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SPECTROPHOTOMETRIC STUDIES OF GASEOUS NEBULAE. XXIII. THE PLANETARY NEBULA NGC 6803*

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ABSTRACT

We have measured line intensities between λλ3299 and 5007, as well as the [Cl III] λ5537/λ5517 and the [S II] λ6731/λ6716 ratios, by a combination of photographic and photoelectric techniques. The electron density of the nebula increases strongly toward the center. There appears to be a small but definite excess of helium.
Subject headings: abundances, nebular — planetary nebulae

I. INTRODUCTION

The object NGC 6803 (46−4°1) is a small, bright planetary nebula in Aquila, which displays a uniform disk and no apparent structure. It shows moderate excitation with weak He II λ4686 and [O II] λ3727. The relative line intensities have been studied previously in detail by Aller (1951), Liller and Aller (1963), Vorontsov-Velyaminov *et al.* (1965), and Peimbert and Torres-Peimbert (1971*a*).

II. THE OBSERVATIONS

We used a combination of photoelectric and photographic techniques in this study. The stronger lines were observed with a photoelectric scanner attached to the 60-inch (1.5-m) telescope at Mount Wilson. The relative line intensities were reduced to outside the atmosphere by observation of α Lyrae.

The weaker lines, where higher resolution is needed, were observed photographically with a variety of instruments. The photographic plates used in this study are listed in table 1, which give in column order, plate number, telescope, exposure time in minutes, and the standard star used. The Lick and Mount Wilson observations were calibrated, respectively, by means of step slit and wedge calibrating spectrographs, and the Kitt Peak observations were calibrated with a spot sensitometer. The change of slope of the characteristic curve was taken into account by establishing curves approximately every 300 Å. We corrected the line intensities to outside the atmosphere by observations of the standard stars listed in column (4) of table 1. We adopted the energy distributions given by Hayes (1970) for α Lyrae, θ Vir, and 58 Aql, and assumed BD

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TABLE 1

THE OBSERVATIONS OF NGC 6803

Plate	Telescope	Exposure (min)	Standard
ES 1097	Lick 120-inch (3-m) prime focus	30	BD +28°4211
ES 1362a	Lick 120-inch prime focus	10	BD +28°4211
ES 1362b	Lick 120-inch prime focus	45	BD +28°4211
ES 1367	Lick 120-inch prime focus	6	BD +28°4211
CE 10863	Mount Wilson 100-inch coudé	140	58 Aql
A 2781	KPNO 36-inch (91-cm)	88	θ Vir
A 2783a	KPNO 36-inch	246	θ Vir, 58 Aql
A 2783b	KPNO 36-inch	10	θ Vir, 58 Aql
A 2778	KPNO 36-inch	81	θ Vir
CIT 936	KPNO 84-inch (2-m) image tube	1, 22	58 Aql
CIT 1245	KPNO 84-inch image tube	15	...
CIT 1251	KPNO 84-inch image tube	6, 43	...
CIT 1256	KPNO 84-inch image tube	7.5, 37	...

TABLE 2
THE SPECTRUM OF NGC 6803

λ (1)	ID (2)	I (3)	I_{PEP} (4)	I_{PTP} (5)	I_c (6)
7325	[O II]	...	...	12.9	6.5
6723	[S II]	...	...	22.4	12.9
6584	[N II]	...	...	186	111
5876	He I	...	...	25.1	18.1
5754	[N II]	...	...	2.57	1.9
5007	[O III]	...	1255	1290	1210
4959	[O III]	408:	399	426	398
4921	He I	2.2	...	...	2.1
4861	Hβ	...	100	100	100
4740	[Ar IV]	2.87	...	...	2.99
4713	He I	0.21	...	...	0.22
4711	[Ar IV]	2.15	...	...	2.27
4686	He II	3.76	...	3.63	3.93
4650	C III }	0.5	...	...	0.5
4647	C III }				
4640	N III	1.67	...	...	1.81
4634	N III	0.44	...	...	0.48
4471	He I	5.41	...	5.36	6.25
4387	He I	0.53	...	...	0.63
4363	[O III]	5.85	...	5.63	6.95
4340	Hγ	37.4:	...	39.8	48.3
4267	C II	0.38	...	...	0.48
4143	He I	0.35	...	...	0.46
4120	He I	0.28	...	...	0.37
4101	Hδ	18.3	19.0	21.8	26.4
4097	N III	0.98	...	...	1.31
4076	[S II]	0.79	...	...	1.07
4072	O II	0.13	...	...	0.18
4068	[S II]	2.40	...	...	3.25
4026	He I	1.84	...	2.18	2.77
4009	He I	0.27	...	...	0.37
3970	H7	10.2	35.0	...	14.7
3967	[Ne III]	24.8	...	...	34.4
3889	H8, He I	12.7	14.0	...	18.7
3868	[Ne III]	110	87.8	...	147
3835	H9	6.0	...	...	9.1
3819	He I	0.98	...	...	1.5
3797	H10	4.2	...	...	6.5
3770	H11	2.9	...	...	4.5
3760	O III	0.4	...	...	0.7
3754	O III	0.3	...	...	0.5
3750	H12	2.5	...	...	3.9
3734	H13	1.8	...	...	2.8
3729	[O II]	8.34 }	21.6	31.6	43
3726	[O II]	18.8 }			
3721	{ H14, [S III] }	2.37	...	...	3.8
3712	H15	1.5	...	...	2.3
3704	He I }	1.8	...	...	2.9
3703	H16 }				
3697	H17	0.88	...	...	1.4
3691	H18	0.73	...	...	1.2
3686	H19	0.63	...	...	1.0
3682	H20	0.59	...	...	0.95
3444	O III	2	...	...	4
3428	O III	< 1	...	...	< 2
3342	{ [Ne III], [Cl III] }	< 2	...	...	< 4
3340	O III	2	...	...	4
3312	O III	1	...	...	2
3299	O III	< 1	...	...	< 2

