

The electronic character of the excited state is indicated as singlet by the strong absorption intensity. The presence of two bands in which definitely one quantum of the antisymmetrical vibration is excited, taken in connection with a consideration of the vibronic selection rules, show that the excited state must be either  ${}^1A_1$  or  ${}^1B_2$  (cf. reference 12, Table XI). Were it possible to determine whether the bands under discussion are of the perpendicular or parallel type, one could determine uniquely the nature of the upper electronic state ( ${}^1B_2$  if these bands are of the parallel type,  ${}^1A_1$  if they are perpendicular).

In conclusion, a few remarks may be made concerning the prospects of a rotational analysis of this system. As a result of a decrease in the apex angle ( $2\alpha' = 100^\circ$ ) in the transition, the regularity of symmetric top levels must be

entirely lost (cf. Fig. 4 of reference 12), thus rendering the analysis more difficult. In addition, there should be greater overlapping of sub-band structure. Another point is the scarcity of bands free from overlapping; those bands which are intense enough at low pressures, where low temperatures could then be used to reduce the complexity, are considerably overlapped, as we have seen. Those near the system origin require higher pressures to obtain sufficient absorption. The increased pressure precludes work at low temperatures, tends to broaden the rotational lines and makes probable the presence of overlapping, low lying excited vibrational levels of the normal state.

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## Spectra of Argon in the Extreme Ultraviolet

L. W. PHILLIPS AND W. L. PARKER

*Department of Physics, University of Illinois, Urbana, Illinois*

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A simple method for the excitation of spectra of higher stages of ionization of rare gases is described. Applied to argon, the method has yielded spectra of all stages of ionization from A III to A IX. Classified lines in the extreme ultraviolet and term tables for the ions V to IX are given. Some minor additions and corrections to previous analyses of Cl V and Cl VI are pointed out.

### GENERAL AND EXPERIMENTAL

THE extreme ultraviolet spectra of argon have been studied by a number of investigators, the latest work being that of Boyce.<sup>1</sup> References to earlier work may be found in his paper. As a result of these investigations, the spectra of the first four stages of ionization are quite well known. Two multiplets in A V due to transitions from the first excited configuration to the ground state configuration were found by Boyce, but nothing else was known in V or in higher stages. The present investigation was undertaken in the hope of extending the analysis

to higher stages of ionization. A preliminary report has already been published.<sup>2</sup>

The method of excitation used is simple and effective. It consists of introducing the gas directly into the space between the two electrodes of an ordinary vacuum spark such as is usually used for the excitation of the spectra of other highly ionized elements. To accomplish this a one-eighth-inch hole is drilled axially into the lower electrode. The gas is fed into the bottom of this hole through a small bronze capillary, which passes through the bottom of the lower electrode holder and is connected to a reservoir in which

<sup>1</sup> J. C. Boyce, *Phys. Rev.* **48**, 396 (1935).

<sup>2</sup> W. L. Parker and L. W. Phillips, *Phys. Rev.* **58**, 93 (1940).

the gas is kept at low pressure. The gas then passes up into the spark gap where it is excited. Mercury diffusion pumps operating continually keep the gas from accumulating in the spark chamber and building up the pressure to a point where an arc discharge could occur.

In the original installation the rate of flow of argon was controlled both by the reservoir pressure and by a needle valve placed between the reservoir and the spark chamber. In later work the needle valve was removed and the flow controlled entirely by adjustment of the reservoir pressure. With an electrode separation of from four to six millimeters, argon was admitted from the storage bulb into the reservoir until a pressure was reached at which sparking occurred at a rate of from 60 to 100 sparks per minute. The optimum flow of argon was about 1 cc per minute.

The condensed discharge was obtained by means of a condenser bank consisting of nine General Electric pyranol capacitors arranged

