The Ionization Structure of Planetary Nebulae

VI. NGC 7662

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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 7662. The variation of the Balmer decrement with position in the nebula suggests that there may be internal dust, consistent with the findings of Harrington, Seaton, Adams, and Lutz (HSAL). The O^{++} and Balmer continuum electron temperatures decrease with increasing distance from the central star, in very close agreement with the model by HSAL. The observed fractional ionic abundances at the different positions also agree quite well with the model predictions. The λ4267 C II line intensity implies a C^{++} abundance that is higher than that determined from the λ1906, 1909 C III] lines. Although the discrepancy is not as serious as that found in the previous studies in this series, it again is correlated with distance from the central star, again suggesting that the excitation mechanism for the λ4267 line is not understood. Standard equations used to correct for the existence of elements in other than the optically observable ionization stages give results that are

consistent and in approximate agreement with abundances calculated using ultraviolet lines. The logarithmic abundances (relative to H=12.00) are: He=10.97, O=8.63, N=8.04, Ne=7.96, C=8.83, Ar=6.18, and S=6.62. Except for S, these abundances are in excellent agreement with the model calculations by HSAL. This agreement is particularly gratifying for N, where only about 0.1% of the element is in the optically-observable form of N^+. The discrepancy for S may be due to the inapplicability of the ionization correction equation to a nebula as highly-ionized as NGC 7662; although more observations are necessary to conclude definitely, the S determination by HSAL is to be preferred at the present time. The abundances of C, and, to some extent, N, are somewhat high, indicating that some mixing of CNO-processed material into the nebular shell may have occurred in NGC 7662; the low He abundance, however, indicates that little or no He enrichment has occurred. The Ar, Ne, and, to some extent, O and S abundances appear to be somewhat low, suggesting that the progenitor to NGC 7662 may have formed out of somewhat metal-poor material.

I. INTRODUCTION

The five previous papers in this series (Barker 1980, 1982, 1983, 1984, and 1985, hereafter Papers I, II, III, IV, and V, respectively) analyzed optical and ultraviolet observations of different positions in the planetary nebulae NGC 6720, NGC 7009, NGC 6853, and NGC 3242. 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 that are too faint to observe with the International Ultraviolet Explorer (IUE) satellite; (2) by averaging measurements made in different parts of the nebula, to get particularly accurate total abundances 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, and V 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 7662 as the next planetary in this series in part because it has a high surface brightness and so can be observed with reasonable exposure times using the smaller of the two IUE entrance apertures and because the very ionization in it provides a stringent test of ionization correction formulae. More importantly, NGC 7662 has been studied very extensively by other workers and so is a useful calibration object. In particular, the study by Harrington, Seaton, Adams, and Lutz (1982, hereafter HSAL), which combined UV and optical measurements of both the nebula and its central star with a detailed theoretical model, is perhaps the most exhaustive study of its kind ever made. I felt that it was important to see if the ionization correction procedures that I have been using in this series of studies would give total abundances in agreement with those found in the model analysis by HSAL. In addition, HSAL did not make optical measurements of the same positions as their UV ones, and even their UV measurements were apparently affected by guiding errors; I felt that I could overcome both of these difficulties by making optical measurements in the same positions as UV ones and by using a different offsetting technique for the UV observations.

II. OBSERVATIONS

a) Optical Observations

Preliminary observations were made with the Intensified Reticon Scanner at Kitt Peak National Observatory in 1982 December using the No. 1 90 cm telescope. The primary goal was to select positions with the widest possible range of ionization, but these measurements also provided useful checks on subsequent ones. The rest of the optical observations were made in 1983 December and 1984 August, using the 2.1m telescope and the intensified image dissector scanner (IIDS). Spectra were obtained through a 3.4" diameter aperture using two grating settings covering the range 3400-5100 Å and

4600-7200 Å with resolutions of about 10 Å (FWHM); each spectral region was observed on three different nights at each of the five positions in the nebula.

