ν(Vac.)	Combination
2301.42	15	M*	43438.1	$4s^5F_2-4p^5G_2^\circ$
2299.77	25	M*	43469.1	$4s^5P_3-4py^5D_3^\circ$
2298.74	10	M*	43488.6	$4s^5P_3-4py^5D_2^\circ$
2293.41	30	M*	43589.8	$4s^5F_3-4p^5G_3^\circ$
2292.00	40	M*	43616.6	$4s^5P_3-4py^5D_4^\circ$
2286.17	150	M*	43727.7	$4s^5F_5-4p^5G_6^\circ$
2283.54	20	M*	43778.2	$4s^5F_4-4p^5G_4^\circ$
2280.98	4	M*	43827.3	$4s^5F_3-4p^5G_2^\circ$
2272.28	20	M*	43995.1	$4s^5F_5-4p^5G_5^\circ$
2265.76	6	M*	44121.6	$4s^5F_4-4p^5G_3^\circ$
2248.68	8	M*	44456.7	$4s^5F_5-4p^5G_4^\circ$
2245.13	100	M*	44527.0	$4s^5F_4-4p^3G_5^\circ$
2232.08	50	M*	44787.4	$4s^5F_3-4p^3G_4^\circ$
2220.14	15	M*	45028.3	$4s^5P_1-4p^5P_2^\circ$
2217.30	4	M*	45085.7	$4s^5F_2-4p^3G_3^\circ$
2214.80	20	M*	45136.6	$4s^5F_3-4p^3F_4^\circ$
2211.44	30	M*	45205.3	$4s^5F_5-4p^3G_5^\circ$
2207.93	50	M*	45277.1	$4s^5P_1-4p^3P_2^\circ$
2206.21	75	M*	45312.4	$4s^5P_2-4p^5P_3^\circ$
2205.88	10	M*	45319.2	$4s^5F_4-4p^3G_4^\circ$
2205.53	20	M*	45326.4	$4s^5P_1-4p^5P_1^\circ$
2205.09	20	M*	45335.4	$4s^5P_2-4p^5P_2^\circ$
2203.44	5	M*	45369.4	$a^3F_3-4pz^5D_4^\circ$
2202.96	100	M*	45379.3	$a^3F_4-4p^5F_4^\circ$
2200.42	25	M*	45431.5	$4s^5F_2-4p^3F_3^\circ$
2198.30	20	M*	45475.3	$4s^5F_3-4p^3G_3^\circ$
2193.61	100	M*	45572.7	$4s^5P_3-4p^5P_3^\circ$
2192.51	50	M*	45595.5	$4s^5P_3-4p^5P_2^\circ$
2190.69	75	M*	45633.5	$4s^5P_2-4p^5P_1^\circ$
2189.00	25	M*	45668.7	$4s^5F_4-4p^3F_4^\circ$
2187.05	25	M*	45709.4	$4s^5F_1-4p^3F_2^\circ$
2181.73	10	F	45820.8	$4s^5F_3-4p^3F_3^\circ$
2180.61	20	M*	45844.2	$4s^5P_3-4p^3P_2^\circ$
2174.94	2	M*	45963.9	$4s^5F_2-4p^3F_2^\circ$
2174.54	50	F	45972.3	$a^3F_4-4p^5F_3^\circ$
2173.33	60	M*	45997.9	$4s^5F_5-4p^3G_4^\circ$
2172.90	7	M*	46007.0	$4s^5F_4-4p^3G_3^\circ$
2158.16	2	M*	46321.2	$a^3F_4-4pz^5D_4^\circ$
2156.95	40	M*	46347.1	$4s^5F_5-4p^3F_4^\circ$
2156.69	10	M*	46352.7	$\{4s^5F_4-4p^3F_3^\circ$
				$\{4s^5F_3-4p^3F_2^\circ$
2147.38	2	M*	46553.6	$a^3F_2-4p^5G_3^\circ$
2146.99	10	M*	46562.1	$4s^5F_2-4p^3D_3^\circ$
2136.50	4	M*	46790.7	$a^3F_2-4p^5G_2^\circ$
2133.47	10	M*	46857.2	$a^3F_3-4p^5G_4^\circ$
2129.17	1	M*	46951.8	$4s^5F_3-4p^3D_3^\circ$
2125.87	3	M*	47024.6	$4s^5F_1-4p^3D_2^\circ$
2117.95	8	M*	47200.4	$a^3F_3-4p^5G_3^\circ$
2114.40	2	M*	47279.7	$4s^5F_2-4p^3D_2^\circ$
2111.46	50	M*	47345.5	$a^3F_4-4p^5G_5^\circ$
2105.49	2	M*	47479.8	$4s^5F_1-4p^3D_1^\circ$
2105.34	3	M*	47483.1	$4s^5F_4-4p^3D_3^\circ$
2097.12	5	M*	47669.3	$4s^5F_3-4p^3D_2^\circ$
2094.24	1	M*	47734.8	$4s^5F_2-4p^3D_1^\circ$
2091.09	6	M*	47806.7	$a^3F_4-4p^5G_4^\circ$
2065.55	50	M*	48397.7	$a^3F_3-4p^3G_4^\circ$
2063.80	35	M*	48438.8	$a^3F_2-4p^3G_3^\circ$
2058.84	30	M*	48555.5	$a^3F_4-4p^3G_5^\circ$
2050.75	10	F	48746.8	$a^3F_3-4p^3F_4^\circ$
2049.19	2	M*	48784.1	$a^3F_2-4p^3F_3^\circ$

TABLE IV. *Continued.*

λ(Air)	Int.	Auth.	ν(Vac.)	Combination
2036.61	3	M*	49085.4	$a^3F_3-4p^3G_3^\circ$
2027.08	20	M*	49316.1	$a^3F_2-4p^3F_2^\circ$
2025.80	10	M*	49347.2	$a^3F_4-4p^3G_4^\circ$
2022.35	20	M*	49431.4	$a^3F_3-4p^3F_3^\circ$
2011.52	5	F	49697.8	$a^3F_4-4p^3F_4^\circ$
2000.80	10	F	49963.7	$a^3F_3-4p^3F_2^\circ$
1997.93	3	F	50035.5	$a^3F_4-4p^3G_3^\circ$
1984.21	1	F	50381.5	$a^3F_4-4p^3F_3^\circ$
1974.38	1	F	50632.2	$a^3F_2-4p^3D_2^\circ$
1956.78	30	F	51087.6	$a^3F_2-4p^3D_1^\circ$
1949.46	20	F	51279.5	$a^3F_3-4p^3D_2^\circ$
1940.64	50	F	51512.3	$a^3F_4-4p^3D_3^\circ$

M—Meggers
M*—Meggers corrected
F—Author

equation to correct the calculation such that it may more nearly conform to results obtained from a Ritz formula, these ionization potentials become, respectively, 16.7 and 17.1 volts, which are in practically exact agreement with H. N. Russell's[6] predictions.

Table IV gives all the identified lines of the spectrum.

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