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CHEMICAL ENRICHMENT IN HALO PLANETARY NEBULAE

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RESUMEN

Se presentan nuevas observaciones fotoeléctricas de la nebulosa planetaria 108–76° 1(BB1). A partir de estas observaciones se determinaron las abundancias de He, C, N, O, y Ne con respecto a H. La composición química de las planetarias de halo (BB1, H4-1 y K648) se compara con las predicciones de la teoría de evolución estelar bajo la hipótesis de que la envolvente debería tener la composición química de la materia situada entre la cáscara de trasmutación del H y la superficie. Se encuentra que los cocientes de He/H y C/O son mucho mayores que las predicciones teóricas lo que implica que la nebulosa contiene materia que estuvo situada en capas más profundas que la cáscara de trasmutación del H. Los cocientes de O/Ar, N/Ar y Ne/Ar en las nebulosas planetarias de halo son mayores que en la vecindad solar; se demuestra que parte de este enriquecimiento es causado por la evolución de las estrellas que producen nebulosas planetarias.

ABSTRACT

Photoelectric spectrophotometry of emission lines in the 3400-7400 A region is presented for the planetary nebula 108–76° 1 (BB1). From these observations the relative abundances of H, He, C, N, O and Ne are derived. The abundances of the halo PN (BB1, H4-1 and K648) are compared to those predicted by stellar evolution theory under the assumption that the envelope has the chemical composition of the matter located between the H burning shell and the surface. The observed He/H and C/O values are higher than predicted which implies that halo PN contain matter from deeper layers than the H burning shell. Futhermore the O/Ar, N/Ar and Ne/Ar values in halo PN are higher than in the solar neighborhood, at least part of this enrichment is produced by the PN progenitors.

Key Words: ABUNDANCES – NEBULAE-PLANETARY – STARS-EVOLUTION

I. INTRODUCTION

Halo PN, defined as type IV by Peimbert (1978), are very important to establish the abundances in the interstellar medium of heavy elements that are not affected by the evolution of PN progenitors. Moreover the study of the enrichment in He, C, N, O and Ne of their nebular shells provides us with observational restrictions for models of stellar evolution and of the chemical evolution of the interstellar medium.

In §II we present new observations of BBI. In §III we derive chemical abundances from these observations. In §IV by combining the abundances of BBI with those of H4-1 and K648, derived elsewhere, a discussion of chemical enrichment in halo PN is given; a similar discussion, based on preliminary data for BB1, was given by Peimbert (1981).

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II. OBSERVATIONS

The observations were carried out in 1979-1980 with the 2.1 m at KPNO and the Intensified Image Dissector Scanner IIDS. The observational procedure has been described before (Torres-Peimbert and Peimbert 1977). The dual entrance slits used correspond to 3.8 × 12.4 arcsec on the plane of the sky, the slits were oriented east-west and the separation between the centers of both slits corresponds to 99 arcsec. Several gratings were used that covered the following wavelength ranges: λλ3400-5200, 4800-6600 and 5600-7400. Each spectrum of about 20 mm is recorded into 1024 channels. The FWHM resolution was of 3.3 channels (∿ 6 A).

BB1 and the standard stars were observed alternating both slits. Measurements of the sky were obtained at the same time with the other slit. Each beam was treated independently and in all cases the sky was subtracted from the source. The data were reduced to absolute fluxes using the standard stars observed by Stone (1977) and Oke (1974). The continuum contribution to each emission line was subtracted by interpolating the continuum at both sides of the emission line.

In Table 1 we present the intrinsic line intensities in erg cm^{-2} s^{-1}, I(λ), given by

