The Ionization Structure of Planetary Nebulae

IX. NGC 1535

TIMOTHY BARKER[1,2]
Department of Physics and Astronomy
Wheaton College

Received____________________

[1] Visiting Astronomer, Kitt Peak National Observatory, National Optical Astronomy Observatories, operated by the Association of Universities for Research in Astronomy, Inc., under contract with the National Science Foundation.

[2] Guest observer with the International Ultraviolet Explorer Satellite, NASA grant NSG 5376.

(NASA-CR-184566) THE IONIZATION STRUCTURE
OF PLANETARY NEBULAE. 9: NGC 1535 (Wheaton
Coll.) 32 p CSCL 03B
N89-14204
Unclas
G3/90 0177192

ABSTRACT

Spectrophotometric observations of emission-line intensities over the spectral range 1400-7200 Å have been made in five positions in the planetary nebula NGC 1535. There is some evidence for variation in the Balmer decrements between these positions. The O^{++} electron temperature varies little from 11500 K across these positions; the Balmer continuum electron temperature averages a few hundred K higher than this, but this difference is insignificant when compared to measurement errors. As found for most of the other planetaries in this series, the λ4267 C II line intensity near the central star implies a C^{++} abundance that is several times higher than that determined from the λ1906, 1909 C III] lines. The discrepancy again decreases with increasing distance from the central star, again suggesting that the excitation mechanism for the λ4267 C II line is not understood. Standard equations used to correct for the existence of elements in other than the optically observable ionization stages give consistent results for the different positions; there is no evidence for any abundance gradient in the nebula. The logarithmic abundances (relative to H = 12.00) are He = 10.99, O = 8.51, N = 7.63, Ne = 7.89, C = 8.34, and Ar = 6.08. The abundances agree well with determinations by Aller and Czyzak and by Torres-Peimbert and Peimbert and are nearly identical to those found for NGC 6826 (the previous paper in this series). As for NGC 6826, the rather low

abundances of He, N, and C suggest that there was little if any mixing of CNO-processed material into the nebular shell in the progenitor to NGC 1535. The O, Ne, and Ar abundances appear to be somewhat low, suggesting that the progenitor to NGC 1535 may have formed out of somewhat metal-poor material.

I. INTRODUCTION

The previous papers in this series analyzed optical and ultraviolet observations of different positions in the planetary nebulae NGC 6720 (Barker 1980, 1982, 1987, hereafter Papers I, II, and VII, respectively), NGC 7009 (Barker 1983, hereafter Paper III), NGC 6853 (Barker 1984, hereafter Paper IV), NGC 3242 (Barker 1985, hereafter Paper V), NGC 7662 (Barker 1986, hereafter Paper VI), and NGC 6826 (Barker 1988, hereafter Paper VIII). The purpose of these studies is to measure optical and UV emission-line intensities in the same nebular positions using similar entrance apertures. Since the ionization frequently changes drastically with position in an extended nebula, this procedure is almost essential in order to make a meaningful comparison between UV and optical measurements. The ultimate goals include the following: (1) to observe elements in more stages of ionization than is possible from optical spectra alone; this provides a check on optical ionization correction procedures, which are still useful for nebulae which are too faint to observe with the *International Ultraviolet Explorer* (*IUE*) satellite; (2) to get particularly accurate total abundances by averaging measurements made in different parts of the nebula, so that small differences between nebulae will become apparent; such differences can be sensitive tests of theoretical predictions regarding CNO processing and mixing in the progenitors of planetaries; and (3) to further investigate the discrepancies found in Papers II, III, IV, V, VI, and VIII between optical and UV measurements of the abundance of C^{++}; these discrepancies need to be understood before we can have confidence in optical measurements of that important element.

I chose NGC 1535 as the next planetary in this series because it has a fairly high surface brightness and so can be observed with reasonable exposure times using the smaller of the two *IUE* entrance apertures. In addition, it has measurable He II UV and optical emission in most positions, facilitating the difficult task of combining the UV and optical observations.