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 decrements for the different positions are significantly different, and the differences were consistent for each night the nebula was observed. The resulting values of the reddening parameter, c, for each position are listed in the second row of Table 1. Some of the larger measurements of c and the large variations in the values are surprising in view of the rather large galactic latitude (-17°) of NGC 7662. Some of this variation in reddening may in fact be due to internal dust in the nebula as well as to nonuniformities in the interstellar dust in the line of sight to the nebula. HSAL used the measured thermal infrared emission to estimate a dust optical depth of ~0.1 in NGC 7662, corresponding to a c of roughly 0.04. Although this is much less than the range of 0.23 in the values of c estimated from the Balmer decrements, such a large variation might be caused by clumpiness in the dust distribution. Further evidence for the reddening being caused in part by internal dust comes from the work of Doughty and Kaler (1982), who measured an internal reddening corresponding to $c=0.15 \pm .04$ (quite close to the range in c values found here), based on the intensities of the Balmer lines at the near (blueshifted) and far (redshifted) sides of NGC 7662; it would clearly be worthwhile to repeat their measurements using photoelectric, rather than photographic, observations. The average value of c for the five positions, 0.31, is quite close to the value of 0.23 found by HSAL.

The intensities listed in Table 2 have all been calculated by multiplying the observed intensities by $10^{cf(\lambda)}$; the values of $f(\lambda)$ are also listed in Table 2. Note that there is very good agreement between the observed and theoretical (Brocklehurst 1971) intensities of $H\alpha$, $H\beta$, $H\gamma$, $H\delta$, $H9$, and $H10$ (283, 100, 47, 26, 7.4, and 5.3, respectively) for all five positions. Two other corrections have been applied to the intensities in Table 2: the intensities of $H\beta$ 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. The latter correction resulted in the observed intensities being multiplied by factors of 0, 0.42, 0.54, 0.68, and 0.86 for positions 1-5, respectively.

c) Ultraviolet Observations

The ultraviolet observations were made using the small (~3.2" diameter) entrance aperture of the IUE satellite in 1983 May. Table 1 lists the IUE exposure numbers and times. In addition to the exposures listed in Table 1, several trial exposures were made in 1982 July during a period of high radiation background when photometric observations were impossible. Exposures at the position of the center of light found by the IUE fine error sensor showed little or no stellar continuum, indicating that the center of light does not coincide with the central star and so may not be used at an offset point. (A similar conclusion was reached by HSLA, who experienced guiding errors as a result of trying to offset from the center of light.) The 1983 May observations were therefore made by offsetting from a nearby bright star, SAO 053026, which was measured to be 490.5" east and 74.4" north of the central star by K. Cudworth using Yerkes refractor and reflector plates obtained in 1982. As a check on the offsetting procedure, several short exposures of the assumed position of the central star were taken during the course of the IUE observing run. The observed stellar continuum was generally about as strong as in exposures obtained by other observers through the large IUE entrance aperture, indicating that the IUE observations were made within 1-2" of the offsets from the central star given in Table 1. The data were reduced in 1983 June at the IUE Regional Data Analysis Facility at Goddard Space Flight Center using the 1980 May calibration (the same calibration used in the previous papers in this series).

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 could be observed in common. One method is to directly compare absolute flux measurements, after correcting for the small difference in the areas of the entrance apertures. A check on this method is provided by the intensities of the He II lines; for NGC 7662, I(λ1640) should equal 7.03 I(λ4686) (HSAL). The predicted and observed _fluxes_ (uncorrected for interstellar extinction) are compared in Table 1. Unfortunately, the agreement is only fair and is significantly poorer than found in Papers II, IV, and V. In positions 1, 2, and 3, He II emission is strong, and I decided that the most reliable method for combining the UV and optical observations was to require that I(λ1640)=7.03 I(λ4686). (This method has the advantage of being unaffected by uncertainties in the photometric areas of 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 positions 4 and 5, where the He II emission is much weaker, the normalization was done by comparing absolute fluxes. Finally, the SWP and LWR intensities were combined by assuming that the small LWR aperture has an effective area of 0.83 times that of the SWP (HSAL). This ratio is in good agreement with the value of 0.79 ± 0.05 found in Paper V and the value of 0.85 ± 0.09 found here by comparing the λ1906, 1909 emission-line intensities on the SWP and LWR spectra.

Unfortunately, two lines of evidence indicate that the UV-optical normalization may be somewhat systematically in error. One test is the ratio of the UV and optical O III Bowen lines, I(λ3133)/I(λ3444), which should be 3.33 (Saraph and Seaton, 1980). The observed ratios are 3.53, 5.83, 5.40, and 8.20 for positions 1, 2, 3, and 4, respectively. Even neglecting position 4 (where the lines are very faint), the average observed ratio is 1.47 times too large. Another check is provided by the [Ne IV] I(λ2422)/I(λ4714-4726) ratio. As discussed in the next section, this ratio is sensitive to electron temperature. HSAL predict an electron temperature of 14250 K for the Ne^{3+} region, implying a ratio of 93; the average observed ratio for positions 1, 2, and 3 is 227, 2.4 times too large. Both lines of evidence indicate that the intensities of the UV lines relative to the optical ones may be somewhat overestimated, perhaps as a result of offsetting errors made with the IUE, despite the precautions described above. As a result, I feel that the possibility exists that the the UV-optical ratio of line intensities may be in error by as much as a factor of two in some positions.

