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SPECTROPHOTOMETRY OF 12 PLANETARY NEBULAE

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ABSTRACT

A dozen planetary nebulae have been observed between Hδ and [O II] λ7325 with the Red Reticon at the 2.3 m telescope of Steward Observatory, with the most extensive spectrophotometry done between Hγ and [Ar III] λ7135. The objects are a mixture of types, all but two drawn from wide-aperture surveys. For most of the nebulae [O III] and/or [N II] electron temperatures, [S II] electron densities, and He/H, O/H, and N/O ratios are derived. Since the red [O II] lines are observed for only three objects, [S II] and [O I] lines are used to estimate the [O II] λ3727 intensities, and consequently O^+/H^+ ratios, through the linear correlations established by the author. The results confirm the high N/O ratio found earlier for NGC 6537 from wide-aperture photometry; within rather wide errors, this extended nebula appears to be homogeneously enriched. In addition, NGC 6563 may have enhanced abundances; the object needs further observation. Both rings of the double shell nebula NGC 6804 are observed, with no difference found in their He/H ratios. NGC 6894 has an [O I] line that is anomalously weak for the [S II] strength, and NGC 6578 has a Wolf-Rayet nucleus.

A major feature of this work is an exhaustive discussion of errors. Internal errors are derived from measured line widths. The external, systematic, variety is evaluated from comparisons between: (1) Reticon and Kitt Peak IRS data acquired for M1-4; (2) observed and theoretical line intensity ratios; and (3) the observations of Me 2-1 presented here and those published by Aller, Keyes, and Czyzak. The last shows agreement to within about ±20%, except for $\lambda > 7000$ Å. Error corrections are applied to the data prior to analysis.

The extinctions derived here from Hα/Hβ compare well with those found by the author from wide-aperture photometry. Other comparisons indicate considerable ionic stratification for some nebulae.

Subject headings: nebulae: abundances — nebulae: planetary — spectrophotometry

I. INTRODUCTION

Several extensive spectral surveys over the past decade, together with numerous smaller studies, have allowed us to examine the chemical compositions of planetary nebulae with regard to the evolution of the Galaxy and to that of the individual stars within it. Particular examples are the works of Terres-Peimbert and Peimbert (1978), Barker (1978), and Aller and Czyzak (1979). From these and others we have been able to use the planetaries as markers of the changing galactic environment, wherein we see the increase of helium, oxygen, and nitrogen abundances with time.

Perhaps of greater significance, we have now begun to relate nebular compositions to stellar evolutionary processes that took place prior to the event that produced the planetary. A number of these objects are clearly enriched in helium, nitrogen, and/or carbon, a result of convective dredge-up processes that took place in giant-branch states of the parent star's life, which cycle products of nuclear burning into the outer stellar envelope; see Kaler, Iben, and Becker (1978). In effect, the planetaries are probes for studying internal processes in stars and for testing theories of stellar evolution. Various theoretical calculations predict that chemical abundances in excess of the ambient interstellar medium correlate positively with initial stellar mass (Becker and Iben 1979, 1980; Renzini and Voli 1981), as does final core mass (Iben and Truran 1978). Iben and Renzini (1983) consequently predicted a correlation between core mass and nebular composition, which was subsequently qualitatively confirmed in a survey of large planetary nebulae made by Kaler (1983*c*).

Summaries of current research in this subject have been written by Aller (1983), Peimbert and Torres-Peimbert (1983), and Kaler (1983*b*). For interpretation in terms of theory, we currently have reasonably sufficient data on about 75 nebulae. But these planetaries, in spite of their unifying name, are a remarkably heterogeneous group. They extend through all population classes from the extreme disk to the distant halo, and represent initial masses from under the Sun's to 6 or more times it. Some are so compact as to appear stellar; others are well over a parsec across. Central star temperatures encompass values from 25,000 K to considerably over 100,000 K, and luminosities range from only a few times solar to the Eddington limit near $10^4 L_\odot$. Some have powerful winds and complex and varied spectra; others do not. In an evolutionary sense, the nuclei range from those that have recently expelled the last of their red giant envelopes to ones that are essentially white dwarfs, and the stars reflect all the varied natures both of their predecessors and their successors. In this context, our set of 75 is very small, and it is little wonder that there is considerable controversy regarding a number of topics.

For proper statistics, and to enable quantitative correlations and comparisons to theory to be made among all varieties of planetaries, we must considerably increase the amount of data available. This paper begins an extended series of articles on digital spectrophotometry of planetary nebulae designed to do just that, opening here with a study of a dozen objects, observed primarily in the red part of the spectrum. Half of these were selected from the survey of large planetaries by Kaler (1983*c*), and another four from Kaler's (1983*a*) study of more compact nebulae. Absolute line fluxes have been observed for all these planetaries, and the purpose here is to examine them in more detail and to confirm abundance ratios derived from the interference filter photometry. One other is an interesting double shell object, chosen to examine abundance variations, and the last is simply an underobserved target of opportunity. The observations, data, and errors are discussed in the next section, and physical parameters and abundances in § III.

II. THE OBSERVATIONS

The nebulae were observed with the Red Reticon system attached to the 2.3 m University of Arizona Steward Observatory telescope on Kitt Peak. The instrument is sensitive primarily from the He II λ4686 line through [Ar III] λ7135, but for a few of the brighter objects the data could be extended down to Hδ and longward to the [O II] λ7325 lines. The effective resolution is about 6 Å.

The journal of observations is given in Table 1, which includes the common and Perek-Kohoutek (1967) names in the first two columns, and the date and integration times in the second two. Column (5) gives the position within the nebula observed through the 5 second of arc aperture used. One object, NGC 6804, was observed at two locations, one point in each of the two rings. Column (6) lists a capsule description of each planetary, and column (7) gives the principal references to earlier spectral studies. Note that one nebula, NGC 6578, has not been spectroscopically examined for 40 yr, and another, NGC 6563, not at all.

All nebulae were observed in the normal beam-switching mode, with calibrators selected from the Kitt Peak Standard Star Manual. The larger nebulae were observed near their edges in order to place one aperture on the sky. NGC 6537 was examined in an extreme position in the outer halo far from the central source. For NGC 6804, a classic double-ring structure (see Curtis 1918), the outer ring served as the "sky" background for the inner, in order to subtract it properly, so that a relatively pure spectrum of the inner nebula could be acquired.

a) Reductions and Intensities

The data were reduced with Steward Observatory software and a mean atmospheric extinction function in order to provide fluxes. Most of the objects observed on June 9 and 10 were affected by occasional light cirrus, which should not significantly alter the relative line intensities, but which renders absolute surface brightnesses useless.

The Steward data are supplemented with one spectrum scan taken of M1-4 with the Intensified Reticon Scanner (IRS) at the No. 1 91 cm telescope at Kitt Peak, drawn from a study to be reported on at a later time. The observing technique was the same as described above, and there was a similar problem with light cirrus.

