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Chemical abundances of disk planetary nebulae*

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Abstract. New determinations of chemical abundances of disk planetary nebulae in the southern hemisphere are reported. Most objects belong to Type II according to the classification scheme proposed by Peimbert. We present line fluxes, colour excesses, electron temperatures and densities, and abundances of He, N, O, Ne, S, and Ar for 33 nebulae, several of which for the first time. Distance-independent correlations are used to classify these objects according to the population types within the subsystem of planetary nebulae.

Key words: planetary nebulae: general – interstellar medium: abundances

1. Introduction

The number of known planetary nebulae in the Milky Way is about 1500 (Acker et al. 1987; Acker & Stenholm 1990; Zijlstra et al. 1990), which is a small fraction of the total number of such objects in the whole Galaxy (Maciel 1989; Phillips 1989). An even smaller fraction has accurately measured properties, which include plasma diagnostics and chemical abundances. On the other hand, recent work has emphasized the considerable variety of these properties within the subsystem of galactic planetary nebulae (see for example Peimbert 1990; Maciel 1992), the same being true for the space distribution and kinematics of these objects (Schneider et al. 1983; Dutra & Maciel 1990; Maciel & Dutra 1992). Therefore, it is important to obtain accurately determined diagnostics and abundances, as these properties provide the most reliable means of understanding the phenomenon of planetary nebulae, especially due to its connection with AGB stars and other phases of stellar evolution.

As a consequence, a project was launched involving the Astronomy Department of the IAG/USP and the National Observatory (ON) with the aim of determining chemical abundances of southern planetary nebulae. Past contributions include de Freitas Pacheco & Veliz (1987a, b); de Freitas Pacheco et al. (1989, 1991), and Maciel et al. (1990). The present paper adds to the series by presenting spectroscopic data and derived quantities of a sample of 33 disk planetary nebulae.

2. The observations

The observations reported in this work were performed mainly in the last three years. The spectra were obtained using a Boller and Chivens Cassegrain Spectrograph attached to the 1.6 m telescope of the National Astrophysical Observatory (Brazopolis, Brazil). Two detectors were used during our observational runs: a 1024 pixels intensified Reticon and a 375 × 586 pixels GEC/CCD. Both detectors were used with a grating allowing a reciprocal dispersion of about 4.3 Å pxl^{-1}. A long slit of width 350 μm (4.4 arcsec) aligned east–west was used in all cases. Typical exposure times were about 30 min for observations with the Reticon detector and of about 15–20 min for spectra obtained with the CCD detector. The logbook of the observations is shown in Table 1, which gives the common name, the PK number (Perek & Kohoutek 1967), coordinates, date and type of detector used.

Data reduction followed standard procedures, including wavelength calibration, flat-fielding and correction for atmospheric extinction. Flux calibration was obtained by observing some standard stars during the observation nights.

Emission line intensities were derived by adopting gaussian profiles and by fitting the local continuum using spline techniques. The code also allows a de-blending procedure by fitting different gaussians into a given feature. Constraints like wavelength differences, expected relative intensities (lines originated from the same upper level) or FWHM can be imposed to the fitting when known a priori. The line intensities (relative to Hβ) are given in Table 2, which lists both the measured value (I) and the intensities corrected for interstellar extinction (I_0). Typical errors in the intensities are of about 15% for lines stronger than 10 [in the scale I (Hβ) = 100] and of about 30% for weaker lines. No total fluxes are given, since the projected slit area covers in general only a small fraction of the nebulae.

For a few nebulae, more than one observation were available, so that the line intensities are average values. For two nebulae, long slit spectroscopy allowed measurements to be made at different spatial positions. Spectra were obtained in two distinct positions for NGC 3195, and in three positions for Mz 2.

The colour excesses were based on Balmer ratios, assuming case B, and are given in Table 3. A few nebulae present evidences of a severe reddening [$E(B-V) \geq 1.0$ mag], so that their derived physical parameters are more uncertain.

3. Plasma diagnostics and chemical abundances

To derive nebular ionic concentrations requires a previous determination of the electron temperature and density. From optical spectra, these parameters can usually be estimated from the following line intensity ratios:

$$R(\text{O III}) = \frac{\lambda 4363}{\lambda 5007}, \quad R(\text{N II}) = \frac{\lambda 5754}{\lambda 6584}, \quad R(\text{S II}) = \frac{\lambda 6717}{\lambda 6730}.$$

The obtained values are given in Table 3. For a few objects, the

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* Based on observations obtained at the National Astrophysical Observatory (LNA), Brazil

