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SERIES SPECTRA OF BORON, CARBON, NITROGEN, OXYGEN, AND FLUORINE

By I. S. Bowen

Abstract

Practically all of the unidentified strong lines of boron, carbon, nitrogen, oxygen, and fluorine occurring in the extreme ultra-violet spectra of the vacuum spark have been classified as due to jumps between levels in B_{I}, C_{I}, C_{II}, N_{II}, N_{III}, O_{II}, O_{III}, O_{IV}, F_{I}, F_{II}, F_{III}, and F_{IV}. The levels thus found are correlated with those demanded by the Russell-Heisenberg-Pauli-Hund theory.

I. Introduction

IN previous articles by Professor Millikan and the author[1] the series spectra of one and two-valence-electron atoms of the elements in the first row of the periodic table have been traced. The present paper is an extension of the methods there used to the more complex atoms of this same group of elements.

Since the spectra of these elements are much more complex than those previously studied and as the Russell-Heisenberg-Pauli-Hund theory has shown, there is, in general, no direct connection between the type of the term, i. e. S, P, D, F, and the corresponding k value of the electrons involved, a further extension of the notation is necessary. The notation used throughout this paper is as follows: All terms arising from the normal state of the atom of any n electron system, i. e. that due to the configuration of 2 s electrons and $(n-2)$ p electrons or in Russell's notation the s^2p^{n-2} configuration, are designated by a. Those terms due to the configuration formed when one of the s electrons is moved to a 2 $p$orbit, i. e. the sp^{n-1} configuration are designated by b, while terms which have their origin in the p^n configuration, i. e. the arrangement attained when both of the s electrons are raised to $2p$ orbits, are indicated by c. When one of the p electrons is moved to an excited s orbit making an $s^2p^{n-3}\cdot s$ configuration, the terms thus formed are marked with k preceded by a numeral indicating the total quantum number of the orbit occupied by the excited electron. Likewise, when one of the p electrons is raised to an excited p or d orbit forming an $s^2p^{n-3}\cdot p$ or an $s^2p^{n-3}\cdot d$ configuration, the terms produced are designated by m and n respectively.

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[1] Bowen and Millikan, Proc. Nat. Acad. Sci. **10**, 199 (1924).
Bowen and Millikan, Phys. Rev. **26**, 310 (1925); **28**, 256 (1926).

The maximum term multiplicity is indicated in the usual way by a small figure written above and at the left of the letter indicating the type of the term. In the tables where no ambiguity can arise as to the multiplicity of the term, the indices are omitted. In the present notation primes are omitted as no longer necessary.

TABLE I

Series lines of B_I

Int.	λ I. A. Vac.	ν	$\Delta\nu$	Designation	Term Values	
1	1825.89	54767.8	15.9	aP_1-3nD	aP_1	67544.6
2	1826.42	54751.9		aP_2-3nD	aP_2	67529.1
3	2089.59	47856.3	15.1	aP_1-bD	bD	19688.1
3	2090.25	47841.2		aP_2-bD		
	2497.53	40039.6	15.3	aP_1-3kS	$3kS$	27504.9
	2498.48	40024.3		aP_2-3kS	$3nD$	12777.0

II. THREE-ELECTRON SYSTEMS

Since in atoms of this type one electron only is in an uncompleted group, the Hund theory predicts that the type of any term is the same as that of the orbit in which the excited electron finds itself, i. e. when the electron is in an *s* orbit it gives rise to a ^2S term, when in a *p* orbit to a ^2P term, etc. All of these terms belong to the doublet system. This, of course, is true only so long as the *p* electron alone is excited and the completed group of 2*s* electrons is left undisturbed. Jumps between terms thus formed by the excitation of the single *p* electron result in the regular doublet series of lines in these atoms. In C_{II} these series have been very completely analyzed by Fowler.[2] Table II includes only those of Fowler's lines for which much greater accuracy and resolution can now be obtained than were available at the time his article was written. For this reason the present table of C_{II} lines should be considered as supplementary to his. In the case of N_{III} Fowler[3] has also identified the first term of the principal and of the second diffuse series, but was unable to obtain the lines corresponding to jumps of the electron to its normal position in the atom. The position of these resonance lines can be predicted with a considerable degree of accuracy by extrapolation from the corresponding

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[2] A. Fowler, Proc. Roy. Soc. **105**, 299 (1924).

[3] A. Fowler, Series in Line Spectra, p. 165.