d) Observational Errors

Aside from possible systematic errors discussed above, the UV intensities are judged to be accurate to within a factor of 2 for the faintest lines (less than 20% of Hβ), to ~40% for those of intermediate intensity (between 20% and 80%) and to ~20% for the strongest lines. While these errors may seem high, errors in electron temperatures generally have a greater effect on the accuracy of the abundances determined from collisionally-excited UV lines than do errors in line intensities.

Based on a comparison 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%. An exception is the λ3727 line intensity, which is good to only a factor of 2 for positions 2, 3, and 4 because of the large corrections for blending there (see § IIb). Position 5 is a bright knot of low ionization at the edge of the nebula; as a result, guiding is very critical for this position, and the intensities of low-ionization lines in particular are more uncertain than in the other positions. Finally, intensities in Table 2 labeled with colons are uncertain by approximately a factor of 2.

III. TEMPERATURES, DENSITIES, AND IONIC ABUNDANCES

Calculations of the electron temperature (T_e), electron density (N_e), and ionic abundances in the different positions were made using the same methods and atomic constants as in Paper III. The results for N_e and T_e are summarized in Table 3. The [S II], [Cl III], and [Ar IV] lines are all rather faint, and so the values of N_e in the different positions are all somewhat uncertain. In addition, it was necessary to correct the [Ar IV] ratios for blending with a faint He I line at 4713 Å, leading to a further uncertainty. Finally, the Ar^{3+} atomic constants may be somewhat in error (Czyzak et al. 1980). Despite these difficulties, the different indicators give generally consistent values of N_e, and the average for the five positions is 4000 ± 500 cm^{-3}, in reasonable agreement with the average value of 2930 cm^{-3} determined by HSAL for the whole nebula. In any event, the calculated ionic abundances are very insensitive to N_e for densities this low.

The ionic abundances are, however, very sensitive to the electron temperature. Of the four indicators for T_e listed in Table 3, the O^{++} ratio is by far the most accurate, and this value was therefore adopted for all five positions. The Ne^{3+} $I(\lambda4720)/I(\lambda2422)$ ratio is particularly uncertain due to the problem of combining the UV and optical measurements (see §IId); as discussed earlier, I think that it is probable that T_e in the Ne^{3+} region is actually several thousand K higher than indicated in Table 3. Evidence for T_e being this high in regions of high ionization comes from the O^{3+} T_e. This value of T_e can be estimated from the $I(\lambda1402)/I(\lambda1640)$ ratio and the procedure described by HSAL. The results for positions 1 and 2 are 16000 K and 13600 K, respectively, consistent with the average value of 14580 found from the model by HSAL (this paper references only the "Model 2" calculations by HSAL, since the authors believe them to be the more appropriate ones).

The Balmer continuum T_e was measured as explained in Paper V and is also 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 Paper V, the T_e measured this way is systematically somewhat higher (by an average of 1200 K in this case) than the O^{++} T_e. As discussed in Paper V, this difference may be due in part to measurement errors, but it is encouraging that it is in very good agreement with the difference of 1460 K from the model by HSAL. At least it is clear that there is no evidence that the T_e's measured from the Balmer continuum are lower than the O^{++} T_e's, as has been claimed for some planetary nebulae (see Barker 1979 for a discussion). Low Balmer continuum T_e's have been used to justify using large values for the mean square temperature fluctuation, t^2, leading to larger calculated metal abundances in gaseous nebulae. The evidence for NGC 7662 suggests that such an approach is unwarranted, and indeed the model calculations of HSAL imply a small value for t^2. The average observed value for the Balmer continuum T_e, 13600 K, is in good agreement with HSAL's model result of 13170 K, and the average observed O^{++} T_e, 12400 K, is very close to their value of 12140 K.

