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A SPECTROPHOTOMETRIC ANALYSIS OF THE HOT HELIUM-RICH WHITE DWARF HD 149499 B

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ABSTRACT

A comprehensive analysis is presented of the hot helium-rich white dwarf HD 149499 B based upon *International Ultraviolet Explorer* (*IUE*) ultraviolet spectra along with available optical spectra and photometry.

Line strengths, line profiles, and continuum fluxes are analyzed in terms of a new grid of hot, high-gravity, mixed-composition stellar atmospheres. The line strengths provide the strongest temperature and gravity diagnostics because they are not affected by the contamination of the white dwarf optical spectrum and photometric properties by the K0 V companion, 2''35 away. We derive the following parameters for HD 149499 B: $T_e = 55{,}000$ K $\pm$ 5000 K; log g near 8; log $(N_{\rm He}/N_{\rm H}) \geq 0$, with a value as large as 4 possible; $M_v = +8.95$; $L = 1.35\ L_\odot$; log $(R/R_\odot) = -1.89$. We thus confirm Wegner's classification of HD 149499 B as a DO star. Our derived effective temperature, however, is significantly lower than that obtained by Wray, Parsons, and Henize on the basis of continuum fluxes only.

Subject headings: stars: individual — stars: white dwarfs — ultraviolet: spectra

I. INTRODUCTION

In order to understand the still uncertain final evolutionary connection between the hottest fully degenerate stars and the nuclei of planetary nebulae, the horizontal branch stars, and the hot subdwarfs, it is of the greatest theoretical importance to know how hot a degenerate star can be. Most of the hottest known white dwarfs are DA stars in binaries (cf. Greenstein 1979). However, a few of these hottest degenerates have atmospheres containing substantial amounts of helium. The optical spectra of these hot white dwarfs are usually dominated by He II lines, and they are classified DO (cf. Greenstein 1960). The prototype of these stars, HZ 21, has $T_e = 48{,}000$ K and log $(N_{\rm He}/N_{\rm H}) = 0.8$ (Koester, Liebert, and Hege 1979). Another recently discovered DO star, Lanning 14, is both hotter ($T_e = 55{,}000$ K) and more helium-rich [log $(N_{\rm He}/N_{\rm H}) \gtrsim 2$] than HZ 21 (Liebert *et al.* 1981), while the DAO star HZ 34, at $T_e = 50{,}000$ K, has a much smaller helium abundance, log $(N_{\rm He}/N_{\rm H}) = -1.7$ (Koester, Liebert, and Hege 1979). This spread in helium content in mixed-composition objects above 50,000 K is in sharp contrast to the abundances observed in cooler hybrid composition stars which have abundances near the DB limit of log $(N_{\rm He}/N_{\rm H}) \sim 4$ (cf. Liebert 1979). Clearly, the DO stars are of importance for our understanding of the nature of the progenitors of the DB white dwarfs, and of the spectral evolution of these stars. In the present paper, we determine the atmospheric parameters of another DO star, HD 149499 B. The pair HD 149499 AB ($\alpha = 16^{\rm h}34^{\rm m}19^{\rm s}$, $\delta = -57°22'12''5$[1950.0]), containing a K0 V star (Houk and Cowley 1975) and a hot stellar source separated by 2''35, was discovered by Rossiter (1955) and first observed in the ultraviolet from the *Skylab* ultraviolet experiment by Parsons *et al.* (1976).