TABLE 1

LINE INTENSITIES[a], REDDENING CORRECTIONS AND FLUXES FOR BB1

λ	Ident.	f(λ)	F(λ) this paper	I(λ) this paper	I(λ) HM
3444	O III	+0.390	−1.58:	−1.50:	...
3727	[O II]	+0.315	−0.99	−0.93	−1.13
3835	H 9	+0.280	−1.26:	−1.20:	...
3869	[Ne III]	+0.270	+0.19	+0.24	0.00
3889	H 8, He I	+0.265	−0.76	−0.71	−0.91
3921	He II, He I, C II	+0.255	−2.32	−2.27	...
3970	H 7, [Ne III]	+0.235	−0.22	−0.17	−0.36
4026	He I	+0.225	−1.78	−1.74	...
4070	C III, O II	+0.210	−1.82	−1.78	...
4102	Hδ	+0.200	−0.65	−0.61	−0.72
4187	C III, O II	+0.180	−2.42:	−2.39:	...
4200	He II	+0.175	−2.40	−2.37	...
4267	C II	+0.155	−2.38	−2.35	...
4340	Hγ	+0.135	−0.37	−0.34	−0.40
4363	[O III]	+0.130	−1.35	−1.32	−1.30
4387	He I	+0.125	−2.39	−2.36	...
4471	He I	+0.105	−1.48	−1.46	−1.47
4541	He II	+0.080	−2.13	−2.11	−1.62
4648	C III, O II	+0.050	−1.81	−1.80	...
4686	He II	+0.045	−0.60	−0.59	−0.63
4861	Hβ	0.000	+0.00	0.00	0.00
4922	He I	−0.015	−1.99	−1.99	−2.15
4959	[O III]	−0.020	+0.05	+0.05	+0.05
5007	[O III]	−0.030	+0.56	+0.55	+0.56
5200	[N I]	−0.075	−2.51:	−2.53:	...
5755	[N II]	−0.190	−2.30	−2.34	−2.22
5876	He I	−0.210	−0.95	−1.01	−0.92
6548	[N II]	−0.330	−0.98	−1.07	−0.97
6563	Hα	−0.335	+0.50	+0.43	+0.46
6583	[N II]	−0.340	−0.50	−0.57	−0.49
6678	He I	−0.360	−1.51	−1.58	−1.57
6717+31	[S II]	−0.370	<−2.27	<−2.34	...
7065	He I	−0.400	−1.35	−1.43	−1.36
C(Hβ)				0.2	0.22
log I (Hβ)				−12.26	−12.39

a. Given in log I(λ)/I(Hβ).

$$\log I(\lambda) / I(H\beta) = \log F(\lambda) / F(H\beta) + C(H\beta) f(\lambda) \quad , \qquad (1)$$

where F(λ) is the observed line flux corrected for atmospheric extinction and C(Hβ) is the logarithmic reddening correction at Hβ. The reddening function, f(λ), normalized at Hβ was derived from the normal extinction law (Whitford 1958) and is also presented in Table 1. C(Hβ) was determined by fitting the observed Balmer decrement to the one computed by Brocklehurst (1971) for $T_e = 10000°K$ and $N_e = 10000\ cm^{-3}$.

The rms errors for the line intensity ratios have been estimated by comparing results of different nights and in all cases are smaller than 0.04 dex, with the exception of the measurements marked with a colon where the rms error is twice as large. The rms error for the absolut flux at Hβ is 0.06 dex.

Figure 1 shows the $4f^2 F_0 \rightarrow 3d^2 D$ C II line at λ426 which is, in general, very faint and difficult to measure However, as can be seen from this figure, the line i clearly present.

Table 1 also includes the observations by Hawley an Miller (1978). The C(Hβ) derived by us is in very goo agreement with that derived by Hawley and Miller and i considerably higher than the average C(Hβ) in th direction of the south galactic pole. The agreement in th bright line intensities is good; but the faint lines mea sured by us tend to be fainter than those measured b Hawley and Miller, moreover there is a systematic trend i the sense that for shorter wavelengths the intensities mea sured by Hawley and Miller are fainter than ours.

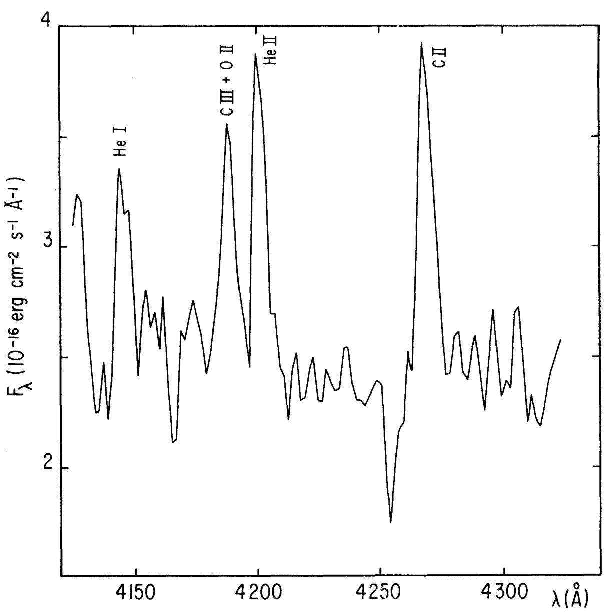

Fig. 1. Portion of a blue spectrogram of BB1, showing faint lines of C II, He II, He I and a blend of C III and O II.

