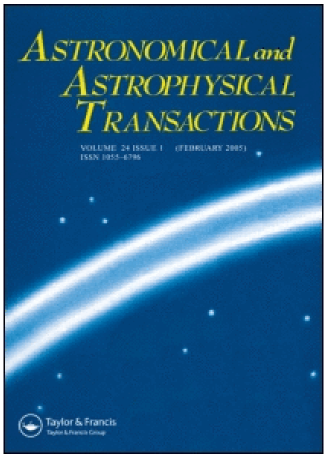

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DETERMINATION OF THE HELIUM ABUNDANCES IN GALACTIC PLANETARY NEBULAE

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We present the results of detailed studies on the He ionic abundances in galactic planetary nebulae. They are based on the newest emissivity data obtained by Benjamin *et al*. and take into account both the radiative transfer effects in the He I emission lines and the impact excitation of He and H atoms. The new values of the He^+-to-H^+ and He-to-H ratios are obtained for different cases of He I line conjunctions.

Keywords: Planetary nebulae; He abundances

For accurate determination of He abundances in planetary nebulae (PNs) it is necessary to calculate correctly the relative ionic abundance ratios of He^+ to H^+ and He^{2+} to H^+, based on the observed intensities of the corresponding He I and He II lines. It has been proven that the He^+-to-H^+ ratios determined by means of the emissivities reported by Brocklehurst (1972) and Smits (1996) differ notably from each other (see Izotov *et al.* (1997)). The reason for this difference is that the emissivities obtained by Brocklehurst and by Smits do not take into account the radiative transfer effects in the He I emission lines. In the recent paper by Benjamin *et al.* (2002), new relations were presented for the emissivities which account for both the radiative transfer effects in the He I lines and the impact excitation of H and He atoms. Those coefficients are used in our work for determining the He abundance of the galactic planetary nebulae.

While calculating the He^+-to-H^+ ratio, we deal with two unknown parameters; the electron concentration n_e(H II) and the optical depth of the He I ($\lambda = 3889$ Å) line (denoted hereafter as τ_{3889}). The latter parameter is concerned with the radiative transfer effects in He I lines. As a result, this factor has caused the intensity of the He I ($\lambda = 3889$ Å) line to decrease, while the intensities of most of the other He I lines have increased. Since the contribution of the underlying stellar absorption in the nuclei of PNs is not so large, we shall neglect it. Thus, the relative abundance of singly ionized He (i.e. the He^+-to-H^+ ratio) y^+ is given by the relation

$$y^+(\lambda) = \frac{I(\lambda)}{I(H\beta)} \frac{F(n_e, T_e)}{f(n_e, T_e, \tau_{3889})}. \tag{1}$$

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Here the ratio $I(\lambda)/I(H\beta)$ gives the relative intensity of the He I line, while $F(n_e, T_e)$ and $f(n_e, T_e, \tau_{3889})$ denote the approximation functions (Benjamin *et al.*,, 2002) introduced in order to calculate the emissivity and to take into account the radiative transfer effects in He I line respectively. The impact excitation coefficient may be derived from the corresponding formulae taken from the work of Kingdon and Ferland (1995). Thus, y^+ depends in our case on the two unknown parameters: n_e(He II) and τ_{3889}. In our calculations, the electron temperature T_e in the He II zone is assumed to be equal to T_e in the [O III] zone (Izotov *et al.*, 1997). In order to obtain n_e(He II) and τ_{3889}, we used the method described by Olive and Skillman (2000), which offers a self-consistent determination of the parameters mentioned above.

Similarly to the study by Olive and Skillman (2000), we consider the conjunctions of three, four, five and six different emission lines of He I: case 1 (three lines: $\lambda = 4471$, 5876 and 6678 Å); case 2 (four lines: $\lambda = 4471$, 5876, 6678 and 7065 Å); case 3 (five lines: $\lambda = 4026$, 4471, 5876, 6678 and 7065 Å); case 4 (six lines: $\lambda = 3889$, 4026, 4471, 5876, 6678 and 7065 Å). Depending on the number of the lines used, our next step is to determine the average ionic He abundance y^+_{aver}:

$$y^+_{\text{aver}} = \frac{\sum_\lambda y^+(\lambda)/\sigma(\lambda)^2}{\sum_\lambda 1/\sigma(\lambda)^2}. \tag{2}$$

This represents a weighted average He-to-H ratio, where the uncertainties $\sigma(\lambda)$ are the uncertainties of relative intensities of the observed lines and y^+ is calculated from equation (1). The list of PNs and the corresponding bibliography, from which the relative intensities of the observed lines for our PNs have been taken, are located at the FTP server of Lviv National University, Astronomical Observatory, at fttp://astro.franko.lviv.ua/pub/PN/JPS/PNList.txt.

