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MULTIPLETS AND TERMS IN THE FIRST TWO SPECTRA OF COLUMBIUM

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ABSTRACT

In the decade which has passed since the first indications of structure in these spectra were found, efforts have been made to improve the fundamental data so that the analyses might be extended. Careful estimates of relative intensities and accurate measurements of wave lengths have been compiled for about 3000 Cb I lines and 2000 Cb II lines. Results are now reported for the principal multiplets found in each spectrum. They reveal sextet and quartet terms for Cb I, quintet and triplet terms for Cb II, and account for most of the stronger lines. The normal state of neutral Cb atoms is represented by $(4d^4 5s)\ ^6D$ and for singly ionized atoms by $(4d^4)\ ^5D$.

CONTENTS

I. INTRODUCTION

Three multiplets involving sextet terms of the arc spectrum of columbium (Cb I) were published[1] in 1924, and five quintet-system multiplets for the spark spectrum (Cb II) were announced[2] in 1926. The theory of spectral structure predicted that the Cb I spectrum would exhibit terms belonging to sextet, quartet, and doublet systems, while the Cb II spectrum would be fully accounted for by quintet, triplet, and singlet terms. Although this was known even before the first regularities were discovered in Cb spectra, no further classification of Cb lines has appeared in a decade characterized by an avalanche of such regularities in other spectra. The reasons for this delay in further progress with analysis of Cb spectra were anticipated in the first paper referred to. These spectra are extremely rich in lines and the precision of the published wave lengths was not sufficient for unambiguous use of the combination principle, nor were the intensity estimates of arc and spark lines reliable enough for discrimination of ionization stages. No data existed for the absorption spectrum nor for furnace spectra at various temperatures, the results of which have been so helpful in the analysis of other complex spectra. Furthermore, the published Zeeman effects which gave the clue in the interpretation of the first regularities in these spectra were entirely inadequate for the extension of these analyses. Finally, the general experience that heavier ele-

[1] W. F. Meggers, J. Wash. Acad. Sci. **14**, 442 (1924).
[2] W. F. Meggers and C. C. Kiess, J. Opt. Soc. Am. **12**, 432 (1926).

ments show larger separations of sublevels in polyfold terms with consequent overlapping and perturbation of intervals, intensities, and magnetic splitting made it imperative to obtain improved and more complete descriptive data for these spectra before proceeding with the analyses of their structures. A considerable part of the required material is now at hand, and its analysis has resulted in the discovery and interpretation of a large number of atomic energy states characteristic of the neutral and of the singly ionized atoms of columbium. Although the spectral-line classifications are still far from complete, a majority of the strong lines in each spectrum is now accounted for and the results may be useful in connection with other investigations. In the present paper only those results are given which have been established and interpreted with a fairly high degree of certainty. The remainder are reserved for later publication together with observations of Zeeman effects essential for their interpretation.

II. DATA OF Cb SPECTRA ($Z=41$, $M=93.3$)

No wave length measurements of columbium have been published since those of Exner and Haschek [3] in 1912. Their arc and spark lists contain several thousand lines (7046.9 to 2155.68 A) and, although the errors do not often exceed 0.05 A, they are occasionally as large as 0.10 A. In such complex spectra the combination principle can be applied with confidence only if the errors in wave length values are less than 0.01 A, and the use of less precise values inevitably leads to hopelessness and despair in separating the real "constant differences" from the spurious ones. Furthermore, it is usually impossible to tell by comparing the published intensity values for arc and spark lines whether they belong to neutral or to ionized atoms and so the confusion in analysis is multiplied by chaos. After wasting many hours in attempting to extend the analysis with inadequate data, it became obvious that success depended on obtaining reliable basic facts concerning columbium spectra.

In 1927 Dr. C. W. Balke kindly presented some rods of columbium metal of high purity for spectroscopic investigations. With this material the arc and spark spectra have been accurately measured from 2000 to 12000 A, the furnace spectra and hyperfine structures have been studied by King,[4] and preliminary observations of Zeeman effects have been made.

The results of the furnace investigations have already been published, and the remainder should be published in the near future. The present paper excerpts only a fraction of the complete results but includes most of the stronger lines. It suffices here to state that a complete separation of Cb I, Cb II, and Cb III lines has been obtained and that the average probable error of wave length measurements is less than 0.01 A for more than 3000 Cb I lines and approximately 2000 Cb II lines.

In 1912 Jack [5] published observations of the Zeeman patterns for about 100 lines of Cb (2600 to 4700 A). These deserve the credit for revealing the first regularities in Cb I and Cb II spectra, but

[3] Die Spektren der Elemente bei Normalen Druck, 2 and 3, Deuticke, Wien (1911 and 1912).
[4] A. S. King, Astrophys. J. **73**, 441 (1931).
[5] Proc. Roy. Irish Acad. Dublin **30**, 42 (1912).

unfortunately they are not sufficiently numerous or precise to complete the analysis. Some preliminary observations made at this bureau indicate that most of the splitting factors deviate from Landé values and that still more extensive and accurate determinations are desirable. Since this program must be deferred to the future, a decision was made to present without further delay a portion of the new results as a group of selected multiplets and identified spectral terms characteristic of Cb I and Cb II spectra.

III. MULTIPLETS AND TERMS

It was the fashion some years ago to present all new spectral regularities in multiplet form, but the more recent custom is to give a list of classified lines and one of spectral terms. Each presentation has its advantages, but in this case we have elected the first in order to exhibit the interval, intensity, and combination rules for the principal groups of lines in the first two spectra of columbium. For each spectrum we give a multiplet table in which the term symbols and level values appear in the margins. The observed combinations are represented by measured wave lengths, estimated relative intensities (in parentheses), and by vacuum wave numbers.

The multiplet table is followed by a term table in which successive columns contain electron configurations, term symbols, level values and separations. Since, at the present time, it is impossible to assign absolute values to the spectral terms because no series have been found in these spectra, the term values are relative and based upon the assumption that the ground level or normal state has the value 0.00.

1. Cb I

The first spectrum of columbium arises from five valence electrons, and the theoretically possible low terms are those indicated in table 1, the last being the lowest of each group. Only ^{4,6}(D) ($4d^45s$) and ^{4}(F)($4d^35s^2$) have been identified with certainty thus far, but there can be no doubt that ^{6}(D)($4d^45s$) represents the normal state of the neutral Cb atom.

TABLE 1.—*Low terms of the* Cb I *spectrum*

Electron configuration	Terms
$4d^35s^2$	^{2}(D) ^{2}(PDFGH) ^{4}(PF).
$4d^45s$	^{2}(SDG) ^{2,4}(PF) ^{2}(SDFGI) ^{2,4}(PDFGH) ^{4,6}(D).
$4d^5$	^{2}D ^{2}(PDFGH) ^{4}(PF) ^{4}(SDFGI) ^{4}(DG) ^{6}S.

Remembering that terms from configurations in which a single penetrating *s* electron, interacting with an atomic nucleus having a mechanical moment of spin, show the largest hyperfine splitting [6] it was observed that most of the combinations with ^{4,6}(D)($4d^45s$) were complex lines (designated c or cw). Indeed, some of the ^{4}D levels were found on this assumption, and the fact that they exhibit large hyperfine splitting may be regarded as confirming their identity.

[6] W. F. Meggers and Keivin Burns, J. Optical Soc. Am., 14, 453 (1927).

