Similarly, the 85.5 MHz point seems to indicate an electron temperature of $\sim 11\,000\,^\circ K$. At this frequency the entire region out to the 0.2° contour at 15.4 GHz will be opaque, and a very significant portion of the flux will come from the tenuous outer skirts of the nebula. For example, Figure 2* shows that the nebulosity NGC 1973,5,7 30° north of the trapezium is quite likely to be responsible for the northern extension of the 85.5 MHz contours of Rishbeth; however, it was completely unaccounted for in the 15.4 GHz map. It is therefore evident that the inadequate sensitivity of the high frequency observations can account for the discrepancy at 85.5 MHz. The situation may be further complicated by the presence of temperature variations through the nebula.

Various attempts have been made to reverse the problem and to derive the electron temperature of this and other nebulae from the radio frequency spectrum. The difficulties considered above suggest that such efforts are not promising, unless high frequency observations of very high resolution and sensitivity are available. The use of models does not bypass the problem because observations of the same high quality are required in order to determine their parameters to sufficient accuracy. Alternative methods for determining electron temperatures from radio frequency continuum observations have been discussed elsewhere.5

Forbidden Lines and Electron Temperatures in Gaseous Nebulae

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Electron temperatures of compact gaseous nebulae such as planetaries may be derived from radio-frequency data combined with isophotic contours accurately corrected for resolution effects, from the continuum jump at the Balmer limit and other features of the nebular continuum, and from forbidden line ratios.2 Traditionally, the $I(\lambda 4363)/[I(\lambda 5007) + I(\lambda 4959)]$ [OIII] ratio, which is insensitive to electron density for all diffuse nebulae and most planetaries, has been used to determine electron temperatures. Other ratios such as $I(\lambda 4668)/[I(\lambda 6716) + I(\lambda 6730)]$ [SII] are sensitive to both electron density and temperature, while ratios such as $I(\lambda 6716)/I(\lambda 6730)$ [SII] (see Figure 1) or $I(\lambda 3372)/I(\lambda 3379)$ [OIII] are sensitive primarily to electron density. The [NeIV] auroral transitions are of especial interest since ions must be excited to 7.7 eV above the ground level to produce them. The $\lambda 4714,4715$ lines

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are blended with λ4713 He I at the low dispersions customarily employed, but λ4724, 4725 often can be observed in moderately high excitation nebulae. One can calculate the concentrations of Ne ++, Ne +3 and Ne +4 ions from the corresponding lines of [Ne III], [Ne IV] and [Ne V], and compare these concentrations with what one would expect for dilute black-body temperature radiation.

If we assume a temperature, $T_0$, for the central star and use the concentrations of Ne ++ and Ne +4 ions to fix the dilution factor, we can predict the intensities of these [Ne IV] lines as a function of $T_0$. As an example, consider NGC 2022, for which Harman and Seaton$^3$ assigned central star properties ($T_0 = 91 000 ^\circ$K, $\log L/L_\odot = 4.29$) and a nebular radius $6.0 \times 10^{17}$ cm. The predicted geometrical dilution factor is then $10.6 \times 10^{-16}$. We then find that the relative intensities of the [NeIII], [Ne IV] and [Ne V] lines are consistent with $T_0 = 16 000 ^\circ$K and a dilution factor $W_g = 6.6 \times 10^{-16}$. In view of the crudeness of the approximation (simplified ionization equation, assumption that the radiation field can be described as dilute black-body radiation, and that the same electron temperature holds for the [NeIII] and [Ne IV] zones), $W_g$ could easily be $10^{-15}$ while $T_0$ could easily be as low as $13 000 ^\circ$K, indicated by the [OIII] lines but not as low as $8000 ^\circ$K or $10 000 ^\circ$K. If we adopt the ionization equilibrium defined by neon, $\log N(\text{Ne})/N(\text{H}) = -3.00$ and $\log N(\text{Ne})/N(\text{H}) \sim -4.20$.

Other nebulae showing strong [Ne IV] lines, e.g. NGC 2392, NGC 4361, NGC 6309, NGC 6741, NGC 7662, IC 1747, IC 2003 and CD $-23^\circ$12238 all require electron temperatures well above $10 000 ^\circ$K, unless for some special reason the concentration of Ne ++ is enhanced unduly or the $^2p$ level in Ne +3 is fed by recombinations and cascade from Ne +4 ions. If such processes are important, the [Ne IV] line intensities should be closely correlated with those of [Ne V]. Such a correlation does not appear to hold; e.g. [Ne IV] is observed with measurable intensity in IC 1747 and IC 2003 and in the outer part of NGC 6309 where [Ne V] has not been observed. In most of the nebulae studied there is some suggestion that [Ne IV] emission is produced in strata where the electron temperature is actually higher than the value suggested by the [OIII] lines. We cannot place much emphasis on electron temperatures derived from fitting an ionization equilibrium, since the radiation field may deviate strongly from dilute black-body radiation, but in none of the above nebulae can temperatures as low as $8000 ^\circ$K or even $10 000 ^\circ$K be reconciled with the appearance of the forbidden line neon spectrum. Stratification effects, differences in electron temperature and density from point to point in the nebula must all be taken into account in any realistic treatment of the problem.$^4$

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