TABLE I. *Classified lines of A V.*

INT.	$\lambda(\text{VAC.})$	$\nu(\text{CM}^{-1})$	CLASSIFICATION
2*	836.126	119,599	$3s^23p^2\ ^3P_2 - 3s3p^3\ ^3D_1$
1*	835.792	119,647	$\ ^3P_2 - \ ^3D_2$
4b*	834.878	119,778	$\ ^3P_2 - \ ^3D_3$
3*	827.349	120,868	$\ ^3P_1 - \ ^3D_1$
5*	827.055	120,911	$\ ^3P_1 - \ ^3D_2$
4*	822.159	121,631	$\ ^3P_0 - \ ^3D_1$
3*	715.645	139,734	$3s^23p^2\ ^3P_2 - 3s3p^3\ ^3P_2$
4*	715.599	139,743	$\ ^3P_2 - \ ^3P_1$
5*	709.195	141,005	$\ ^3P_1 - \ ^3P_{0,1,2}$
3*	705.353	141,773	$\ ^3P_0 - \ ^3P_1$
5	558.481	179,057	$3s^23p^2\ ^1D_2 - 3s3p^3\ ^1P_1$
6	527.693	189,504	$3s^23p^2\ ^3P_2 - 3s3p^3\ ^3S_1$
5	524.189	190,771	$\ ^3P_1 - \ ^3S_1$
3	522.090	191,538	$\ ^3P_0 - \ ^3S_1$
0	517.250	193,330	$3s^23p^2\ ^3P_2 - 3s3p^3\ ^1P_1$
1	513.914	194,585	$\ ^3P_1 - \ ^1P_1$
0	511.886	195,356	$\ ^3P_0 - \ ^1P_1$
7	463.938	215,546	$3s^23p^2\ ^3P_2 - 3s^23p3d\ ^3P_2$
3	462.415	216,256	$\ ^3P_2 - \ ^3P_1$
6b	461.227	216,813	$\ ^3P_1 - \ ^3P_2$
1	459.728	217,520	$\ ^3P_1 - \ ^3P_1$
2	458.975	217,877	$\ ^3P_1 - \ ^3P_0$
3	458.121	218,283	$\ ^3P_0 - \ ^3P_1$
1	450.079	222,183	$3s^23p^2\ ^3P_2 - 3s^23p3d\ ^3D_1$
4	449.493	222,473	$\ ^3P_2 - \ ^3D_2$
18	449.065	222,685	$\ ^3P_2 - \ ^3D_3$
4	447.527	223,450	$\ ^3P_1 - \ ^3D_1$
8	446.949	223,739	$\ ^3P_1 - \ ^3D_2$
5	445.997	224,217	$\ ^3P_0 - \ ^3D_1$
3	350.878	284,999	$3s^23p^2\ ^1D_2 - 3s^23p4s\ ^1P_1$
3	339.886	294,216	$3s^23p^2\ ^3P_2 - 3s^23p4s\ ^3P_1$
3	339.009	294,977	$\ ^3P_1 - \ ^3P_0$
2	338.426	295,486	$\ ^3P_1 - \ ^3P_1$
6	337.998	295,860	$\ ^3P_2 - \ ^3P_2$
3	337.555	296,248	$\ ^3P_0 - \ ^3P_1$
3	336.555	297,128	$\ ^3P_1 - \ ^3P_2$

\* Classified by Boyce, reference 1.

TABLE II. *A V term values.*

CONFIGURATION	J	RELATIVE TERM VALUE
$3s^2p^2\ ^3P$	0	0
	1	765
	2	2,032
$^1D$	2	16,301
	$3s3p^3\ ^3D$	1
2		121,678
3		121,810
$^3P$	2	141,764
	1, 0	141,773
$^3S$	1	191,537
$^1P$	1	195,356
$sp3d\ ^3P$	2	217,578
	1	218,286
	0	218,642
$^3D$	1	224,216
	2	224,505
	3	224,717
$sp4s\ ^3P$	0	295,742
	1	296,249
	2	297,893
$^1P$	1	301,300

TABLE III. *Observed nebular lines.*

OBSERVER	$^3P_1 - ^1D_2$	$^3P_2 - ^1D_2$
Stoy <sup>3</sup>	6435.0	7007
Bowen <sup>6</sup>	6435	7005
Bowen and Wyse <sup>7</sup>		
	NGC 7662	6435.2
NGC 7027	6434.6	
Average $\lambda$	6435	7006
$\nu - \text{cm}^{-1}$	15,536	14,270
From term table	15,536	14,269

three in series, three in parallel, to give a combination having a capacity of 0.35 microfarad. The pictures were taken on the twenty-one-foot grazing incidence vacuum spectrograph at voltages ranging from 100 to 120 kilovolts. A three-quarter-inch air gap in series with the vacuum gap kept the spark from passing before the condensers were charged to full potential.

The pictures were taken with aluminum or carbon electrodes; the exposures ranged from 15,000 to 25,000 sparks. Commercial tank argon, contaminated with oxygen and nitrogen, was used for all but one exposure, which was made

