The Spectra of Argon in the Extreme Ultraviolet

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The term tables of A II, A III and A IV have been revised or extended upon the basis of new wavelength measurements in the extreme ultraviolet. A few lines of A I previously known have been remeasured. In the other stages the known lines have been remeasured and new lines added as follows: 23 in A II, 57 in A III, 23 (including some intersystem combinations) in A IV, and 10 in A V (where none were previously known). These results confirm the identification of the nebular lines λ4711.4 and λ4740.2 as due to "forbidden" transitions in A IV. The intervals in possible pairs of "forbidden" lines from A III and A V are discussed. Accurate ionization potentials are given, 15.69 volts for A I, 27.80 volts for A II and 40.78 volts for A III, while rough estimates yield 61 volts for A IV and 78 volts for A V.

THE spectra of argon in the extreme ultraviolet have been investigated by Lyman and Saunders,[1] Hertz and Abbink,[2] Saunders,[3] Hopfield and Dieke,[4] Dorgelo and Abbink,[5] Saunders,[6] Compton, Boyce and Russell,[7] Boyce and Compton,[8] and von Keussler.[9] Increased dispersion and resolving power have now been made possible by the two-meter normal incidence vacuum spectrograph[10] of the Carnegie Institution of Washington which is located in the Spectroscopy Laboratory of the Massachusetts Institute of Technology. Exposures made with an electrodeless discharge at different gas pressures distinguished between the spectra of the various stages of ionization. Traces of oxygen were present as an impurity and an examination of the group of lines of O II and O III near λ834 was a very convenient method of estimating the excitation of a particular exposure. The principal group of lines was already known for all of the spectra investigated except A V. The plates were measured by Dr. Carol A. Rieke and Mr. D. H. Clewell, both of whom it is a pleasure to thank for their careful work and for their assistance in the reduction of the measurements. The method of reduction has been given in the description of the instrument[10] and in the discussion of the results for neon.[11] The standards used have recently been published.[12] Wavelengths given to three decimal places are believed to be accurate to somewhat less than 0.01A. For those less certainly determined the error may be as great as 0.02A and such lines are given to two decimal places. Lines newly or differently identified in the present investigation are denoted by an asterisk.

A I

The electrodeless discharge is not particularly suitable for the excitation of first spectra. Only two lines were obtained with sufficient intensity to permit precise measurement. Four weak lines were also present. The lines are listed in Table I with term designations taken from the tables of Bacher and Goudsmit.[13] A few of the term values

TABLE I. *A I classified lines.*

λ(OBS.)	INT. SPARK	INT. ARC	ν	λ(CALC.)	CLASSIFICATION
1066.660	9	15	93750.0		$^1S_0-4s\ 2_1°$
1048.218	8	25	95400.0		$^1S_0-4s\ 4_1°$
894.30	1	4	111820	894.310	$^1S_0-3d\ 2_1°$
		3		879.949	$^1S_0-5s\ 2_1°$
876.06	2	4	114148	876.063	$^1S_0-3d\ 8_1°$
869.75	1	2	114975	869.754	$^1S_0-5s\ 4_1°$
866.80	3	4	115367	866.805	$^1S_0-3d\ 12_1°$
		2		842.808	$^1S_0-4d\ 2_1°$
		6 {		835.003	$^1S_0-6s\ 2_1°$
				834.397	$^1S_0-4d\ 8_1°$
		2		826.371	$^1S_0-4d\ 12_1°$
		1		825.348	$^1S_0-6s\ 4_1°$
		0		820.129	$^1S_0-5d\ 2_1°$
		4 {		816.466	$^1S_0-7s\ 2_1°$
				816.233	$^1S_0-5d\ 8_1°$
				809.933	$^1S_0-6d\ 2_1°$
		2d {		807.702	$^1S_0-5d\ 12_1°$
				807.220	{ $^1S_0-8s\ 2_1°$; $^1S_0-7s\ 4_1°$
				806.875	$^1S_0-6d\ 8_1°$

[1] T. Lyman and F. A. Saunders, Nature **116**, 358 (1925).
[2] G. Hertz and J. H. Abbink, Naturwiss. **14**, 648 (1926).
[3] F. A. Saunders, Proc. Nat. Acad. Sci. **12**, 556 (1926).
[4] J. J. Hopfield and G. H. Dieke, Phys. Rev. **27**, 638 (1926).
[5] H. B. Dorgelo and J. H. Abbink, Zeits. f. Physik **41**, 753 (1927).
[6] F. A. Saunders, Proc. Nat. Acad. Sci. **13**, 596 (1927).
[7] K. T. Compton, J. C. Boyce and H. N. Russell, Phys. Rev. **32**, 179 (1928).
[8] J. C. Boyce and K. T. Compton, Proc. Nat. Acad. Sci. **15**, 656 (1929).
[9] V. von Keussler, Zeits. f. Physik **84**, 42 (1933).
[10] K. T. Compton and J. C. Boyce, Rev. Sci. Inst. **5**, 218 (1934).
[11] J. C. Boyce, Phys. Rev. **46**, 378 (1934).
[12] J. C. Boyce and C. A. Rieke, Phys. Rev. **47**, 653 (1935).
[13] R. F. Bacher and S. Goudsmit, *Atomic Energy States*, (McGraw-Hill, 1932).

given by Bacher and Goudsmit have been revised by Meggers and Humphreys.[14] On the basis of the present results the lowest state, $(3s)^2(3p)^6\ ^1S_0$, should be revised to read 127,111 cm^{-1} as referred to the $(3s)^2(3p)^5\ ^2P_{1\frac{1}{2}}°$ limit. The ionization potential remains 15.69 volts.

Discharges in mixtures with argon are frequently used in the excitation of molecular spectra. Since no accurate measurements were previously available it seemed worth while to compute the wavelengths for some additional lines. This has been done by using the ground state as here revised and for the upper states the values of Meggers and Humphreys.[14] Intensities designated "spark" represent those of the present electrodeless discharge. Those designated "arc" are taken from the earlier observations of Compton, Boyce and Russell[7] for excitation by controlled electron impact.[15]