II. OBSERVATIONS

a) *Optical Observations*

The optical observations were made at Kitt Peak National Observatory in 1983 December, using the 2.1 m telescope and the intensified image dissector scanner (IIDS). Spectra were obtained through a 3".4 diameter aperture using two grating settings covering the ranges 3400-5100 Å and 4600-7200 Å with resolutions of about

10 Å (FWHM). The blue spectral region was observed on two nights and the red spectral region on one night at each of five different positions in the nebula; offsets with respect to the central star are listed in Table 1.

b) *Correction for Interstellar Reddening*

The amount of interstellar reddening for each position was measured by comparing the observed and theoretical intensities of the H recombination lines (the "Balmer decrement"). The resulting values of the reddening parameter, c, for each position are listed in the second row of Table 1. Several lines of evidence suggest that these values are somewhat too high, especially for positions 1 and 5, where c~0.4. First, the H I/galaxy count study by Burstein and Heiles (1982) suggests that there should be little or no reddening in this direction in the galaxy. Second, Balmer decrement determinations of c for the entire nebula by Peimbert and Torres-Peimbert (1971), Torres-Peimbert and Peimbert (1977), Aller and Czyzak (1983), and Gutiérrez-Moreno, Moreno, and Cortés (1985) give values of 0.16, 0.1, 0.0, and 0.14, respectively; all of these measurements are smaller than the value of 0.26 found here for the average of the five positions. Third, the values of c listed in Table 1 lead to a systematic underestimate of the predicted UV He II $\lambda 1640$

intensity (see the last two rows of Table 1 and the discussion in the next section). It is not clear why the observed decrements are anomalously steep and also vary across a small angular distance. It is conceivable that both effects may be partly due to some internal dust in the nebula, combined with some collisional excitation of H, although both effects are expected to make at most very small contributions to the steepness of the Balmer decrements in planetaries. On the other hand, I have found some evidence for variable reddening in several other planetaries (see Papers V, VI, VII, and VIII). It is also not clear how the effect could be due to observational errors. The $H\beta$, HT, and $H\delta$ intensities agree very well (typically within a few percent--small compared to the differences between the different positions) on the two nights that they were observed, and other planetary nebulae observed on the same nights did not show anomalously steep decrements. I believe that there is now sufficient evidence for variable Balmer decrements in different positions in planetaries to warrant further theoretical observational and theoretical study. In the end, I decided to use the values of c listed in Table 1; fortunately, the abundances and general conclusions found in this study are insensitive to uncertainties in c of this magnitude (about 0.15).

The intensities listed in Table 2 have been calculated by multiplying the observed intensities by $10^{cf(\lambda)}$; the values of $f(\lambda)$ are also listed in Table 2. Note that the adopted reddening parameters lead to Balmer decrements that are consistent with the theoretical (Brocklehurst 1971) intensities of Hα, Hβ, HΥ, Hδ, H9, and H10 of 283, 100, 47, 26, 7.4, and 5.3, respectively. Two other corrections have been applied in Table 2: the intensities of Hβ have been corrected for blending with He II emission, and the intensities of the λ3727 [O II] lines have been corrected for blending with other lines as described in Paper III. Because of the faintness of the [O II] lines, the blending correction was quite large, resulting in the observed intensities being multiplied by factors of 0.47, 0.41, 0.49, 0.51, and 0.44, respectively.

c) *Ultraviolet Observations*

The ultraviolet observations were made using the small (~3".2 diameter) entrance aperture of the *IUE* satellite in 1986 February. Table 1 lists the *IUE* exposure numbers and times. The *IUE* offsets were made under the assumption that the center-of-light position measured by the *IUE* fine error sensor coincides with the central star. Since NGC 1535 is a highly symmetric object, this assumption is reasonable, but as a check, exposures were taken with both the small and large apertures centered on the assumed position of the central star. After allowing for the lower throughput of the small aperture, the observed continuum was about the same for both apertures, and it therefore seems probable that the *IUE* exposures were made within 1" to 2" of the positions given in Table 1. The data were reduced in 1986 February and 1987 February at the IUE Regional Data Analysis Facility at Goddard Space Flight Center using the 1980 May calibration for the SWP camera and the December 1983 calibration (given in *IUE* Newsletter 23) for the LWP camera.