TABLE IV. *Classified lines of A VI.*

INT.	$\lambda(\text{VAC.})$	$\nu(\text{CM}^{-1})$	CLASSIFICATION
4	596.694	167,590	$3s^23p^2P_{3/2}-3s3p^2^2S_{1/2}$
5	588.921	169,802	$^2P_{1/2}-^2S_{1/2}$
3	594.096	168,323	$3s3p^2^4P_{5/2}-3p^3^4S_{3/2}$
2	589.783	169,554	$^4P_{3/2}-^4S_{3/2}$
1	587.006	170,356	$^4P_{1/2}-^4S_{3/2}$
4	555.639	179,973	$3s^23p^2P_{3/2}-3s3p^2^2P_{1/2}$
8	551.371	181,366	$^2P_{3/2}-^2P_{3/2}$
5	548.905	182,181	$^2P_{1/2}-^2P_{1/2}$
4	544.731	183,577	$^2P_{1/2}-^2P_{3/2}$
4	466.932	214,164	$3s3p^2^4P_{5/2}-3s3p3d^4P_{5/2}$
2	465.586	214,783	$^4P_{5/2}-^4P_{3/2}$
4	464.257	215,398	$^4P_{3/2}-^4P_{5/2}$
1	461.898	216,498	$^4P_{3/2}-^4P_{1/2}$
6 <sup>b</sup>	461.227	216,813	$^4P_{1/2}-^4P_{3/2}$
1	460.202	217,296	$^4P_{1/2}-^4P_{1/2}$
4	462.146	216,382	$3s^23p^2P_{3/2}-3s^23d^2D_{3/2}$
25	462.007	216,447	$^2P_{3/2}-^2D_{5/2}$
20 <sup>b</sup>	457.475	218,591	$^2P_{1/2}-^2D_{3/2}$
1	460.058	217,364	$3s3p^2^4P_{5/2}-3s3p3d^4D_{3/2}$
3	459.603	217,579	$^4P_{5/2}-^4D_{5/2}$
10	459.320	217,713	$^4P_{5/2}-^4D_{7/2}$
1	458.039	218,322	$^4P_{3/2}-^4D_{1/2}$
20 <sup>b</sup>	457.475	218,591	$^4P_{3/2}-^4D_{3/2}$
5	457.007	218,815	$^4P_{3/2}-^4D_{5/2}$
3	456.375	219,118	$^4P_{1/2}-^4D_{1/2}$
2	455.813	219,388	$^4P_{1/2}-^4D_{3/2}$
6	294.052	340,076	$3s^23p^2P_{3/2}-3s^24s^2S_{1/2}$
5	292.154	342,285	$^2P_{1/2}-^2S_{1/2}$
3	283.164	353,152	$3s3p^2^4P_{3/2}-3s3p4s^4P_{1/2}$
1	282.556	353,912	$^4P_{3/2}-^4P_{3/2}$
6	282.423	354,079	$^4P_{5/2}-^4P_{5/2}$
4	281.915	354,717	$^4P_{1/2}-^4P_{3/2}$
3	281.433	355,324	$^4P_{3/2}-^4P_{5/2}$
5	220.946	452,600	$3s^23p^2P_{3/2}-3s^24d^2D_{5/2}$
3	219.896	454,760	$^2P_{1/2}-^2D_{3/2}$
3	180.719	553,345	$3s^23p^2P_{3/2}-3s^25d^2D_{5/2}$
2	180.074	555,327	$^2P_{1/2}-^2D_{3/2}$

<sup>b</sup> Blend.

with s.p. argon. The oxygen and nitrogen lines in the region are all well known and were, in many cases, used as standards. In addition, carbon and aluminum lines, and in some instances copper lines from an overlapping picture, were used as standards.

The argon spectrograms were quite rich in lines. All stages of ionization from III to IX appear on the plates. The spectrum of argon VI appears to have been the most strongly excited, with V, VII, and VIII less intense but still quite strong. Known lines of argon IV in the region are quite weak, and only the strongest argon III lines given by Boyce appear. The spectrum of argon II seems to be definitely absent.

## ARGON V

Argon V is isoelectronic with silicon I. The spectra of all other ions in the sequence through titanium IX are known, and references to the

work on these ions may be found in the bibliography recently published by Boyce.<sup>3</sup> The ground state of silicon-like ions is  $3s^23p^2$ , giving a normal  $^3P$  ground state with  $^1D$  and  $^1S$  lying above it. In phosphorus II and succeeding ions the first excited configuration is  $3s3p^3$ , giving  $^5S$  and  $^3(P, D)$  terms. The next configurations are  $3s^23p3d$  and  $3s^23p4s$ . Boyce classified the  $^3P-^3D$  and  $^3P-^3P$  multiplets coming from the  $3s^23p^2-3s3p^3$  transition. Most of the other lines coming from this transition, and the triplet multiplets arising from the transitions  $3s^23p^2-3s^23p3d$ ,  $3s^23p4s$ , have now been identified. The intercombination lines  $3s^23p^2^3P_{0,1,2}-3s3p^3^1P_1$  have been found, hence it is possible to tie the singlet and triplet systems together. A complete list of all the argon V lines so far classified is given in Table I, and the term values in Table II.

TABLE V. A VI term values.

