

ROTATIONAL ANALYSIS OF THE COLUMBIUM OXIDE BANDS

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(Communicated by K. Rangadhama Rao, F.N.I.)

(Received October 1, 1954; read May 27, 1955)

INTRODUCTION

The spectrum of columbium oxide has been first obtained in this laboratory by Ramakrishna Rao (1950) in the course of an investigation of the line spectrum of columbium. They have been obtained in three different sources: (1) in the flame of a D.C. arc between columbium electrodes run at 220 volts and 3 amperes, (2) in the flame of a D.C. arc between graphite rods fed by columbium pentachloride, and (3) in a heavy current discharge from 2 kW. D.C. Generator with columbium pentachloride in the quartz discharge tube. The band spectrum consists of well-marked, red-degraded heads extending from about λ 4200 towards the red to the limit of sensitivity of the panchromatic plate. The bands have been divided into three systems, designated as *A*, *B* and *C* in the respective spectral regions λ 4200–5100, λ 5000–6300 and λ 6000 upwards. The systems *B* and *C* considerably overlap each other. Ramakrishna Rao has suggested a vibrational analysis of the three systems and has indicated a general correspondence between the bands of columbium oxide and the analogous α , β and γ systems in titanium oxide (Lowater, 1929) and zirconium oxide (Lowater, 1932). For the vanadium oxide molecule (Mahanti, 1935) only one system has so far been identified.

Describing the features of the three systems of columbium oxide Ramakrishna Rao has observed that the structure of the bands conspicuously differs from group to group. There is an apparent partially open structure in system *A*; the structure is much less open in system *B* while in system *C* there is no rotational structure at all. Further, as observed by him, while the systems *C* and *B* give evidence of multiplicity, in system *A* 'the multiplet structure is complicated by the existence of rotational structure'.

The determination, if possible, of the rotational structure of the bands is considered necessary in the light of the above observations. Such a study would also be interesting in view of the fact that spectra of only a few of the oxides of the elements of transition groups have so far been analysed, namely, titanium oxide, zirconium oxide and vanadium oxide. The present paper describes the results obtained in an attempt in this direction.

EXPERIMENTAL

For preliminary studies, all the sources mentioned by Ramakrishna Rao have been employed using spectrographs of comparatively low dispersion: (1) A Hilger two prism glass Littrow instrument, with which an exposure of about 15 minutes was sufficient, (2) the first order of a 10' concave grating with 15,000 lines per inch (dispersion 5.7 Å/mm.) giving exposures of about 10 to 30 minutes, and (3) final pictures for the measurements of the bands were taken in the first order of a 21' concave grating with 30,000 lines per inch (dispersion 1.2 Å/mm.) and having a 6-inch ruled surface set up in the Paschen mounting. An exposure of about 2

hours on Ilford S.R. Panchromatic plates was sufficient to get the bands well developed. The last spectra were taken using the flame of a D.C. arc between columbium electrodes run at 220 volts and 4 amperes. The electrodes were of the 'Specpure' variety supplied specially by Johnson, Matthey & Co. This 21' grating is the one mounted in the Applied Physics department of the University of Calcutta.

In addition to the plates mentioned above, three plates of the (1, 0), (0, 0) and (0, 1) bands have been made available to the author by Dr. V. R. Rao who has taken the arc spectra of columbium on the 21' grating mounted in the Yerkes observatory, U.S.A. The author is much indebted to him for these plates. The spectra have been measured employing usual iron arc international standards.