Here the uncertainties for every line have been assumed to be 10%. From the averaged y^+_{aver} value, we are able to find χ^2 as a deviation of the individual He abundances $y^+(\lambda)$ from the averaged value:

$$\chi^2 = \sum_\lambda \frac{[y^+(\lambda) - y^+_{\text{aver}}]^2}{\sigma(\lambda)^2}. \tag{3}$$

Then we can minimize χ^2 in order to obtain the most reliable values of n_e and τ_{3889}. In this paper, we have used the version 2.1 of the program he10 (Benjamin *et al.*, 2002). The program calculates the emissivities of He emission lines using the results from Benjamin *et al.* (1999). These emissivities are calculated by trilinear interpolation on a grid of runs in the temperature–density–optical depth space. They have been found for T_e located between 5000 and 20 000 K, electron concentrations less than $10^8\,\text{cm}^{-3}$ and optical depths τ_{3889} lying in the range 0–100. The values of n_e(He II), T_e, τ_{3889}, y^+_{aver}, y^{2+}_{4686} (the He^{2+}-to-H^+ ratio) and the relative He abundances (the He-to-H ratios) (for the two cases) calculated by the method presented above, together with the corresponding minimal χ^2_{min}, are gathered in the table located at the FTP server of Lviv National University, Astronomical Observatory at fttp://astro.franko.lviv.ua/pub/PN/Odesa/HeAllRes.txt.

The first case described in this table corresponds to an ICF of 1, when the He-to-H ratio equals the sum of the He^+-to-H^+ and the He^{2+}-to-H^+ ratios, and the second case to our ICFs determined from the calculations of the grid for photoionization models of PNs (Havrylova *et al.*, 2002). It should be noted that the uncertainties in our T_e values, obtained using the program DIAGN (Holovatyy *et al.*, 1999), are not more than ±20%. These uncertainties may be also caused by the presence of gas density fluctuations in the PN shells. As an example, we present in Table I the calculated values of y^+_{aver}, y^{2+}_{4686}, T_e and the He abundances

TABLE I The Calculated Values of $y^{+}_{\rm aver}$, y^{2+}_{4686}, $T_{\rm e}$ and the He-to-H Ratios for Four Cases of He I Line Conjunctions together with the Corresponding $\chi^2_{\rm min}$.