CONFIGURATION	J	RELATIVE TERM VALUE
$3s^23p^2P$	Doublets	
	$1/2$	0*
	$3/2$	2,210
$3s3p^2^2S$	$1/2$	169,801
	$^2P$	
	$1/2$	182,182
	$3/2$	183,577
$3s^23d^2D$	$3/2$	218,592
	$5/2$	218,657
$3s^24s^2S$	$1/2$	342,286
$3s^24d^2D$	$3/2$	454,760
	$5/2$	454,810
$3s^25d^2D$	$3/2$	555,330
	$5/2$	555,555
$3s3p^2^4P$	Quartets	
	$1/2$	0**
	$3/2$	802
	$5/2$	2,034
$3p^3^4S$	$3/2$	170,356
	$sp3d^4P$	
	$5/2$	216,199
	$3/2$	216,815
	$1/2$	217,298
$^4D$	$1/2$	219,121
	$3/2$	219,393
	$5/2$	219,615
	$7/2$	219,747
$sp4s^4P$	$1/2$	353,954
	$3/2$	354,716
	$5/2$	356,115

\* (721,300±300) cm<sup>-1</sup> below ground state of A VII.\*\* Estimated (100,000±1000) cm<sup>-1</sup> above  $3s^23p^2P$ .<sup>3</sup> J. C. Boyce, Rev. Mod. Phys. 13, 1 (1941).

Robinson<sup>4</sup> has suggested that the pair of nebular lines at 6435 and 7005A are due to transitions from the metastable  $3s^23p^2\ ^1D_2$  to  $3s^23p^2\ ^3P_{1,2}$ . This suggestion can now be verified. Taking 6434.8 and 7005A as averages of values given by Stoy,<sup>5</sup> Bowen,<sup>6</sup> and Bowen and Wyse<sup>7</sup> for the wave-lengths of the nebular lines (see Table III), one obtains wave numbers of 15,536  $\text{cm}^{-1}$  and 14,270  $\text{cm}^{-1}$ , respectively. These are in good agreement with the values of 15,536  $\text{cm}^{-1}$  and 14,269  $\text{cm}^{-1}$  derived from the term table.

No series have been discovered so the only estimate of the ionization potential which is possible is a rough one based on data for the earlier members of the isoelectronic sequence. Boyce's value of 78 volts is still retained.

### ARGON VI

Argon VI is isoelectronic with aluminum I. The spectra of all other ions in the sequence are quite well known through scandium IX and references to previous work on these ions are given by Boyce.<sup>3</sup> Beyond scandium IX, Edlén<sup>8</sup> has identified the transition  $3s^23p\ ^2P - 3s^24d\ ^2D$  in

TABLE VI. Classified lines of A VII.

INT.	$\lambda(\text{VAC.})$	$\nu(\text{CM}^{-1})$	CLASSIFICATION
2	644.388	155,186	$3s3p\ ^3P_2 - 3p^2\ ^3P_1$
2	641.318	155,929	$\ ^3P_1 - \ ^3P_0$
1	637.466	156,871	$\ ^3P_1 - \ ^3P_1$
4	637.052	156,973	$\ ^3P_2 - \ ^3P_2$
2	634.208	157,677	$\ ^3P_0 - \ ^3P_1$
2	630.306	158,653	$\ ^3P_1 - \ ^3P_2$
15	585.754	170,720	$3s^2\ ^1S_0 - 3s3p\ ^1P_1$
2	479.485	208,557	$3s3p\ ^3P_2 - 3s3d\ ^3D_2$
12	479.379	208,603	$\ ^3P_2 - \ D_3$
2	475.733	210,202	$\ ^3P_1 - \ D_1$
8	475.656	210,236	$\ ^3P_1 - \ D_2$
4	473.938	210,998	$\ ^3P_0 - \ D_1$
6	297.701	335,907	$3s3d\ ^3D_3 - 3s4f\ ^3F_4$
4	297.658	335,956	$\ ^3D_2 - \ ^3F_3$
3	297.621	335,998	$\ ^3D_1 - \ ^3F_2$
7	250.940	398,502	$3s3p\ ^3P_2 - 3s4s\ ^3S_1$
5	249.886	400,183	$\ ^3P_1 - \ ^3S_1$
2	249.384	400,988	$\ ^3P_0 - \ ^3S_1$
7	192.635	519,116	$3s3p\ ^3P_2 - 3s4d\ ^3D_3$
5	192.041	520,722	$\ ^3P_1 - \ ^3D_2$
3	191.759	521,489	$\ ^3P_0 - \ ^3D_1$
10	176.566	566,362	$3s^2\ ^1S_0 - 3s4p\ ^1P_1$
3	152.259	656,775	$3s3p\ ^3P_2 - 3s5d\ ^3D_3$
2	151.876	658,430	$\ ^3P_1 - \ ^3D_2$
1	151.698	659,205	$\ ^3P_0 - \ ^3D_1$

<sup>4</sup> H. A. Robinson, Nature **137**, 992 (1936).