Relative fluxes were determined with the Illinois Gaussian fitting program, SPEC. Gaussian profiles fit the line shapes reasonably well, and their adoption is needed for the resolution of blends. Up to four lines can be fitted at a time, and three options are available: (1) the widths are allowed to be a free parameter (the *f*, or floating mode); (2) the widths can be constrained so that all lines reduced in the set of two to four are forced to have equal width, as they should, since the lines are unresolved and are simply aperture images (the *e* mode); and (3) a special iteration routine for the Hα + [N II] trio, the *i* mode, in which the line widths are similarly constrained, and [N II] λ6548 is required to be $\frac{1}{3}$ the strength of [N II] λ6584. The latter two options are needed to resolve blends. The *i* mode is required, since at typical dispersions, [N II] λ6548 is lost within Hα, and is subtracted from it on the basis of the Gaussian fit to [N II] λ6584.

Since errors in the fluxes will be reflected in the line widths (see below), all lines except genuine blends were allowed to float. Four blending problems are important: (1) Hγ and [O III] λ4363, (2) [O I] λ6300 and [S III] λ6312, (3) [S II] λ6717, λ6731, and (4) Hα + [N II]. The mode selected for the first depended upon the appearance of the spectrum; usually, the results of both the *f* and *e* options were simply averaged. Even though the widths must theoretically be the same, the floating solution must be included in order better to evaluate errors. For the [O I]–[S III] and for the [S II] blends, the lines were so close that the *e* mode was used exclusively. For Hα + [N II], the results of all three types of fits, *f*, *e*, and *i*, were averaged in order to derive the most meaningful results, and to allow for error estimation.

The results, relative line fluxes on the usual scale $F(\mathrm{H}\beta) = 100$ (here called intensities, *I*), are given in Table 2.

TABLE 1

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Nebula (1)	PK (2)	Date (3)	Exp. (min) (4)	Position (5)	Description[a] (6)	References (7)
NGC 6058	64+48°1	1980 Jun 9	10	Off star	Large, med ex, high Z	1, 2, 3
NGC 6537	10+0°1	1980 Jun 10	10	Arc, 1′N	Large, med ex	2, 4
NGC 6563	358−7°1	1980 Jun 10	5	N arc	Large, low ex	
NGC 6578	10−1°1	1980 Jun 10	20	Center	Compact, low ex	2
NGC 6765	62+9°1	1979 Oct 14	5	NE lobe	Large, high ex	1, 5
NGC 6804	45−4°1	1980 Jun 9	10	S, inner ring	Double shell, high ex	2, 3
			20	S, outer ring		
NGC 6894	69−2°1	1980 Jun 9	15	N ring	Large, low ex	1, 2, 6
IC 972	326+42°1	1980 Jun 9	20	N ring	Large, low ex, high Z	1
IC 1454	117+18°1	1980 Jun 10	10	S ring	Large, low ex, high Z	7
M1-4	147−2°1	1979 Oct 4	5	Center	Compact, low ex	4, 6
		1980 Oct 13[b]	4	Whole		
M2-2	147+4°1	1979 Oct 14	5	W edge	Compact, low ex	4
Me 2-1	342+27°1	1980 Jun 10	6	Center	Compact, high ex	4, 8, 9

[a] "ex" = excitation, "Z" = distance from galactic plane.
[b] IRS at Kitt Peak.

REFERENCES.—(1) Kaler 1983*c* (2) Minkowski 1942. (3) Chopinet 1963. (4) Kaler 1983*a*. (5) Sabbadin and Hamzaoglu 1981. (6) Kaler, Aller, and Czyzak 1976. (7) Kaler 1978. (8) Aller, Keyes, and Czyzak 1981. (9) Aller and Czyzak 1970.

TABLE 2

Relative Observed Emission-Line Fluxes, or Intensities, Uncorrected for Reddening

λ	Ident.	NGC 6058	NGC 6537	NGC 6563	NGC 6578[a]	NGC 6765	NGC 6804 inner ring	NGC 6804 outer ring	NGC 6894	IC 972	IC 1454	M1 4	M2 2	Me2 1	f_λ[b]
4101	Hδ	24.4±0.8			14:		25:±7					17±9		22.4±2.7	0.195
4267	C II[c]				0.3±0.2		3.2±1.4								0.145
4340	Hγ	48.6±1.8		38±13:	25±1.4[d]	39.1±1.0	33.9±2.5	31.3±7.9	32.1±2.1		34.5±9.5	27.7±3.4[e]	28.7±6.1	36.4±1.7	0.135
4363	[O III][f]	16.4±1.4		18±6:[c,g]	1.7:[d,g]	13.0±3.4	8.6±1.6	6±6:	< 5			9.7±0.3	< 6	11.0±1.2	0.130
4471	He I				2.9±0.5		1.0±0.6							0.80±0.36	0.105
4541	He II						4.0±2.0							2.33±0.60	0.085
4634	N III				1.0±0.3		1.6±0.9								0.060
4658	C IV													1.4:	0.050
4686	He II	57±2		16:	1.0±0.3	67.0±1.3	89.1±0.6	38±5	< 4	< 36	16.4±5.2	4.1±0.4	< 7	81±3	0.045
4712	[Ar IV],He I	4.8±1.2			0.8±0.4	3.8±2.5	8.6±1.7					2.6±0.3		10[h]	0.040
4740	[Ar IV]	5.5±1.4			0.7±0.4	6.8±1.2	5.2±1.5					2.4±0.3		5.9±0.8	0.035
4861	Hβ	100±2	100±22	100±12	100±3	100±2	100±1	100±3.6	100±4.5	100±16	100±3.1	100±3[e]	100±2	100±4	0.000
4959	[O III]	380±6	501±14	318±14	315±8	497±10	289±5	522±18	293±13	230±19	377±10	497±6[e]	448±7	450±3	-0.020
5007	[O III]		1640±30	993±29	1060±25	1585±30	928±46	1543±56	942±28	745±60	1060±25	1560±20[e]	1530±20		-0.035
5191	[Ar III]											0.7±0.3			-0.075
5200	[N I]					8.5±1.2									-0.075
5411	He II	2.9±0.9				5.9±1.2	9.2±1.7					0.8±0.4		5.8±0.8	-0.120
5517	[Cl III]					1.6±0.6									-0.145
5537	[Cl III]					0.8±0.4			4.7±1.3						-0.150
5754	[N II]		56±23			7.4±1.1			7.3±5.0						-0.190
5876	He I	5.2±1.3		20:	35±0.8	10.0±1.8	3.3±1.3	17±6	21.5±3.5	32±20	6.9±3.5	28.9±3.2[e]	27±6	3.6±0.7	-0.215
6101	[K IV]													0.2±0.2	-0.255
6300	[O I]		218±50	42±7		36.9±0.7			2.1±0.8	48±11		1.5±0.3		1.5±0.5	-0.290
6312	[S III]				1.2±0.4	10.3±1.1			5.1±1.4			2.0±0.3		1.35±0.5	-0.290
6363	[O I]			20±8		13.4±0.9				17±6				0.5±0.3	-0.300
6406	He II													0.6±0.4	-0.310
6435	[Ar V]													1.05±0.4	-0.315
6548	[N II]		2960±190	236±14		240±17			199±10	111±6	37±3			7.1±1.7	-0.330
6563	Hα	295±8	1515±200	302±40	940±22	455±30	610±3	548±25	564±55	279±33	311±31	1270±115[e]	969±31	304±10	-0.335
6584	[N II]	≤ 6	9930±170	731±21	70±28	829±14			631±25	365±22	113±9	74±4[e]	4:	22±6	-0.335
6678	He I	3.2±1.0		4:	12.4±1.3	3.4±1.0	2.3±1.1	6.8±3.3	7.0±1.5			12.8±0.4	8.8±3.4	1.7±0.5	-0.350
6717	[S II]		326±33	23.2±6.5	1.8±0.4	109±13			91±8		15±5	1.4±0.3		1.5±0.6	-0.355
6731	[S II]		470±47	21.7±5.2	3.4±0.6	109±13			73±6		11±6	1.8±0.3		2.5±1.0	-0.355
7005[i]	[Ar V]					2.2±0.7								1.3±0.5	-0.390
7065	He I			6.7±3.3	14.7±1.5	6.3±1.1						29.3±0.8		1.02±0.6	-0.395
7135	[Ar III]	3.5±1.0		18.6±6.0	48.0±1.1	46.7±0.9	7.86±3.0	10.5±4.6	50±5			32.8±0.9		6.0±0.9	-0.405
7177	He II						4.7±2.1							0.9±0.4	-0.415
7237	[Ar IV]				0.9±0.6							2.8±1.1			-0.420
7281	He I				1.8±0.4	3±3						2.8±0.3			-0.425
7320	[O II]					8.3±1						2.9±0.3		1.2±0.5	-0.430
7330	[O II]					7.7±1						3.5±0.4		0.9±0.4	-0.430