As in the previous papers in this series, putting the UV and optical observations on the same intensity scale is a difficult task because no emission lines can be observed in common. One method is to directly compare absolute flux measurements, after correcting for the difference in the areas of the entrance apertures. A check on this method is provided by the intensities of the He II lines; for the physical conditions in NGC 1535, I(λ1640) should equal 6.7 I(λ4686) (Seaton 1978). The predicted and observed *fluxes* (uncorrected for interstellar extinction) are compared in the last two rows of Table 1. As discussed in the previous section, the predicted fluxes are systematically low, suggesting that the reddening parameters, c, have been overestimated; values of c near 0 would give better agreement for all but position 2. As for all the other nebulae in this series with measurable He II emission, I decided that the most reliable method for combining the UV and optical observations is to require that I(λ1640) = 6.7 I(λ4686). This method has the advantage of being unaffected by uncertainties in the photometric areas in the apertures, as well as possibly non-photometric conditions when the optical measurements were made, and it is nearly unaffected by errors in the correction for interstellar reddening. For position 5, however, there was no measurable He II emission, and it was necessary to combine the UV and optical measurements by comparing absolute fluxes.

d) *Observational Errors*

Aside from possible systematic errors discussed above, the UV intensities are judged to be accurate to within a factor of two for the weakest lines and those marked with colons, to ~40% for those of intermediate intensity (between 20% and 80% of Hβ), and to ~20% for the strongest lines. While these errors may seem high, errors in electron temperatures generally have a greater effect than errors in line intensities on the accuracy of the abundances determined from collisionally excited UV lines.

Based on experience with the equipment and a comparison with between the IIDS measurements made on different nights, the intensities of the strongest optical lines are judged to be accurate to ~10%, those weaker than half of Hβ to be accurate to ~20%, and even the faintest lines to be accurate to ~30%. Exceptions are the λ3727 line intensities, good to only a factor of 2 because of the large corrections for blending (see §IIb), and the λ6583 [N II] lines, good to only a factor of 2 because of their faintness and proximity to Hα.

III. TEMPERATURES, DENSITIES, AND IONIC ABUNDANCES

Calculations of the electron temperature (T_e) and ionic abundances in the different positions were made using the same methods and atomic constants as in Paper III. The results for T_e are summarized in Table 3. Unfortunately, emission from low-ionization species such as [N II], [S II], and [Cl III] is not measurable, and so there is very little plasma diagnostic information available in the current data. The [O III] T_e's are quite similar in the different positions and are also consistent with measurements by others (eg., Peimbert and Torres-Peimbert (1971), Torres-Peimbert and Peimbert (1977), Aller and Czyzak (1983), and Gutiérrez-Moreno, Moreno, and Cortés (1986)) for the nebula as a whole. The Balmer continuum T_e was measured as explained in Paper V and is subject to greater uncertainties than the O^{++} T_e because of its extreme sensitivity to errors in c, uncertainties in estimating the continuum, and uncertainties in the instrumental calibration at the Balmer limit. As in Papers V, VI, and VIII, however, there is no evidence that the T_e's measured this way are systematically lower than the O^{++} T_e's, as has been claimed for some nebulae; considering the uncertainties, the agreement may be said to be quite good.

It was impossible to determine electron densities from the existing data. The value of 6000 cm^{-3} was adopted from the measurements of Peimbert and Torres-Peimbert (1971), Torres-Peimbert and Peimbert (1977), Aller and Czyzak (1983), and Gutiérrez-Moreno, Moreno, and Cortés (1986), all of whom found results close to this value. Fortunately, the calculated ionic abundances are very insensitive to electron temperature for densities in this range.

The ionic abundances calculated using the values of T_e and electron density given at the bottom of Table 3 are listed in Table 4.