<sup>5</sup> R. H. Stoy, Lick Obs. Bull. No. 480, 179 (1935).

<sup>6</sup> I. S. Bowen, Rev. Mod. Phys. **8**, 55 (1936).

<sup>7</sup> I. S. Bowen and A. B. Wyse, Lick Obs. Bull. No. 495, 1 (1939).

<sup>8</sup> B. Edlén, Zeits. f. Physik **103**, 536 (1936).

TABLE VII. A VII term values.

CONFIGURATION	J	RELATIVE TERM VALUE
	<i>Singlets</i>	
$3s^2\ ^1S$	0	0*
$3s3p\ ^1P$	1	170,720
$3s4p\ ^1P$	1	566,362
	<i>Triplets</i>	
$3s3p\ ^3P$	0	0**
	1	805
	2	2,486
$3p^2\ ^3P$	0	156,734
	1	157,675
	2	159,459
$3s3d\ ^3D$	1	211,002
	2	211,041
	3	211,089
$3s4s\ ^3S$	1	400,988
$3s4d\ ^3D$	1	521,489
	2	521,527
	3	521,602
$3s4f\ ^3F$	2, 3, 4	546,997
$3s5d\ ^3D$	1	659,205
	2	659,230
	3	659,260

\* Estimated 1,005,000  $\text{cm}^{-1}$  below ground state of A VIII.

\*\* Estimated 114,000  $\text{cm}^{-1}$  above  $3s^2\ ^1S_0$ .

the ions titanium X to cobalt XVI. The ground state configuration of aluminum-like ions is  $3s^23p$ , giving a normal  $^2P$  ground state. The  $3p$  electron may be excited to higher states giving a system of doublet levels similar to those of the alkali metals. Another series of levels is obtained by excitation of one of the  $3s$  electrons. The resulting configurations of the type  $3s3pnl$  give rise to quartet as well as doublet terms. The first excited configuration of this type is  $3s3p^2$ , which gives rise to  $(^3P)\ ^2\ ^4P$ ,  $(^1D)\ ^2D$  and  $(^1S)\ ^2S$ . Of these, the  $(^3P)\ ^4P$  lies deepest and is the ground state of the quartet system. A third possibility is the excitation of both  $3s$  electrons, giving rise to the states  $3p^3\ ^4S$ ,  $^2(P, D)$ .

All of the lines so far identified in the spectrum of argon VI are given in Table IV. Terms are listed in Table V. No intercombinations have been found, so the doublet and quartet systems cannot be tied together accurately. Accordingly, the two systems of terms are listed separately. The location of  $3s3p^2\ ^4P_{1/2}$  is estimated to be  $100,000 \pm 1000\ \text{cm}^{-1}$  above  $3s^23p\ ^2P_{1/2}$ .

TABLE VIII. *Classified lines of A VIII.*

INT.	$\lambda(\text{Vac.})$	$\nu(\text{cm}^{-1})$	CLASSIFICATION
*	713.990	140,058	$3s\ ^2S_{1/2} - 3p\ ^2P_{1/2}$
*	700.398	142,776	$\ ^2S_{1/2} - \ ^2P_{3/2}$
1	526.870	189,800	$3p\ ^2P_{3/2} - 3d\ ^2D_{3/2}$
5	526.457	189,949	$\ ^2P_{3/2} - \ ^2D_{5/2}$
3	519.429	192,519	$\ ^2P_{1/2} - \ ^2D_{3/2}$
0d	338.222	295,664	$3d\ ^2D_{3/2} - 4p\ ^2P_{1/2}$
2d	337.257	296,510	$\ ^2D_{5/2} - \ ^2P_{3/2}$
6	260.332	384,125	$3d\ ^2D_{5/2} - 4f\ ^2F_{7/2}$
4	260.253	384,242	$\ ^2D_{3/2} - \ ^2F_{5/2}$
7	230.875	433,135	$3p\ ^2P_{3/2} - 4s\ ^2S_{1/2}$
5	229.437	435,850	$\ ^2P_{1/2} - \ ^2S_{1/2}$
5	184.315	542,550	$3d\ ^2D_{5/2} - 5f\ ^2F_{7/2}$
3	184.273	542,672	$\ ^2D_{3/2} - \ ^2F_{5/2}$
15	180.254	554,772	$3p\ ^2P_{3/2} - 4d\ ^2D_{5/2}$
10	179.400	557,413	$\ ^2P_{1/2} - \ ^2D_{3/2}$
5	159.175	628,240	$3s\ ^2S_{1/2} - 4p\ ^2P_{1/2}$
8	158.923	629,236	$\ ^2S_{1/2} - \ ^2P_{3/2}$
3	149.333	669,644	$3p\ ^2P_{3/2} - 5s\ ^2S_{1/2}$
2	148.725	672,385	$\ ^2P_{1/2} - \ ^2S_{1/2}$
5	138.440	722,335	$3p\ ^2P_{3/2} - 5d\ ^2D_{5/2}$
3	137.926	725,025	$\ ^2P_{1/2} - \ ^2D_{3/2}$
1	123.033	812,790	$3p\ ^2P_{3/2} - 6d\ ^2D_{5/2}$
0	122.624	815,500	$\ ^2P_{1/2} - \ ^2D_{3/2}$
1	120.157	832,250	$3s\ ^2S_{1/2} - 5p\ ^2P_{1/2}$
2	120.093	832,690	$\ ^2S_{1/2} - \ ^2P_{3/2}$

