THE DETERMINATION OF ELECTRON DENSITIES, ELECTRON TEMPERATURES AND CENTRAL-STAR TEMPERATURES FOR A SERIES OF PLANETARY NEBULAE

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From theoretical treatments of the physical processes in planetary nebulae, the *average* physical conditions in these objects are known with some certainty. However, the physical parameters of the *individual* nebulae have not been determined exactly. This may be due to the different methods used for determining these quantities, and to the inhomogeneous data available. Therefore, it seems to be of great importance to obtain individual physical parameters for a large number of planetaries in a homogeneous system.

In our preceding paper (Vorontsov-Velyaminov *et al.*, 1968) we measured the intensities of emission lines, the intensities of the continuous spectra of the nuclei, and the diameters of the monochromatic images of several dozen planetaries by the same method. In the present paper we used the data obtained for the determination of the following parameters: the electron temperature, T_e, the electron density, n_e, and the temperature of the central star, T_* for 65 planetary nebulae.

The temperatures of the central stars, T_* were obtained by the well-known Zanstra methods. We applied the 'hydrogen' method to each of the first four lines of hydrogen, Hα, Hβ, Hγ and Hδ, and derived an average hydrogen temperature, T_H. The 'nebulium' method was applied to all the strong forbidden lines seen in our spectra. The same was done for the HeI lines λλ 5876, 4471, and for the HeII line λ 4686. The necessary values of $\mathbf{q}=\sum_2^\infty C_j N_e N_+/A_{i2}N_i$ ($i=3, 4, \ldots$) for hydrogen and helium were taken from the works of Zanstra, and Zanstra and Aller. It should be noticed that for about 20 of these planetaries either the continuous spectrum of the nucleus was not drawn exactly or the presence of the nuclear spectrum on the spectrograms was rather doubtful. In such cases, using the Zanstra method, we can obtain only a lower limit of the star temperatures.

The electron densities, n_e, were obtained from the measured nebular surface brightness in the hydrogen lines. As this method requires the knowledge of the distance to the nebula, we used three distance scales for the calculations, the scales of Vorontsov-Velyaminov, Shklovsky, and O'Dell. The derived density of a particular nebula, varies according to which distance is adopted, but by no more than a factor 3 even in the worst cases.

Osterbrock and O'Dell (eds.), Planetary Nebulae, 155–158. © *I.A.U.*

The electron temperatures were obtained by the following four methods:

The first is the well-known method, which uses the ratio of intensities of the nebular lines of [O III] to the auroral line;

The second is the method suggested by Sobolev, based on the energy balance of the free electrons in the nebula;

The third is the method based on the energy distribution in the Balmer continuum of the nebular spectra;

Finally, the fourth is the method of the Balmer discontinuity. The electron densities, necessary for this method, were taken from our results described above.

The results obtained are shown in Figure 1, where the planetary nebulae are arranged in order of decreasing Zanstra hydrogen temperatures. In the upper part of the figure the dots represent the hydrogen temperatures of the central stars, the open

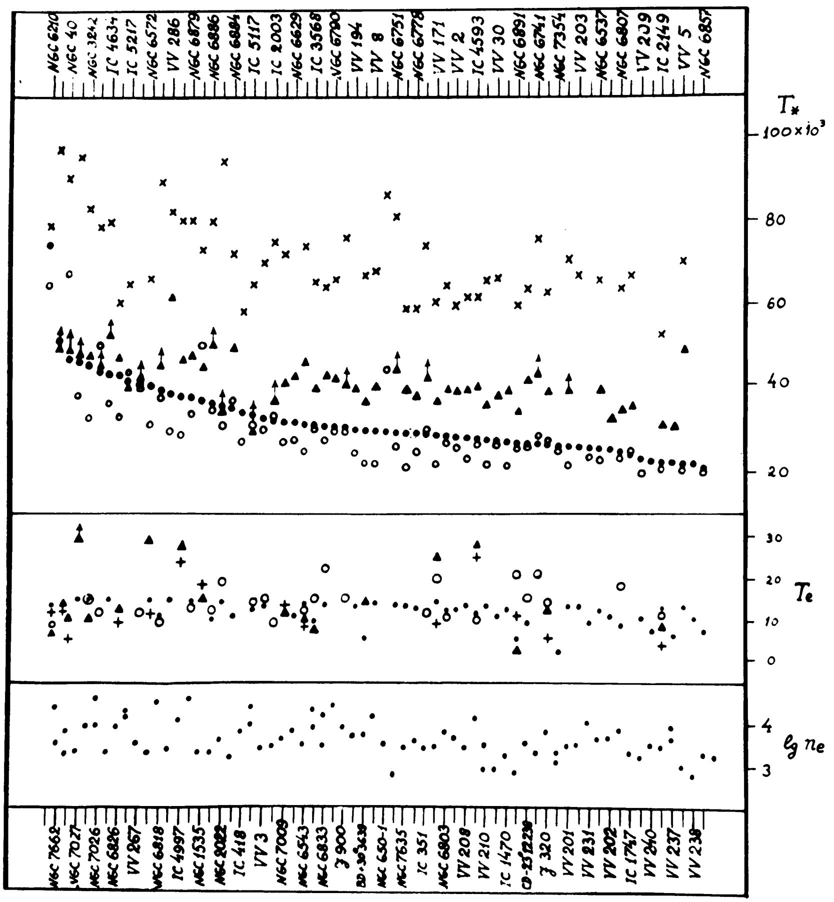

FIG. 1. *Temperature of central star, electron temperature, and electron density for 65 planetary nebulae, arranged in order of decreasing Zanstra hydrogen temperature of central star.*

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circles show their 'nebulium' temperatures, T_{neb}, the triangles show the nuclear temperatures obtained by means of He I lines, and those obtained by means of He II lines are represented by crosses. In the middle of the figure the electron temperatures obtained for the same planetaries by the four methods described above are plotted; the electron densities are plotted at the bottom of the figure.