IV. TOTAL ABUNDANCES

Total abundances may be found by simply adding together all the ionic abundances or by using only optically measured ionic abundances and correcting for the presence of elements in optically unobservable stages of ionization. The former procedure would appear to be the more reliable, but unfortunately relatively small errors in T_e will cause large errors in abundances measured from UV lines. In addition, the UV lines in NGC 1535 are generally faint or not present. At the very least, however, this method serves as a valuable check on the second procedure, which is commonly used when no UV data are available for a nebula. Both methods were used wherever possible, and the results are summarized in Table 4. The abundances labeled "optical" have been calculated by multiplying the optically measured ionic abundances by the listed values of i_{cf}, the ionization correction factor (the equations used to calculate i_{cf} values are given in Paper III). The abundances labeled "UV + optical" are simple sums of all the ionic abundances.

Except for He, the errors assigned to the abundances are based on the errors estimated for the electron temperatures, densities, and ionic abundances. (For He, the errors are the formal mean errors based on the scatter in the measured values.) In most cases, the errors in T_e dominate the other sources.

The average abundances and errors are given in the first row of Table 5. NGC 1535 is one of many planetary nebulae recently studied by Aller and Czyzak (1983, hereafter AC), whose models are based on extensive UV and optical observations; their results are listed in the second row of Table 5 for comparison. An older study by Torres-Peimbert and Peimbert (1977, hereafter TPP) using only optical data is listed in the third row. Considering the differences in observing techniques and methods of analysis, the agreement between the three studies is remarkably good; a detailed discussion is given below.

a) *Helium*

The three different He I lines agree very well, and the average He^+/H^+ abundance given in Table 4 for each position is an unweighted sum of the three measurements. The total He abundance is the sum of the He^+ and He^{++} abundances. Since He II emission is present in all but the outermost position, little if any He is expected to be in the form of He^0. The constancy of the total measured He abundance throughout the nebula supports this conclusion. The He abundance given in Table 5 is a weighted average of the five positions and is in excellent agreement with measurements by AC and TPP.

b) *Oxygen*

The λ1661, 1666 O III] lines are very faint, and so it is not surprising that there is very poor agreement between the O^{++} abundances determined using them and using the λ5007 [O III] line in positions 2 and 3. The total calculated O abundances for the different positions are extremely consistent. Since the i_{cf}'s vary by only 50% across these positions, however, this agreement gives little support for the applicability of the ionization correction procedure for O. The average O abundance for NGC 1535 listed in Table 5 agrees very well with the determinations by AC and TPP.

c) *Nitrogen*

The UV nitrogen lines are also quite faint and so it is not surprising that there is poor agreement between the optical and UV + optical determinations of the total N abundance. The very large UV + optical abundances measured for positions 2 and 3 may well be due to the known tendency of the measurer to overestimate intensities of lines that are very weak. It is also possible that the electron temperature in the N^{3+} region may be higher than that in the O^{++} region; not allowing for this effect would also lead to an overestimate of the N abundance. It is unfortunate that the measurements of the UV lines are not more accurate, since more than 99% of the N in NGC 1535 is in a higher ionization state than the optically-observable N^{+} form. The UV nitrogen lines are, of course, more easily seen in an *IUE* spectrum of the entire nebula, but then contamination by light from the bright central star is a significant problem. An alternative approach would have been to take a much longer--perhaps four hour or so--IUE exposure in a bright position such as position 2 so that the total N abundance could have been measured from UV lines in at least one position as a comparison with the optical measurements. As it is, we are left with only the optical determinations, which in fact agree remarkably well in the different positions, considering the faintness of the λ6583 [N II] lines and the uncertainties in the λ3727 [O II] line intensities (needed to compute i_{cf} for N) after they have been corrected for blending (see § IIb). The average abundance listed in Table 5 is the first estimate of the N abundance in NGC 1535, but the uncertainty is probably considerably greater than the formal error quoted, since the error does not allow for the possibility that the ionization correction scheme for N may not be applicable when so little N is in the form of N^+.