\* Calculated from the term table.

The  $3s^25d\ ^2D$  term may be open to question because of the anomalously large separation. However, both in Cl V<sup>9</sup> and Ca VIII<sup>10</sup> the  $5d$  separation is found to be larger than the  $4d$  separation, though not as much larger proportionately. The values for the  $4d\ ^2D$ ,  $5d\ ^2D$  separations are, respectively, 33 and 73  $\text{cm}^{-1}$  in chlorine, 50 and 225  $\text{cm}^{-1}$  in argon, and 191 and 210  $\text{cm}^{-1}$  in calcium. These are the only ions beyond aluminum for which both separations are known.

A calculation of the series limit, based on three members of the  $3s^23p - 3s^2nd$  series, gives  $721,300 \pm 300\ \text{cm}^{-1}$ . This corresponds to an ionization potential of  $89.00 \pm 0.05$  volts for argon VI.

## ARGON VII

Argon VII is isoelectronic with magnesium I. The spectra of all other ions in the sequence through cobalt XVI are known and references to the work on these ions are given by Boyce.<sup>3</sup> The ground state of the magnesium-like ions is  $3s^2\ ^1S$ . The first excited state is  $3s3p$ , giving a  $^1P$ , and a  $^3P$  which is the deepest term of the triplet system.

<sup>9</sup> See Table XII.<sup>10</sup> L. W. Phillips, Phys. Rev. **55**, 708 (1939).

Above these states are terms of the type  $3snl$ , giving rise to  $^1,^3L$  levels. Other series of terms come from the excitation of both electrons, i.e., configurations of the type  $3pnl$ , etc. The lowest of these is  $3p^2$ , giving  $^3P$ ,  $^1D$  and  $^1S$  terms.

A few of the strong singlet lines and a number of triplets have been identified and are listed in Table VI. Term values are given in Table VII. No intercombinations have been found. A series limit calculation based on three members of the series  $3s3p - 3snd$  yields  $891,000 \pm 200\ \text{cm}^{-1}$  for  $3s3p\ ^3P_0$  with respect to the ground state of A VIII. The  $3s^2\ ^1S_0 - 3s3p\ ^3P_1$  interval can be estimated by extrapolation of data on other ions in the sequence, or can be calculated by Houston's

TABLE IX. A VIII term values and effective quantum numbers.

CONFIGURATION	$J$	ABSOLUTE TERM VALUES	$n^*$
$3s\ ^2S$	1/2	1,157,400	2.4633
$3p\ ^2P$	1/2	1,017,342	
	3/2	1,014,624	2.6310
$3d\ ^2D$	3/2	824,824	
	5/2	824,673	2.9183
$4s\ ^2S$	1/2	581,490	3.4753
$4p\ ^2P$	1/2	529,160	
	3/2	528,163	3.6466
$4d\ ^2D$	3/2	459,929	
	5/2	459,852	3.9080
$4f\ ^2F$	5/2	440,582	
	7/2	440,548	3.9927
$5s\ ^2S$	1/2	344,978	4.5120
$5p\ ^2P$	1/2	325,155	
	3/2	324,709	4.6507
$5d\ ^2D$	3/2	292,316	
	5/2	292,289	4.9019
$5f\ ^2F$	5/2	282,152	
	7/2	282,123	4.9894
$6d\ ^2D$	3/2, 5/2	201,840	5.8989

TABLE X. *Classified lines and term values of A IX.*

CONFIGURATION	TERM VALUE	$2p^53s\ ^3P_1$	$2p^53s\ ^1P_1$
		2,033,350	2,052,120
$2p^6\ ^1S_0$	0	Int. $\lambda(\text{vac.})$	(5) 48.730
		$\nu(\text{cm}^{-1})$	2,033,350

TABLE XI.  $sp^2\ ^4P - sp3d\ ^4P$  multiplet in Cl V.