NOTES.—The corrected intensities are appropriate to c = 0.6. $I(\lambda 6731)/I(\lambda 6716)$[S II] = 1.30. $I(\lambda 5537)/I(\lambda 5517)$[Cl III] = 1.65. Balmer continuum flux density A^{-1} at $\lambda 3646$/Hβ flux = 0.0032.

+28°4211 to be a blackbody radiating at 50,000° K. The last three plates were used to measure the line ratios observed in the yellow and red.

Since the stronger lines are generally heavily exposed on the plates, the photographically derived intensities were placed on the usual scale of I(Hβ) = 100 by a comparison with the lines that were observed photoelectrically. We incorporate the results of Peimbert and Torres-Peimbert (1971*a*) (hereafter called PTP) into this study as they photoelectrically observed lines weaker than we did and they also covered the yellow and red.

We present the final intensities in table 2. The columns give, in order, wavelength (λ), identification (ID), the photographically derived intensities (I_{PEP}), those intensities of PTP (I_{PTP}) which are included in the wavelength region studied or which are used in the analysis in § III and are not included in table 3, and finally, the adopted intensities corrected for interstellar extinction I_c (see § III). The ratio of the flux density of the Balmer continuum at the Balmer limit to the Hβ flux, and values of the [Cl III] λ5537/λ5517 and [S II] λ6731/λ6717 ratios which we also observed are given at the end of the table. From comparison of lines observed on two or more plates, we estimate the accidental errors to be the order of ±5 percent for $I > 5$ and ±10 percent for $I < 5$. Lines with $\lambda < 3727$ were observed on only one plate.

III. ANALYSIS

a) *Interstellar Extinction*

Before an analysis of the data can proceed, we must first determine the value of the extinction constant, c, which represents the logarithmic interstellar extinction at Hβ. For many planetaries c can be found by comparing the observed Hβ flux with the radio flux density at a frequency where the nebula is optically thin. This method does not work for NGC 6803, as Higgs (1971) and Aller and Milne (1972) point out that the radio source is confused. From an analysis made at 6 cm, where the confusion is reduced, Milne and Aller (1974) obtained $c = 0.76$. PTP adopt $c = 0.56$, primarily from the Paschen 7 intensity. In this paper we adopt 0.6 as the most likely value, from a comparison of the hydrogen and helium observations with the theoretical predictions of Brocklehurst (1971, 1972) for a temperature of 7500° K. We use the interstellar reddening function adopted by Seaton (1960). The primary intensity ratios used were P7/Hβ, Hα/Hβ, and λ5876/λ4471. The fit may be seen in table 3.

b) *Hydrogen and Helium Spectra*

In table 3 we present the comparison of the observed hydrogen and helium decrements, corrected for interstellar extinction, with the theoretical decrements of Brocklehurst (1971, 1972) for an electron temperature of 7500° K and an electron density of 10^4 cm^{-3} (see table 4). The helium lines were normalized to λ4471 (triplets) and λ4921 (singlets). In general, the fit is satisfactory. The Balmer lines show an excess of about 20 percent from about H9 onward, which may represent systematic measurement errors, adoption of too high an extinction or too low an electron density.