Wegner (1978), noting the absence of Balmer lines and the possible presence of He II λ4686 in the optical spectrum of HD 149499 B, first suggested that this star be classified as DO. Wray, Parsons, and Henize (1979; hereafter WPH) later obtained *IUE* spectra of this object. These observations revealed lines of moderate strength of He II λ1640 and Lyα + He II λ1215, as well as several weaker He II lines in the middle-ultraviolet. Their analysis, based on continuum fluxes only, indicates an effective temperature of $T_e = 85{,}000$ K $\pm$ 15,000 K, which would make this star the hottest known white dwarf. In addition, on the basis of the slightly greater strength of Lyα + He II λ1215 compared to He II λ1640, WPH suggested that hydrogen is contributing to the feature at 1215 Å, and thus that HD 149499 B has an hydrogen abundance comparable to that of HZ 21. However, because WPH did not measure the equivalent widths of the features they observed, they were not able to set any quantitative limits on the helium to hydrogen ratio in this object. Greenstein (1979) and others have also raised the possibility that HD 149499 B may not be a white dwarf, but rather a hot, high-gravity subdwarf. They base their doubt on its middle-ultraviolet spectral similarity to *IUE*

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spectra of hot hydrogen deficient sdO stars. Finally, Holberg (1981) has recently reported *Voyager 1* and *2* data for this star which have not yet been fully reduced and analyzed. The two spectra obtained with *Voyager 1* reveal the presence of a continuum from $\sim$ 1200 Å down to the Lyman jump.

The present paper presents new *IUE* observations and a spectrophotometric analysis of this important star. In § II, we describe our observational procedure and discuss the observed ultraviolet line spectrum. The model atmosphere calculations and the spectrophotometric analysis are presented in § III. Our conclusions are summarized in § IV.

II. OBSERVATIONS

a) The IUE Observations

Short wavelength (SWP) and long wavelength (LWR) *IUE* spectra at both low dispersion ($\sim$ 6 Å) and high dispersion ($\sim$ 0.5 Å) were obtained on 1978 September 21. All exposures used the large ($10'' \times 20''$) aperture and were unwidened. The low-dispersion SWP 6271 and LWR 5441 spectra had exposure times of 60 s and 90 s respectively, while the high-dispersion SWP 6272 and LWR 5442 exposure times were 90 minutes and 75 minutes, respectively. The low-dispersion exposure times were optimum, although the LWR spectrum was quite noisy due to a high radiation level at the time of observation. The high-dispersion SWP and LWR spectra were underexposed by a factor of 2. Four measurements of HD 149499 AB were made with the Fine Error Sensor (FES) on board the satellite over a 4 hour interval. These measures were converted to V magnitudes by the relation given by Holm and Crabb (1979) and yielded an average value of $\bar{V}$(FES) $= +8.76 \pm 0.05$. There was no indication of variability within ± 0.05, and the above value is in satisfactory agreement with the value of $V = +8.693 \pm 0.005$ found earlier by Wegner (1978).

The instrumental *IUE* intensities were converted to fluxes using the flux calibration of *IUE* of Bohlin *et al.* (1980), which is accurate to $\sim 10\%$. A plot of the combined SWP and LWR fluxes is given in Figure 1*a*, and a plot of the short wavelength spectrum is shown in Figure 1*b*. If we assume the cooler A component to have a K0 V spectral type as assigned by Houk and Cowley (1975) and remove its corresponding flux contribution from the LWR spectrum, we find a larger than expected flux contribution longward of 2200 Å in the LWR spectrum. This matter is further discussed in § III. The absence of an interstellar bump at 2200 Å in the LWR indicates negligible interstellar reddening, in agreement with the result of WPH.

b) The Ultraviolet Line Spectrum

Absorption features of comparable strength at He II λ1640 and Lyα + He II λ1215 are present in our spectra as well as in the spectra of WPH. Our long wavelength spectrum, though noisy, also confirms the reality of most of the middle-ultraviolet lines of the $n = 3$ series of He II detected by WPH. We confirm the presence of He II λ2385, He II λ2511, and He II λ2733, but fail to detect the He II features at λ2306 and λ3203 reported by WPH. Our failure to detect He II λ3203 is probably due to the declining sensitivity of the *IUE* long wavelength camera near 3200 Å. The equivalent widths for the five detected lines were measured on the low-dispersion spectra and are listed in Table 1. The width of He II λ1640 was also measured on the high dispersion SWP spectrum and is also listed. The high dispersion LWR spectrum was seriously underexposed and could not be used. The high dispersion profile of the He II λ1640 feature reveals an extremely sharp and narrow absorption core and broad wings. This core could possibly be due to a peculiar photospheric $T(\tau)$ distribution. Another possibility is that the sharp core arises from circumstellar gas. Other features seen in the high dispersion spectra are C IV λ1550, Mg II H and K, and possibly Si IV λ1394. These features are unlikely to be interstellar, due to the proximity of HD 149499 AB, and will be discussed in detail in a subsequent paper.