A II

The second spectrum has been analyzed by de Bruin[16, 17] and by Compton, Boyce and Russell.[7] An extensive term table has been given by de Bruin.[17] The data from the extreme ultraviolet are with one exception very consistent with the values given by de Bruin for the even terms. Combinations between the ground state $(3s)^2(3p)^5\ ^2P_{1\frac{1}{2},\frac{1}{2}}°$ and de Bruin's $(^1D)3d\ ^2P_{\frac{1}{2}}$ do not occur. There are two lines in the extreme ultraviolet indicating combination with a term 14 cm^{-1} deeper in the atom. De Bruin's $(^1D)3d\ ^2P_{\frac{1}{2}}$ term seems to depend on only two lines in the visible spectrum, of which one is a poor fit and the other comes from a high odd term the validity of which is about to be questioned. It therefore seems reasonable to reject de Bruin's identification of this term and tentatively to substitute the value indicated from the extreme ultraviolet, although it has not been possible to find definite combinations with higher odd terms among the lines of argon observed by Rosenthal.[18] Examination of the configuration assignments given by de Bruin revealed the fact that two groups of his term values were not consistent with any reasonable estimate of the relative positions of the ^3P, ^1D and ^1S states arising from the $(3s)^2(3p)^4$ electron configuration of A III. These states constitute the limits upon which the terms of A II are built. One of these inconsistent groups is the set of five ^2D terms marked by de Bruin $(^3P)3d$, $(^3P)4d$, $(^1D)4s$, $(^1D)5s$, $(^1S)3d$. A reassignment in a different order of these ^2D terms among the same electron configurations has been found which is satisfactory. Additional evidence in favor of the new assignment came from the intensities of the extreme ultraviolet lines associated with these terms, since in the present type of excitation second series members are expected to be considerably weakened. The $^2F°$, $^2D°$ and $^2P°$ terms assigned by de Bruin to $(^1D)5p$ were questioned on the same grounds of incompatibility with their limit. It seems very likely that the first two of these terms came from the $(^3P)4f$ configuration and that the $^2P°$ term may be a fragment of an associated quartet term or may be spurious. Some of the evidence in support of the reality of this $^2P°$ term, apart from its exact designation, came from a visible combination with the $(^1D)3d\ ^2P_{\frac{1}{2}}$ term already questioned. The complete solution of these difficulties requires further investigation. The classified lines given in Table II locate the $(3s)^2(3p)^5\ ^2P_{1\frac{1}{2}}°$ term at 224,755.5 on de Bruin's scale. In Table III term values are given with respect to this ground term as zero. Changes indicated in the discussion above have been made in the term identifications and in one case in the term value and the dubious high $^2P°$ term has been omitted. Evaluation by a Ritz formula of the series limit of the $^4P_{2\frac{1}{2}}$ terms arising from 4s, 5s and 6s electron places that limit, the $(3s)^2(3p)^4\ ^3P_2$ state of A III, at 225,168 cm^{-1} above the ground state of A II. This corresponds to an ionization potential of 27.80 ± 0.02 volts for A II.

A III

The first multiplet in the third spectrum was discovered by Hopfield and Dieke.[4] More recent work by von Keussler[9] and by de Bruin[19] have given three term systems, quintets and triplets

[14] W. F. Meggers and C. J. Humphreys, Bur. Standards J. Research **10**, 427 (1933); W. F. Meggers, ibid. **14**, 487 (1935).

[15] K. T. Compton and J. C. Boyce, J. Frank. Inst. **205**, 497 (1928).

[16] T. L. de Bruin, Zeits. f. Physik **48**, 62 (1928); **51**, 108 (1928).

[17] T. L. de Bruin, Zeits. f. Physik **61**, 307 (1930).

[18] A. H. Rosenthal, Ann. d. Physik (5) **4**, 49 (1930).

[19] T. L. de Bruin, Proc. Amst. Acad. **36**, 724 (1933).

TABLE II. *A II classified lines.*

λ	INT.	ν	CLASSIFICATION	λ	INT.	ν	CLASSIFICATION
*1973.48	1	50671.8	$s\,p^6\,{}^2S_{\frac{1}{2}}-({}^3P)4p\,{}^2D_{1\frac{1}{2}}^{\circ}$	573.360	6	174411	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^1D)3d\,{}^2P_{1\frac{1}{2}}$
*1961.356	2	50985.1	$s\,p^6\,{}^2S_{\frac{1}{2}}-({}^3P)4p\,{}^2P_{\frac{1}{2}}^{\circ}$	572.015	5	174820	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^1D)3d\,{}^2P_{\frac{1}{2}}$
*1941.062	2	51518.2	$s\,p^6\,{}^2S_{\frac{1}{2}}-({}^3P)4p\,{}^2P_{1\frac{1}{2}}^{\circ}$	560.224	7	178500	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-a\,{}^2P_{\frac{1}{2}}$
*1909.58	1	52367.7	$s\,p^6\,{}^2S_{\frac{1}{2}}-({}^3P)4p\,{}^2S_{\frac{1}{2}}^{\circ}$	556.813	6	179594	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-a\,{}^2P_{1\frac{1}{2}}$
*1574.985	4	63492.7	$s\,p^6\,{}^2S_{\frac{1}{2}}-({}^1D)4p\,{}^2P_{1\frac{1}{2}}^{\circ}$	*553.122	1	180791	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)5s\,{}^4P_{1\frac{1}{2}}$
*1560.188	3	64094.8	$s\,p^6\,{}^2S_{\frac{1}{2}}-({}^1D)4p\,{}^2P_{\frac{1}{2}}^{\circ}$	*550.899	1	181521	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)5s\,{}^4P_{\frac{1}{2}}$
932.046	10	107291	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-s\,p^6\,{}^2S_{\frac{1}{2}}$	*550.475	2	181661	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)5s\,{}^2P_{1\frac{1}{2}}$
919.78	15	108722	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-s\,p^6\,{}^2S_{\frac{1}{2}}$	548.779	4	182223	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)5s\,{}^4P_{1\frac{1}{2}}$
762.192	2	131201	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)3d\,{}^4D_{1\frac{1}{2}}$	*547.983	1	182487	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)5s\,{}^2P_{\frac{1}{2}}$
754.817	3	132482	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)3d\,{}^4D_{2\frac{1}{2}}$	547.460	4	182662	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^1D)3d\,{}^2S_{\frac{1}{2}}$
748.193	4	133655	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)4s\,{}^4P_{1\frac{1}{2}}$	*547.164	3	182761	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)4d\,{}^4D_{\frac{1}{2}}$
*745.318	5	134171	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)4s\,{}^4P_{\frac{1}{2}}$	546.176	4	183091	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)5s\,{}^2P_{1\frac{1}{2}}$
*744.920	5	134243	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)4s\,{}^4P_{2\frac{1}{2}}$	543.727	3	183916	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)5s\,{}^2P_{\frac{1}{2}}$
740.263	12	135087	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)4s\,{}^4P_{1\frac{1}{2}}$	543.201	4	184094	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^1D)3d\,{}^2S_{\frac{1}{2}}$
*737.442	1	135604	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)4s\,{}^4P_{\frac{1}{2}}$	*542.910	3	184193	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)4d\,{}^4D_{\frac{1}{2}}$
730.929	8	136812	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)4s\,{}^2P_{1\frac{1}{2}}$	541.304	1	184739	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)4d\,{}^4P_{\frac{1}{2}}$
725.542	9	137828	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)4s\,{}^2P_{\frac{1}{2}}$	537.13	3	186173	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)4d\,{}^4P_{\frac{1}{2}}$
723.353	14	138245	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)4s\,{}^2P_{1\frac{1}{2}}$	*535.035	1	186893	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)4d\,{}^4P_{2\frac{1}{2}}$
718.083	4	139260	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)4s\,{}^2P_{\frac{1}{2}}$	530.489	4	188505	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)4d\,{}^2P_{\frac{1}{2}}$
704.516	3	141941	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)3d\,{}^4F_{1\frac{1}{2}}$	*528.640	2	189165	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)4d\,{}^2P_{1\frac{1}{2}}$
698.760	4	143111	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)3d\,{}^4F_{2\frac{1}{2}}$	526.495	3	189935	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)4d\,{}^2P_{\frac{1}{2}}$
697.944	1	143278	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)3d\,{}^2P_{\frac{1}{2}}$	524.678	4	190593	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)4d\,{}^2P_{1\frac{1}{2}}$
697.484	2	143372	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)3d\,{}^4F_{1\frac{1}{2}}$	*522.791	4	191281	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^1S)3d\,{}^2D_{1\frac{1}{2}}$
693.295	2	144239	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)3d\,{}^2P_{1\frac{1}{2}}$	*519.326	6	192557	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^1S)3d\,{}^2D_{2\frac{1}{2}}$
691.030	1	144711	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)3d\,{}^2P_{\frac{1}{2}}$	*518.89	2	192718	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^1S)3d\,{}^2D_{1\frac{1}{2}}$
686.50	1	145667	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)3d\,{}^2P_{1\frac{1}{2}}$	*514.301	2	194438	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^1D)5s\,{}^2D_{1\frac{1}{2}}$
*679.410	8	147186	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)3d\,{}^2D_{1\frac{1}{2}}$	*510.550	3	195867	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^1D)5s\,{}^2D_{2\frac{1}{2},\,1\frac{1}{2}}$
*672.849	3	148622	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)3d\,{}^2D_{1\frac{1}{2}}$	*505.007	1	198017	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^1D)4d\,{}^2P_{\frac{1}{2}}$
*671.854	10	148842	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)3d\,{}^2D_{2\frac{1}{2}}$	*504.80	1	198099	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^1D)4d\,{}^2D_{1\frac{1}{2}}$
*670.947	10	149043	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^1D)4s\,{}^2D_{1\frac{1}{2}}$	503.642	2	198554	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^1D)4d\,{}^2P_{1\frac{1}{2}}$
666.014	10	150147	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)3d\,{}^2F_{2\frac{1}{2}}$	502.164	2	199138	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)6s\,{}^4P_{1\frac{1}{2}}$
*664.558	6	150476	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^1D)4s\,{}^2D_{1\frac{1}{2}}$	502.01	1	199198	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^3P)6s\,{}^2P_{\frac{1}{2}}$
*661.868	15	151088	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^1D)4s\,{}^2D_{2\frac{1}{2}}$	*501.40	1	199442	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^1D)4d\,{}^2P_{\frac{1}{2}}$
602.854	4	165878	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^1S)4s\,{}^2S_{\frac{1}{2}}$	*501.185	2	199527	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^1D)4d\,{}^2D_{1\frac{1}{2}}$
597.695	5	167309	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^1S)4s\,{}^2S_{\frac{1}{2}}$	*500.800	1	199680	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^1D)4d\,{}^2D_{2\frac{1}{2}}$
583.437	8	171398	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^1D)3d\,{}^2D_{1\frac{1}{2}}$	*499.92	1	200032	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)6s\,{}^2P_{1\frac{1}{2}}$
580.261	8	172335	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^1D)3d\,{}^2D_{2\frac{1}{2}}$	489.191	3	204419	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)5d\,{}^2P_{1\frac{1}{2}}$
578.605	4	172830	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^1D)3d\,{}^2D_{1\frac{1}{2}}$	*488.95	1	204518	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)5d\,{}^2P_{\frac{1}{2}}$
578.107	4	172978	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^1D)3d\,{}^2P_{1\frac{1}{2}}$	488.786	3	204588	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^3P)5d\,{}^2D_{2\frac{1}{2}}$
576.731	5	173391	$s^2p^5\,{}^2P_{\frac{1}{2}}^{\circ}-({}^1D)3d\,{}^2P_{\frac{1}{2}}$	487.227	2	205243	$s^2p^5\,{}^2P_{1\frac{1}{2}}^{\circ}-({}^1D)4d\,{}^2S_{\frac{1}{2}}$