TABLE II

Series lines of C_{II}

Int.	λ I. A. Vac.	ν	Δν	Designation	Term Values	
		Doublets				
2	594.79	168127.	65.	aP_1-4nD	aP_1	196658.8
2	595.02	168062.		aP_2-4nD	aP_2	196595.0
5	687.053	145549.2	63.1	aP_1-3nD	bS	100164.9
5	687.351	145486.1		aP_2-3nD	bP_1	86033.9
5	858.088	116538.2	64.2	aP_1-3kS	bP_2	85992.3
6	858.561	116474.0		aP_2-3kS	bD	121727.4
7	903.620	110666.0		aP_1-bP_2		
8	903.960	110624.4	62.8	aP_1-bP_1		
8	904.133	110603.2	62.7	aP_2-bP_2		
7	904.472	110561.7		aP_2-bP_1		
6	1036.336	96493.8	63.7	aP_1-bS		
6	1037.021	96430.1		aP_2-bS		
2	1141.61	87595.6		$bD-4mP$		
10	1334.539	74932.2	65.4	aP_1-bD		
10	1335.705	74866.8		aP_2-bD		
2	1760.44	56804.0	13.2	$bD-3mP_2$		
1	1760.85	56790.8		$bD-3mP_1$		
		Quartets				
5	1009.870	99022.6	21.5	bP_1-cS		
6	1010.090	99001.1	28.6	bP_2-cS		
6	1010.382	98972.5		bP_3-cS		

lines of B$_{\text{I}}$ and C$_{\text{II}}$ using the method already applied to the identification of similar lines in C$_{\text{III}}$.[1] This method leads to the identification of the 452A and the 374A lines as given in Table III. Since the 374A line falls very close to a strong oxygen line, its wave-length may be somewhat in error.

The Hund theory further predicts that when one of the *s* electrons is removed to a $2p$ orbit the sp^2 configuration thus formed will give rise to a quartet ^4P term and doublet ^2S, ^2P and ^2D terms. If the second *s* electron is moved to a $2p$ position making a p^3 configuration, then ^4S, ^2P and ^2D terms will result. All of the doublet terms due to the sp^2 configuration should combine strongly with the normal doublet a^2p level of the s^2p configuration. Since all of the electrons in both arrangements are in 2-total-quantum-number orbits, all lines due to combinations between them should obey the irregular doublet law.

TABLE III

Series lines of N$_{\text{III}}$

Int.	λ I. A. Vac.	ν	Δν	Designation	Term Values	
	Doublets					
1	374.31	267158.		$aP-3nD$	aP_1 aP_2	382225.8 382051.4
1	451.91	221283.	161.	aP_1-3kS		
1	452.24	221122.		aP_2-3kS	bS	251223.4
5	684.997	145986.0		aP_1-bP_2	bP_1 bP_2	236351.0 236240.2
6	685.519	145874.9	175.1	aP_1-bP_1		
6	685.820	145810.9	174.5	aP_2-bP_2	bD_2 bD_3	281195.6 281201.3
5	686.340	145700.4		aP_2-bP_1	cP	151222.1
5	763.348	131001.8	173.1	aP_1-bS		
5	764.358	130828.7		aP_2-bS	$3kS$	160936.1
2	772.903	129382.3	12.8	bD_3-cP		
2	772.980	129369.5		bD_2-cP	$3mP_1$ $3mP_2$	136572.85 136536.82
7	989.803	101030.2	180.1	aP_1-bD		
7	991.571	100850.1		aP_2-bD	$3nD_2$ $3nD_3$	115000. 114994.14
1	1006.03	99400.6		$bS-cP$		
3	1183.04	84528.2	108.0	bP_1-cP		
3	1184.55	84420.2		bP_2-cP		
	4098.48	24399.30	36.08	$3kS-3mP_2$		
	4104.55	24363,22		$3kS-3mP_1$		
	4635.46	21572.83	35.99	$3mP_1-3nD_2$		
	4641.94	21542.70	5.86	$3mP_2-3nD_3$		
	4643.21	21536.84		$3mP_2-3nD_2$		
	Quartets					
3	771.545	129610.1	60.3	bP_1-cS		
4	771.904	129549.8	80.5	bP_2-cS		
4	772.384	129469.3		bP_3-cS		