[a] Stellar C III λ4650 and C IV λ5801 + 12 present, with approximate equivalent widths of 3 Å and 12 Å, respectively.
[b] Reddening function, f_λ, where $\log I_c$ (corrected) = $\log I_0$ (observed) + cf_λ.
[c] Identification uncertain.
[d] Continuum uncertain: maximum values given.
[e] Observed with both the Reticon and the IRS.
[f] I(λ4363) should be corrected for the error in Hγ found by comparing the latter with theory; λ4267 and Hδ should be used with caution.
[g] Possible confusion with λ4358 Hg (night sky); should be considered as an upper limit.
[h] Probably blended with λ4724 [Ne IV].
[i] Intensities for lines with λ > 7000 Å should be increased by a factor of 1.45 for consistency with the intensities at shorter wavelengths (see § II*c*).

These are as observed, and are *not* corrected for interstellar extinction, which is discussed in the next section. Relative fluxes are not given for λ5007 for NGC 6058 and Me 2-1, since they show clear effects of instrumental saturation. The fluxes of lines observed in common for M1-4 with the Reticon and the IRS are simple averages. The Hβ line of NGC 6537 was only barely detected because of high reddening, and the scaling may be off; however, the nominal Hα/Hβ ration agrees with that found by Kaler (1983*a*) to within 11%. There appears to be uncertain sky cancellation for NGC 6563, and to some extent for IC 1454. The helium line intensities for the former are quite uncertain.

The spectrum of NGC 6578 is confused with noise in the neighborhood of Hγ, and consequently, the intensity of [O III] λ4363 is very poorly determined. Table 2 presents the maximum allowable values for it and for I(Hγ), since the resultant electron temperature from [O III] is still very low (see § III). This object also displays stellar emission lines that may be identified as C III λ4650 and C IV λ5801 + 12. We discuss these again in § III*d*.

b) *Internal Errors*

A serious problem that has afflicted work of this kind since its inception is the general lack of error analysis. The reason is fairly obvious: one frequently has but a single observation (intensity or flux) of an individual line. This difficulty was especially appropriate to the older photographic data, wherein an observation consisted merely of an integrated profile of calibrated photographic density versus wavelength. It was common to guess an error based upon the level of background noise, and a canonical value of ±20% was usually quoted, with little basis in fact. This attitude has generally carried over into the era of photoelectric photometry and digital counting systems, which are more amenable to error analyses.

Detailed error evaluation, in which individual errors are assigned to each line, has been performed by Kaler *et al.* (1976), Barker (1978), Kaler (1983*a*, *c*), and in the other studies undertaken at Illinois' Prairie Observatory cited by the latter. These, where possible, employ comparisons of multiple observations, and the Prairie reductions use photon-counting statistics as well. Excepting M1-4, the present study contains only one observation per nebula, so that an alternative method, one based upon line widths, is employed.

Clearly, there will be random errors in the line fluxes. These will affect areas, line peaks, and widths, w. Errors affecting the widths are directly detectable, since we know that theoretically they should all be the same. We may then assume that the errors in the integrated fluxes are proportional to those in the widths. The first step is to select three or four well-observed, unblended, lines for a given object (e.g., Hβ, [O III] λ4959, [Ar III] λ7135, unblended Hα). These widths are averaged to determine a mean value, $\bar{w}$. The average percentage deviations of the widths of these standard lines from the mean is adopted as the minimum allowed error, $e_{\min}$. A preliminary error, e_p, for each of the other lines is then found from $[w(\text{line}) - \bar{w}]/\bar{w}$, with e_p not allowed to drop below $e_{\min}$.

We must now allow for the possibility that a line with a high intrinsic error in flux can accidently have the correct width, $\bar{w}$, leading us erroneously to believe that the error is low. To counter this difficulty, e_p is plotted versus relative flux for each object. The plots show that maximum e_p increases with decreasing intensity, as expected. The next step is to draw in the upper envelope of the point distribution, after rejecting what appear to be truly anomalous values, which then represents the final percentage error curve as a function of relative flux. This relation is applied to each line to find the errors that are assigned in Table 1. Note that Hβ is given an error as well, and that to find the error of a line relative to that at Hβ, the two must be quadratically compounded. In a few instances, the line is so odd or uncertain that the usual all-encompassing colon is used, here really meaning "detection." For the lines observed in common with the two instruments for M1-4, the error is simply the deviation of each from the mean, so that individual values can be recovered.

In principle this scheme should provide a realistic assessment of the accidental errors. In practice, the results must still be considered only as a relatively crude indicator of error. First, there are usually not enough lines to establish the upper envelope of the error curve with surety, and it often rests on few points. Second, the error curve should be applied *before* reduction to outside the atmosphere rather than after. The second effect, however, is likely to be small compared to the first. In spite of the problems, the attempt is made to provide errors that are as meaningful as practicable.

c) *Systematic Error and Interstellar Extinction*

The accidental errors, of course, do not provide the complete picture. We must also consider the systematic variety that may be dependent upon wavelength and/or line strength. In order to evaluate these, we must compare our data with externally derived flux ratios. This study uses two ways of examining these errors: (1) comparison of repeated observations, principally those made with different instrumental systems, which tests only relative error; and (2) comparison of the data with theoretical ratios.