Table 4 gives a more detailed comparison between observed quantities and the calculations for Model II

(Model I for O) by HSAL. (The values for the model given in Table 4 were obtained from the model calculations by numerically integrating the appropriate quantities through lines of sight corresponding to the observed positions.) Two limitations must be borne in mind when making such a comparison. First, the model by HSAL is for a spherically-symmetric nebula. In reality, NGC 7662 displays azimuthal variations in ionization. Positions 4 and 5, for example, are at essentially the same angular distance (12") from the central star, and so the model predicts the same values for these positions. In reality, however, Position 5 corresponds to a knot of much lower ionization than Position 4 (indeed it was observed for this reason). Second, the He^{++}/He ratio (discussed in the next section) is systematically somewhat higher at each position than predicted by the model. This discrepancy could well be due at least in large part to an error in the angular scale of the H and He isophotes employed by HSAL. Whatever the explanation, it should be kept in mind that the observed positions correspond to slightly higher ionization than the model ones. In view of these difficulties, the model and observed values of N_e and T_e agree extremely well.

The ionic abundances calculated using the alues of T_e and N_e given at the bottom of Table 3 are listed in Table 5.

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 intensities of the UV lines relative to the optical ones are particularly uncertain in NGC 7662, as discussed in §IIc. 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 whenever possible, and the results are summarized in Table 5. 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 T_e, N_e, and the line intensities. In most cases, the errors in T_e dominate over the other sources.

a) Helium

The three different He I lines agree very well, and the average He^+/H^+ abundance given in Table 5 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 even the positions of lowest ionization, little if any He is expected to be in the form of He^0. The constancy of the total measured He abundance and the model calculations of HSAL support this conclusion. The average He abundance (see Table 6) is identical to that found by HSAL.

b) Oxygen

The λ1661, 1666 O III] lines are faint, and so one could not expect good agreement between the optical and UV abundance determinations for O^{++}. Even so, the fact that the UV measurements are systematically higher than the optical ones again suggests that the intensities of the UV lines relative to the optical ones may have been overestimated (see §IIc). The i_{cf}'s for O cover the largest range of any planetary nebula in this series of papers, and so it is gratifying that the total O abundances agree so well for each position. The O^{++}/O ratios also agree quite well with the model calculations (see Table 4), considering the fact that the model positions correspond to regions of slightly lower ionization (see §III). Finally, the average O abundance given in Table 6 is in excellent agreement with the model calculation by HSAL.

HSAL expressed some concern that their model did not generally reproduce the observed intensities of singly-ionized ions. The predicted intensity of [O II] λ3727, for example, was 30% less than observed value of 13.5. Note (see Table 2), however, that this observed value is greater than any I measured for any position except position 5. I suspect that the explanation is that the low-resolution observations that HSAL compared their model to were strongly affected by line blending (see §IIc) near 3727 Å; the integrated intensity of the [O II] lines over the entire nebula is actually undoubtedly less than 13.5 and could well be in good agreement with HSAL's calculations.

c) Nitrogen

The optical abundances are again systematically lower than the optical + UV measurements. This again suggests that the UV intensities may have been somewhat overestimated, although it is also due in part to the use of the O^{++} T_e for the N^{++} and N^{3+} regions, where the model of HSAL suggests that the appropriate electron temperatures may be as much as 1200 K higher. For this reason, the optical measurements are preferred. The optical values for the N abundances are in generally good agreement for the different positions, considering the enormous size of the i_{cf}'s for N (the largest for any planetary nebula in this series of papers). It is likely that the N abundance measured for position 5 is high because of the difficulty (discussed in §IId) of guiding for this position. The i_{cf} for N is inversely proportional to the measured [O II] λ3727 intensity. Since this intensity was not measured at the same time as the [N II] λ6583 intensity, guiding errors can significantly affect the calculated N abundance. The average N abundance given in Table 6 is 1.8 ± 0.7 times the model calculation; this may be considered good agreement considering the difficulties described above. If position 5 is not included in the average, the N/H ratio is $0.75 \pm 0.13 \times 10^{-4}$, in excellent agreement with the HSAL value of 0.60×10^{-4}. In view of the large i_{cf}'s, I consider that this agreement is the strongest evidence yet that the N abundances in planetary nebulae can be determined from optical measurements using a simple ionization correction procedure.

d) Neon

The Ne^{4+} abundance was calculated after first correcting for blending of the λ3426 [Ne V] line with λ3429 O III, taking I (λ3429) = 0.33 I (λ3444) (Saraph and Seaton 1980). The total Ne abundance inferred from the Ne^{++} abundance is in reasonable agreement with that found by summing the Ne^{++}, Ne^{3+} and Ne^{4+} abundances. In addition, the total optically-measured Ne abundance is constant and not overestimated in the outer positions (as in Papers I and IV); in NGC 7662, as in NGC 3242 and NGC 7009, the ionization is so high 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 6 agrees well with that determined by HSAL.