Table 1. Logbook of the observations

Object	PK	α (1950)	δ (1950)	Date	Detector
NGC 2792	256+04 1	09 10 34	−42 13 08	Dec. 21, 1989	Reticon
NGC 2818	261+08 1	09 13 59	−36 24 58	May 12, 1991	CCD
NGC 3195	296−20 1	10 10 02	−80 36 19	May 10, 1991	CCD
NGC 4361	294+43 1	12 21 55	−18 30 32	May 04, 1989	Reticon
NGC 5307	312+10 1	13 47 53	−50 57 21	May 08, 1989	Reticon
NGC 5882	327+10 1	15 13 25	−45 27 56	May 12, 1991	CCD
NGC 6439	011+05 1	17 45 26	−16 27 50	May 08, 1989	Reticon
NGC 6563	358−07 1	18 08 45	−33 52 46	May 11, 1991	CCD
NGC 6565	003−04 5	18 08 43	−28 11 23	May 08, 1989	Reticon
NGC 6620	005−06 1	18 19 47	−26 50 49	May 11, 1991	CCD
NGC 6629	009−05 1	18 22 42	−23 13 45	May 09, 1989	Reticon
NGC 7009	037−34 1	21 01 28	−11 33 54	May 09, 1989	Reticon
IC 418	215−24 1	05 25 10	−12 44 15	Dec. 20, 1989	Reticon
IC 2501	281−05 1	09 37 20	−59 51 34	Dec. 20, 1989	Reticon
IC 2621	291−04 1	10 58 23	−64 58 40	Dec. 21, 1989	Reticon
IC 4406	319+15 1	14 19 16	−43 55 53	May 08, 1989	Reticon
IC 4634	000+12 1	16 58 35	−21 45 34	May 08, 1989	Reticon
IC 4776	002−13 1	18 42 36	−33 23 58	May 09, 1989	Reticon
He 2-5	264−12 1	07 45 57	−51 08 01	May 09, 1989	Reticon
He 2-9	258−00 1	08 26 39	−39 13 38	May 04, 1989	Reticon
He 2-15	261+02 1	08 51 40	−39 51 44	May 10, 1991	CCD
He 2-21	275−04 2	09 12 22	−55 15 43	May 11, 1991	CCD
He 2-86	300−02 1	12 27 39	−64 35 02	Dec. 20, 1989	Reticon
				May 11 1991	CCD
He 2-112	319+06 1	14 37 00	−52 22 35	May 10, 1991	CCD
He 2-113	321+03 1	14 56 15	−54 06 13	July 03, 1987	Reticon
				June 22, 1988	Reticon
He 2-115	321+02 1	15 01 39	−55 00 15	May 11, 1991	CCD
He 2-117	321+02 2	15 02 17	−55 47 47	May 12, 1991	CCD
He 2-138	320−09 1	15 51 22	−65 59 58	May 08, 1989	Reticon
He 2-141	325−04 1	15 55 09	−58 14 50	May 12, 1991	CCD
He 2-164	332−03 1	16 25 59	−3 16 11	May 12, 1991	CCD
M 1-38	002−03 5	18 02 55	−28 40 50	May 11, 1989	Reticon
M 3-6	254+05 1	08 38 39	−32 11 56	Dec. 21, 1989	Reticon
Mz 2	329−02 2	16 10 29	−54 49 42	May 11, 1991	CCD

de-blending procedure applied to the ionized sulphur red lines did not produce trustful results, due to the low signal-to-noise ratio in the spectrum. In these cases, an average electron density of 10^4 cm^{-3} was adopted (see for example Pottasch 1984).

The determination of the ionic abundances was performed using a three level atom model, and we have included in the solution of the statistical equilibrium equations radiative transitions and collisional excitation and de-excitation. The relevant atomic data were those compiled by Mendoza (1983). The elemental abundances were estimated using the ionization correction factors (icf) given by Peimbert & Torres-Peimbert (1977) and Dennefeld & Stasinska (1983) for nitrogen and sulphur, respectively. For argon, if only the ion Ar^{2+} was observed, the icf was obtained from model calculations by Aller & Czyzak (1983; cf. de Freitas Pacheco et al. 1989). These abundances are given in Table 4. For two objects (IC 4634 and IC 4776) we present averages taking also into account the results by de Freitas Pacheco et al. (1989). In the derivation of the He abundance, collisional effects in He I lines were taken into account using formulae by Clegg (1987).

4. Discussion

According to the classification scheme by Peimbert (1978), each PN type can be characterized by average abundances. Based on a larger sample of galactic objects, Maciel (1992) presented a table of average values of the abundances of the best observed elements, namely He, N, O, S, C, Ne, Ar, and Cl. In view of these results, the abundances given in Table 4 permit us to tentatively classify the objects of the present sample as Type I (8 nebulae, see Table 5), Type IIa (12 nebulae), Type IIb (9 nebulae) and Type III (4 nebulae). From the data in Tables 4 and 5 we have the average abundances of N, Ne, Ar, and S relative to oxygen given in Table 6, within the uncertainties of 0.1–0.2 dex generally associated to PN abundances. Exceptions are the nitrogen abundances

Table 2. Relative line fluxes (I: observed, I_0: corrected)

Ion	NGC 2792		NGC 2818		NGC 3195[a]		NGC 4361		NGC 5307	
	I	I_0	I	I_0	I	I_0	I	I_0	I	I_0
[Ne III] λ3869	—	—	—	—	—	—	—	—	—	—
[Ne III] λ3967 + Hε	—	—	—	—	—	—	23.1	24.1	—	—
Hδ λ4101	13.7	23.6	—	—	—	—	—	—	—	—
Hγ λ4340	32.8	47.0	—	—	29.1	—	47.6	48.8	—	—
[O III] λ4363	10.2	14.3	—	—	—	—	8.8	9.0	12.7	15.1
He I λ4471	—	—	—	—	8.5	—	—	—	—	—
He II λ4686	90.4	101.3	86.4	86.4	14.6	23.0	120.0	121.0	32.7	34.7
Hβ λ4861	100	100	100	100	100	100	100	100	100	100
[O III] λ4959 + 5007	1492	1373	1268	1268	824.4	726.5	308.5	306.7	2170	2079
[N II] λ5754	1.7	1.0	9.8	9.8	3.3	2.2	—	—	—	—
He I λ5875	5.7	3.3	8.5	8.5	16.6	14.9	1.8	1.7	11.6	8.7
[O I] λ6300	—	—	22.4	22.4	12.2	10.7	—	—	1.2	0.8
[S III] λ6312	3.8	1.8	5.9	5.9	—	—	3.6	3.4	1.8	1.2
Hα λ6563	664	286	286	286	285	285	302	285	445	282
[N II] λ6548 + 6584	32.3	13.9	739	739	487.4	280.3	—	—	61.1	38.7
He I λ6678	—	—	2.3	2.3	4.4	3.9	—	—	3.6	2.3
[S II] λ6717 + 6730	—	—	10.0	10.0	85.8	40.4	—	—	1.4	0.9
He I λ7065	—	—	3.5	3.5	2.4	—	—	—	3.0	1.7
[Ar III] λ7135	23.5	8.2	23.7	23.7	21.3	16.2	—	—	9.1	5.3
[O II] λ7320 + 7330	—	—	11.6	11.6	6.3	3.2	—	—	3.6	2.0

[a] $I = I_1$, $I_0 = I_2$.