First, we can compare the intensities derived for M1-4 by the Reticon and the IRS; these are graphed by their logarithms in Figure 1, where the dotted lines indicate a ±20% error. There are only seven lines in common, but the relation is linear, with little suggestion of a systematic trend. We may also compare the Hα/Hβ and Hγ/Hβ ratios of the inner and outer rings of NGC 6804, under the assumption that the interstellar extinction is uniform over the nebular surface. These agree to within

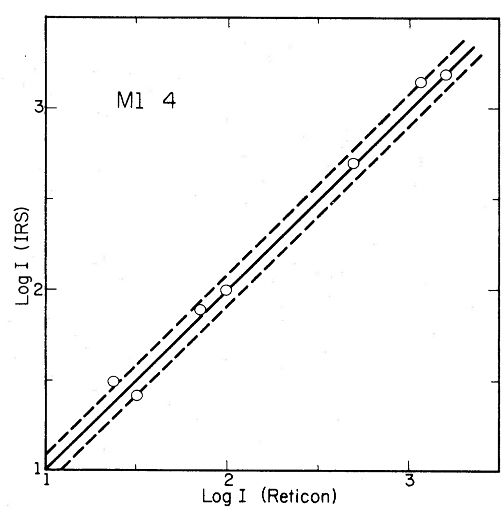

FIG. 1.—The logarithms of the intensities derived independently for M1-4 from the Red Reticon and from the Kitt Peak IRS plotted against one another. The solid line is the 45° slope, and the dashed lines indicate an error of ±20%.

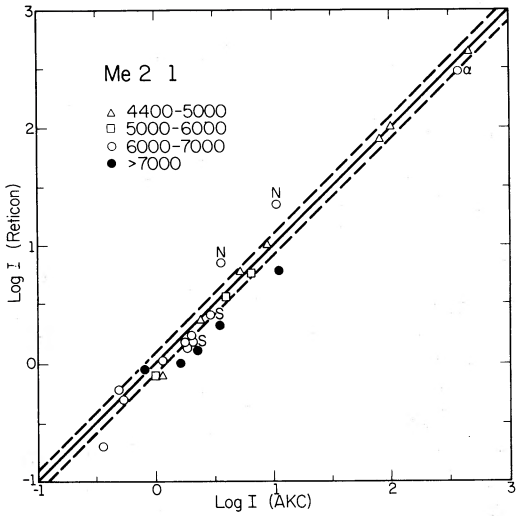

FIG. 2.—The logarithms of the intensities for Me 2-1 from this paper, log I (Reticon), plotted against those from Aller, Keyes, and Czyzak (1981), log I (AKC). The solid and dashed lines again are the 45° slope and the ±20% error indicators, respectively. Different wavelength regions are indicated by the symbols in the figure legend. The letters N, S, and α represent the [N II], [S II], and Hα lines. [N II] appears to show substantial stratification. Note the systematic shift for lines with $\lambda > 7000$ Å, discussed in the text.

about ±10%. Note that this difference is roughly double that expected from the given internal errors.

The only nebula observed with digital techniques by anyone else with similar precision is Me 2-1, which was examined by Aller, Keyes, and Czyzak (1981, hereafter AKC). The logarithms of the intensities of Table 2 are plotted against theirs in Figure 2. Here, we see a much more extensive comparison, wherein trends within different wavelength regions can be examined. The [N II] and [S II] lines are denoted by "N" and "S" respectively, with Hα indicated by "α."

Figure 2 shows good linear agreement over a range of nearly three orders of magnitude. The [N II] lines fall well off the 1:1 line, the new ones being about twice as strong as AKC's. This divergence is almost certainly the result of ionic stratification, since the two studies used different apertures, although it is curious that [S II] (and [O I], not indicated) do not share it. In general, AKC measure the line strengths to be systematically greater, with the largest divergence seen for $\lambda > 7000$ Å. If we ignore the weakest line, and [N II], the AKC intensities for $\lambda < 7000$ Å average 10% larger; but two-thirds of the points still fit within the ±20% error limits drawn, overall not inconsistent with internal error estimates. The Hα/Hβ ratios differ by 24%, however, well in excess of expectations. It is possible that Hα was saturated with the Reticon, as was λ5007, although the present value is supported by Kaler's (1983*a*) measurement of $I(\mathrm{H}\alpha) = 310$. The lines with $\lambda > 7000$ Å clearly lie outside the error limits drawn; for these, the AKC intensities average 60% larger.

Further tests, and an evaluation of the problem for $\lambda > 7000$ Å, can be obtained through comparison of the observations with a number of theoretical ratios derived for hydrogen, helium, and forbidden lines. First, however, the data must be corrected for the effects of interstellar reddening.

The logarithmic extinctions at Hβ, c, are given in Table 3. They are calculated from the Hα, Hβ, and Hγ intensities, where the Whitford (1958) reddening function and Brocklehurst's theoretical Balmer decrement are employed. As usual,

TABLE 3

EXTINCTION CONSTANTS

Nebula (1)	Hα/Hβ (2)	Hγ/Hβ (3)	c(PO)[a] (4)
NGC 6058	0.04	−0.12	0.18 ± 0.19
NGC 6537	2.16	...	2.02 ± 0.14
NGC 6563	0.07	0.68:	...
NGC 6578	1.54	2.18	...
NGC 6765	0.60	0.59	0.46 ± 0.15
NGC 6804R_i[b]	0.98	1.04	...
NGC 6804R_o[b]	0.84	1.30	...
NGC 6894	0.88	1.22	0.92 ± 0.16
IC 972	−0.05	...	0.08 ± 0.08
IC 1454	0.11	0.99	...
M1-4	1.94[c]	1.69	1.36 ± 0.22
M2-2	1.58	1.58	1.25 ± 0.15
Me 2-1	0.08	0.81	0.11 ± 0.17

[a] Prairie Observatory; Kaler 1983*a*, *c*.
[b] R_i and R_o represent inner and outer rings, respectively.
[c] Reticon data alone yield $c = 1.82$.

$\log I_c = \log I_o + cf_\lambda$, where I_c and I_o are the corrected and observed intensities; the f_λ used are given in the last column of Table 2. Columns (2) and (3) of Table 3 give the extinctions found from the Hα/Hβ and Hγ/Hβ intensity ratios, respectively. The Hγ line seems to be subject to some systematic error, which is discussed below, and $c(\mathrm{H}\alpha/\mathrm{H}\beta)$ is adopted for subsequent analysis. For NGC 6804, the two values are averaged to obtain $\bar{c} = 0.91$, which is used for both data sets. For comparison, column (4) presents the extinctions derived by Kaler (1983*a*, *c*) from interference filter photometry, c(PO). The results are generally quite satisfactory, the notable exception being M1-4, for which c(PO) is clearly too small. This comparison is probably more of a check on the systematic errors in the Prairie Observatory data than on the present observations. Note that AKC adopt $c = 0.36$ for the test object Me 2-1 from the Balmer decrement (see above).

For external testing against theoretical ratios, the most extensive data available are $I(\mathrm{H}\gamma)$, $I(\lambda6678)/I(\lambda5876)$ of He I, and $I(\lambda5007)/I(\lambda4959)$ of [O III]. These are plotted, after correction for extinction, in Figure 3, each point indicated by object name.