Boeshaar and Bond (1977) detected two lines in the 4070 Å region which they ascribed to [S II]. We have detected a blend in the same region which we think is due to O II and C III, based on the values of N_e and T_e presented in Table 2 and on the computations by Pradhan (1978). If the features at λ4070 were due to [S II] then the nebular lines of [S II] at λλ6717 and 6731 would be at least one order of magnitude brighter than the 2σ upper limit presented in Table 1; furthermore we also detected features at λλ4187 and 4648 which also seem to be due to permitted lines of O II and C III.

TABLE 2

DENSITY AND TEMPERATURE FOR BB1

Parameter	Ion	Notes
N_e = 1500 ± 200 cm^{-3}	O II	a,b
T_e = 12500 ± 500 °K	O III	a
T_e = 10000 ± 500 °K	N II	a

a. This paper.
b. Boeshaar and Bond 1977.

III. TEMPERATURES, DENSITIES AND CHEMICAL ABUNDANCES

The relevant references to the atomic parameters used to derive electron temperatures, electron densities and chemical abundances are those used by Peimbert and Torres-Peimbert (1977) and Torres-Peimbert and Peimbert (1977), with the addition of the newer values for the collision strengths for S^+ computed by Pradhan (1978).

In Table 2 we present the [O II] density which is based on the λλ3726/3729 ratio measured by Boeshaar and Bond (1977) and the collisional cross sections computed by Pradhan (1976), our density is slightly smaller than theirs because they used the collisional cross sections by Eissner *et al.* (1969). Also in Table 2 we present the [O III] and [N II] temperatures which for this object are density independent.

The ionic chemical abundances presented in Table 3 were derived assuming that the emission lines originate in two zones: one of high degree of ionization for which T_e(O III) was adopted and where the He^+, He^{++}, C^{++}, O^{++} and Ne^{++} ions are located, and another of low degree of ionization for which T_e(N II) was adopted and where the O^+, N^+ and S^+ ions are located.

TABLE 3

IONIC CHEMICAL ABUNDANCES[a]

Ion	BB1
He^+	0.073
He^{++}	0.0224
log C^{++}	−3.31
log N^+	−5.29
log O^+	−5.26
log O^{++}	−4.23
log Ne^{++}	−4.13
log S^+	<−7.94

a. By number relative to H^+.

A uniform temperature for each zone was also adopted, which implies values for the mean temperature fluctuation, t^2, of 0.00. This rough scheme, considering the difference between T(O III) and T(N II), was supplemented with results from ionization structure models (see below).

To determine the He^+ abundance we made use of the λλ4471, 5876 and 6678 lines giving them equal weight. We corrected the λλ4471, 5876 line intensities for self-absorption based on the λλ7065/4471 ratio, and the computations by Robbins (1968) normalized to the maximum values for total self-absorption presented by Cox and Daltabuit (1971); this correction amounted to 2% in the case of λ5876 and was negligible for λ4471. From computations by Robbins and Bernat (1973) the effect of self-absorption on λ6678 is expected to be small and was not considered.

In Table 4 we present the total abundances for BB1. The total He abundance was obtained from

$$\frac{N(He)}{N(H)} = \frac{N(He^+ + He^{++})}{N(H^+)} . \qquad (2)$$

TABLE 4

TOTAL CHEMICAL ABUNDANCES[a]

Object	He	C	N	O	Ne	Ar	Source
Halo[b]	10.89	6.32	5.64	6.57	5.77	4.40	c
K648	11.00	8.75::	6.07	7.67	6.53	4.26	d,e
H4-1	10.99	9.31	7.75	8.36	6.70	4.69	d,e
BB1	10.98	9.09	8.34	7.90	8.00	4.59	c,e
Sun	...	8.67	7.99	8.92	8.12	6.75	e,f,g,h

a. Given in 12+log N(X)/N(H).
b. Assumed abundances, see text.
c. This paper.
d. Torres-Peimbert and Peimbert (1979).
e. Barker (1980).
f. Lambert (1978).
g. Lambert and Luck (1978).
h. Bertsch *et al.* (1972).