TABLE 2.—*Multiplets*

Term symbol	Value	$a^6D_{0\frac{1}{2}}$ 0.00	$a^6D_{1\frac{1}{2}}$ 154.19	$a^6D_{2\frac{1}{2}}$ 391.99	$a^6D_{3\frac{1}{2}}$ 695.25	$a^6D_{4\frac{1}{2}}$ 1050.26	$a^4F_{1\frac{1}{2}}$ 1142.79
$z^6D^\circ_{0\frac{1}{2}}$	19623.96	5094.40(10c) 19623.94	5134.751(40) 19469.82				
$z^6D^\circ_{1\frac{1}{2}}$	19765.20	5057.999(40) 19765.17	5097.764(5c) 19611.00	5160.335(50) 19373.20			5368.390(4) 18622.39
$z^6D^\circ_{2\frac{1}{2}}$	19993.78		5039.032(40) 19839.56	5100.161(30) 19601.78	5180.305(50) 19298.52		5303.272(3) 18851.05
$z^6D^\circ_{3\frac{1}{2}}$	20315.74			5017.743(40c) 19923.74	5095.298(80c) 19620.48	5189.197(20) 19265.45	
$z^6D^\circ_{4\frac{1}{2}}$	20733.88				4988.972(40) 20038.64	5078.959(150) 19683.60	
$y^6F^\circ_{0\frac{1}{2}}$	23984.87	4168.121(250c) 23984.89	4195.096(80) 23830.66				
$y^6F^\circ_{1\frac{1}{2}}$	24164.79	4137.090(200) 24164.79	4163.657(250) 24010.60	4205.308(120) 23772.80			4342.459(7) 23021.98
$y^6F^\circ_{2\frac{1}{2}}$	24396.80		4123.811(400) 24242.60	4164.661(300) 24004.81	4217.946(150c) 23701.57		
$y^6F^\circ_{3\frac{1}{2}}$	24769.91			4100.918(600c) 24377.93	4152.576(400c) 24074.67	4214.732(100c) 23719.64	
$y^6F^\circ_{4\frac{1}{2}}$	25199.81				4079.723(1000c) 24504.57	4139.701(400cw) 24149.55	
$y^6F^\circ_{5\frac{1}{2}}$	25680.36					4058.931(2000c) 24630.10	
$z^6P^\circ_{1\frac{1}{2}}$	24283.34	4116.894(50) 24283.33	4143.201(80c) 24129.15	4184.440(50c) 23891.35			
$z^6P^\circ_{2\frac{1}{2}}$	24543.13		4099.066(30) 24388.95	4139.430(90c) 24151.13	4192.065(100c) 23847.90		
$z^6P^\circ_{3\frac{1}{2}}$	24904.86			4078.343(6) 24512.87	4129.429(100c) 24209.62	4190.889(150c) 23854.59	
$y^6D^\circ_{0\frac{1}{2}}$	25879.81	3862.927(20c) 25879.80	3860.074(20) 25725.65				4041.392(1) 24736.99
$y^6D^\circ_{1\frac{1}{2}}$	26067.06	3835.177(40) 26067.05	3858.00(1) 25912.84	3893.734(40) 25675.04			
$y^6D^\circ_{2\frac{1}{2}}$	26386.36		3811.035(50) 26232.17	3845.900(40) 25994.37	3891.303(60) 25691.08		
$y^6D^\circ_{3\frac{1}{2}}$	26832.43			3781.017(80) 26440.43	3824.882(100) 26137.21	3877.558(60) 25782.15	
$y^6D^\circ_{4\frac{1}{2}}$	27419.62				3740.845(40) 26724.36	3791.209(300r) 26369.35	
$x^6D^\circ_{0\frac{1}{2}}$	26552.40	3765.074(40) 26552.39	3787.064(150) 26398.21				3934.405(20) 25409.64
$x^6D^\circ_{1\frac{1}{2}}$	26713.30	3742.393(200r) 26713.31	3764.115(25) 26559.15	3798.127(300r) 26321.32			3909.664(4) 25570.43
$x^6D^\circ_{2\frac{1}{2}}$	26983.34		3726.235(250) 26829.14	3759.556(200r) 26591.36	3802.928(400r) 26288.09		
$x^6D^\circ_{3\frac{1}{2}}$	27427.07			3697.850(200) 27035.08	3739.804(300r) 26731.80	3790.138(200r) 26376.80	
$x^6D^\circ_{4\frac{1}{2}}$	27974.88				3664.691(80) 27279.59	3713.017(300r) 26924.64	
$y^6P^\circ_{1\frac{1}{2}}$	28278.25	3535.304(400c) 28278.06	3554.667(80) 28124.03	3584.972(100) 27886.29			3684.175(1) 27135.42
$y^6P^\circ_{2\frac{1}{2}}$	28652.66		3507.960(80) 28498.48	3537.475(150) 28260.70	3575.850(200) 27957.43		
$y^6P^\circ_{3\frac{1}{2}}$	28973.12			3497.815(30) 28581.13	3535.304(400c) 28278.06	3580.276(400r) 27922.87	

in the Cb I *spectrum*

$a^4F_{2\frac{1}{2}}$ 1586.90	$a^4F_{3\frac{1}{2}}$ 2154.11	$a^4F_{4\frac{1}{2}}$ 2805.36	$a^4D_{0\frac{1}{2}}$ 8410.90	$a^4D_{1\frac{1}{2}}$ 8705.32	$a^4D_{2\frac{1}{2}}$ 9043.14	$a^4D_{3\frac{1}{2}}$ 9497.52
			8915.76(4w) 11213.02			
5499.531(7) 18178.33				9039.18(7c) 11059.92		
5431.253(12c) 18406.85	5603.924(7) 17839.70				9129.42(7w) 10950.60	
5337.872(4c) 18728.86	5504.581(20c) 18161.66	5709.326(12) 17510.36				9241.0(15cw) 10818.4
	5380.705(4c) 18579.77	5576.157(15c) 17928.53				
4427.866(1) 22577.92						
4382.856(9c) 22809.79						
	4420.455(10) 22615.78	4551.520(3) 21964.54				
		4464.151(20) 22394.41				
		4370.361(15) 22875.00				
4404.740(1) 22696.46						
	4465.232(4) 22388.99					
	4394.229(3) 22750.75	4523.727(5) 22099.48				
4083.776(5) 24480.25						
	4125.571(12) 24232.26					
3959.977(4) 25245.55	4051.000(6) 24678.32	4160.807(8) 24027.05			5619.78(1h) 17789.36	
		4061.540(10) 24614.28				
			5510.695(1h) 18141.50			
3978.753(12) 25126.42						
3936.442(10) 25396.47	4026.384(6) 24829.19			5469.547(5c) 18277.98	5572.519(2) 17940.24	
	3955.681(20) 25272.97	4060.320(10) 24621.67			5437.998(2c) 18384.02	
	3871.763(5) 25820.73	3971.932(15) 25169.57				
3745.476(6) 26691.32					5197.37(2c) 19235.16	
3693.667(4) 27065.69	3772.721(3) 26498.57					5219.09(15cw) 19155.11

