STRIPPED OXYGEN, O_{VI} , THE PP' GROUP IN O_V , AND
NEW ALUMINUM LINES IN THE EXTREME
ULTRA-VIOLET

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ABSTRACT

Lines of stripped oxygen O_{VI} and of O_V .—The oxygen atom holds its last electrons so tenaciously that hitherto no lines assignable to stripped oxygen have been obtained. Using aluminum electrodes and high resolution, the "lithium doublet" of stripped oxygen has been definitely located at 1031.98, 1037.69A (see Plate I) the component of shorter wave-length being, as usual with this doublet, the more intense. The use of pure Al electrodes has also enabled the pp' group of O_V to be obtained in the fourth order, definitely resolved as a sextuplet (see Plate II) the ratio p_1p_2/p_3p_3 coming out 2.27, reasonably close to the value 2 called for by Lande's interval rule.

New aluminum lines between 1250 and 500A.—Fifteen new faint lines have been discovered and all definitely placed in their proper series, belonging to Al_{III} and Al_{II} .

Ionization potentials of stripped atoms.—Extrapolation from the known values for stripped atoms in the first and second rows of the periodic table, gives values for the $2s$ term which correspond to the following ionization potentials: for N_V 97.39; for O_{VI} 137.35; for F_{VII} 184.07; and for Cl_{VII} 113.73 volts. These are probably accurate to within 0.2 volt.

1. STRIPPED OXYGEN

IN preceding work we have been able to strip off completely the valence electrons from all of the elements contained in the first two rows of the periodic table^{1,2,3} save only oxygen and fluorine. These two atoms hold the last of their valence electrons more tenaciously than do any of the others—the quantitative analysis follows later—and would therefore be expected to be the most difficult to reduce to the stripped condition.

In our earlier plates we sought for evidences of the stripped oxygen atom (O_{VI}) without finding any lines which could be unambiguously assigned to it. Since we have been using a very narrow slit and high resolution, some of our plates have revealed two faint but very definite lines which we can now obtain in both first and second order spectra and which, as is conclusively proved below, constitute the "lithium-doublet" of stripped oxygen.

¹ Millikan and Bowen, *Nature*, **114**, p. 380 (1924).

² Bowen and Millikan, *Phys. Rev.* **24**, p. 209-222 (1924).

³ Bowen and Millikan, *Phys. Rev.* **25**, p. 295-305 (1925).

These lines come out best when the electrodes used are pure aluminum, rather than salt-impregnated cores, for the latter tend to lower somewhat the vacua and especially the potentials to which the tips of the electrodes are raised before the spark occurs. It may be remembered that we have shown previously⁴ that so-called "chemically pure aluminum" furnished primarily the oxygen spectra between 250A. and 1300A. The two new oxygen lines are shown in Plate I. Their measured wave-lengths are shown in Table I.

TABLE I
Lines of stripped oxygen O_{VI}

Intensity	λ I.A. Vac.	ν	$\Delta\nu$	Series designation
1	1031.98	96901.6	533.8	$2s-2p_1$
0	1037.69	96367.8		$2s-2p_2$

When the frequency ν and the frequency-separation $\Delta\nu$, corresponding to these two lines are subjected to the test of the regular and irregular doublet-law-progressions with atomic number, such as we have brought to light in preceding papers^{2,5} there result Tables II and III,

TABLE II
Regular L doublets, one-electron systems
 $2p_2-2p_1$

Element	$\Delta\nu$	$\sqrt[4]{\Delta\nu/.365}$	s
LiI	.338	.981	2.019
BeII	6.61	2.063	1.937
BIII	34.4	3.116	1.884
CIV	107.4	4.142	1.858
NV	259.1	5.162	1.838
OVI	533.8	6.184	1.816

TABLE III
Irregular L doublets
 $2s-2p_2$

Element	$\Delta\nu$	Diff.	2nd Diff.
LiI	14903.8	17023.8	
BeII	31927.6	16431.1	592.7
BIII	48358.7	16122.5	308.6
CIV	64481.2	15973.9	148.6
NV	80455.1	15912.7	61.2
OVI	96367.8		

respectively. The perfect fitting of these two lines into both these tables removes all uncertainty as to the correctness of their identifica-

⁴ Millikan and Bowen, Phys. Rev. **23**, p. 1-34 (1924).

⁵ Bowen and Millikan, Phys. Rev. **26**, p. 310-318 (1925).

tion as the "lithium doublet" lines of stripped oxygen (O_{VI}). It will be noticed, also, from a glance at Plate I that these lines follow the rule which also holds for this lithium doublet that the component on the short wave-length side is the stronger.