In carbon, nitrogen, and oxygen[4] Professor Millikan and the author have already identified a *pp′* group fulfilling these conditions. This group is evidently the combination between the a^2P and the b^2P levels. In C_{II} Fowler has found an *x* level which combines strongly with the low a^2P level to produce the strong lines at 1036A. This is unquestionably the b^2S term of the sp^2 configuration, since the lines connecting it with the ^2P levels have, within experimental error, exactly the separation of the ^2P levels. The strongest lines in the carbon spectrum are a pair at 1335A, which is shown by the data in the present paper, and also by some of Lang and Smith's data,[5] to have a separation about 2 frequency units larger than that of the true a^2P separation as obtained from the a^2P-b^2P group at 904A. These lines are definitely due to C_{II}, for if we assume them to be due to a jump into the a^2P level then the levels from which this jump starts combining with the $3m^2P$ and the $4m^2P$ levels would give rise to lines at 1760A and 1141A. These lines are observed at almost exactly their calculated position, and the 1760A doublet which is the only one that can be resolved shows a separation about 2 frequency units larger than that of the $3m^2P$ levels involved. These considerations make it practically certain that this unidentified level is the b^2D term of the sp^2 configuration. Since all combinations with ^2P terms show separations slightly larger than that of the ^2P terms themselves it is evident that these b^2D terms are inverted.

TABLE IV

Irregular doublets, three-electron systems

Element	ν	$\Delta\nu$	ν	$\Delta\nu$
	aP_2-bS		aP_2-bP_1	
C_{II}	96430.1		110561.7	
		34398.6		35138.7
N_{III}	130828.7		145700.4	
		33152.3		34392.6
O_{IV}	163981.		180093.	
	aP_2-bD		bP_3-cS	
B_I	47841.2			
		27025.6		
C_{II}	74866.8		98972.5	
		25983.3		30496.8
N_{III}	100850.1		129469.3	
		25699.3		30313.7
O_{IV}	126549.4		159783.	

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[4] Bowen and Millikan, Phys. Rev. **26**, 150 (1925).

[5] Lang and Smith, J.O.S.A. & R.S.I. **12**, 523 (1926).

The line due to the change from these b^2S and b^2P levels to the a^2P levels can be traced from C_{II} to O_{IV} while those due to the jump from b^2D to a^2P can be traced from B_I to O_{IV}. In each case, where accuracy of measurement is sufficient to detect it, this last pair shows a separation slightly larger than that of the other two. In all cases the lines due to these jumps follow the irregular doublet law as shown in Table IV.

That lines involving the b^2S and b^2P levels are missing in B_I, or at least are so weak that they cannot be obtained in high enough orders to be resolved, is probably due to the fact that these levels have negative term values, i. e. it requires more energy to produce these levels than it does to ionize the atom by removing the p electron.

In N_{III} and O_{IV} additional lines are observed which are obviously due to the combination between the b^2S, b^2P, and b^2D terms and the c^2P term of the p^3 configuration. That these lines are missing or very weak in C_{II} is probably due to the fact that the c^2P term involves an energy nearly equal to that of ionization of C_{II}.

In addition to the doublet lines already mentioned, we should expect the lines due to the combination between the quartet b^4P and the quartet c^4S term. Such a group of lines following the irregular doublet law (see Table IV) and having the relative separations characteristic of quartets, has been traced from C_{II} to O_{IV}. While no other lines involving the b^4P level can be located to check this identification, yet it seems certain since the variation of intensity of the lines in going from element to element is such as to indicate that they belong to a three-electron system. Further there is no place for such lines in the Hund scheme for either the two or four-electron systems.

The term values in C_{II} given in Table II are based on Fowler's value for the $3m^2P$ term, while those given in Tables I and III for B_I and N_{III} are based on that of the $3n^2D$ term which was assumed equal to 1/4 and 9/4 respectively of that of the corresponding term in C_{II}. This method gives results that are probably accurate to 1000 frequency units in B_I and 3000 or 4000 in N_{III}. Since it has not been possible to make any positive identification of the a^2P-$3k^2S$ and a^2P-$3n^2D$ lines in O_{IV} no term values are given in Table V. Methods similar to those used in identifying these lines in N_{III} seem to indicate that a^2P-$3k^2S$ is the 279.7A line[6] and a^2P-$3n^2D$ is the 238.6A line. In any case the lines must fall very close to these positions. If we assume the identification of 238.6A is correct and further assume a value for $3n^2D$ 16/4 times as great as in C_{II} we get $a^2P=623500$ fre-

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[6] Millikan and Bowen, Phys. Rev. **23**, 1 (1924).