DESCRIPTION OF THE BANDS

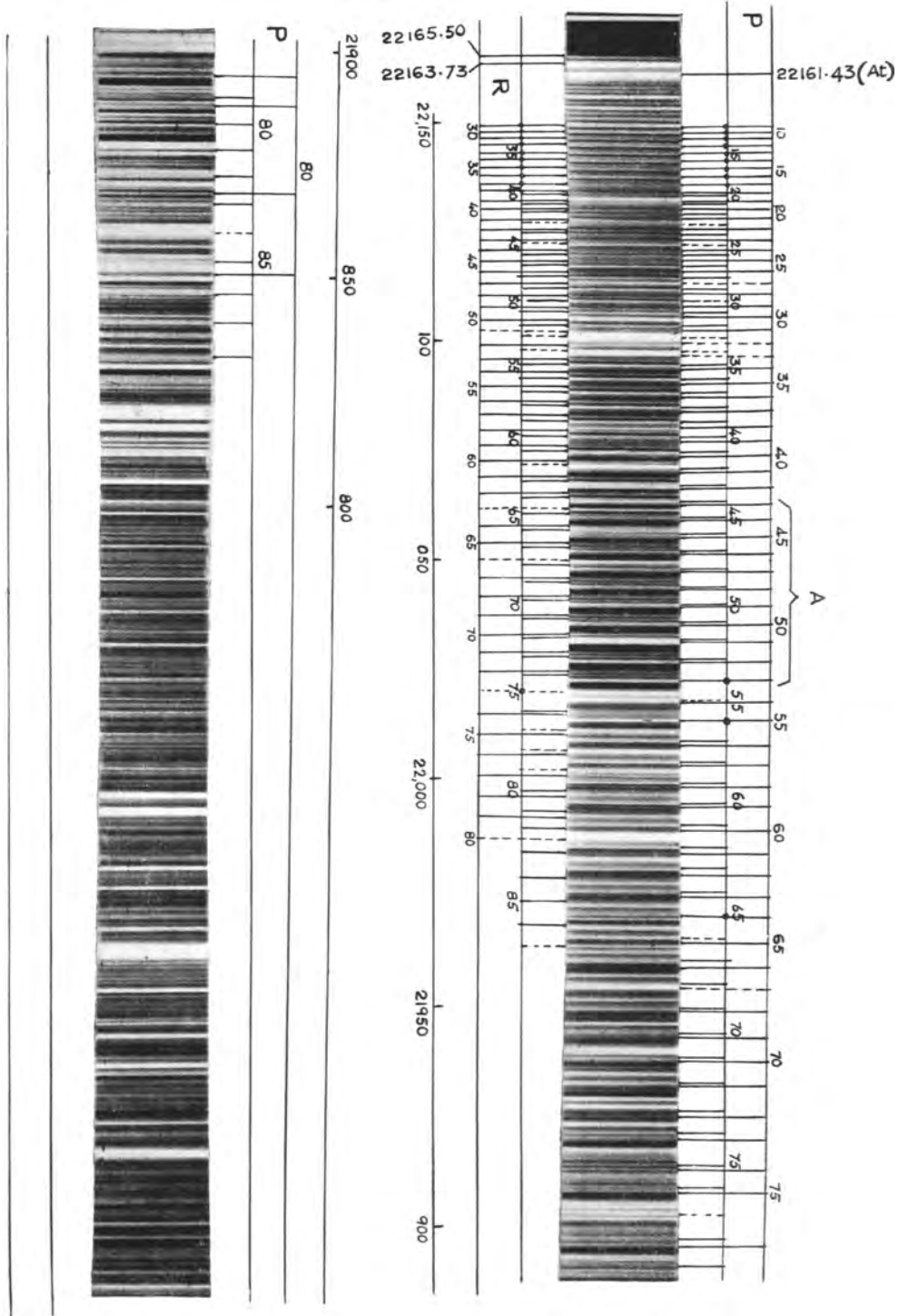
(0, 0) *Band*: The photographs have shown three clear and closely situated heads (ν 21322.7, ν 21321.3 and ν 21319.8) of gradually increasing intensity, the one at the long wavelength side being the most intense. The resolution is not good in the immediate vicinity of these heads. A little away from the head on the red side a series of strong lines starts. Each of these strong lines breaks up into two close lines one of which (the one on the violet side) is more intense than the other. These pairs of close lines continue up to a short distance when the more intense component line in each pair will be resolved into two very close lines and thus we get groups of three close lines. Still farther, these groups of three lines become groups of four lines.

Another point that is brought out clearly in the spectrograms is the nature of the three component heads mentioned above. The least refrangible component at ν 21319.8 is sharp and gives the impression of head formed due to the accumulation of close lines. The other two components are diffuse and headless and their appearance* is such as to justify a conclusion that these may not form part of this band at all.

(0, 1) *Band*: This also exhibits clearly three heads (ν 20342.2, ν 20340.4 and ν 20339.0). A little further to the red at ν 20328.9 is a band which apparently looks like another head. Immediately from this line follow a few lines among which there is first a slight increase and then a gradual fall in intensity. It is after these that a series of strong lines occurs, corresponding to the one observed in the (0, 0) band mentioned above. These strong lines become broad and diffuse and after a short distance, each line of the series gets resolved into a close group of four component lines. These close groups get wider further off from the band and the structure is broadened and a short region presents a clearly open structure. This helped considerably in serving as a starting point for the identification of the branches. At about ν 20210 there is the appearance of a head which indicates that the (1, 2) band may start here. This is evident from the low dispersion spectrograms. Thus there is a complication of the structure due to overlapping by the (1, 2) band.

(1, 0) *Band*: In this band two heads (ν 22165.5 and ν 22163.7) can be clearly discerned, the red side one being more intense than the other. It is quite likely that the third head might have been masked by the strong atomic line at ν 22161.4 occurring close to the above-mentioned two heads. The resolution is not enough very near the heads and a little away from the heads commence two clear series of lines and continue up to a short distance where due to an increase in the resolution there is a fall in intensity and a complexity in the rotational structure. This region is followed by a very distinct region in which groups, each of four distinct component lines, are prominently present. Even a cursory examination of the spectrogram points out the members of the four branches distinctly, which could

* This feature is common to (0, 1) and (1, 0) bands also.



be followed up on either side and the complete branches identified. From about ν 22018.6 which could be clearly noticed in the low dispersion pictures commences the (2, 1) band due to which there is a complication in the structure.

All the features mentioned above can be seen from the reproduction of the bands in Plates X, XI and XII. There is still a considerable amount of confusion due to the occurrence of a number of atomic lines. These have been carefully sifted out by comparison with the list due to Humphreys and Meggers (1945).

ANALYSIS

Columbium occurs in the same vertical group of the periodic table as vanadium. Hence the rotational structure of the bands of columbium oxide and the electronic transition involved in their emission may be expected to be similar to that of vanadium oxide. The similarity between the two band systems is evident from an examination of the general structure and appearance of the bands. In vanadium oxide although the electronic transition has not been conclusively established, four distinct series of lines constituting branches of the type R_1 and R_2 and P_1 and P_2 have been identified by Mahanti (1935) in the (0, 0), (1, 0) and (0, 1) bands and rotational analysis has been suggested consistent with the combination relationships expected from the assignments of the bands. The presence of what is considered as a short and strong Q branch led Mahanti to suggest that ${}^2\Delta - {}^2\Delta$ is the transition concerned in the emission of the system.