Table 2 (continued)

Ion	NGC 5882		NGC 6439		NGC 6563		NGC 6565		NGC 6620	
	I	I_0	I	I_0	I	I_0	I	I_0	I	I_0
[Ne III] λ3869	—	—	73.2	171.6	—	—	60.1	76.3	—	—
[Ne III] λ3967 + Hε	—	—	—	—	—	—	48.4	59.3	—	—
Hδ λ4101	—	—	—	—	—	—	—	—	—	—
Hγ λ4340	42.3	47.1	32.6	49.2	38.7	47.0	47.6	53.4	32.0	46.8
[O III] λ4363	4.0	4.5	4.7	7.0	8.9	10.2	9.4	10.5	3.6	5.1
He I λ4471	5.4	5.8	—	—	—	—	8.3	9.0	—	—
He II λ4686	4.6	4.8	23.5	26.8	18.8	19.9	15.4	16.0	23.8	26.8
Hβ λ4861	100	100	100	100	100	100	100	100	100	100
[O III] λ4959 + 5007	1374	1341	2348	2134	1255	1200	1872	1822	1650	1512
[N II] λ5754	0.22	0.19	2.2	1.3	5.8	4.4	6.0	5.1	4.1	2.4
He I λ5875	17.7	15.0	23.6	12.6	19.4	14.4	13.5	11.3	28.4	15.8
[O I] λ6300	0.4	0.3	2.8	1.2	24.5	16.4	23.1	18.2	23.7	10.8
[S III] λ6312	1.3	1.0	1.9	0.8	—	—	2.4	1.9	6.3	2.6
Hα λ6563	367	285	756	287	448	285	379	289	696	286
[N II] λ6548 + 6584	20.7	16.1	400.8	151.6	443	280	803	612	858	351
He I λ6678	8.5	6.5	9.3	3.4	5.9	3.6	2.9	2.1	10.5	4.1
[S II] λ6717 + 6730	3.3	2.5	38.8	13.8	41.6	25.6	101.0	75.5	139	53.3
He I λ7065	7.4	5.4	15.1	4.7	5.2	3.0	5.9	4.2	11.3	3.8
[Ar III] λ7135	20.5	14.9	89.9	27.0	32.7	18.6	40.0	28.5	90.2	29.8
[O II] λ7320 + 7330	2.6	1.9	16.2	4.5	13.1	7.2	23.0	16.1	27.4	8.5

Table 2 (continued)

Ion	NGC 6629		NGC 7009		IC 418		IC 2501		IC 2621	
	I	I_0	I	I_0	I	I_0	I	I_0	I	I_0
[Ne III] λ3869	52.3	91.4	58.4	65.7	—	—	—	—	—	—
[Ne III] λ3967 + Hε	36.1	63.1	45.5	50.5	—	—	14.2	27.3	—	—
Hδ λ4101	20.5	32.6	29.2	31.8	23.4	27.0	18.4	31.0	—	—
Hγ λ4340	43.5	59.0	44.8	47.4	42.8	47.1	34.5	49.0	29.3	47.0
[O III] λ4363	3.5	4.7	8.3	8.8	2.0	2.2	4.8	6.7	11.8	18.6
He I λ4471	5.6	7.0	4.4	4.6	2.2	2.3	6.0	7.8	—	—
He II λ4686	—	—	15.5	15.8	—	—	—	—	32.2	37.4
Hβ λ4861	100	100	100	100	100	100	100	100	100	100
[O III] λ4959 + 5007	1157	1078	1957	1931	204.6	200.2	1513	1394	2984	2674
[N II] λ5754	—	—	0.20	0.18	2.2	1.9	1.7	1.0	8.2	4.3
He I λ5875	18.6	11.6	12.5	11.4	10.5	9.1	21.7	12.5	19.6	9.5
[O I] λ6300	—	—	0.13	0.11	2.3	1.9	6.7	3.2	22.3	8.4
[S III] λ6312	—	—	0.94	0.83	0.5	0.4	1.3	0.6	7.1	2.7
H α λ6563	605	290	328	285	356	285	664	286	870	286
[N II] λ6548 + 6584	38.5	18.8	36.4	31.8	301	241	190	82	630	206
He I λ6678	5.9	2.8	2.8	2.4	2.2	1.7	6.4	2.6	5.9	1.8
[S II] λ6717 + 6730	2.4	1.1	3.3	2.8	5.8	4.6	9.0	3.7	18.7	5.7
He I λ7065	10.2	4.2	4.5	3.8	5.8	4.4	16.1	5.8	—	—
[Ar III] λ7135	31.2	12.8	16.3	13.8	6.7	5.1	33.6	11.8	89.5	22.5
[O II] λ7320 + 7330	4.9	1.9	1.7	1.4	31.2	23.3	25.6	8.4	76.4	17.7

Table 2 (continued)

Ion	IC 4406		IC 4634		IC 4776		He 2-5		He 2-9	
	I	I_0	I	I_0	I	I_0	I	I_0	I	I_0
[Ne III] λ3869	25.1	35.1	42.9	61.1	41.6	49.4	59.0	83.2	—	—
[Ne III] λ3967 + Hε	19.7	26.5	38.3	52.4	35.9	41.8	24.3	32.9	—	—
Hδ λ4101	20.0	25.6	20.4	26.5	26.9	30.5	31.2	40.0	—	—
Hγ λ4340	43.0	50.0	42.2	50.0	44.0	47.8	46.2	54.5	22.7	44.3
[O III] λ4363	8.6	10.1	6.1	7.2	8.2	8.9	8.1	9.5	0.35:	0.66:
He I λ4471	—	—	7.3	8.3	5.4	5.7	—	—	4.0	6.5
He II λ4686	21.3	22.4	—	—	—	—	—	—	6.7	8.3
Hβ λ4861	100	100	100	100	100	100	100	100	100	100
[O III] λ4959 + 5007	1835	1768	1731	1664	1640	1609	941	905	1003	859
[N II] λ5754	4.8	3.8	—	—	1.2	1.1	—	—	5.4	2.2
He I λ5875	14.7	11.5	14.8	11.4	14.0	12.3	15.3	11.8	39.2	14.0
[O I] λ6300	29.6	21.2	1.9	1.3	3.3	2.8	—	—	13.1	3.3
[S III] λ6312	9.2	6.6	1.0	0.7	1.5	1.3	0.83	0.60	5.4	1.4
Hα λ6563	424	290	442	290	365	280	430	290	1476	290
[N II] λ6548 + 6584	667	445	29.5	19.7	59.3	48.7	77.7	52.4	516	106
He I λ6678	3.7	2.5	3.8	2.5	3.6	2.9	3.7	2.4	16.0	3.0
[S II] λ6717 + 6730	16.0	10.6	2.6	1.7	4.6	3.7	2.8	1.8	16.7	3.1
He I λ7065	3.6	2.2	7.9	4.8	9.4	7.4	10.1	6.3	46.7	6.9
[Ar III] λ7135	30.0	18.7	15.0	9.1	16.8	13.2	11.5	7.1	71.5	10.1
[O II] λ7320 + 7330	14.6	8.9	5.5	3.2	15.0	11.6	11.4	6.8	97.1	12.2