124792—35——8

TABLE 2.—*Multiplets in the*

Term symbol	Value	$a^6D_{0\frac{1}{2}}$ 0.00	$a^6D_{1\frac{1}{2}}$ 154.19	$a^6D_{2\frac{1}{2}}$ 391.99	$a^6D_{3\frac{1}{2}}$ 695.25	$a^6D_{4\frac{1}{2}}$ 1050.26	$a^4F_{1\frac{1}{2}}$ 1142.79
$z^4D^{\circ}_{0\frac{1}{2}}$	18791.09	5320.205(3) 18791.05					5664.698(100) 17648.31
$z^4D^{\circ}_{1\frac{1}{2}}$	19036.57	5251.629(15c) 19036.43	5294.473(2) 18882.38	5362.003(6) 18644.58			5586.987(30) 17893.78
$z^4D^{\circ}_{2\frac{1}{2}}$	19427.90		5186.986(15) 19273.67	5251.805(10) 19035.79	5336.797(6) 18732.63		5467.410(3) 18285.13
$z^4D^{\circ}_{3\frac{1}{2}}$	19916.69			5120.297(20) 19524.69	5201.289(3) 19221.41	5298.951(4) 18866.42	
$y^4D^{\circ}_{0\frac{1}{2}}$	20107.36	4971.917(10c) 20107.37					5271.526 (60c) 18964.58
$y^4D^{\circ}_{1\frac{1}{2}}$	20383.62	4904.534(25) 20383.62	4941.905(2h) 20229.48	5000.712(4) 19991.59			5195.837(20) 19240.83
$y^4D^{\circ}_{2\frac{1}{2}}$	20837.98		4833.362(40) 20683.77	4889.551(7c) 20446.08	4963.189(7) 20142.73		5075.971(5c) 19695.19
$y^4D^{\circ}_{3\frac{1}{2}}$	21512.18			4733.483(30c) 21120.20	4802.442(9) 20816.94	4885.765(5) 20461.93	
$z^4F^{\circ}_{1\frac{1}{2}}$	23243.87	4300.989(100) 23243.95	4329.732(20c) 23089.65	4374.789(12c) 22851.84			4523.409 (200) 22101.04
$z^4F^{\circ}_{2\frac{1}{2}}$	23574.15		4268.667(15) 23419.95	4312.454(25) 23182.15	4369.618(8) 22878.88		4456.800(30) 22431.35
$z^4F^{\circ}_{3\frac{1}{2}}$	24015.11			4231.954(25) 23623.14	4286.987(60) 23319.87	4353.266(20) 22964.83	
$z^4F^{\circ}_{4\frac{1}{2}}$	24506.53				4198.510(30) 23811.29	4262.056(100) 23456.28	
$z^4P^{\circ}_{1\frac{1}{2}}$	23006.86	4345.315(20c) 23006.84		4420.637(30c) 22614.84			Masked 21864.07
$z^4P^{\circ}_{2\frac{1}{2}}$	23684.44		4248.658(8) 23530.24	4292.035(20c) 23292.44	4348.652(40cw) 22989.19		4434.997(3) 22541.62
$y^4F^{\circ}_{1\frac{1}{2}}$	25930.01	3855.456(15) 25929.94		Masked 25538.02			4033.192(40) 24787.27
$y^4F^{\circ}_{2\frac{1}{2}}$	26060.65		3858.953(40) 25906.45	3894.704(10) 25668.65	3941.266(40c) 25365.41		4012.056(6) 24917.86
$y^4F^{\circ}_{3\frac{1}{2}}$	26165.79			3878.818(40) 25773.77	3924.995(40c) 25470.55	3980.483(60c) 25115.50	
$y^4F^{\circ}_{4\frac{1}{2}}$	26440.33				3883.141(80) 25745.08	3937.437(150) 25390.07	
$x^4D^{\circ}_{0\frac{1}{2}}$	26717.73	3741.776(30c) 26717.71	3763.492(40) 26563.55				3908.971(40) 25574.96
$x^4D^{\circ}_{1\frac{1}{2}}$	26936.86	3711.343(60) 26936.79	3732.702(5c) 26782.66	3766.140(30c) 26544.87			3875.764(20) 25794.08
$x^4D^{\circ}_{2\frac{1}{2}}$	27359.70		3674.691(15) 27205.45	3707.088(7c) 26967.70	3749.248(1) 26664.46		
$x^4D^{\circ}_{3\frac{1}{2}}$	27596.74			3674.787(40c) 27204.74	3716.214(30c) 26901.48		
$y^4P^{\circ}_{0\frac{1}{2}}$	27666.46	3613.455(7c) 27666.48	3633.717(20) 27512.22				3769.145(20) 26523.71
$y^4P^{\circ}_{1\frac{1}{2}}$	27782.57	3598.343 (12vd) 27782.67	3618.441(15) 27628.36	3649.854(60) 27390.58			3752.723(9) 26639.77
$y^4P^{\circ}_{2\frac{1}{2}}$	28445.33		3533.667(40) 28291.16	3563.624(80) 28053.34	3602.561(60) 27750.14		

Cb I *spectrum*—Continued

$a^4F_{2\frac{1}{2}}$ 1586.90	$a^4F_{3\frac{1}{2}}$ 2154.11	$a^4F_{4\frac{1}{2}}$ 2805.36	$a^4D_{0\frac{1}{2}}$ 8410.90	$a^4D_{1\frac{1}{2}}$ 8705.32	$a^4D_{2\frac{1}{2}}$ 9043.14	$a^4D_{3\frac{1}{2}}$ 9497.52
			9631.10(25c)	9912.21(15)		
			10380.19	10085.80		
5729.185(80)			9408.58(10)	9676.75(30c)	10003.80(25)	
17449.66			10625.68	10331.22	9993.44	
5603.512(30)	5787.523(80)			9323.50(20c)	9626.85(50w)	10067.34(15w)
17841.01	17273.77			10722.66	10384.77	9930.45
	5628.253(8c)	5842.467(30)				9595.03(30w)
	17762.58	17111.32				10419.21
			8547.25(20c)	8767.97(12)		
			11696.46	11402.02		
5318.597(50)			8350.04(10h)	8560.54(30c)	8815.56(100w)	
18796.74			11972.70	11678.30	11340.47	
5193.076(40c)	5350.723(100c)			8240.00	8475.98	8815.56(100w)
				(50cw)	(150cwl)	
19251.06	18683.88			12132.59	11794.81	11340.47
5017.362(3c)	5164.367(40c)	5344.160(200c)			8017.64(3c)	8320.93
19925.25	19358.08	18706.83			12469.07	12014.59
						(500cwl)
4616.162(50)			6739.88(80)	6876.36(50)		
21656.97			14832.97	14538.57		
4546.820(150)	4667.224(50)			6723.62(100c)	6879.91(10c)	7102.01(20cw)
21987.25	21420.03			14868.84	14531.07	14076.65
4457.424(50)	4573.077(200c)	4713.496(80)			6677.33(100cw)	6886.32(30cw)
22428.21	21861.01	21209.76			14971.92	14517.55
	4472.536(40c)	4606.759(200c)				6660.84(200cw)
	22352.43	21701.17				15008.98
Masked			6849.34(20c)	6990.31(80)	7159.43(100)	
21419.96			14595.93	14301.58	13963.75	
4524.128(20)	4643.315(10)				6828.10(100)	7046.80(200)
22097.53	21530.33				14641.33	14186.93
4106.777(6)			5706.472(50)	5804.020(30)	5920.14(2c)	
24343.15			17519.11	17224.67	16886.82	
4084.856(40)	4181.784(6)			5760.329(80)	5874.681(40c)	
24473.78	23906.52			17355.32	17017.50	
	4163.474(40)	4279.53(5)			5838.608(100c)	5997.861(40cw)
	24011.66	23360.50			17122.63	16668.01
	4116.400(5)	4229.832(25)				5900.586
						(150cw)
	24286.24	23634.97				16942.79
			5460.938(4c)	5550.179(2)		
			18306.80	18012.45		
3943.663(60)			5396.336(7c)	5483.485(8)	5586.987(30)	
25349.99			18525.96	18231.52	17893.78	
3878.966(20)	3966.246(150)			5359.183(7)	5458.043(10c)	5596.868(4h)
25772.79	25205.65			18654.39	18316.51	17862.19
3843.615(4)	3929.295(30c)	4032.523(150)			5388.299(6)	5523.569(25)
26009.82	25442.68	24791.39			18553.59	18099.22
				5272.480(5)		
				18961.14		
3816.342(15)				5240.392(5c)	5334.864(30c)	
26195.69				19077.25	18739.42	
3722.170(4)	3802.480(4)			5064.451(3c)	5152.623	5276.197(60cw)
					(12cw)	
26858.44	26291.19			19739.99	19402.20	18947.79