TABLE V

Series lines of O_{IV}

Int.	λ I. A. Vac.	ν	$\Delta\nu$	Designation
		Doublets		
4	553.318	180728.		aP_1-bP_2
5	554.066	180484.	388.	aP_1-bP_1
5	554.507	180340.	391.	aP_2-bP_2
4	555.270	180093.		aP_2-bP_1
4	608.390	164368.	387.	aP_1-bS
4	609.828	163981.		aP_2-bS
1	616.93	162093.		$bD-cP$
6	787.716	126949.3	399.9	aP_1-bD
6	790.205	126549.4		aP_2-bD
1	802.21	124656.		$bS-cP$
2	921.27	108546.	240.	bP_1-cP
3	923.31	108306.		bP_2-cP
		Quartets		
3	624.609	160100.	132.	bP_1-cS
4	625.126	159968.	185.	bP_2-cS
4	625.848	159783.		bP_3-cS

quency units which cannot be an error by more than 1 percent regardless of whether the above identifications are correct or not.

III. FOUR-ELECTRON SYSTEMS

The Hund theory predicts that the different configurations of a four-electron system will be characterized by terms as follows:

s^2p^2 — $^1S,\ ^1D,\ ^3P$
sp^3 — $^1P,\ ^1D,\ ^3S,\ ^3P,\ ^3D,\ ^5S$
$s^2p\cdot s$ — $^1P,\ ^3P$
$s^2p\cdot p$ — $^1S,\ ^1P,\ ^1D,\ ^3S,\ ^3P,\ ^3D$
$s^2p\cdot d$ — $^1P,\ ^1D,\ ^1F,\ ^3P,\ ^3D,\ ^3F$

Fowler[7] has already analyzed many of the lines in the spectra of N_{II}. His triplet terms should be correlated with those of the Hund

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[7] A. Fowler, Proc. Roy. Soc. **107**, 31 (1925).

theory as follows: p_1, p_2, p_3, are due to the $s^2p \cdot 3s$ configuration, d_1, d_2, d_3, and p_1', p_2', p_3' to the $s^2p \cdot 3p$ configuration, d_1', d_2', d_3', to the $s^2p \cdot 3d$ configuration, and p_1^2, p_2^2, p_3^2 to the $s^2p \cdot 4s$ configuration.

TABLE VI

Series lines in C I

Int.	λ I. A. Vac.	ν	Δν	Designation
		Triplets		
3	1328.839	75253.7	14.6	aP_0-bP
4	1329.100	75238.9	27.6	aP_1-bP
4	1329.583	75211.6		aP_2-bP
3	1560.267	64091.6	16.1	aP_0-bD
4	1560.660	64075.5	29.6	aP_1-bD
5	1561.381	64045.9		aP_2-bD
2	1656.27	60376.6		aP_1-3kP_2
3	1657.01	60349.7		$aP_{0,2}-3kP_{1,2}$
2	1657.37	60336.6		aP_1-3kP_1
2	1657.92	60316.5		aP_1-3kP_0
2	1658.13	60308.9		aP_2-3kP_1

If this correlation is correct, then p_1, p_2, p_3 and p_1^2, p_2^2, p_3^2 are the first two members of a series of corresponding levels. Due to this fact one can obtain an estimate of the term values, with an error not greater than 1000 or 2000 frequency units, by making these two terms fit a Rydberg formula. Such a calculation indicates that Fowler's term values should be increased by 20300 frequency units. That this value is approximately correct is shown by the fact that it gives to his d' term a value just above 50000 which is similar to that of the terms due to the $s^2p^{n-3} \cdot d$ configuration of other singly ionized atoms of this group of elements.

From the triplet separations of Fowler's terms, lines connecting these terms with the normal ^3P levels were identified and the term value of these levels determined as given in Table VII.