Table 2 (continued)

Ion	He 2-15		He 2-21		He 2-86		He 2-112		He 2-113	
	I	I_0	I	I_0	I	I_0	I	I_0	I	I_0
[Ne III] λ3869	—	—	—	—	—	—	—	—	—	—
[Ne III] λ3967+Hε	—	—	—	—	—	—	—	—	—	—
Hδ λ4101	—	—	—	—	—	—	—	—	—	—
Hγ λ4340	—	—	31.8	47.2	—	—	—	—	—	—
[O III] λ4363	—	—	8.5	12.4	—	—	—	—	—	—
He I λ4471	—	—	—	—	—	—	8.5	12.4	—	—
He II λ4686	53.0	61.0	29.8	33.8	—	—	41.7	49.0	—	—
Hβ λ4861	100	100	100	100	100	100	100	100	100	100
[O III] λ4959+5007	1430	1290	1480	1351	1259	1011	2461	2186	—	—
[N II] λ5754	38.9	21.1	—	—	10.7	2.9	12.7	6.2	13.3	8.6
He I λ5875	25.2	12.7	20.3	11.1	89.9	20.9	29.1	13.2	39.7[b]	23.7
[O I] λ6300	57.5	23.0	—	—	21.2	3.0	25.6	8.9	44.8	22.4
[S III] λ6312	9.1	3.6	1.1	0.49	12.5	1.75	12.7	4.4	—	—
Hα λ6563	814	285	722	286	2667	287	954	285	631	297
[N II] λ6548+6584	4021	1405	17.2	6.8	1382	147	1067	318	426	201
He I λ6678	9.9	3.3	7.7	2.9	54.3	5.2	13.5	3.8	8.2[b]	3.6
[S II] λ6717+6730	332	108	3.6	1.3	75.6	6.9	100.8	27.7	—	—
He I λ7065	—	—	11.7	3.8	150.4	10.0	24.1	5.6	20.6[b]	7.8
[Ar III] λ7135	111.3	30.3	15.9	3.7	455	28.4	97.5	21.7	—	—
[O II] λ7320+7330	42.7	10.8	3.8	1.1	127	6.7	70.8	14.5	129.4	48.3

[b] Also stellar contribution; central star is of WC type.

Table 2 (continued)

Ion	He 2-115		He 2-117		He 2-138		He 2-141		He 2-164	
	I	I_0	I	I_0	I	I_0	I	I_0	I	I_0
[Ne III] λ3869	—	—	—	—	—	—	—	—	—	—
[Ne III] λ3967+Hε	—	—	—	—	—	—	—	—	—	—
Hδ λ4101	—	—	—	—	—	—	—	—	—	—
Hγ λ4340	17.6	47.0	—	—	40.5	46.0	39.3	47.0	—	—
[O III] λ4363	2.4	6.4	—	—	—	—	19.2	22.8	—	—
He I λ4471	—	—	—	—	—	—	7.9	9.0	—	—
He II λ4686	—	—	—	—	—	—	77.6	82.1	73.3	78.9
Hβ λ4861	100	100	100	100	100	100	100	100	100	100
[O III] λ4959+5007	822	655	1171	960	—	—	1639	1573	1348	1278
[N II] λ5754	8.9	2.3	9.3	2.8	0.76	0.64	1.6	1.2	0.56	0.40
He I λ5875	79.9	17.6	92.9	24.8	0.80	0.66	7.4	5.6	11.7	8.2
[O I] λ6300	29.0	3.8	27.6	4.7	—	—	5.8	4.0	6.3	3.9
[S III] λ6312	7.5	1.0	10.3	1.7	—	—	2.4	1.6	2.6	1.6
Hα λ6563	2893	287	2156	287	378	285	434	285	493	285
[N II] λ6548+6584	1083	106	1485	196	333	250	128.4	84.1	40.6	23.5
He I λ6678	49.3	4.3	41.9	5.0	—	—	3.4	2.2	5.7	3.2
[S II] λ6717+6730	41.2	3.5	83.1	9.6	27.4	20.2	13.7	8.7	15.1	8.4
He I λ7065	126	7.6	107	9.2	—	—	2.9	1.7	2.2	1.1
[Ar III] λ7135	254	14.4	336	27.3	—	—	31.7	18.8	34.2	17.3
[O II] λ7320+7330	456	21.8	108	7.6	2.5	1.7	8.1	4.7	5.7	2.8

Table 2 (continued)