TERM	$sp3d\ ^4P$										
	J	1/2		3/2		5/2					
$sp^2\ ^4P$	1/2	184,746	[3]	322	184,424		[8]				
		539			539						
	3/2	184,207	[4]	322	183,885	[1]	437	183,448	[10]		
		181,450	(2)	[7]	173	181,277	(1)	[1]	415	180,862	(2B)
					845			843			
				840			839				
5/2				183,040	[6]	435	182,605	[10]			
				180,437	(1)	[6]	414	180,023	(1)	[10]	

method. An average of  $114,000\text{ cm}^{-1}$  is found for the interval  $3s^2\ ^1S_0 - 3s3p\ ^3P_0$ . The final value for  $3s^2\ ^1S_0$  with respect to the ground state of A VIII is  $1,005,000 \pm 1000\text{ cm}^{-1}$ . The ionization potential of argon VII is  $124.0 \pm 0.1$  volts.

### ARGON VIII

Argon VIII is isoelectronic with sodium I. The spectra of all other ions in the sequence, through copper XIX, are known and references may be found in Boyce's report and in a previous paper

TABLE XII. *Classified lines and term values of Cl V.*

INT.	$\lambda(\text{Vac.})$	$(\text{cm}^{-1})$	CLASSIFICATION	TERM VALUES*
10	547.630	182,605	$sp^2\ ^4P_{5/2} - sp3d\ ^4P_{5/2}$	
6	546.329	183,040	$^4P_{5/2}$	$^4P_{3/2}$
10	545.114	183,448	$^4P_{3/2}$	$^4P_{5/2}$
1	543.818	183,885	$^4P_{3/2}$	$^4P_{3/2}$
4	542.868	184,207	$^4P_{3/2}$	$^4P_{1/2}$
8	542.229	184,424	$^4P_{1/2}$	$^4P_{3/2}$
3	541.284	184,746	$^4P_{1/2}$	$^4P_{1/2}$
3	537.461	186,060	$sp^2\ ^4P_{3/2} - sp3d\ ^4D_{1/2}$	
2	237.231	421,530	$s^2p\ ^2P_{3/2} - s^25d\ ^2D_{5/2}$	$s^25d\ ^2D$
1	236.435	422,949	$^2P_{1/2}$	$^2D_{3/2}$
				3/2 124,051
				5/2 123,978

\* See Table VI, reference 11.

TABLE XIII. *Classified lines and term values of Cl VI.*

INT.	$\lambda(\text{Vac.})$	$(\text{cm}^{-1})$	CLASSIFICATION	TERM VALUES
2	580.444	172,282	$3p^2\ ^3P_2 - 3p3d\ ^3P_2$	
1	577.444	173,177	$^3P_2$	$^3P_1$
2	576.419	173,485	$^3P_1$	$^3P_2$
1	571.376	175,016	$^3P_0$	$^3P_1$
0	570.881	175,168	$^3P_1$	$^3P_0$
0	571.435	174,998	$3p^2\ ^3P_2 - 3p3d\ ^3D_1$	
2	570.529	175,276	$^3P_2$	$^3D_2$
4	570.025	175,431	$^3P_2$	$^3D_3$
1	567.479	176,218	$^3P_1$	$^3D_1$
2	566.630	176,482	$^3P_1$	$^3D_2$
6*	565.480	176,841	$^3P_0$	$^3D_1$
				3 314,081

\* Blend with Cl III line.

\*\* See Table V, reference 13.

from this laboratory.<sup>11</sup> The ground state of sodium-like ions is  $3s\ ^2S$ . Excitation of the single valence electron yields the well-known doublet spectrum.

Table VIII gives all the lines which have been identified in argon VIII. The resonance lines,  $3s\ ^2S - 3p\ ^2P$ , are just out of the range of the spectrograph. The  $3d - 4p$  transition has been found, and this serves to tie the whole term table together. Calculated wave-lengths and wave numbers for the resonance lines have been entered in the list of classified lines for convenience. Four members of the series  $3p - nd$  have been identified, so that a more accurate calculation of absolute term values is possible. The ionization potential is  $142.82 \pm 0.05$  volts. Absolute term values and effective quantum numbers are given in Table IX.

### ARGON IX

Argon IX is isoelectronic with neon I. References to work on the spectra of neon I—silicon V, chlorine VIII, and potassium X—cobalt XVIII are given in Boyce's bibliography. The ground state of neon-like ions is  $2p^6\ ^1S$ . The first excited configuration is  $2p^53s$ , giving  $^1,^3P$ , of which  $^3P_1$  and  $^1P_1$  combine with the ground state. The two lines which have been identified as arising from these transitions in argon IX, together with term values calculated therefrom, are given in Table X. The lines were measured with respect to nearby Cl VIII lines, and may be in error by as much as  $100\text{ cm}^{-1}$  (equivalent to 0.002 angstrom).

