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A SPECTROSCOPIC SURVEY OF 51 PLANETARY NEBULAE

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ABSTRACT

We present spectroscopic data for some 51 additional planetary nebulae (PNs) observed with the image-tube scanner (ITS) on the Shane 3 m telescope at Lick Observatory. Likely sources of error are discussed, including the influence of a possible nonlinearity of the ITS detector as mentioned by Peimbert and his associates. Plasma diagnostics are obtained and used to compute ionic abundances from the observed line intensities. Elemental abundances for 48 of these objects are then derived with the aid of ionization correction factors supplied from theoretical models. These data are then supplemented with published material to provide a sample of more than 100 PNs.

Abundance patterns of C, N, and to some extent O show a considerable spread owing to differing nuclear process rates in progenitor stars. The mean N and C abundances exceed their solar value, while the mean O abundance is smaller, a result in accord with the findings of previous investigators. The mean Ne abundance seems to agree with the solar value, whereas those of S, Cl, and Ar may be smaller in the PNs. If agreement between nebular and solar O abundances is forced by adopting appropriate T_ϵ fluctuations as suggested by Peimbert, Rubin, Dinerstein, and others, the nebular abundances of S, Cl, and Ar will fall closer to the solar value, but that of Ne will be too large.

Subject headings: nebulae: abundances — nebulae: planetary

I. INTRODUCTION

The importance of planetary nebulae (PNs) as suppliers of material to the interstellar medium is becoming increasingly appreciated (see, e.g., Kaler 1983*a*, 1985*b*, and references cited therein). Of particular interest is the fraction of new products of nucleogenesis. Stars of low mass contribute only small quantities of newly manufactured nuclides, while those of larger mass may contribute substantial amounts of elements such as C and N. See, e.g., Peimbert (1978, 1983). In certain PNs such as NGC 6537, there is some evidence that O is actually destroyed (Feibelman, Aller, and Keyes 1985), although the "oxygen deficiency" noted by many observers may be partially an artifact of neglecting T_ϵ fluctuations (Peimbert 1967; Rubin 1969; Dinerstein, Lester, and Werner 1985; Zuckerman and Aller 1986). It is generally agreed that Ne and heavier elements such as S, Cl, and Ar are not manufactured in the progenitors of PNs. Presumably, the proportions of these elements with respect to H should remain essentially unchanged. That is, the Ne/H, S/H, Cl/H, and Ar/H ratios should be the values appropriate to the interstellar medium (ISM) from which the progenitor stars were formed. An intrinsic spread in these ratios must arise from the fact that the observed population of PNs includes objects of greatly differing masses, ages, and points of origin in the Galaxy. Unfortunately, except for Ne, we appear to be bedeviled by inadequacies in the atomic parameters, A-values, and collision strengths, Ω, among these heavier elements (see, e.g., a discussion by Czyzak, Keyes, and Aller 1986). Uncertainties in T_ϵ and ionization correction factors (ICFs) produce a further dispersion of results.

The objective of this program is to extend the previous survey (Aller and Czyzak 1983, hereafter AC 83) to mostly fainter objects, many in the Galactic central bulge, and others distributed along the Milky Way and in the anticenter region. We determine nebular diagnostics (N_ϵ, T_ϵ) and ionic concentrations. Ultimately with the aid of models, which yield the ICFs, we derive the elemental abundances. We describe the abundance pattern or distribution for each element with the aid of appropriate block graphs. In this paper we discuss only the total sample. Subsequent papers will treat the abundance data with respect to topics such as dependence of compositions on distance from the Galactic center, on population type, on excess nitrogen content, and on the mass of progenitor stars (as far as this quantity can be estimated).

II. SELECTION OF OBJECTS

The observing list was compiled from the Perek-Kohoutek catalog (1967), from objects observed with the VLA by the Groningen workers (Gathier *et al.* 1983) and from the Acker *et al.* catalog (1982). The list also includes a number of relatively bright objects mostly described in Curtis (1918). A special effort was made to select objects at presumably great distances. Alas, many of these nebulae are severely dimmed by interstellar extinction.

Table 1 lists the objects observed in the present program. Column (1) gives the name of or usual designation of the nebula; column (2) gives its designation in the catalog of Perek and Kohoutek (1967); columns (3) and (4) give the position for the epoch 1950. Adopted values of the logarith-

TABLE 1

FUNDAMENTAL DATA

(1) Name of Object	(2) PN	(3) α(1950)	(4) δ(1950)	(5) log F(Hβ)	(6) Diameter	(7) Ex	(8) PNN	(9) Sp	(10) C	(11) V_{LSR}	(12) $T_{\epsilon}/10^4$	(13) $N_{\epsilon}/10^3$	(14) Table	(15) References
M1-4	147-2°1	3 37 59.1	+52 07 26	-12.14	4"	6	16.7V	Of	1.86	- 34.1	1.16	4.0	2B	1,7,11,12,13,15,16,23,26,30
M2-2	147+4°1	4 09 10.2	+56 49 20	-12.22	12"	6		cs	2.0	- 7.4	1.20	5.0	2A	1,3,6,12,16,23,24,30
K3-67	165-6°1	4 36 27.5	+36 39 52		15"	4.5		cw	1.38	- 84.2	1.35	3.0	2B	2,3,7
K3-68	178-2°1	5 28 25.0	+28 56 31			10		cw	1.36	54.7	1.96	0.5	2F	2,3
M2-6	353+6°2	17 01 06	-30 49 21		0.9	4.5		cw	1.3	- 79.3	(0.94)	9.2	2C	3,8
M4-3	357+7°1	17 07 34.7	-27 05 03		0.75	4		cw	1.8	166.5	0.93	11	2C	3,8
M2-10	354+4°1	17 10 53.5	-31 16 16		1.2	3		cw	1.65	- 65.6	(0.68)	(3.)	2C	3,8,16
H1-18	357+2°4	17 26 31.6	-29 30 32		0.85	4.5		---	2.92	-193.9	1.0	7.5	2C	8
NGC 6369	2+5°1	17 26 18	-24 43 12	-11.34	29"	5	16.6	WR	2.23	- 90.0	1.2	6.0	2A	1,2,5,7,9,15,18,19,20,21,25
H1-23	357+1°1	17 29 35	-29 58 09		1.3	4		Of?	2.85	- 62.0	0.95	2.3	2C	1,8
Hubble 4	3+2°1	17 38 48	-29 40 12	-11.94	6"	7	16.16B	WC	1.94	- 51.1	1.05	5.6	2E	1,5,7,11,15,18,23,28
H2-18	6+4°1	17 40 29.3	-21 08 33		1.8"	5.5		Of?	1.83	-103.5	1.2	7.5	2C	1,8
M3-15	6+4°2	17 42 32.4	-20 56 52		3.0	5		WC	2.68	112.8	1.12	2.5	2C	1,3,8
Hubble 5	359-0°1	17 44 44.5	-24 58 53	-11.50	20	9		cw	2.28	- 17.9	1.25	5.5	2F	1,2,7,15,18,25
NGC 6439	11+5°1	17 45 26.3	-16 27 47	-11.68	6"	7		---	1.11	- 80.1	1.09	4.0	2E	1,2,7,11,15,18,20,21,25,29
Cn 2-1	356-4°1	17 51 13.6	-34 21 50	-11.63	2.5	5.6		Of	1.09	-262	0.79	4.0	2B	3,7,29
Hubble 6	7+1°1	17 52 06.7	-21 44 12	-11.75	6"	6.5	16.38B	cw	2.40	21.7	1.10	6.0	2E	1,5,7,11,15,18,22
M2-21	0-2°4	17 54 57.5	-23 44 06	-12.50	<5"	6.5		cw	1.60	-123	1.26	2.8	2E	18,29
M3-20	2-2°2	17 56 09.7	-21 13 35	-12.40	<5"	5		Of	1.91	65.7	1.04	4.5	2A	16,18,29
M2-23	2-2°4	17 58 33.7	-28 25 44	-11.57	0.40	5		Of	1.36	234.7	1.26	3.0	2C	8,18
IC 4673	3-2°3	18 00 10.4	-27 06 32	-11.81	17"	8		cw	1.20	- 4.9	1.10	1.3	2F	1,7,15,16,18,29
M1-35	3-2°1	18 00 31.9	-26 43 66	-12.85		4.5			2.2	93.1	1.05	5.5	2A	16,28
M1-38	2-3°5	18 02 58.5	-26 40 50		2.0	1			1.80	- 59.5			2A	8,28
M1-42	2-4°2	18 07 04.3	-28 59 40	-11.62	9"	6		cs	0.60	- 33.3	0.83	1.5	2E	1,7,15,16,29
H1-59	3-4°3	18 08 20.3	-27 47	-12.54	6"	8		cw	0.90		1.2	0.8	2F	16,29
M2-30	3-4°8	18 09 24.9	-27 59 01	-11.95	5"	7		cw	0.77	184.7	1.11	8.0	2F	18,29
NGC 6567	11-0°2	18 10 48	-19 05	-10.89	11"	5.5	15.0	WC	0.72	132.9	1.06	16.6	2B	1,4,5,7,9,10,13,15,16,17,18, 19,20,21,23,25,29
M2-33	2-6°1	18 11 53.9	-30 16 33		2.0	4		Of	0.75	-101.9	(0.85)	(2.3)	2C	1,8
M1-44	4-4°2	18 13 09.5	-27 05 37	-12.00		2		wc	1.17	- 64	0.66	1.2	2A	1,16,29
NGC 6578	10-1°1	18 13 18	-20 28	-11.00	8.5	5	14.78B	Of	1.76	17.3	0.85	3.8	2D	1,7,9,12,15,16,18,19,20,21,25, 29
Cn 3-1	38+12°1	18 15 12.24	10 07 51.8	-11.05	5"	2		Of	0.79	22.5	See Text	4.0	2B	1,2,3,4,5,7,11,13,17,18,25
HI-65	7- 4°1	18 17 05.07	-24 16 26.3		1.3"	1		cw	0.83				2C	3,8
NGC 6620	5- 6°1	18 19 46.8	-26 50 58	-11.72	5"	6.5		cs	0 ?	83.6	0.99	1.85	2E	1,3,5,7,11,15,18,19,20,22,29
NGC 6629	9- 5°1	18 22 40	-23 13 57	-10.84	16"	4	13.0B	Of	0.96	26.6	0.89	1.26	2D	1,2,5,7,9,15,16,18,19,20,21, 23,25,26,29
IC 4732	10- 6°1	18 30 53.2	-22 41 02.8	-11.52	5"	5	>16 ?	Of	0.4	-13.3	1.30	12.5	2B	1,3,7,11,15,16,18,19,20,26,29
NGC 6781	41- 2°1	19 16 02	+06 25 48	-11.19	106"	4	15.9B		1.0	21.5	1.07	0.37	2D	1,5,7,15,16,18,19,20,23,25
NGC 6804	45- 4°1	19 29 12.0	+09 07 13	-11.51	63"	9	14.4B		0.9	5.3	1.29	1:	2C	1,2,5,7,12,13,15,17,18,20,21, 23,25,30

TABLE 1—*Continued*

(1) Name of Object	(2) PK	(3) α(1950)	(4) δ(1950)	(5) log F(Hβ)	(6) Diameter	(7) Ex	(8) PNN	(9) Sp	(10) C	(11) V_{LSR}	(12) $T_\varepsilon/10^4$	(13) $N_\varepsilon/10^3$	(14) Table	(15) References
NGC 6807	42− 6°1	19 32 03.4	+05 34 30.3	−11.46	2" "	5	>15.5B	Of	0.64	−51	1.12	4.0	2B	1,5,7,11,15,16,18,19,20,22, 26,30
Me 1-1	52− 2°2	19 36 53.5	+15 49 52	−11.52	1.5	5		Of	0.9	11.7	1.0	12	2B	1,5,7,15,16,23,24
NGC 6833	82+11°1	19 48 20.9	+48 50 01	−11.22	2"	5	13.8B	Of	0.5	−91.6	1.42	20	2B	1,7,4,15,11,16,23,22,26,20,19
MI-75	68− 0°1	20 02.8	+31 19		20"	9			2.4	8.5	1.2	3.4	2F	1,7,15,16
NGC 6881	74+29°1	20 09 01.6	+37 15 44	−12.26	4"		16.8B	cw	2.0	2.9	1.27	10	2F	1,5,7,11,15,16,20,22,23,26,30
NGC 6879	57− 8°1	20 09 10.1	+16 46 22	−11.57	5"	5.5		Of	0.61	25.7	1.2	5.6	2A	1,7,5,15,16,23,27,29,30
NGC 6891	54−12°1	20 12 47.7	+12 32 59	−10.67	12"	5	12.3	Of	0.44	58.6	0.93	5.0	2D	1,2,5,7,14,15,16,17,18,19,20, 23,26,27,29
NGC 6894	69− 2°1	20 14 22.8	+30 24 36	−11.41	44"	8	17.6B		0.9	−40.9	See Text		2D	1,5,7,12,13,15,16,19,20,21, 23,25
MI-78	93+ 1°1	21 19 05.5	+51 40 41	−12.88		4		cw	4.1	−73.8	1.13	2.5	2D	1,11,16,30
K3-60	98+ 4°1	21 25 57.9	+57 26 09	−13.17		7			2.9		1.3	4.0	2E	1,2,3,4,5,7,11,13,17,18,25,30
K3-61	96+ 2°1	21 28 23.8	+54 14 17		6"	5		WR	2.0		0.91	0.24	2D	16
Me 2-2	100− 8°1	22 29 37.7	+47 32 37.5	−11.17	4"	4.5	11.4B	Of	0.44	140.5	1.1	4.0	2A	1,3,4,11,15,22,23,26
NGC 7354	107+ 2°1	22 38 26.2	+61 01 17	−11.60	20"	7	>16.2		1.90	−30.6	1.3	4.0	2F	1,7,5,15,16,19,20,21,23,25,26
MI-80	107− 2°1	22 54 14.6	+56 53	−12.81	8"	7		cw	1.5	−47.4	1.23	1.0	2E	1,7,15
Vy 2-3	107−18°1	23 20 36	+46 37 32	−11.96		5	14.9V	cs	0.48	−40.6	1.1	2.0	2D	1,26,30

REFERENCES.—(1) Acker 1978; (2) Acker *et al.* 1982; (3) Aller and Keyes 1985; (4) Barker 1978; (5) Cahn and Kaler 1971; (6) Carrasco, Serrano, and Costero 1983; (7) Daub 1982; (8) Gathier *et al.* 1983; (9) Gathier, Pottasch, and Goss 1986; (10) Gathier, Pottasch, and Pel 1986; (11) Isaacman 1984; (12) Kaler 1985*a*; (13) Kaler 1986; (14) Kaler, Mo Jing-Er, and Pottasch 1985; (15) Khromov 1985; (16) Maciel 1984; (17) Maciel and Pottasch 1984; (18) Milne and Aller 1975; (19) Minkowski 1965; (20) O'Dell 1962, 1963; (21) Pottasch 1984; (22) Sabbadin 1984*a*; (23) Sabbadin 1984*b*; (24) Sabbadin, Bianchini, and Hamzaoglu 1984; (25) Sabbadin 1986; (26) Shaw and Kaler 1985; (27) Turner and Terzian 1984; (28) Viadana and de Freitas-Pacheco 1985; (29) Webster 1983; (30) Kaler 1983*b*.

mic Hβ fluxes are listed in column (5). These data come largely from O'Dell (1962, 1963), Kaler (1983*b*), Webster (1983), and Shaw and Kaler (1985) as referenced in column (15). Column (6) gives the diameters in seconds of arc as selected from various sources beginning with Curtis (1918). Column (7) gives the excitation class (cf. Aller 1956; Aller and Liller 1968). For low-excitation objects, this quantity is based primarily on the [O II] λ3727/[O III] λ4959 ratio. For objects of higher excitation, He II λ4686/Hβ is an important criterion of excitation. Column (8) gives the (mostly *B* and *V*) magnitudes of the central stars when these are available; Shaw and Kaler (1985) have published measurements for a number of these objects. Column (9) refers to the spectrum of the central star. Here the notations Of, O9, and so on, have their usual spectral class meanings; WR denotes a spectrum of the Wolf-Rayet type; cw means a weak continuum is observed; cs means a strong continuum. Descriptions of most of these spectra may be found in Aller and Keyes (1985); further data for many of these objects are given by Acker *et al.* (1982). Column (10) gives $C = \log[I(H\beta)/F(H\beta)]$, where $F(H\beta)$ is the flux in ergs cm^{-2} s^{-1} received at the top of the Earth's atmosphere and $I(H\beta)$ is the flux corrected for extinction by the interstellar medium. We determined C primarily from the Balmer decrement in the conventional way. Column (11) gives V_{LSR}, the radial velocity in km s^{-1} referred to the local standard of rest as taken from the catalog of Schneider *et al.* (1983). Columns (12) and (13) contain the derived plasma diagnostics. For some southern objects we adopted T_ε and N_ε values kindly supplied by S. Pottasch (1986, private communication). Column (14) lists the table in which the intensity data for the particular nebula are to be found. The numbers in column (15) pertain to references listed at the end of the table. We include references not only to published spectroscopic, photometric, and morphological data for the individual nebulae, but also to distance estimates such as those by Acker, O'Dell, Minkowski, Daub, and others.