d) *Neon*

Again, the UV lines are too faint to be of much value. The total optically measured Ne abundance is approximately constant and apparently not overestimated in the outer positions (as in Papers I, IV, and VI); in NGC 1535, as in NGC 3242, NGC 6826, NGC 7009, and NGC 7662, the ionization is high enough that there is little O^+ and so the different efficiencies of the O and Ne charge transfer reactions are not important (see Paper I and references therein). The average

Ne abundance listed in Table 5 agrees very well with the determinations by AC and TPP.

e) *Carbon*

As in NGC 3242, NGC 6720, NGC 6826, NGC 6853, NGC 7009, and NGC 7662, the C^{++} abundance inferred from the λ4267 line is generally larger than that found using the UV λ1906, 1909 lines. The ratio of the two measurements is 6.3, 2.4, 3.3, and <1.2 for positions 1-4, respectively, so the discrepancy decreases approximately monotonically with increasing projected distance from the central star, as it did in nearly all of the other planetaries. The magnitude of the discrepancy is also similar to that observed in other objects and is again significantly greater than can be explained by observational errors, uncertainties in the reddening parameter, or uncertainties in the electron temperature. I believe that NGC 1535 provides further evidence that the excitation mechanism for the λ4267 line is not well understood. For a more extensive discussion of this issue, see Paper VII and references therein, as well as the recent review by Clegg, 1988.

The total C abundance for each position is the sum of the ionic abundances, using the UV rather than the optical measurement of

C^{++}. In view of the uncertainties in the ionic abundances, the total C abundances agree quite well for the different positions. The average C abundance listed in Table 5 is somewhat smaller than AC's, but they list their value as uncertain because of contamination of their IUE spectrum by the light from the central star; considering this, the agreement is satisfactory.

f) *Argon*

Since nearly all the oxygen in NGC 1535 is in a higher ionization stage than O^+ (ionization potential: 35 ev), almost all Ar should be in a higher ionization stage than Ar^+ (ionization potential: 28 ev) and hence in the optically observable stages Ar^{++}, Ar^{3+}, and Ar^{4+}. In other words, the ionization correction factors should be very close to 1.00. This conclusion is supported by the high consistency for the different positions of the total Ar abundances found assuming ionization correction factors of 1.00. The equation $Ar/H = 1.5\ Ar^{++}$ (see Paper I), which is a useful factor-of-two approximation for faint planetaries where only the λ7135 [Ar III] line is observable, gives an average Ar/H ratio of 0.53×10^{-6}, which is about half the measured value (see Table 5). The average Ar abundance listed in Table 5 is somewhat smaller than AC's but I believe that it is likely to be more accurate, since it is based on an average of several positions and is also based on more ionization stages than were observed by AC.

g) *Comparison of Abundances in Different Objects*

In general, the abundances in the objects in Table 5 are similar, but there are some interesting differences. The abundances of He, O, Ne, and Ar in NGC 1535 are quite similar to those in NGC 3242, NGC 6826, and NGC 7662. The helium abundances in these four planetaries, which are lower than in any of the other objects listed, imply that there has been little (perhaps no) enhancement of He-rich material in NGC 1535. The abundances of N and C in NGC 1535, like those in NGC 6826, are lower than those in any of the other planetaries and are in agreement with the values in the Sun and H II regions, further supporting the view that little mixing of CNO-processed material occurred in the preplanetary envelope of NGC 1535 or NGC 6826. The Ne, Ar, and O abundances in NGC 1535 and NGC 6826 are also a bit low, suggesting that NGC 1535, like NGC 3242, NGC 6826 and NGC 7662, may have formed out of material that was slightly more metal-poor than did the other objects listed in the table.

V. CONCLUSIONS

In summary, NGC 1535 is another planetary nebula for which total abundances can apparently be accurately determined from optical measurements alone, although the small optically-observable N^+ abundance makes the determination extremely difficult for N. It would be valuable to confirm the N abundance by obtaining more accurate UV line intensities, perhaps by taking a longer exposure while excluding light from the central star. As for the other nebulae observed in this series, the UV and optical measurements of the C^{++} abundance do not agree; the dependence on distance from the central star again indicates that the $\lambda4267$ line intensity is not being interpreted correctly. The abundances in NGC 1535 suggest that it is a planetary nebula that formed initially in a somewhat metal-poor region and has undergone little or no enhancement of its original abundances by mixing with nuclear-processed material.