In analysing the rotational structure of the columbium oxide bands the method adopted has been first to identify the four different branches R and P analogous to those of vanadium oxide. As has already been mentioned in the description of the bands, a few distinct groups, each consisting of four lines, stand out prominently in all the three bands (1, 0), (0, 0) and (0, 1). (Cf. regions marked A , B and C in Plates X, XI and XII respectively.) These have provided a clue. The four lines in these groups are taken as constituting the four branches, R_1 , R_2 , P_1 and P_2 and when they are extrapolated towards the head, the groups of four lines become groups of three lines, one of the lines in each group being common to two of the branches. Extrapolating further towards the head, it is found that all the four branches merge giving rise to a series of strong lines—a feature which is very prominent in all the three bands. Thus four branches are picked out in each of the bands. In this arrangement the successive members (of the series of strong lines near the head) have formed into a branch.

As a next step in the analysis, a comparison is made of the B values of the oxide molecules of all elements round about columbium in the periodic table from beryllium to molybdenum. From that comparison the B value of columbium oxide molecule is taken to lie between 0.15 and 0.6 cm.^{-1} . By counting the lines almost up to the head and allowing for a small deviation because of lack of resolution at the head, the lower limit of the combination difference for a chosen line is calculated using the above lower limit for B value and a value for K which is definitely less than the number of lines between the head and that particular line, while the upper limit of the combination difference is determined by an upper limit to the increase in combination difference with K , consistent with the upper limit of the B value given above. Then for all pairs of the branches (which would be twelve in number for each band, each branch being treated as an R and a P branch since the nature of the branches is not known) all possible sets of frequency differences are formed in the three bands between the limits of the combination difference mentioned above. Altogether about 400 sets of frequency differences are written down and a thorough attempt at checking up the combination relations among the above sets of frequency differences in the three bands is made systematically. Ultimately, for only one particular relative numbering of the branches in the three bands, the combination relations between the bands are found to be satisfied with

at least a reasonable agreement of the combination differences. Then the determination of the absolute numbering is taken up.

This is done graphically by two usual methods described in detail elsewhere (refer Jevons' Report, 1932, pages 46 and 48 and Herzberg's 'Molecular Spectra and Molecular Structure', Vol. I, second edition, 1950, pages 189 and 190). Using the approximate relation $\Delta_2 F(K) = 4B_v(K + \frac{1}{2})$, the combination differences are plotted against an arbitrary numbering and the absolute numbering is obtained by shifting the abscissa scale until the straight line representing the above relation passes through the point, $-\frac{1}{2}$. The absolute numbering thus obtained is checked up by the second method by plotting the intervals between successive lines of the *P* and *R* branches in each band and ensuring that a single continuous line is obtained for the two branches, in the three bands (1, 0), (0, 0) and (0, 1).

The structure thus determined is shown in Tables I, II and III. Of the two series of lines of *R* branches it is not possible to identify which of the series is *R*₁ and which, *R*₂. Similar is the case with the *P* branches. The last two columns in all the three tables represent the combination differences formed by taking the mean value of $\Delta_2 F_1(K)$ and $\Delta_2 F_2(K)$, for the upper and lower states. The accuracy of measurements is generally within 0.05 cm.⁻¹. The agreement between the combination differences is seen from Tables I, II and III to be satisfactory and is hence taken to indicate the correctness of the analysis and the assignment of the absolute rotational numbering.

CALCULATION OF THE CONSTANTS

The rotational constants of the columbium oxide molecule for this system have been determined by the method of least squares by fitting the values $\frac{\Delta_2 F(K)}{(K + \frac{1}{2})}$ to the equation,

$$\frac{\Delta_2 F(K)}{(K + \frac{1}{2})} = 4B_v - 8D_v(K + \frac{1}{2})^2$$

and are given in Table IV below. The $\Delta_2 F(K)$ values used in these calculations for the determination of B'_0 and B''_0 are the mean values of the quantities of (0, 0) and (0, 1) bands, and of (1, 0) and (0, 0) bands, respectively.

The nature of the electronic transition involved in the emission of the system and of the satellite branches will be discussed in another paper, to be communicated shortly.

EXPLANATION OF THE PLATES

Plates X to XII show the rotational structure of the three bands (1, 0), (0, 0) and (0, 1) of system *A* of columbium oxide photographed in the first order of a 21-ft., 30,000 lines per inch concave grating. On one side are marked the lines of *P* branches with their respective *K* values. The dotted lines indicate superposition by columbium atomic lines. The lines of the *R* branches are similarly denoted on the other side. When the confusion is great, the marking is omitted.

ACKNOWLEDGEMENTS

The author is deeply indebted to Prof. K. R. Rao for his constant and invaluable guidance in the course of this work. He also wishes to express his grateful thanks to Prof. P. C. Mahanti who kindly permitted him to take pictures on the 21-ft. grating in his laboratory and gave him all facilities for work. His grateful thanks are also due to Dr. V. Ramakrishna Rao who kindly made available to the author three plates of columbium oxide spectrum taken by him in America, which have proved helpful in the analysis.