III. THE OBSERVATIONS

The observational data were all secured with the Robinson-Wampler image-tube scanner (ITS) on the Shane Telescope at Lick Observatory. Figures 1 and 2 show reduced scans for the low-excitation planetary nebula, NGC 6833, and for the moderately high-excitation nebula, NGC 6620. The observing procedures are conventional; they are described, for example, in Aller and Czyzak (1979), where sources of error are also discussed. We append herewith additional comments pertaining to far southern objects, for which likely sources of

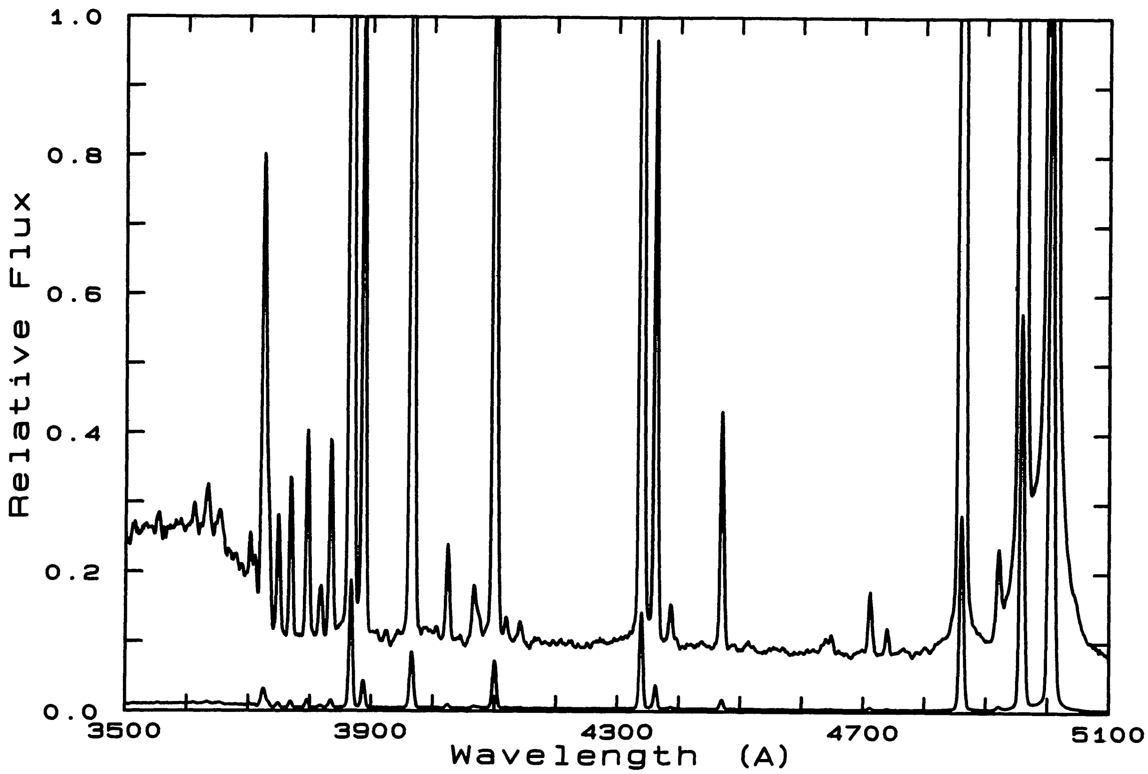


FIG. 1*a*

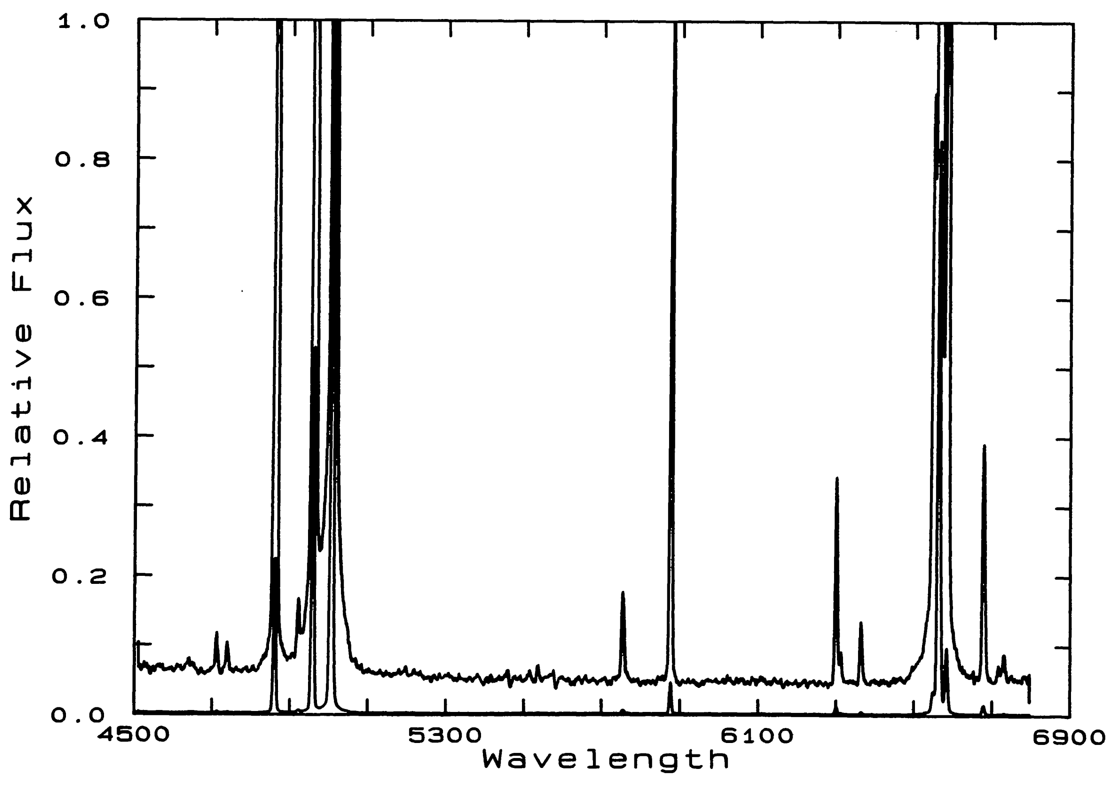


FIG. 1*b*

FIG. 1.—Spectral scans of the low-excitation planetary NGC 6833. All scans are corrected for effects of atmospheric extinction, response functions, and nonlinearity of dispersion. Nebular fluxes were measured in units of ergs cm^{-2} s^{-1} $Å^{-1}$. We give here relative fluxes. All data were secured with the 3 m Shane telescope and image-tube scanner on 1981 August 7. All scans of NGC 6833 have a resolution of 9 Å. (*a*) The regions 3500–5100 Å. The two magnifications are 1× (scaled to strongest line λ5007) and 25×. Note the strong background continuum. (*b*) The region 4500–6800 Å, magnifications 1× and 25×. (*c*) The region 6200 to 7800, magnifications 1× and 25×. Neither [N II] nor [S II] is prominent in this object, although the [S III] auroral-type transition λ6312 is fairly strong.

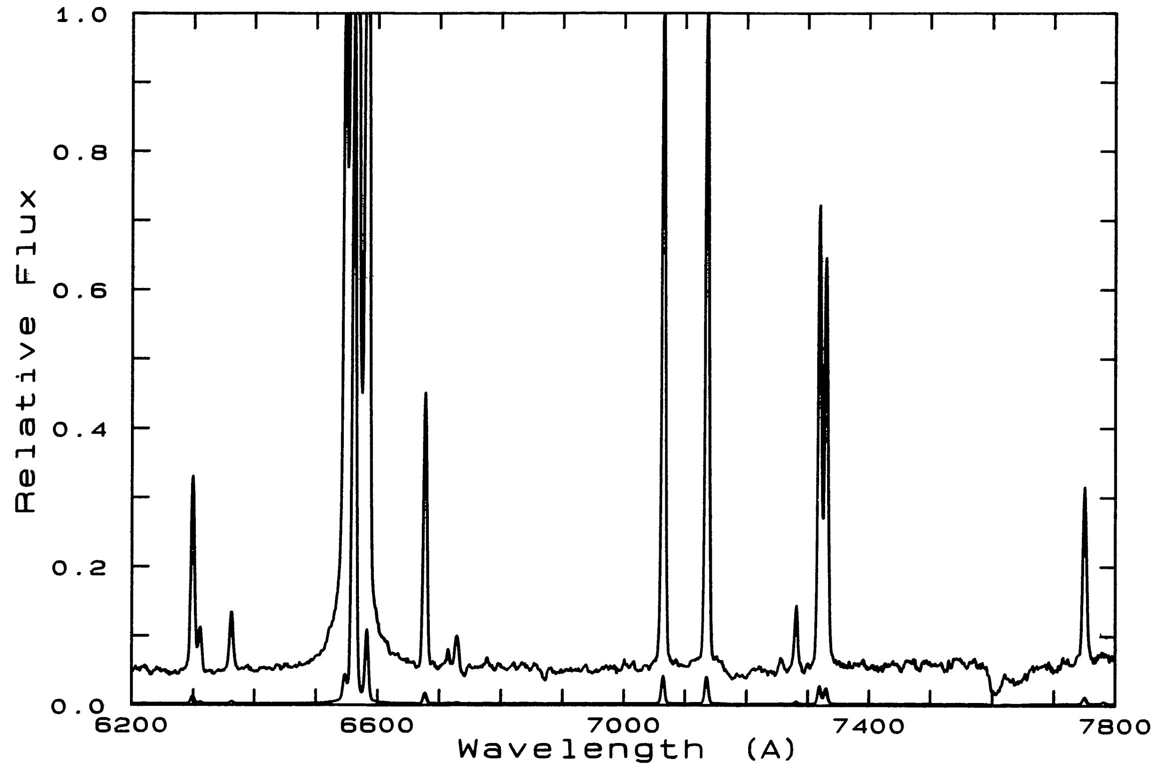


FIG. 1c

inaccuracies are the following:

1. Atmospheric extinction which is severe at low altitudes.

2. Atmospheric dispersion which can be eliminated by rotation of the Cassegrain tube on which the ITS is mounted so that the longer dimension of the slot is perpendicular to the horizon. Because of this effect, except in some crowded fields, we used a 2″×10″ slot.

3. The contamination of λ4363 by the strong Hg λ4359 line from the lights of San Jose and other nearby communities is sometimes serious and poses particular difficulties for the determination of electron temperatures.

4. Crowded Milky Way fields often cause trouble for faint nebulae. By a slight rotation of the tube, it is usually possible to avoid the contaminating star, but there still may be faint stars that are not visible on the slot.

5. If the sweeps of the ITS are set when the telescope is pointed to the zenith, they may drop when the telescope is turned south and then bounce back when the telescope is set north again. This problem can be avoided by setting the sweeps at the same altitude as the southern objects which are to be observed, some 2–4 hours before starting work.

To test at least some altitude-dependent effects, we reduced some nebular spectra using both our oft-used comparison star, BD +28°4211, and the star LTT 6248, which lies at nearly the same declination as several of the southern planetary nebulae. From a comparison of the two derived sets of line intensities for the rather heavily reddened object H1-23, we found closely comparable interstellar extinction factors and a mean discordance between the two sets of line intensities of 4.2%±2.4%. We chose $C=2.85$. The differences between the two sets of values involved the combined effects of errors in the assumed stellar flux distribution and in atmospheric extinction.

Note that our intensity measurements refer to a 2″×10″ slot across the brightest portions of extended nebulae, across the centers of very compact objects, or through the ring just avoiding the central star in PNs such as NGC 6891. These measurements are thus often not immediately comparable to those made in the integrated light of the nebula, a fact which must be kept in mind in comparing these data with those obtained from other sources.

Table 2 lists the line intensity measurements. For each line we list the identification, and the value of the wavelength-dependent Seaton extinction function (Seaton 1979), f_λ, by which C has to be multiplied to obtain the logarithm, Cf_λ, of the correction factor by which the observed line flux has to be multiplied to obtain the corrected intensity, I_λ(corr), relative to Hβ. We tabulate the thus corrected intensities throughout, all on the scale $I(\mathrm{H}\beta)=100$. The columns headed σ give the percentage dispersion error found from the spread of the individual measurements. These errors depend on the spectral region involved, being larger for lines in the ultraviolet. They are also larger for intrinsically weak lines of low flux, and therefore for most lines in faint nebulae. The error can become large for any weak line blended with strong artificial or natural night-sky radiation. Fortuitous agreement is often found; we do not tabulate σ-values less than 3%. Note, however, that the *total* error involves effects accruing from uncertainties in the response function, in the accepted value of C, in the atmospheric extinction, and perhaps other systematic causes such as items 2, 4, and 5 noted at the begin-