I am grateful to the *IUE* and Kitt Peak staffs for their assistance in obtaining the observations, and the use of the Regional Data Analysis Facility at Goddard is also gratefully acknowledged.

TABLE 1

PARAMETERS OF OBSERVED POSITIONS

	POSITION				
	1	2	3	4	5
Offset (arcsec)	3N	5E,1N	6W,1S	9W,1S	7W,10S
c	0.35	0.20	0.15	0.13	0.45
SWP number	27777	27801	27800	27792	27791
Exposure (min)	80	60	70	80	150
LWP number	7709	7721	7714	7720	7719
Exposure (min)	15	70	30	110	150
$F(H_\beta)^a$, 3.4" ent.	3.5	4.2	4.8	2.8	1.4
F $(\lambda 1640)^a$, predicted	2.5	3.1	4.4	1.0	0
F $(\lambda 1640)^a$, observed	7.4	2.9	8.0	1.7	0

[a] Units: 10^{-13} ergs cm^{-2} s^{-1}, uncorrected for interstellar extinction.

TABLE 2
LINE INTENSITIES

λ(Å)	ID	f (λ)	I (λ)				
			Position 1	Position 2	Position 3	Position 4	Position 5
1403,1409	O IV]	1.31	...	...	...	...	...
1487	N IV]	1.23	...	75.:	51.:	...	...
1548,1550	C IV	1.18	156.	140.	37.:	66.:	41.
1640	He II	1.14	221.	153.	163.	62.	...
1661,1666	O III]	1.13	...	55.:	68.:	...	...
1747	N III]	1.12	36.	104.	29.	...	...
1906,1909	C III]	1.23	162.	236.	143.	183.	179.
2326,2328	C II]	1.35	...	...	...	...	...
2422,2424	[Ne IV]	1.12	...	...	...	...	...
3133	O III	0.45	...	...	...	...	...
3426	[Ne V],O III	0.38	...	...	2.0	...	...
3444	O III	0.37	7.6	8.7	9.9	7.7	3.2
3727	[O II]	0.29	4.0^{a}	3.1^{a}	4.4^{a}	4.7^{a}	3.5^{a}
3798	H 10	0.27	5.0	5.1	5.3	5.6	5.0
3835	H 9	0.26	5.7	5.9	6.9	7.7	6.5
3869	[Ne III]	0.25	92.3	89.5	96.2	61.2	84.9

TABLE 2 continued

4096-4076	(blend)	0.21	0.7	0.7	1.0	...	...
4102	$H\delta$	0.20	24.8	26.7	27.7	28.3	26.3
4267	C II	0.17	0.74	0.45	0.40	<0.2	...
4340	$H\gamma$	0.15	45.6	47.0	46.3	46.7	46.8
4363	[O III]	0.15	13.2	13.6	13.3	13.5	12.5
4471	H I	0.11	3.1	3.8	3.4	4.7	5.5
4686	He II	0.05	33.8	23.5	24.9	9.4	...
4711	[Ar IV],He I	0.04	5.1	...	0.2	4.8	4.0
4740	[Ar IV]	0.03	4.1	4.0	3.7	3.3	3.3
4861	H_β	0.00	100.	100.	100.	100.	100.
4959	[O III]	-0.03	370.	396.	391.	410.	391.
5007	[O III]	-0.04	1143.	1215.	1223.	1258.	1231.
5518	[Cl III]	-0.15	...	...	...	...	...
5538	[Cl III]	-0.15	...	...	...	...	...
5755	[N II]	-0.20	...	...	...	...	...
5876	He I	-0.22	8.9	9.4	8.3	12.2	11.7
6300	[O I]	-0.29	...	...	...	...	...
6312	[S III]	-0.29	...	...	...	...	...
6563	$H\alpha$	-0.33	288.	273.	272.	286.	295.
6583	[N II]	-0.34	2.1:	1.4:	1.4:	2.4:	0.9:

TABLE 2 continued

6678	He I	-0.35	2.8	3.0	2.3	3.7	2.4
6717	[S II]	-0.36	...	...	...	...	...
6731	[S II]	-0.36	...	...	...	...	...
7005	[Ar V]	-0.39	...	...	...	...	...
7065	He I	-0.40	3.2	1.7	2.1	3.1	3.1
7135	[Ar III]	-0.41	6.2	4.7	6.7	4.9	7.3

[a] Corrected for blending; see text.