III. MODEL ATMOSPHERES AND SPECTROPHOTOMETRIC ANALYSIS

a) The Model Atmosphere Calculations

In order to analyze the spectrum of HD 149499 B and other similar objects, model atmosphere calculations were performed for a grid of 50 hot, high-gravity models

TABLE 1

MEASURED EQUIVALENT WIDTHS

Feature	Wavelength Range (Å)	Equivalent Width: This Paper (low-dispersion)	Equivalent Width: This Paper (high-dispersion)	Equivalent Width: WPH[a]
Lyα + He II λ1215 ...	1205.0–1225.0	4.4 ± 0.4	...	4.7 ± 0.5
He II λ1640	1627.5–1650.0	5.0 ± 0.4	4.0 ± 0.6	3.1 ± 0.5
He II λ2385	2365.0–2420.0	4.7 ± 0.5[b]	...	4.8 ± 0.6[b]
He II λ2511	2475.0–2542.0	3.2 ± 0.5	...	3.5 ± 0.6
He II λ2733	2712.5–2767.5	3.3 ± 0.5	...	...

[a] As measured on Fig. 1 of their paper.

[b] Uncertain because of difficult continuum placement and of noise level.

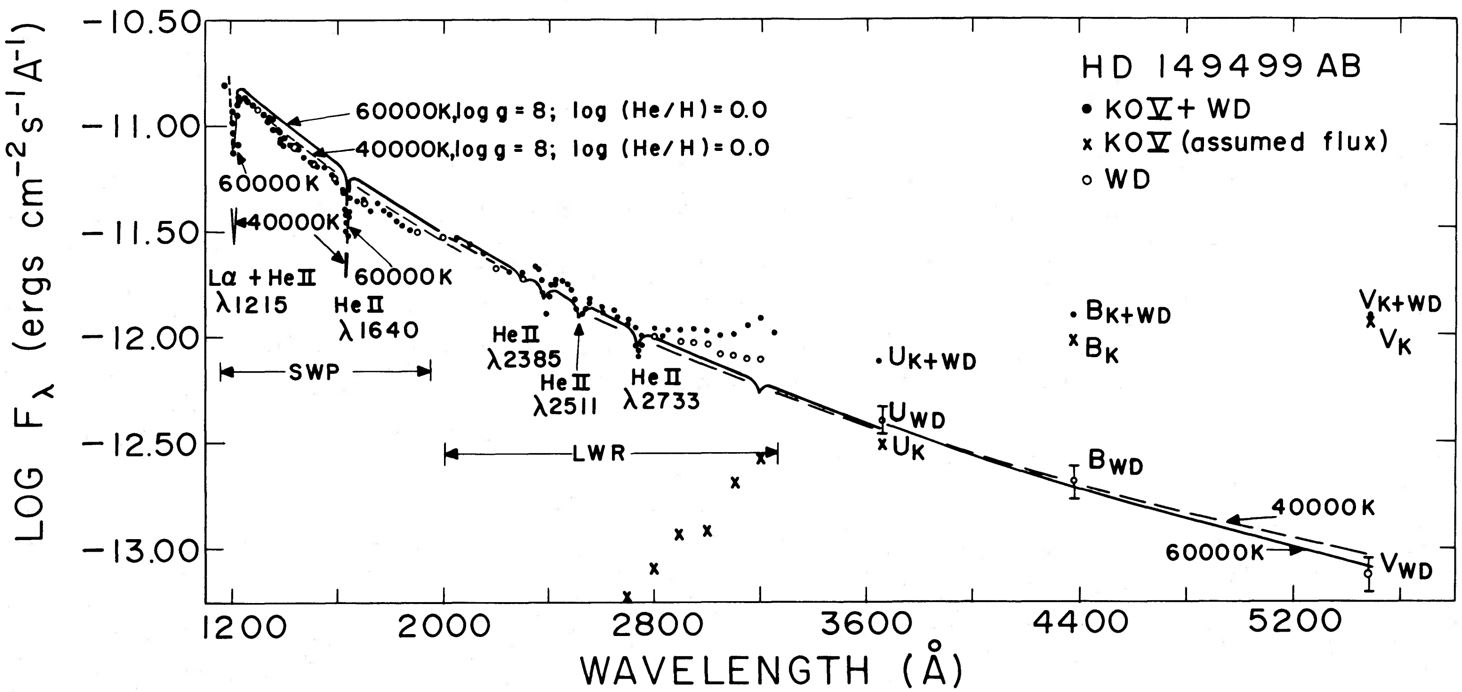

FIG. 1*a*