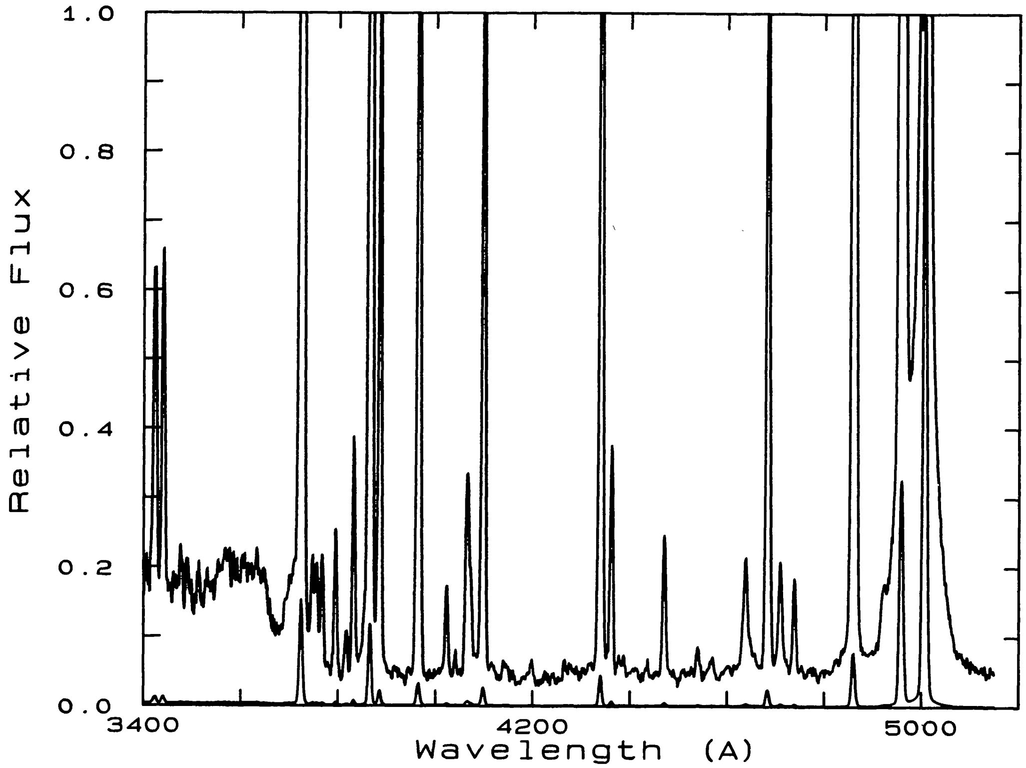


FIG. 2*a*

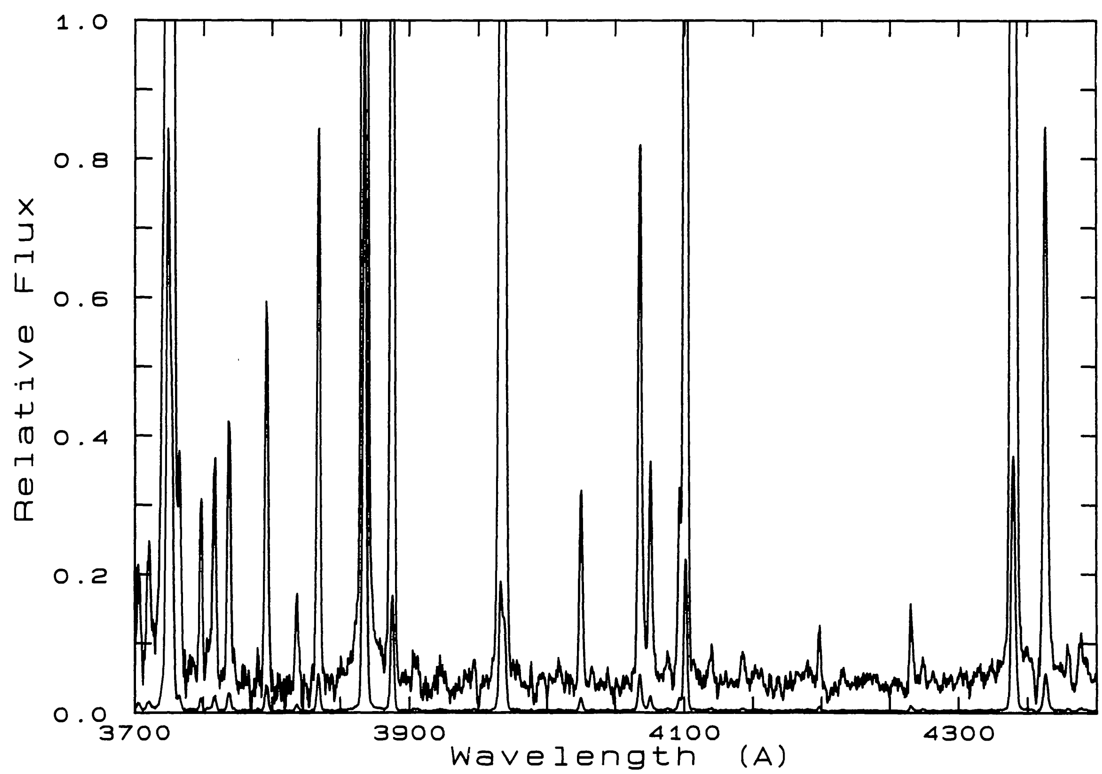
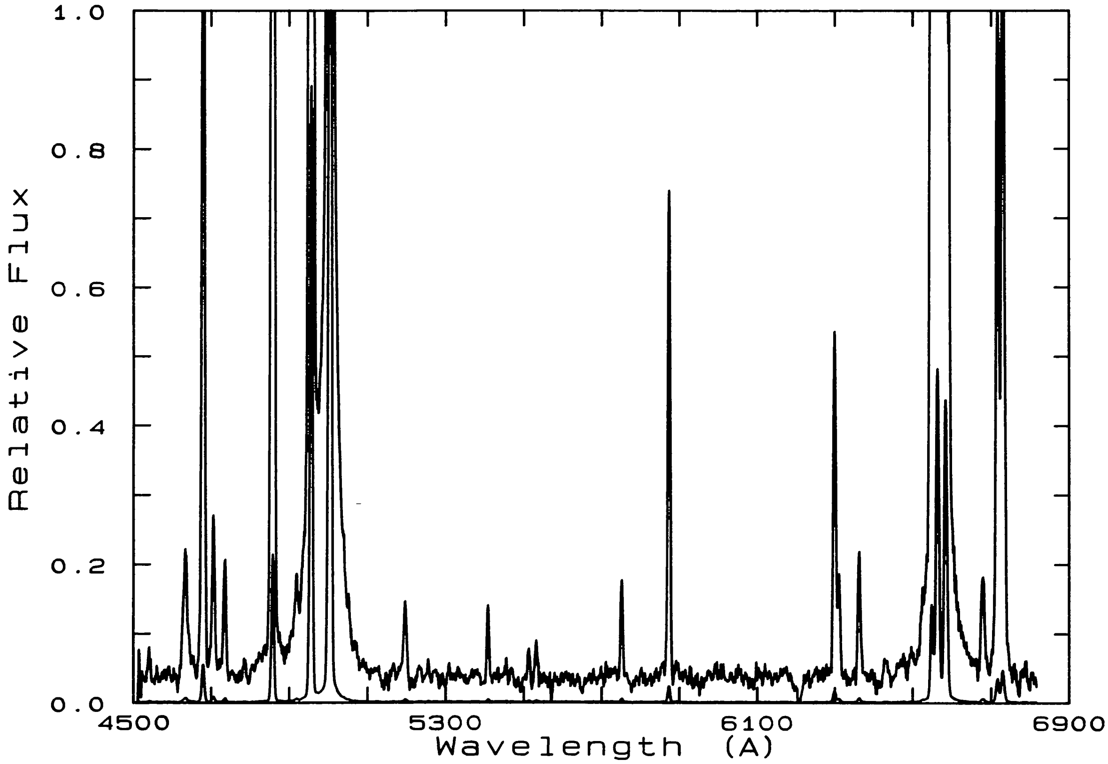


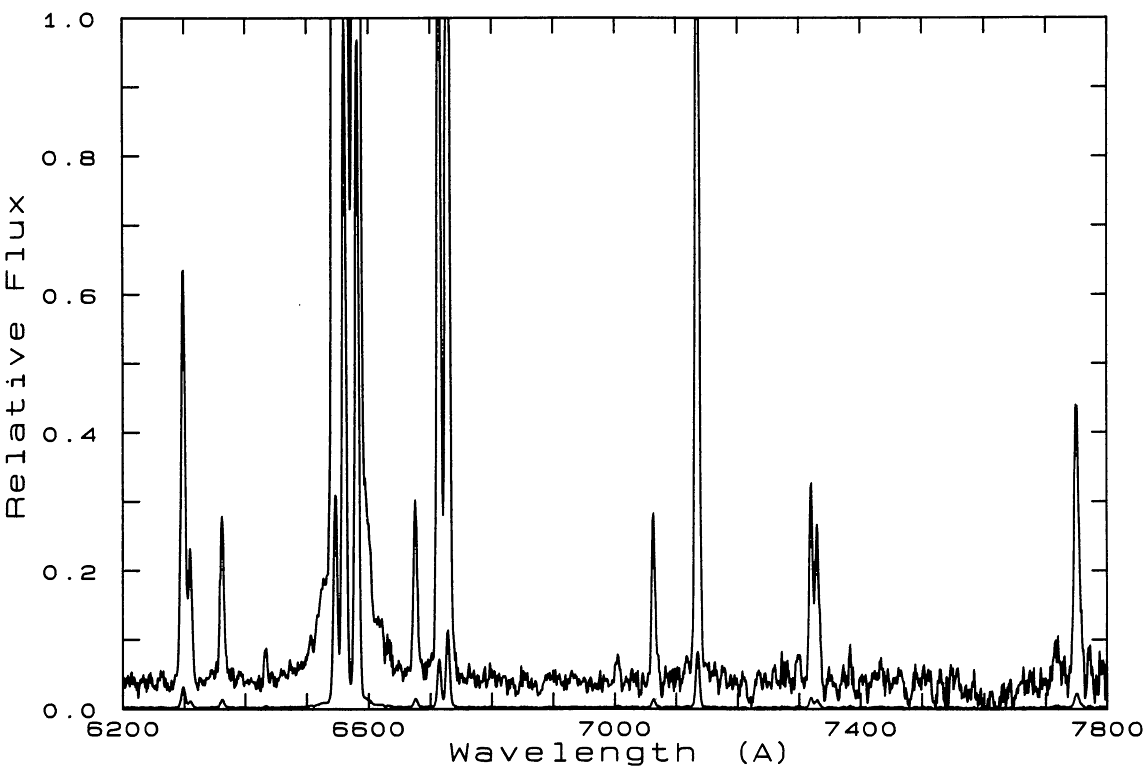
FIG. 2*b*

FIG. 2.—Spectral scans of the moderately high excitation planetary NGC 6620. The scans involve the same reduction procedure as for Fig. 1. All the data were secured with the Shane 3 m telescope and image-tube scanner 1982 May 29. The resolution of Fig. 2*b* is 3.5 Å; all other scans have a resolution of 9 Å. (*a*) Lower dispersion tracing of the region 3400–5100 Å. Note the strength of low-excitation [S II] λλ4068, 4076, and high-excitation [Ne V] λ3426. Magnifications are 1× and 15×. (*b*) Higher dispersion tracing of the region 3700–4500 Å. Magnifications are 1× and 50×. Lines of the Bowen fluorescent mechanism such as O III λ3759 and N III λλ4097, 4103 appear in this object. (*c*) Lower dispersion tracing of the region 4500–6900 Å. Relative magnifications are 1× and 30×. Note the great strength of [N I] λ5200 and [N II] λλ5755, 6548, and 6584. (*d*) Lower dispersion tracing of the region 6200–7800 Å. Magnifications are 1× and 20×. Although [Ar III] λ7135 is strong, [Ar V] λ7005 is relatively weak.



1.0
0.8
0.6
0.4
0.2
0.0
Relative Flux
4500
5300
6100
6900
Wavelength (A)

FIG. 2c



1.0
0.8
0.6
0.4
0.2
0.0
Relative Flux
6200
6600
7000
7400
7800
Wavelength (A)

FIG. 2d

TABLE 2

LINE INTENSITIES CORRECTED FOR INTERSTELLAR EXTINCTION

A.

λ	Ident.	fλ	NGC 6879 I	σ	Me 2-2 I	σ	M2-2 I	σ	NGC 6369 I	σ	M3-20 I	σ	M1-35 I	σ	M1-38 I	σ	M1-44 I	σ
3727	[O II]	0.256	14.7	10	20.9	13	6.7:	5	48.6	50	39.0	21	34.6	3	85	24	33.5	9
3750	H	0.251	3.7	20	2.94	9					5.5	30					3.1	30
3770	H	0.247	3.8	20	3.55	11					6.1				3.8		3.6	10
3797	H	0.242	5.2	14	5.10	13					7.5	27			8	9	4.2	10
3819	He I	0.239	0.14	32	1.83	20												
3835	H	0.235	7.5	19	7.23	4	7.1	17			6.7	42			7.4		5.54	22
3868	[Ne III]	0.228	94.0	9	58.8	4	98.5	3	84.2	8	99.7	4	46.1	22	(2:)			
3889	H, He I	0.224	19.7	4	16.5	12	17.7	2	18.9	17	23.6	12	14.8	12	17		13.7	20
3970	[Ne III], H	0.207	42.4	12	29.7	25	35.5	13	37.1	5	40		18	37	14.4	24	10.6	10
4009	He I	0.198			0.25	30												
4026	He I	0.194	2.8	30	3.02	10					2.4:	24						
4068	[S II]	0.185	1.17		0.90	17					2.7:				7.9	60		
4076	[S II]	0.183																
4101	Hδ	0.177	25.6	11	26.0	6	28.4	12	26.3		29.4	9	27.5		24.5	18	25.9	11
4121	He I	0.173			0.42													
4143	He I	0.167			0.46	8												
4267	C II	0.139			0.46	8												
4340	Hγ	0.121	49.2	8	46.3	4	45.5		46.4		49.3	6	44.3	5	46.2	4	46.7	7
4363	[O III]	0.116	7.9:	5	5.4	8	15.9	13	14.2	31	9.6	12	7.7:	68				
4388	He I	0.110	0.82	10	0.84	7												
4471	He I	0.090	4.94	8	7.05	3	5:	38	7.0	10	4.6	8	8.0	11	1.7		2.7	15
4609		0.058																
4634	N III	0.055	0.7	30	0.08	35												
4640	N III	0.051	2.6	30	0.27	14					1.8							
4648,50	O III	0.049			0.19													
4658	[Fe III] C IV	0.046	0.9	20	0.17	23												
4686	He II	0.040	3.1	30		10	8.96	3	2.4	55	1.6:	34						
4711,13	[Ar IV] He I	0.034	3.5	8	1.25	12	4.5	20			1.8	25						
4740	[Ar IV]	0.034	2.8	8	0.36	12	2.2:	50			1.5	9						
4861	Hβ	0	100	4	100	65	100	5	100	5	100	6	100		100	8	100	2
4921	He I	−0.014	0.58	20	1.3	18			1.55	14	2.1	6						
4959	[O III]	−0.022	375	5	242	4	390		448	5	454	6	270	5			2.9	4
5007	[O III]	−0.033	1165	7	723	4	1159		1307	5	1347	6	833	6			8.8	5
5200	[N I]	−0.074															1.76	16
5517	[Cl III]	−0.139	0.38	20	0.13	19			0.48		0.63:							
5537	[Cl III]	−0.142	0.38	20	0.19	19			0.91		0.78:							
5755	[N II]	−0.183	0.19	14	4.14	8			1.77	7			2.3	17				
5876	He I	−0.205	14.1	12	19.3	9	13.0	15	15.2	19	13.8		20.6	11	1.31		6.93	
6300	[O I]	−0.275	0.26	22	1.68	7			3.2		1.55		3.26	12	2.0	14		
6312	[S III]	−0.277	0.52	30	0.61	28			1.3	5	1.03		0.92:	11				
6363	[O I]	−0.285			0.54	13			1.17				1.44	16				
6548	[N II]	−0.312			(43)				(22.5)		4.6	13	51:		(45)		(54)	6
6563	Hα	−0.315	298	5	285	5	287	15	285	10	297		272		274		283	4
6584	[N II]	−0.317	7.05	20	157	16	3.65	50	62.2	7	11.1		166	8	146	5	178	3
6678	He I	−0.331	3.55	4	4.93	2	2.62	16	3.8	23	3.47	7	4.89	7			2.2	16
6717	[S II]	−0.336	0.36	20	0.39	8			2.81	13	1.0	12	5.65	5	7.3	6	8.7	13
6730	[S II]	−0.338	0.66	20	0.57	4			5.25	8	1.8	4	10.1	8	15	18	11.5	4
7065	He I	−0.382	3.8	23	13.4	16	3.35	19	5.4	5	4.5	3	5.28	12			1.42	8
7135	[Ar III]	−0.391	8.55		7.4	20	3.86	6	16.6	11	6.6	3	18.5				0.88	68
7237	C II	−0.403			0.42				0.55									
7278	He I	−0.408	0.48	14	0.67	21			0.69									
7325	[O II]	−0.413	1.33	19	7.0				5.93	15	3.26	14	3.65	8	3.0			
7530	[Cl IV]	−0.436																
7751	[Ar III]	−0.460							3.97	7	1.3	15	3.7	2				
8045	[Cl IV]	−0.489																

TABLE 2—*Continued*

B.