TABLE 2.—*Multiplets in the*

Term symbol	Value	$a^6D_{0\frac{1}{2}}$ 0.00	$a^6D_{1\frac{1}{2}}$ 154.19	$a^6D_{2\frac{1}{2}}$ 391.99	$a^6D_{3\frac{1}{2}}$ 695.25	$a^6D_{4\frac{1}{2}}$ 1050.26	$a^4F_{1\frac{1}{2}}$ 1142.79
$x^4F^{\circ}_{1\frac{1}{2}}$	29779.44						3491.024(50) 28636.73
$x^4F^{\circ}_{2\frac{1}{2}}$	29987.45						3465.860(30) 28844.64
$x^4F^{\circ}_{3\frac{1}{2}}$	30161.56					3434.118(4) 29111.24	
$x^4F^{\circ}_{4\frac{1}{2}}$	30279.23					3420.287(4) 29228.96	
$w^4F^{\circ}_{1\frac{1}{2}}$	31707.94						3270.760(20) 30565.16
$w^4F^{\circ}_{2\frac{1}{2}}$	32139.78						3225.194(9) 30996.97
$w^4F^{\circ}_{3\frac{1}{2}}$	32451.99						
$w^4F^{\circ}_{4\frac{1}{2}}$	32605.39					3168.141(2h) 31555.15	
$w^4D^{\circ}_{0\frac{1}{2}}$	31907.75						3249.517(50) 30764.96
$w^4D^{\circ}_{1\frac{1}{2}}$	32248.69						
$w^4D^{\circ}_{2\frac{1}{2}}$	32545.51						
$w^4D^{\circ}_{3\frac{1}{2}}$	33003.89						
$v^4D^{\circ}_{1\frac{1}{2}}$	33717.01						3069.023(10) 32574.22
$v^4D^{\circ}_{2\frac{1}{2}}$	33872.18				3013.266(3h) 33176.93		3054.47(1) 32729.42
$v^4D^{\circ}_{3\frac{1}{2}}$	34168.94						
$u^4D^{\circ}_{1\frac{1}{2}}$	36016.26						2866.672(8) 34873.44
$u^4D^{\circ}_{2\frac{1}{2}}$	36180.11						2853.264(3) 35037.31
$u^4D^{\circ}_{3\frac{1}{2}}$	36334.21						
$t^4D^{\circ}_{0\frac{1}{2}}$	37536.56						2746.910 (20rv) 36393.80
$t^4D^{\circ}_{1\frac{1}{2}}$	37954.99						2715.692(8) 36812.14
$t^4D^{\circ}_{2\frac{1}{2}}$	38393.49						2683.714(5) 37250.75
$t^4D^{\circ}_{3\frac{1}{2}}$	38854.14					2644.444 (3c) 37803.89	
$x^4P^{\circ}_{0\frac{1}{2}}$	38730.17	2581.194(7) 38730.18					
$x^4P^{\circ}_{1\frac{1}{2}}$	38709.66						
$x^4P^{\circ}_{2\frac{1}{2}}$	38763.33						
$v^4F^{\circ}_{1\frac{1}{2}}$	38903.00						2647.500 (100R) 37760.25
$v^4F^{\circ}_{2\frac{1}{2}}$	39248.30						2623.510(30) 38105.52
$v^4F^{\circ}_{3\frac{1}{2}}$	39620.13						
$v^4F^{\circ}_{4\frac{1}{2}}$	40008.52						

Cb I *spectrum*—Continued

$a^4F_{2\frac{1}{2}}$ 1586.90	$a^4F_{3\frac{1}{2}}$ 2154.11	$a^4F_{4\frac{1}{2}}$ 2805.36	$a^4D_{0\frac{1}{2}}$ 8410.90	$a^4D_{1\frac{1}{2}}$ 8705.32	$a^4D_{2\frac{1}{2}}$ 9043.14	$a^4D_{3\frac{1}{2}}$ 9497.52
3546.031(12) 28192.52			4678.48(20cw) 21368.50	4743.839(15) 21074.10	4821.116(3) 20736.31	
3520.055(40) 28400.56	3591.790(9) 27833.36			4697.468(30c) 21282.13	4773.241(20c) 20944.29	
3498.608(30) 28574.65	3569.464(40) 28007.45	3654.430(10c) 27356.28			4733.885(60cw) 21118.41	4837.982(20cw) 20664.02
	3554.524(60) 28125.16	3638.792(20c) 27473.85				4810.584(100cw) 20781.70
3318.981(50) 30121.09			4291.196(25) 23296.99	4346.120(10) 23002.58	4410.882(2) 22664.86	
3272.073(25) 30552.89	3333.970(10) 29985.68			4266.020(50) 23434.48	4328.428(30c) 23096.61	
3238.975(2) 30865.09	3299.608(30) 30297.94	3372.100(10) 29646.63			4270.691(50cw) 23408.85	4355.245(5c) 22954.39
	3282.990(5) 30451.29	3354.742(80) 29800.02				4326.320(100cw) 23107.86
			4254.693(30) 23496.87	4308.692(20c) 23202.40		
			4193.828(10c) 23837.87	4246.293(20) 23543.35	4308.117(15c) 23205.49	
3229.189(4) 30958.62	3289.460(8) 30391.40			4193.420(1) 23840.19	4253.693(50cw) 23502.39	4337.561(12cw) 23047.97
	3240.582(3) 30849.78	3310.467(25) 30198.56			4172.34(1c) 23960.64	4252.977(80cw) 23506.35
3111.446(20) 32130.11						
3096.492(10) 32285.27	3151.870(30) 31718.04				4026.42(2) 24829.0	
	3122.646(15) 32014.87	3187.497(40) 31363.54				4052.132(6c) 24671.42
2903.648(10) 34429.38			3621.450(1) 27605.36	3660.498(2) 27310.94		
2889.892(10) 34593.25	2938.066(15) 34026.07			3638.673(2c) 27474.74	3683.973(5c) 27136.91	
	2924.822(10) 34180.14	2981.634(15) 33528.90			3663.167(8cw) 27291.04	3725.195(20cw) 26836.63
			3432.419(15c) 29125.65	3467.474(15) 28831.24		
2748.848(20rv) 36368.14			3383.802(15) 29544.10	3417.867(15) 29249.65	3457.800(20) 28911.87	
2716.104(10) 36806.55	2758.610(50r?) 36239.45			3367.382(25) 29688.16	3406.138(40) 29350.37	3459.703(25) 28895.97
	2723.990(10) 36700.00	2773.197(50) 36048.84			3353.509(15) 29810.97	3405.417(60) 29356.59
			3297.286(8c) 30319.27	3329.622(10) 30024.83		
			3299.53(1) 30298.7	3331.895(10) 30004.35	3369.840(20d) 29666.51	
				3325.946(1) 30058.02	3363.750(15d) 29720.22	3415.984(30c) 29265.78
2679.016(20r?) 37316.07			3278.599(4) 30492.08			
2654.449(70R) 37661.41	2695.039(40r) 37094.22			3273.139(3) 30542.94		
2628.495(20) 38033.25	2668.290(40r) 37466.06	2715.503(6) 36814.70			3269.493(3c) 30576.99	
	2640.913(20vd) 37854.43	2687.148(50r?) 37203.15				3276.567(4) 30510.99