TABLE 3

COMPARISON OF HYDROGEN AND HELIUM LINE INTENSITIES TO THEORY*

Series	n	λ	I_c	I_T
		a) Hydrogen		
Paschen	6	10,938	11.1†	9.4
	7	10,049	5.42†	5.76
	8	9229	3.4†	5.6
Balmer	3	6563	296†	292
	4	4861	100	100
	5	4340	48.3†	46.4
	6	4101	26.4	25.6
	7	3970	14.6	15.7
	9	3835	9.1	7.24
	10	3797	6.5	5.27
	11	3771	4.5	3.96
	12	3750	3.9	3.06
	13	3734	2.8	2.42
	15	3712	2.3	1.62
	17	3697	1.4	1.16
	18	3691	1.2	1.00
	19	3686	1.0	0.88
	20	3682	0.95	0.78
		b) Helium		
$2\,^3P$–$n\,^3D$‡	3	5876	296†	289
	4	4471	100	100
	5	4026	40	46.7
	6	3819	24	25.8
	7	3705	21:	15.9
$2\,^3P$–$n\,^3S$‡	3	7065	160†	28.6
	4	4713	3.8:	7.8
	5	4120	5.6	3.2
$2\,^3S$–$n\,^3P$‡	2	10,830	1580†	419
	3	3889	110	208
$2\,^1P$–$n\,^1D$§	4	4921	100:	100
	5	4387	30	46
	6	4143	22	25
	7	4009	18	15

* For $c = 0.6$, $T_e = 7500°$ K, and $N_e = 10^4$ cm^{-3}.

† Intensities taken from Peimbert and Torres-Peimbert (1971*a*).

‡ Intensities normalized to $I(\lambda 4471) = 100$.

§ Intensities normalized to $I(\lambda 4921) = 100$.

Some large discrepancies can be seen in the case of the He I lines, for the $2\,^3P$–$n\,^3S$ and $2\,^3S$–$n\,^3P$ series. The disagreement for the λλ7065, 10,830, and 3889 lines is due to the optical depth in the lines which arise from the metastable $2\,^3S$ term. A comparison of the λλ7065 and 3889 lines with the predictions of Robbins (1968) suggest that $\tau(3889)$ is about 20. The λ4713 line intensity is only poorly known, as it is blended with the much stronger [Ar IV] λ4711 line.

c) *Physical Conditions*

We have calculated values of electron temperature and density for every available ion from the current observations and those of PTP. The results are given in table 4. Values derived from forbidden lines are tabulated in order of increasing upper ionization potential with hydrogen placed last. Column (1) gives the spectrum from which the temperature or density was derived, column (2) the lines whose intensity ratio was used in the calculation. The columns (3), (4), and (5) give, in order, the values of T_e, $x = 10^{-2}N_e/(T_e)^{1/2}$, and N_e which we have derived. Column (6) gives the assumptions used to derive the value of T_e or N_e given.

The values of T_e and N_e derived from p^3 ions are given both as based upon the calculations of Krueger, Aller, and Czyzak (1970) and upon those of Saraph and Seaton (1970) as indicated in table 4. Note the systematic differences between the two. Saraph and Seaton suggest empirical corrections to quantities derived from [Cl III] and [S II]. These corrections were not applied to obtain the result of table 4. If they are applied, x([Cl III]) = 0.66, x([S II]) = 0.31, and T_e([S II]) = 22,000° K. The consistency among all ions is better if the corrections are not applied. Quantities from p^2 and p^4 ions are calculated from the equations given by Aller (1956), the collision cross-sections of Saraph, Seaton, and Shemming (1969), Czyzak *et al.* (1968), and the transition probabilities given by Garstang (1968) and Nussbaumer (1971).

Some problems encountered in making these calculations must be noted. The λ4713 He I line is difficult to separate from λ4711 [Ar IV], and λ4711 may be overestimated. If λ4713 is estimated from the λ4471 intensity and the work of Brocklehurst (1972), and the result subtracted from the blend, the electron density is increased. The electron temperature derived from [S II] is based upon λ4076 (and of course λ6723) as λ4068 is likely to be blended with O II. It is quite possible that λ4076 is also blended with O II, in which case the electron temperature derived will be too high. The value of temperature derived from [S III] must be considered shaky. The intensity of the λ9532 line was taken from Liller and Aller (1963) where we used PTP's value of I(Hα) and subtracted the intensity of the blended P8 line by interpolation from PTP. We derived the λ3721 line intensity by subtracting the intensity of H14 as interpolated from the Balmer decrement. Obviously these procedures will greatly increase the expected error of the result. Further infrared observations are needed.

The observed ratio of the Balmer continuum flux (Ba C) A^{-1} to that of Hβ given in table 2, is used to find a value of electron temperature, where we use the atomic data of Brown and Mathews (1970) and Brocklehurst (1971). The values of 7500° K which we derive is in good accord with the average temperature of 7700° K calculated in the same way from three planetaries by Peimbert (1971). If the Balmer continuum flux density is decreased by 20 percent (the excess of the higher Balmer lines) the electron temperature is increased to 10,000° K, more in accord with the value derived from [O III].