TABLE 3

ELECTRON TEMPERATURES AND DENSITIES

QUANTITY	ION	RATIO	POSITION				
			1	2	3	4	5
T_e (K)	O^{++}	I(5007)/I(4363)	11700	11600	11500	11400	11200
T_e (K)	H^+	I(Bac)/I(H_β)	...	11900	12400	10300	17500:
T_e (adopted;K)			11700±500	11600±500	11500±500	11400±500	11200±500
N_e (adopted;cm^{-3})			6000±2000	6000±2000	6000±2000	6000±2000	6000±2000

TABLE 4
IONIC AND TOTAL ABUNDANCES

		POSITION				
λ(Å)	ABUNDANCE	1	2	3	4	5
4471	He^+/H^+	0.065	0.079	0.071	0.097	0.114
5876	He^+/H^+	0.068	0.072	0.064	0.093	0.089
6678	He^+/H^+	0.076	0.081	0.062	0.100	0.064
Average	He^+/H^+	0.070	0.077	0.066	0.097	0.089
4686	He^{++}/H^+	0.029	0.020	0.021	0.008	--
	He/H	0.099±0.004	0.097±0.004	0.087±0.004	0.105±0.003	0.089±0.014
3726,3729	$10^4 XO^+/H^+$	0.016	0.013	0.019	0.021	0.017
5007	$10^4 XO^{++}/H^+$	2.34	2.54	2.63	2.77	2.87
1661,1666	$10^4 XO^{++}/H^+$	...	7.2:	9.5:	...	...
	i_{cf}	1.41	1.26	1.32	1.08	1.00
Optical	$10^4 XO/H$	3.3±0.8	3.2±0.8	3.5±0.8	3.0±0.7	3.0±0.8
6583	$10^4 XN^+/H^+$	0.0028:	0.0019:	0.0020:	0.0035:	0.0013:
1747	$10^4 XN^{++}/H^+$	1.5	4.7	1.4	...	...

TABLE 4 cont.

1487	$10^4 X N^{3+}/H^+$	...	4.2:	3.1:	...	...
	i_{cf}	206.	246.	184.	143.	176.
Optical	$10^4 X N/H$	0.58±0.3	0.47±0.3	0.37±0.2	0.50±0.3	0.23±0.2
UV+Optical	$10^4 X N/H$	1.8	11.:	5.6:	...	...
3869	$10^4 X Ne^{++}/H^+$	0.54	0.54	0.60	0.39	0.58
2422	$10^4 X Ne^{3+}/H^+$	...	...	...	...	...
3426	$10^4 X Ne^{4+}/H^+$	...	...	...	...	...
	i_{cf}	1.44	1.29	1.38	1.09	1.02
Optical	$10^4 X Ne/H$	0.89±0.2	0.80±0.2	0.95±0.3	0.50±0.2	0.69±0.2
2326,2328	$10^4 X C^+/H^+$	...	...	...	...	...
1906,1909	$10^4 X C^{++}/H^+$	1.2	1.9	1.2	1.7	1.9
4267	$10^4 X C^{++}/H^+$	7.5	4.6	4.0	<2.	...
1548,1550	$10^4 X C^{3+}/H$	1.0	1.0	0.3	0.5:	0.4
UV	$10^4 X C/H$	2.2±1.5	2.9±1.7	1.5±1.0	2.2:	2.3±1.5
7135	$10^6 X Ar^{++}/H^+$	0.37	0.28	0.41	0.31	0.47
4740	$10^6 X Ar^{3+}/H^+$	0.90	0.91	0.86	0.79	0.83

TABLE 4 cont.