based on the $({}^4S^{\circ})$ state of A IV and triplets based on the $({}^2D^{\circ})$ state of that ion. No quintet to triplet intercombinations were known and the connection between the two triplet systems rested on one group of lines in the region of λ512. In the present investigation the quintet system has been related to the ground triplet state by two multiplets and an additional connection between the two triplet systems has been found. All classified lines for A III are given in Table IV. The three term systems of de Bruin have been reduced to the common zero of Table V, the ground $(3s)^2(3p)^4\,{}^3P_2$ state of the atom, and the error between systems is believed to be less than 1 cm^{-1}. In the system of triplets based on $({}^4S^{\circ})$ the $3d\,{}^3D^{\circ}$ has been added with certainty. Tentative identifications are given for $3d\,{}^3D^{\circ}$ and $3d\,{}^3P^{\circ}$ based on $({}^2D^{\circ})$ and for $3d\,{}^3D^{\circ}$, $3d\,{}^3F^{\circ}$ and $3d\,{}^3P^{\circ}$ based on $({}^2P^{\circ})$. These tentative identifications rest on extreme ultraviolet combinations with the ground state and have not yet been confirmed by combinations with higher even terms. They seem consistent with such isoelectronic data[20] as are available and with the position of the limits as known from A IV. Isoelectronic data and the limit assignments in A II as here revised suggest that the $(3s)^2(3p)^4$ term lies about 14,000 cm^{-1} above the ground $(3s)^2(3p)^4\,{}^3P$ term. Two strong single lines, of proper excitation for A III, are believed to be $(3s)^2(3p)^4\,{}^1D_2-3s(3p)^5\,{}^1P_1^{\circ}$ and $(3s)^2(3p)^4\,{}^1S_0-3s(3p)^5\,{}^1P_1^{\circ}$ combinations and fix two other singlet terms with reference to this assumed value for the $(3s)^2(3p)^4\,{}^1D_2$. Two additional terms are tentatively suggested, but the whole singlet system floats with an uncertainty of several hundred inverse centimeters until triplet singlet intercombinations can be found. The same information could be obtained if the "forbidden" pair ${}^3P_2-{}^1D_2$, ${}^3P_1-{}^1D_2$ could be found in nebular spectra. Bowen has estimated the approximate position of these lines[21] in the near infrared and their separation must be 1112.4 ± 1.0 cm^{-1}. The line at λ508.615, not resolved in this investigation, was resolved by von Keussler[9] into two

[20] *S I.*: R. Frerichs, Zeits. f. Physik **80**, 150 (1933); J. E. Reudy, Phys. Rev. **44**, 757 (1933). *Cl II.*: I. S. Bowen, Phys. Rev. **31**, 34 (1928); K. Murakawa, Zeits. f. Physik **69**, 507 (1931). *K IV, Ca V.*: I. S. Bowen, Phys. Rev. **46**, 791 (1934).

[21] I. S. Bowen, Astrophys. J. **81**, 1 (1935).

Table III. *A II term values.*

$(3s)^2(3p)^5\ ^2P_{1\frac{1}{2}}^{\circ}$ 0.0 $\quad 3s(3p)^6\ ^2S_{\frac{1}{2}}$ 108722.5
$^2P_{\frac{1}{2}}^{\circ}$ 1432.0

