the system $n\nu_3-\nu_2$; only the members $5\nu_3-\nu_2$ and $6\nu_3-\nu_2$ have been located. The system $n\nu_3-\nu_1$ may be expected to lie at approximately 921$\mu\mu$, 754$\mu\mu$, 644$\mu\mu$ and 566$\mu\mu$ for $n=5$, 6, 7 and 8, respectively.[6] $7\nu_3-\nu_1$ and $8\nu_3-\nu_1$ cannot be located in the spectra of the major planets. However, the spectra of Neptune and Uranus, where the bands $5\nu_3-\nu_1$ and $6\nu_3-\nu_1$ are most likely to be discovered, are unknown in this region.

We come finally to the group of bands $5\nu_3-\nu_4$, $6\nu_3-\nu_4$, $7\nu_3-\nu_4$ and $8\nu_3-\nu_4$, which may be expected to lie approximately at 802$\mu\mu$, 673$\mu\mu$, 584$\mu\mu$ and 519$\mu\mu$, respectively. The band $5\nu_3-\nu_4$ at 802$\mu\mu$ is very prominent in the spectrum of Jupiter. In Uranus and Neptune, $6\nu_3-\nu_4$ is hidden by the mass of absorption $5\nu_3+\nu_1$,[2] while $7\nu_3-\nu_4$ is definitely present at 584$\mu\mu$.[7]

It is evident that $n\nu_3-\nu_4$ is the strongest sequence with bands observable out to $n=7$: $n\nu_3-\nu_2$ is second, with n reaching to 6; while $n\nu_3-\nu_1$ is very weak and, thus far, completely unobserved in the planetary spectrum.[8]

The allocation of observed difference bands relative to the several planets is given in Fig. 2.

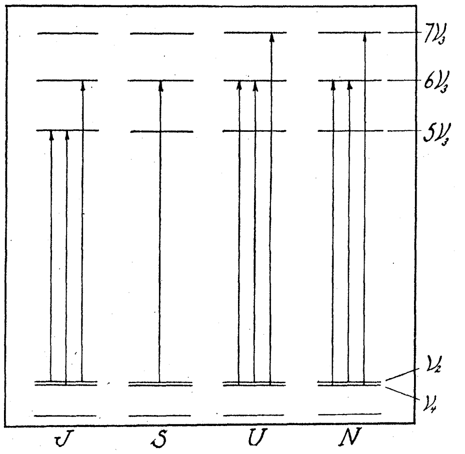

FIG. 2. Allocation of observed difference bands relative to the several planets.

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[6] The absorption bands 5, 6, 7 and $8\nu_3$ are centered at approximately 726$\mu\mu$, 619$\mu\mu$, 543$\mu\mu$ and 486$\mu\mu$, respectively.

[7] V. M. Slipher, Lowell Observatory Bulletin No. 13.

[8] The correlation of these five difference bands brings the total of identified methane bands in the major planet spectrum to forty-one.[1]

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Provisional Wavelength Standards for the Extreme Ultraviolet

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This paper discusses the criteria for suitable wavelength standards in the extreme ultraviolet, and presents provisional values (obtained with a two-meter focus normal incidence vacuum spectrograph) for a number of lines of C, N, O and A falling in the spectral range between λ1850 and λ800. These are compared with the previous results of Edlén and of Bowen and of Bowen and Ingram. Further independent determinations are desirable. The present values, as those obtained by previous investigators, may be subject to a small systematic error inherent in the method of overlapping orders. This source of error is believed to be small, but must be eliminated before permanent standards can be established.

THE report of the commission on standards of wavelength of the International Astronomical Union contains the following criteria for auxiliary standards: "It is recommended that the mean wavelengths of the lines in certain groups of lines which give high orders of interference, and are satisfactorily distributed in the spectrum, and have been referred to the primary standard by three observers whose measurements are in satisfactory agreement, be adopted as working standards."[1] Tertiary standards are further defined as those obtained by interpolation between these secondary standards. It is well known that no standards which come anywhere near meeting

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[1] Trans. Int. Astron. Union 1, 35 (1922).

TABLE I. *Hydrogen.*

λ Observed	Wt.	λ Computed[2]
1215.666	23*	**1215.664**
1025.725	9	**1025.717**
972.538	6	**972.532**
949.740	4	**949.739**
937.792	1	**937.799**

TABLE II. *Helium* (He II).