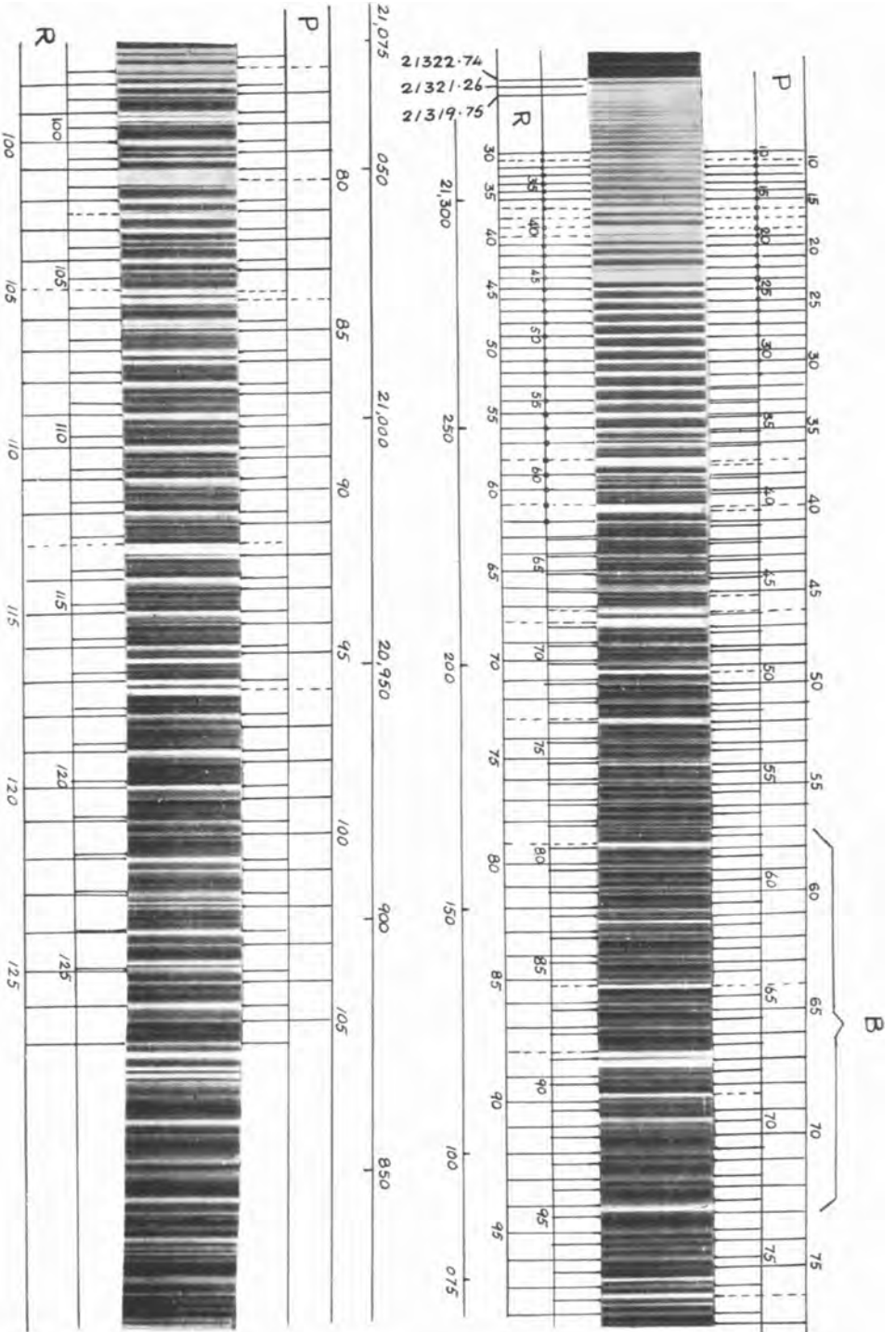


TABLE I

(1, 0) Band

* in all these tables indicates rotational lines overlapped by columbium atomic lines.

Columns 4 and 5 in these tables give the mean value of $\Delta_2 F'_1(K)$ and $\Delta_2 F''_2(K)$ for the upper and lower states respectively.

K	R	P	$\frac{\Delta_2 F'_1(K)}{= R(K) - P(K)}$	$\frac{\Delta_2 F''_2(K)}{= R(K-1) - P(K+1)}$
11		22149.59 146.63		
12		148.14 145.00		
13		146.63 143.29		
14		145.00 141.60		
15		143.29 139.74		
16		141.60 138.01		
17		139.74 136.07		
18		137.70* 134.11		
19		135.70 132.14		
20		133.70 130.43		
21		131.60 128.26		
22		129.39 125.94		
23		127.15 123.66		
24		124.86 121.25		
25		122.50 118.81		
26		120.05 116.29		
27		117.38 113.64*		
28		114.80 111.09		
29		22112.12 108.36		

TABLE I—(Contd.)