Limits in A III $(3s)^2(3p)^4$	$^3P_2$ 0.0 $^3P_1$ 1112.4 $^3P_0$ 1570.2				$^1D_2$ 14000		$^1S_0$ 31863	
3d	$^4D_{3\frac{1}{2}}$	132328.22	$^2D_{1\frac{1}{2}}$	148621.14	^2G		$^2D_{2\frac{1}{2}}$	192557.81
	$^4D_{2\frac{1}{2}}$	132482.20	$^2D_{2\frac{1}{2}}$	148843.49	^2G		$^2D_{1\frac{1}{2}}$	192712.93
	$^4D_{1\frac{1}{2}}$	132631.82			$^2F_{3\frac{1}{2}}$			
	$^4D_{\frac{1}{2}}$	132738.85			$^2F_{2\frac{1}{2}}$	171110.79		
	$^4F_{4\frac{1}{2}}$	142187.42	$^2F_{3\frac{1}{2}}$	149494.74?	$^2D_{2\frac{1}{2}}$	172336.42		
	$^4F_{3\frac{1}{2}}$	142718.01	$^2F_{2\frac{1}{2}}$	150148.63	$^2D_{1\frac{1}{2}}$	172830.97		
	$^4F_{2\frac{1}{2}}$	143108.63			$^2P_{1\frac{1}{2}}$	174410.84		
	$^4F_{1\frac{1}{2}}$	143372.48			$^2P_{\frac{1}{2}}$	174821?		
	$^4P_{2\frac{1}{2}}$	144495.24	$^2P_{\frac{1}{2}}$	144711.00	$^2S_{\frac{1}{2}}$	184094.10		
	$^4P_{1\frac{1}{2}}$	144986.79	$^2P_{1\frac{1}{2}}$	145669.91				
	$^4P_{\frac{1}{2}}$	145212.44						
4s	$^4P_{2\frac{1}{2}}$	134242.62	$^2P_{1\frac{1}{2}}$	138244.62	$^2D_{1\frac{1}{2}}$	150475.92	$^2S_{\frac{1}{2}}$	167308.66
	$^4P_{1\frac{1}{2}}$	135087.02	$^2P_{\frac{1}{2}}$	139259.36	$^2D_{2\frac{1}{2}}$	151088.35		
	$^4P_{\frac{1}{2}}$	135602.78						
4p	$^4P_{2\frac{1}{2}}^{\circ}$	155044.37	$^2P_{\frac{1}{2}}^{\circ}$	159707.52	$^2F_{2\frac{1}{2}}^{\circ}$	170401.88	$^2P_{1\frac{1}{2}}^{\circ}$	191975.16
	$^4P_{1\frac{1}{2}}^{\circ}$	155352.12	$^2P_{1\frac{1}{2}}^{\circ}$	160240.48	$^2F_{3\frac{1}{2}}^{\circ}$	170531.29	$^2P_{\frac{1}{2}}^{\circ}$	192334.09
	$^4P_{\frac{1}{2}}^{\circ}$	155705.42						
	$^4D_{3\frac{1}{2}}^{\circ}$	157234.92	$^2D_{2\frac{1}{2}}^{\circ}$	158731.22	$^2P_{1\frac{1}{2}}^{\circ}$	172214.80		
	$^4D_{2\frac{1}{2}}^{\circ}$	157674.28	$^2D_{1\frac{1}{2}}^{\circ}$	159394.31	$^2P_{\frac{1}{2}}^{\circ}$	172817.30		
	$^4D_{1\frac{1}{2}}^{\circ}$	158168.85			$^2D_{1\frac{1}{2}}^{\circ}$	173348.78		
	$^4D_{\frac{1}{2}}^{\circ}$	158429.17			$^2D_{2\frac{1}{2}}^{\circ}$	173394.43		
	$^4S_{1\frac{1}{2}}^{\circ}$	161049.90	$^2S_{\frac{1}{2}}^{\circ}$	161090.42				
4d	$^4D_{3\frac{1}{2}}$	183676.42	$^2D_{2\frac{1}{2}}$	186728.50	$^2G_{3\frac{1}{2}}$	198595.91	^2D	
	$^4D_{2\frac{1}{2}}$	183798.22	$^2D_{1\frac{1}{2}}$	186751.14	$^2G_{4\frac{1}{2}}$	198604.78	^2D	
	$^4D_{1\frac{1}{2}}$	183986.83			$^2P_{\frac{1}{2}}$	199447.56		
	$^4D_{\frac{1}{2}}$	184193.12			$^2P_{1\frac{1}{2}}$	199982.96		
	$^4F_{4\frac{1}{2}}$	185093.92	$^2F_{3\frac{1}{2}}$	186817.12	$^2D_{1\frac{1}{2}}$	199525.96		
	$^4F_{3\frac{1}{2}}$	185625.47	$^2F_{2\frac{1}{2}}$	187589.62	$^2D_{2\frac{1}{2}}$	199680.58		
	$^4F_{2\frac{1}{2}}$	186075.06			$^2F_{3\frac{1}{2}}$	200139.84		
	$^4F_{1\frac{1}{2}}$	186341.39			$^2F_{2\frac{1}{2}}$	200235.70		
	$^4P_{\frac{1}{2}}$	186172.32	$^2P_{\frac{1}{2}}$	189935.62				
	$^4P_{1\frac{1}{2}}$	186471.32	$^2P_{1\frac{1}{2}}$	190593.62	$^2S_{\frac{1}{2}}$	205243.96		
	$^4P_{2\frac{1}{2}}$	186891.92						
4f	$^4G^{\circ}$		$^2G^{\circ}$		$^2H^{\circ}$		$^2F^{\circ}$	
	$^4G^{\circ}$		$^2G^{\circ}$		$^2H^{\circ}$		$^2F^{\circ}$	
	$^4G^{\circ}$				$^2G^{\circ}$			
	$^4G^{\circ}$				$^2G^{\circ}$			
	$^4F^{\circ}$		$^2F_{2\frac{1}{2}}^{\circ}$	194842.37?	$^2F^{\circ}$			
	$^4F^{\circ}$		$^2F_{3\frac{1}{2}}^{\circ}$	194883.98?	$^2F^{\circ}$			
	$^4F^{\circ}$				$^2D^{\circ}$			
	$^4F^{\circ}$				$^2D^{\circ}$			
	$^4D^{\circ}$		$^2D_{1\frac{1}{2}}^{\circ}$	196622.78	$^2P^{\circ}$			
	$^4D^{\circ}$		$^2D_{2\frac{1}{2}}^{\circ}$	196634.04	$^2P^{\circ}$			
	$^4D^{\circ}$							
	$^4D^{\circ}$							
5s	$^4P_{2\frac{1}{2}}$	181595.12	$^2P_{1\frac{1}{2}}$	183091.32	$^2D_{2\frac{1}{2}}$	195865.61	$^2S_{\frac{1}{2}}$	
	$^4P_{1\frac{1}{2}}$	182222.88	$^2P_{\frac{1}{2}}$	183915.32	$^2D_{1\frac{1}{2}}$	195867.68		
	$^4P_{\frac{1}{2}}$	182952.02						
5p	$^4P_{2\frac{1}{2}}^{\circ}$	189160.21	$^2P_{1\frac{1}{2}}^{\circ}$	190106.84	$^2F^{\circ}$		$^2P^{\circ}$	
	$^4P_{1\frac{1}{2}}^{\circ}$	189411.40	$^2P_{\frac{1}{2}}^{\circ}$	190196.80	$^2F^{\circ}$		$^2P^{\circ}$	
	$^4P_{\frac{1}{2}}^{\circ}$	189700.30			$^2D^{\circ}$			
	$^4D_{3\frac{1}{2}}^{\circ}$	189986.00	$^2D_{2\frac{1}{2}}^{\circ}$		$^2D^{\circ}$			
	$^4D_{2\frac{1}{2}}^{\circ}$	190369.07	$^2D_{1\frac{1}{2}}^{\circ}$	190528.00	$^2P^{\circ}$			
	$^4D_{1\frac{1}{2}}^{\circ}$	190774.08			$^2P^{\circ}$			
	$^4D_{\frac{1}{2}}^{\circ}$	191264.06						
	$^4S_{1\frac{1}{2}}^{\circ}$		$^2S_{\frac{1}{2}}^{\circ}$	191708.46				
5d	^4D		$^2D_{2\frac{1}{2}}$	204586.40	^2G		^2D	
	^4D		$^2D_{1\frac{1}{2}}$		^2G		^2D	
	^4D				^2F			
	^4D				^2F			
	^4F		^2F		^2D			
	^4F		^2F		^2D			
	^4F				^2P			
	^4F				^2P			
	^4P		$^2P_{1\frac{1}{2}}$	204418.50				
	^4P		$^2P_{\frac{1}{2}}$	204515.81	$^2S_{\frac{1}{2}}$			
	^4P							
6s	$^4P_{2\frac{1}{2}}$	198813.17	$^2P_{1\frac{1}{2}}$	200032.65	^2D		$^2S_{\frac{1}{2}}$	
	$^4P_{1\frac{1}{2}}$	199138.92	$^2P_{\frac{1}{2}}$	200624.00	^2D			
	$^4P_{\frac{1}{2}}$	200111.16						