λ Computed[2]	λ Computed[2]
303.7788	**1640.409**
256.3145	**1215.129**
243.0244	**1084.940**
237.3297	**1025.270**
234.3452	**992.361**
	972.109
	958.696
	949.326

these requirements have ever been established for the vacuum region of the extreme ultraviolet. Neither have interferometric determinations been made nor have three investigators obtained satisfactory agreement by any other method. The purpose of the present paper is to present the best values the authors have been able to obtain by the method of overlapping orders, together with a statement of the limitations of that method. It is believed that these preliminary values are more dependable in the region they cover than any previously published. It is hoped that independent work in this laboratory and elsewhere will soon confirm or revise them, and that in the interim they will be of use.

Comparison spectra in this region of the spectrum are most conveniently introduced by some form of gas discharge or by the presence of gases driven out by spark electrodes. Working standards should therefore be sought among the more common elements easily excited in a gas discharge, namely H, He, C, N, O, Ne and A. Lines of these light elements may not be so sharp as those of metals; nevertheless their widths are less than the available resolution of most vacuum spectrographs. For special purposes another set, such as the lines of Cu II, would be desirable. The present discussion wil be restricted to lines of these lighter elements.

Helium I and the various stages of ionization of neon are omitted, as their principal lines lie at shorter wavelengths than are considered here. While not literally satisfying the criteria quoted, the wavelengths calculated by Paschen[2] for the Lyman series of hydrogen and for the two series of ionized helium rest on a sound theoretical foundation and appear to be by far the most reliable in this region of the spectrum. For convenience these values (for a few of the strongest lines of each series) have been included in Tables I and II. The spectral range covered by these lines is limited, and their higher series members, particularly those of helium, are hard to excite.

Comparisons of these wavelengths have been made with values published by Edlén[3] and by Bowen[4] and by Bowen and Ingram.[5] The average difference between the wavelengths of Bowen and of Bowen and Ingram and the present preliminary standards is not more than a few thousandths of an Angstrom unit, though the individual values differ considerably, especially above λ1500 (here their wavelengths are usually given to only 0.01A). There is a good comparison with Edlén's standard lines only between λ800 and λ1200. The difference is constant and around 0.005A from λ800 to λ1050; it then increases to about 0.017A at λ1200. Below λ800, where we have compared with additional lines given by Edlén, we find the systematic difference to be less than 0.005A. We have made some use of Edlén's values, corrected for this systematic difference, below λ800 in drawing our reduction curves for neon and argon. The present article will therefore be restricted to the region from λ800 to λ1850. Adequate standards over such a range are urgently needed. When there is opportunity to obtain further independent measurements in the region of shorter wavelength they will be published, since it is important that Edlén's results obtained at grazing incidence be checked at more nearly normal incidence.

The standards of Bowen and Bowen and In-

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[2] F. Paschen, Preuss. Akad. (1929), 662. See also W. G. Penney, Phil. Mag. **9**, 661 (1930).

[3] B. Edlén, Nova Acta Reg. Soc. Sci. Upsaliensis, Ser. IV **9**, No. 6 (1934), and Zeits. f. Physik **85**, 85 (1933).

[4] I. S. Bowen, Phys. Rev. **29**, 231 (1927).

[5] I. S. Bowen and S. B. Ingram, Phys. Rev. **28**, 444 (1926).

gram, those of Edlén, and the provisional values proposed in the present paper, were all obtained by a comparison, direct or indirect, of high orders of the lines in question with first orders of the secondary and tertiary standards obtained from an iron arc. They are all subject to the possible error inherent in the use of overlapping orders. This source of error has been investigated by Michelson[6] and by Kayser.[7] The amount of the error varies greatly with the imperfections of the grating used. It is also very sensitive to focal adjustment, and a grating in which this error is known to be small may suddenly develop a large error of this type if its adjustment is even slightly disturbed. The plates used in the present investigation are believed to be reasonably free of this type of error, to perhaps 0.005 to 0.010A. This belief is based upon a set of intercomparisons between different series of orders and upon the good agreement obtained with some of the wavelengths of H calculated by Paschen.[2]

The instrument used in this investigation was the two-meter normal incidence broad range vacuum spectrograph of the Carnegie Institution of Washington, which is located in the spectroscopy laboratory of the Massachusetts Institute of Technology. It has already been described in a paper,[8] which discusses the method of reduction of its plates. Results with neon have been published;[9] these depend to some extent on Edlén's wavelengths below λ800. For the wavelengths given in the accompanying tables, twelve exposures on five plates have been measured against the iron arc in the region λ2250 to λ2540, and three long exposures (on neon, argon and krypton plates) have been measured over their entire range. For the argon standards two additional exposures on argon were reduced, using the preliminary standards for C, N and O, which occurred as impurities in these exposures. Each plate was measured independently in both directions by two observers. The iron comparisons provide standards for those lines whose higher orders fall in this region of the plate. The reduction curves for other regions were drawn using as standards these lines and their intermediate orders, and on the krypton plate, lines of Kr II computed using the combination principle.[10] In addition the various orders of a given line were intercompared, and a few corrections were applied to those sections of the plate which had a relatively small number of standards. The three plates used have, of course, been reduced independently.

