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PLANETARY NEBULAE. III. CHEMICAL ABUNDANCES

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ABSTRACT

Chemical abundances of thirteen planetary nebulae have been obtained from new photoelectric observations. The helium/hydrogen abundance ratio of planetary nebulae is very similar to that of H II regions. The average value derived from ten objects is $N(\mathrm{He})/N(\mathrm{H}) = 0.110 \pm 0.015$; in this determination the effect of temperature fluctuations was taken into account. When the effect of collisional excitation in the intensities of λλ4472 and 5876 is considered, the value $N(\mathrm{He})/N(\mathrm{H}) = 0.095 \pm 0.015$ is obtained. By comparing the intensity values of λλ4472 and 5876 it is suggested that the theoretical estimate of the collisional effect might be too large by a factor of 3.

It is found that the nitrogen/oxygen abundance ratio is a factor of 3–5 times higher in planetary nebulae than in H II regions. This result is interpreted as due to the CNO bi-cycle in the nucleus of the parent star and subsequent convective mixing to the outer shells that later constitute the nebular envelope.

I. INTRODUCTION

An excellent review on chemical abundance determinations of gaseous nebulae is given by Osterbrock (1970). There have been many abundance determinations. In particular, Kaler (1970) derived the abundance of many objects by compiling all the observations available to him; the accuracy of the observations on which his results are based vary widely from object to object. It was thus felt that a study which used the same observational techniques and reduction procedures was needed to make a comparative analysis of the chemical abundances of H II regions and planetary nebulae. The abundances determined here are compared with those determined by Peimbert and Costero (1969) for H II regions.

In this paper we report the chemical abundances derived from the line intensities presented in Paper I (Peimbert and Torres-Peimbert 1971) and the electron densities and temperatures presented in Paper II (Peimbert 1971). These chemical abundances will be compared with those predicted from stellar evolutionary models in the mass range 1–1.45 $\mathfrak{M}_{\odot}$ in Paper IV (Torres-Peimbert and Peimbert 1971).

In § II we obtain ionic abundance ratios of helium, nitrogen, oxygen, neon, and sulfur relative to hydrogen. The effect of temperature fluctuations was included in all determinations, and the possibility of collisional excitation for the lines λλ4472 and 5876 of He I was also taken into account. In § III we obtain the total abundance ratios of helium, nitrogen, oxygen, and neon relative to hydrogen. For the case of IC 418 we have considered the presence of neutral helium inside the ionized-hydrogen region. In § IV we compare the chemical abundances with those of H II regions, the Sun, and OB stars. The conclusions are presented in § V.

II. IONIC CHEMICAL ABUNDANCES

a) Nitrogen, Oxygen, Neon and Sulfur

To compute the ionic chemical abundances we will take into account the spatial temperature fluctuations of all the objects. The average temperature T_0 was found by adopting a fractional mean square variation of the temperature, t^2, of 0.055 which is an average value obtained from six different objects (see Paper II), and by using $T_{(4363/5007)}$ for all the objects with the exception of BD+30°3639 for which $T_{(5755/6584)}$ is used. The temperature T_0 is thus obtained from

$$T_{(4363/5007)} = T_0\left[1 + \frac{1}{2}\left(\frac{90800}{T_0} - 3\right) t^2\right], \tag{1}$$

and a similar equation is used for $T_{(5755/6584)}$ in the case of BD+30°3639.

In general, the ionic abundance ratios are obtained from relations of the type

$$\frac{N(X^{+p})}{N(\mathrm{H}^+)} = K(X^{+p}, x) \frac{T^{1/2}(\lambda_{nm})}{T^{0.84}(\mathrm{H}\beta)} \frac{I(\lambda_{nm})}{I(\mathrm{H}\beta)} \exp\left[\frac{\Delta E}{kT(\lambda_{nm})}\right]; \tag{2}$$