Ion	M 1-38		M 3-6		Mz 2		Mz 2		Mz 2	
	I	I_0	I	I_0	I_1	I_{10}	I_2	I_{20}	I_3	I_{30}
[Ne III] λ3869	—	—	—	—	—	—	—	—	—	—
[Ne III] λ3967 + Hε	—	—	—	—	—	—	—	—	—	—
Hδ λ4101	—	—	—	—	—	—	—	—	—	—
Hγ λ4340	—	—	36.4	47.0	—	—	—	—	—	—
[O III] λ4363	—	—	3.2	4.1	—	—	—	—	—	—
He I λ4471	—	—	4.5	5.4	—	—	—	—	—	—
He II λ4686	—	—	—	—	84.4	96.6	89.7	103	78.1	89.4
Hβ λ4861	100	100	100	100	100	100	100	100	100	100
[O III] λ4959 + 5007	—	—	1131	1066	2704	2442	2516	2272	2559	2311
[N II] λ5754	1.8	1.0	—	—	6.9	3.9	8.1	4.5	7.5	4.2
He I λ5875	4.7	2.4	18.8	12.7	13.8	7.2	14.2	7.4	16.1	8.4
[O I] λ6300	5.7	2.3	—	—	32.2^c	13.4^c	—	—	13.9	5.8
[S III] λ6312	—	—	—	—	—	—	—	—	12.9	5.3
Hα λ6563	799	287	522	286	777	285	777	285	777	285
[N II] λ6548 + 6584	582	208	25.2	13.7	497	183	478	176	701.3	258
He I λ6678	—	—	7.2	3.8	8.0	2.8	12.8	4.4	7.3	2.5
[S II] λ6717 + 6730	67.0	22.4	2.0	1.0	127	43.5	138	47.3	151.2	51.7
He I λ7065	—	—	5.6	2.7	5.4	1.6	6.7	2.0	8.0	2.4
[Ar III] λ7135	—	—	18.3	8.6	115	33.1	121	34.8	121	34.8
[O II] λ7320 + 7330	13.8	3.6	2.4	1.1	15.9	4.3	28.8	7.7	26.4	7.1

[c] Includes [S III] λ6312.

for Types I and III in the present sample, which seem to be 0.2 dex lower than the objects considered by Maciel (1992).

The relative abundances can be better analyzed with the use of distance-independent correlations, as discussed for example by Maciel (1992) and Henry (1990). Figure 1 shows log(N/O) vs. He/H for the objects of Table 4, where it can be noted that; (i) a general trend is obtained, in the sense that N/O increases with He/H, reflecting the enrichment in He and N due to the dredge-up episodes in the PN progenitors, as proposed by theoretical models (see for example Renzini & Voli 1981; Peimbert 1992); (ii) the separation of the different types of PN is clear, and Type I nebulae (squares) are generally located at the upper right corner of Fig. 1, Type II (IIa: open circles, IIb: filled circles) are in the middle of the diagram, and Type III (crosses) are near the bottom left corner.

Such separation is not as clear in Figs. 2 and 3, where Ar/H and S/H are plotted against O/H, respectively. According to Maciel (1992), the total difference in the abundances of Ar and S among Types I–III is of the order of 0.3–0.5 dex, so that some overlapping is to be expected, as confirmed by Figs. 2 and 3. These differences are essentially due to the galactic evolution, as the progenitors of these nebulae do not produce significant amounts of these elements. However, the general trends shown in Figs. 2 and 3 follow closely the relationships obtained for a larger sample by Maciel (1992).

Few objects present deviations relative to the general trends of Figs. 1–3; (i) the nebula He2-164 has large He abundances, but does not seem to present a significant N enrichment, which is normal to Type I objects. The N lines are relatively weak, so that the derived abundances are uncertain, and have not been included in the calculation of the average N/O of Table 6. This can be clearly seen in Fig. 4, where log(N/O) is plotted against N/H. According to the analysis by Maciel (1992), Type I objects are located on the upper right corner of the diagram, which is not the case for He2-164. The object is similar to M1-17, which is discussed by de Freitas Pacheco et al. (1991); (ii) the nebula He2-5 has intermediate characteristics of Types II and III. In particular, N abundances are uncertain, and the O/H ratio is very low, as can be seen from Table 4 and Figs. 2 and 3; (iii) the nebulae IC 4634 and IC 4776 do not fit well in any of the considered types. As discussed below (cf. Maciel et al. 1990), these nebulae seem to have very low mass progenitors, and their evolution is not clearly understood in terms of the commonly adopted evolutionary tracks.

The results given in Table 4 indicate a positive correlation between the N/O ratio and the argon abundance, although a large scatter is present in the plot. Such a significant correlation was also noted by Köppen et al. (1991), and the first impression is that this result is quite unexpected. The N/O ratio is altered in the outer layers of the progenitor stars due to different dredge-up episodes; however, argon is certainly not affected by the nucleosynthesis of intermediate mass stars. As we have seen, the chemical abundances have been used to classify the nebulae in different classes: I, IIa, IIb, and III. These types probably reflect the mass spectrum of the progenitors: Type I nebulae originated from more massive stars, while Type III are the end products of less massive stars. Figure 5 shows a plot of the average log(N/O) ratio for each type as a function of the average argon abundance

Table 3. Physical parameters

Object	$E(B-V)$	T_e [O III]	T_e [N II]	n_e (cm^{-3})
NGC 2792	0.74	12400		10^4[a]
NGC 2818	0.0:		10460	$5.7\,10^2$
NGC 3195	0.0:		8320	$5.9\,10^2$
NGC 4361	0.05	20400		10^3[a]
NGC 5307	0.40	10940		10^4[a]
NGC 5882	0.22	9260	9260	$5.0\,10^3$
NGC 6439	0.85	8700	8700	$6.3\,10^3$
NGC 6563	0.40	11650	11650	$5.2\,10^2$
NGC 6565	0.25	10300	8900	$1.0\,10^3$
NGC 6620	0.78	8930	8930	$4.1\,10^3$
NGC 6629	0.66	9360		10^4[a]
NGC 7009	0.12	9460		$8.3\,10^3$
IC 418	0.19	10000		$1.3\,10^4$
IC 2501	0.74	8400	8400	$4.1\,10^4$
IC 2621	0.98	10900	10900	$1.9\,10^4$
IC 4406	0.35	10400	8350	10^4[a]
IC 4634	0.30	9450		$1.0\,10^4$[b]
IC 4776	0.14	9000	9000	$3.0\,10^4$[b]
He 2-5	0.36	12400		10^4[a]
He 2-9	1.44		11960	$9.4\,10^3$
He 2-15	0.92		10700	$3.0\,10^3$
He 2-21	0.81	12400		$4.7\,10^3$
He 2-86	1.96		9440	$3.5\,10^4$
He 2-112	1.06		12280	$1.8\,10^3$
He 2-113	0.69		10400	$1.0\,10^5$
He 2-115	2.03		10770	$2.1\,10^4$
He 2-117	1.77		9270	$1.8\,10^4$
He 2-138	0.25		5930	$6.1\,10^3$
He 2-141	0.37		10500	$2.9\,10^3$
He 2-164	0.48		11670	$6.6\,10^2$
M1-38	0.90		6500	$2.0\,10^4$
M3-6	0.53	9000		10^4[a]
Mz 2	0.88		12700	$2.0\,10^3$

[a] Adopted.
[b] Averages with de Freitas Pacheco et al. (1989).