FIG. 1.—(*a*) Composite energy distribution of HD 149499 AB. The *IUE* wavelength ranges, SWP and LWR, are indicated with arrows. Flux point symbols are defined on the diagram. The dashed line is a 40,000 K model atmosphere fit, and the solid line is a 60,000 K fit. Both models have log g = 8.0 and log $(N_{He}/N_H) = 0$. The result of the attempted K star subtraction is shown. Note the Lyα + He II λ1215 and the He II λ1640 line depths for the 40,000 K model. Estimated error bars are indicated for the *UBV* optical fluxes. (*b*) Low-dispersion short wavelength spectrum of HD 149499 AB, showing log F_λ as a function of log λ(Å) in the range 1150–1900 Å. The spectrum shown is essentially that of the hot white dwarf component.

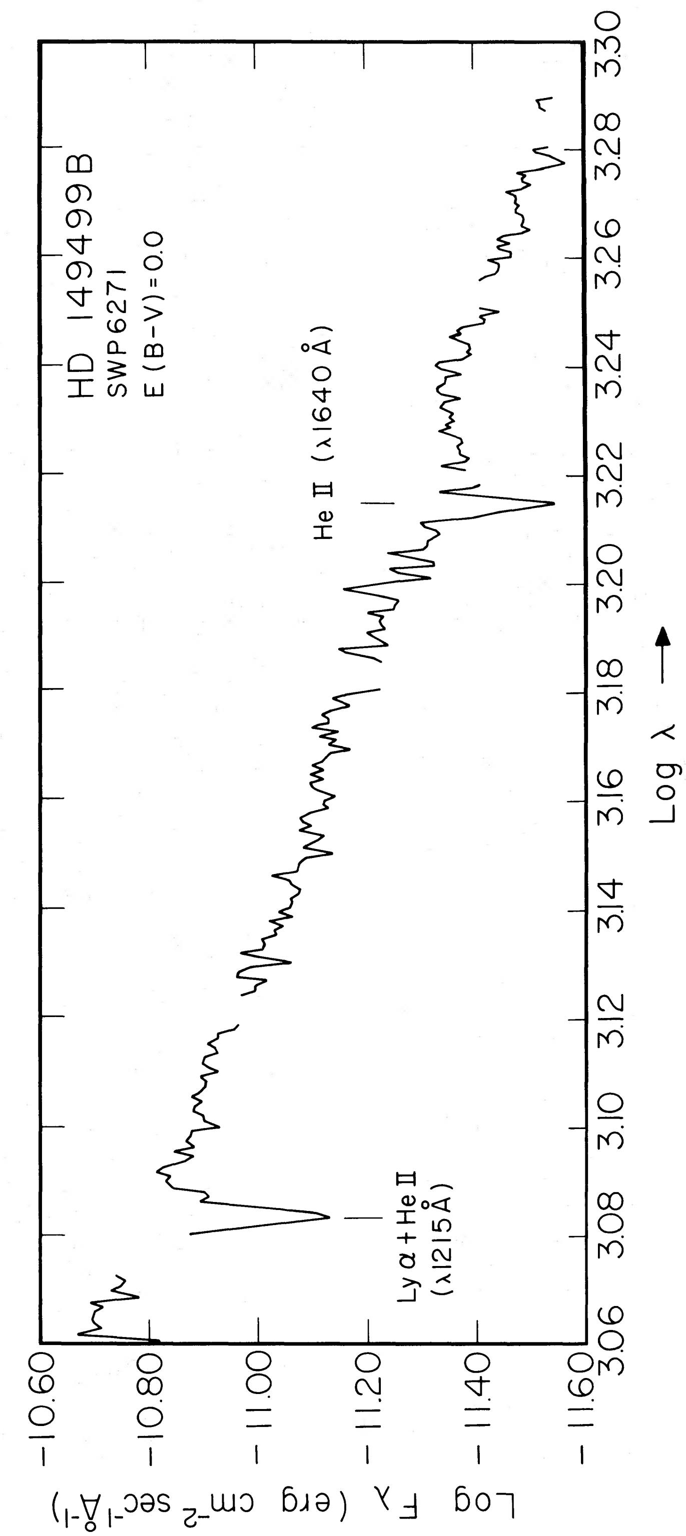
HD 149499 B
SWP6271
E(B−V)=0.0
He II (λ1640 Å)
Lyα + He II (λ1215 Å)
Log λ
Log F_λ (erg cm^{-2} sec^{-1} Å^{-1})
−10.60
−10.80
−11.00
−11.20
−11.40
−11.60
3.06
3.08
3.10
3.12
3.14
3.16
3.18
3.20
3.22
3.24
3.26
3.28
3.30