As for most planetaries, the distance is not well known. Cahn and Kaler's (1971) distance of 3.1 kpc is clearly too high as seen from the very high value of the extinction ($c = 1.75$) that is predicted. Cahn and Kaler (1971) suggest a distance of 1.3 kpc based upon their dust model and an extinction of $c = 0.83$, and Mottmann (1973) suggests 0.7 kpc, also on the basis

TABLE 4

Physical Conditions in NGC 6803

Spectrum	λ_1/λ_2	T_e (° K)	x	N_e	Assume
[S II]	6731/6717	...	0.56*	6×10^3	$T = 13{,}000°$ K
		...	0.56†	7×10^3	$T = 16{,}000°$ K
[S II]	6723/4076	13,000*	...	...	$x = 0.56$
		16,000†	...	...	$x = 0.56$
[N II]	6584/5755	9900	...	...	$x = 0.91$
[O II]	3729/3726	...	0.91†	9×10^3	$T = 10{,}000°$ K
[O II]	7325/3727	10,000	...	...	$x = 0.91$
[S III]‡	9532/3721	9400	...	...	$x = 0.91$
[Cl III]	5537/5517	...	1.3*	1.3×10^4	$T = 10{,}000°$ K
		...	1.0†	1.0×10^4	...
[O III]	5007/4363	9500	...	...	$x = 0.91$
[Ar IV]	4740/4711	...	3.5*	3×10^4	$T = 9500°$ K
		...	2.3†	2×10^4	...
H	Ba C/Hβ	7500	...	7×10^3	...

* From calculations of Krueger *et al.* (1970).

† From calculations of Saraph and Seaton (1970); the empirical corrections suggested for [S II] and [Cl III] are not made.

‡ $I(\lambda 9532) = 77$ from Liller and Aller (1963), and $I(\lambda 3721) = 1.23$ after subtracting H14, both values corrected for reddening.

of extinction. A distance of 1 kpc then seems reasonable, which corresponds to a radius of 0.014 pc. From the above distance, radius, the temperature derived from the Balmer continuum, and Liller's (1955) Hβ flux we computed the mean electron density presented for hydrogen in table 4. Note that this density (7×10^3 cm^{-3}) is less than the densities (except for one entry) derived from forbidden lines, which is expected if there is clumping or filamentation within the nebula.

We would expect the ions to be stratified, with those of highest ionization potential being closest to the central star. There is little doubt that an electron-density gradient exists, with the density increasing strongly toward the center. The [O III] temperature of this nebula is among the lowest known among the well-studied objects.

d) *Chemical Composition*

The chemical and ionic composition of NGC 6803 is presented in table 5. The temperatures and densities used in the calculations were taken from table 4 (the first of the two entries, where necessary) and are appropriate to the ion. The line intensities are again both from the new data and from PTP. The [O III] value of 9500° K was used where no value was explicitly calculated. In all cases the effective recombination coefficient for Hβ and for the helium lines was for $T_e = 7500°$ K. Abundance ratios with respect to hydrogen that are derived from forbidden lines would be decreased by 20 percent if 9500° K were adopted for the Hβ recombination coefficient. References to the atomic data were given in § III*c*.

The helium to hydrogen ratio is based upon both λλ4471 and 5876. Following Peimbert and Torres-Peimbert (1971*b*), we adopt one-third of the collisional excitation correction suggested by Cox and Daltabuit (1971), whereupon the He/H ratio is essentially independent of electron temperature (Kaler 1974).

TABLE 5

Chemical Abundances in NGC 6803

Ion Ratio	Relative Abundance
He^+/H^+	0.124
He^{2+}/H^+	0.003
Element ratio He/H	0.127
O^+/H^+	4.5×10^{-5}
O^{2+}/H^+	5.6×10^{-4}
O^{3+}/H^+	1.5×10^{-6}
Element ratio O/H	6.1×10^{-4}
Ne^{2+}/H^+	2.2×10^{-4}
Ar^{3+}/H^+	2.5×10^{-6}
N^+/H^+	3.2×10^{-5}
S^{2+}/H^+	8×10^{-6}

The He/H ratio is somewhat higher than is found in H II regions.

The O^{3+}/H^+ ratio was calculated from the relation $O^{3+}/(O^+ + O^{2+}) = He^{2+}/He^+$ as suggested by Seaton (1968). The Ne^{2+} to oxygen ratio is 0.36. Kaler (1973) finds a mean neon to oxygen ratio of 0.41, which means that nearly all the neon is in the Ne^{2+} stage. NGC 6803 was the one discrepant point in Kaler's (1973) analysis of the neon to oxygen ratio; the discrepancy is now removed by the results presented in this paper. Other workers (see Aller and Czyzak 1973) find Ne/O to be more nearly 0.24, in which case NGC 6803 is certainly neon rich.

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