(for log H = 12.0). These averages minimize the gradient effects due to different radial distances to the galactic centre. Bars indicate the rms deviation for each class. We observe that there is a clear trend, in the sense that the average N/O ratio increases with the average argon abundance, and also a net correlation with the type of the nebula. From our point of view, this plot reflects an age effect. Type I nebulae had more massive progenitors, and are probably younger than nebulae originated from less massive stars. Therefore, Type I nebulae have been formed out of a medium more enriched in argon than the other types. In other words, the variation of the average argon abundance is a consequence of a gradual enrichment in heavy elements of the interstellar medium out of which the progenitors were formed. On the other hand, the average N/O ratio reflects for each type the average mass of the progenitors, which is one of the most important parameters determining the effect of the dredge-up episodes.

The relatively complete sets of abundances for several of the nebulae of Table 4 are being published for the first time. Here we present some remarks on those that have been included in previous studies of abundance determinations:

NGC 2818: Our results generally agree with those presented by Peimbert & Torres-Peimbert (1983).

NGC 6620: Our results are in good agreement with Aller & Keyes (1987). For He/H our value is somewhat higher than the abundances given by Aller & Keyes (1987) and Köppen et al. (1991), and in agreement with the recent determination by Shaw & Kaler (1989).

NGC 2792: He/H and O/H agree with Torres-Peimbert & Peimbert (1977) and Kaler (1979). Nitrogen was not determined due to the weakness of the lines. This is a Type II nebula, tentatively classified as IIa for its high oxygen abundance.

NGC 3195: The He abundance agrees with Shaw & Kaler (1989). Oxygen is higher than given by Kaler (1978).

NGC 6439: Our abundances are similar to those by Aller & Keyes (1987), except for a lower He/H ratio. N and O seem also more abundant, so that the object has been placed in Type IIa.

NGC 6563: The abundances of Table 4 agree with those by Kaler (1985) and Köppen et al. (1991), but He seems less abundant (cf. Shaw & Kaler 1989).

NGC 6565: Our He/H value is similar to those given by Aller et al. (1988) and Pottasch (1984). Oxygen seems slightly more abundant than found by Aller et al. (1988). The abundances are generally similar to the values reported by Köppen et al. (1991).

NGC 7009: This object has been studied by several people (Köppen et al. 1991; Pottasch 1984; Barker 1986; Kaler 1980), and the results generally agree with each other.

IC 2501: Our values agree with Peimbert & Serrano (1980) and Kaler (1980). He is somewhat lower than found by these authors.

IC 4406: Our He/H ratio is much lower than quoted by Peimbert & Torres-Peimbert (1983) and Kaler (1980). N is higher, so that the object is probably of Type I–IIa.

He2-138: He seems to be very low (cf. Shaw & Kaler 1989), but oxygen is higher than measured before (Kaler 1980).

NGC 5307: Our abundances are slightly higher than published values by Torres-Peimbert & Peimbert (1977) and Kaler (1980), except for helium. The object is probably well classified as Type IIb.

NGC 5882: The values of Table 4 agree with Pottasch (1984). The N abundance is somewhat lower than previous results by Torres-Peimbert & Peimbert (1977) and Köppen et al. (1991).

NGC 6229: There is a good agreement with the results by Aller & Keyes (1987).

IC 418: Our results agree with those by Aller & Czyzak (1983) and Pottasch (1984).

NGC 4361: Our He/H abundance is somewhat higher than given by Torres-Peimbert et al. (1990), and agrees with Shaw & Kaler (1989). Oxygen seems also more abundant than given by Torres-Peimbert et al. (1990), and is similar to the value by Pottasch (1984). The object is certainly underabundant in metals, and has been classified as a halo nebula (Torres-Peimbert et al. 1990;

Table 4. Abundances[a]

Object	He/H	log (N/O)	N	O	Ne	S	Ar
NGC 2792	0.115			8.75			6.23
NGC 2818	0.136	−0.26	8.74	9.00		7.30	6.94
NGC 3195	0.124	−0.52	8.38	8.90			6.85
NGC 4361	0.121			≥8.28	≥7.51		
NGC 5307	0.088	−0.82	8.01	8.83		6.98	
NGC 5882	0.108	−1.08	7.61	8.69		6.92	6.38
NGC 6439	0.107	−0.60	8.51	9.11	8.65	6.98	6.80
NGC 6563	0.118	−0.35	8.08	8.43			6.33
NGC 6565	0.095	−0.64	8.40	9.04	8.19	6.98	6.80
NGC 6620	0.130	−0.49	8.51	9.00		7.32	6.90
NGC 6629	0.074	−0.92	7.69	8.61	8.09		6.28
NGC 7009	0.088	−0.60	8.29	8.89	8.04	7.01	6.37
IC 418	0.110	−0.74	7.72	8.46			6.43
IC 2501	0.078	−0.92	8.06	8.98			6.45
IC 2621	0.088	−0.52	8.48	9.00		7.00	6.58
IC 4406	0.095	−0.41	8.54	8.95		7.25	6.67
IC 4634	0.071	−1.24	7.54	8.78	8.01	6.86	6.21
IC 4776	0.090	−1.12	7.78	8.90	7.98	6.94	6.47
He 2-5	0.090	−0.64	7.57	8.20	7.64	6.09	5.80
He 2-9	0.103	−0.66	7.62	8.28		6.36	6.05
He 2-15	0.139	+0.23	9.02	8.79		7.22	6.79
He 2-21	0.102	−0.85	7.59	8.45		6.45	5.62
He 2-86	0.132	−0.36	8.28	8.63		7.00	6.67
He 2-112	0.137	−0.42	8.34	8.76		6.99	6.48
He 2-113		−0.72	7.76	8.48			
He 2-115	0.110	−0.89	7.55	8.43		6.34	6.43
He 2-117	0.143	−0.42	8.23	8.65		6.98	6.59
He 2-138		−0.77	8.31	9.08			
He 2-141	0.119	−0.66	8.34	9.00		7.00	6.75
He 2-164	0.132	−1.00	7.68	8.68		6.83	6.51
M 1-38		−0.77	8.14	8.91		6.91	
M 3-6	0.094	−0.89	7.76	8.64			6.16
Mz 2	0.138	−0.19	8.75	8.93		6.93	6.82

[a] Abundances given are log (X/H) + 12 except for He/H and log (N/O).