TABLE IV. *A III classified lines.*

λ	Int.	ν	Classification
1973.780	4	50664.2	$(^4S)4s\ ^3S_1^\circ - (^2D)4p\ ^3P_2$
1962.74	2	50949.3	$(^4S)4s\ ^3S_1^\circ - (^2D)4p\ ^3P_1$
1957.83	1	51076.9	$(^4S)4s\ ^3S_1^\circ - (^2D)4p\ ^3P_0$
*1919.515	4	52096.8	$(^4S)3d\ ^3D_1^\circ - (^4S)4p\ ^3P_1$
*1918.667	4	52119.5	$(^4S)3d\ ^3D_1^\circ - (^4S)4p\ ^3P_2$
*1918.06	1	52135.8	$(^4S)3d\ ^3D_1^\circ - (^4S)4p\ ^3P_0$
*1915.564	7	52203.9	$(^4S)3d\ ^3D_2^\circ - (^4S)4p\ ^3P_1$
*1914.653	3	52228.8	$(^4S)3d\ ^3D_2^\circ - (^4S)4p\ ^3P_2$
*1914.398	9	52235.7	$(^4S)3d\ ^3D_3^\circ - (^4S)4p\ ^3P_2$
1675.637	4	59678.8	$(^4S)3d\ ^5D_2^\circ - (^4S)4p\ ^5P_1$
1675.484	7	59684.2	$(^4S)3d\ ^5D_{01}^\circ - (^4S)4p\ ^5P_1$
1673.425	7	59757.7	$(^4S)3d\ ^5D_3^\circ - (^4S)4p\ ^5P_2$
1673.241	3	59764.2	$(^4S)3d\ ^5D_2^\circ - (^4S)4p\ ^5P_2$
1673.14	1	59767.9	$(^4S)3d\ ^5D_1^\circ - (^4S)4p\ ^5P_2$
1669.671	7	59892.0	$(^4S)3d\ ^5D_4^\circ - (^4S)4p\ ^5P_3$
1669.304	5	59905.2	$(^4S)3d\ ^5D_3^\circ - (^4S)4p\ ^5P_3$
1669.10	1	59912.6	$(^4S)3d\ ^5D_2^\circ - (^4S)4p\ ^5P_3$
*1468.006	2	68119.6	$(^4S)3d\ ^3D_1^\circ - (^2D)4p\ ^3D_2$
*1467.841	3	68127.3	$(^4S)3d\ ^3D_1^\circ - (^2D)4p\ ^3D_1$
*1465.712	3	68226.2	$(^4S)3d\ ^3D_2^\circ - (^2D)4p\ ^3D_2$
*1465.532	2	68234.6	$(^4S)3d\ ^3D_2^\circ - (^2D)4p\ ^3D_1$ $(^4S)3d\ ^3D_3^\circ - (^2D)4p\ ^3D_2$
*1460.234	2	68482.2	$(^4S)3d\ ^3D_2^\circ - (^2D)4p\ ^3D_3$
*1460.077	4	68489.5	$(^4S)3d\ ^3D_3^\circ - (^2D)4p\ ^3D_3$
887.404	10	112688.2	$s^2p^4\ ^3P_1 - sp^5\ ^3P_2^\circ$
883.179	9	113227.3	$s^2p^4\ ^3P_0 - sp^5\ ^3P_1^\circ$
879.622	8	113685.2	$s^2p^4\ ^3P_1 - sp^5\ ^3P_1^\circ$
878.728	12	113800.8	$s^2p^4\ ^3P_2 - sp^5\ ^3P_2^\circ$
875.534	9	114216.0	$s^2p^4\ ^3P_1 - sp^5\ ^3P_0^\circ$
871.099	10	114797.5	$s^2p^4\ ^3P_2 - sp^5\ ^3P_1^\circ$
*769.152	12	130013	$s^2p^4\ ^1S_0 - sp^5\ ^1P_1^\circ$
*697.74	2	143319	$s^2p^4\ ^3P_0 - (^4S)3d\ ^5D_1^\circ$
*695.537	6	143774	$s^2p^4\ ^3P_1 - (^4S)3d\ ^5D_{012}^\circ$
*690.170	8*d*	144892	$s^2p^4\ ^3P_2 - (^4S)3d\ ^5D_{123}^\circ$
*676.241	6	147876	$s^2p^4\ ^1D_2 - sp^5\ ^1P_1^\circ$
*643.256	9	155495	$s^2p^4\ ^3P_0 - (^4S)3d\ ^3D_1^\circ$
*641.808	12	155810	$s^2p^4\ ^3P_1 - (^4S)3d\ ^3D_2^\circ$
*641.364	5	155918	$s^2p^4\ ^3P_1 - (^4S)3d\ ^3D_1^\circ$
*637.282	20 bl	156916	$s^2p^4\ ^3P_2 - (^4S)3d\ ^3D_2^\circ$
*636.818	3	157031	$s^2p^4\ ^3P_2 - (^4S)3d\ ^3D_1^\circ$
*604.152	10	165521	$s^2p^4\ ^1D_2 - (^2D)3d\ ^1F_3^\circ$?
*577.153	3	173264	$s^2p^4\ ^3P_1 - (^4S)4s\ ^5S_2^\circ$
*573.468	4	174378	$s^2p^4\ ^3P_2 - (^4S)4s\ ^5S_2^\circ$
558.321	5	179109	$s^2p^4\ ^3P_0 - (^4S)4s\ ^3S_1^\circ$
556.893	6	179568	$s^2p^4\ ^3P_1 - (^4S)4s\ ^3S_1^\circ$
553.470	9	180678	$s^2p^4\ ^3P_2 - (^4S)4s\ ^3S_1^\circ$
*538.788	6	185602	$s^2p^4\ ^3P_0 - (^2D)3d\ ^3D_1^\circ$
*537.459	6	186061	$s^2p^4\ ^3P_1 - (^2D)3d\ ^3D_1^\circ$
*536.745	8	186308	$s^2p^4\ ^1D_2 - (^2D)4s\ ^1D_2^\circ$?
*535.580	7	186714	$s^2p^4\ ^3P_1 - (^2D)3d\ ^3D_2^\circ$
*534.26	1	187174	$s^2p^4\ ^3P_2 - (^2D)3d\ ^3D_1^\circ$
*532.413	7	187825	$s^2p^4\ ^3P_2 - (^2D)3d\ ^3D_2^\circ$
*529.900	9	188715	$s^2p^4\ ^3P_2 - (^2D)3d\ ^3D_3^\circ$
512.769	7	195020	$s^2p^4\ ^3P_0 - (^2D)4s\ ^3D_1^\circ$
511.565	7	195479	$s^2p^4\ ^3P_1 - (^2D)4s\ ^3D_1^\circ$
511.497	8	195504	$s^2p^4\ ^3P_1 - (^2D)4s\ ^3D_2^\circ$
508.615	6	196612	$s^2p^4\ ^3P_2 - (^2D)4s\ ^3D_{12}^\circ$
508.434	9	196682	$s^2p^4\ ^3P_2 - (^2D)4s\ ^3D_3^\circ$
*492.228	3	203158	$s^2p^4\ ^3P_0 - (^2P)3d\ ^3D_1^\circ$
*491.121	4	203620	$s^2p^4\ ^3P_1 - (^2P)3d\ ^3D_1^\circ$
*490.68	3	203799	$s^2p^4\ ^3P_1 - (^2P)3d\ ^3D_2^\circ$
*488.452	7	204728	$s^2p^4\ ^3P_2 - (^2P)3d\ ^3D_1^\circ$
*487.988	7	204923	$s^2p^4\ ^3P_2 - (^2P)3d\ ^3D_2^\circ$
*487.025	7	205331	$s^2p^4\ ^3P_2 - (^2D)3d\ ^3D_3^\circ$
*485.515	4	205967	$s^2p^4\ ^3P_0 - (^2D)3d\ ^3P_1^\circ$
*485.150	6	206122	$s^2p^4\ ^3P_1 - (^2D)3d\ ^3P_2^\circ$
*484.445	5	206422	$s^2p^4\ ^3P_1 - (^2D)3d\ ^3P_1^\circ$
*484.116	5	206562	$s^2p^4\ ^3P_1 - (^2D)3d\ ^3P_0^\circ$
*482.548	8	207233	$s^2p^4\ ^3P_2 - (^2D)3d\ ^3P_2^\circ$
*481.848	6	207534	$s^2p^4\ ^3P_2 - (^2D)3d\ ^3P_1^\circ$
*476.432	7	209894	$s^2p^4\ ^3P_1 - (^2P)3d\ ^3F_2^\circ$
*473.918	6	211011	$s^2p^4\ ^3P_2 - (^2P)3d\ ^3F_2^\circ$
*473.025	6	211405	$s^2p^4\ ^3P_2 - (^2P)3d\ ^3F_3^\circ$
*469.968	4	212780	$s^2p^4\ ^3P_0 - (^2P)3d\ ^3P_1^\circ$
*469.831	4	212842	$s^2p^4\ ^3P_1 - (^2P)3d\ ^3P_2^\circ$
*468.956	3	213240	$s^2p^4\ ^3P_1 - (^2P)3d\ ^3P_1^\circ$
*468.467	4	213462	$s^2p^4\ ^3P_1 - (^2P)3d\ ^3P_0^\circ$
*467.390	6	213945	$s^2p^4\ ^3P_2 - (^2P)3d\ ^3P_2^\circ$
*466.530	5	214349	$s^2p^4\ ^3P_2 - (^2P)3d\ ^3P_1^\circ$
*398.86	1	250714	$s^2p^4\ ^3P_2 - (^4S)5s\ ^5S_2^\circ$
*397.67	1	251466	$s^2p^4\ ^3P_1 - (^4S)5s\ ^3S_1^\circ$
*396.38	4	252288	$s^2p^4\ ^3P_2 - (^4S)4d\ ^3D_3^\circ$
*395.92	1	252576	$s^2p^4\ ^3P_2 - (^4S)5s\ ^3S_1^\circ$