TABLE 3.—*Terms of the* Cb I *spectrum*

Electron configuration	Term symbol	Term value	Level separation
$3d^44s$	$a^6\mathrm{D}_{0\frac{1}{2}}$	0.00	
	$a^6\mathrm{D}_{1\frac{1}{2}}$	154.19	154.19
	$a^6\mathrm{D}_{2\frac{1}{2}}$	391.99	237.80
	$a^6\mathrm{D}_{3\frac{1}{2}}$	695.25	303.26
	$a^6\mathrm{D}_{4\frac{1}{2}}$	1,050.26	355.01
$3d^34s^2$	$a^4\mathrm{F}_{1\frac{1}{2}}$	1,142.79	
	$a^4\mathrm{F}_{2\frac{1}{2}}$	1,586.90	444.11
	$a^4\mathrm{F}_{3\frac{1}{2}}$	2,154.11	567.21
	$a^4\mathrm{F}_{4\frac{1}{2}}$	2,805.36	651.25
$3d^44s$	$a^4\mathrm{D}_{0\frac{1}{2}}$	8,410.90	
	$a^4\mathrm{D}_{1\frac{1}{2}}$	8,705.32	294.42
	$a^4\mathrm{D}_{2\frac{1}{2}}$	9,043.14	337.82
	$a^4\mathrm{D}_{3\frac{1}{2}}$	9,497.52	454.38
$d^3sp(^5\mathrm{F})$	$z^6\mathrm{D}^\circ_{0\frac{1}{2}}$	19,623.96	
	$z^6\mathrm{D}^\circ_{1\frac{1}{2}}$	19,765.20	141.24
	$z^6\mathrm{D}^\circ_{2\frac{1}{2}}$	19,993.78	228.58
	$z^6\mathrm{D}^\circ_{3\frac{1}{2}}$	20,315.74	321.96
	$z^6\mathrm{D}^\circ_{4\frac{1}{2}}$	20,733.88	418.14
$d^4p(^5\mathrm{D})$	$y^6\mathrm{F}^\circ_{0\frac{1}{2}}$	23,984.87	
	$y^6\mathrm{F}^\circ_{1\frac{1}{2}}$	24,164.79	179.92
	$y^6\mathrm{F}^\circ_{2\frac{1}{2}}$	24,396.80	232.01
	$y^6\mathrm{F}^\circ_{3\frac{1}{2}}$	24,769.91	373.11
	$y^6\mathrm{F}^\circ_{4\frac{1}{2}}$	25,199.81	429.90
	$y^6\mathrm{F}^\circ_{5\frac{1}{2}}$	25,680.36	480.55
$d^4p(^5\mathrm{D})$	$z^6\mathrm{P}^\circ_{1\frac{1}{2}}$	24,283.34	
	$z^6\mathrm{P}^\circ_{2\frac{1}{2}}$	24,543.13	259.79
	$z^6\mathrm{P}^\circ_{3\frac{1}{2}}$	24,904.86	361.73
$d^4p(^5\mathrm{D})$	$y^6\mathrm{D}^\circ_{0\frac{1}{2}}$	25,879.81	
	$y^6\mathrm{D}^\circ_{1\frac{1}{2}}$	26,067.06	187.25
	$y^6\mathrm{D}^\circ_{2\frac{1}{2}}$	26,386.36	319.30
	$y^6\mathrm{D}^\circ_{3\frac{1}{2}}$	26,832.43	446.07
	$y^6\mathrm{D}^\circ_{4\frac{1}{2}}$	27,419.62	587.19
$d^3sp(^5\mathrm{P})$	$x^6\mathrm{D}^\circ_{0\frac{1}{2}}$	26,552.40	
	$x^6\mathrm{D}^\circ_{1\frac{1}{2}}$	26,713.30	160.90
	$x^6\mathrm{D}^\circ_{2\frac{1}{2}}$	26,983.34	270.04
	$x^6\mathrm{D}^\circ_{3\frac{1}{2}}$	27,427.07	443.73
	$x^6\mathrm{D}^\circ_{4\frac{1}{2}}$	27,974.88	547.81
$d^3sp(^5\mathrm{P})$	$y^6\mathrm{P}^\circ_{1\frac{1}{2}}$	28,278.25	
	$y^6\mathrm{P}^\circ_{2\frac{1}{2}}$	28,652.66	374.41
	$y^6\mathrm{P}^\circ_{3\frac{1}{2}}$	28,973.12	320.46
?	$z^4\mathrm{D}^\circ_{0\frac{1}{2}}$	18,791.09	
	$z^4\mathrm{D}^\circ_{1\frac{1}{2}}$	19,036.57	245.48
	$z^4\mathrm{D}^\circ_{2\frac{1}{2}}$	19,427.90	391.33
	$z^4\mathrm{D}^\circ_{3\frac{1}{2}}$	19,916.69	488.79
$d^3sp(^3\mathrm{F})$	$y^4\mathrm{D}^\circ_{0\frac{1}{2}}$	20,107.36	
	$y^4\mathrm{D}^\circ_{1\frac{1}{2}}$	20,383.62	276.26
	$y^4\mathrm{D}^\circ_{2\frac{1}{2}}$	20,837.98	454.36
	$y^4\mathrm{D}^\circ_{3\frac{1}{2}}$	21,512.18	674.20
$d^3sp(^3\mathrm{F})$	$z^4\mathrm{F}^\circ_{1\frac{1}{2}}$	23,243.87	
	$z^4\mathrm{F}^\circ_{2\frac{1}{2}}$	23,574.15	330.28
	$z^4\mathrm{F}^\circ_{3\frac{1}{2}}$	24,015.11	440.96
	$z^4\mathrm{F}^\circ_{4\frac{1}{2}}$	24,506.53	491.42
$d^4p(^5\mathrm{D})$	$z^4\mathrm{P}^\circ_{0\frac{1}{2}}$	- - - - - -	
	$z^4\mathrm{P}^\circ_{1\frac{1}{2}}$	23,006.86	
	$z^4\mathrm{P}^\circ_{2\frac{1}{2}}$	23,684.44	677.58
$d^4p(^5\mathrm{D})$	$y^4\mathrm{F}^\circ_{1\frac{1}{2}}$	25,930.01	
	$y^4\mathrm{F}^\circ_{2\frac{1}{2}}$	26,060.65	130.64
	$y^4\mathrm{F}^\circ_{3\frac{1}{2}}$	26,165.79	105.14
	$y^4\mathrm{F}^\circ_{4\frac{1}{2}}$	26,440.33	274.54
$d^4p(^5\mathrm{D})$	$x^4\mathrm{D}^\circ_{0\frac{1}{2}}$	26,717.73	
	$x^4\mathrm{D}^\circ_{1\frac{1}{2}}$	26,936.86	219.13
	$x^4\mathrm{D}^\circ_{2\frac{1}{2}}$	27,359.70	422.84
	$x^4\mathrm{D}^\circ_{3\frac{1}{2}}$	27,596.74	237.04
$d^3sp(^3\mathrm{P})$	$y^4\mathrm{P}^\circ_{0\frac{1}{2}}$	27,666.46	
	$y^4\mathrm{P}^\circ_{1\frac{1}{2}}$	27,782.57	116.11
	$y^4\mathrm{P}^\circ_{2\frac{1}{2}}$	28,445.33	662.76
$d^3sp(^3\mathrm{G})$	$x^4\mathrm{F}^\circ_{1\frac{1}{2}}$	29,779.44	
	$x^4\mathrm{F}^\circ_{2\frac{1}{2}}$	29,987.45	208.01
	$x^4\mathrm{F}^\circ_{3\frac{1}{2}}$	30,161.56	174.11
	$x^4\mathrm{F}^\circ_{4\frac{1}{2}}$	30,279.23	117.67
$d^3sp(^5\mathrm{F})$	$w^4\mathrm{F}^\circ_{1\frac{1}{2}}$	31,707.94	
	$w^4\mathrm{F}^\circ_{2\frac{1}{2}}$	32,139.78	431.84
	$w^4\mathrm{F}^\circ_{3\frac{1}{2}}$	32,451.99	312.21
	$w^4\mathrm{F}^\circ_{4\frac{1}{2}}$	32,605.39	153.40
$d^3sp(^5\mathrm{F})$	$w^4\mathrm{D}^\circ_{0\frac{1}{2}}$	31,907.75	
	$w^4\mathrm{D}^\circ_{1\frac{1}{2}}$	32,248.69	340.94
	$w^4\mathrm{D}^\circ_{2\frac{1}{2}}$	32,545.51	296.82
	$w^4\mathrm{D}^\circ_{3\frac{1}{2}}$	33,003.89	458.38
$d^3sp(^3\mathrm{P})$	$v^4\mathrm{D}^\circ_{0\frac{1}{2}}$	- - - - - -	
	$v^4\mathrm{D}^\circ_{1\frac{1}{2}}$	33,717.01	
	$v^4\mathrm{D}^\circ_{2\frac{1}{2}}$	33,872.18	155.17
	$v^4\mathrm{D}^\circ_{3\frac{1}{2}}$	34,168.94	296.76
?	$u^4\mathrm{D}^\circ_{0\frac{1}{2}}$	- - - - - -	
	$u^4\mathrm{D}^\circ_{1\frac{1}{2}}$	36,016.26	
	$u^4\mathrm{D}^\circ_{2\frac{1}{2}}$	36,180.11	163.85
	$u^4\mathrm{D}^\circ_{3\frac{1}{2}}$	36,334.21	154.10
$d^4p(^3\mathrm{F})$	$t^4\mathrm{D}^\circ_{0\frac{1}{2}}$	37,536.56	
	$t^4\mathrm{D}^\circ_{1\frac{1}{2}}$	37,954.99	418.43
	$t^4\mathrm{D}^\circ_{2\frac{1}{2}}$	38,393.49	438.50
	$t^4\mathrm{D}^\circ_{3\frac{1}{2}}$	38,854.14	460.65
?	$x^4\mathrm{P}^\circ_{0\frac{1}{2}}$	38,730.17	
	$x^4\mathrm{P}^\circ_{1\frac{1}{2}}$	38,709.66	−20.51
	$x^4\mathrm{P}^\circ_{2\frac{1}{2}}$	38,763.33	53.67
$d^4p(^3\mathrm{F})$	$v^4\mathrm{F}^\circ_{1\frac{1}{2}}$	38,903.00	
	$v^4\mathrm{F}^\circ_{2\frac{1}{2}}$	39,248.30	345.30
	$v^4\mathrm{F}^\circ_{3\frac{1}{2}}$	39,620.13	371.83
	$v^4\mathrm{F}^\circ_{4\frac{1}{2}}$	40,008.52	388.39