K	R	P	$\Delta_2 F''(K)$ $= R(K) - P(K)$	$\Delta_2 F''(K)$ $= R(K-1) - P(K+1)$
30		109.45 105.53		
31	22149.59 146.63	106.64 102.72	43.43	
32	148.14 145.00	103.74 099.44	44.77	49.23
33	146.63 143.29	100.81 096.95	46.08	50.76
34	145.00 141.60	097.82 093.80	47.49	52.31
35	143.29 139.74	094.78 092.52	48.87	53.76
36	141.60 138.01	091.65 087.44	49.76	55.11
37	139.74 136.07	088.63 084.18	51.50	56.83
38	137.70* 134.11	085.12 080.84	52.93	58.30
39	135.70 132.14	081.79 077.42	54.32	59.37
40	133.70 129.73	078.10 073.97	55.68	61.39
41	131.60 127.72	074.63 070.43	57.13	62.76
42	129.39 125.36	071.10 066.81*	58.42	64.36
43	127.15 123.12	067.46 063.15	59.83	65.84
44	124.86 120.68	063.69 059.38	61.24	67.39
45	122.50* 118.16	060.05 055.45	62.58	68.90
46	120.05 115.68	056.10 051.65	63.99	70.36
47	117.38 112.98	052.24 047.70	65.21	71.93
48	114.80 110.32	048.21 043.66	66.63	73.32
49	112.12 107.57	044.18 039.55	67.98	74.80
50	109.45 104.60	040.13 035.39	69.27	76.36

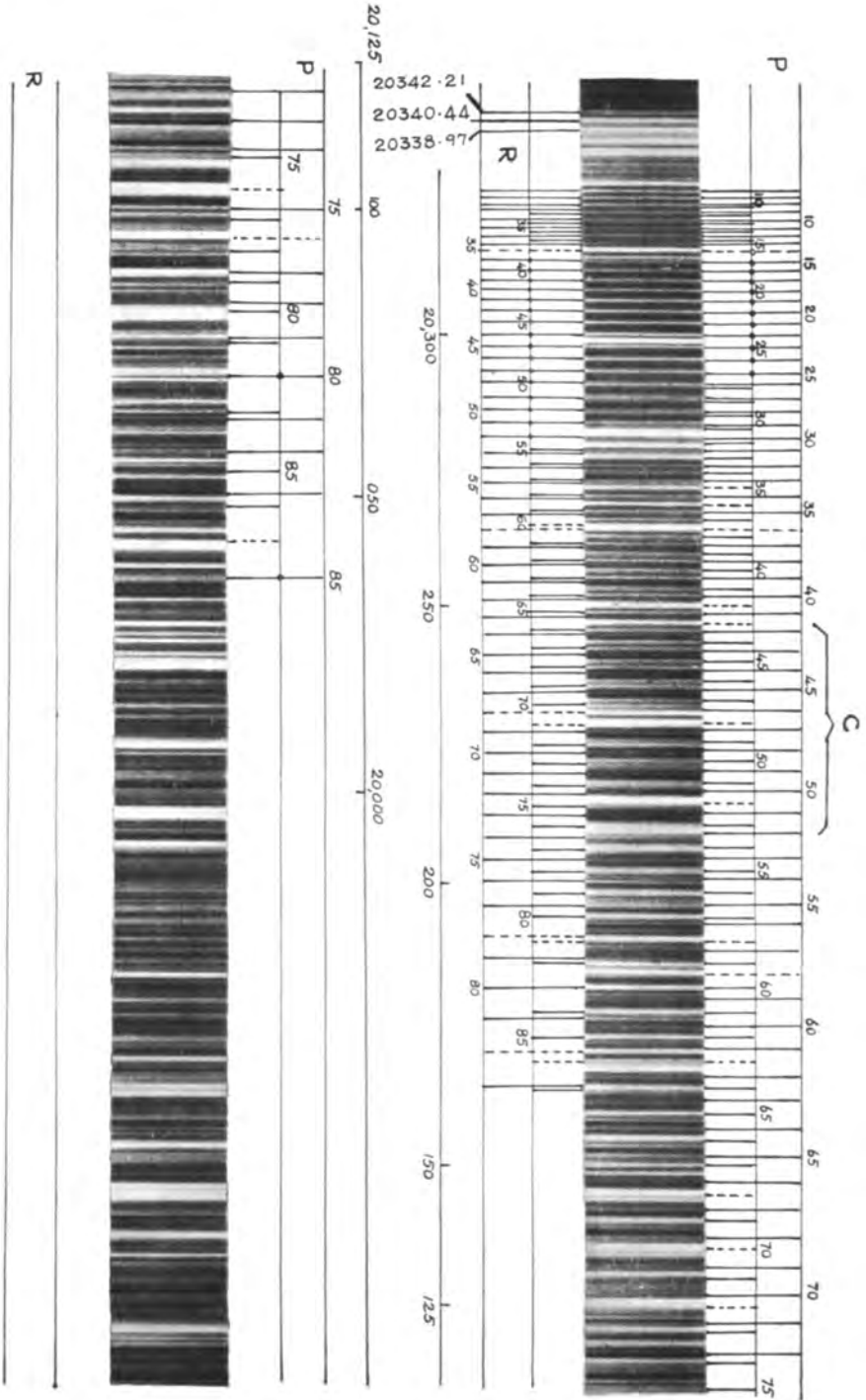


TABLE I—(Contd.)