the coefficients that enter into equation (2) are presented in Table 1. The Hβ emission coefficient was obtained from Brocklehurst (1971) for case B, $N_e = 10000\ \mathrm{cm}^{-3}$, and it was interpolated for the temperature range 5000°–10000° K. For this particular application the result is very similar to that obtained from Pengelly (1964). The collision strengths for O^+, O^{++}, N^+, and Ne^{++} were obtained from Czyzak *et al.* (1968); the atomic transition probabilities for O^{++}, N^+, and Ne^{++} from Garstang (1968); and those for O^+ from Seaton and Osterbrock (1957) (for O^+ the results of Seaton and Osterbrock are more accurate than the results quoted by Garstang). The expressions for forbidden line emission of S^+ and S^{++} were obtained from Aller and Czyzak (1968); the newer results by Krueger and Czyzak (1970) and Czyzak *et al.* (1970) on the collision strengths would affect the $N(S^{++})$ results by about 1 percent and the $N(S^+)$ results by less than 20 percent. The density that enters into the collisional de-excitation factor of K in equation (2) was determined from the λλ3727/7325 line intensity ratio and, for those cases where this ratio had not been measured, from the λλ3726/3729 line intensity ratio (see Paper II). $T(\lambda_{nm})$ and $T(\mathrm{H}\beta)$ have been given in Paper II as

$$T^{-1/2}(\lambda_{nm}) \exp\left[-\Delta E/kT(\lambda_{nm})\right]$$

$$= T_0^{-1/2} \exp(-\Delta E/kT_0)\left\{1 + \left[\left(\frac{\Delta E}{kT_0}\right)^2 - \frac{3\Delta E}{kT_0} + \frac{3}{4}\right]\frac{t^2}{2}\right\}, \tag{3}$$

and

$$T(\mathrm{H}\beta) = T_0(1 - 1.84t^2/2). \tag{4}$$

From equations (1)–(4), the line intensities of Paper I, and the temperatures and densities of Paper II, the ionic abundances presented in Table 2 were obtained.

b) Helium

The abundance of helium with respect to hydrogen can be derived from the intensity ratio of two permitted emission lines. In the presence of spatial temperature variations

TABLE 1

ABUNDANCE PARAMETERS

X^{+p}	$10^5 K$*	λ_{nm}	$10^{-4}\ \Delta E/k$
O^+..........	$1.72\left\{\frac{1+7.7x[1+0.39\epsilon+0.66\epsilon'+0.94x(1+0.71\epsilon+2.50\epsilon')]}{1+0.24\epsilon+5.7x(1+0.65\epsilon)}\right\}$	3727	3.86
O^{++}..........	4.14 (1+0.01x)	5007	2.89
N^+..........	4.16 (1+0.14x)	6584	2.20
Ne^{++}........	5.86 (1+0.001x)	3869	3.72
S^+..........	2.22	4069+4076	3.57
S^{++}..........	2.82 (1+0.01x)	9069+9532	1.58

* Where $\epsilon = \exp(-19600/T)$ and $\epsilon' = \exp(-38600/T)$.

TABLE 2

IONIC CHEMICAL ABUNDANCES

Object	$10^5\,N(O^+)/N(H^+)$	$10^4\,N(O^{++})/N(H^+)$	$10^5\,N(N^+)/N(H^+)$	$10^4\,N(Ne^{++})/N(H^+)$	$10^6\,N(S^+)/N(H^+)$	$10^6\,N(S^{++})/N(H^+)$
NGC 6572	6.29	5.87	2.01	1.44	1.32	3.35:
IC 418	34.1	0.96	6.27	0.048	...	5.70:
NGC 6803	8.51	9.12	4.12	...	...	...
NGC 7009	1.90	7.15	0.513	2.15	0.701:	...
NGC 7027	1.99	1.99	1.23	...	0.404	...
BD+30°3639	54.9	0.051:	21.3	...	27.3:	...
NGC 6884	6.87	9.93	1.68	...	1.35:	...
NGC 7662	0.29	2.20	0.049	...	0.091:	...
IC 5217	2.62:	4.02	0.55	...	1.46:	...
NGC 1535	0.66:	3.40	<0.055	...	...	...
NGC 6720	...	8.46	1.89:	...	...	...
IC 4593	...	6.02	...	...	...	...
IC 3568	...	3.70	...	...	...	...