FIG. 1b

with varying He/H ratios and no metals. These models are plane-parallel, homogeneous, in LTE, and include blanketing by the lines of hydrogen and by the lines of both He I and He I ions. The physics included in these calculations is described in detail in Wesemael *et al.* (1980) and Wesemael (1981) and will not be repeated here.

With the help of these blanketed calculations, detailed fully synthetic ultraviolet spectra were computed in the range 1200 Å $\leq \lambda \leq$ 3200 Å. The broadening theory for Lyα is that of Vidal, Cooper, and Smith (1973). For the He II lines, the theory of Kepple (Griem 1974) was used for $\lambda\lambda$1215, 1640, and 3203; a version of the approximate theory devised by Auer and Mihalas (1972) was used for the remaining lines of the $n = 3$ series ($\lambda\lambda$2733, 2511, and 2385; see Wesemael 1981 for details).

Spectra were also computed in the optical region of the spectrum (4000 Å $\leq \lambda \leq$ 5000 Å) in order to analyze the upper limits on the equivalent width of Hγ + He II λ4340 and of He II λ4686 given by Wegner (1978). Here also, the Vidal, Cooper, and Smith (1973) theory was used for the hydrogen lines, while both Kepple's (Griem 1974) theory (λ4686) and our version of the Auer and Mihalas (1972) theory (for the other lines) were used for the lines of ionized helium. Furthermore, near the low-temperature end of our model grid, numerous He I lines are present and were included in the optical spectrum calculation. The broadening theories and parameters used for these lines are discussed in Wesemael (1981).

As mentioned previously, all our models are assumed to be in LTE. This appears to be quite a good approximation for the hydrogen-rich models, both in the visual and ultraviolet continua and in the Lyman and Balmer lines (Wesemael *et al.* 1980; Holberg *et al.* 1980). For the helium-rich models, preliminary calculations, computed under the assumption of detailed radiative balance in the lines, indicate departures from LTE in the far-ultraviolet and visual continua of the order of or less than $\sim$5% at $T_e = 50{,}000$ K, $\log g = 8.0$ (Wesemael 1981). For the He II lines, however, these preliminary calculations also indicate possible non-LTE effects in the widths of He II $\lambda\lambda$1640 and 4686 of the order of $\sim$ 15–20%. Further calculations, relaxing the assumption of detailed radiative balance in the lines, will be necessary for an accurate assessment of the importance of departures from LTE in the He II line profiles and widths of these objects.