e) Carbon

As in NGC 6720, NGC 7009, NGC 6853, and NGC 3242, the C^{3+} abundance in the inner positions inferred from the λ4267 line is larger than that found using the UV λ1906, 1909 lines. The ratio of the two measurements is 3.5, 2.0, 1.4, 0.90, and 0.63 for positions 1-5, respectively, so the discrepancy is again worst nearest the central star. Although this discrepancy is somewhat less than that found in the other nebulae, it should be borne in mind that the UV line intensities have probably been overestimated relative to the optical ones (see §IIc); if this is true, the actual discrepancy might be as much as a factor of two worse. HSAL found a similar discrepancy between their model calculation and the observed λ4267 intensity (which they took to be 0.76) and commented that the observed value should be checked. The intensity measured here is nearly the same value, 0.35, for all positions, a value that is in much better agreement with HSAL's calculated value of 0.18.

Even so, I feel that the discrepancy is greater than can be explained by observational errors and gives still more evidence that the λ4267 intensity is not understood theoretically. A number of possibilities were discussed in Paper II, but there is still no fully satisfactory explanation for this phenomenon.

The total C abundance for each position is the sum of the ionic abundances, using the UV rather than the optical measurement of C^{++}. There are two reasons why the calculated C abundance is systematically lower in the inner positions. First, Table 4 shows that 0.29 of the C in position 1 and 0.16 in position 2 is predicted to be in the unobservable C^{4+} state; in reality, these fractions may be even higher, since the model predictions probably refer to regions of lower ionization than the observed ones (see §III). Second, HSAL have convincing evidence that internal dust in the nebula absorbs λ1549 C IV resonance photons, decreasing the measured C^{3+} abundance; indeed, their predicted λ1549 intensity for the nebula as a whole not allowing for dust absorption is 1955, larger than the observed intensity even in the position of highest ionization. For these reasons, the total C abundance given in Table 6 is an average from only the outer three positions; note that it is in excellent agreement with the determination by HSAL. This agreement is fortuitous to some degree in view of the uncertain ratio of the UV-optical line intensities (see§IIc).

f) Argon

The calculated abundances are in excellent agreement for the five positions, although nearly all the Ar in the nebula is in an observable ionization state and so this agreement does not provide a confirmation of the ionization correction procedure for Ar. The equation $Ar/H = 1.5\ Ar^{++}$ (see Paper I), which is a useful approximation for faint planetaries where only the λ7135 [Ar III] line is observable, gives an average Ar/H ratio of 0.54×10^{-6}, only about a third the measured value (see Table 6); this error is not surprising in view of the very high ionization of NGC 7662.

g) Sulfur

The total S abundance is reasonably consistent at the different positions, but the average S abundance (Table 6) is nearly a factor of four less than measured by HSAL, by far the biggest discrepancy of any element. Since HSAL's model gives a good fit to the observed intensities of lines due to S in three different stages of ionization (one more than observed here), their result is probably more reliable. I feel that it would nevertheless be helpful to have infrared observations of the 10.5 μm [S IV] lines in the same positions as the optical measurements before drawing definite conclusions about the S abundance in NGC 7662.

h) Comparison of Abundances

In general, the abundances in all the objects in Table 6 are similar, but there are some interesting differences. The C, and, to some extent, N abundance is somewhat higher than the values for the sun and H II regions, suggesting that there may have been some mixing of CNO-processed material into the envelope before it was ejected. The C/O ratio, which is greater than one only for NGC 7662, supports this conclusion. On the other hand, the He abundance in NGC 7662, like that in NGC 3242, is definitely lower than in the other planetary nebulae or in H II regions, suggesting that there has been significantly less (perhaps no) enhancement of He-rich material in NGC 7662.

The Ne, Ar, and possibly O and S abundances in NGC 7662 are also a bit low, suggesting that NGC 7662, like NGC 3242, may have formed out of material that is more metal-poor than did the other objects listed in Table 6.