λ	Ident.	fλ	M1-4 I	σ	K3-67 I	σ	CN 2-1 I	σ	NGC 6567 I	σ	IC 4732 I	σ	NGC 6807 I	σ	Me 1-1 I	σ	NGC 6833 I	σ
3727	[O II]	0.256	14.8	3	47.1	6	20.3	5	18.6	6	18.4	4	24.8	4	71	13	15.8	4
3750	H 12	0.251	3.0	18	4.7	25	2.4	25	3.5	15	2.8	18	3.2		3.7	20	2.6	
3770	H 11	0.247	3.5	18	5.1	20	2.4	30	4.0	15	3.8	15	5.6	6	4.0	15	3.3	
3797	H 10	0.242	5.1	18	6.0	15	3.3	30	4.6	15	5.4	18	4.7	9	4.7	15	4.5	6
3819	He I	0.239	1.4	20	2.4	14	1.23	19	1.02	20	1.35	15	1.26	6	1.39	14	1.09	9
3835	H 9	0.235	6.8	20	7.4	10	5.1	35	6.01	25	7.7	12	6.8		6.4	6	6.8	
3868	[Ne III]	0.228	84.7	3	115	5	106	5	62.5	5	130	9	114	9	151	5	71.0	3
3889	H, He I	0.224	17.5	3	22.5	5	13.8	6	18.8	11	19.9	10	16.7	12	18.0	8	15.5	2
3970	[Ne III], H	0.207	42.7	4	48.5	8	44.1	6	29.3	8	51.4	11	47.6	4	61.3	6	35.3	2
4009	He I	0.198	0.54	20									0.31					
4026	He I	0.199	1.9	40	2.8	23	2.4	7	2.4	18	2.3	18	2.4	7	2.53	7	2.07	10
4068	[S II]	0.185	9.2	15	3.2	13	3.2	5	0.90	16	2.3	13	3.5	22	11.8	23	1.9	3
4076	[S II]	0.183							0.35	73	1.22	30	1.1	22	3.0	27		
4101	Hδ	0.177	27.1	3	26	5	25.2	5	28.4	9	27.1	9	27.5	4	26.8	3	26.5	3
4121	He I	0.173											0.21		0.39	20	0.59	4
4267	C II	0.139	0.52	34					0.88	18	0.8				1.21	30	0.16	.0
4340	Hγ	0.121	49.7	3	45.9	5	46	5	50.4	5	46	12	46.6	6	46.9	3	47.3	4
4363	[O III]	0.116	12.5	4	16.3	6	3.8	6	7.9	4	21	10	12.2	10	9.8	6	12.4	3
4388	He I	0.110	0.77	11					0.80	14	0.78	27	0.75	6	0.7	20	1.1	20
4471	He I	0.090	4.34	6	4.85	7	4.8	11	4.88	9	5.6	12	5.6	15	5.7	3	4.65	3
4609	N II, C II	0.058											0.26	15	0.5			
4634	N III	0.052	2.4	18					0.20	40			0.54	9	0.52	33	0.39	7
4640	N III	0.050					3.3	19	0.59	40			0.6	50	1.46	4	0.36	7
4648,50	C III	0.049							0.58	40					0.78	7		
4658	[Fe III, C IV]	0.046							0.56	30			0.54	7	0.72	11		
4686	He II	0.040	6.46	10			4.6	7	1.87	18	1.06	33	0.36	34	3.4	12		
4711,13	He I, [Ar IV]	0.034	3.0	10	2.2	14	2.5	20	1.38	15	2.65	11	1.5	5	3.7	14	1.17	7
4740	[Ar IV]	0.031	2.63	12	2.2	12	3.1	12	0.83	13	3.1	9	1.87	3	4.4	14	0.70	16
4861	Hβ	0.00	100	2	100	5	100	5	100	5	100	6	100	6	100	5	100	4
4921	He I	-0.014	0.88	12	2.6	35	0.71	22	1.9	20	0.92	20	0.92	7	1.33		1.0	6
4959	[O III]	-0.023	418	2	372	3	553	4	337	3	494	3	458	4	480	5	250	24
5007	[O III]	-0.033	1255	2	1109	6	1597	4	967	3	1523	3	1376	10	1407	10	765	2
5200	[N I]	-0.074	0.66	20														
5517	[Cℓ III]	-0.139	0.26	10	0.43	30	0.40	15	0.26		0.18	20						
5537	[Cℓ III]	-0.142	0.31	10	0.56	23	0.73	15	0.38		0.26	32						
5755	[N II]	-0.183	0.15	40	1.84	13	0.74	25	0.33		0.24	50	1.2	18	5.1	23	1.86	6
5876	He I	-0.205	14.5	17	14.8	10	14.1	15	15.1	12	13.0	6	16.3	10	17.0	5	13.4	5
6300	[O I]	-0.275	0.40	50	4.33	25	2.36	20	1.7	30	3.0	11	4.1	26	8.35	4	3.1	17
6312	[S III]	-0.277	0.63	19	1.85	26	1.6	20	0.84	20	1.5	17	1.6	20	3.65	13	0.74	25
6363	[O I]	-0.285	0.19	20	1.08	20	0.92	20	0.57	30	1.1	19	1.4	10	3.0	22	1.03	25
6548	[N II]	-0.312					(8.7)	15					(4)	6	(63)	5		
6563	Hα	-0.315	300	5	289	10	276	3	303	12	286	7	275	4	282	5	288	9
6584	[N II]	-0.317	7.25	12	58.1	17	33.4	10	12.4	15	13.1	4	19.7	4	206	3	28.0	3
6678	He I	-0.331	3.34	7	3.26	14	3.38	13	4.1	10	3.53	21	3.62	11	4.0	6	4.4	14
6717	[S II]	-0.336	0.43	24	2.06	30	1.3	12	0.48	14	0.96	30	0.86	33	9.5	6	0.285	20
6730	[S II]	-0.338	0.78	20	3.48	10	2.59	15	1.06	14	2.00	20	1.86	10	20.4	9	0.549	15
7065	He I	-0.382	5.6	7	8.29		6.35	13	7.8		8.65	13	9.16		6.8	8	9.8	
7135	[Ar III]	-0.391	6.37	6	8.5	12	13.0	14	6.1		6.94	20	11.4		28.5	11	9.0	3
7237	C II	-0.403	0.12	36					0.58		0.8	40	0.73	45				
7278	He I	-0.408	0.64	10	0.79	51			0.86								0.88	4
7325	[O II]	-0.413	1.54	11	6.66	13	5.43	12	4.53		10.20	14	11.8	3	12.2	10	11.4	5
7530	[Cℓ IV]	-0.436							0.16									
7751	[Ar III]	-0.460	1.3	18	1.89	23	3.25	10	1.58		1.7	10	2.13	23	6.55	6	2.27	9
8045	[Cℓ IV]	-0.489							0.41									

TABLE 2—*Continued*

C.

λ	Ident.	f_λ	M2-6 I	M2-6 σ	M4-3 I	M4-3 σ	M2-10 I	M2-10 σ	H1-18 I	H1-18 σ	H1-23 I	H1-23 σ	H2-18 I	H2-18 σ	M3-15 I	M3-15 σ	M2-23[a] I	M2-23[a] σ	M2-33 I	M2-33 σ	H1-65 I	H1-65 σ	NGC 6804 I	NGC 6804 σ
3727	[O II]	0.256	61.5	9			74	16	40	36			20.3	10			8.9	12	34	21	15.8	13		
3797	H 10	0.242	4.5		4.6	30											4.6	6	4.5	47	(6)			
3835	H 9	0.235	6.1	5	6.5	30	6.6	13									7.4	35	7.1	18	8	18		
3868	[Ne III]	0.228	42.9	4	58	10	7.5	14	114	1.6	66.7	7	93	7	57	15	90	8	35.7	21			78	
3889	H, He I	0.224	19.2		15.4	5	16.4	19	26.7		19.7	4	21.2	19	20	36	13.1	6	19.7	17	9.5	8	15	48
3970	H, [Ne III]	0.207	21.7	10	34.7	10	19.3	13	52.3		39	17	39	6	30	10	38.2	8	19.3	11	13.0	15	40	20
4068,76	[S II]	0.185			3.5	30											2.4	20			9.1	7		
4101	Hδ	0.177	27.8		26.7	3	25.5	21	27.7	8	26.7	4	26.6	20	27	9	24.9	6	25.5	4	27.1		23	9
4340	Hγ	0.121	49.8		47.7	5	49.2	6	47	6	45.3	5	46.2	6	45.4	7	48.1	2	46.6	3	43.2	2	45.6	16
4363	[O III]	0.116	6.4		6.5								17	9	7.6	21	12.6	4	2.2					
4471	He I	0.090	4.8		4.7	10	6.0	13	9.1		6.7	38	6.4	9	8.4	24	4.4	4	5.1					
4686	He II	0.040											5.4	21									87	
4711,13	He I	0.034																						
	[Ar III]	0.034											4.3				1.2	27	0.6				8.6	10
4740	[Ar IV]	0.031											7.2				0.5	18					2	10
4861	Hβ	0.0	100		100	5	100		100	6	100	5	100	6	100	3	100	4	100		100		100	8
4921	He I	−0.014	1.3	40	1.4	10					4.0	2					1.0	28	1.3					
4959	[O III]	−0.023	235	7	302	3	44.9	6	426	3	406	2	483	8	336	14	378	3	201				251	8
5007	[O III]	−0.033	611	8	930	3	142	6	1287	3	1221	2	1491	11	1026	10	1203	5	592				794	9
5200	[N I]	−0.074					1.5																	
5755	[N II]	−0.183					1.6	14	5.5		3.4						0.76							
5876	He I	−0.205	12.2		13	15	14.7	4	22.4		19.5	8	15.4	8	14.1	8	13.1	2	13		1.2		7.8	50
6300	[O I]		1.4		2.2	16			6.9	15	2.7	5					2.83		0.7					
	[S III]	−0.275							1.8	30	1.1						1.47	5	0.3					
6363	[O I]	−0.285			0.9	20			2.6	45							0.30							
6563	Hα	−0.315	297	6	288	3	293	10	300	4	293	4	285	4	272	3	290	5	272	4	280	7	287	
6584	[N II]	−0.317	40.2	5	21.0	9	237	10	236	5	72.2	3	9.0	16	38.7	8	12.5	11	7.0	19	151	5		
6678	He I	0.331	3.3		3.3	10	4.3	14	5.0	28	4.2		3.7	12	3.4	20	2.90	5	3.5					
6717	[S II]	0.336	1.2	6	1.13	7	6.5		4.1	15	3.65	8	1.1	30	2.1	15	0.44	7	0.63	8	5.9	3		
6730	[S II]	0.338	2.1	19	1.81	7	10.4		8.1	15	5.63	5	1.3	30	3.6	13	0.87	14	0.69	8	12.1	4		
7065	He I	0.382	5.0	5			3.7		9.4		5.8		3.4	12	6.2	10	8.13		2.8					
7135	[Ar III]	0.391	7.0	10			9.2		30.3	5	19.2		5.4	7	13.4	150	7.82		8.65					
7278	He I	−0.408	0.5	60					0.85								0.56	18	0.72					
7319	[O II]	−0.413	8.6	11			1.7		3.76		1.52	21					5.9	11	0.78					
7330	[O II]	−0.413							3.52		2.34	21			4.1	11	4.1	11	0.85					
7751	[Ar III]	−0.460							5.9		4.4	7					1.55	18	1.8					

[a] M2-23 $I(5517) = 0.14$, $I(5537) = 0.19$ [Cl III].

TABLE 2—*Continued*

D.

λ	Ident.	f_λ	NGC 6578 I	NGC 6578 σ	NGC 6629 I	NGC 6629 σ	NGC 6781[a] I	NGC 6781[a] σ	NGC 6891 I	NGC 6891 σ	NGC 6894 I	NGC 6894 σ	M1-78 I	M1-78 σ	Vy 2-3 I	Vy 2-3 σ	K3-61 I	K3-61 σ
3727	[O II]	0.256	21.2		41.1	11	319		16.2	10	236		81.4	4	13.0		21	16
3750	H 12	0.251	4.7:		3.2	22			2.1									
3770	H 11	0.247	5.0		4.2				3.41	23	4	30						
3797	H 10	0.242	6.45	16	3.9				4.25		5.9							
3819	He I	0.239	2.0		1.0	26			1.1	41	3.5							
3835	H 9	0.235	8.08		6.02	7			6.7	8	7.6	14			6.5	30		
3868	[Ne III]	0.228	68.9		33.3	10	85		55.8	6	63.7				89		52.6	16
3889	H, He I	0.224	22.8		18.8	12	11.1		19.0	10	16.9	6			22		20.5	
3970	[Ne III], H	0.207	37.3		27.5		36.7		31.7	5	37.7	3			40	17	22.3	8
4009	He I	0.198																
4026	He I	0.194	3.0		2.94	12			2.3		4.66							
4068	[S II]	0.185	3.1	10	1.39	13			0.39		7.7							
4076	[S II]	0.183							0.41									
4101	Hδ	0.177	27.6	8	27.2		30.7		25.5	6	26.9		27.1		25.8		25.9	22
4121	He I	0.173			0.67													
4144	He I	0.167			1.16	22			0.22									
4267	C II	0.139	1.1	20					0.48	8								
4340	Hγ	0.121	47.2		46.5	4.3	43.1		49.3	5	44.3		49.8	29	47.4		47.2	28
4363	[O III]	0.116	2.8	20	2.8				4.54	14	2.3				8.78	5		
4388	He I	0.110	1.11	19					0.75	21								
4471	He I	0.090	4.91		4.43				5.14	12	4.65	7			6.2	20		
4609		0.058																
4634	N III	0.052							0.81									
4640	N III	0.050	3.51	18	1.26	27			0.91						2.5	14		
4648,50	O III	0.049							0.49									
4658	[Fe III]	0.046																
	C IV														1.44	23		
4686	He III	0.040	1.0	30							6.64	22			3.16	7		
4711,13	He I, [Ar IV]	0.034	1.30	21	0.50				1.02	4					2.5	50		
4740	[Ar IV]	0.031	0.84	12					0.47	40					1.7	32		
4861	Hβ	0	100	6	100	6	100	5	100	5	100	6	100	9	100		100	9
4921	He I	-0.014	1.07		1.03	16			0.98	12	1.14	27						
4959	[O III]	-0.023	286	6	226	6	331	4	299	11	235	6	123	7	334	6	300	7
5007	[O III]	-0.053	800	6	674	6	1169		917	5	749	9	362	11	1010	7	937	6
5200	[N I]	-0.074									5	44						
5517	[Cℓ III]	-0.139	0.45	27					0.18	30								
5537	[Cℓ III]	-0.142	0.51	15					0.26	40								
5755	[N II]	-0.183	0.23:								9.0							
5876	He I	-0.205	15.8	6	12.0	18	17		13.2	6	12.3	28	12.6	12	7.5	19	16	23
6300	[O I]	-0.275	0.64	12	0.53						10.1	13						
6312	[S III]	-0.277							0.19	12	4.0							
6363	[O I]	-0.285																
6548		-0.312	(4.3)	5	(4)	22	(71)	18			(110)	5	(18.3)	13			(59)	13
6563	Hα	-0.305	293		289	9	286	9	271	4	284	5	302		286		285	
6584	[N II]	-0.317	11.2	5	11.0	11	258	9	(3.1)	9	337	6	57.8	6			168	19
6678	He I	-0.331	4.16	5	3.4	17	7.11		3.15	15	6.2:	21	3.0	17	3.42	7	3.85	15
6717	[S II]	-0.336	0.46	25	0.53	55	15.0	24	0.10	18	50	5	1.85	24			3.4	30
6730	[S II]	-0.338	0.82	19	0.71	34	14.9	24	0.10	15	44.6	7	3.0	16			3.0	30
7065	He I	-0.382	4.13	6	4.2	6			3.38	10	3:	50	5.27	14	3.4	7	3.3	1.5
7135	[Ar III]	-0.341	12.2		12.1	5			8.8	12	19.7		11.3	7	6.4		9.3	25
7237	C II	-0.403	0.45	12														
7278	He I	-0.408	0.54	34	0.66								1.14					
7325	[O II]	-0.413	1.66	17	1.67	21			9.5	9	7.4		12.94	8				
7751	[Ar III]	-0.460	2.4		2.57				2.0	16			2.21	8			(2.1)	

[a] See also Table 3.

TABLE 2—*Continued*

E.