For all models, the merging of the He II lines near the series limits was taken into account by using the value of the quantum number of the last visible He II line given by Wesemael (1981). We also took into account, in an approximate manner, the effect of the transition from singly-charged to doubly-charged perturbers on the profiles of He II lines in the hot ($T_e \geq 60{,}000$ K), helium-rich (log [He/H] $\geq$ 2) models. This was done by increasing the meanfield strength by a factor $2^{1/3}$ over its value in an atmosphere composed of singly-charged perturbers only.

Theoretical equivalent widths for all observed lines were computed using the same continuum positions as those assumed for the measured widths in Table 1.

b) The Spectrophotometric Analysis

i) *The Line Spectrum*

The most reliable temperature and gravity diagnostics available are the observed ultraviolet line strengths because these features are essentially uncontaminated by the light from the K0 V companion and are insensitive to possible calibration errors. The temperature and gravity analysis is thus independent of the uncertainties in optical photometry and optical spectra imposed by the proximity of the close companion. Equivalent widths for Lyα + He II λ1215 and the other detected He II ultraviolet lines were measured by assuming triangular profiles, counting boxes, and with a planimeter, with consistency achieved by all three methods. The errors quoted in Table 1 represent our estimate of the uncertainty involved in this procedure. The determination of the equivalent width of Lyα + He II λ1215, in addition, is affected by the rapidly declining sensitivity of the *IUE* short-wavelength camera on the blue wing of this feature. Furthermore, the measured width of He II λ2385 may be critically affected by difficulties encountered in defining the continuum level for this line and by the characteristic noise level of the LWR spectrum.

In addition to the line widths measured on our spectra, we have also measured the equivalent widths of four lines in the spectra of WPH (see Fig. 1 of their paper), and these are also given in Table 1.

A detailed comparison was carried out between our observed ultraviolet line strengths and the grid of theoretical equivalent widths from our model atmosphere calculations. The He II λ1640 line appears quite sensitive to gravity, as shown in Figure 2, and its strength indicates log g near 8 rather than 6 for this star, and an effective temperature near that of the peak line strength. This conclusion is strengthened by the rough line profile fit to our low-dispersion *IUE* line fluxes shown in Figure 3. On the other hand, it appears that the middle-ultraviolet He II lines are not as gravity sensitive. Thus the appear-

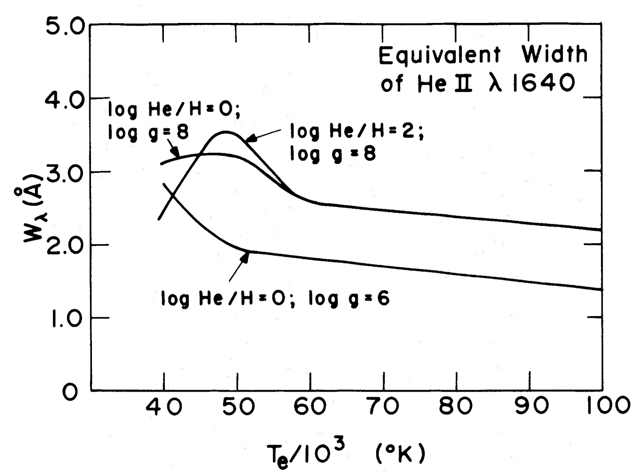

FIG. 2.—Theoretical equivalent width of He II λ1640 as a function of effective temperature for gravities log $g = 6.0$ and 8.0, and two compositions.