In addition to these lines which are produced when a p electron is excited, other very strong lines should be expected when one of the s electrons is displaced to a $2p$ orbit. As before all lines produced by the return of this electron should follow the irregular doublet law. Such groups of lines, all obeying the irregular doublet law, (see Table VIII)

TABLE VII

Series lines of NII

Int.	λ I. A. Vac.	ν	Δν	Designation
		Triplets		
3	533.53	187431.		$aP_{0,1}-3nD_{1,2}(-d'_{2,3})$
3	533.71	187368.		$aP_2-3nD_{1,2,3}(-d'_{1,2,3})$
4	644.633	155127.0		aP_0-bS
			48.8	
5	644.836	155078.2		aP_1-bS
			82.7	
5	645.180	154995.5		aP_2-bS
2	671.027	149025.3		$aP_1-3kP_2(-p_1)$
3	671.397	148943.2		$aP_{0,2}-3kP_{1,2}(-p_{2,1})$
1	671.650	148887.1		$aP_1-3kP_1(-p_2)$
2	671.780	148858.3		$aP_1-3kP_0(-p_3)$
2	672.026	148803.8		$aP_2-3kP_1(-p_2)$
6	915.603	109217.6		aP_0-bP_1
			42.9	
6	915.963	109174.7		aP_1-bP_0
			6.5	
6	916.018	109168.2		$aP_1-bP_{1,2}$
			81.0	
8	916.698	109087.2		$aP_2-bP_{1,2}$
6	1083.983	92252.4		aP_0-bD_1
			49.6	
7	1084.566	92202.8		$aP_1-bD_{1,2}$
			82.7	
3	1085.540	92120.1		$aP_2-bD_{1,2}$
			13.7	
8	1085.701	92106.4		aP_2-bD_3
1	1275.06	78427.7		$bD_3-3mP_2(-p'_1)$
1	1276.18	78358.9		$bD_{1,2}-3mP_1(-p'_2)$
0	1276.74	78324.5		$bD_{1,2}-3mP_0(-p'_3)$

Term Values*	
aP_0	239373.3
aP_1	239324.7
aP_2	239241.6
bS	84246.3
bP_0	130150.0
$bP_{1,2}$	130155.3
$bD_{1,2}$	147121.4
bD_3	147135.2

*Assuming $3kP_2$ (p_1). =90300.

have been traced through the four-electron atoms of this row of the periodic system, with characteristics as follows:

a^3P-b^3S. This group appears as three sharp lines with no further structure. It does not appear in CI for the same reason that a^2P-b^2S does not appear in BI.

a^3P-b^3P. The separations of these lines are very similar to those of the preceding ones. The center component is double in two instances where it has been possible to obtain particularly good resolutions.

These separations are such as to indicate that b^3P_1-b^3P_2 is so small that it cannot be resolved while b^3P_0-b^3P_1 can just be separated with the highest resolution.

TABLE VIII

Irregular doublets, four-electron systems

	aP_2-bS		aP_2-bP		aP_2-bD_3	
	ν	$\Delta\nu$	ν	$\Delta\nu$	ν	$\Delta\nu$
C_I			75211.6		64045.9	
				33875.6		28060.5
N_{II}	154995.5		109087.2		92106.4	
		41785.5		32987.9		27612.8
O_{III}	196781.		142075.1		119719.2	
		40918.		32551.9		27514.8
F_{IV}	237699.		174627.		147234.	

a^3P-b^3D. In this group of lines the long wave-length component is double, the main line having a weak satellite on the short wave-length side. The separation of the extreme components is a little greater than in the preceding groups, thus indicating an inverted D term.

In O_{III} it has been possible to classify a few singlets by means of constant frequency differences occurring between certain lines.

In Table VII none of the lines of N_{II} identified by Fowler have been included. Many of the lines, however, involve levels classified by him. In such cases where his designation differs from the present one, his has been added in parenthesis.

No term values for C_I and O_{III} are given in Tables VI and IX since no sequence of corresponding levels has been found and no certain identification of the a^3P-$3n^3D$ lines can be made. In C_I the a^3P-$3n^3D$ lines should be found at about 1300A. It may be that a partially resolved group at 1277A should be identified as these lines. If this is correct and $3n^3D$ is assumed 1/4 of its value in N_{II} then a^3P has a value of 91300 which, regardless of the correctness of the identification of 1277A, can hardly be an error by more than 5 percent. Similarly the 374.3A and the 305.7A lines[6] in oxygen are probably a^3P-$3k^3P$ and a^3P-$3n^3D$ respectively, which, if $3n^3D$ is 9/4 of its value in N_{II}, would give a value of $a^3P=443900$, which is probably correct to 2 percent.