The total O and Ne abundances were obtained from (cf. Peimbert and Costero 1969)

$$\frac{N(O)}{N(H)} = \frac{N(O^+ + O^{++})}{N(H^+)} \frac{N(He^+ + He^{++})}{N(He^+)} , \quad (3)$$

and

$$\frac{N(Ne)}{N(H)} = \frac{N(O)}{N(O^{++})} \frac{N(Ne^{++})}{N(H^+)} . \quad (4)$$

The total N abundance was obtained from

$$\frac{N(N)}{N(H)} = i_{cf}(N) \frac{N(O)}{N(O^+)} \frac{N(N^+)}{N(H^+)} , \quad (5)$$

where i_{cf} (N), the N ionization correction factor, is equal to unity for objects of relatively low degree of ionization. Alternatively, from ionization structure models (Torres-Peimbert 1981) and *IUE* observations (Peimbert 1981) it has been found that for objects of high degree of ionization i_{cf} (N) is considerably larger than unity. From ionization structure models by Torres-Peimbert (1981) we have adopted for BB1 a i_{cf} (N) of 2.95. Similarly for C we have

$$\frac{N(C)}{N(H)} = i_{cf} (C) \frac{N(C^{++})}{N(H^+)} , \quad (6)$$

and from the models by Torres-Peimbert (1981) we have estimated that $i_{cf}(C) = 2.5$ for BB1.

The C^{++} abundance was derived from the λ4267 C II line based on the effective recombination coefficients computed by Pengelly (1963). Storey (1981) has foun that at nebular temperatures di-electronic recombinatio has a negligible effect on the intensity of λ4267.

X. DISCUSSION AND CONCLUSIONS

In order to discuss the halo PN analyzed to date, i addition to the abundances of BB1 we present in Table the abundances of K648 and H4-1. The C abundance for BB1 and H4-1 were derived from the intensity of th λ4267 C II lines and from ionization structure model the C/O values are more than an order of magnitud larger than the solar value. Aldrovandi (1980), fro ionization structure models where the C abundance wa kept as a free parameter, also found that to explain th observed electron temperature in K648, H4-1 and BB1 C/O excess of about a factor of three was needed. The value for K648 in Table 4 has been estimated fro Aldrovandi's work and on the observational results fo H4-1 and BB1.

Barker (1980) found that Ar is underabundant by 2. to 2.5 dex relative to the solar value for the three PN The underabundances of O are of 0.6 to 1.3 dex whil those of Ne are of 0.1 to 1.6 dex. To explain differen underabundances of Ar and Fe relative to O and Ne tw possibilities have been discussed in the literature: *a)* tha the enrichment of O and Ne in the interstellar mediur has proceeded faster than that of Ar and Fe, and *b)* tha the O and Ne excesses relative to Ar and Fe are product of the evolution of the progenitors of the PI themselves (Peimbert 1973; Hawley and Miller 1978 Torres-Peimbert and Peimbert 1979; Barker 1980). Th excesses in the C/O ratios support the second possibilit without ruling out a combination of the two.

Additional observational evidence in favor of enrich ment in the PN envelopes is given by the He/H ratios From observations of metal-poor extragalactic H I regions it has been found that the pregalactic heliur abundance, Yp, is equal to 0.228 ± 0.012 (3σ) and that $\Delta Y/\Delta Z = 2.8 \pm 0.6$ (1σ) (Peimbert and Torres-Peimbert 1976; Lequeux *et al.* 1979). By assuming that halo PN started with the He/H pregalactic value it follows that the three PN of type IV show an excess in their He/H values. In Table 5 we present the excess abundances in He, C, N, O and Ne where we have assumed that: *a)* the initial values were N(He)/N(H) = 0.074, *b)* Ar has not been affected by stellar evolution and *c)* the relative initial abundances of C, N, O, Ne, and Ar were the same as in the sun. Under these same assumptions we show in Table 4 typical values for the chemical composition of the halo when the progenitors of the type IV PN were formed.

TABLE 5

RELATIVE ENRICHMENT BY MASS IN HALO PN[a]

Object	He	C	N	O	Ne
K648	14.0	0.90::	0.0016	0.10	0.009
H4-1	3.3	0.87	0.028	0.13	0.003
BB1	5.1	0.93	0.19	0.07	0.14

a. Normalized at $\Delta(C)+\Delta(O)$ = 1.00.