Table 5. Classification of planetary nebulae

Type I	Type IIa	Type IIb	Type III
NGC 2818	NGC 2792	NGC 5307	NGC 4361
NGC 6620	NGC 3195	NGC 5882	IC 4634
He 2-15	NGC 6439	NGC 6629	IC 4776
He 2-86	NGC 6563	IC 418	He 2-5
He 2-112	NGC 6565	He 2-9	
He 2-117	NGC 7009	He 2-21	
He 2-164	IC 2501	He 2-113	
Mz 2	IC 2621	He 2-115	
	IC 4406	M3-6	
	He 2-138		
	He 2-141		
	M1-38		

Table 6. Average abundances relative to oxygen

	Type I	Type IIa	Type IIb	Type III
log (N/O)	−0.27	−0.61	−0.84	−1.00
log (Ar/O)	−2.09	−2.32	−2.32	−2.47
log (Ne/O)		−0.72		−0.76
log (S/O)	−1.73	−1.97	−1.93	−2.00

Peimbert 1991). However, its distance from the galactic plane and peculiar velocity are not very large (see below).

IC 4634: Our abundances are similar to those by Aller & Czyzak (1983). He/H is lower than given by Shaw & Kaler (1989). The classification is uncertain. The nebula is strongly metal deficient,

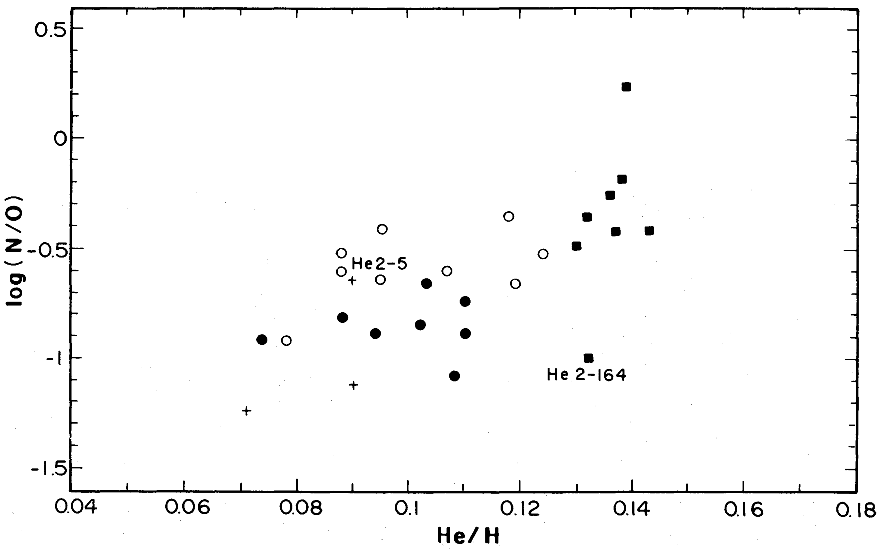

Fig. 1 log(N/O) vs. He/H for the planetary nebulae of Table 4. Symbols are as follows: Type I (squares); Type IIa (empty circles); Type IIb (filled circles); Type III (crosses)

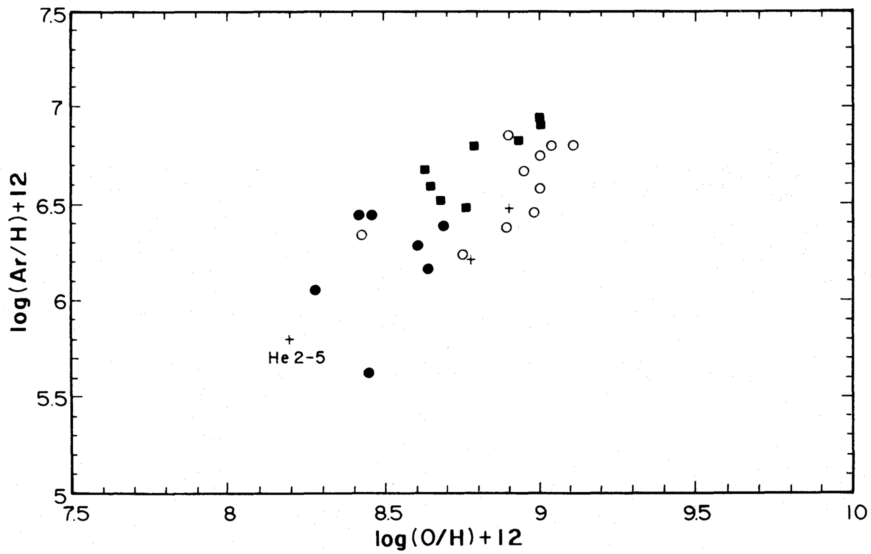

Fig. 2 log(Ar/H) vs. log(O/H) for the planetary nebulae of Table 4. Symbols as in Fig. 1