2. IONIZING POTENTIALS OF STRIPPED ATOMS

The excitation of the O_{VI} atom from which these lines originate requires the highest energy of any optical series with which any one has thus far worked. The ionizing potentials of all the stripped atoms of the first row of the periodic table may be easily computed. Since the inmost p orbits of all the stripped atoms of the elements of this row are circular, for in this row they are $2p$ orbits, the progression of their terms and convergence frequencies with atomic number will follow closely the square law of the simple Bohr theory, i.e., the frequency of the $2p$ term of O_{VI} must be nearly 6^2 times that of lithium. More accurately, the study of the empirical progression of the value of

$$Z - \sigma = \sqrt{\nu n^2 / R} \quad (1)$$

for the $2p_1$ term of the series of stripped atoms from Li through C yields, as previously pointed out by us,¹ the first four numbers of Table IV. The results of our extrapolation with the aid of these four values to corresponding values for N, O and F is shown in the last three numbers of the second column of Table IV. These numbers could scarcely be in error by as much as .005, which would correspond to not

TABLE IV

Element	<i>Ionization potentials of stripped atoms</i>			λ^{2s}
	$2p_1$	Diff.	Ionization Potential	
Li _I	1.02074			
Be _{II}	2.04694	.02620		
B _{III}	3.06401	.01707		
C _{IV}	4.07457	.01056		
N _V	5.08097	.00640	97.39	126.75
O _{VI}	6.08478	.00381	137.35	89.88
F _{VII}	7.08702	.00224	184.07	67.07

more than 0.2 volts in the resulting ionization potential. Computing from the foregoing formula the values of ν corresponding to these values of $Z - \sigma$ and then adding the frequency given in Table III of the $(2s - 2p_1)$ line gives the frequencies of the $2s$ terms. These correspond to the ionization potentials shown in the fourth column of Table

Plate I. The "lithium doublet" lines of stripped oxygen (O_{VI}).

Plate II. The pp' group of stripped oxygen (O_V).

IV. The corresponding convergence wave-length of the principal series is given in the fifth column.

By a similar procedure the highest ionizing potential of any stripped atom of the elements in the second row of the periodic table, viz: that of chlorine (Cl VII), is found to be 113.73 volts. The corresponding value for sulfur is 87.6 volts, as we have previously shown.³ It is obvious that the higher the value of this ionizing potential the more rapidly will the atom when once stripped begin to regain its valence electrons and hence the less the chance that it will be found emitting in the stripped state. This explains why the lines corresponding to stripped oxygen are more difficult to bring out than those corresponding to sulphur or even to chlorine.

3. THE pp' GROUP IN O_V

The added sharpness and strength with which the O_{VI} and O_V lines come out when pure aluminum is used as electrode material has recently enabled us to obtain the pp' group in O_V in the fourth order spectrum where the resolution is so excellent that all of its six components are clearly separated, as is shown in Table V. This separation makes it

TABLE V

<i>pp' Group in two-valence electron oxygen O_V</i>					
	p_1		p_2		p_3
Int. :			(4)		
λ :			761.131		
ν :			131383.4		p'_3
$\Delta\nu$:			155.4		
Int. :	(4)		(3)		(4)
λ :	762.004		760.232		759.453
ν :	131232.9	305.9	131538.8	134.9	131673.7
$\Delta\nu$:	267.0		268.2		p'_2
Int. :	(5)		(4)		
λ :	760.457		758.685		
ν :	131499.9	307.1	131807.0		p'_1

possible to obtain, for the first time among the two valence electron atoms of the first row of the periodic table except Be (already known), the value of the ratio $p_1 p_2 / p_2 p_3$. As may be seen from the numbers in Table V, the ratio comes out 2.27, in much closer agreement with the value 2 called for by Lande's interval-rule than is Be, which quite anomalously has the value⁶ 3.57. Plate II shows the pp' group in O_V in the fourth order, with all of the six components definitely resolved and labelled.

⁶ Sommerfeld, *Atombau und Spektrallinien*, 4th ed., p. 661.

4. NEW ALUMINUM LINES IN THE EXTREME ULTRA-VIOLET

In our former cataloguing of extreme ultra-violet lines we listed⁴ but two lines between 1250Å and 500Å as certainly belonging to aluminum, viz., 859.9 and 695.9, and these of intensity 0 and 1, respectively. On our new plates we have been able to bring out these lines with greater intensity and resolution, and to cause fifteen other faint lines to appear, as shown in Table VI. All save four of these lines were

TABLE VI

Intensity	<i>Series lines of aluminum, Al_{II} and Al_{III}</i>				Stage of ionization
	λ I.A. Vac.	ν	Series designation		
0	560.24	178494.9	$3s-5p$		III
3	695.82	143715.3	$3s-4p_1$		III
2	696.23	143630.7	$3s-4p_2$		III
0	725.74	137790.4	$3p_2-6s$		III
0	726.95	137561.0	$3p_1-6s$		III
3	854.98	116961.8	$3p_2-5s$		III
3	856.80	116713.4	$3p_1-5s$		III
1	892.00	112107.6	$3p_2-4d$		III
1	893.93	111865.6	$3p_1-4d$		III
0	1048.83	95344.3	$3p_2-5d$		II
0	1050.01	95237.2	$3p_1-5d$		II
0	1162.59	86014.8	$3d-6f$		III
1	1189.07	84099.3	$3p_3-4d$		II
2	1190.07	84028.7	$3p_2-4d$		II
2	1191.83	83904.6	$3p_1-4d$		II
0	1209.25	82695.9	$3p_3-5s$		II
1	1210.12	82636.4	$3p_2-5s$		II
1	1211.93	82513.0	$3p_1-5s$		II

predicted by Paschen,⁷ his predicted values differing from our observed values only by a few hundredths angstroms, which is in close agreement as could be expected when we are working with lines so faint that they cannot be obtained in orders higher than the second.

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⁷ Paschen, Ann. d. Physik, **71**, p. 142-161, 537-561 (1923).

Plate I. The "lithium doublet" lines of stripped oxygen (O_{VI}).

Plate II. The pp' group of stripped oxygen (Ov).