V. CONCLUSIONS

In summary, NGC 7662 is another planetary nebula for which total abundances can apparently be accurately determined from optical measurements alone. Although there is some evidence that the UV intensities may have been overestimated relative to the optical ones, there is fairly good agreement between abundances measured optically and those found by combining optical and UV data. More importantly, the excellent agreement between the optically-measured abundances and the model calculations by HSAL gives one new confidence in the optical technique. It is particularly gratifying that the N abundance determinations agree so well for a nebula in which as little as 0.1% of the N is in an optically-observable form. The close agreement between the calculated and observed electron temperatures and ionic abundances for the different nebular positions (Table 4) is also very reassuring. The discrepancy between the S abundance measured here and the model value by HSAL is cause for concern; it is possible that the ionization correction scheme for S is not applicable to a nebula that is as highly ionized as NGC 7662, but observations of the S^{3+} abundances in the different positions should be made to check this. As for the other nebulae in this series, the UV and optical measurements of the C^{++} do not agree; although the agreement is better than for the other objects, the systematic dependence on distance from the central star again indicates that the λ4267 line intensity is not being interpreted correctly. Finally, as in NGC 3242, there is evidence for the presence of internal dust in NGC 7662; it would be worthwhile to make a direct observational test for dust using an improved version of the technique described in §IIb.

I am grateful to the IUE and Kitt Peak staffs for their assistance in obtaining the measurements, and to K. Cudworth for providing measurements of the position of the offset star used for the IUE observations.

TABLE 1

PARAMETERS OF OBSERVED POSITIONS

PARAMETER	POSITION 1	2	3	4	5
Offset (arcsec)	4N	3.7E,5S	8N	12N	7.4E,10S
c	0.26	0.17	0.38	0.40	0.35
SWP number	20095	20103	20102	20105	20097
Exposure (min)	30	30	60	127	65
LWR number	16036	16030	16034	16033	16035
Exposure (min)	60	75	120	150	100
$F(H_\beta)^a$; 3".4 ent.	1.19	2.40	1.13	0.35	1.01
$F(\lambda 1640)^a$ predicted	2.75	5.80	0.87	0.02	0.06
$F(\lambda 1640)^a$ observed	4.29	2.48	1.42	0.04:	0.05:

[a]Units: 10^{-12} ergs cm^{-2} s^{-1}, uncorrected for interstellar extinction.

TABLE 2

LINE INTENSITIES

λ(Å)	ID	f (λ)	I (λ)				
			Pos.1	Pos.2	Pos.3	Pos.4	Pos.5
1403,1400	O IV]	1.31	89.	27.:	...	...	...
1487	N IV]	1.23	121.:	21.:	...	31.:	33.
1548,1550	C IV	1.18	1392.	1266.	678.	427.	155.
1640	He II	1.14	628.	516.	274.	41.:	17.:
1661,1666	O III]	1.13	53.:	20.:	48.:	24.:	22.:
1747	N III]	1.12	33.:	11.:	14.	26.	10.:
1906,1909	C III]	1.23	423.	517.	523.	539.	542.
2326,2328	C II]	1.35	...	...	...	...	82.
2422,2424	[Ne IV]	1.12	201.	205.	98.	...	...
2734	He II	0.74	30.	32.	...	...	...
3133	O III	0.45	137.	242.	135.	26.	...
3204	He II	0.42	52.	39.	36.	...	...
3426	[Ne V],O III	0.38	33.6	26.7	7.3	1.9	...
3444	O III	0.37	38.8	41.5	25.0	3.2	4.5
3727	[O II]	0.29	...[a]	3.5[a]	5.7[a]	10.5[a]	27.9[a]
3798	H 10	0.27	5.3	5.2	5.1	4.7	5.2
3835	H 9	0.26	7.3	7.4	6.6	6.5	7.4
3869	[Ne III]	0.25	75.4	91.6	110.	126.	131.

TABLE 2 continued

4069-4076	(blend)	0.21	1.3	1.4	1.4	1.1	2.0
4102	Hδ	0.20	28.4	28.5	27.4	27.2	28.1
4267	C II	0.17	0.35	0.34	0.35	0.35	0.32
4340	Hγ	0.15	48.0	47.4	46.4	46.6	47.2
4363	[O III]	0.15	15.5	17.6	19.0	16.9	15.9
4471	He I	0.11	1.1	1.4	2.8	4.5	4.5
4686	He II	0.05	89.4	73.4	39.0	3.3	2.8
4711	[Ar IV]	0.04	8.5	8.2	6.2	4.5	2.66
4714-4726	[Ne IV]	0.04	0.96	0.90	0.40	...	...
4740	[Ar IV]	0.03	7.5	7.4	5.0	3.1	2.2
4861	Hβ	0.00	100.	100.	100.	100.	100.
4922	He I	-0.02	1.0	0.12	5.0	1.2	1.6
4959	[O III]	-0.03	306.	388.	497.	535.	521.
5007	[O III]	-0.04	953.	1223.	1518.	1567.	1621.
5200	[N I]	-0.08	...	...	...	...	0.14
5412	He II	-0.13	5.3	5.1	3.5	0.42	...
5518	[Cl III]	-0.15	0.07	0.17	0.18	0.30	0.61
5538	[Cl III]	-0.15	0.08	0.15	0.26	0.33	0.58
5755	[N II]	-0.20	...	...	...	...	0.56
5876	He I	-0.22	3.5	4.5	6.29	11.0	11.9
6300	[O I]	-0.29	...	...	...	...	1.15
6312	[S III]	-0.29	0.82	0.80	0.78	0.91	1.44