TABLE IX

Series lines in $\mathrm{O_{III}}$

Int.	λ I. A. Vac.	ν	Δν	Designation
		Singlets		
0	328.34	304562.	22919.	$aD-3nP$
0	355.06	281643.		$aS-3nP$
2	395.52	252832.	22899.	$aD-3kP$
2	434.91	229933.		$aS-3kP$
6	525.79	190190.	22916.	$aD-bP$
4	597.82	167274.		$aS-bP$
		Triplets		
4	507.384	197089.	116.	aP_0-bS
5	507.684	196973.	192.	aP_1-bS
6	508.180	196781.		aP_2-bS
6	702.327	142383.8	99.3	aP_0-bP_1
6	702.817	142284.5	16.3	aP_1-bP_0
6	702.898	142268.2	193.1	$aP_1-bP_{1,2}$
7	703.853	142075.1		$aP_2-bP_{1,2}$
7	832.926	120058.7	117.4	aP_0-bD_1
8	833.741	119941.3	194.3	$aP_1-bD_{1,2}$
3	835.094	119747.0	27.8	$aP_2-bD_{1,2}$
9	835.288	119719.2		aP_2-bD_3

IV. FIVE-ELECTRON SYSTEMS

For atoms of this type the Hund theory predicts that the terms produced by the various electron configurations will be of the following types:

s^2p^3 — $^4S,\ ^2D,\ ^2P$

sp^4 — $^4P,\ ^2P,\ ^2D,\ ^2S$

$s^2p^2 \cdot s$ — $^4P,\ ^2P,\ ^2D,\ ^2S$

$s^2p^2 \cdot p$ — $^4S,\ ^4P,\ ^4D,\ ^2S,\ ^2P,\ ^2D,\ ^2P,\ ^2D,\ ^2F,\ ^2P$

$s^2p^2 \cdot d$ — $^4P,\ ^4D,\ ^4F,\ ^2P,\ ^2D,\ ^2F,\ ^2S,\ ^2P,\ ^2D,\ ^2F,\ ^2G,\ ^2D$

Hopfield[8] and Kiess[9] have classified the lines of N$_{\text{I}}$ while A. Fowler[10] has classified many of the lines of O$_{\text{II}}$ in the region between 2000A and 7000A, and R. H. Fowler and Hartree[11] have correlated the levels obtained by A. Fowler with those demanded by the Hund theory.

TABLE X

Series lines of F$_{\text{IV}}$

Int.	λ I. A. Vac.	ν	Δν	Designation
		Triplets		
0	419.95	238124.	425.	$aP_{0,1}-bS$
0	420.70	237699.		aP_2-bS
2	570.63	175245.	224.	aP_0-bP
3	571.36	175021.	394.	aP_1-bP
4	572.65	174627.		aP_2-bP
4	676.06	147916.	243.	aP_0-bD
5	677.17	147673.	439.	aP_1-bD
5	679.19	147234.		aP_2-bD

In A Fowler's list of levels there were no ^4P terms that could be correlated with the ^4P level due to the $s^2p^2 \cdot d$ configuration. For that reason R. H. Fowler and Hartree identified A. Fowler's x_3 term as this level but marked the correlation as doubtful. While this work was in progress, Professor H. N. Russell pointed out a group of strong lines in the violet that evidently were due to jumps from three levels to all of the quartet terms due to the $s^2p^2 \cdot p$ configuration. Since the term values of these new levels are very close to that of the other quartet terms arising from the $s^2p^2 \cdot d$ configuration it is obvious that they should replace x_3 in R. H. Fowler and Hartree's classification. With Professor Russell's permission his lines and the term values calculated from them are included in Table XI. Still another group of lines which represent combinations between a second triple level and the quartets of the $s^2p^2 \cdot p$ configuration has been found in the region near 2000A. The position and separations of these levels make their assignment as the ^4P term of the $s^2p^2 \cdot 5s$ configuration very certain. Since Fowler has already identified the ^4P terms due to the

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[8] Hopfield, Phys. Rev. **27,** 801 (1926).

[9] Kiess, J.O.S.A. & R.S.I. **11,** 1 (1925).

[10] A. Fowler, Proc. Roy. Soc. **110,** 476 (1926).

[11] R. H. Fowler and Hartree, Proc. Roy. Soc. **111,** 83 (1926).