λ	Ident.	f_λ	M2-21 I	M2-21 σ	Hubble 4 I	Hubble 4 σ	NGC 6439[a] I	NGC 6439[a] σ	Hubble 6[a] I	Hubble 6[a] σ	M1-42 I	M1-42 σ	K3-60 I	K3-60 σ	NGC 6620[b] I	NGC 6620[b] σ	M1-80 I	M1-80 σ
3727	[O II]	0.256	35.7	6	32.7	12	61.4		34.8	13	51	7	95	10	152	4	168	9
3750	H 12	0.251	5.3:	5			2.85	8			3.1	19			2.3			
3770	H 11	0.247	5.84	8			3.9				4:				3.6	10		
3797	H 10	0.242	5.5				5.5	9			4.6	40			4.4	6	6.6	28
3819	He I	0.238	2.18	21			1.9	29			3.0	44			1.1	12		
3835	H 9	0.235	8.67		11	30	7.7	7	8.8	33	7.4	15			6.8		7.52	22
3868	[Ne III]	0.228	101.7	5	88.8	20	125.7		112.5	11	53		123	5	120	5	74.2	6
3889	H,He I	0.229	22.2	11	12:	44	19.1	4	17	19	19.7	10			20.7	8	19	24
3968	[Ne III],H	0.207	36.0	2.4	38.1	20	49.7	4	47.7	4	25.8	7	41.4	25	35.6		36.3	
4026	He I	0.194	2.35				3.5	24	3.48	6	3.4	29			2.3		4:	
4068	[S II]	0.185					5.95	11	7.91	32	6.4	15			6.8	11	3	
4076	[S II]	0.183													2.7	10		
4101	Hδ	0.177	25.9	3	23.4	20	28.7	10	29.0		26.9	8	30	19	27.6	5	25.4	6
4227	[Fe V]	0.148							1.65	21								
4267	C II	0.139					0.65	33	0.9	43	2.24	5			0.6	26		
4340	Hγ	0.121	48.4	8	42.2	8	48.1		46		46.7	10	43	20	50	10	47.4	
4363	[O III]	0.116	16.6		7.2:	36	9.13	5	13.0	10	4:	54			7.86		16.8	6
4388	He I	0.110							1.0	18					0.74	8		
4471	He I	0.090	4.56		4.84	10	5.34	8	5.18		8.0	4			5.15	9	2.7	19
4541	He II	0.074	0.84						1.14	22					0.88	21	2.4	
4609	N II,C II	0.058							0.6	47								
4634	N III	0.052							1.9	22					1.57			
4640	N III	0.051	3.91	28			7.0	22	4.60		9.7	11			3.84		3.8	
4650	C III	0.048							1.23	11					1.2			
4658	C IV	0.046							0.83	5								
4686	He II	0.040	30.2	8	21.5		22.3	14	26.8		11.7	9	50.3	10	26.1	5	39.3	5
4711,13	[Ar IV]	0.034																
	He I		3.24	16	4.26		5.3	24	5.05	8	2.7	34			4.16	6	1.2	
4725	[Ne IV]	0.031					0.64		0.97	7					0.3			
4740	[Ar IV]	0.028	2.79	14	2.79		5.3	16	7.30	8	1.7	40			2.81		2.2	
4861	Hβ		100	4	100	3	100	9	100	2	100	11	100	5	100	4	100	6
4921	He I	-0.014	1.01	30	1.11	9	0.95	23	1.6	69	1.7	35			1.09	15		
4959	[O III]	-0.022	460	6	411		423	8	516	4	180	4	484	4	445	5	432	8
5007	[O III]	-0.033	1310	5	1204	7	1198	8	1467	3	547	4	1484	8	1292	5	1387	7
5200	[N I]	-0.074					0.74	14	0.95		3.0	15			2.4	19		
5411	He II	-0.118	1.92	8	1.65	5	1.77	19	1.92		1.46				1.57	13	4.4:	45
5517	[Cℓ III]	-0.139			0.78	19	0.90	15	0.50		1.33				0.58	17		
5537	[Cℓ III]	-0.142			0.90	9	0.86	15	0.88	14	0.90				0.96	17		
5755	[N II]	-0.183			1.32	7	2.0	21	2.20	6	27.6	28			2.4	24	3.4	49
5876	He I	-0.205	13.2		15.2		16.0	12	14.2	5	22.6	4	11	46	11.3	8	7.14	13
6102	[K IV]	-0.243							0.32	24								
6300	[O I]	-0.275	2.93	6	2.89		3.37	8	3.39		3.5	20			7.6	11	4.2	25
6312	[S III]	-0.277	0.90	16	2.30	10	2.21		2.51	6	1.39	5			2.07	5	2.0	31
6363	[O I]	-0.285	0.66	13	1.18		1.03	10	1.20		1.43	25			2.9	5		
6435	[Ar V]	-0.296					0.37		0.16	19								
6548	[N II]	-0.312	(4.8)		(23.5)		(38)	7	34		(90)	6	(33)	4	(78)	18	(44)	10
6563	Hα	-0.315	289	5	297	4	288		298	2	283	5	290	4	283	9	288	5
6584	[N II]	-0.317	13.5	8	68.5	4	119		101	4	267	6	98	4	225	9	145	9
6678	He I	-0.331	2.98	5	3.6	8	3.90	8	3.37	6	5.72	14	2.8	15	3.23	8	4.0	12
6717	[S II]	-0.336	0.79	27	3.5	9	5.57	7	4.26	4	13.2	6	3.4	32	18.7	9	9.06	8
6730	[S II]	-0.338	1.27		6.7	8	9.97	4	8.18		18.0		5.8	21	27.6	10	10.9	8
7005	[Ar V]	-0.375					0.29	17	0.65	5					0.4:			
7065	He I	-0.382	4.50	6	5.75		5.33	4	5.90	4	4.0	10	4.26	7	3.0	22	2.2	14
7135	Ar III	-0.391	4.05		21.4		5.82		27.5		18.6	9	12.6	8	21.4	29	8.4	14
7237	C II	-0.403			0.14	12			0.3	42								
7263	[Ar IV]	-0.406							0.3	34								
7281	He I	-0.408			0.50	28	0.7		0.63	14					1.4		0.92	
7325	[O II]	-0.414	4.02	10	4.88	5	5.4	11	6.3		4.8	15	17.1	10	6.6	24	5.2	11
7530	[Cℓ IV]	-0.436			0.47	10			0.4	24								
7751	[Ar III]	-0.460			5.45		1.22		6.08	5	2.86	15	3.2:		5.1	12		
8048	[Cℓ IV]	-0.489							0.82	11								
8577	[Cℓ II]	-0.535							0.32									

[a] See Table 3 for some additional data.
[b] See notes for additional data pertaining to helium lines.

TABLE 2—*Continued*

F.

λ	Ident.	f_λ	K3-68		Hubble 5		IC 4673		H1-59		M2-30		M1-75		NGC 6881		NGC 7354	
			I	σ	I	σ	I	σ	I	σ	I	σ	I	σ	I	σ	I	σ
3341	[Ne V], O III	0.373			39.3	10									46			
3428	[Ne V]	0.345			161	22	32:						189	31	137	9		
3444	O III	0.339			14.3	10	37:								17.7	5		
3727	[O II]	0.255	26	38	62.3	4	29.6	25	23.0	18	12.5	3	129	8	64.4	7	32.3	17
3750	H 12	0.251													3.7	32		
3760	O III	0.249													4.0	20		
3770	H 11	0.247													4.2	9		
3797	H 10	0.242			4.52		7.8				5.4	27			5.1	11		
3835	H 9	0.235			6.9	30	10.9	30			5.9	36			7.0	23		
3868	[Ne III]	0.228	72.7	8	120		102	5	69.0	10	95.9	9	142	4	144	15	96.8	
3889	He I, H8	0.224	23	23	14.0	25	17.1	7	15.9	8	17.0	20	23.5	4	18.4	10	22.7	33
3967	[Ne III], H 7	0.207	32	32	52.3	10	46.7	8	29.6	14	48.4	18	70.8	9	53.9	7	44	
4024,26	He I, He II				3.2	19	4.3:		5.5		2.8	20			3:	41		
4068	[S II]	0.184													7.7	10		
4076					10.5	19	5.3	30	9.4		2.65		14	39	2.3	10		
4101	Hδ	0.177	28·	34	28.9	4.1	30.3		27.7		28.9	6	26.1	19	26.1		26.2	13
4340	Hγ	0.121	44.1	15	42.7	6	46.8	6	44.5	17	44.8	12	46.7	8	46.2	19	42.5	
4363	[O III]	0.116	26	36	24.6	8	10.1		12.5	9	12.4	8			22.2	18	18.6	17
4471	He I	0.090			3.7:	48	4.2	16	1.8:	56	4.3	6			3.8	23		
4541	He II	0.074					2.3		5.1		1.8		9.3?	10	1.7	35		
4634,40	C III	0.052			8.54		15.0		10.4	32	8.4	16	12	32	4.6:		11.1	21
4658	C IV	0.046			2.55	10												
4686	He II		101	10	65	4	76.0		81.9	5	42.6	6	99	12	43.4	12	49.4	5
4711,13	He I, Ar IV		8	13	9.8	25	11.8	7	13.6	11	7.8	5	25.1	24	6.1	19	7.4	13
4724	[Ne IV]	0.031			1.2	31									1.7	5		
4740	[Ar IV]	0.028	11:		18.5	11	9.3		9.5	8	6.6	4	17.4	22	8.8	13	6.0	22
4861	Hβ	0.00	100	4	100	3	100	8	100	4	100	11	100	16	100	4	100	4
4921	He I	-0.014					1.4	8			3.6							
4959	[O III]	-0 022	273	8	642	4	406	5	384	6	455	7	461	4	577	3	417	4
5007	[O III]	-0.033	835	6	1888	7	1211	5	1169	7	1368	9	1376	5	1736	4	1328	8
5200	[N I]	-0.074			3.66	5												
5411	He II	-0.118	6.7:	45	5.06		6.4	9	3.8:	40	3.43		18.4	9	1.8		2.2	
5517	[Cℓ III]	-0.139			0.7	47									2.7	9	4.5	28
5537	[Cℓ III]	-0.143			1.2	47									0.7	34		
5722	[Fe VII]	-0.177			0.95													
5755	[N II]	-0.183			11.25	11							23.8	16	4.9	20	1.50	
5876	He I	-0.205			12.1	12	10.0	16	2.64		10.4	4	12.9	7	9.8	7	10.9	15
6074	He II	-0.239			0.25	30												
6089	[Ca V], [Fe VI]	-0.241			1.83													
6104	[K IV]	-0.243			0.51													
6300	[O I]	-0.275			19.0	5							22.0	5	10.5	6	2.5	24
6312	[S III]	-0.277			1.8	16	2.8	27			1.50	18	10.7	32	2.9	15		
6363	[O I]	-0.283			6.0	15							6.9	18	3.7	13		
6435	[Ar V]	-0.296			3.40	4							3.6:		1.3	5		
6548	[N II]	-0.312			116	9	(8.5)		(14.3)		(2.3)		338		(51.4)	5	(21)	9
6563	Hα	-0.315	281	17	281	5	288		281	10	262	11	286	9	290	3	296	8
6584	[N II]	-0.317	10	19	379	3	31.6	9	42.4	10	6.9	10	1205		165	5	61.8	5
6678	He I	-0.331			2.8	8	3.6	18	3.6:		2.8	36	2.7	16	2.7	5	3.0	13
6717	[S II]	-0.336			5.2	11	3.7	11	6.5	30	0.80	10	44.9	9	2.3	17	2.0	13
6730	[S II]	-0.338			9.9	5	4.9	14	7.5	18	1.22		64.4	3	4.9	19	3.8	14
7005	[Ar V]	-0.375			5.6	11							2.6	11	2.9	20		
7065	He I	-0.382			4.4	13	1.7:				2.7	28	4.4	28	5.0	12	2.5	31
7135	[Ar III]	-0.391	11.1	8	35.7	9	19.0		16.8		13.4	5.8	32.5	17	24.0	15	14.2	14
7237	[Ar IV]	-0.403			0.6										0.57	30		
7263	[Ar IV]	-0.406			0.41	20												
7281	He I	-0.408			0.33	23									0.50	22		
7325	[O II]	-0.413			19.8	5	2.1	19			1.72	12	12.2	16	23.1	18		
7530	[Cℓ IV]	-0.436			0.42										0.35	8		
7592	He II	-0.443			0.6													
7751	[Ar III]	-0.460			7.78		4.0	30			2.4	40	8.4	20	5.3	23	4.21	
8046	[Cℓ IV]	-0.489			1.2	32									0.89	6		

COMMENTS ON INDIVIDUAL NEBULAE LISTED IN TABLE 2

M1-4.—Kaler 1985*a* obtained results in reasonable accord with ours, although he finds $T(\mathrm{O}^{++})=12{,}800\pm800$ K versus our 11,600 K, and also a lower N_ϵ. The discordance in the He abundance may be attributed partly to differences in measurement of $I(5876)$.

M2-2.—See also Kaler 1985*a*, who obtains smaller values of T_ϵ and N_ϵ. We adopted $T=12{,}000$ K, $N=5000$ cm^{-3} as a compromise. The quality of the line intensities is only fair.

K3-68.—Probably a higher temperature stellar flux model should have been used, but improved observational data, requiring long dwell times, would be needed.

M2-6.—We use T_ϵ, N_ϵ values based on Groningen results. The assumed $T(*)$ may be too high.

M4-3.—The finally adopted T_ϵ, N_ϵ values differ slightly from those found by the Groningen workers.

H1-23.—The [S II] λλ6717,6730 and [N II] λ5755 lines are stronger than predicted, suggesting an unresolved structure of high-density blobs. This is a relatively N-rich object.

Hubble 4.—This is a relatively N-rich object.

H2-18.—The Kudritzki model atmosphere for $T=77{,}000$ K, $\log g=4.72$ was adopted on the basis of the assumption that λ4686 was at least 70% of nebular origin. The T_ϵ predicted by the nebular model fits that from the diagnostics if we accept the uncertain $I(4363)$ at its face value, but the model seems to fail for nitrogen.

Hubble 5.—The observed intensity of [Ne V] λ3426 appears to be stronger than predicted; a blackbody central star flux may not be suitable. Observations should be obtained with a more favorable zenith distance.

NGC 6439.—Ultraviolet lines [Ne V], O III λ3340 [Ne V] λ3426, and O III λ3444 are measured with intensities 13, 5.4, and 16.8, respectively, but with large errors of 24%–38%. They have not been used in the abundance analysis.

IC 4673.—Because of severe atmospheric extinction the [Ne V] λ3426 intensity is very uncertain.

M1-42.—In constructing a nebular model we assumed λ4686 to be of nebular origin.

M1-44.—Note that in this object [Ne III] λ3868 is missing. If [N II] $I(5755)\lesssim0.8$, as seems likely, $T_\epsilon\lesssim6600$ K. The excitation is very low; [O III] is very weak. No theoretical model is possible.

NGC 6620.—The intensities of He I λλ4121, 4143 and He II, N III λ4200 are, respectively, 0.63, 0.67, and 0.50 on the scale $I(\mathrm{H}\beta)=100$. See Fig. 2.

NGC 6629.—Note that the [S II] λλ6717/6730 ratio is poorly determined, so that no really good electron density is available, and $N(S)$ is poorly determined. We choose $T\approx8900$ K, $N_\epsilon=1260$ cm^{-3}.

IC 4732.—Our data do not support the low density, $N_\epsilon\approx2700$ cm^{-3}, reported by Shaw and Kaler 1985. The [S II] lines indicate a much higher density. Accordingly, we have adopted $T_\epsilon=13{,}000$ K, $N_\epsilon=12{,}500$ cm^{-3}.

NGC 6781.—In this extended object the left and right slots were treated separately, the left slot being compared with the model. In spite of its low surface brightness (the relative exposure is equal to 80 [Curtis 1918]), reasonably good data appear to have been found for this object. Table 2D gives data for the brightest position in the nebula. The data for the right slot (not compared with the model) are given in Table 3.

NGC 6804.—Because of the faintness of this object, only a few lines are observed. No model was attempted; abundances were found from ionic concentrations by approximate conventional extrapolation formulae, with $T_\epsilon=12{,}000$ K and $N_\epsilon=1000$ cm^{-3} (Kaler).

NGC 6807.—We take $N_\epsilon=4000$ cm^{-3} from Shaw and Kaler 1985, since the [S II] line ratio is not determined accurately.

NGC 6833.—Analyses were carried out with $10{,}000<N_\epsilon<40{,}000$ cm^{-3}; $N_\epsilon\approx20{,}000$ cm^{-3}; $T_\epsilon=14{,}160$ K from [O III] seems the best compromise. See Fig. 1.

M1-75.—An interesting object, unusually rich in N and He. It is difficult to reproduce the strong He II λ4686 and [Ne V] λ3426.

NGC 6881.—Curiously, [Ne V] λ3426 seems strong, while λ4686 looks abnormally weak for a nebula of high excitation; [O II] λ3727 is strong.

NGC 6879.—For this object and also NGC 6881, the measured intensities seem to be in good accord with those of Kaler, Pratap, and Kwitter 1987 when allowance is made for the fact that they measured the integrated light of the entire nebular image, while we used a 2″×10″ slot centered on the nebula. Ionic concentrations and electron temperatures are in good accord, but the electron density is poorly determined in NGC 6879.

NGC 6891.—Our adopted model density $N_\epsilon=2500$ cm^{-3} may be too high for this frequently observed, rather bright nebula. Both Maciel and Pottasch 1984 and Shaw and Kaler 1985 suggest $N_\epsilon\approx2500$. The central star has received a great deal of attention (see Acker *et al.* 1982; Heap 1977; de Freitas-Pacheco, Codina, and Viadana 1986).

NGC 6894.—No suitable theoretical model yet has been found. There is a large discordance between our N abundance and that found by Kaler 1985*a*. Here λ3727 and λ4686 are strong. The excitation class, 8, is ambiguous.

M1-78.—An extremely high extinction is indicated for this object. The close agreement of the ICF and model results is probably fortuitous.

K3-60.—The very large interstellar extinction limits the accuracy attainable for this nebula.

NGC 7354.—See also Shure *et al.* 1983, who have found from infrared lines a higher density, $N_\epsilon=5600$, than we had used.

ning of this section. Errors arising from the response function and atmospheric extinction appear to be of the order of 4%. The total errors are smallest for the stronger lines, typically amounting to 5%–10% for $I\gtrsim40$, 10%–20% for $10<I<40$, 20%–30% for $1<I<10$, and 25%, 50%, or even greater for $I<1.0$, except for faint nebulae, where the errors can be larger. The σ-values are useful in flagging lines for which the random errors are serious; in southern and low surface brightness planetaries, the line λ4363 is often subject to a large uncertainty. Comments following Table 2 call attention to factors that may limit the accuracy of results for individual nebulae. Table 3 gives some additional data for NGC 6439, Hubble 6, and NGC 6781.