The same notations are used in Figure 2, but the planetaries are arranged in order of decreasing He II star temperatures.

Figures 1 and 2 show that for the majority of planetaries the 'nebulium' star temperatures, T_{neb}, are lower than the Zanstra temperatures, T_H. This may be due to the fact that not all of the forbidden lines were considered, particularly in the infrared and perhaps also in the ultraviolet. It may also testify to the complete absorption of

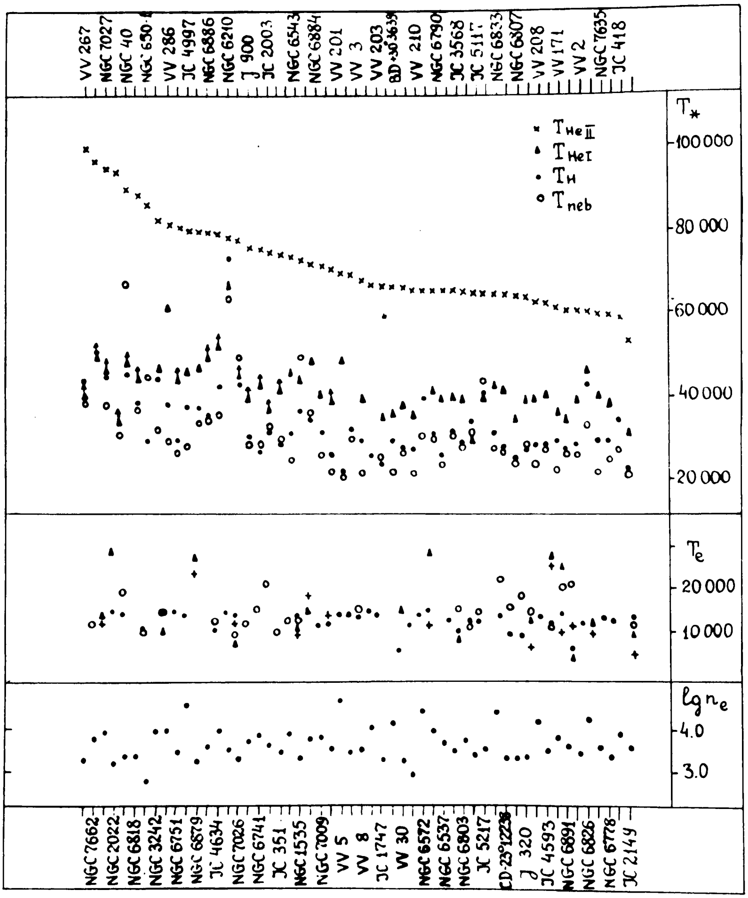

FIG. 2. *Temperature of central star, electron temperature, and electron density for 65 planetary nebulae, arranged in order of decreasing Zanstra He II temperature of central star.*

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the ionizing ultraviolet quanta by the hydrogen atoms in the nebula. Only a few planetaries show 'nebulium' temperatures exceeding their 'hydrogen' temperatures, $T_{\rm neb} > T_H$, most of them being in agreement with Zanstra's results. The nuclear temperatures obtained from the He I lines are on the average about 10000° higher than T_H, and the He II temperatures are still higher.

The ratios of line intensities $I(\lambda\,4686)/I(\mathrm{H}\beta)$ and $I(\lambda\,4686)/I(\lambda\,5876)$ were obtained, and when interpreted according to Seaton's criteria they showed that in the large majority of these planetaries there is complete absorption of the ionizing quanta by hydrogen atoms. Also, according to the second criterion of Seaton, many planetaries, especially those with the hottest nuclei, have incomplete absorption of quanta $\lambda < 504$Å, mainly by He I atoms. This means that we have obtained only a lower limit to the He I temperatures for them. In Figures 1 and 2 such cases are marked by arrows.

We prefer to explain the differences between the derived star temperatures of a particular nebula by a deviation of the star radiation in the ultraviolet from black-body radiation, rather than by the influence of optical thickness.

Finally, we can see in Figure 1 that the electron temperatures (and even the electron densities) of the planetaries studied show on the average a slight increase with increasing nuclear temperature, which probably means that conditions in planetary nebulae are not entirely thermostatic.

Reference

Vorontsov-Velyaminov, B. A., Kostjakova, E. B., Dokuchaeva, O. D., Arhipova, V. P. (1968) in the present volume, p. 57.

DISCUSSION

Seaton: I agree with the authors of this paper that the 'nebulium' method of determining star temperatures may be in error due to emission in the infrared and ultraviolet. The only sure procedure is to make a detailed study of the thermal balance.

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