and if the emission lines depend on a power of the temperature, (which is a valid approximation for lines produced by recombination), the relative abundance is given by (Peimbert and Costero 1969)

$$\frac{N(X^{+p})}{N(H^+)} = KT_0^{\alpha-\beta}\{1 + \tfrac{1}{2}[\alpha(\alpha - 1) - \beta(\beta - 1)]t^2\}\,\frac{I(\lambda_{nm})_{\rm rad}}{I(H\beta)}\,, \tag{5}$$

where the effects of self-absorption and collisional excitation have been neglected. In equation (5), K is a constant, α is the power dependence of the temperature corresponding to $I(H\beta)$, and again we will adopt $t^2 = 0.055$. Since the recombination coefficients for He^{++} have been computed for 10000° and 20000° K only, we will interpolate the line emission between these two temperatures for helium and for hydrogen to derive the temperature dependence.

The $N(He^+)/N(H^+)$ abundance can be derived from the $I(5876)/I(H\beta)$ line intensity ratios and equation (5); where $\alpha = -0.91$, $\beta = -1.12$ and $K = 0.105$, these results were obtained for case B and $N_e = 10^4$ cm^{-3} from Brocklehurst (1971) and Robbins (1968). Similarly for $I(4472)/I(H\beta)$ we obtain $\alpha = -0.91$, $\beta = -1.04$, and $K = 0.615$. The results are presented in Table 3. In Table 3 we have considered the Pickering contribution to the Balmer lines by means of $I(4686)$ and the work of Brocklehurst. This contribution ranged from zero to 2 percent.

Cox and Daltabuit (1971) have computed the contribution of collisional excitation from 2 ^3S to the intensities of λλ5876 and 4472. The calculated line intensity for purely radiative recombination is related to the line intensity including collisional excitation by

$$I(\lambda_{nm})_{\rm rad} = I(\lambda_{nm})/(1 + \gamma_{\rm CE})\,, \tag{6}$$

where

$$\gamma_{\rm CE}(T) = \gamma_{\rm CE}^{\infty}(T)/[1 + N_C(T)/N_e]\,. \tag{7}$$

Cox and Daltabuit have tabulated the collisional-excitation parameter $\gamma_{\rm CE}^{\infty}(T)$ as well as the critical density, $N_C(T)$; the critical density varies between 4100 and 2700 cm^{-3} for the temperature range of interest. We have computed the $N(He^+)/N(H^+)$ ratio considering the collisional effects by means of equations (5), (6), and (7); the results are also presented in Table 3. The temperature used in equation (7) was $T_{(4363/5007)}$ since the collisional effect increases with temperature and $T_{(4363/5007)}$ represents the high-

TABLE 3

HELIUM CHEMICAL ABUNDANCES

Object	$N(He^+)/N(H^+)$ (4472)	$N(He^+)/N(H^+)$ (5876)	$N(He^{++})/N(H^+)$	$N(He)/N(H)$
NGC 6572	0.109* (0.099)	0.109* (0.083)	0.0004	0.109* (0.091)
IC 418†	0.063 (0.059)	0.074 (0.059)	...	0.102 (0.089)
NGC 6803	0.121 (0.114)	0.126 (0.105)	0.0036	0.127 (0.113)
NGC 7009	0.095 (0.088)	0.105 (0.086)	0.0129	0.113 (0.100)
NGC 7027	0.074 (0.054)	0.087 (0.049)	0.0441	0.125 (0.096)
NGC 6884	0.111 (0.104)	0.102 (0.083)	0.0154	0.122 (0.109)
NGC 7662	0.054 (0.045)	0.055 (0.036)	0.0445	0.099 (0.085)
IC 5217	0.077 (0.068)	0.113 (0.080)	0.0062	0.091 (0.080)
NGC 1535	0.098 (0.088)	0.076 (0.056)	0.0122	0.099 (0.084)
NGC 6720	0.074 (0.067)	0.066 (0.050)	0.0424	0.112 (0.101)
Average	0.088 (0.079)	0.091 (0.069)	...	0.110 (0.095)

NOTE.—Numbers in parentheses denote values derived by considering collisional excitation as predicted by Cox and Daltabuit (1971).

* Without considering collisional excitation of λλ4472 and 5876.

† Large quantities of neutral helium present in the H^+ region.

temperature regions. The densities used are those given by the λλ3726, 3729 line intensity ratio (see Paper II), except IC 418, NGC 6884, and IC 5217 where the values 10000, 6000, and 7500 cm^{-3} were adopted.