The nuclear moment of columbium has been determined from hyperfine structure by Ballard.[7] A value of $I=9/2$ is indicated, but this leads to wrong quantum numbers for some of the classified lines (e. g., 5344 and 6661 A).

The low even terms of Cb I named in table 1 combine with a great many higher odd terms which occur when a p electron is substituted in one of the listed configurations. A large number of these middle levels have been established but it is difficult at present to group them into terms and assign configurations. Thus far the guiding principles of these attempts have been interval and intensity rules, and comparison with the analogous spectrum of vanadium. The sextet system is well established, the quartet system somewhat less complete and certain, while the doublet system still remains unrecognized. The average deviations of an observed wave number from the corresponding term combination is 0.02 cm^{-1} for classified Cb I lines.

The raie ultime of columbium in low excitation sources where neutral atoms predominate is the line at 4058.931 A, which is classified as $(4d^4 5s)a^6D_{4\frac{1}{2}} - (4d^4 5p)y^6F^{\circ}_{5\frac{1}{2}}$.

[7] Phys. Rev., 46, 806 (1934).

TABLE 4.—*Terms of the* Cb II *spectrum*

Electron configuration	Term symbol	Term value	Level separation	Electron configuration	Term symbol	Term value	Level separation
$4d^4$	a^5D_0	0.00	159.00	$4d^35p(^4F)$	$z^5F^\circ_1$	36731.78	231.00
	a^5D_1	159.00	279.38		$z^5F^\circ_2$	36962.78	414.15
	a^5D_2	438.38	363.00		$z^5F^\circ_3$	37376.93	151.45
	a^5D_3	801.38	423.47		$z^5F^\circ_4$	37528.38	495.95
	a^5D_4	1224.85			$z^5F^\circ_5$	38024.33	
$4d^35s(^4F)$	a^5F_1	2356.76	272.34	$4d^35p(^4F)$	$z^5D^\circ_0$	37298.20	181.82
	a^5F_2	2629.10	400.48		$z^5D^\circ_1$	37480.02	317.27
	a^5F_3	3029.58	512.95		$z^5D^\circ_2$	37797.29	419.09
	a^5F_4	3542.53	603.49		$z^5D^\circ_3$	38216.38	74.89
	a^5F_5	4146.02			$z^5D^\circ_4$	38291.27	
$4d^4$	a^3P_0	5562.25	630.06	$4d^35p(^4F)$	$z^3D^\circ_1$	34886.35	634.50
	a^3P_1	6192.31	1069.02		$z^3D^\circ_2$	35520.85	1032.42
	a^3P_2	7261.33			$z^3D^\circ_3$	36553.27	
$4d^4$	a^3F_2	7505.82	394.85	$4d^35p(^4F)$	$z^3G^\circ_3$	38684.94	650.35
	a^3F_3	7900.67	419.77		$z^3G^\circ_4$	39335.29	768.31
	a^3F_4	8320.44			$z^3G^\circ_5$	40103.60	
$4d^4$	a^3G_3	10247.08	357.17	$4d^35p(^4F)$	$z^3F^\circ_2$	38984.42	795.57
	a^3G_4	10604.25	442.90		$z^3F^\circ_3$	39779.99	451.98
	a^3G_5	11047.15			$z^3F^\circ_4$	40231.97	
$4d^35s(^4P)$	a^5P_1	10653.41	182.53	$4d^35p(^4P)$	$y^5D^\circ_0$	?	
	a^5P_2	10835.94	503.63		$y^5D^\circ_1$	43649.15	−358.70
	a^5P_3	11339.57			$y^5D^\circ_2$	43290.38	596.72
$4d^25s^2$	b^3F_2	12805.96	884.31		$y^5D^\circ_3$	43887.10	1083.62
	b^3F_3	13690.27	−24.55		$y^5D^\circ_4$	44970.72	
	b^3F_4	13665.72		$4d^35p(^4P)$	$z^5P^\circ_1$	43450.05	776.78
$4d^35p(^4F)$	$z^5G^\circ_2$	33351.00	568.24		$z^5P^\circ_2$	44226.83	544.72
	$z^5G^\circ_3$	33919.24	712.80		$z^5P^\circ_3$	44771.55	
	$z^5G^\circ_4$	34632.04	842.18	$4d^35p(^4P)$	$z^3P^\circ_0$	44936.01	438.94
	$z^5G^\circ_5$	35474.22	981.28		$z^3P^\circ_1$	45374.95	1170.37
	$z^5G^\circ_6$	36455.50			$z^3P^\circ_2$	46545.32	
				$4d^35p(^4P)$	$z^5S^\circ_2$	47072.88	

2. Cb II

When a columbium atom loses one electron it can be excited to emit another spectrum which is characteristic of four valence electrons. The low terms which may be expected in this case are indicated in table 5.

TABLE 5.—*Low terms of the* Cb II *spectrum*

Electron configuration	Terms
$4d^2\ 5s^2$	^{1}(SDG) ^{3}(PF)
$4d^3\ 5s$	^{1,3}(D) ^{1,3}(PDFGH) ^{3,5}(PF)
$4d^4$	^{1}(SDG) ^{3}(PF) ^{1}(SDFGI) ^{3}(PDFGH) ^{5}(D)

All of the quintet terms have been found, but only a portion of the triplet terms, and none of the singlets thus far. Here, as in Cb I, the terms arising from the configuration with a single s electron are outstanding in connection with hyperfine structure. Nearly all of the lines involving ^{5}(PF) ($4d^3\ 5s$) show hyperfine structure in grating spectrograms, and some unclassified complex lines were suspected of belonging to ^{3}(PF) ($4d^3\ 5s$) but a search for these terms was unsuccessful. However, it can be stated positively that ^{5}(D) $4d^4$ represents the normal state of the singly ionized Cb atom.