The probable error of a single observation has been computed from the differences of the measures on lines in their first order, according to Peters' formula. The lines used are those in the accompanying tables—all of shorter wavelengths than the iron comparisons. Hence the probable error includes the error in drawing the reduction curves in the regions where iron was not directly available; it is slightly less than ±0.007A for an observation of unit weight (one measurement in the first order). No considerable sources of systematic error suggest themselves with the exception of an error in the mean value of the twelve iron comparisons, and the possible error arising from the method of overlapping orders. The first of these might arise if the light from the arc failed to fill the grating, or if slight temperature changes occurred during the long gas exposure. Due precautions were taken to reduce both these sources of error, and they are believed to be less than the accidental error. The probable error of a single iron comparison has been found from the differences between the twelve plates measured. It equals ±0.007A for a single comparison and hence ±0.002A for the mean. Those lines measured against iron on fewer than the twelve exposures have been corrected to the mean system. Obviously, the accidental error of a line measured in the second order is one-half that in the first, etc. Some close multiplets were suspected of being affected by photographic errors in their first orders; for these lines the adopted wavelength depends only on measures in higher orders. The weight assigned to a measured wavelength is the summation of the products, number of plates times order.

In Tables III to VI the adopted wavelengths are given, followed by the results of Bowen or of

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[6] A. A. Michelson, Astrophys. J. **18**, 278 (1903).

[7] H. Kayser, Astrophys. J. **19**, 157 (1904); **20**, 327 (1904).

[8] K. T. Compton and J. C. Boyce, Rev. Sci. Inst. **5**, 218 (1934).

[9] J. C. Boyce, Phys. Rev. **46**, 378 (1934).

[10] T. L. de Bruin, C. J. Humphreys and W. F. Meggers, Bur. Standards J. Research **11**, 409 (1933).

Table III. *Carbon.*

λ	Bowen	Edlén	Int.	Spectrum	Wt.
1930.900			5	I	3
1760.818	.85		4	II	3
1760.412	.44		3	II	3
1658.126	.13		3	I	3
1657.916	.92		3	I	3
1657.380	.37		2	I	2
1657.005	.01		6	I	3
1656.280	.27		4	I	2
(1561.42)	.381		8	I	
1560.699	.660		5	I	3
1560.316	.267		4	I	3
1550.790	.774		10	IV	2
1548.214	.189		12	IV	2
1463.33			3	I	3
1335.71	.705	.684	40	II	3
1334.54	.539	.515	30	II	3
(1329.58)	.583		6	I	
1329.101	.100		5	I	2
1328.831	.839		4	I	3
1323.94		.916	15	II	2
1280.340			2	I	2
1277.550			4	I	3
1277.274			4	I	3
1261.560			1	I	3
(1261.12)			1	I	
1260.955			2	I	2
1247.387	.391	.368	7	III	3
1194.491			3	I	3
(1194.08)			1−	I	
1193.243			3	I	3
1193.012			1	I	3
1176.370	.359	.351	10	III	20*
1175.986	.988	.973	9	III	14*
1175.716	.711	.700	15	III	18*
1175.582	.577		5	III	16*
1175.259	.261	.248	9	III	18*
1174.934	.922	.916	10	III	18*
1141.745			1	II	2
1141.623	.61		3	II	8*
1139.343			3	II	4
1066.138			5	II	6
1065.895			7−	II	9
1037.020	.021	.017	10	II	8
1036.332	.336	.330	9	II	5
1010.374	.382	.369	7	II	6
1010.092	.090	.074	5+	II	6
1009.862	.870	.854	5	II	6
977.020	.031	.026	30	III	6
945.566			3	I	3
945.336			2	I	3
945.193			1	I	3
904.482	.472	.468	8	II	9
904.144	.133	.134	8+	II	6
903.952	.960	.950	8−	II	6
903.614	.620	.609	8	II	9
858.559	.561	.561	6	II	6
858.091	.088	.094	5	II	5

Bowen and Ingram, and those of Edlén. The intensity was estimated on an arbitrary scale. The state of ionization is denoted by a roman numeral, and the final column gives the weight assigned to the determination. The probable error of each wavelength is then ±0.007A divided by the square root of the weight. Lines which have been measured in their higher orders against iron are indicated by an asterisk; a few below λ800 have been included. Some members of multiplets are included for identification purposes, although on account of blending they are not considered suitable for standards; these are given to two decimals and placed in parentheses. A few other lines are given to two decimals because the measurements are somewhat uncertain because of their great intensity or close companions. The computed hydrogen values are reprinted here for convenience and with them are our observed values of those lines for comparison. The computed values seem to us to be the more fundamental and should be used as standards, though in practice the lines are unfortunately often so broad as to be unsuitable.