TABLE V. *A III term values.* (Singlets based on assumed value 14,000 for $(3s)^2\ (3p)^4\ ^1D_2$.)

$(3s)^2\ (3p)^4\ ^3P_2$	0.0	$3s\ (3p)^5\ ^3P_2^\circ$	113800.7
$^3P_1$	1112.4	$^3P_1^\circ$	114797.6
$^3P_0$	1570.2	$^3P_0^\circ$	115328.4
$(3s)^2\ (3p)^4\ ^1D_2$	14000	$3s\ (3p)^5\ ^1P_1^\circ$	161876
$(3s)^2\ (3p)^4\ ^1S_0$	31863		

Limits in *A* IV $(3s)^2\ (3p)^3$	$^4S_{1\frac{1}{2}}^\circ$	0	$^2D_{1\frac{1}{2}}^\circ$	21090	$^2P_{\frac{1}{2}}^\circ$	34854
			$^2D_{2\frac{1}{2}}^\circ$	21219	$^2P_{1\frac{1}{2}}^\circ$	35034
3*d*	$^5D_0^\circ$		$^3F_4^\circ$	186404.45	$^3D_1^\circ$	204726
	$^5D_1^\circ$	144883.8	$^3F_3^\circ$	186660.50	$^3D_2^\circ$	204923
	$^5D_2^\circ$	144887.3	$^3F_2^\circ$	186905.35	$^3D_3^\circ$	205331
	$^5D_3^\circ$	144894.3	$^1F_3^\circ$	179521?	$^1D_2^\circ$	
	$^5D_4^\circ$	144907.8				
			$^3G^\circ$		$^3F_2^\circ$	211009
	$^3D_3^\circ$	156916	$^3G^\circ$		$^3F_3^\circ$	211405
	$^3D_2^\circ$	156923	$^3G^\circ$		$^3F_4^\circ$	
	$^3D_1^\circ$	157030				
			$^1G_4^\circ$		$^1F_3^\circ$	
			$^3D_1^\circ$	187173.42	$^3P_2^\circ$	213145
			$^3D_2^\circ$	187825.35	$^3P_1^\circ$	214350
			$^3D_3^\circ$	188716.35	$^3P_0^\circ$	214574
			$^1D_2^\circ$		$^1P_1^\circ$	
			$^3P_2^\circ$	207233		
			$^3P_1^\circ$	207534		
			$^3P_0^\circ$	207674		
			$^1P_1^\circ$			
4*s*	$^5S_2^\circ$	174375.00	$^3D_1^\circ$	196591.50	$^3P^\circ$	
			$^3D_2^\circ$	196616.21	$^3P^\circ$	
	$^3S_1^\circ$	180679.00	$^3D_3^\circ$	196682.10	$^3P^\circ$	
			$^1D_2^\circ$	200308?	$^1P_1^\circ$	
4*p*	$^5P_1$	204565.95	$^3D_2$	225150.23	^3D	
	$^5P_2$	204651.66	$^3D_1$	225157.48	^3D	
	$^5P_3$	204799.79	$^3D_3$	225404.89	^3D	
	$^3P_1$	209127.04	$^1D_2$		$^1D_2$	
	$^3P_2$	209151.82	$^3F_2$	226358.26	^3P	
	$^3P_0$	209166.35	$^3F_3$	226505.52	^3P	
			$^3F_4$	226648.36	^3P	
			$^1F_3$		$^1P_1$	
			$^3P_2$	231344.10	$^3S_1$	
			$^3P_1$	231628.59	$^1S_0$	
			$^3P_0$	231756.78		
			$^1P_1$			