TABLE XI

Series lines of O_{II}

Int.	λ I. A. Vac.	ν	Δν	Designation	Term Values	
		Doublets				
0	440.49	227020.		$aD-3nP(-bp'')$	aP	242554.
1	441.93	226280.		$aD-3nD(-cd')$	aD_2 aD_3	256192. 256208.
0	470.30	212630.		$aP-3nD(-cd')$		
2	481.53	207671.		$aD-3n'D(-bd')$	bP_1 bP_2	70262. 70430.
2	483.82	206688.		$aD-3n'P(-ap'')$	bD	117029.
3	485.48	205982.		$aD-3nF$		
2	515.47	193998.	57.	$aP-3n'D_3(-bd'_3)$		
2	515.62	193941.		$aP-3n'D_2(-bd'_2)$		
3	518.23	192965.		$aP-3n'P(-ap'')$		
3	537.813	185938.	153.	$aD-bP_1$		
4	538.258	185785.		$aD-bP_2$		
3	580.409	172292.	168.	$aP-bP_1$		
4	580.975	172124.		$aP-bP_2$		
2	600.583	166505.		$aP-3kD(-ad')$		
5	616.309	162256.	198.	$aD-3kP_2(-2p_2)$		
5	617.064	162058.		$aD-3kP_1(-2p_1)$		
6	644.159	155241.		$aP-3kS(-as')$		
5	672.913	148608.	185.	$aP-3kP_2(-2p_2)$		
5	673.752	148423.		$aP-3kP_1(-2p_1)$		
7	718.495	139179.8	14.3	aD_3-bD		
7	718.569	139165.5		aD_2-bD		
6	796.665	125523.3		$aP-bD$		
		Quartets			Term Values*	
2	430.06	232526.		$aS-3nP$		
3	539.067	185506.	157.	$aS-3kP_3(-ap_3)$	aS	283366.
2	539.524	185349.	108.	$aS-3kP_2(-ap_2)$		
1	539.837	185241.		$aS-3kP_1(-ap_1)$	bP_1 bP_2 bP_3	163282.8 163364.9 163528.3
8	832.756	120083.2	82.1	$aS-bP_1$		
9	833.326	120001.1	163.4	$aS-bP_2$	$5kP_1$ $5kP_2$ $5kP_3$	25665.5 25561.3 25395.4
10	834.462	119837.7		$aS-bP_3$		

*Assuming $3kP_3(ap_3)=97860$.

TABLE XI (*continued*)

Int.	λ I. A. Air	ν	Δν	Designation	Term Values	
0	1956.78	51087.7		$3mD_3-5kP_3(d_3-)$	$3nP_1$	50756.79
1	1959.70	51011.6		$3mD_2-5kP_2(d_2-)$	$3nP_2$	50823.28
3	1961.60	50962.2		$3mD_4-5kP_3(d_4-)$	$3nP_3$	50896.37
2	1963.20	50920.6		$3mD_3-5kP_2(d_3-)$		
0	1963.61	50910.0		$3mD_2-5kP_1(d_2-)$		
2	2016.60	49572.4		$3mP_2-5kP_3(p'_2-)$		
2	2020.44	49478.0		$3mP_3-5kP_3(p'_3-)$		
1	2021.45	49453.3		$3mP_1-5kP_2(p'_1-)$		
4	2182.72	45799.9		$3mS-5kP_3(s_2-)$		
2	2190.66	45634.0		$3mS-5kP_2(s_2-)$		
2	2195.70	45529.3		$3mS-5kP_1(s_2-)$		
1	3872.45	25816.15		$3mD_2-3nP_1(d_2-)$		
2	3874.10	25805.16		$3mD_1-3nP_2(d_1-)$		
1	3882.45	25749.66		$3mD_2-3nP_2(d_2-)$		
2	3893.53	25677.05		$3mD_2-3nP_3(d_2-)$		
1	3896.30	25658.13		$3mD_3-3nP_2(d_3-)$		
4	3907.45	25584.92		$3mD_3-3nP_3(d_3-)$		
4	4121.48	24256.31		$3mP_1-3nP_1(p'_1-)$		
2	4129.34	24210.14		$3mP_2-3nP_1(p'_2-)$		
6	4132.82	24189.74		$3mP_1-3nP_2(p'_1-)$		
0	4140.74	24143.49		$3mP_2-3nP_2(p'_2-)$		
7	4153.31	24070.42		$3mP_2-3nP_3(p'_2-)$		
3	4156.54	24051.70		$3mP_3-3nP_2(p'_3-)$		
4	4169.23	23978.50		$3mP_3-3nP_3(p'_3-)$		
4	4890.93	20440.31		$3mS-3nP_1(s_2-)$		
5	4906.88	20373.87		$3mS-3nP_2(s_2-)$		
6	4924.60	20300.57		$3mS-3nP_3(s_2-)$		

$s^2p^2 \cdot 4s$ and $s^2p^2 \cdot 3s$ configurations, this gives a series of three consecutive terms from which it is possible to determine term values with an error of not greater than 30 or 40 frequency units. The progression of k^4P_1 terms was used for this purpose since they are based on the most stable state of the O^{++} ion. This calculation showed that all of Fowler's term values of quartet levels should be decreased by 2140 frequency units.