Peimbert, Peña, and Torres-Peimbert (1986) suggest that the detector used on an image-tube scanner is a nonlinear device, the intensity I being related to the instrumental signal S by an expression of the form $I\propto S^k$. Now $k<1$. If we express the reduced signals in terms of Hβ, the stronger lines will be measured as too strong, the weaker lines as too weak. The response function will also be affected, and one will derive spuriously high interstellar extinction coefficients. In particular, there will result an electron temperature that is too low. The derived abundances will be affected as noted in § V.

We tested this hypothesis with our data in two ways. First, we compared the measured $I(5007)/I(4959)$ ratio with the expected value. Next, we compared the He II λ4686 Paschen-α line with the Pickering lines λλ5411 and 4541. The [N II] λ6584/λ6548 ratio is not usable, since the line λ6548 is not well enough deconvolved from Hα. The "best" value of the *theoretical* λ5007/λ4959 ratio lies between 2.88 and 2.90 (see, e.g., Czyzak, Keyes, and Aller 1986). The mean observed ITS value is 3.01 ± 0.02. Measurements of this ratio by photoelectric photometry of 45 PNs gave 2.98 (Czyzak, Keyes, and Aller 1986). If we take the theoretical ratio as valid, we find

TABLE 3

ADDITIONAL DATA FOR NGC 6439, HUBBLE 6, AND NGC 6781

A. NGC 6439

λ (Å)	Identification	I	σ
3340	[Ne V]+O III	13	24
3428	[Ne V]	5.4	24
3444	O III	17	38
3760	O III	2.3	12

B. HUBBLE 6

λ (Å)	Identification	I	λ (Å)	Identification	I
5592 ...	O III	0.69	8467 ...	$P17$	0.054
5631 ...	[Fe VI]	0.28	8502 ...	$P16$	0.29
5670 ...	[Fe VI]	0.72	8545 ...	$P15$	0.46
8236 ...	He I	0.52	8598 ...	$P14$	0.53

C. NGC 6781[a]

λ (Å)	Identification	I	λ (Å)	Identification	I
4861 ...	Hβ	100	6563...	H α	285
4959 ...	[O III]	94.1	6584...	[N II]	660
5007 ...	[O III]	350	6717...	[S II]	38.4
6548 ...	[N I I]	208	6730...	[S II]	41.2

[a] The data in Table 2D pertain to the left slot; these were compared with the models. The right-slot intensities (not compared with the model) are given here.

$k = 0.96$, somewhat larger than the corresponding value found by Peimbert, Peña, and Torres-Peimbert (1986). The λ4686/λ5411 and λ4686/λ4541 ratios may be calculated exactly for a given T_ε. Thus, we can predict $I(4686)$ from $I(5411)$ and compare it with observed $I(4686)$. Excluding the data for H1-59 and M1-42, which were subject to large errors, we find $I_{\rm pred}(4686)/I_{\rm obs}(4686)$ to be 1.00 ± 0.05. The comparison for λ4541 is less accurate but also gives no support for a systematic relative line intensity error. In § V, however, we will examine the influence of such a nonlinear response effect upon the derived abundances. For this comparison we choose $k = 0.96$.

IV. ANALYSIS OF DATA

The electron temperatures are found from the [O III] λ4363/(λ4959+λ5007) ratio and from the [N II] λ5755/λ6584 ratio (if available). The largest source of uncertainty here is in the λλ4363 and 5755 measurements. The electron density is often estimated from the [S II] λ6717/λ6730 ratio or from the surface brightness (plus some assumption about the nebular distance). The [S II] lines are most likely to originate in regions of low ionization or even in interfaces between ionized and neutral (H I) regions. Thus, they do not necessarily give us the proper electron densities for the O^{++} and Ne^{++} zones. It is always preferable to use N_ε found from the [O II] λ3726/λ3729 ratio (M. Barlow 1986, private communication), but unfortunately it is not possible to resolve these lines with the spectral dispersions available on the ITS.

In principle, a further clue should be provided by the ratio of the auroral to the nebular type of transition in [O II], i.e., λ3727/(λ7319+λ7330), although the measured line ratio would be affected by wavelength-dependent photometric errors and by any uncertainty in the interstellar extinction. An even more aggravating circumstance is the fact that the $2p^3\ ^2P$ term and even the $2p^2\ ^2D$ term may not be populated exclusively by collisional excitation as has been usually assumed. In low-excitation, low T_ε nebulae, particularly, dielectronic recombination of O^{++} ions which produce excited O^+ ions may play an important role (Rubin 1986). Consequently, if one interprets the λ3727/(λ7319+λ7330) ratio as involving only collisional excitations to the ^2P and ^2D terms, the derived N_ε and/or T_ε will be too high. This effect has been noted by Barker (1978) and in the present work.

Once values of N_ε and T_ε are adopted, the calculation of ionic concentrations is straightforward (see, e.g., Seaton 1960; Aller and Liller 1968; Osterbrock 1974; Aller 1984). The largest source of uncertainty in the derived ionic concentrations arises from the error in T_ε, although uncertainties in N_ε can play a role in lines involving p^3 configurations. Atomic parameters may still need improvement for some ions in $3p^n$ configurations.

We employ the same approach in analyzing the data as has been described previously (Shields *et al.* 1981; AC 83). We calculate a theoretical nebular model to represent the line intensities, and then we use this model to obtain the ionization correction factors (ICFs). The agreement between the model abundances and those derived with the aid of ionic concentrations and model ICF factors gives us a critique of the process, but it must be emphasized that although an excellent fit may be a *necessary* condition for obtaining good abundances, it is *not* a *sufficient* condition.

Let us illustrate the method as applied to one planetary nebula, NGC 6439, excitation class 7 (see Table 1). For the emergent flux from the central star, we use a Kudritzki-type model (Husfeld *et al.* 1984) with $T_{\rm eff} = T(*) = 85{,}000$ K and $\log g = 4.72$. From the nebular diagnostics we find T_ε([O III]) = 10,560 K, T_ε([N II]) = 11,260 K, and $N_\varepsilon \sim 4000$ cm^{-3}. For the nebular model we used, $N_{\rm H} = 3550$ H atoms cm^{-3}, which yields $\langle N_\varepsilon \rangle = 4028$ cm^{-3} for the emitting volume of assumed uniform density. This nebula appears to be radiation-bounded, i.e., a full Strömgren sphere. The mean predicted T_ε([O III]) in the radiating volume is 10,800 K. Table 4 compares observed and predicted intensities. The near-ultraviolet [Ne V] lines were detected but could not be measured with requisite accuracy. The most serious discordance is found for argon. If we fit [Ar IV] λ4740 approximately, we predict too large an intensity for [Ar III] λ7135. We suspect that this discordance may arise from errors in atomic parameters or effects of concentrations in dense blobs. Columns (1)–(4) in Table 5 give the lines utilized, their observed wavelengths, the observed intensity as corrected for interstellar extinction, and $N({\rm ion})/N({\rm H}^+)$ denoted as N(ion) in the table. This quantity is calculated from I, N_ε, and T_ε, using a special computer program which solves the equations of statistical equilibrium to obtain the level populations. Then it uses the observed intensities to derive the total number of ions in the ground configuration, which is closely equivalent to the total number of ions of that species with respect to the number of H ions. A

TABLE 4

REPRESENTATION OF LINE INTENSITIES IN NGC 6439

λ (Å)	IDENTIFICATION	*I* Observed	*I* Predicted	λ (Å)	IDENTIFICATION	*I* Observed	*I* Predicted
5876	He I	16.0	15.2	3868	[Ne III]	126	133
4471	He I	5.3	5.5	4726	[Ne IV]	0.6	0.2
4686	He II	22.3	22.8	5517	[Cl III]	0.9	0.7
4267	C II	0.65	0.76	5537	[Cl III]	0.86	0.8
6583	N II	119	121	6717	[S II]	5.8	7.2
5755	N II	2.0	2.9	6730	[S II]	10.0	10.4
3727	O II	61.4	69.4	6312	[S III]	2.2	2.1
4959, 5007	O III	1621	1707	7135	[Ar III]	5.8	10.5
4363	O III	9.1	10.4	4740	[Ar IV]	5.3	4.9

TABLE 5

ANALYSIS OF NGC 6439

ION	λ (Å)	*I*	*N*(ion)	ΣN_i(ion)	ICF	*N*(element) ICF Method	*N*(element) Model
He I ...	5876	16	0.110	...	...	...	...
	4471	5.3	0.121	0.14	1.0	0.14	0.132
He II ...	4686	22.3	0.019	...	...	...	...
N II ...	6583	119	1.9(−5)	1.9(−5)	16.4	3.12(−4)	2.9(4)
O II ...	3727	61.4	2.6(−5)	...	...	...	...
O III ...	4959, 5007	1621	3.4(−4)	3.66(−4)	1.21	4.43(−4)	4.6(−4)
				...	...	...	...
Ne III ..	3868	126	9.2(−5)	9.2(−5)	1.27	1.17(−4)	1.25(−4)
S II	6717, 6730	5.6, 10.0	4.7(−7)	3.97(−6)	3.62	1.44(−5)	1.4(−5)
S III ...	6312	2.2	3.5(−6)	...	...	...	...
Cl III ..	5517, 5530	0.9, 0.86	1.0(−7)	1.0(−7)	4.2	4.2(−7)	3.6(−7)
Ar IV ..	7135	5.8	4.5(−7)	...	...	...	...
Ar IV ..	4740	5.3	1.8(−6)	2.28(−6)	1.11	2.53(−6)	3.0(−6)
Ar V ...	7005	0.29	2.5(−8)	...	...	...	...

total of 15 levels can be accommodated in the program. Column (5) gives the sum of the observed ions, ΣN_i(ion) in units of $N(H^+)$. Column (6) gives the ionization correction factor, ICF $=1/\Sigma x_i$, where x_i is the ionic fraction in an observed stage i, and the summation is taken over all observed ionization stages. Columns (7) and (8) compare the thus derived abundances with those adopted for the model. The finally adopted values of log *N* in Table 6 represent the presumed "best" choice based on the two approaches. For most elements in NGC 6439, the two sets of calculations differ by less than 10%. Exceptions are Cl and Ar, where we deal with $3p^3$ configurations, where the atomic parameters may be in need of revision, and clumpiness in the density distributions may complicate the analysis. Note that we have assumed a sphere of uniform density. One could use a shell, but various trials suggest that the changes in the ICFs would not be significant.

In AC 83, comparisons between model and "ICF method" abundances for each nebula, as well as numerous diagnostic diagrams, were presented. We shall not list results in such detail here, but instead in Table 6 give the equivalent of Table 29 in AC 83. Successive columns in Table 6 list the object followed by the logarithmic abundances of He, N, O, Ne, S, Cl, and Ar on the scale log N(H) = 12.0. *Q* denotes the expected quality of the overall determinations; the expected errors, Δ log *N* may be correlated with the letters as in AC 83, viz., A = Δ log $N \lesssim 0.1$, B = 0.1 < Δ log *N* < 0.2, C = 0.2 < Δ log *N* < 0.3, C− = 0.3 < Δ log *N* < 0.5, while D means that we have little better than an order of magnitude. A colon after an element's abundance in columns (3)–(8) indicates only an order-of-magnitude result.

Column (10) denotes the model adopted for the stellar flux; K refers to a Kudritzki-type model (Husfeld *et al.* 1984), while BB denotes a Planckian distribution. Column (11) gives the assumed effective temperature of the star, $T_{\rm eff}$, in units of 1000 K, while log *g* denotes the logarithm of the surface gravity, *g* (in units of cm s^{-2}). Column (12) lists notes relevant to the abundance determinations; these notes are intended to condense extensive discussion. Frequently, discordances occur for ions represented by lines of the $3p^3$ configuration, viz., S, Cl, and Ar. Some of the difficulty may be attributed to the existence of dense blobs and condensations which are not handled in the theoretical models. Additional notes are given for some of the individual nebulae. Comparisons are given with results of other workers, and distinguishing characteristics of some of the objects are noted.

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TABLE 6

ADOPTED ELEMENTAL ABUNDANCES FOR THE NEBULAE

Object	He	N	O	Ne	S	Cl	Ar	Q	T_{eff}	log g	Notes
M1-4	11.02	7.96	8.50	7.73	6.7	5.15	6.18	B	K 80	4.72	1,2,3,4
M2-2	11.0:	7.95	8.43	7.77	...	...	5.95	C−	K 80	4.72	2,3
K3-67	11.04	8.16	8.26	7.62	6.7	5.18	6.0	B	K 62.5	4.72	1,4,5
K3-68	10.99	7.56	8.12	7.60	...	...	6.30	C−	K 115	5.25	6
M2-6	10.98	7.68	8.56	7.77	6.7	...	6.25	C	K 50	3.8	6,7
M4-3	10.98	8.26	8.68	7.92	7.04	...	6.20	C	K 50	3.8	3,4
M2-10	10.99	8.43	8.73	8.08	> 6.3	...	> 6.4	D	...	...	6,8
H1-18	11.24	8.96	8.71	8.08	7.09	...	6.92	C−	K 62.5	4.7	6,7,9
NGC 6369 ...	11.12	8.08	8.46	7.61	6.78	5.42	6.62	B	K 75.0	4.7	4,9,10
H1-23	11.15	8.58	8.76	7.93	6.98	...	6.74	C	K 50.0	3.8	6,7
Hubble 4	11.10	8.45	8.68	7.96	7.29	5.70	6.5:	A	K 85	4.7	2,3,4
H2-18	11.10	8.7:	8.52	7.69	7.01	...	6.30	C	K 77.5	4.7	2,6
M3-15	11.03	8.08	8.41	7.48	6.7:	...	6.5	G	K 62.5	4.7	1,6,9
Hubble 5	11.16	9.06	8.82	8.09	6.95	5.60	7.00	B	BB 150	...	1,4,5,10
NGC 6439 ...	11.13	8.46	8.65	8.06	7.15	5.59	6.45	A	K 80	4.72	4
Cn 2-1	11.00	8.66	9.22	8.58	7.51	5.7	6.77	B	K 50	3.8	5,6,10
Hubble 6	11.04	8.65	8.71	8.00	7.30	5.41	6.70	B	K 85	4.72	4,5,10
M2-21	11.10	7.95	8.49	7.76	6.61	...	6.01	B+	K 82.5	4.72	4
M3-20	10.99	7.73	8.70	8.0	6.74	5.21	6.08	B	K 50	3.8	1,4
M2-23	11.00	7.68	8.40	7.60	6.6	...	5.75	C	K 50	3.8	1,3,10
IC 4673.......	11.16	8.45	8.72	8.15	7.26	...	6.9:	B	K 107.5	5.15	1,4,10
M1-35	11.21	8.79	8.48	7.63	6.75	...	6.63	B−	K 62.5	4.78	2,4,6
M1-42	11.23	8.91	8.67	8.13	7.28	5.85	6.66	C	K 81	4.7	6,7
H1-59	11.00	8.67	8.63	7.90	7.65	...	6.79	B−	K 115	5.25	1,11
M2-30	11.08	8.06	8.75	8.07	7.11	...	6.68	B	K 100	4.72	1,4,10
NGC 6567 ...	11.03	7.78	8.50	7.78	6.76	5.00	5.9:	A−	K 75	4.72	2,3,5
M2-33	10.97	7.60	8.62	7.90	6.46	...	6.42	B	K 50	3.8	11
M1-44	> 10.7	8.1:	8.2	...	> 6.45	...	> 5.4	D	...	...	6,8
NGC 6578 ...	11.04	8.04	8.75	8.18	6.98	5.41	6.5	B−	K 50	3.8	2,3,4
NGC 6620 ...	11.06	8.65	8.84	8.18	7.1	5.48	6.60	B	K 85	4.72	1,4
NGC 6629 ...	10.94	7.76	8.60	7.77	6.55	...	6.6	B	K 50	3.8	1
IC 4732.......	11.03	7.94	8.42	7.71	6.79	4.9	5.98	B	K 62.5	4.72	10
NGC 6781 ...	11.11	8.35	8.64	7.83	7.0	...	6.60	C	K 62.5	4.72	4
NGC 6804 ...	11.14	...	8.5	7.7	...	...	> 5.6	D	...	...	8,10,11
NGC 6807 ...	11.09	7.92	8.56	7.88	6.97	...	6.78	C	K 62.5	4.72	3,4,10
Me 1-1	11.10	8.60	8.74	8.15	7.11	...	6.81	B	K 62.5	4.72	1,3
NGC 6833 ...	11.01	8.13	8.05	7.34	6.20	...	5.7:	B−	K 62.5	4.72	1,2,3,10
M1-75	11.27	9.03	8.79	8.23	7.32	...	6.84	B	BB 160	...	1,4
NGC 6881 ...	11.06	8.58	8.74	8.03	7.05	5.73	6.65	B	K 115	5.25	4,5
NGC 6879 ...	11.02	7.89	8.61	7.95	6.6	5.12	6.28	B	K 50	3.8	1,4
NGC 6891 ...	11.00	7.68	8.65	7.90	6.36	4.96	6.11	B	K 50	3.8	3,4
NGC 6894 ...	11.00	8.2	8.6	7.97	...	...		D	...	...	8
M1-78	10.98	7.74	8.07	...	6.40	...	6.15	C−	K 50	3.8	1,4,10
K3-60	11.11	8.27	8.63	7.95	6.9	...	6.42	C−	K 115	3.8	1,10,11
K3-61	11.06	9.08	8.69	7.93	7.26	...	6.52	C	K 62.5	4.7	1,11
Me 2-2	11.16	8.84	8.32	7.63	6.50	4.70	6.0:	C	K 57.5	4.7	3,4
NGC 7354 ...	11.11	8.52	8.60	7.81	7.0	...	6.60	B	K 115	5.25	4
M1-80	10.96	8.31	8.59	7.72	6.72	...	6.12	B	K 100	5.0	1,4