The points representing $I(\mathrm{H}\gamma)$ are noticeably and consistently under the theoretical ratio. It seems clear that the intensities in the Hγ region are low by perhaps 10%, really not unsatisfactory since the Red Reticon was not designed to work this far into the blue. Obviously, any lines shortward of Hγ (C II λ4267 and Hδ) must be viewed with caution; the C II identifications are only tentative, in any case.

The λ6678/λ5876, ratio, in the center of the Reticon sensitivity region, provides a truer test, although the lines are weaker and the accidental errors larger. The theoretical ratio is from Brocklehurst (1972), for low density and $T = 10{,}000$ K, and the observations were corrected for self-absorption according to Kaler (1978) and the densities listed in the next section. We see good agreement with theory; the error bars either overlap the theoretical ratio or are very close to it (as they are in fact for the Hγ/Hβ ratio), testimony to realism in their calculation. Here, however, no genuine systematic trends are clear. The formal average is 22% high, but the lower error limit is only 6% above theory. The objects with larger error bars are elevated more than those with smaller; if we confine our analysis to the five nebulae with the best observations, then λ6678 is 18% too weak relative to λ5876, not significant for these lines.

The λ5007/λ4959 ratio from [O III] provides a distinctive result. From Figure 3, we see that the ratio is systematically high (averaging 7%) as compared to the theoretical ratio of 2.88 from Mendoza (1983). This ratio is so well researched that theory seems quite secure. This departure suggests a nonlinearity in the detector at high count rates and indicates that without further tests no result derived from the data (or, to be bold, from any system of this sort) should be trusted to better than ±5% to ±10%.

Some other ratios are less extensively available. Comparison of λ4471 of He I with λ5876 for three nebulae shows nothing untoward. The λ6300/λ6363 [O I] ratio is observed for four objects with a mean ratio 15% below the Mendoza (1983) prediction, good agreement considering the weakness of the lines and the partial blend of [O I] λ6300 with [S III] λ6312.

Three line pairs are potentially available to test the contended region longward of 7000 Å. The observed λ7065/λ5876 He I ratio, averaged for five nebulae, is nearly 3 times the theoretical, clearly the result of self-absorption, wherein λ7065 is pumped by λ3889 (see Osterbrock 1974). Although an interesting physical result, the effect renders λ7065 useless for an error examination. That leaves the λ7281/λ5876 He I and the λ7177/λ4686 He II intensity ratios, observed in two objects each. The mean He II ratio agrees very well with theory (from Brocklehurst 1971), but He II λ7177 is likely to be blended with [Ar IV], the correction for which would lower it. The two good values of λ7281/λ5876, all that are left, are 0.024 ± 0.005 (NGC 6578) and 0.034 ± 0.004 (M1-4, Reticon results only). These average 0.029, 75% under the theoretical value of 0.051, reasonably consistent with the 60% difference between the new data and AKC's for $\lambda > 7000$ Å. On this meager evidence we may conclude that systematic error affects the Reticon data in this region and not those of AKC. For subsequent analysis, it is recommended that the intensities in Table 2 for lines with $\lambda > 7000$ Å be increased by a factor of 1.45, which is the correction required to make them consistent with the 10% systematic offset discussed in § IIc for $\lambda < 7000$ Å.

Note that all of these tests against theoretical ratios include the error in the extinction constant. Unfortunately, NGC 6578 and M1-4, used to test intensities for $\lambda > 7000$ Å, are heavily reddened. However, an error of ±0.3 in c, which is unreasonably high, produces an error of only 16% in the λ7281/λ5876 He I ratio, and somewhat less in $I(\lambda6678)/I(\lambda5876)$.

d) Comparisons with Other Data

The differences among the intensities in Table 2 and those from the references in Table 1 are of some interest; most can clearly be ascribed to stratification, since the tendency was to observe in lower excitation regions near the peripheries of the nebulae. Kaler (1983*a*) found strong λ4686 in NGC 6537, in agreement with Minkowski (1942), and roughly equal Hα and [N II] λ6584. The λ4686 line cannot be detected here because of high reddening, but the λ6584 [N II]/Hα ratio is 6.5 at a distance 1′ from the center (see also Aller 1976*a*): stratification in the extreme! Similar, but less pronounced, effects are seen for NGC 6765, IC 972, and NGC 6894. In the case of the first of these, Kaler (1983*c*) found $I(\lambda4686)$ to be almost twice as high as the present value, and [N II] to be over 3 times weaker; for the other two, Kaler (1983*c*) detected λ4686, but it is not found here. The present λ4686 intensity limit for M2-2 is also much lower than Kaler's (1983*a*) measured value, but curiously, the new [N II] strength is lower as well. Kaler's [N II] intensity has a very high error, and that result is likely to be spurious, which is consistent with lower Hα intensity from that study (i.e., [N II] and Hα were probably over- and underestimated, respectively, from the filter photometry). In this context, also note from Table 2 the large excitation difference between the inner and outer rings of NGC 6804.

III. ANALYSIS

a) Parameters and Abundances

Here, the data are used to compute electron temperatures and densities, and abundances ratios, all of which are summarized in Table 4. The usual methodology is employed (see Aller 1956 or Osterbrock 1974), with the recombination coefficients of Brocklehurst (1971, 1972) for hydrogen and helium, and the atomic parameters of Mendoza (1983) for the forbidden lines. We processed the data with the Illinois analysis code ABUNDR, which employs strict 3- and 5-level atom solutions for (p^2, p^4), and p^3 ions, respectively. This analysis

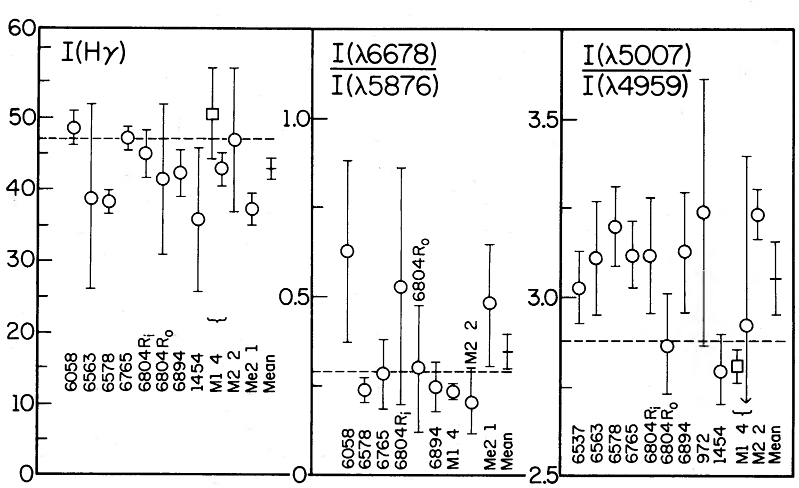

FIG. 3.—Comparisons between observed and theoretical line ratios, indicated respectively by the points and the dashed line. The names of the nebulae are given along the bottom. The mean, with the formal mean error, is given to the right of each set. The inner and outer rings of NGC 6804 are denoted by R_i and R_o, respectively. For Hγ and the [O III] lines, M1-4 is plotted twice, for the Reticon data only (*circle*) and for the mean from the Reticon and the IRS (*box*). Note the systematic trends in both the Hγ and [O III] plots.