Transitions to the above-listed low even terms from higher excited odd terms represented by a p electron in the outer atomic structure account for the first spark spectrum of columbium. The establishment of these odd terms for Cb II is now practically complete for the quintet system, much less so for the triplet system, and entirely lacking for the singlets. Further search for the missing terms is considered a waste of time until more Zeeman effects are available.

When the spectra of ionized atoms are produced at atmospheric pressure by highly condensed sparks, it is commonly observed that most of the lines are broadened and somewhat unsymmetrical, the displacement being usually toward longer waves. Wave-length measurements from such spark spectrograms are thus affected by Stark effects and do not represent simple atomic constants. Since practically all of the spark lines here reported appeared also in arc spectrograms, the wave length values in table 6 represent measurements in arc spectra, but the intensities are estimated from spark spectrograms. The average deviation of observed wave numbers from term combinations is ± 0.04 cm^{-1} for classified Cb II lines.

The raie ultime for columbium in sources in which singly ionized atoms predominate is the line at 3094.171 classified as ($4d^3\ 5s$) $^5F_5-(4d^3\ 5p)\ ^5G^\circ_6$. This is by far the strongest line in the Cb II spectrum, and even though it does not involve the normal state, it can be relied upon as the most persistent line because it involves the largest quantum numbers permitted in a simple s, p interchange of electrons.[8]

[8] W. F. Meggers and B. F. Scribner, Research J. NBS **13**, 657 (1934).

TABLE 6.—*Multiplets in the* Cb II *spectrum*

Term symbol / Value		a^5D_0 0.00	a^5D_1 159.00	a^5D_2 438.38	a^5D_3 801.38	a^5D_4 1224.85	a^5F_1 2356.76	a^5F_2 2629.10	a^5F_3 3029.58	a^5F_4 3542.53	a^5F_5 4146.02
Term symbol	Value										
$z^5D^o_0$	37298.20		2691.774(60r) 37139.21				2861.091(100) 34941.46				
$z^5D^o_1$	37480.02	2667.300(30) 37479.97	2678.663(10) 37320.98	2698.866(100r) 37041.62			2846.280(60) 35123.28	2865.524(200r) 34850.92			
$z^5D^o_2$	37797.29		2656.076(80r) 37638.34	2675.945(80r) 37358.89	2702.197(70r) 36995.97		2820.803(12) 35440.49	2842.642(100r) 35168.22	2875.386(300Rc) 34767.76		
$z^5D^o_3$	38216.38			2646.258(100r) 37777.97	2671.933(150r) 37414.98	2702.521(40) 36991.53		2807.170(8) 35587.22	2841.141(100) 35186.80	2883.168(400Rc) 34673.92	
$z^5D^o_4$	38291.27				2666.595(40) 37489.87	2697.067(300r) 37066.33			2835.112(50) 35261.70	2876.956(200) 34748.79	2927.804(600Rc) 34145.33
$z^5F^o_1$	36731.78	2721.632(6) 36731.80	2733.464(10) 36572.81	2754.523(40) 36293.22			2903.236(200r) 34375.06	2931.458(70) 34102.77			
$z^5F^o_2$	36962.78		2716.310(15) 36803.76	2737.083(60) 36524.50	2764.561(10) 36161.45		2888.824(150r) 34606.04	2911.740(300r) 34333.70	2946.105(60) 33933.23		
$z^5F^o_3$	37376.93			2706.395(40) 36938.58	2733.258(40r) 36575.57	2765.271(10) 36152.16		2877.030(200r) 34747.90	2910.580(400r) 34347.38	2954.720(4) 33834.30	
$z^5F^o_4$	37528.38				2721.986(150r) 36727.02	2753.74(3) 36303.54			2897.803(200r) 34498.82	2941.536(500R) 33985.94	2994.724(300c) 33382.35
$z^5F^o_5$	38024.33					2716.63(200r) 36799.41				2899.230(200r) 34481.84	2950.878(800c) 33878.36
$z^5G^o_2$	33351.00						3225.480(500Rc) 30994.22	3254.070(200r) 30721.91	3297.055(20) 30321.40		
$z^5G^o_3$	33919.24							3194.983(700R) 31290.06	3236.403(300r) 30889.62	3291.055(30) 30376.67	
$z^5G^o_4$	34632.04								3163.403(1000R) 31602.41	3215.595(300rc) 31089.49	3279.248(20c) 30486.04
$z^5G^o_5$	35474.22					2918.916(3) 34249.29				3130.780(1500Rc) 31931.69	3191.096(200c) 31328.17
$z^5G^o_6$	36455.50										3094.171(2000Rc) 32309.48
$z^5P^o_1$	43450.05	2300.785(50) 43450.02	2309.239(100) 43290.97	2324.237(60) 43011.74							
$z^5P^o_2$	44226.83		2268.527(150) 44067.81	2283.004(300) 43788.40	2302.086(200) 43425.47						
$z^5P^o_3$	44771.55			2254.953(60) 44333.05	2273.566(150) 43970.15	2295.681(300) 43546.61					

$z^3D_1^\circ$	34886.35	2865.609(60) 34886.38	2878.739(8) 34727.27				3073.234(50) 32529.59	3099.179(100) 32257.28			
$z^3D_2^\circ$	35520.85		2827.071(50) 35361.91	2849.580(100) 35082.60	2879.380(15) 34719.54		3014.438(15) 33164.04	3039.399(10) 32891.70	3076.864(200) 32491.21		
$z^3D_3^\circ$	36553.27			2768.124(100r) 36114.90		2829.750(15) 35328.44		2946.890(80) 33924.19	2982.100(100) 33526.66	3028.437(300c) 33010.75	
$z^3G_3^\circ$	38684.94			2613.854(8) 38246.27	2638.877(5) 37883.63				2803.810(15) 35655.27		
$z^3G_4^\circ$	39335.29				2594.337(10) 38533.98	2623.170(8) 38110.46			2753.58(5) 36305.69	2793.044(80) 35792.70	
$z^3G_5^\circ$	40103.60					2571.324(60) 38878.83				2734.360(15) 36560.83	2780.235(150c) 35957.60
$z^3P_0^\circ$	44936.01										
$z^3P_1^\circ$	45374.95	2203.170(5) 45374.94	2210.917(20) 45215.96	2224.667(30) 44936.53							
$z^3P_2^\circ$	46545.32		2155.13(2) 46386.27	2168.188(4) 46106.94	2185.398(5) 45743.89						
$y^5D_1^\circ$	43649.15	2290.289(5) 43649.12	2298.662(6) 43490.15	2313.524(15) 43210.79							
$y^5D_2^\circ$	43290.38		2317.784(8) 43131.38	2332.896(10) 42852.01	2352.837(60) 42488.87						
$y^5D_3^\circ$	43887.10			2300.854(10) 43448.72	2320.238(20) 43085.77	2343.271(10) 42662.30					
$y^5D_4^\circ$	44970.72				2263.312(15) 44169.34	2285.223(60) 43745.88					

