THE ORIGIN OF THE CHIEF NEBULAR LINES

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Several of the strongest lines in the spectra of the gaseous nebulae have not been observed in terrestrial sources. Since the spectra of the light elements, which are thought to form the chief constituents of nebulae, have been thoroughly studied, this leads to the conclusion that some cause, such as low density, must be operating in the nebulae to bring out lines in addition to those found in laboratory sources.

An atom in an excited state may give up its energy and return to a lower state either by radiating this energy or by transferring it to another atom through a collision of the second kind. If the mean life of the excited state before spontaneous emission is very long, as in the case of a metastable state, and if the mean time between impacts is short (in the most rarified terrestrial sources this is never more than 1/1000 second) practically all of the atoms will return by the second process and no radiation will take place. In the nebulae, however, where the mean time between impacts is estimated at from 10^4 to 10^7 seconds the first process may predominate even in the case of jumps from metastable states. This suggests at once that jumps from metastable states may be the source of lines appearing in nebulae but not in terrestrial sources.

The elements known to exist in the nebulae are H, He, C, N, O. CI, NI, NII, OI, OII, OIII, are the only ions of these elements that have metastable states so placed that jumps from them will produce lines in the range of wavelengths that can be observed in nebulae. Of these CI, NI, and OI can be eliminated because of the high ionization found in nebulae. In NII and OIII, which have similar structures, the metastable states are ^3P, ^1D, ^1S all arising from the normal configuration of two 2s and two 2p electrons. Likewise OII has the states ^4S, ^2D, ^2P due to the normal configuration of two 2s and three 2p electrons.

In only two cases are the differences between these levels accurately known from combinations with a third level[1]. These are $^1D-^1S$ of OIII and $^2D-^2P$ of OII whose differences are 22916 and 13646 frequency units corresponding to wavelengths of 4362.54A and 7326.2A respectively. Two of the strongest nebular lines are found at 4363.21A and 7325.A. Since the differences are calculated from lines in the 500A region, these deviations are well within the error of the predictions.

The ^4S and ^2D levels of OII are known roughly from series formulae, but as no intercombinations between quartets and doublets have been observed the difference between them cannot be determined accurately. This approximate difference predicts a pair[2] which agrees as well as can be expected in both separation and position with two of the strongest nebular lines at 3728.91A and 3726.16A.

Two other strong pairs in the nebular spectrum are found at 5006.84A, 4958.91A, and 6583.6A, 6548.1A. These have separations of 193 and 82.3 frequency units, respectively, while the separation of $^3P_1-^3P_2$ in OIII is 192 and in NII is 82.7. This suggests at once that these lines are $^3P_2-^1D_2$ and $^3P_1-^1D_2$ in these elements. In NII it is possible to check this identification because other singlet terms are known[3] which should combine strongly with this $^1D_2$ term. Calculating the value of $^1D_2$ from the frequency of the red nebular pair one finds that the position of these combinations should be 746.98A and 582.15A. Strong lines are observed in the nitrogen spectrum at 746.97A and 582.16A.

The lines thus far identified on the basis of this hypothesis are collected in Table 1. The table includes all of the lines of an easily observable wavelength which would be excited by this mechanism in NII, OII, and OIII. Only two or three of the strong nebular lines are left unidentified.

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[1]Bowen, *Phys. Rev.* **29**, 231, 1927.

[2]At 3681.25A and 3678.81A. The position of the pair is subject to an uncertainty of many angstroms.

[3]Fowler, *Proc. Roy. Soc.*, **114**, 662, 1927.

TABLE 1

IDENTIFICATION OF NEBULAR LINES

I. A.	Source	Series Designation
7325.	OII	$^2D - ^2P$
6583.6	NII	$^3P_2 - ^1D$
6548.1	NII	$^3P_1 - ^1D$
5006.84	OIII	$^3P_2 - ^1D$
4958.91	OIII	$^3P_1 - ^1D$
4363.21	OIII	$^1D - ^1S$
3728.91	OII	$^4S - ^2D_3$
3726.16	OII	$^4S - ^2D_2$

A study of the intensities of the nebular lines in various nebulae as given by Wright[4] shows that 5007, 4959, and probably 4363, all identified as OIII, behave in the same manner as 4686 of HeII. This would be expected from the similarity of their ionization potentials (54.8 and 54.2 volts). 3729, 3726 of OII and 6584, 6548 of NII show characteristics similar to the lines of HeI and other atoms of lower ionization potential.

In addition to the above identifications, it may be noted that the lines at 3313, 3342, 3445, and 3759 agree in position with four of the five strongest OIII lines as classified by Mihul[5], the fifth line being obscured by a hydrogen line. The behavior of these lines in the nebulae is in agreement with this identification.

As was recognized by Wright, 3426.2 and 3346 behave in such a way as to indicate a still higher ionization potential than OIII or HeII. The only strong line of NIV to be expected in the 3000-7000 region is $3^3S - 3^3P$ which is predicted at 3460 ± 50, and the only strong line of OIV in this region is $3^2P - 3^2D$ expected at 3440 ± 100. This makes the identification of 3426 as NIV and 3346 as OIV quite probable.

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[4]Wright, *Publ. Lick Obs.* **13**, 193, 1918.
[5]Mihul, *C. R.* **183**, 1035; **184**, 89, 874, 1055.