NOTES.—Let $\Delta(\mathrm{el}) = \log N(\mathrm{el})_{\mathrm{ICF}} - \log N(\mathrm{el})_{\mathrm{model}}$. (1) $\Delta(\mathrm{S}) \geq 0.15$. (2) $\Delta(\mathrm{Ar}) \geq 0.15$. (3) If we fit [Ar III] λ7135, [Ar IV] λ4740 is predicted to be too strong. (4) The agreement between predicted and observed intensities and between the model and the ICF method abundance determinations generally is good, with exceptions as noted in notes 1, 2, 3, and 5 or remarks for the individual nebulae. (5) $\Delta(\mathrm{Cl}) \geq 0.15$. (6) The electron temperature, T_ϵ, is uncertain. (7) We rely essentially on the nebular model, since [O III] λ4363 is poorly determined or not even seen. (8) Abundances are estimated by extrapolation methods (see, e.g., Barker 1983), usually because the level of excitation is so low no model is available. (9) The intensities of λ3727 and neighboring lines are poorly determined because of the large interstellar extinction, the faintness of the nebula, or both. (10) The observed intensity of [O II] $\lambda\lambda$7319, 7330 is greater than predicted, probably as a consequence of dielectronic recombination (Rubin 1986). (11) The observational scatter is above average because of the faintness of the nebula.

We have also examined the consequences of adopting the hypothesis that $I \propto S^k$, with $k = 0.96$. Rigorously, one should repeat the entire reduction procedure with this additional constraint. In view of the uncertainty in the value of k, such a large enterprise is not justified. We note that the interstellar extinction was chosen so that the hydrogen lines would fit the theoretical Balmer decrement. For example, we can recalculate T_ϵ([O III]) by comparing λλ4959 and 5007 with Hβ and λ4363 with Hγ, i.e., we do not directly compare $S(5007)$ with $S(4363)$, since interstellar extinction must be taken into account. Since the oxygen abundance depends primarily on the intensities of λλ4959 and 5007, its value will be reduced for two reasons. The [O III] lines are almost always stronger than Hβ, so their corrected intensities will always be lowered. The electron temperature will be increased, because λ4363 is always weaker than Hγ and its corrected intensity will be larger. Thus, the ratio $[I(4959)+I(5007)]/I(4363)$ will be lowered, and T_ϵ will be increased. These ΔT_ϵ corrections range from about 100 K to as much as 1400 K in extreme cases. The neon abundance always tends to be reduced, primarily because of the increased T_ϵ value. On the average, we find that abundances of other elements, that depend on weak lines, will tend to be slightly increased. With $k = 0.96$, the mean changes in the sense $N(k=0.96)/N(k=1.0)$ are as follows: He, 1.08 ± 0.05; N, 1.01 ± 0.09; O, 0.85 ± 0.09; Ne, 0.83 ± 0.12; S, 1.06 ± 0.13; Cl, 1.03 ± 0.23, and Ar, 1.06 ± 0.12. In the remainder of our discussion, we have not included these effects, since the determination of the value of k is so very uncertain.

V. DISCUSSION

In this section we consider the mean abundances, and mean abundance ratios, and the spread or dispersion of "observed" abundances, being mindful of the fact that some of this dispersion arises from errors of observation. Inaccuracies in electron temperatures will have a major effect on derived chemical composition. We then examine some of the implications for an enrichment of the interstellar medium by the products of nucleosynthesis, particularly for C, N, and O.

Table 7 gives the mean abundances for the present sample of planetaries. We have excluded nebulae of quality D analyses, viz., M2-10, M1-44, NGC 6804, NGAC 6894, and all entries flagged by a colon. Successive columns give for each element the number of data values, the mean value of the abundance in the nebulae and the dispersion in the mean thereof, solar abundances, all on the scale $N(\mathrm{H}) = 10^{12}$, and the mean value of the ratio with respect to oxygen for both nebulae and the sun. The solar abundances of C, N, and O are taken from Lambert (1978). For Ne, S, Cl, and Ar the solar abundances are from Aller (1987) and references quoted therein.

One might subdivide the material further, e.g., discuss the statistics of N-rich objects, or discuss nebular chemical composition characteristics as a function of population type or distance from the Galactic center, in which instance one must address the troublesome problems of nebular distances. We defer these particular topics to a later paper. Here we concentrate on the abundance distributions of individual elements in the sample.

We deem it instructive to consider also additional planetaries for which data are to be found in the literature. In selecting published analyses, we have emphasized those which have employed model nebulae for abundance determination (or have used models to estimate contributions from nonobserved stages of ionization), or which have (as in the work of Barker) utilized a number of selected areas in extended objects and have thereby obtained reasonable estimates of missing ionization stages. We combine these data with those employed in the construction of Table 7 to obtain mean abundance estimates for a broader sample. Thus, Table 8 gives mean abundances and ratios from a sample containing the data described in this paper plus data from AC 83 updated and extended by material from other sources as detailed in the notes to the table.

Carbon abundances can be determined from the ultraviolet lines C III λλ1906,1909 and C IV λλ1548,1550, which have been measured in many nebulae with the *International Ultraviolet Explorer* (*IUE*). They have also been derived from permitted ionic carbon lines, particularly C II λ4267, although abundances estimated from this line (interpreted as a pure recombination feature) often tend to exceed those found from the ultraviolet collisionally excited transitions (see, e.g., the discussions by AC 83 and particularly those by Barker 1984, 1985 and by Kaler 1986, who examined the important role of the electron temperature in the C III zone). We give $\langle N(\mathrm{C})\rangle$ and $\langle N(\mathrm{C})/N(\mathrm{O})\rangle$ for the sample of 29 nebulae for which only the ultraviolet data are used. The larger sample (49 nebulae) includes determinations from both the ultraviolet and 4267 Å lines (see Fig. 3). Notice that the mean values are raised substantially when the 4267 Å data are included.

TABLE 7

MEAN ABUNDANCES AND ABUNDANCE RATIOS FOR 44 PLANETARY NEBULAE COMPARED WITH CORRESPONDING SOLAR VALUES

Element	n	Mean Abundance in Nebulae	Solar Abundance	Mean Ratio N(element)/N(oxygen) for Nebulae	Solar Ratio
N	44	$(3.06 \pm 0.47)\times 10^8$	0.98×10^8	0.71 ± 0.11	0.112
O	44	$(4.30 \pm 0.33)\times 10^8$	8.3×10^8	...	...
Ne	44	$(0.89 \pm 0.09)\times 10^8$	1.12×10^8	0.20 ± 0.01	0.135
S	42	$(1.20 \pm 0.14)\times 10^7$	1.7×10^7	0.028 ± 0.004	0.020
Cl........	18	$(2.86 \pm 0.45)\times 10^5$	3.1×10^5	$(0.60 \pm 0.08)\times 10^{-3}$	0.38×10^{-3}
Ar	44	$(3.22 \pm 0.33)\times 10^6$	3.7×10^6	$(0.76 \pm 0.07)\times 10^{-2}$	0.45×10^{-2}

TABLE 8

Mean Abundances and Abundance Ratios for an Extended Sample of Planetary Nebulae

Element	n	Mean Abundances	Mean Ratio N(element)/N(oxygen)	Solar Ratio
C	29[a]	$(5.52\pm0.92)\times10^8$	1.29 ± 0.19	0.56
	49[b]	$(6.95\pm0.70)\times10^8$	1.50 ± 0.14	...
N	101	$(2.43\pm0.25)\times10^8$	0.60 ± 0.08	0.118
O	104	$(4.43\pm0.19)\times10^8$	...	...
Ne	102	$(1.03\pm0.06)\times10^8$	0.24 ± 0.01	0.135
S	93	$(1.09\pm0.085)\times10^7$	0.025 ± 0.0022	0.020
Cl........	60	$(2.08\pm0.18)\times10^5$	$(0.47\pm0.04)\times10^{-3}$	0.38×10^{-3}
Ar	98	$(2.91\pm0.19)\times10^6$	$(0.69\pm0.05)\times10^{-2}$	0.45×10^{-2}

Sources (Aller and Czyzak 1983 is denoted by AC 83).—NGC 40: Clegg *et al.* 1983; M1-1: Aller, Keyes, and Feibelman 1986*a*; IC 2165: Aller 1987; NGC 2440: Shields *et al.* 1981; NGC 2392: Aller and Czyzak 1981; IC 2448, 2501, 5315: Peimbert and Torres-Peimbert 1977; NGC 2818: Dufour 1984; NGC 2867: Aller *et al.* 1981*b*; NGC 3242; AC 83, Barker 1985; NGC 3918: Clegg *et al.* 1987; IC 3568: Harrington and Feibelman 1983; Me 2-1: Aller, Keyes, and Czyzak (1981); IC 4642: Penn *et al.* (1983); NGC 6302: Aller *et al.* 1981*a*; NGC 6445: Kaler, Czyzak, and Aller, 1972; NGC 6537: Feibelman, Aller, and Keyes 1985; NGC 6720: Barker 1981, 1982, Aller 1984, p. 278; NGC 6741: Aller, Keyes, and Czyzak 1985; IC 1297: Aller, Keyes, and Feibelman 1986*b*; NGC 6818: Aller 1984, p. 279; NGC 6826: Barker 1978; NGC 6853: Barker 1984; NGC 7009: Barker 1983, Czyzak and Aller 1979, Perinotto and Benvenuti 1981; NGC 7027: Shields 1978, Perinotto, Panagia, and Benvenuti 1980, Péquignot and Stasińska 1980; NGC 7662: Harrington *et al.* 1982.

[a] UV lines only.

[b] UV lines and λ4267 data.

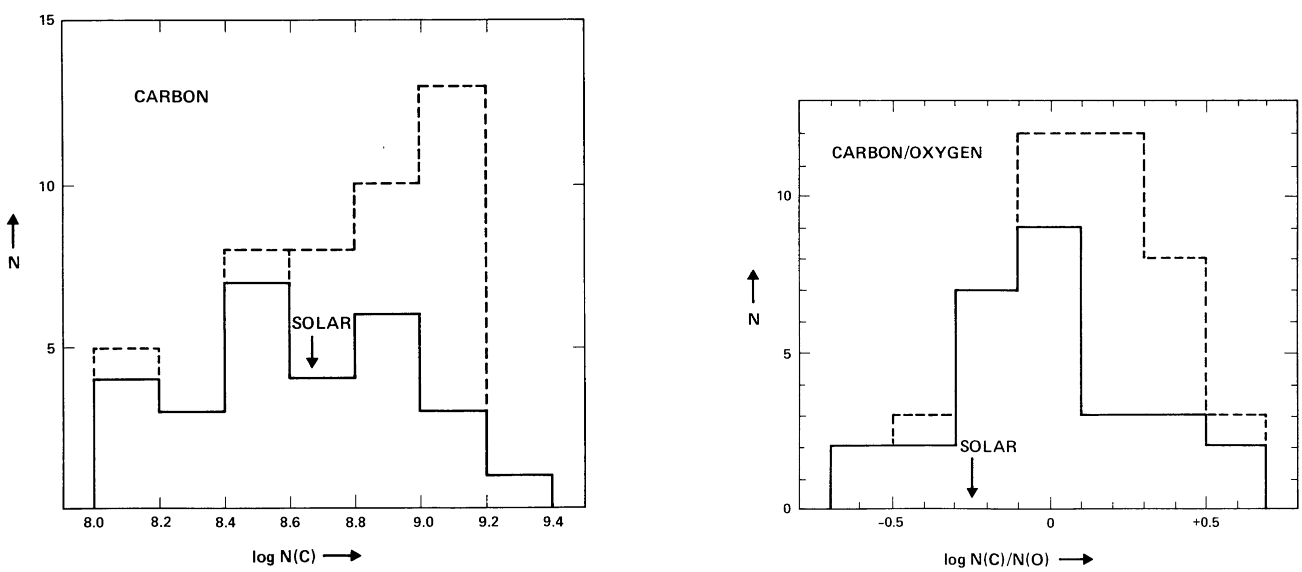

Fig. 3*a* Fig. 3*b*

Fig. 3.—Distribution of carbon abundances and the C/O ratio. The solid lines depict the distribution of carbon abundances and C/O ratios as determined from the ultraviolet carbon lines observed with the *IUE*. The dashed lines include carbon abundances found from the C II λ4267 lines plus those found from the C III and C IV ultraviolet lines. The arrow indicates the solar carbon abundance and C/O ratio. The average nebular C/O ratio exceeds the solar value.

Furthermore, in comparing Tables 7 and 8, we note that there exist a number of differences in the mean abundances and ratios, often exceeding the disparities one would expect from the dispersions. Part of this effect may arise from the fact that the literature "grab bag" contains perhaps a greater variety of nebulae including intrinsically bright and massive planetaries and objects of unusual composition such as NGC 6537 than did our present program.

We must emphasize that, in any case, taking "mean values" of PN chemical compositions is somewhat analogous to taking mean values of meteorite compositions. We are averaging over objects with different nucleogenesis histories, different progenitor masses, and different original chemical compositions. We are guided by the belief that only C, N, and possibly O are modified by element building in the energy-generating cores. The heavier elements, Ne, S, Cl, and Ar, are presumed to be untouched by the alchemy within progenitor stars. Kaler (1978) discussed the mean abundances of Ne, Ar, and Cl.

The solar carbon abundance, 4.7×10^8, is definitely smaller than the mean nebular carbon abundance, 5.5×10^8, deduced from the ultraviolet lines. There is a very large range in intrinsic carbon abundances from low values such as 0.38×10^8 for NGC 6537 (Feibelman *et al.* 1985) to high values such as 2.5×10^9 for NGC 7027 (Shields 1978). These two objects represent rather extreme cases, in one of which C and O appear to have been burned into N, and the other where results of the He burning into carbon have been ejected with relatively little further processing. The mean nebular C/O ratio is higher than the solar value (see Figs. 3*a* and 3*b*).

Turning to N, we again note a large spread in nebular abundances (see the block diagram in Figs. 4*a* and 4*b*). Some objects, such as M2-33 and IC 4634, appear to have little N; N/O ~ 0.095–0.125. Others such as NGC 2440 and NGC 6537 are N-rich, the N/O ratios being 6.4 and 5.4, respectively. The mean N/O ratios for both the new sample and the extended sample are considerably in excess of the solar value.

Our data reflect the well-known result that the nebular mean oxygen abundance is appreciably lower than the solar value. (See Fig. 5.) We can remove this discrepancy by invoking T_ε fluctuations (Peimbert 1967; Rubin 1969; Dinerstein, Lester, and Werner 1985; Zuckerman and Aller 1986). For all except a very few objects on our list we do not have sufficient information to deduce $\langle\Delta T_\varepsilon\rangle$, since the requisite infrared data are not available. If an agreement between solar and mean nebular O abundances is found by choosing an appropriate ΔT_ε fluctuation, then Ne, S, Cl, and Ar will all be somewhat "overabundant" in the PNs. Perhaps this is the true explanation. Comparing the mean abundances for S, Cl, and Ar with the solar values, especially for the larger sample, we see that such a correction would work in the right direction.