TABLE 6.—*Multiplets in the* Cb II *spectrum*—Continued

Term symbol	Value	a^5P_1 10653.41	a^5P_2 10835.94	a^5P_3 11339.57	a^3P_0 5562.25	a^3P_1 6192.31	a^3P_2 7261.33
$z^5D^\circ_0$	37298.20	3752.01(1) 26644.8				3213.912(3) 31105.77	
$z^5D^\circ_1$	37480.02	3726.58(10c) 26826.6	3752.08(1) 26644.3		3132.440(4) 31917.83	3195.216(5) 31287.77	
$z^5D^\circ_2$	37797.29	3683.0(10C) 27144.0	3707.96(60C) 26961.35	3378.50(1) 26458 7		3163.149(10) 31604.95	3273.888(15) 30535.95
$z^5D^\circ_3$	38216.38		Masked 27380.44	3719.63(25c) 26876.78			3229.567(100) 30955.00
$z^5D^\circ_4$	38291.27			3709.29(100C) 26951.70			
$z^5F^\circ_1$	36731.78				3207.341(20) 31169.50	3273.511(20) 30539.47	
$z^5F^\circ_2$	36962.78					3248.941(80) 30770.41	3365.883(10) 29701.38
$z^5F^\circ_3$	37376.93						3319.590(100) 30115.57
$z^5F^\circ_4$	37528.38						
$z^5F^\circ_5$	38024.33						
$z^5S^\circ_2$	47072.88	2744.97(20c) 36419.52	2758.807(50c) 36236.86	2797.693(100c) 35733.22		2445.402(2) 40880.68	
$z^5P^\circ_1$	43450.05	3048.216(80c) 32796.56	3065.260(100c) 32614.21		2638.591(7) 37887.73	2683.216(6) 37257.62	2762.48(3) 36188.69
$z^5P^\circ_2$	44226.83	2977.668(150c) 33573.56	2993.971(20c) 33390.75	3039.819(150c) 32887.15		2628.408(3) 38034.51	2704.417(5) 36965.60
$z^5P^\circ_3$	44771.55		2945.890(100c) 33935.70	2990.262(200c) 33432.16			
$z^3D^\circ_1$	34886.35				3409.191(100) 29324.09	3484.054(80) 28694.01	3618.89(4) 27624.92
$z^3D^\circ_2$	35520.85					3408.678(100) 29328.50	3537.625(40) 28259.50
$z^3D^\circ_3$	36553.27						3412.934(150) 29291.93

$z^3P^\circ_0$	44936.01	2916.091(8c) 34282.47				2580.284(30) 38743.83	
$z^3P^\circ_1$	45374.95		2894.436(20c) 34538.95		2511.004(100) 39812.72	2551.382(120) 39182.69	2622.952(20) 38113.62
$z^3P^\circ_2$	46545.32			2839.62(7c) 35205.7		2477.379(150) 40353.05	2544.802(200) 39284.00
$y^5D^\circ_1$	43649.15	3029.81(60d) 32995.79	3046.67(6c) 32813.20				
$y^5D^\circ_2$	43290.38	3063.126(40d) 32636.93	3080.345(100c) 32454.50	3128.915(10c) 31950.73		2694.753(4) 37098.16	
$y^5D^\circ_3$	43887.10		3024.735(200c) 33051.15	3071.547(90c) 32547.56			2729.524(2) 36625.60
$y^5D^\circ_4$	44970.72			2972.568(200c) 33631.15			

TABLE 6.—*Multiplets in the* Cb II *spectrum*—Continued

Term symbol value / Value		a^3F_2 7505. 82	a^3F_3 7900. 67	a^3F_4 8320. 44	a^3G_3 10247. 08	a^3G_4 10604. 25	a^3G_5 11047. 15	b^3F_2 12805. 96	b^3F_3 13690. 27	b^3F_4 13665. 72
Term symbol	Value									
$z^5D_1^{\circ}$	37480.02	3335.245(10) 29974.22								
$z^5D_2^{\circ}$	37797.29	3300.337(6) 30291.24	3343.903(4) 29896.61		3628.70(2) 27550.3				4146.99(4) 24106.98	
$z^5D_3^{\circ}$	38216.38	3255.270(5) 31710.59	3297.673(15) 30315.71	3343.968(80) 29896.03		3620.560(6) 27612.19				4072.064(15) 24550.66
$z^5D_4^{\circ}$	38291.27		3289.551(10) 30390.56	3335.672(5) 29970.38					4063.734(10) 24600.99	4059.670(10) 24625.61
$z^5F_1^{\circ}$	36731.78	3420.633(80) 29226.00						4178.396(6) 23925.91		
$z^5F_2^{\circ}$	36962.78	3393.809(10) 29456.99	3439.925(60) 29062.10					4138.453(10) 24156.83	4295.71(4) 23272.51	
$z^5F_3^{\circ}$	37376.93	3346.760(30) 29871.09	3391.593(9) 29476.24	3440.589(120) 29056.50	3684.932(4) 27129.85			4068.712(5) 24570.89	4220.598(15) 23686.68	4216.228(50) 23711.23
$z^5F_4^{\circ}$	37528.38		3374.252(50) 29627.72	3422.770(5) 29207.76	3664.47(2) 27281. 3	Masked 26924. 13			4193.80(10) 23838.03	4189.475(1) 23862.64
$z^5F_5^{\circ}$	38024.33			3365.594(100) 29703.93		3645.944(6) 27419.95				4104.163(50) 24358.65
$z^5G_2^{\circ}$	33351.00							4865.989(15) 20545.09		
$z^5G_3^{\circ}$	33919.24	3684.878(5) 26413.46						4735.04(2) 21113.26	4941.998(4) 20229.10	
$z^5G_4^{\circ}$	34632.04		Masked 26731.37						4773.799(7) 20941.84	4768.232(3) 20966.29
$z^5G_5^{\circ}$	35474.22			3681.679(6) 27153.88		4019.79(1) 24869.92				4584.10(6) 21808.44
$z^3D_1^{\circ}$	34886.35	3651.182(200) 27380.62						4527.648(100) 22080.35		
$z^3D_2^{\circ}$	35520.85	3568.510(30) 28014.93	3619.514(200) 27620.17		3955.549(3) 25273.81			4401.172(50) 22714.86	4579.446(100) 21830.61	
$z^3D_3^{\circ}$	36553.27	3441.663(10) 29047.43	3489.093(90) 28652.57	3540.961(250) 28232.88		3852.624(6) 25949.00			4372.645(40) 22863.05	4367.966(100) 22887.54
$z^3F_2^{\circ}$	38984.42	3175.856(150) 31478.50	3216.193(6) 31083.71		3478.790(100) 28737 43			3818.862(200) 26178.41	3952.367(100) 25294.16	
$z^3F_3^{\circ}$	39779.99		3133.920(30) 31879.36	3177.766(6) 31459.58		3426.562(200) 29175.43			3831.840(200) 26089.75	3828.242(40) 26114.27

$z^3F^\circ_4$	40231.97			3132.767(60) 31911.44		3374.252(50) 29627.72	3425.431(300) 29185.07			3763.13(8) 26566.1
$z^3G^\circ_3$	38684.94	3206.349(300) 31179.14	3247.478(150) 30784.27	3292.365(10) 30364.59	3515.421(100) 28437.99			3863.056(150) 25878.93	3999.706(8) 24994.80	
$z^3G^\circ_4$	39335.29		3180.290(400) 31434.58	3223.324(100) 31014.94	3436.834(20) 29088.24	3479.567(150) 28731.01	3534.05(10) 28288.1		3898.292(200) 25645.02	3894.56(5) 25669.6
$z^3G^\circ_5$	40103.60			3145.405(500) 31783.23		3388.938(30) 29499.33	3440.589(200) 29056.50			3781.379(200) 26437.90
$z^3P^\circ_1$	45374.95	2639.883(5) 37869.20						3069.51(5) 32569.05		
$z^3P^\circ_2$	46545.32	2560.741(3) 39039.50	2586.911(4) 38644.59						3042.789(15) 32855.05	

WASHINGTON, January 29, 1935.