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HIGH HELIUM ABUNDANCES IN TWO PLANETARY NEBULAE

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ABSTRACT

Two planetary nebulae, Me 2-2 and Hu 1-2, are found to have helium to hydrogen ratios of 0.14 and 0.15, respectively, well in excess of the ratios for H II regions. Absolute Hβ fluxes are measured for both nebulae.

Subject headings: abundances, nebular — planetary nebulae

I. INTRODUCTION

For a number of years planetary nebulae were generally considered to have helium-to-hydrogen ratios substantially higher than do the diffuse nebulae. Harman and Seaton (1966), Aller and Czyzak (1968), and Kaler (1970) derived mean ratios of 0.17, 0.18, and 0.14, respectively. Kaler (1970) found a range of from 0.1 to about 0.2. However, Peimbert and Torres-Peimbert (1971*a*), in analyzing their photoelectric observations (Peimbert and Torres-Peimbert 1971*b*) of 10 bright nebulae, found a mean He/H of 0.105, in agreement with their value for H II regions. This finding prompted a restudy of some of the nebulae which earlier appeared to have high helium content. In the meantime Aller *et al.* (1973) found that NGC 6445 had a helium-to-hydrogen ratio of about 0.2. This *Letter* reports on the confirmation of high He/H ratios for two more nebulae, Me 2-2 (100−8° 1 in Perek and Kohoutek 1967 = Anon 22^h29^m in Kaler 1970), and Hu 1-2 (86−8° 1 = VV 267 in the references above = Anon 21^h31^m in Aller 1951).

II. THE OBSERVATIONS

The observations were all made with the 40-inch (102-cm) Cassegrain reflector at the Prairie Observatory of the University of Illinois. A single-channel photoelectric photometer and a set of narrow-band interference filters which isolate Hβ, λ4471 of He I, and λ4686 of He II were used to make measurements of line fluxes. Filters at 4428 and 5500 Å were used to measure the strength of the background continuum. For all filters the background sky was subtracted by observing successively on and off the nebula. Each nebula was observed on two nights. The observations were calibrated by employing 55 Cyg as a secondary standard which was tied, through observations made on several nights, to η UMa. The energy distribution of η UMa was taken from Schild, Peterson, and Oke (1971). Line blanketing for the two stars was determined from spectra taken at Kitt Peak and Mount Wilson by the author and E. C. Olson.

The absolute Hβ fluxes were measured by adopting $V = 4.83$ for 55 Cyg (Hoffleit 1964) and by using the relative energy distribution and the known line-blanketing correction to establish the stellar flux density at Hβ. The absolute calibration of stellar magnitudes in terms of flux density was taken from Oke and Schild (1970). Atmospheric extinction was measured by observing several four-color standards (Crawford and Barnes 1970). The extinction was measurable to within about 0.02 mag, and is not a significant source of error.

The filter transmission functions were all measured on a Carey spectrometer by Baird Atomic, Inc. A final calibration of the transmission of the line filters was made by observing NGC 7027 on four nights. The means of these observations are given in the first row of table 1. The true relative line intensities adopted for NGC 7027

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TABLE 1

OBSERVED RELATIVE LINE INTENSITIES (I) AND ABSOLUTE Hβ FLUXES ($\mathfrak{F}$) WITH MEAN ERRORS FOR NGC 7027, Me 2-2, AND Hu 1-2

Nebula	$I(\lambda4471)$ (1)	$I(\lambda4471)$ (2)	$\bar{I}(\lambda4471)$	$I(\lambda4686)$	log $\mathfrak{F}$(Hβ) (ergs cm^{-2} s^{-1})
NGC 7027........	(observed)	...	3.37±0.14	37.2±1.2	−10.16±0.01
NGC 7027........	(adopted)	...	2.7	40.4	−10.19
Me 2-2...........	7.1±1.1	7.3±0.7	7.2 ±0.7	...	−11.28±0.03
Hu 1-2...........	2.9±1.2	2.5±0.5	2.6 ±0.5	93 ±3	−11.27±0.03

NOTE.—The scale for the relative intensities is I(Hβ) = 100. The Hβ fluxes of Hu 1-2 and NGC 7027 include the blend with He II Pi 8.

are an average of the measurements of Peimbert and Torres-Peimbert (1971*b*), Miller and Mathews (1972), and O'Dell (1963). O'Dell's measurements were normalized to the Hayes (1970) system with the others. The absolute Hβ flux, $\mathfrak{F}$(Hβ), of NGC 7027 (which includes the He II Pi 8 line blend) was taken from Miller and Mathews (1972). The adopted true values are given in the second row of table 1. In order to bring the observed values of $I(\lambda4471)/I(H\beta)$, $I(\lambda4686)/I(H\beta)$, and $\mathfrak{F}(H\beta)$ into agreement with the adopted values, they must be multiplied by factors of 0.80, 1.09 and 0.93 respectively. These scaling factors were then applied to the filter observations of Me 2-2 and Hu 1-2.