For neon the mean nebular abundance (Table 8) agrees to about 10% with the solar value. The $\langle N(\mathrm{Ne})\rangle$ determination should be more reliable than for S, Cl, and Ar, since the coverage of ionization stages is better for Ne and the reliability of atomic parameters is greater. The spread in observed values (Fig. 6) is smaller than for other elements.

For S, Cl, and Ar, the spread is larger (see Figs. 7, 8, 9). Some of the dispersion must certainly be attributed to observational error, arising from the fact that we do not observe the predominant ionization stage of S, viz., S^{+3}. Furthermore, our measurement of $N(S^{++})$, being based on the weak auroral line [S III] λ6312, is subject to a large uncertainty if T_ε is not accurately known. The Cl and Ar abundances, being based on [Cl III], [Ar III], and [Ar IV] lines, involve predominating stages of ionization, but here uncertainties in atomic parame-

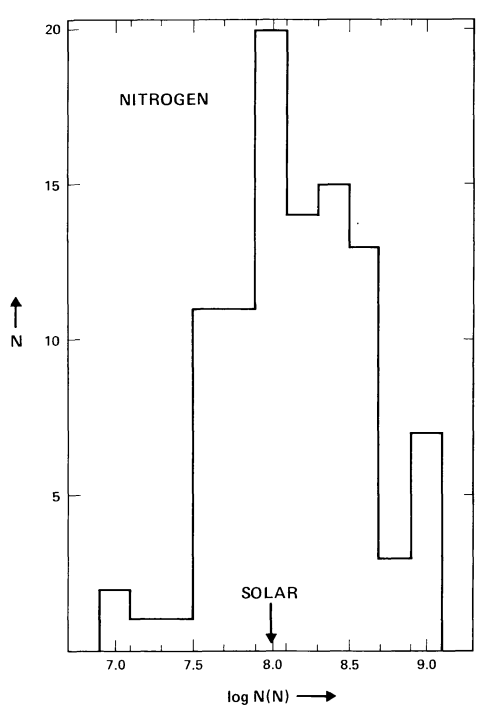

FIG. 4*a*

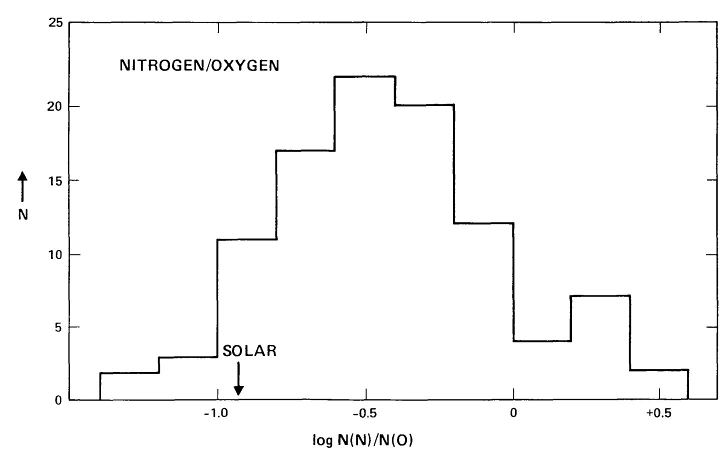

FIG. 4*b*

FIG. 4.—Distribution of nitrogen abundances and the N/O ratio. The total sample appears to be enriched in N, and the average N/O ratio greatly exceeds the solar value. For both N and C the large element/oxygen ratios are at least partly to be attributed to a reduced O abundance.

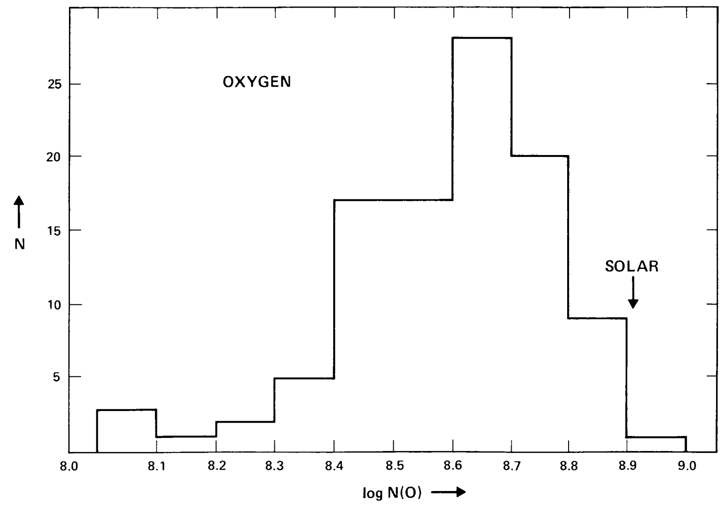

FIG. 5.—Distribution of O abundances. The vast majority of PNs appear to be depleted in O, as previously noted by many observers. Some of the spread in this and other distributions is certainly to be attributed to observational errors, most notably errors in T_ε. To bring the average O abundances up to the solar value, one could introduce temperature fluctuations, ΔT_ε. Then the abundances of all other elements except He would be enhanced.

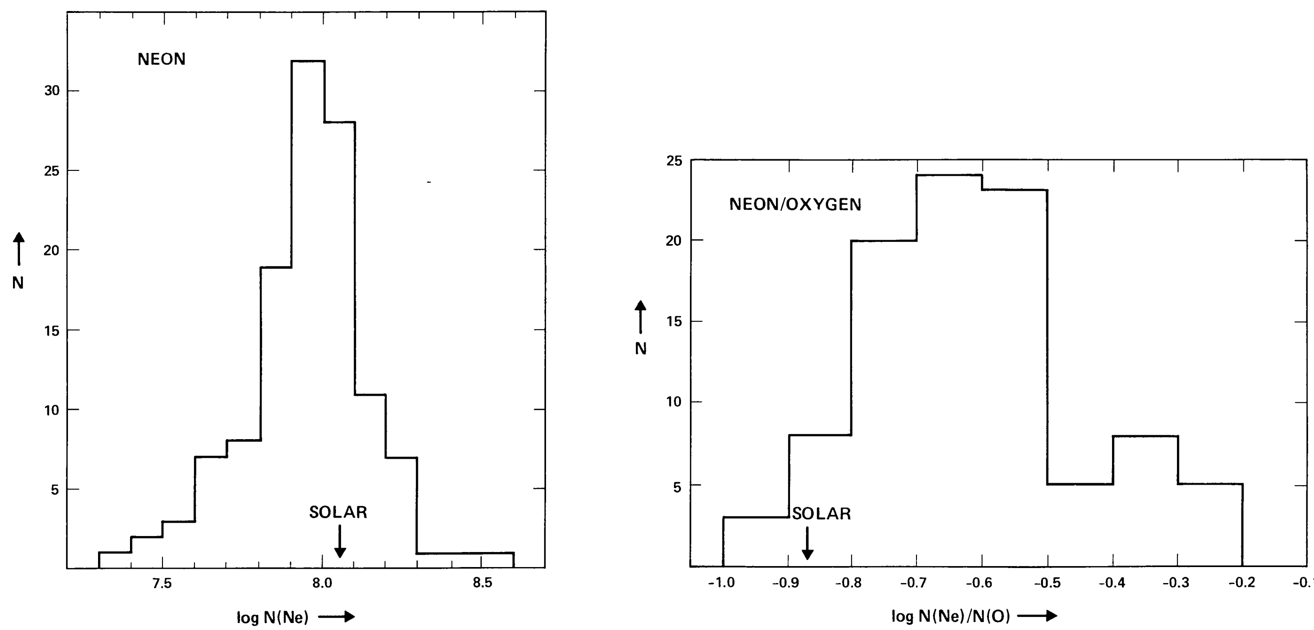

FIG. 6*a* FIG. 6*b*

FIG. 6.—Abundance distribution of neon and the Ne/O ratio. The average neon abundance does not appear to be far from the solar value. Note that the spread in neon abundance values is smaller than for other elements, reflecting partly an intrinsically smaller spread and the fact that the ionization correction factors are better determined than for S, Cl, and Ar.

ters appear to play a role. Effects of N_ε fluctuations, especially knots and condensations, are particularly serious in $3p^3$ configurations. Compare the final two columns of Table 8. Note that the mean nebular S/O and Cl/O ratios only slightly exceed the solar value, while the Ar/O ratio is a little higher.

The mean nebular abundances of Ne, S, Cl, and Ar may well agree with solar values if we allow for uncertainties arising from atomic parameters, plus some effects of T_ε fluctuations, but it is clear that if we adjusted ΔT_ε to force solar and nebular O abundances to agree, neon would be overabundant in the planetaries. Clearly, an intensive effort must be made to establish the scale of the ΔT_ε fluctuations.

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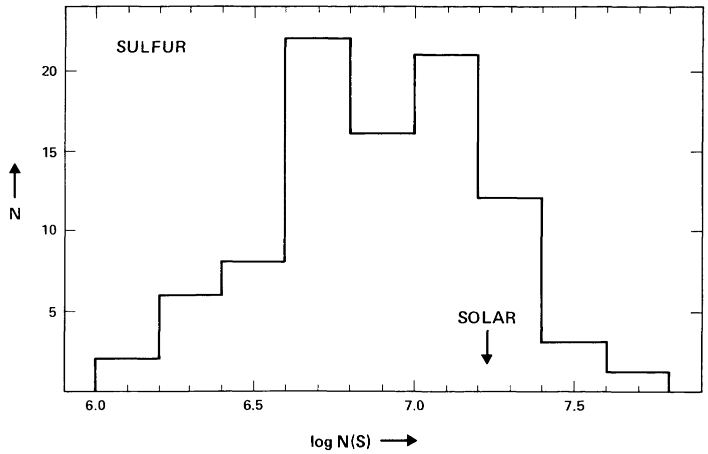

FIG. 7a

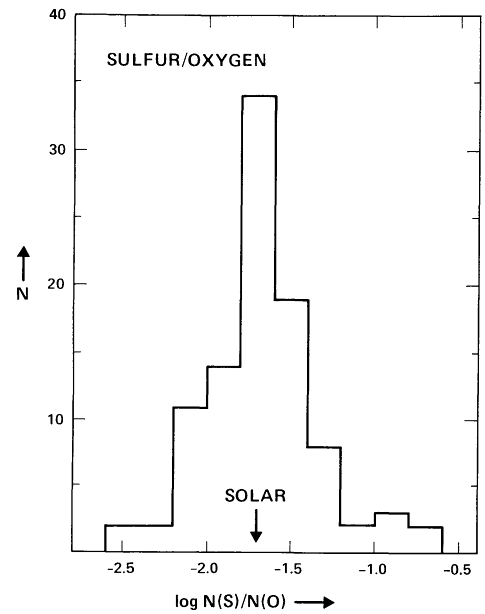

FIG. 7b

FIG. 7.—Abundance distribution of sulfur and the S/O ratio. This element shows a very wide dispersion, at least partly attributable to the fact that individual abundance determinations are subject to a larger error than for, e.g., Ne because the ionization correction factors are so uncertain. In most PNs, the bulk of the S must exist as S^{++} and S^{+3}. The S^{++} abundance is based on the auroral transition [S III] λ6312 and is very sensitive to errors in T_ϵ. Again for S, Cl, and Ar we could bring the average abundances into accord with solar values by invoking a T_ϵ fluctuation, ΔT_ϵ.

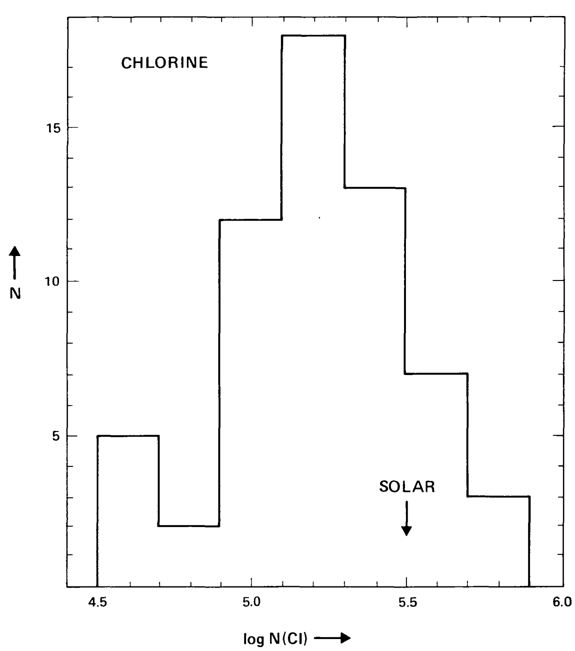

FIG. 8a

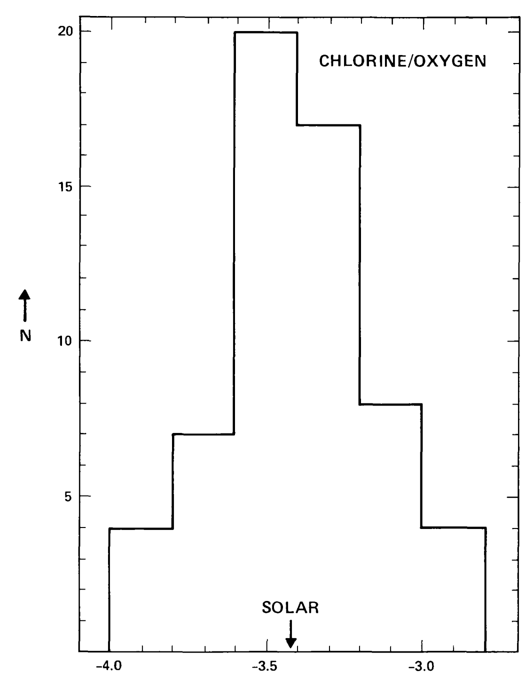

FIG. 8b

FIG. 8.—Abundance distribution of chlorine and the Cl/O ratio. Although lines of [Cl II], [Cl III], and [Cl IV] are all observed in some PNs, in most instances the determination is based on the [Cl III] lines. For these lines a revision of the atomic parameters would appear to be desirable.

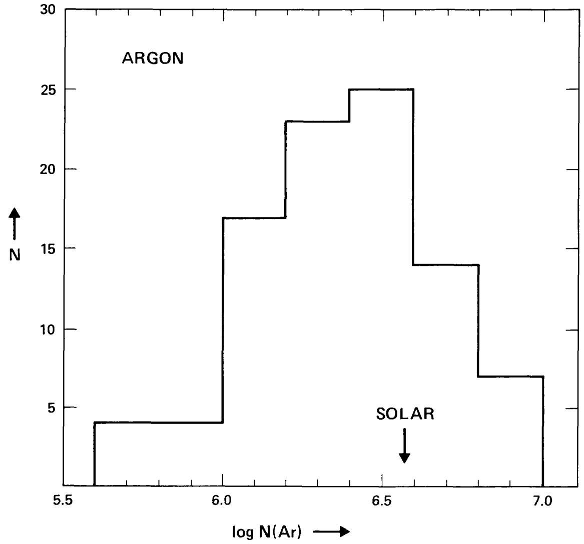

FIG. 9*a*

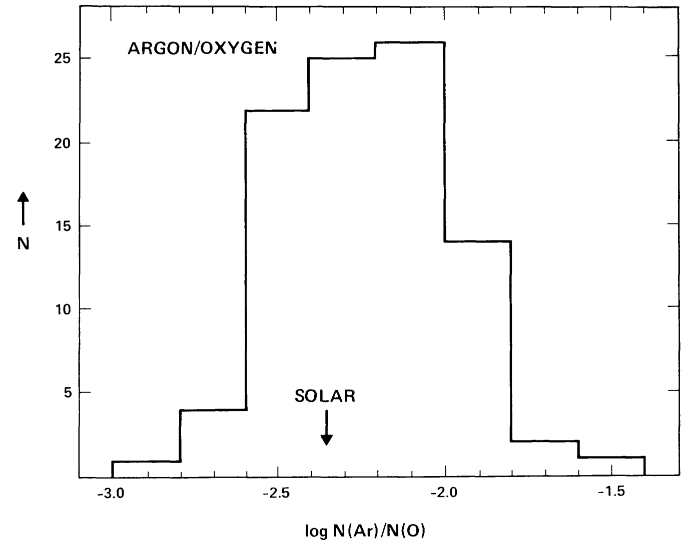

FIG. 9*b*

FIG. 9.—Abundance distribution of argon and the Ar/O ratio. As with Cl and Ar, much of the spread may be due to uncertainties in the abundance determination, since [Ar III] and [Ar IV] often do not yield concordant results, possibly as a consequence of inadequate atomic parameters.

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