The provisional values given here should be checked by other investigators. A few preliminary results provided by Professor Harrison in the current program of the Massachusetts Institute of Technology 21-foot normal incidence vacuum spectrograph indicate good agreement. Both the 21-foot spectrograph and the broad range two-meter instrument have gratings ruled at The Johns Hopkins University. It is important that

Table IV. *Nitrogen.*

λ	Bowen	Int.	Spectrum	Wt.
1745.246	.260	2	I	3
1742.734	.740	3	I	2
1494.669		4	I	3
1492.630		5	I	3
1243.297		3	I	8*
1243.170		4	I	7*
1200.706	.681	4	I	19*
1200.220	.200	5	I	22*
1199.547	.533	6	I	23*
1134.980	.987	7	I	13*
1134.419	.420	5+	I	13*
1134.171	.180	5	I	7*
(1085.74)	.701	10	II	
1085.546	.540	7	II	4
1084.579	.566	9	II	9
1083.991	.983	7	II	9
(991.58)	.571	10	III	
989.804	.803	7	III	9
916.708	.698	8	II	7
(916.01)	.018	6	II	
(915.96)	.963	5	II	
915.612	.603	5	II	9
775.966		6	II	9*

TABLE V. *Oxygen.*

λ	BOWEN	EDLÉN	INT.	SPECTRUM	WT.
1306.038			9	I	3
1304.864			12	I	3
1302.192			12	I	2
1217.645			10	I	10*
999.494			6	I	9
990.797			4	I	6
990.213			8	I	4
990.121			3	I	4
988.775			8	I	9
(988.64)			3	I	
935.183			4	I	3
898.956			2	III	3
835.293	.288	.292	7	III	18*
(835.10)	.094	.096	5	III	
834.467	.462	.462	20	II	30*
833.749	.741	.742	11	III	18*
833.332	.326	.326	12	II	30*
(832.93)	.926	.927	5	III	
832.762	.756	.754	8	II	30*
796.667	.665	.661	9	II	9*
617.060	.064		7	II	8*
616.304	.309		9	II	8*
600.585	.583		5	II	8*
599.594	.600	.598	10	III	16*
580.974	.975		7	II	8*

TABLE VI. *Argon.*

λ	INT.	SPECTRUM	WT.
1066.660	9	I	9
1048.218	8	I	9
932.046	10	II	9
(919.78)	15	II	
887.404	10	III	9
883.179	9	III	9
879.622	8	III	9
878.728	11	III	9
875.534	9	III	9
871.099	10	III	9

these results be checked by another investigator having a grating ruled by another engine.

When half the criteria for standards of the International Astronomical Union are satisfied, namely, satisfactory agreement between the results of three different observers, there still remains the question of a more certain method of comparison with the primary standard, or at least with the present secondary standards. Two lines of approach suggest themselves to eliminate the difficulty of the possibility of systematic error due to the use of the method of overlapping orders. The first is most direct and involves the use of some form of interferometer in a vacuum. Experiments along this line, under the direction of Professor Harrison, are in progress at this laboratory. The second depends on the combination principle and was suggested by Professor Shenstone. In an as yet unpublished investigation, Shenstone has examined the extreme ultraviolet spectrum of copper as excited in a Schüler lamp. He finds that many of the lines of Cu II in this region are those with wavelengths which can be predicted with great accuracy from terms calculated by visible or near ultraviolet combinations. It is now proposed to make exposures with the Carnegie Institution vacuum spectrograph under conditions which will give from the same source these copper lines and some of the provisional standards suggested in the present article. Direct comparisons of lines in the same orders will then eliminate the possible error inherent in the present results.

The program of research with its two-meter vacuum spectrograph was made possible by a grant to Dr. K. T. Compton from the Carnegie Institution of Washington. Grateful acknowledgment is also made of a grant to one of the writers from the Permanent Science Fund of the American Academy of Arts and Sciences. We wish to thank Mr. D. H. Clewell for his careful assistance in some of the measurements. The subject of this paper has been under discussion for several years with a number of spectroscopists, all of whom are thanked for many helpful suggestions. It is a pleasure to thank particularly Dr. Compton, Professor G. R. Harrison and Professor A. G. Shenstone.