TABLE 2 continued

6364	[O I]	-0.30	...	...	...	...	0.47
6563	Hα	-0.33	284.	284.	278.	277.	287.
6583	[N II]	-0.34	2.2	1.4	2.1	3.8	24.8
6678	He I	-0.35	1.3	1.4	1.8	2.8	3.0
6717	[S II]	-0.36	...	...	0.27	0.48	2.0
6731	[S II]	-0.36	...	...	0.29	0.63	2.9
7005	[Ar V]	-0.39	1.4	1.1	0.51	...	...
7065	He I	-0.40	1.2	1.4	1.9	3.0	3.4
7135	[Ar III]	-0.41	4.9	5.0	5.9	6.6	9.9

[a] Corrected for blending; see text.

TABLE 3

ELECTRON TEMPERATURES AND DENSITIES

QUANTITY	ION	RATIO	POSITION 1	2	3	4	5
N_e (cm^{-3})	S^+	I(6731)/I(6717)	...	...	890	1800	2500
N_e (cm^{-3})	Cl^{++}	I(5538)/I(5518)	3400	1500	6000	3000	1700
N_e (cm^{-3})	Ar^{3+}	I(4740)/I(4711)	6300	7000	4600	2300	12000
T_e (K)	N^+	I(6583)/I(5755)	...	...	...	...	11000
T_e (K)	O^{++}	I(5007)/I(4363)	13800	13100	12300	11600	11200
T_e (K)	Ne^{3+}	I(4720)/I(2422)	10100	10000	9700	...	...
T_e (K)	H^+	I(Bac)/I(Hβ)	16400	15400	13100	10800	12400
N_e (adopted)			4800±1500	3200±2000	4000±2000	2400±1000	5400±4000
T_e (adopted)			13800±500	13100±500	12300±500	11600±500	11200±500

TABLE 4

COMPARISON WITH MODEL CALCULATIONS

QUANTITY	POSITION 1		POSITION 2		POSITION 3		POSITION 4		POSITION 5	
	OBSERVED	MODEL	OBSERVED	MODEL	OBSERVED	MODEL	OBSERVED	MODEL	OBSERVED	MODEL
Ne (cm^{-3})	4800	2600	3200	2700	4000	3100	2400	2900	5400	2900
Te (K)	13800	14000	13100	13500	12300	12500	11600	11900	11200	11900
He^{++}/He	0.73	0.63	0.65	0.50	0.60	0.25	0.03	0.006	0.02	0.006
O^{+}/O	0.0	0.002	0.001	0.003	0.004	0.005	0.009	0.021	0.016	0.021
O^{++}/O	0.27	0.44	0.35	0.59	0.61	0.83	0.96	0.97	0.99	0.97
C^{+}/C	0.0	0.009	0.0	0.01	0.C	0.02	0.0	0.05	0.09	0.05
C^{++}/C	0.30	0.22	0.36	0.28	0.49	0.43	0.59	0.66	0.80	0.66
C^{3+}/C	0.70	0.50	0.64	0.55	0.51	0.52	0.41	0.30	0.20	0.30
C^{4+}/C	-	0.29	-	0.16	-	0.04	-	0.0	-	0.0