Since the collisional effect is more important for λ5876 than for λ4472, then by considering only radiative effects the helium abundances derived from λ5876 are expected to be higher than those derived from λ4472. From Table 3 it can be seen that indeed λ5876 yields on the average a higher value for the helium abundance than λ4472. However, the observed strengthening of λ5876 with respect to λ4472 shows that the collisional effect is not as great as predicted by Cox and Daltabuit (1971), which indicates that the excitation cross-sections are smaller than they assumed. To obtain the same average helium abundance from λλ4472 and 5876 we will assume that the collisional effect is one-third of that predicted by Cox and Daltabuit. Under this assumption we derive that the average value for the ten objects is $N(He^+)/N(H^+) = 0.085$.

From equation (5), $I(4686)$, and $I(H\beta)$ we have derived the $N(He^{++})/N(H^+)$ abundance ratio; these results are also given in Table 3. For this case $\alpha = -0.91$, $\beta = -0.99$, and $K = 0.0490$ (Brocklehurst 1971; Harman and Seaton 1966).

III. TOTAL CHEMICAL ABUNDANCES

Since we do not observe all the stages of ionization of the different elements, it is necessary to estimate the fraction of atoms in the ionization stages that have not been observed.

For oxygen we have

$$\frac{N(O)}{N(H)} = \frac{N(He^+ + He^{++})}{N(He^+)} \frac{N(O^+ + O^{++})}{N(H^+)} . \tag{8}$$

This relation is an excellent approximation because even if [O I] lines are present in some of these objects the same fraction of oxygen and hydrogen is expected in the neutral stage since the ionization potentials of O^0 and H^0 are practically the same. Furthermore, the $N(He^+ + He^{++})/N(He^+)$ factor considers the fraction of oxygen atoms in higher ionization stages than the second since the ionization potentials of O^{++} and He^+ are very similar. For normal H II regions and for planetary nebulae of low ionization, like IC 418 and BD+30°3639, $N(O)/N(H) = N(O^+ + O^{++})/N(H^+)$.

The total nitrogen/hydrogen abundance ratio can be obtained from

$$\frac{N(N)}{N(H)} = \frac{N(O)}{N(O^+)} \frac{N(N^+)}{N(H^+)} . \quad (9)$$

Again this equation is a valid approximation because the first and second ionization potentials of oxygen are very similar to the first and second ionization potentials of nitrogen and it is expected that the N^+ lines originate in the same regions as the O^+ lines. From the model by Flower (1969*b*) for IC 418 it can be seen that equations (8) and (9) yield accurate abundances.

The neon/hydrogen abundance ratio was obtained from

$$\frac{N(Ne)}{N(H)} = \frac{N(O)}{N(O^{++})} \frac{N(Ne^{++})}{N(H^+)} . \quad (10)$$

This relation is also based on the similarity of the ionization potentials of oxygen and neon. Equation (10) yielded very similar neon/hydrogen abundance ratios in three regions of the Orion Nebula with different degrees of ionization (Peimbert and Costero 1969). The total chemical abundances derived from equations (8), (9), and (10) are presented in Table 4.

The presence of neutral helium inside H II regions was established by Peimbert and Costero (1969), who found a variation of the $I(5876)/I(H\beta)$ ratio dependent on position in the Orion Nebula. In particular, in the case of NGC 1982 which is ionized by HD 37061, a B1 V star, they found that the $N(He^0)/N(He^+)$ ratio is higher than 10. Thus the total helium/hydrogen abundance ratio in an H^+ region is given by

$$\frac{N(He)}{N(H)} = \frac{N(He^0 + He^+ + He^{++})}{N(H^+)} . \quad (11)$$

If one examines the $N(O^{++})/N(O^+)$ ratio, which is a measure of the ionization, it is clear that only two objects may have substantial amounts of neutral helium inside the H^+ region: IC 418 and BD+30°3639.

The degree of ionization of IC 418 is very similar to that of Ori III (Peimbert and Costero 1969); consequently, we will assume that the ionization correction factor, i_{cf}, is 1.5; i.e., $N(He)/N(H) = 1.5\, N(He^+)/N(H^+)$. This correction is very similar to that obtained from the model by Flower (1969*b*) and yields a value of the helium/hydrogen ratio for IC 418 very close to the average value for all planetary nebulae.