TABLE 4

ANALYSIS

Name (1)	T[O III] (K) (2)	T[N II] (K) (3)	N_e[S II] (4)	He^+/H^+ (5)	He^{++}/H^+ (6)	He/H (7)	10^4 O^+/H^+ (8)	Ref.[a] (9)	10^4 O^{++}/H^+ (10)	10^4 O/H (11)	N/O (12)	Notes[b] (13)
NGC 6058	13200 ± 500	(11000)	2300	0.063 ± 0.025	0.051 ± 0.002	0.114 ± 0.025	0.027	1, 2	1.88	3.5	0.32	1
NGC 6537	(8800)	8800 ± 1400	1900	...	...	...	7.4	3	8.2	...	0.70	2
							5.6	4		...	0.92	
NGC 6563	16300 ± 3000	(16300)	500	0.132 ± 0.03:	0.015:	0.15:	0.47	3	0.97	1.6	0.98	3
							0.17	4		1.3	2.6	
NGC 6578	8300:	(8300)	6400	0.095 ± 0.010	0.001	0.096 ± 0.010	0.27	4	6.7	7.0	0.28	4
NGC 6765	11700 ± 1100	8740 ± 500	500	0.059 ± 0.005	0.064 ± 0.001	0.123 ± 0.005	3.95	5	3.59	15.7	0.32	5
							2.44	3		12.6	0.52	
							3.73	4		15.3	0.34	
NGC 6804R_i[c]....	12900 ± 1200	(10800)	(700)	0.025 ± 0.005	0.090 ± 0.002	0.115 ± 0.005	0.19	1, 6	1.57	...	...	6
NGC 6804R_o....	9900:	(9900)	(300)	0.083 ± 0.007	0.036 ± 0.005	0.119 ± 0.009	...	...	5.8	...	...	7
NGC 6894	(9900)	9900 ± 2800	200	0.097 ± 0.009	< 0.003	0.100 ± 0.010	1.58	4	3.32	4.9	0.40	8
							1.34	1, 7		4.7	0.47	
IC 972	(10000)	(10000)	(100)	...	...	...	2.91	3	2.74	6.8:	0.25	9
IC 1454	(10000)	(10000)	100	0.049 ± 0.025	0.014 ± 0.005	0.063 ± 0.025	0.56	4	4.00	5.88	0.36	
M1-4	12800 ± 600	(12800)	1500	0.079 ± 0.006	0.004 ± 0.001	0.083 ± 0.006	0.04	5	2.43	2.60	0.42	
							0.01	3			1.35	
							0.01	4			1.28	
							0.04	1, 7			0.42	
M2-2	(10000)	(10000)	(2000)	0.083 ± 0.013	< 0.006	0.089	...	...	4.96	...	...	10
Me 2-1	11900 ± 200	(9900)	3800	0.031 ± 0.007	0.074 ± 0.003	0.105 ± 0.008	0.24	5	2.99		0.18	11
							0.14	3			0.31	
							0.18	4			0.24	
							0.20	1, 8			0.21	

[a] SOURCE OF O^+/H^+.—(1) O^+ from [O II] λ3727. (2) L. H. Aller and S. J. Czyzak (photographic) 1974, private communication. (3) λ3727 intensity estimated from [O I], ratios called [O] values. (4) λ3727 intensity from [S II], ratios called [S] values. (5) O^+ from [O II] λ7325. (6) L. H. Aller and S. J. Czyzak (photoelectric) 1974, private communication. (7) Kaler, Aller, and Czyzak 1976. (8) Aller, Keyes, and Czyzak 1981.

[b] NOTES.—(1) N/O = 0.42 if T[N II] = T[O III]; N_e from [O II] ACPG; He/H = 0.24 ± 0.10 from Kaler 1983*a*. (2) T_e = 12,000 K gives O/H ≈ 6 × 10^{-4}, and an average N/O of 1.3. (3) Helium lines and T_e uncertain. If T_e = 10,000, He/H = 0.135, N/O [O] = 0.53, N/O [S] = 1.4, and O/H ≈ 6 × 10^{-4}. (4) Maximum I(λ4363) used (see Table 2). (5) O/H probably overcorrected. (6) O/H correction unreliable; Ne estimated. (7) λ4363 marginal. (8) Limit adopted for He^{++}/H^+; [O I] weak; see Table 5. (9) Oxygen correction approximate, calculated from Kaler 1983*c* (10) Limit adopted for He^{++}/H^+. (11) O/H correction unreliable. If T_e[N II] = T_e[O III], as indicated by AKC, N/O (λ7325) = 0.31.

[c] R_i and R_o for NGC 6804 denote inner and outer rings, respectively.

program has been rigorously tested with hand checks and through comparison with an independent program (Y.-H. Chu 1983, private communication).

Electron temperatures, in columns (2) and (3), are available from the [O III] and/or [N II] lines for all but IC 972, IC 1454, and M2-2, for which a default value of 10,000 K is used. This figure is compatible with the upper limit for $I(\lambda 4363)$ given for M2-2. In the calculation of [O III] temperatures, all the $\lambda 4363$ data are corrected for systematic error by the scale factor required to bring Hγ to the theoretical value. Although these two lines are generally partially blended (see § II*a*), they are well enough separated so that the systematic weakness in Hγ is more likely to be caused by a wavelength dependent effect than it is by an overestimate in [O III]. For M1-4, only the intensity of Hγ determined by the Reticon alone was used for the correction. If only one value of T_e is known (from [O III] or [N II]), the other was set equal to it, except for the three high-excitation objects (NGC 6058, the inner ring of NGC 6804, and Me 2-1), for which T_e[O III]/T_e[N II] = 1.2 (Kaler 1985) is adopted; these are set in parentheses. The errors assigned to the temperatures are derived from the errors stated for the intensities in Table 2.

The electron densities are generally derived from the [S II] lines, and are given in column (4) of Table 4. The [Ar IV] ratios observed for several nebulae are unsatisfactory due to high errors and blends (with He I and [Ne IV]), as is the one [Cl III] ratio; these are potentially useful for abundance determinations, however. The analysis for NGC 6058 uses an unpublished [O II] ratio from Aller and Czyzak, and for the other three nebulae without [S II] data, densities (in parentheses) are simply estimated from size and distance.

Ionic and total helium abundances are given in columns (5)–(7). The He^+/H^+ ratios are derived from $\lambda 4471$, $\lambda 5876$, and $\lambda 6678$, weighted approximately according to inverse error. The triplets are corrected for self-absorption with the method given by Kaler (1978), which is based upon electron density. Errors are derived from the deviations of individual ratios from the weighted means (col [5]) or from the errors in the line intensities (cols. [5] and [6]), and include errors in electron temperature, which are taken to be ± 2000 K unless otherwise given.