<sup>11</sup> P. G. Kruger and L. W. Phillips, Phys. Rev. **55**, 352 (1939).

## NOTE ON CHLORINE SPECTRA

From consideration of data on isoelectronic sequences involving the above argon ions, it was possible to make some minor additions and corrections to previous analyses of chlorine V and chlorine VI spectra.

The latest and most complete report on the

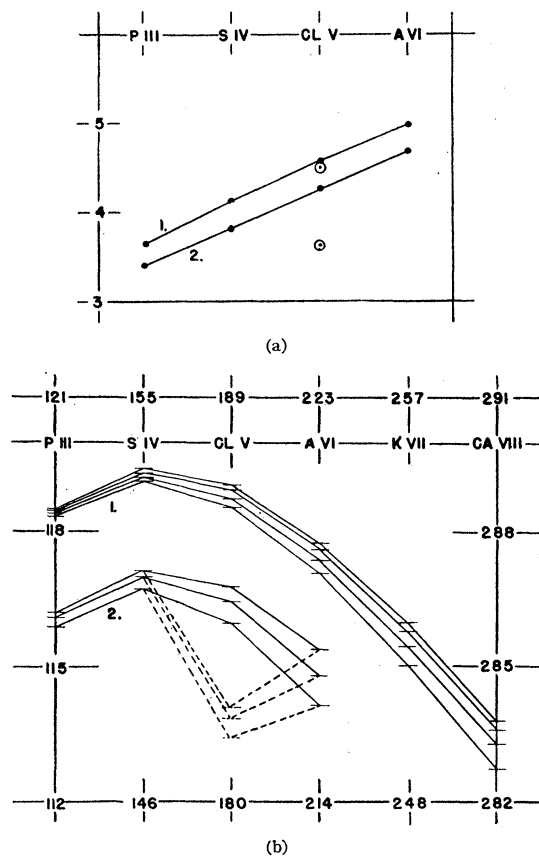


FIG. 1. (a) Term separations for  $spd\ ^4P$ . Ordinate- $[\Delta v]^2$ . Curve 1,  $^4P_{5/2}-^4P_{3/2}$ . Curve 2,  $^4P_{3/2}-^4P_{1/2}$ . Bowen's data indicated by  $\odot$ . (b) Term values for (1)  $spd\ ^4D$ , (2)  $spd\ ^4P$  states with respect to  $sp^2\ ^4P_{1/2}$ . Scale in thousands of  $\text{cm}^{-1}$ . Bowen's data indicated by dotted lines.

spectrum of chlorine V was given by Bowen.<sup>12</sup> Work done in this laboratory confirms all of his results except for the multiplet  $sp^2\ ^4P-sp3d\ ^4P$ . Table XI shows Bowen's classification (in italics) and the alternative classification. Intensities in parentheses are Bowen's; those in brackets are taken from our plates. The new identifications seem better for several reasons. (1) One should be able to find transitions to the  $sp^2\ ^4P_{1/2}$  level, but no such lines can be found to accompany Bowen's values. (2) The separations of the  $spd\ ^4P$  levels (Fig. 1(a)) are more in line with corresponding separations for other ions in the sequence. (3) Figure 1(b), showing the trend of the  $spd\ ^4(P, D)$  term values for several ions of the sequence, supports the new identification. The fact that three of Bowen's lines show an increase in intensity on our plates, while two do not, may indicate that the five lines identified by Bowen do not all belong to the same stage on ionization. The necessity for classifying 552.908 as a blend with  $s^2p^3\ ^2D_{5/2}-s^2p^2(^1D)3d\ ^2P_{3/2}$  of Cl III is now removed. The multiplet  $sp^2\ ^4P-sp3d\ ^4D$  is found to be more intense on our plates than on Bowen's, as is evidenced by the fact that  $^4P_{3/2}-^4D_{1/2}$  appears. The above-mentioned lines, together with two lines which are tentatively identified as  $s^2p\ ^2P-s^25d\ ^2D$ , are listed in Table XII. Term values given there are adjusted to fit Bowen's Table VI.

Two additional multiplets in chlorine VI have now been identified. Classifications and term values are given in Table XIII. We wish to take this opportunity to point out a typographical error in Table V of a previous report on magnesium-like spectra.<sup>13</sup> The term value for  $sp^2\ ^3P_0$  of Cl VI should read 136,813 instead of 136,713.

<sup>12</sup> I. S. Bowen, Phys. Rev. **45**, 401 (1934).

<sup>13</sup> W. L. Parker and L. W. Phillips, Phys. Rev. **57**, 140 (1940).