TABLE 4

TOTAL CHEMICAL ABUNDANCES*

Object	N	O	Ne
NGC 6572	8.32	8.81	8.20
IC 418	7.91	8.64	7.34
NGC 6803	8.72	9.01	...
NGC 7009	8.34	8.91	8.38
NGC 7027	8.31	8.52	...
BD+30°3639	8.33	8.74	...
NGC 6884	8.47	9.08	...
NGC 7662	7.83	8.61	...
IC 5217	7.98	8.66	...
NGC 1535	<7.54:	8.62	...

* Given in log $N(X)$, with H = 12.00.

In the case of BD+30°3639, $I(4472)$ and $I(5876)$ are a blend of the stellar and nebular components; from these intensities we find a helium abundance at least a factor of 2 smaller than the average value for planetary nebulae, a value that suggests an i_{cf} greater than 2. Furthermore, a tracing of this object by Aller (1968) shows that λ4686 is broad and originates in the star, and that most of the emission at λλ4472 and 5876 is due to stellar features and only a small fraction is due to the nebula. Moreover, by comparing the $N(O^{++})/N(O^{+})$ ratios of NGC 1982 and BD+30°3639 it is clear that the low-density envelope of BD+30°3639, where the forbidden and sharp emission lines originate, has a lower ionization than that produced by a B1 V star. This condition implies that $N(He^0)/N(He^+)$ should be considerably higher than 10 in the envelope of this object.

In Table 3 we present the total helium abundance where He^0 has been neglected, except for IC 418.

IV. COMPARISON WITH OTHER DETERMINATIONS

a) *Nitrogen/Oxygen Ratio*

The planetary nebulae studied here, with the exception of NGC 1535, have higher $N(N)/N(O)$ values than those H II regions studied by Peimbert and Costero (1969). In order to investigate whether this excess is real or is produced by differences in ionization, Figure 1 was prepared; this graph is a plot of the nitrogen abundance, $[N/O] = \log N(N)/N(O) - \log [N(N)/N(O)]_{\odot}$, versus the ionization degree, $N(O^{++})/N(O^{+} + O^{++})$, where the solar value by Lambert (1968) was adopted. The accuracy of the nitrogen/oxygen abundance determination is from 0.1 to 0.2 in the logarithm for the low-ionization objects, as can be derived from the four regions of Orion which yield similar ratios even though they have widely different degrees of ionization. The accuracy of the determina-

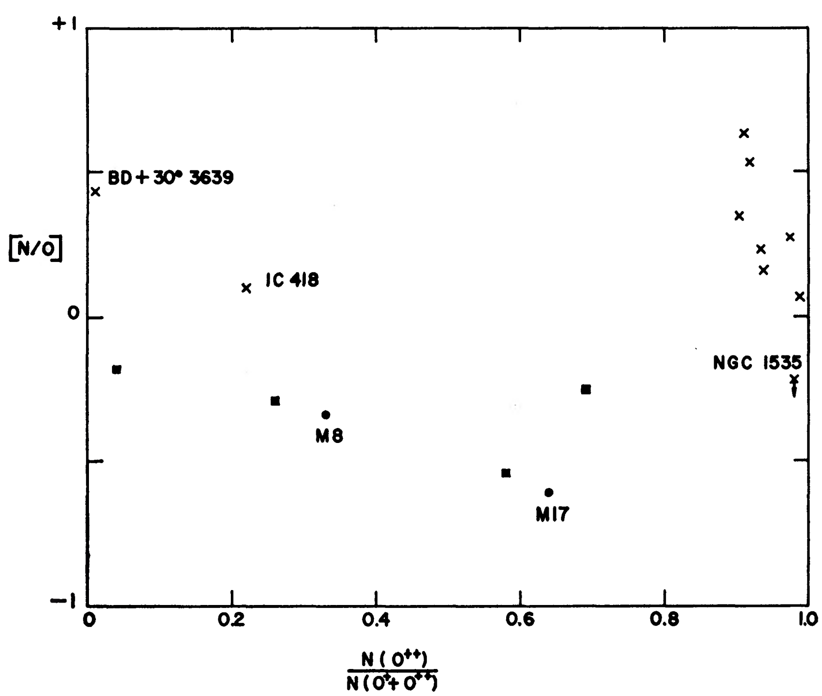

FIG. 1.—Nitrogen/oxygen abundance ratios of different objects; where $[N/O] = \log N(N)/N(O) - \log [N(N)/N(O)]_{\odot}$. *Crosses*, planetary nebulae studied here. Other symbols represent H II regions; in particular, squares correspond to four different regions of the Orion Nebula (Peimbert and Costero 1969).