The high radial velocity of Me 2-2 (−152 km s^{-1}, see Perek and Kohoutek 1967) required a 2 percent increase in the initially measured Hβ flux and an increase of 5 percent in the $I(\lambda4471)/I(H\beta)$ ratio due to the shift of the lines within the filter passbands. The velocity of Hu 1-2 is too low (+10 km s^{-1}) to require a correction.

The error introduced by the use of only two continuum filters is negligible. The lines of interest are bracketed by the continuum filters so that the continuum can be drawn under each of them. The Hβ line is so strong that errors in measurement of the continuum have virtually no effect, and the weaker lines are close to the λ4428 continuum filter, so that little or no error is introduced.

The results of the observations normalized to the adopted true values for NGC 7027 are presented in the third and fourth rows of table 1. The columns give, in order, the nebula name, the intensities of λ4471 relative to $I(H\beta) = 100$ for each of the two nights of observation (with the mean error), the average λ4471 intensity, the intensity of λ4686, and the log of the Hβ + He II Pi 8 flux. The λ4686 line is absent in Me 2-2 and was observed on only one night in Hu 1-2. The errors were derived from the scatter in the observations of each nebula, combined with the scatter in the data for NGC 7027.

Confirmation for Hu 1-2 comes from the λ4686 intensity of 90 found by Aller (1951), and that of 81 found by D'Odorico, Rubin, and Ford (1973) (hereafter referred to as DRF), which is close to the value measured here. The expected ratio of $I(\lambda5876)/I(\lambda4471)$ is 3.0 when collisions are included (see § III for references). The λ5876 line is observed by DRF; and the observed ratio, after the reddening correction is applied is 2.8, in good agreement with the theoretical value.

III. RESULTS AND DISCUSSION

Before the helium-to-hydrogen ratios can be calculated, the line intensities must undergo some corrections and various parameters must be evaluated. In the following discussion, all effective recombination coefficients are taken from Brocklehurst (1971, 1972).

The interstellar extinction constant for Me 2-2 is apparently low, and is taken to be zero from the Balmer decrement measured by Aller (1951). The Hα/Hβ ratio of Hu 1-2 from DRF indicates c (the logarithmic extinction of Hβ) to be 0.7. The radio spectrum of Hu 1-2 appears confused (see Higgs 1971 for references, and also Cahn and Rubin 1974). From the formulation in Cahn and Kaler (1971), the comparison of the flux density at high frequencies (8–10 GHz) with the Hβ flux given in table 1 yields $c = 0.4$ at $T_e = 10{,}000°$ K, and $c = 0.3$ at $T_e = 16{,}500°$ K (see below). A value of $c = 0.5$ is adopted as reasonable. Since the lines of interest are fairly close together, the He/H ratio is not very dependent upon the exact value of c.

The Hβ flux of Hu 1-2 must be decreased by 5 percent to allow for the He II Pi 8 blend. The effect of self-absorption on the λ4471 line intensities is at most 5 percent (Robbins 1968) and is ignored. The final line intensities corrected for all the above are presented in columns (2) and (3) of table 2. The third row of table 2 presents the same data for NGC 7027, for $c = 1.15$ (from Miller and Mathews 1972) and for a 2 percent decrease in the Hβ flux to allow for the He II blend.

The above values of c are used to compute electron temperatures from the [O III] lines of 11,500° and 16,500° K for Me 2-2 and Hu 1-2, respectively. The intensities of the [O III] lines are taken from Aller (1951) and DRF. The value of $I(\lambda4363)$ for Me 2-2 was decreased by the ratio of $I(\lambda4471)$ measured here over that measured by Aller (1951). There is evidence for believing that temperature fluctuations exist in nebulae (see Peimbert 1971) and that a temperature less than that derived from [O III] must be adopted for the effective recombination coefficients. This problem, as seen below, turns out to be of little consequence.

A part of the radiation in the λ4471 line is produced by collisional excitation of the 4 ^3D term from 2 ^3S (Cox and Daltabuit 1971). From a comparison of $I(\lambda5876)/I(\lambda4471)$ ratios, Peimbert and Torres-Peimbert (1971*a*)

TABLE 2

CORRECTED INTENSITIES AND HELIUM-TO-HYDROGEN RATIOS WITH MEAN ERRORS

Nebula	$I(\lambda4471)$ (1)	$I(\lambda4686)$ (2)	He^+/H^+ (3)	He^{2+}/H^+ (4)	He/H (5)
Me 2-2	7.2±0.7	...	0.14±0.013	...	0.14±0.013
Hu 1-2	3.1±0.6	103±4	0.06±0.012	0.09±0.003	0.15±0.012
NGC 7027	3.7	46.0	0.7	0.04	0.11

NOTE.—The intensities are corrected for interstellar extinction and are relative to the true Hβ intensity corrected for He II Pi 8.