Renzini and Voli (1981), based on evolution models of intermediate mass stars by Iben and collaborators, have predicted the He/H and C/O values of the matter located between the H burning shell and the surface at the time of the PN ejection. Their predictions for metal poor stars with $M = 1\ M_{\odot}$ are log N(He)/N(H) = 10.93 and log C/O = −0.31. These values are considerably smaller than those of BB1 and H4-1, and indicate that these objects have ejected mass from regions where incomplete or even complete helium burning has taken place. From nuclear reaction rates some freshly made O and Ne^{22} is expected if C is produced, therefore at least a fraction of the excesses in O and Ne in Table 5 could be due to the evolution of the progenitors themselves.

The enriched material in BB1 and H4-1 has a composition by mass of C/He $\sim$ 0.20, C/O $\sim$ 10 and $5.6 < C/Ne < 290$ (Table 5). The Ne enrichment could be made up of Ne^{22}. These values produce observational constraints for stellar evolution models and can be used as input parameters for models of galactic chemical evolution.

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REFERENCES

Aldrovandi, S.M.V. 1980, *Ap. and Space Sci.*, **71**, 393.
Barker, T. 1980, *Ap. J.*, **237**, 482.
Bertsch, D.L., Fichtel, C.E., and Reames, D.V. 1972, *Ap. J.*, **171**, 169.
Boeshaar, G.O. and Bond, H.E. 1977, *Ap. J.*, **213**, 421.
Brocklehurst, M. 1971, *M.N.R.A.S.*, **153**, 471.
Cox D.P. and Daltabuit, E. 1971, *Ap. J.*, **167**, 257.
Eissner, W., Martins, P. de A.P., Nussbaumer, H., Saraph, H.E., and Seaton, M.J. 1969, *M.N.R.A.S.*, **146**, 63.
Hawley, S.A. and Miller J.S. 1978, *Ap. J.*, **220**, 609.
Lambert, D.L. 1978, *M.N.R.A.S.*, **182**, 249.
Lambert, D.L. and Luck, R.E. 1978, *M.N.R.A.S.*, **183**, 79.
Lequeux, J., Peimbert, M., Rayo, J.F., Serrano, A., and Torres-Peimbert, S. 1979, *Astr. and Ap.*, **80**, 155.
Oke, J.B. 1974, *Ap. J. Suppl.*, **27**, 21.
Peimbert, M. 1973, *Mem. Soc. Roy. Sci. Liège 6e serie*, **5**, 391.
Peimbert, M. 1978, in *Planetary Nebulae, Observations and Theory*, IAU Symp. 76, ed. Y. Terzian (Dordrecht: D. Reidel), p. 215.
Peimbert, M. 1981, in *The Universe in Ultraviolet Wavelengths: The First Two Years of IUE*, NASA CP-2171, ed. R.D. Chapman, p. 557.
Peimbert, M. 1981, in *Physical Processes in Red Giants*, ed. I. Iben Jr. and A. Renzini (Dordrecht: D. Reidel), 409.
Peimbert, M. and Costero, R. 1969, *Bol. Obs. Tonantzintla y Tacubaya*, **5**, 3.
Peimbert M. and Torres-Peimbert, S. 1976, *Ap. J.*, **203**, 581.
Peimbert, M. and Torres-Peimbert, S. 1977, *M.N.R.A.S.*, **179**, 217.
Pengelly, R.M. 1963, Ph. D. thesis, University of London.
Pradhan, A.K. 1976, *M.N.R.A.S.*, **177**, 31.
Pradhan, A.K. 1978, *M.N.R.A.S.*, **183**, 89p.
Renzini, A. and Voli, M. 1981, *Astr. and Ap.*, **94**, 175.
Robbins, R.R. 1968, *Ap. J.*, **151**, 511.
Robbins, R.R. and Bernat, A.P. 1973, *Mem. Soc. Roy. Sci. Liège 6e serie*, **5**, 263.
Stone, R.P.S. 1977, *Ap. J.*, **218**, 267.
Storey, P.J. 1981, *M.N.R.A.S.*, **195**, 27 p.
Torres-Peimbert, S. 1981, in preparation.
Torres-Peimbert, S. and Peimbert, M. 1977, *Rev. Mexicana Astron. Astrof.*, **2**, 181.
Torres-Peimbert, S. and Peimbert, M. 1979, *Rev. Mexicana Astron. Astrof.*, **4**, 341.
Whitford, A.E. 1958, *A.J.*, **63**, 201.

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