Ionic and total oxygen abundances are given in columns (8)–(11). There is a problem with the data set in that there is little information on [O II], from which O^+/H^+ is found: the Red Reticon does not extend to $\lambda 3727$, and $\lambda 7325$ is detected in only three spectra. The analysis of O^+ is approached in three ways, in all cases using the [N II] electron temperatures. First, of course, $\lambda 7325$ is used when it is available, where the observed intensities are multiplied by a factor of 1.45 in accord with the error analysis of the last section.

Second, this study employs a new way of deriving approximate O^+ abundances that is particularly useful for the study of faint, highly reddened objects for which neither $\lambda 3727$ nor $\lambda 7325$ are readily detectable as a result of a combination of high reddening and intrinsic [O II]–line weakness, or are unavailable due to limited wavelength coverage. The procedure uses the extensive line analyses by Kaler (1980, 1981), which show that the intensity of $\lambda 3727$ correlates linearly with both [O I] $\lambda 6300$ and the [S II] $\lambda 6723$ blend, although differently for optically thick and thin nebulae. We can predict what $\lambda 3727$ should be on the basis of the reddening-corrected [O I] and [S II] line strengths and enter this value into the analysis code. From Kaler's compilation, we then find for optically *thin* nebulae (defined as those with central star temperatures >45,000 K):

$$\log I([\text{O II}]\ \lambda 3727) = 1.039 + 0.821 \log I([\text{S II}]\ \lambda 6723) \quad (1)$$

$$\log I([\text{O II}]\ \lambda 3727) = 1.245 + 0.974 \log I([\text{O I}]\ \lambda 6300); \quad (2)$$

and for *thick* nebulae:

$$\log I([\text{O II}]\ \lambda 3727) = 1.537 + 0.652 \log I([\text{S II}]\ \lambda 6723) \quad (3)$$

$$\log I([\text{O II}]\ \lambda 3727) + 1.782 + 0.875 \log I([\text{O I}]\ \lambda 6300). \quad (4)$$

Any abundance ratios involving O^+ that are so derived from [S II] or [O I] are hereafter commonly referred to as "[S]" or "[O]" values, respectively.

Obviously, this procedure must be used cautiously: the scatter in Kaler's figures shows that errors of a factor of 2 can easily be made in individual cases with the [O I] relations, rising perhaps to a factor of 3 when the [S II] equations are employed, with even larger possible extremes (an example, discussed below, is NGC 6578, which has an anomalously weak [O I] line not used in this analysis). The method's great advantage, however, is that [S II] is considerably stronger than $\lambda 7325$, and it enables crude calculations of O^+ abundances in situations in which it would otherwise be very difficult or impossible. It is certainly useful for statistical survey work when a large number of nebulae are involved, and it is employed here out of necessity. All of the nebulae fall into the optically thin case above, since they are either large or exhibit He II $\lambda 4686$ (see either Table 2 or the references in Table 1), and therefore we here use equations (1) and (2).

Finally, we can adopt $I(\lambda 3727)$ observed by others, but unless the object is quite compact, this procedure is probably less satisfactory than the use of [O I] and [S II], because of stratification. Recall from § II*d* that most of the observations were made near the edges of the nebulae to allow for beam switching, and the intensities presented here may not be at all consistent with others.

The O^+/H^+ ratios that result from these methods are presented in column (8) of Table 4, with the method used given in column (9). The agreement among values ranges from good to poor. In all three instances, the results from $\lambda 7325$ are greater than those derived by other methods. Particular disagreement, up to a factor of 3, is seen for M1-4 and Me 2-1, for which the [O I] and [S II] lines are particularly weak; perhaps this method should not be used at the low end of the intensity scale, or perhaps the $\lambda 7325$ correction factor was too high. In any case, since the O^+/H^+ ratio is usually a minor part of total O/H, these errors do not propagate greatly.

The calculation of O^{++}/H^+ (col. [10]) is straightforwardly based on $\lambda 4959$ and $\lambda 5007$, and T_e [O III]. The total O/H ratios are produced by assuming, as usual, that the higher ionization states are related to the lower (O^+ and O^{++}) by the ratio of He^{++} to He^+ (Seaton 1968) because of the coincidence in ionization potential. The correction is not made here for the two highest excitation nebulae NGC 6804 (inner ring) and Me 2-1, since it is so large. We may similarly be suspicious of the very large O/H for NGC 6765, for which the correction is also fairly high, and for which the [N II] electron temperature appears low (rendering O^+/H^+ high).

Finally, N/O is determined by the standard procedure of setting it equal to N^+/O^+, where N^+/H^+ is calculated from the [N II] $\lambda 6584$/Hα intensity ratio and the [N II] electron temperature. These are given in column (12). Note that they are much more sensitive to the uncertainties in the O^+/H^+ ratios than is O/H. The λ7325 result should be primary, of course. In order to reduce error, it would probably be best to average the [O] and [S] values. From the table, we see that the [O] and [S] values are generally in reasonable qualitative agreement with one another and with those derived from the other methods. But the danger of this procedure is clearly seen for M1-4 in which the [O I] and [S II] lines imply very high N/O; here, the λ3727 intensity, adopted from the literature, gives a result in good agreement with λ7325.

b) [S II] *and* [O I]

As part of the above discussion, we should examine further the balance among the low-ionization species O^+ and S^+. The reddening-corrected intensities of [S II] λ6723 and [O I] λ6300 are given in Table 5, with the ratio in the last column. Excepting NGC 6894, the ratios are reasonably consistent with the mean found by Kaler (1981), and the error bars of the new (this paper) and previous averages overlap. But NGC 6894 is decidedly odd: the λ6300 line is nearly 20 times too weak! This behavior is not seen in any other nebula and is not understood, but it does illustrate the problems of using the [O I] and [S II] lines to predict the strength of λ3727, and relying heavily upon the method for individual cases.

c) *Chemical Variations*

A purpose of this work is to search for, and examine, nebulae with peculiar abundances. Kaler (1982*a*) found that NGC 6537 is highly enriched in helium and nitrogen (He/H = 0.24 ± 0.10, N/O = 1.8). This study confirms the high N/O ratio with the techniques of using the [O I] and [S II] correlations, wherein N/O ≈ 0.8. We may have some confidence in the elevated value since the [O] and [S] ratios agree (but again, witness M1-4). The very low electron temperature, which results in an unrealistically high O/H ratio, may be an artifact of the high error associated with [N II] λ5754. At the upper error limit, $T_e = 10{,}000$ K, O/H ≈ 9×10^{-4} (ignoring any states higher than O^{++}), and N/O (from both [O I] and [S II]) = 1.0. A temperature of 12,000 K yields O/H = 5×10^{-4}, more in line with Kaler (1983*a*), and N/O = 1.3. It is significant that the outer fringe of the nebula, observed here, has an enrichment level qualitatively similar to the bright inner region, indicating that the enriching matter was reasonably well mixed into the envelope of the star before planetary ejection began. This object can apparently take a place alongside NGC 6302 and NGC 6445, which have similar extreme overabundances (Peimbert and Torres-Peimbert 1983; Aller and Czyzak 1978; Aller *et al.* 1973, 1981). All three of these are in the plane of the Milky Way toward the galactic center and likely had progenitors near the upper mass limit of stars that produce planetaries (see the references cited in § I).