adopt a collisional contribution one-third of that calculated by Cox and Daltabuit (1971), which will be adopted here also. The electron density of Me 2-2 is 9×10^3 cm^{-3} from the [O II] observations of Seaton and Osterbrock (1957) and the calculations of Saraph and Seaton (1970). That of Hu 1-2 is 7×10^3 cm^{-3} from the [Cl III] observations of Aller and Walker (1970) and the calculations of Krueger, Aller, and Czyzak (1970). For the likely temperature range (from 7000° K up to the temperature given by the [O III] lines), the temperature dependences of the collisional excitation term and the effective recombination coefficient almost exactly cancel one another, so that *the resulting* He^+/H^+ *ratios are independent of electron temperature*. The He^{2+}/H^+ ratios are somewhat dependent upon T_e, however. Values of 16,500° and 14,000° K (Kaler 1970) are adopted for Hu 1-2 and NGC 7027, respectively.

The He^+/H^+, He^{2+}/H^+, and total He/H ratios are presented for the two nebulae and for NGC 7027 in the last three columns of table 2. If $T_e = 10{,}000°$ K is adopted for Hu 1-2 and NGC 7027, He/H drops to 0.14 and 0.10, respectively.

The He/H ratio for Me 2-2 may well represent a lower limit, as the extinction is certainly greater than zero; and since λ4686 is not present, there may be some neutral helium which cannot be accounted for (Harman and Seaton 1966). Precision of the data is clearly sufficient to show that the helium content of Me 2-2 and Hu 1-2 is greater than that of NGC 7027 (to which the observations are tied and which is close to that of H II regions) and thus greater than that of the H II regions themselves. These data and the He/H ratio of 0.22 recently measured by Aller *et al.* (1973) amply demonstrate the exixtence of planetary nebulae which have a high helium content.

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REFERENCES

Aller, L. H. 1951, *Ap. J.*, **113**, 125.
Aller, L. H., and Czyzak, S. J. 1968, in *Planetary Nebulae, IAU Symposium No. 34*, ed. D. Osterbrock and C. R. O'Dell (New York: Springer), p. 209.
Aller, L. H., Czyzak, S. J., Craine, E., and Kaler, J. B. 1973, *Ap. J.*, **182**, 509.
Aller, L. H., and Walker, M. F. 1970, *Ap. J.*, **161**, 917.
Brocklehurst, M. 1971, *M.N.R.A.S.*, **153**, 471.
———. 1972, *ibid.*, **157**, 211.
Cahn, J. H., and Kaler, J. B. 1971, *Ap. J. Suppl.*, No. 189, **22**, 319.
Cahn, J. H., and Rubin, R. H. 1974, *A.J.*, in press.
Cox, D. P., and Daltabuit, E. 1971, *Ap. J.*, **167**, 257.
Crawford, D. L., and Barnes, J. V. 1970, *A.J.*, **75**, 978.
D'Odorico, S., Rubin, V. C., and Ford, W. K. 1973, *Astr. and Ap.*, **22**, 469 (DRF).
Harman, R. J., and Seaton, M. J. 1966, *M.N.R.A.S.*, **132**, 15.
Hayes, D. S. 1970, *Ap. J.*, **159**, 165.
Higgs, L. A. 1971, *Catalog of Radio Observations of Planetary Nebulae and Related Data* (National Research Council of Canada, N.R.C. 12129).
Hoffleit, D. 1964, *Catalogue of Bright Stars* (3d ed.; New Haven: Yale University Observatory).
Kaler, J. B. 1970, *Ap. J.*, **160**, 887.
Krueger, T. K., Aller, L. H., and Czyzak, S. J. 1970, *Ap. J.*, **160**, 921.
Miller, J. S., and Mathews, W. G. 1972, *Ap. J.*, **172**, 593.
O'Dell, C. R. 1963, *Ap. J.*, **138**, 1018.
Oke, J. B., and Schild, R. E. 1970, *Ap. J.*, **161**, 1015.
Peimbert, M. 1971, *Bol. Obs. Tonantzintla y Tacubaya*, No. 36, **6**, 29.
Peimbert, M., and Torres-Peimbert, S. 1971*a*, *Ap. J.*, **168**, 413.
———. 1971*b*, *Bol. Obs. Tonantzintla y Tacubaya*, No. 36, **6**, 21.
Perek, L., and Kohoutek, L. 1967, *Catalog of Galactic Planetary Nebulae* (Prague: Czechoslovakian Academy of Sciences).
Robbins, R. R. 1968, *Ap. J.*, **151**, 511.
Saraph, H. E., and Seaton, M. J. 1970, *M.N.R.A.S.*, **148**, 367.
Schild, R., Peterson, D. M., and Oke, J. B. 1971, *Ap. J.*, **166**, 95.
Seaton, M. J., and Osterbrock, D. E. 1957, *Ap. J.*, **125**, 66.