TABLE 5

IONIC AND TOTAL ABUNDANCES

		POSITION				
λ(Å)	ABUNDANCE	1	2	3	4	5
4471	He^+/H^+	0.023	0.030	0.059	0.094	0.093
5876	He^+/H^+	0.028	0.036	0.049	0.084	0.091
6678	He^+/H^+	0.036	0.039	0.049	0.076	0.080
Average	He^+/H^+	0.029±0.004	0.035±0.003	0.052±0.003	0.085±0.005	0.088±0.004
4686	He^{++}/H^+	0.079	0.064	0.034	0.003	0.002
	He/H	0.108±0.006	0.099±0.005	0.086±0.005	0.088±0.005	0.090±0.004
3726,3729	$10^4 \times O^+/H^+$	...	0.0072	0.016	0.031	0.061
5007	$10^4 \times O^{++}/H^+$	1.25	1.83	2.69	3.28	3.77
1661,1666	$10^4 \times O^{++}/H^+$	3.47:	1.99:	8.12:	6.87:	8.76:
..	i_{cf}	3.72	2.83	1.65	1.04	1.02
Optical	$10^4 \times O/H$	4.7±0.9	5.2±1.0	4.4±0.9	3.4±0.7	3.8±0.8
6583	$10^4 \times N^+/H^+$	0.0021	0.0014	0.0025	0.0050	0.0369
1747	$10^4 \times N^{++}/H^+$	0.45:	0.21:	0.41	1.17	0.64:
1487	$10^4 \times N^{3+}/H^+$	1.68:	0.43:	...	1.74:	2.53
	i_{cf}	...	722.	275.	110.	62.
Optical	$10^4 \times N/H$	...	1.0±0.1	0.69±0.06	0.55±0.05	2.3±0.2
UV +Optical	$10^4 \times N/H$	2.1:	0.64:	0.41	2.9:	3.2:

TABLE 5 Cont.

3869	$10^4 \times Ne^{++}/H^+$	0.25	0.36	0.54	0.76	0.90
2422	$10^4 \times Ne^{3+}/H^+$	0.97	1.08	0.71	...	...
3426	$10^4 \times Ne^{4+}/H^+$	0.06	0.05	...	...	...
	i_{cf}	3.76	2.84	1.63	1.04	1.01
Optical	$10^4 \times Ne/H$	0.94±0.18	1.02±0.20	0.88±0.17	0.79±0.16	0.91±0.18
UV + Optical	$10^4 \times Ne/H$	1.3	1.5	1.3	0.76	0.90
2326,2328	$10^4 \times C^+/H^+$	...	...	...	...	0.62
1906,1909	$10^4 \times C^{++}/H^+$	1.15	1.92	2.89	4.40	5.66
4267	$10^4 \times C^{++}/H^+$	4.06	3.91	3.98	3.95	3.59
1548,1550	$10^4 \times C^{3+}/H$	2.5[illegible]	3.42	2.98	3.02	1.48
UV	$10^4 \times C/H$	3.7±1.9	5.3±2.6	5.9±2.8	7.4±3.5	7.1±3.3
7135	$10^6 \times Ar^{++}/H^+$	0.21	0.24	0.31	0.40	0.64
4711,4740	$10^6 \times Ar^{3+}/H^+$	1.03	1.15	0.97	0.74	0.52
7005	$10^6 \times Ar^{4+}/H^+$	0.40	0.35	0.19	...	...
	i_{cf}	1.00	1.00	1.01	1.01	1.14
Optical	$10^6 \times Ar/H$	1.6±0.6	1.7±0.6	1.5±0.5	1.2±0.4	1.3±0.3
6717,6731	$10^6 \times S^+/H^+$	...	...	0.011	0.020	0.12
6312	$10^6 \times S^{++}/H^+$	0.70	0.81	0.98	1.43	0.83
	i_{cf}	...	6.22	4.51	3.33	2.76
Optical	$10^6 \times S/H$	...	5.0±2.6	4.5±2.5	4.8±2.6	2.6±1.4

TABLE 6

COMPARISON OF ABUNDANCES

Object	He/H	10^4 XO/H	10^4XN/H	10^4XNe/H	10^4XC/H	10^6XAr/H	10^6XS/H	Reference
NGC 7662	0.094±0.004	4.3±0.3	1.1±0.4	0.91±0.04	6.8±0.5	1.5±0.1	4.2±0.6	1
NGC 7662	0.094	3.6	0.60	0.70	6.2	...	15.	2
NGC 3242	0.091	4.4	0.91	1.1	2.6	1.4	3.2	3
NGC 6853	0.110	8.4	3.0	2.7	7.6	3.3	5.9	4
NGC 6720	0.110	6.2	2.2	1.6	3.9	3.7	10.	5,6
NGC 7009	0.117	4.8	1.3	1.5	1.5	2.3	13.	7
H II regions	0.117	4.0	0.4	1.3	...	...	18.	8
Sun	0.100	7.4	0.9	1.1	4.5	3.7	17.	9,10

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