7005	$10^6 X\mathrm{Ar}^{4+}/\mathrm{H}^+$	...	...	...	...	...
	i_{cf}	1.00	1.00	1.00	1.00	1.00
Optical	$10^6 X\mathrm{Ar}/\mathrm{H}$	1.3±0.3	1.2±0.3	1.2±0.3	1.1±0.3	1.3±0.4

TABLE 5

COMPARISON OF ABUNDANCES

Object	He/H	10^4XO/H	10^4XN/H	10^4XNe/H	10^4XC/H	10^6XAr/H	10^6XS/H	Reference
NGC 1535	0.097±0.003	3.2±0.1	0.43±0.06	0.77±0.08	2.2±0.2	1.2±0.1	...	1
NGC 1535	0.093	4.0	$>$ 0.04:	0.83	3.7:	1.9	...	2
NGC 1535	0.091	3.8	...	0.93	...	...	...	3
NGC 3242	0.091	4.4	0.91	1.1	2.6	1.4	3.2	4
NGC 6720	0.110	11.2	2.3	1.8	12.	2.4	10.	5
NGC 6826	0.09	4.0	0.51	0.92	3.4	3.4	5.9	6
NGC 6853	0.110	8.4	3.0	2.7	7.6	3.3	5.9	7
NGC 7009	0.117	4.4	1.3	1.5	1.5	2.3	13.	8
NGC 7662	0.094	4.3	1.1	0.9	6.8	1.5	4.2	9
H II regions	0.117	4.0	0.4	1.3	...	...	18.	10
Sun	0.100	7.4	0.9	1.1	4.5	3.7	17.	11,12

REFERENCES - (1) This paper; (2) Aller and Czyzak 1983; (3) Torres-Peimbert and Peimbert 1977; (4) Paper V; (5) Paper VII; (6) Paper VIII; (7) Paper IV; (8) Paper III; (9) Paper VI; (10) Hawley 1978; (11) Ross and Aller 1976; (12) Aller and Czyzak 1983.

REFERENCES

Aller, L. H., and Czyzak, S. J. 1983, *Ap. J. Suppl.*, **51**, 211 (AC).

Barker, T. 1980, *Ap. J.*, **240**, 99 (Paper I).

________ . 1982, *Ap. J.*, **253**, 167 (Paper II).

________ . 1983, *Ap. J.*, **267**, 630 (Paper III).

________ . 1984, *Ap. J.*, **284**, 589 (Paper IV).

________ . 1985, *Ap. J.*, **294**, 193 (Paper V).

________ . 1986, *Ap. J.*, **308**, 314 (Paper VI).

________ . 1987, *Ap. J.*, **322**, 922 (Paper VII).

________ . 1988, *Ap. J.*, **326**, 164 (Paper VIII).

Brocklehurst, M. 1971, *M.N.R.A.S.*, **153**, 471.

Burstein, D., and Heiles, C. 1982, *A.J.*, **87**, 1165.

Clegg, R. E. S. 1988, in IAU Symposium 131, ed. S. Torres-Peimbert (Dordrecht: Reidel).

Gutiérrez-Moreno, A., Moreno, H., and Cortés, G. 1985, *P.A.S.P.*, **97**, 397.

Moreno, H., Gutiérrez-Moreno, A., and Cortés, G. 1986, *P.A.S.P.*, **98**, 498.

Hawley, S. A. 1978, *Ap. J.*, **244**, 417.

Peimbert, M., and Torres-Peimbert, S. 1971, *Rev. Mexicana Astr. Ap.*, **4**, 341.

Ross, J. E., and Aller, L. H. 1976, *Science*, *191*, 1223.

Torres-Peimbert, S., and Peimbert, M. 1977, *Rev. Mexicana Astr. Ap.*, **2**, 181.

TIMOTHY BARKER: Department of Physics and Astronomy,
Wheaton College, Norton, MA 02766