Table XII

Irregular doublets, five-electron systems

	$aS-bP_3$	
	ν	$\Delta\nu$
N_I	88169.4 88150.8 88106.7	
		31731.0
O_{II}	119837.7	
		32059.3
F_{III}	151897.	

The normal terms of both quartet and doublet systems were then obtained through the various combinations with the terms identified by Fowler and by Russell.

As before the lines due to changes from an sp^4 to an s^2p^3 configuration follow the irregular doublet law as seen in Table XII.

Table XIII

Series lines of F_{III}

Int.	λ I. A. Vac.	ν	$\Delta\nu$	Designation
		Doublets		
2	429.49	232834.		$aD-bP_1$
			357.	
4	430.15	232477.		$aD-bP_2$
2	464.25	215401.		$aP-bP_1$
			384.	
2	465.08	215017.		$aP-bP_2$
7	567.70	176149.		$aD-bD$
4	630.17	158687.		$aP-bD$
		Quartets		
7	656.10	152416.		$aS-bP_1$
			177.	
8	656.86	152239.		$aS-bP_2$
			342.	
8	658.34	151897.		$aS-bP_3$

In Table XI none of the lines identified by Fowler have been included, but where lines involve levels classified by him his designation in parenthesis has been placed after the regular designation. All of the wave-lengths of lines above 1900A are taken from unclassified lines in Fowler's table of $\mathrm{O_{II}}$.

TABLE XIV

Series lines of $\mathrm{F_{II}}$

Int.	λ I A. Vac.	ν	Δν	Designation
		Triplets		
4	546.84	182869.	344.	aP_2-3kS
3	547.87	182525.	150.	aP_1-3kS
2	548.32	182375.		aP_0-3kS
8	605.67	165106.		aP_2-bP_1
7	606.27	164943.		aP_1-bP_0
9	606.81	164796.		aP_2-bP_2
4	606.95	164758.		aP_1-bP_1
7	607.48	164614.		aP_0-bP_1
8	608.06	164457.		aP_1-bP_2

V. SIX- AND SEVEN-ELECTRON SYSTEMS

Of the six-electron systems of this group the $\mathrm{O_I}$ spectra has already been classified by others.[12] In $\mathrm{F_{II}}$ only two groups can be classified

TABLE XV

Series lines of $\mathrm{F_I}$

Int.	λ I. A. Vac.	ν	Δν	Designation
		Doublets		
4	806.92	123928.	410.	aP_2-3nx
3	809.60	123518.		aP_1-3nx
5	951.81	105063.		aP_2-3kP_1
7	954.78	104736.	409.	aP_2-3kP_2
6	955.53	104654.	405.	aP_1-3kP_1
5	958.49	104331.		aP_1-3kP_2

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[12] A. Fowler, Series in Line Spectra, p. 166.
Hopfield, Astrophys. J. 59, 114 (1924).

with certainty as shown in Table XIV. It is quite likely that the a^3P-$3n^3D$ line can be identified as a rather weak partially resolved group at 472A. If this is correct and $3n^3D$ is assumed to have a value four times as great as in O_I, then a^3P is equal to 261300 with an error not larger than 5 percent.

In F_I only two groups have been identified in this region, while De Bruin[13] has identified a third doublet pp' group in Carragan's data in the red. Since it involves a separation of 325.6 frequency units, doubtless should be identified as $3k^2P$-$3m^2P$. No term values can be determined with great accuracy, but if we assume $3nx$ equal to 13000 we obtain a^2P equal to 136900, a value which is probably correct to 1 or 2 percent.

Norman Bridge Laboratory of Physics,
California Institute of Technology.
November 11, 1926.

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[13] De Bruin, K. Akad. Amsterdam Proc. **35**, 751 (1926).