K	R	P	$\Delta_2 F''(K)$ = $R(K) - P(K)$	$\Delta_2 F''(K)$ = $R(K-1) - P(K+1)$
51	22106.64 101.72	22035.81 031.16	70.70	77.68
52	103.74 098.83	031.57* 027.13	71.94	79.27
53	100.81 095.83	027.13 022.70	73.41	81.14
54	097.85 092.69	022.70 017.59	75.13	82.32
55	094.78 089.37	018.29 013.71	76.07	84.24
56	091.65 086.26	013.71 008.35	77.93	85.81
57	088.63 082.90	009.10 003.44	79.50	87.39
58	085.12 079.59	004.36 21998.77	80.79	88.93
59	081.79 076.09	999.63 994.05	82.10	90.38
60	078.38 072.58	994.89 989.06	83.51	91.46
61	075.15 069.01	989.96 984.95	84.63	92.99
62	071.77* 065.29	984.95 980.04	86.04	95.01
63	067.94 061.68	980.04 974.10	87.36	96.34
64	064.28 057.67	974.87 969.72	88.68	98.08
65	060.62 053.87	969.72 963.74	90.52	99.64
66	056.10 049.95*	964.55* 958.12	91.69	100.90
67	052.75* 045.83	959.36 953.33	92.95	102.36
68	049.01 041.76	953.33* 948.01	94.72	104.07
69	044.97 037.57	948.52 941.93	96.05	105.75
70	040.95 033.26*	943.05 936.32	97.42	106.96
71	036.78 029.01	937.47 931.16	98.58	108.93

TABLE I—(Concl'd.)

K	R	P	$\frac{\Delta_2 F''(K)}{= R(K) - P(K)}$	$\frac{\Delta_2 F''(K)}{= R(K-1) - P(K+1)}$
72	22032.59 024.65	21931.95 924.41	100.44	110.53
73	028.32 019.84*	925.33 919.51	101.66	112.11
74	024.05 015.01	920.52 912.51	103.02	113.51
75	019.84* 010.48	913.56 907.59	104.59	114.68
76	015.63 005.81	908.70 901.01	105.87	..
77	011.25* 001.15	902.03* ..	..	118.23
78	006.89* 21996.41	896.82 888.16	109.16	120.14
79	22002.33* 21991.59	890.57 881.55	110.80	..
80	21997.68 ..	884.50 ..	..	122.76
81	993.29 981.74	879.16 869.25	113.31	..
82	988.23 977.74	872.64 863.67	114.83	126.12
83	982.64 ..	866.66 856.13	..	127.80
84	977.74 ..	859.98 850.39		
85	972.84 ..	853.33 ..		
86	967.59 .	846.73 ..		
87	962.28* ..	840.19 .		
88	.. ..	833.06 ..		
89	.. ..	826.14 ..		

TABLE II
(0, 0) Band

K	R	P	$\frac{\Delta_2 F'(K)}{= R(K) - P(K)}$	$\frac{\Delta_2 F''(K)}{= R(K-1) - P(K+1)}$
10		21307.46 305.82*		
11		305.82* 304.39		
12		304.39 302.79		
13		302.79 301.16		
14		301.16 299.46		
15		299.46 297.72		
16		297.72 295.87		
17		295.87 293.96		
18		293.96 291.95		
19		291.95 289.93		
20		289.93 287.93		
21		287.93 285.84		
22	21317.43 316.52	285.84 283.62	32.25	
23	316.52 315.61	283.62 281.34	33.59	36.81
24	315.61 314.70	281.34 279.10	34.94	38.19
25	314.70 313.60	279.10 276.66	36.27	39.69
26	313.60 312.55	276.66 274.27	37.61	41.14
27	312.55 311.26	274.27 271.76	38.89	42.59
28	311.26 310.03	271.76 269.22	40.16	44.05
29	310.03 308.73	269.22 266.50*	41.52	45.55

TABLE II—(Contd.)

K	R	P	$\Delta_2 F'(K)$ $= R(K) - P(K)$	$\Delta_2 F''(K)$ $= R(K-1) - P(K+1)$
30	308.73 307.46	266.50* 263.70	43.00	46.87
31	307.46 305.82*	263.70 261.33*	44.13	48.45
32	21305.82* 304.59	21260.83 258.46	45.46	49.83
33	304.39 302.79	257.98 255.65	46.78	51.23
34	302.79 301.16	255.02 252.73	48.10	52.65
35	301.16 299.46	252.10 249.78	49.37	54.09
36	299.46 297.72	249.09 246.68	50.71	55.58
37	297.72 295.87	245.96 243.51	52.06	57.04
38	295.87 293.96	242.75* 240.36	53.36	58.49
39	293.96 291.95	239.47 237.15	54.64	59.95
40	291.95 289.93	236.19 233.75	55.97	61.32
41	289.93 287.93	232.83 230.44	57.30	62.86
42	287.93 285.84	229.38 226.78	58.85	64.39
43	285.84 283.62	225.84 223.25	60.19	65.90
44	283.62 281.34	222.31 219.67	61.49	67.39
45	281.34 279.10	218.65 216.03	62.88	68.84
46	279.10 276.66	214.96 212.33	64.24	70.43
47	276.66 274.27	211.03 208.56	65.67	71.84
48	274.27 271.76	207.38 204.70	66.98	73.35
49	271.76 269.22	203.39 200.85	68.37	74.91
50	269.22 266.50*	199.34* 196.87	69.76	76.36

TABLE II—(Contd.)