PN	*Case*	$y^{+}_{\rm aver}$	y^{2+}_{4686}	*T_e[O III]*[a] *(K)*	*He-to-H ratio*[b]	$\chi^2_{\rm min}$
BB 1	1 (3 lines)	0.0663 ± 0.00076	0.0220 ± 0.00227	13 400	0.0884 ± 0.0024	1.34×10^{-3}
	2 (4 lines)	0.0669 ± 0.0018	0.0220 ± 0.00227		0.0889 ± 0.0029	1.30×10^{-2}
	3 (5 lines)	0.0669 ± 0.0018	0.0220 ± 0.00227		0.0889 ± 0.0029	1.83×10
	4 (6 lines)	0.0673 ± 0.0026	0.0220 ± 0.00227		0.0894 ± 0.0035	1.85×10
	[c]	0.0712	0.0188	12 400	0.09 ± 0.01	
H 4-1	2 (4 lines)	0.0880 ± 0.0036	0.0083 ± 0.00081	12 100	0.0963 ± 0.0037	1.05
	3 (5 lines)	0.0880 ± 0.0036	0.0083 ± 0.00081		0.0964 ± 0.0037	1.89×10
	4 (6 lines)	0.0883 ± 0.0029	0.0083 ± 0.00081		0.0966 ± 0.0030	1.96×10
	[c]	0.11	0.0087	12 800	0.12 ± 0.02	
Hu 2-1	1 (3 lines)	0.0840 ± 0.00041	$1.60 \times 10^{-4} \pm 0.80 \times 10^{-4}$	9300	0.0842 ± 0.00041	6.29×10^{-1}
	2 (4 lines)	0.0839 ± 0.00087	$1.60 \times 10^{-4} \pm 0.80 \times 10^{-4}$		0.0840 ± 0.00088	8.29×10^{-1}
	3 (5 lines)	0.0873 ± 0.00058	$1.60 \times 10^{-4} \pm 0.80 \times 10^{-4}$		0.0875 ± 0.00058	4.51
	4 (6 lines)	$0.0848 \pm 9.40 \times 10^{-5}$	$1.60 \times 10^{-4} \pm 0.80 \times 10^{-4}$		0.0850 ± 0.00012	1.77×10
	[c]	0.10	1.66×10^{-4}	9100	0.10 ± 0.01	
IC 2165	1 (3 lines)	0.0685 ± 0.00086	0.0350 ± 0.00371	13 300	0.104 ± 0.0038	5.78×10^{-2}
	2 (4 lines)	0.0690 ± 0.0019	0.0350 ± 0.00371		0.104 ± 0.0042	1.11×10^{-1}
	3 (5 lines)	0.0729 ± 0.00045	0.0350 ± 0.00371		0.108 ± 0.0037	3.36
	4 (6 lines)	0.0727 ± 0.00038	0.0350 ± 0.00371		0.108 ± 0.0037	3.56
	[c]	5.52×10^{-2}	3.65×10^{-2}	13 000	0.09 ± 0.01	
J 900	1 (3 lines)	0.0538 ± 0.0015	0.0360 ± 0.0038	12 400	0.0893 ± 0.0040	2.21×10^{-3}
	2 (4 lines)	0.0539 ± 0.0024	0.0360 ± 0.0038		0.0895 ± 0.0044	3.39×10^{-3}
	[c]	6.26×10^{-2}	3.25×10^{-2}	11 600	0.10 ± 0.01	
NGC 1535	2 (4 lines)	0.0707 ± 0.0022	0.0140 ± 0.0015	11 500	0.0850 ± 0.0026	7.31
	[c]	7.38×10^{-2}	9.79×10^{-3}	11 400	0.09 ± 0.01	
NGC 2440	1 (3 lines)	0.0843 ± 0.0038	0.0540 ± 0.00562	13 800	0.138 ± 0.0068	9.31
	2 (4 lines)	0.0836 ± 0.0011	0.0540 ± 0.00562		0.137 ± 0.012	1.09×10
	3 (5 lines)	0.0944 ± 0.00069	0.0540 ± 0.00562		0.148 ± 0.0057	5.98×10
	4 (6 lines)	0.0944 ± 0.00015	0.0540 ± 0.00562		0.148 ± 0.0056	5.98×10
	[c]	5.76×10^{-2}	3.65×10^{-2}	12 600	0.10 ± 0.01	
NGC 2371	1 (3 lines)	0.0481 ± 0.0011	0.0720 ± 0.0076	12 400	0.120 ± 0.0077	1.19×10
	2 (4 lines)	0.0479 ± 0.0071	0.0720 ± 0.0076		0.120 ± 0.01	1.22×10
	[c]	2.55×10^{-2}	7.72×10^{-2}	12 100	0.10 ± 0.01	

[a]Here the uncertainties in the electron temperatures are 20% or less.

[b]Calculated for the case when ICF equals 1.

[c]From Kwitter *et al.* (2002). Here the uncertainties in the ion abundances and the electron temperatures are ±30% and ±10% respectively.

(the He-to-H ratios) for the case when the ICF equals 1 and the four cases for the He I line conjunctions (whenever all these lines are observable) for the eight chosen PNs, together with the corresponding $\chi^2_{\min}$. For comparison, we also present the corresponding data from the work of Kwitter *et al.* (2002) for the same objects.

As seen from the above results, accounting for the radiative transfer effects in He I lines does influence the accuracy of determination of the ionic abundances (the He^+-to-H^+ ratios) and, correspondingly, the accuracy of the He-to-H ratios. The obtained data will be further used for determination of the chemical abundance of gas in PNs, including a pregalactic He abundance Y_p and its enrichment ratio dY/dZ.

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References

Benjamin, R.A., Skillman, E.D. and Smits, D.P. (1999) *Astrophys. J.* **514**, 307.
Benjamin, R.A., Skillman, E.D. and Smits, D.P. (2002) astro-ph/0202227.
Brocklehurst, M. (1972) *Mon. Not. R. Astron. Soc.* **153**, 211.
Havrylova, N.V., Holovatyy, V.V. and Melekh, B.Ya. (2002) *J. Phys. Stud.* (in press).
Holovatyy, V.V., Hershberg, R.E. Malkov, Yu.F. and Pronyk, V.I. (1999) *Izv. Krymsk. Astrofiz. Obs.* **96**, 1.
Izotov, Y.I., Thuan, T.X. and Lipovetsky, V.A. (1997) *Astrophys. J.* **108**, 1.
Kingdon, J. and Ferland, G.J. (1995) *Astrophys. J.* **442**, 714.
Kwitter, K.H., Henry, R.B.C. and Milingo, J.B. (2002) astro-ph/02095432.
Olive, K.A., and Skillman, E.D. (2000) astro-ph/0007081.
Smits, D.P. (1996) *Mon. Not. R. Astron. Soc.* **278**, 683.