Limits in *A* IV $(3s)^2\ (3p)^3$	$^4S_{1\frac{1}{2}}^\circ$	0	$^2D_{1\frac{1}{2}}^\circ$	21090	$^2P_{\frac{1}{2}}^\circ$	34824
			$^2D_{2\frac{1}{2}}^\circ$	21219	$^2P_{1\frac{1}{2}}^\circ$	35034
4*d*	$^5D_0^\circ$		$^3F_2^\circ$	266725.12	$^3F^\circ$	
	$^5D_1^\circ$	246029.76	$^3F_3^\circ$	266879.82	$^3F^\circ$	
	$^5D_2^\circ$	246033.79	$^3F_4^\circ$	267073.52	$^3F^\circ$	
	$^5D_3^\circ$	246036.64	$^1F_3^\circ$		$^1F_3^\circ$	
	$^5D_4^\circ$	246046.57				
			$^3G_3^\circ$	267784.40	$^3D^\circ$	
	$^3D_2^\circ$	252253.69	$^3G_4^\circ$	267835.50	$^3D^\circ$	
	$^3D_1^\circ$	252279.92	$^3G_5^\circ$	267898.12	$^3D^\circ$	
	$^3D_3^\circ$	252289.02				
			$^1G_4^\circ$		$^1D_2^\circ$	
			$^3D_1^\circ$	268981.10	$^3P^\circ$	
			$^3D_3^\circ$	269003.10	$^3P^\circ$	
			$^3D_2^\circ$	269015.10	$^3P^\circ$	
			$^1D_2^\circ$		$^1P_1^\circ$	
			$^3P_2^\circ$	271510.18		
			$^3P_1^\circ$	271674.38		
			$^3P_0^\circ$	271698.52		
			$^1P_1^\circ$			
			$^3S_1^\circ$	272070.75		
			$^1S_0^\circ$			
5*s*	$^5S_2^\circ$	250712.27	$^3D^\circ$	272130.12	$^3P^\circ$	
	$^3S_1^\circ$	252575.88	$^3D^\circ$	272190.46	$^3P^\circ$	
			$^3D^\circ$	272523.20	$^3P^\circ$	
			$^1D_2^\circ$		$^1P_1^\circ$	

components the wavelengths of which, when shifted slightly to fit the present scale, would be λ508.655 and λ508.595. Three lines given by von Keussler without identification at λ1843.19, λ1839.43 and λ1836.42 were also observed on the present plates and seem to be due to this stage of ionization of argon, but attempts to classify them have not been successful. Approximate estimates of series limits to the (${}^4S^\circ$) state of A IV can be made on the basis of two series of two members each, quintet and triplet terms from the 4*s* and 5*s* electronic states. These give 330,723 and 329,980, respectively. Pending the discovery of additional series members the value of 330,350 is adopted as a rounded mean. This corresponds to an ionization potential of 40.78 ± 0.05 volts.

A IV

Table VI gives the classified lines of this spectrum. The large discrepancy in wavelength in the one multiplet discovered by Boyce and Compton[8] has been traced to a clerical error in the preparation of the manuscript of that earlier paper. Intersystem combinations have been located by comparison with the unpublished results of H. A. Robinson on P I. These provide the connection between the doublet and quartet systems, so that all terms given in Table VII are on a common scale. Additional members expected to be strong in the intersystem multiplets would nearly coincide with adjacent strong hydrogen

TABLE VI. *A IV classified lines.*

λ	Int.	ν	Classification
*1197.84	1	83484	$s^2p^3\,{}^2P_{1\frac{1}{2}}^\circ - sp^4\,{}^4P_{1\frac{1}{2}}$
*1190.354	2	84009	$s^2p^3\,{}^2P_{1\frac{1}{2}}^\circ - sp^4\,{}^4P_{\frac{1}{2}}$
*1187.80	1	84190	$s^2p^3\,{}^2P_{\frac{1}{2}}^\circ - sp^4\,{}^4P_{\frac{1}{2}}$
*1037.931	1	96346	$s^2p^3\,{}^2D_{2\frac{1}{2}}^\circ - sp^4\,{}^4P_{2\frac{1}{2}}$
*901.804	2	110889	$s^2p^3\,{}^2P_{1\frac{1}{2}}^\circ - sp^4\,{}^2D_{1\frac{1}{2}}$
*901.168	9	110967	$s^2p^3\,{}^2P_{1\frac{1}{2}}^\circ - sp^4\,{}^2D_{2\frac{1}{2}}$
*900.362	5	111066	$s^2p^3\,{}^2P_{\frac{1}{2}}^\circ - sp^4\,{}^2D_{1\frac{1}{2}}$
850.602	25	117564	$s^2p^3\,{}^4S_{1\frac{1}{2}}^\circ - sp^4\,{}^4P_{2\frac{1}{2}}$
843.772	20	118515	$s^2p^3\,{}^4S_{1\frac{1}{2}}^\circ - sp^4\,{}^4P_{1\frac{1}{2}}$
840.029	15	119044	$s^2p^3\,{}^4S_{1\frac{1}{2}}^\circ - sp^4\,{}^4P_{\frac{1}{2}}$
*801.913	5	124702	$s^2p^3\,{}^2D_{2\frac{1}{2}}^\circ - sp^4\,{}^2D_{1\frac{1}{2}}$
*801.409	10	124780	$s^2p^3\,{}^2D_{2\frac{1}{2}}^\circ - sp^4\,{}^2D_{2\frac{1}{2}}$
*801.086	10	124831	$s^2p^3\,{}^2D_{1\frac{1}{2}}^\circ - sp^4\,{}^2D_{1\frac{1}{2}}$
*800.573	5	124911	$s^2p^3\,{}^2D_{1\frac{1}{2}}^\circ - sp^4\,{}^2D_{2\frac{1}{2}}$
*761.470	5	131325	$s^2p^3\,{}^2P_{1\frac{1}{2}}^\circ - sp^4\,{}^2P_{1\frac{1}{2}}$
*760.439	3	131503	$s^2p^3\,{}^2P_{\frac{1}{2}}^\circ - sp^4\,{}^2P_{1\frac{1}{2}}$
*755.212	3	132415	$s^2p^3\,{}^2P_{1\frac{1}{2}}^\circ - sp^4\,{}^2P_{\frac{1}{2}}$
*754.205	4	132590	$s^2p^3\,{}^2P_{\frac{1}{2}}^\circ - sp^4\,{}^2P_{\frac{1}{2}}$
*700.277	8	142801	$s^2p^3\,{}^2P_{1\frac{1}{2}}^\circ - sp^4\,{}^2S_{\frac{1}{2}}$
*699.408	6	142978	$s^2p^3\,{}^2P_{\frac{1}{2}}^\circ - sp^4\,{}^2S_{\frac{1}{2}}$
*689.007	12 bl	145136	$s^2p^3\,{}^2D_{2\frac{1}{2}}^\circ - sp^4\,{}^2P_{1\frac{1}{2}}$
*688.392	7	145266	$s^2p^3\,{}^2D_{1\frac{1}{2}}^\circ - sp^4\,{}^2P_{1\frac{1}{2}}$
*683.278	10	146353	$s^2p^3\,{}^2D_{1\frac{1}{2}}^\circ - sp^4\,{}^2P_{\frac{1}{2}}$
*399.634	3	250228	$s^2p^3\,{}^4S_{1\frac{1}{2}}^\circ - ({}^3P)4s\,{}^4P_{\frac{1}{2}}$
*398.546	4	250912	$s^2p^3\,{}^4S_{1\frac{1}{2}}^\circ - ({}^3P)4s\,{}^4P_{1\frac{1}{2}}$
*396.869	4	251972	$s^2p^3\,{}^4S_{1\frac{1}{2}}^\circ - ({}^3P)4s\,{}^4P_{2\frac{1}{2}}$