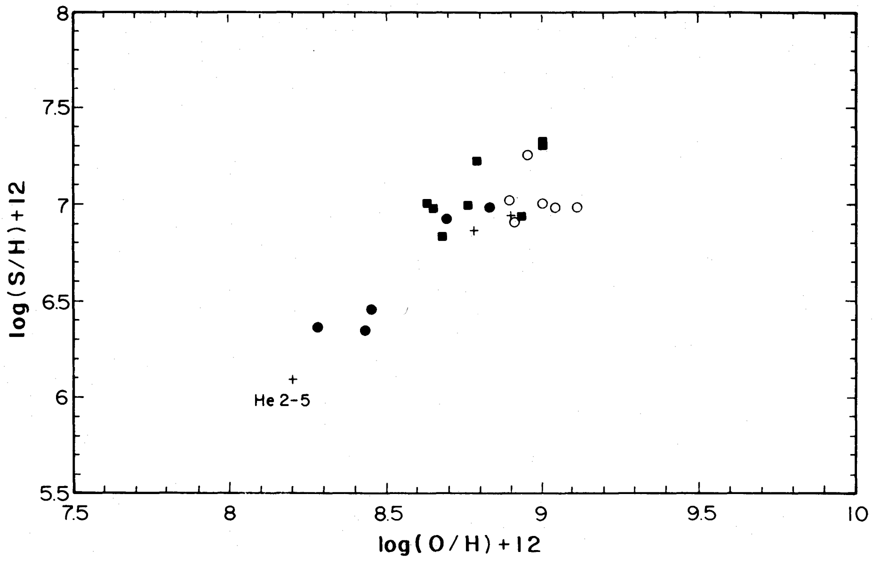

Fig. 3 log(S/H) vs. log(O/H) for the planetary nebulae of Table 4. Symbols as in Fig. 1

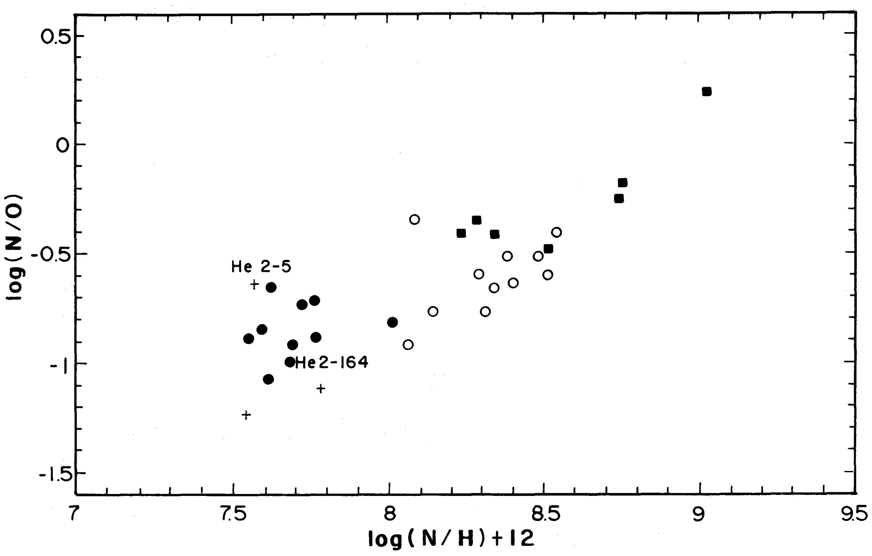

Fig. 4 log(N/O) vs. log(N/H) for the planetary nebulae of Table 4. Symbols as in Fig. 1

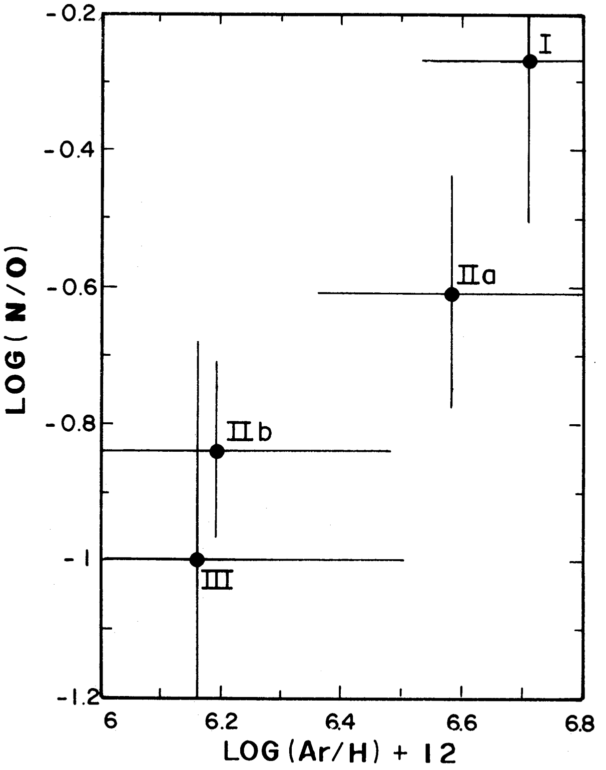

Fig. 5 Average log (N/O) vs. log (Ar/H) for planetary nebulae of Types I, IIa, IIb, and III

and its central star seems to have very low mass (Maciel et al. 1990).

IC 4776: The results agree with Aller & Czyzak (1983). As in the case of IC 4634, the classification is uncertain (IIb–III), but the nebula is definitely underabundant in metals.

For several nebulae (IC 2621, He 2-5, He 2-9, He 2-15, He 2-115, He 2-117) helium abundances have been given by Shaw & Kaler (1989). Their values generally agree with the results of Table 4, especially for He 2-15 and He 2-117, which have He/H$\geq$0.130. A few more objects have been included in the sample by Köppen et al. (1991: He 2-115, M 3-6, He 2-86, He 2-112, and Mz 2). The first two have similar abundances, clearly pointing to a Type II classification. For the last three, our He abundances are somewhat higher, so that new measurements would be welcome to definitely establish their Type I nature.

Some additional information on the objects of Table 5 can be obtained from distance and radial velocity data. In particular, it is interesting to estimate the peculiar radial velocities ΔV, that is, the difference between the observed LSR radial velocity and the velocity determined from an adopted rotation curve (for details, see Dutra & Maciel 1990; Maciel & Dutra 1992). As an example, we have taken distances from Maciel (1984) and Acker (1978) and LSR radial velocities from the catalogue of Schneider et al. (1983), and adopted the rotation curve by Clemens (1985) for $R_0 =$ 8.5 kpc as the distance of the Sun to the galactic centre. It turns out that $|\Delta V| \leq 40$ km s^{-1} for our Type I PN, excluding objects near the direction of the galactic centre and $|\Delta V| \leq 60$ km s^{-1} for Type II and III nebulae of Table 5. This is consistent with the classification criteria adopted and fits nicely into the evolutionary scheme for disk PN discussed by Maciel & Dutra (1992).

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