K	R	P	$\Delta_2 F'(K)$ $= R(K) - P(K)$	$\Delta_2 F''(K)$ $= R(K-1) - P(K+1)$
51	266.50* 263.70	195.42 192.84	70.97	77.84
52	263.70 261.33*	191.24 188.70	72.50	79.27
53	21261.33* 258.46	21187.17 184.50	74.06	80.94
54	258.46 255.65	182.95 180.20*	75.48	82.59
55	255.65 252.73	178.68 175.93	76.89	84.13
56	252.73 249.78	174.29 171.56	78.32	85.70
57	249.78 246.68	169.84 167.15	79.74	87.25
58	246.68 243.51	165.34 162.67	81.09	88.77
59	243.59 240.36	160.84 158.08	82.48	90.26
60	240.36 237.15	156.20 153.47	83.92	91.80
61	237.15 233.75	151.54 148.73	85.32	93.38
62	233.75 230.44	146.73 144.02	86.72	94.91
63	230.44 227.15	141.90 139.18	88.26	96.37
64	226.78 223.70	137.07 134.38*	89.70	98.11
65	223.25 220.14	132.06 129.32	91.23	99.59
66	219.67 216.58	127.04 124.27	92.47	101.15
67	216.03 212.89	121.91 119.18	93.92	102.60
68	212.33 209.10	116.79 114.27	95.19	104.03
69	208.56 205.39	111.91* 108.95	96.51	105.73
70	204.70 201.40	106.38* 103.60	98.06	107.38
71	200.85 197.51	100.80 098.31	99.63	108.85

TABLE II—(Contd.)

K	R	P	$\Delta_2 F'(K)$ $= R(K) - P(K)$	$\Delta_2 F''(K)$ $= R(K-1) - P(K+1)$
72	196.87 193.50	095.40 093.00	100.99	110.45
73	192.84 189.38*	089.88 087.58	102.38	112.02
74	21188.70 185.35	21084.35 081.99*	103.85	113.55
75	184.50 181.10	078.68 076.44	105.24	115.22
76	180.20 176.90	072.99 070.62	106.75	116.72
77	175.93 172.59	067.11 065.05	108.18	118.32
78	171.96 168.22	061.26 059.20	109.86	119.84
79	167.15 163.71	055.41 053.43	111.01	..
80	162.67 159.20	049.48 ..	..	122.92
81	158.08 154.62	043.52 041.50	113.84	124.44
82	153.47 150.16	037.53 035.47	115.32	125.96
83	148.73 145.31	031.33 029.36	116.68	..
84	144.02 140.47	.. .	..	129.00
85	139.18 135.67	019.11 016.93	119.35	130.47
86	134.38 130.78	012.85 010.70	120.81	132.02
87	129.32 125.83	006.56 004.25	122.17	133.57
88	124.27 120.69	000.13 20997.89	123.47	135.06
89	119.18 115.74	993.67 991.36	124.95	136.47
90	113.70 110.67	987.21 984.81	126.18	138.14
91	108.45 105.36	980.52 978.12	127.59	139.53
92	103.14 100.05	973.87 971.45	128.94	140.99

TABLE II—(Contd.)

K	R	P	$\frac{\Delta_2 F'(K)}{= R(K) - P(K)}$	$\frac{\Delta_2 F''(K)}{= R(K-1) - P(K+1)}$
93	097.80 094.64	967.14 964.70	130.30	142.50
94	092.28 089.26	960.32 957.87	131.68	143.99
95	21086.79 083.71	20953.54 950.93	133.02	..
96	081.19 078.17	946.47 ..	..	146.97
97	075.57 072.56	939.60 936.96	135.79	148.54
98	069.74 ..	932.44 929.84	..	150.09
99	063.97 061.26	925.25 922.71	138.64	..
100	058.13 055.41	918.20 915.68	139.80	152.97
101	052.17 049.48	911.05* 908.25	141.18	154.51
102	046.29 043.52	903.63 900.89	142.65	156.15
103	040.47 037.53	896.00 893.36	144.32	157.64
104	034.11 031.33	888.08 885.86	145.45	159.33
105	027.74 ..	881.12 878.22	..	..
106	021.57 019.11	873.61..	..	..
107	015.20 012.85	....	..	..
108	008.77 006.56	..	..	..
109	002.29 000.13	..	..	..
110	20995.77 993.67	..	..	..
111	988.18 987.21	..	..	..
112	982.46 980.52	..	..	..
113	975.68 973.87	..	..	..

TABLE II—(Concl'd.)

K	R	P	$\frac{\Delta_2 F'(K)}{= R(K) - P(K)}$	$\frac{\Delta_2 F''(K)}{= R(K-1) - P(K+1)}$
114	968.86 967.14			
115	961.92 960.32			
116	20954.98 953.54			
117	947.90 946.47			
118	940.81 939.60			
119	933.60 932.44			
120	926.41 925.25			
121	919.17 918.20			
122	911.76 911.05			
123	904.45 903.63			
124	896.67 896.00			
125	889.15 888.68			

TABLE III

(0, 1) Band

K	R	P	$\Delta_1 F'(K)$ $= R(K) - P(K)$	$\Delta_2 F''(K)$ $= R(K-1) - P(K+1)$
9		20327-33 323-53		
10		326-09 322-14		
11		324-50 320-72		
12		323-03 319-21		
13		321-52 317-87		
14		319-91 316-06		
15		318-25 314-29		
16		316-46* 312-54		
17		314-29 310-82		
18		312-93 308-92		
19		310-82 306-96		
20		308-92 304-96		
21		306-96 302-84		
22		304-96 300-66		
23		302-84 298-52		
24		300-66 296-27		
25		298-52 293-92		
26		296-27 291-81		
27		293-92 289-30		
28		291-20 286-55		

TABLE III—(Contd.)