tion is higher for objects with a low degree of ionization since the ionization correction factor approaches unity. In the limit of very high ionization or for density-bounded planetary nebulae the validity of equation (9) breaks down. This equation yields a lower limit for the $N(\mathrm{N})/N(\mathrm{O})$ ratio since the ionization potential of O^+ is slightly larger than that of N^+. This situation might apply to NGC 1535, which has a high degree of ionization and is probably density bounded since it is the only object in which we failed to detect the nebular [S II] and [N II] lines.

A likely explanation for the anomalous nitrogen/oxygen abundance ratio found in planetary nebulae is that in the interior of the star, prior to the planetary-nebula phase, part of the products of the CNO bi-cycle mix to the outer regions that later constitute the planetary envelope. To reach equilibrium conditions the CNO bi-cycle transforms carbon and oxygen into nitrogen (Caughlan and Fowler 1962); in particular, during the phase of thick-shell hydrogen burning, $^{12}\mathrm{C}$ is converted into $^{14}\mathrm{N}$ over extended regions and during the red-giant phase the convective envelope becomes deep enough to include $^{14}\mathrm{N}$-rich material. A moderate increase of the surface nitrogen/oxygen abundance ratio can then take place, and factors between 1.5 and 4 have been predicted by Iben (1964, 1967) from stellar models of 1, 1.25, and 1.50 $\mathfrak{M}_\odot$ and by Torres-Peimbert and Peimbert (1971) from models of 1, 1.25, and 1.45 $\mathfrak{M}_\odot$; these models are in the mass range attributed to the combination of shell and star of planetary nebulae (O'Dell 1963).

We further suggest that the nitrogen/oxygen ratio observed in planetary nebulae is associated with the gradient in the $N(\mathrm{N})/N(\mathrm{O})$ abundance observed in the gaseous component of galaxies (Peimbert 1968; Peimbert and Spinrad 1970; Searle 1971).

Theoretical studies of the mechanism that produces the nebular envelope should predict the chemical composition of the nebular shell and of the central star. Many nuclei of planetary nebulae show emission lines. Some of these objects can be classified as Wolf-Rayet stars of the WC and WN types; others, although not classical Wolf-Rayet objects, also have carbon or nitgrogen emission lines (Aller 1968; Smith and Aller 1969). In particular, in BD+30°3639 the nebular shell is nitrogen rich while the central star is a WC 9 object; this would imply either that the destruction of nitrogen is associated with the mechanism producing the nebular envelope or that chemical abundances do not appreciably affect the spectra of the central stars of planetary nebulae.

b) Neon/Oxygen Ratio

The logarithmic neon/oxygen ratios in NGC 6572, NGC 7009, and IC 418 are −0.61, −0.53, and −1.30, respectively. Part of the difference between IC 418 and the other two objects might reflect the validity of equation (10). According to the models by Flower (1969*a*, *b*) the ionization correction factor of equation (10) is very accurate for planetary nebulae of relatively high ionization, like NGC 6572 and NGC 7009, but it underestimates the neon/oxygen ratio for the low-ionization planetary nebulae like IC 418. For this object this effect is predicted to be smaller than 0.3 in the logarithm; therefore, it seems that IC 418 has a low neon/oxygen abundance value.

There is additional evidence in favor of a low $N(\mathrm{Ne})/N(\mathrm{O})$ abundance ratio in IC 418 since the fine-structure line of Ne II at 12.8 μ has not been detected in this object (Holtz, Geballe, and Rank 1971).