TABLE VII. *A IV term values.*

$(3s)^2\,(3p)^3$	${}^4S_{1\frac{1}{2}}^\circ$	0	$3s\,(3p)^4$	${}^2D_{1\frac{1}{2}}$	145921
				${}^2D_{2\frac{1}{2}}$	146000
$(3s)^2\,(3p)^3$	${}^2D_{1\frac{1}{2}}^\circ$	21090			
	${}^2D_{2\frac{1}{2}}^\circ$	21219	$3s\,(3p)^4$	${}^2P_{1\frac{1}{2}}$	166356
				${}^2P_{\frac{1}{2}}$	167444
$(3s)^2\,(3p)^3$	${}^2P_{\frac{1}{2}}^\circ$	34854			
	${}^2P_{1\frac{1}{2}}^\circ$	35035	$3s\,(3p)^4$	${}^2S_{\frac{1}{2}}$	177833
$3s\,(3p)^4$	${}^4P_{2\frac{1}{2}}$	117564	$({}^3P)\,4s$	${}^4P_{\frac{1}{2}}$	250229
	${}^4P_{1\frac{1}{2}}$	118515		${}^4P_{1\frac{1}{2}}$	250912
	${}^4P_{\frac{1}{2}}$	119044		${}^4P_{2\frac{1}{2}}$	251972

lines and are not observable. These results confirm the identification by Swings and Edlén,[22] and independently by Boyce, Mrs. Payne-Gaposchkin and Menzel[23] of the nebular lines λ4711.4 and λ4740.2[24] as due to the "forbidden" ${}^4S_{1\frac{1}{2}}^\circ - {}^2D_{2\frac{1}{2}}^\circ$ and ${}^4S_{1\frac{1}{2}}^\circ - {}^2D_{1\frac{1}{2}}^\circ$ transitions in A IV. No series have been found but a rough estimate based on the isoelectronic sequence yields 61 volts for the ionization potential.

A V

Two multiplets in this spectrum given in Table VIII have been identified among the fainter lines of high excitation. A number of these lines are unresolved or are blended with the ghosts of the strong oxygen group at λ834. The accuracy for the terms given in Table IX is therefore somewhat less than that for the other stages of ionization. Since this table gives the intervals within the ground $(3s)^2(3p)^2\,{}^3P$ state it is possible to predict the approximate interval between nebular "forbidden" lines due to A V. Bowen[21] has estimated the position where such a pair might be expected to be found, but observational data in the red and infrared are not yet extensive enough to test these predictions for

TABLE VIII. *A V classified lines.*

λ	Int.	ν	Classification
*836.13	2	119599	$s^2p^2\,{}^3P_2 - sp^3\,{}^3D_1^\circ$
*835.79	1	119647	$s^2p^2\,{}^3P_2 - sp^3\,{}^3D_2^\circ$
*834.88	4bl	119778	$s^2p^2\,{}^3P_2 - sp^3\,{}^3D_3^\circ$
*827.350	3	120868	$s^2p^2\,{}^3P_1 - sp^3\,{}^3D_1^\circ$
*827.052	5	120911	$s^2p^2\,{}^3P_1 - sp^3\,{}^3D_2^\circ$
*822.161	4	121631	$s^2p^2\,{}^3P_0 - sp^3\,{}^3D_1^\circ$
*715.65	3	139734	$s^2p^2\,{}^3P_2 - sp^3\,{}^3P_2^\circ$
*715.60	4	139743	$s^2p^2\,{}^3P_2 - sp^3\,{}^3P_{10}^\circ$
*709.197	5	141005	$s^2p^2\,{}^3P_1 - sp^3\,{}^3P_{210}^\circ$
*705.352	3	141773	$s^2p^2\,{}^3P_0 - sp^3\,{}^3P_1^\circ$

[22] P. Swings and B. Edlén, Comptes rendus **198**, 2071 (1934).

[23] J. C. Boyce, C. H. Payne-Gaposchkin and D. H. Menzel, Publ. Astron. Soc. Pacific **46**, 213 (1934).

[24] W. H. Wright, Publ. Lick Observatory **13**, 193 (1918).

TABLE IX. *A V term values.*

$(3s)^2\,(3p)^2\,{}^3P_0$	0	$3s\,(3p)^3\,{}^3D_1°$	121630
${}^3P_1$	764	${}^3D_2°$	121675
${}^3P_2$	2028	${}^3D_3°$	121806
		$3s\,(3p)^3\,{}^3P_2°$	141762
		${}^3P_{10}°$	141771

A V or for A III.[25] As in the previous spectrum only a rough estimate of the ionization potential may be made, the result of which is 78 volts. An isoelectronic sequence makes possible the prediction of the location of the principal multiplet of A VI and it is definitely absent from these spectrograms.

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[25] R. H. Stoy, Publ. Astron. Soc. Pacific **46**, 363 (1934).

Note added July 14, 1935: A recent publication by de Bruin[26] has just been received giving some extensions to his previous analysis of A III. The following terms are added: $(^2D)3d\,{}^3F°$, $(^2D)3d\,{}^3D°$, $(^2D)5s\,{}^3D°$. Table V has been revised to include these results. The first of these new terms gives no observed combination with the ground term of the atom. The second new term was already here identified tentatively as such, upon the basis of a multiplet in the extreme ultraviolet. The combination found by de Bruin now fixes its value more accurately. The discovery of the $(^2D)3d\,{}^3F°$ term by de Bruin may cast some doubt upon the tentative identification here given for its companion singlet term. De Bruin has discovered the $(^4S)4s\,{}^3S° - (^2D)4p\,{}^3P$ combination and so connects the groups of triplet terms based on the (^4S) and (^2D) limits. The connections here given are believed to be more accurate and they give a better fit with the wavelengths obtained in this laboratory for this new multiplet. Using de Bruin's identification but taking values of the wavelengths from the plates here investigated, these lines have now been added to Table IV.

[26] T. L. de Bruin, *Pieter Zeeman Jubilee Volume* (Martinus Nijhoff, The Hague, 1935), p. 413.

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Collisions of Alpha-Particles in Hydrogen

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Experiments on the projection of protons by alpha-particles from polonium are described. The variation of the yield of projected protons with alpha-particle velocity was determined and shows agreement with the Rutherford-Darwin law for low velocities, a smooth rise for higher velocities. No evidence of resonance effects was observed, although experiments were made with the aim of their detection. A discussion is given of the inhomogeneity of the alpha-particles from polonium sources and the limitation it imposes on the observable size of resonance effects.

THE first systematic investigation of the scattering of alpha-particles in hydrogen was undertaken by Chadwick and Bieler.[1] Aside from the angular distribution of the projected protons, they determined the yield of protons as a function of the speed of the incident alpha-particles and discovered the anomalous rise in the yield curve which is now regarded as the effect of the nuclear field. The minimum on the alpha-particle range scale, beyond which more profuse ejection of protons takes place, was determined by these investigations to occur at $R=2.0$ cm. For greater residual ranges of the alpha-particles

[1] Z. Chadwick and E. S. Bieler, Phil. Mag. **42**, 923 (1921).