K	R	P	$\Delta_2 F'(K)$ $= R(K) - P(K)$	$\Delta_2 F''(K)$ $= R(K-1) - P(K+1)$
29		288.76 284.03		
30		20286.19 281.55		
31	20327.33 323.53	283.54 279.30	44.01	
32	326.09 322.14	280.93 276.58	45.36	49.18
33	324.50 320.72	278.15 273.85	46.61	50.65
34	323.03 319.21	275.33 270.99	47.96	52.31
35	321.52 317.87	272.53 268.07	49.40	53.79
36	319.91 316.06	269.54 265.12	50.66	55.33
37	318.25 314.29	266.62 262.11	51.91	56.69
38	316.46* 312.54	263.62 258.98	53.20	58.11
39	314.29 310.82	259.86 255.87	54.69	59.60
40	312.93 308.92	257.08 252.72	56.03	60.86
41	310.82 306.96	253.92 249.47	57.20	62.45
42	308.92 304.96	250.92 246.04	58.46	63.81
43	306.96 302.84	247.42 242.51	59.94	65.39
44	304.96 300.66	244.06 239.05	61.26	66.88
45	302.84 298.52	240.58 235.47	62.66	67.87
46	300.66 296.27	236.97 231.92	64.02	69.84
47	298.52 293.92	233.45 228.26	65.37	71.40
48	296.27 291.89	229.56* 224.57	66.98	72.74
49	293.92 289.30	226.16 220.80	68.13	74.35

TABLE III—(Contd.)

K	R	P	$\frac{\Delta_2 F'(K)}{= R(K) - P(K)}$	$\frac{\Delta_2 F''(K)}{= R(K-1) - P(K+1)}$
50	291.81 286.55	222.36 217.03	69.49	75.87
51	20280.30 284.03	20218.38 213.11	70.92	77.26
52	286.55 281.42	214.55 209.29	72.06	79.06
53	284.03 278.72	210.59 204.63	73.77	80.69
54	281.85 276.00	206.40 200.19	75.63	82.03
55	279.30 273.23	202.40 196.29	76.92	83.46
56	276.50 270.40	198.25 192.69	77.98	85.30
57	273.85 267.42	194.02 187.91	79.67	86.88
58	270.99 264.38	189.51 183.64*	81.11	88.37
59	268.07 261.23	185.38 179.16	82.43	89.86
60	265.12* 258.24	180.99 174.66	83.86	91.25
61	262.11 255.07	176.58 170.32	85.14	93.19
62	258.98 251.85	172.08 164.91*	86.92	94.43
63	255.87 248.55	167.38 160.94	88.05	95.98
64	252.72 245.24	162.95 155.92	89.55	97.75
65	249.74 241.81	158.22 150.71	91.18	99.41
66	246.04 238.29	153.27 145.87	92.60	100.80
67	242.90 234.74	148.88 140.81	93.98	102.21
68	239.45 231.06*	143.69* 136.23	95.30	103.75
69	235.99 227.50	139.24 130.91	96.67	105.08
70	232.44 223.88	134.40* 125.96	97.98	107.00

TABLE III—(Concl'd.)

K	R	P	$\frac{\Delta_2 F''(K)}{= R(K) - P(K)}$	$\frac{\Delta_2 F''(K)}{= R(K-1) - P(K+1)}$
71	228.81 219.97	128.90 120.59	99.65	108.67
72	20225.16 216.09	20123.63 115.35	101.14	109.93
73	221.47 212.23	118.71 110.22	102.39	..
74	217.64 208.21	.. ..	..	112.75
75	213.91 204.20	108.78 099.43	104.95	114.65
76	209.87 200.19	102.51* 094.05	106.75	116.11
77	206.04 195.70	097.61 088.19	107.92	118.23
78	201.90 191.05	091.32 082.29	109.67	119.78
79	197.79 186.25	086.11 076.08	110.93	121.34
80	194.02 180.99*	080.94 069.34	112.37	123.03
81	189.51* 175.35	075.31 062.68	113.44	125.16
82	185.38 169.59*	069.34 055.36	115.14	126.73
83	180.99* 163.46	063.83 047.57	116.53	..
84	.. ..	.. ..	..	130.19
85	172.08 151.81	052.21 032.86	119.41	..
86	167.38 145.87	045.68..	..	..
87	162.25 ..	038.79* ..	..	..
88	156.98 ..	032.86..	..	..

TABLE IV

Constant	Upper State	Lower State
B_0 ..	0.3447 cm. ⁻¹	0.3776 cm. ⁻¹
B_1 ..	0.3420 ,,	0.3746 ,,
B_e ..	0.3461 ,,	0.3791 ,,
α_e ..	0.0027 ,,	0.0030 ,,
I_e ..	80.852×10^{-40} gm. cm. ²	73.814×10^{-40} gm. cm. ²
r_e ..	1.889 Å	1.805 Å

The D values are of the order of 10^{-7} cm.⁻¹

ABSTRACT (SUMMARY)

The spectrum of columbium oxide has been photographed in the first and second orders of a 21-ft., 30,000 lines per inch concave grating with dispersions of 1.2 Å/mm. and 0.6 Å/mm. respectively. The rotational analysis of the (1, 0), (0, 0) and (0, 1) bands of system A at $\lambda\lambda$ 4510, 4689 and 4915 respectively in this spectrum has been carried out for the first time. As in vanadium oxide, four distinct branches, namely R_1 , R_2 , P_1 and P_2 , have been identified in each band. The rotational constants, calculated by the least squares method, are reported.

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Issued December 13, 1955.