In addition to our results, Harrington (1969) found a logarithmic neon/oxygen ratio of −0.91 for NGC 7662, and Aller found an average value of −1.00 for planetary nebulae; these values are very similar to that found in the Orion Nebula. However, the neon/oxygen abundance ratio found in OB stars is 5–10 times larger than that found in gaseous nebulae (cf. Table 5), which is difficult to explain since both ratios are expected to be similar. The low neon abundances are derived from forbidden lines of [Ne III], [Ne V], and the fine-structure line of Ne II whereas the high abundances are obtained from permitted lines of Ne^0 and Ne^+. It is clear that the neon abundance determinations for gaseous nebulae and stars should be critically reexamined.

TABLE 5

COMPARISON OF CHEMICAL ABUNDANCES*

Object	He	N	O	Ne	Source
Planetary nebulae....	11.02	8.24	8.76	...	This paper
Planetary nebulae....	11.23	8.1:	8.9	7.9	Aller and Czyzak 1968
Orion Nebula........	11.00	7.63	8.79	7.9	Peimbert and Costero 1969
Sun................	...	7.93	8.77	...	Lambert 1968
Sun................	...	7.89	8.96	...	Goldberg *et al.* 1960
OB stars............	11.00	...	...	...	Shipman and Strom 1969
OB stars............	11.2	7.9	8.8	8.7	Aller 1961

* Given in log $N(X)$, with H = 12.00.

c) *Helium/Hydrogen Ratio*

From the line intensities by Peimbert and Costero (1969) for the Orion Nebula and the effective recombination coefficients by Robbins (1970) and Brocklehurst (1971) interpolated in the 5000°–10000° K temperature range, $N(\text{He})/N(\text{H}) = 0.102 \pm 0.015$ is obtained; in this computation the collisional excitation of $\lambda\lambda$4472 and 5876 has been neglected. If we adopt one-third of the collisional effect predicted by Cox and Daltabuit (1971), we find $N(\text{He})/N(\text{H}) = 0.100 \pm 0.015$ for Orion. This result is very similar to the helium/hydrogen abundance value derived in § III for planetary nebulae. The collisional effect is considerably smaller for H II regions than for planetary nebulae due to the lower densities and temperatures of the former.

The helium/hydrogen abundance ratio derived here for planetary nebulae is substantially smaller than those derived previously for several reasons: (i) The recombination coefficients (Robbins 1968; Harman and Seaton 1966) yield smaller helium abundances than those given by Seaton (1960) by a factor of about 1.28. (ii) Spatial temperature fluctuations were included which reduced the helium abundance by approximately a factor of 1.05. (iii) The collisional-excitation effect adopted here (one-third of the prediction by Cox and Daltabuit 1971) reduces the helium abundance by about 1.05. (iv) The helium/hydrogen line intensity ratios used here (Paper I) are in general smaller than those obtained by other observers. We ascribe this difference in the line intensities to a tendency to overestimate the intensities of weak lines relative to strong lines; for example, Miller (1971) reports that photographic intensities of the high-n Balmer lines have been overestimated by a factor of 3 in NGC 7027 and by factors ranging from 1.2 to 1.5 in the case of NGC 7662.

d) *Future Work*

It is important to note that this study is based on line intensities integrated over the entire object and that in each planetary nebula there are large spatial variations in temperature, density, and ionization; consequently, it is necessary to try to obtain line intensities of specific condensations of different ionization in a given object to make an improved analysis.

V. CONCLUSIONS

The nitrogen/oxygen abundance ratio in planetary nebulae is approximately a factor of 4 higher than that of H II regions. We suggest that the overabundance of nitrogen in planetary nebulae can be the result of CNO bi-cycle products mixed to the outer layers of the parent star, which later constitute the gaseous envelope. It is also suggested that the nitrogen enrichment of the interstellar medium produced by envelopes of planetary nebulae might be responsible for the nitrogen/oxygen abundance gradient present in nebulae across galactic disks.

It is found that the envelope of BD+30°3639 shows a high nitrogen/oxygen abundance ratio while the central star is a WC 9.

The helium/hydrogen abundance ratio in planetary nebulae is very similar to that of H II regions; consequently, the helium enrichment of the interstellar material by planetary nebulae is not significant.

The planetaries BD+30°3639 and IC 418 have appreciable amounts of neutral helium in their H^+ envelopes.

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