Another candidate for enrichment is NGC 6563, for which He/H ≈ 0.15, and N/O = 1.8. However, the helium line strengths are very uncertain, and T_e (based upon a very uncertain [O III] λ4363 line) seems anomalously high, resulting in a low value of O/H. If $T_e = 10{,}000$ K, N/O drops to about unity, and N/O from [O I] to 0.5. Although the abundances are uncertain, the nebula is clearly worthy of further investigation.

NGC 6804 exhibits a more quantitative homogeneity (as compared to the qualitative result for NGC 6537), where both parts, the outer and inner rings, show nearly identical, nearly normal, He/H ratios, in spite of very different excitation levels. The difference in electron temperatures is not significant given the large error associated with [O III] λ4363 in the outer ring.

At the low end of the abundance distribution we find IC 1454, for which the data yield He/H = 0.063 ± 0.025. Since we see the He I line, it is unlikely that neutral helium plays a role. The upper limit of 0.088 is probably more physically realistic; still the value is near the lower limit observed for planetaries.

In spite of the uncertainties in some of the abundances, it is interesting to examine the correlation between N/O and He/H for these nebulae against the background of earlier determinations. Figure 4 shows a modified version of the detailed plot of log N/O versus He/H from Kaler (1983*b*). The new ratios are plotted as closed symbols, using the first N/O entry in Table 4, or averaging the [O] and [S] values, and for NGC 6537 adopting He/H from Kaler (1983*a*). Error bars are included for He/H but not for N/O, since the latter are not known. We see that our objects are distributed within the general pattern.

TABLE 5

[S II] TO [O I] RATIOS

Nebula (1)	*I*([S II] λ6723) (2)	*I*([O I] λ6300) (3)	Ratio (4)
NGC 6537	136	51.5	2.64
NGC 6563	42.4	40.1	1.06
NGC 6765	133	24.7	5.38
NGC 6894	79.9	1.17	68[a]
M1-4	0.65	0.41	1.6
Me 2-1	3.74	1.42	2.63
Mean			2.66 ± 0.74
Kaler 1981			3.69 ± 0.55

[a] [O I] appears to be nearly 20 times too weak; this ratio is excluded from the mean.

d) *The Nucleus of NGC 6578*

This analysis discussion is concluded with a brief commentary on this planetary, which is of special interest. It is a compact object, and the nucleus was included in the aperture. There is a feature at λ5806, which can be identified with the λ5801–λ5812 doublet of C IV that is characteristic of central star emission (see Aller 1976*b*). The line could also be N IV λ5806 (see Hiltner and Schild 1966), but other nitrogen lines–N V λ4605-22, N III λ4640–are not present. Weak emission at λ4650 that may be C III is also seen, although identifications in this part of the spectrum are uncertain: there is a similar feature at λ4634 that here is called nebular N III, but the ordinarily stronger λ4640 line is not present. The nucleus can thus be identified as a carbon-sequence Wolf-Rayet star. Since C III λ5696 is missing, a later WC type can be ruled out (see Hiltner and Schild 1966 and Méndez and Niemela 1982), although there are insufficient data for an accurate classification. Stellar He II λ4686 does not appear to be present, but it is known from other work that it can be weaker than C III λ4650 (Aller 1968). We estimate the equivalent widths of the C III λ4650 and of the C IV λ5801-12 lines to be 3 and 12 Å, respectively. The star deserves more detailed study with higher resolution, particularly in the region of the λ3820 O VI line.

IV. SUMMARY

In this work, the first of a set of follow-up studies of previous wide-aperture photometry, measurements are presented of the relative fluxes of a dozen planetary nebulae primarily in the

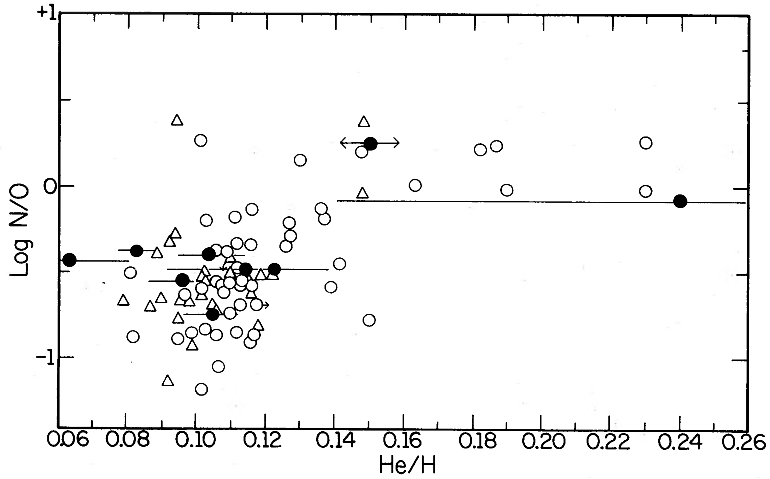

FIG. 4.—Log N/O plotted against He/H, adapted from Kaler (1983*b*). Open circles and boxes represent Populations I and II. The new abundances are overplotted as closed symbols, with error bars given only for He/H. The highest point, representing NGC 6563, is especially uncertain.

yellow-red part of the spectrum, with some extension into the blue.

The data are used to derive electron temperatures from [O III] and [N II], densities from [S II], and abundance ratios, specifically He/H, O/H, and N/O. The latter confirm a case of extreme enrichment (NGC 6537) and suggest another such candidate for further study (NGC 6563). The analysis also suggests the chemical homogeneity of two nebulae with outer structures, both of which exhibit large stratification effects. NGC 6537 appears to be enriched throughout, although an abundance gradient is clearly possible given the large errors involved, and both rings of NGC 6804 exhibit nearly normal He/H ratios. Two other results of interest are the classification of the nucleus of NGC 6578 as WC, and the odd weakness of the [O I] line relative to [S II] in the spectrum of NGC 6894.

Just as important as the above, are two procedures developed for the testing and analysis of the data. The first involves an extensive examination of errors, in which the internal, accidental errors are derived from the line widths, and the external, systematic variety from comparisons between data sets and between observed and theoretical intensity ratios. The latter are employed to make corrections prior to the calculations of [O III] electron temperatures and of the O^+/H^+ ratios derived from the [O II] $\lambda 7325$ lines.

In the second, a new method for deriving approximate O^+/H^+ ratios is presented, applicable to cases in which the [O II] lines are not observed. The procedure uses the correlations between the [O II] $\lambda 3727$, [O I] $\lambda 6300$, and [S II] $\lambda 6723$ line intensities developed by Kaler (1980, 1981) and employs the values observed for the latter two to infer that of the former. The method is useful for nebulae for which only limited wavelength coverage is available, or for those that are both heavily reddened and intrinsically weak in [O II], since then neither $\lambda 3727$ nor $\lambda 7325$ is easily observable; it is largely statistical in nature, with an intrinsic error of a factor of 2 or more in either direction, but it can be useful for checking and exploring nebulae for abundance anomalies.

Most of the nebulae studied here are now deserving of further examination in the blue, and of general observation with an improved signal-to-noise ratio.

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