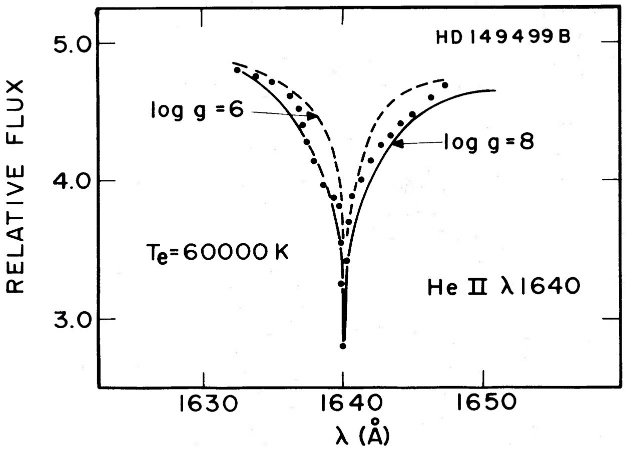

FIG. 3.—Normalized fit of the theoretical He II λ1640 profile to scaled *IUE* line fluxes. The helium abundance is log $(N_{He}/N_H) = 0$.

ance of some of these lines in a fully degenerate star as well as in subdwarf O stars is not unexpected. It would appear that speculation about HD 149499 B being a high-gravity subdwarf can now be laid to rest. It is worth noting that ultraviolet He II lines of strength comparable to those of HD 149499 B have also been detected in the DO prototype HZ 21 (Wesemael *et al.* 1981).

Comparisons between the theoretical and observed ultraviolet line strengths also provide an important constraint upon the permissible effective temperature of HD 149499 B. For log $g = 8$, our Lyα and ultraviolet He II line widths demand $T_{eff} \approx 60{,}000$ K as an upper limit because at higher temperatures these lines become weaker than our observed line strengths. If T_{eff} is lower than 40,000 K, the theoretical He II λ1640 line becomes too weak, and Wegner would likely have detected He I λ4471 in his uncontaminated optical spectra. Moreover, at $T_{eff} \leq 40{,}000$ K, Lyα + He II λ1215 would become too deep at log $(N_{He}/N_H) = 0.0$. Thus our equivalent widths, when compared to the theoretical line strengths, imply (1) an effective temperature range of 50,000–60,000 K; (2) a surface gravity log g near 8; and (3) a composition log $(N_{He}/N_H) \gtrsim 0$, but possibly as high as 4. The strengths of the He II $\lambda\lambda$2733 and 2511 features in HD 149499 B agree with $T_{eff} \approx 50{,}000$ K and log $(N_{He}/N_H) \approx 0$, but with log (N_{He}/N_H) of 4 difficult to rule out. One can definitely rule out log $(N_{He}/N_H) < 0$ for this star, but log (N_{He}/N_H) between 0 and 1 cannot be easily ruled out either. We note, furthermore, that the measured width of He II λ2385 cannot be fitted by any of our models, thus confirming our earlier suspicions about the importance of the adopted continuum level for this line.

For the Hγ + He II λ4340 line, Wegner (1978) quotes a central depth $\leq 5\%$ and a half-width of 50 Å, implying $W_\lambda \leq 2.5$ Å. Our synthetic fluxes have been used to determine theoretical equivalent widths of Hγ + He II λ4340 between 4290 Å and 4390 Å, the wavelength range used by Wegner. In Figure 4, we plot the equivalent width of Hγ + He II λ4340 for the same range of abundance ratios, surface gravities, and effective temperatures as that used in the analysis of the ultraviolet lines. The dashed line at $W_\lambda = 2.5$ Å is Wegner's upper limit estimate to the strength of the feature. Wegner's failure to observe Balmer lines in his spectra is clearly consistent with a temperature between 50,000 K and 60,000 K and an abundance log $(N_{He}/N_H) \geq 0$ at both gravities. However, his upper limit of $W_\lambda(\lambda 4686) < 9.4$ Å does not provide any significant constraint on the effective temperature or

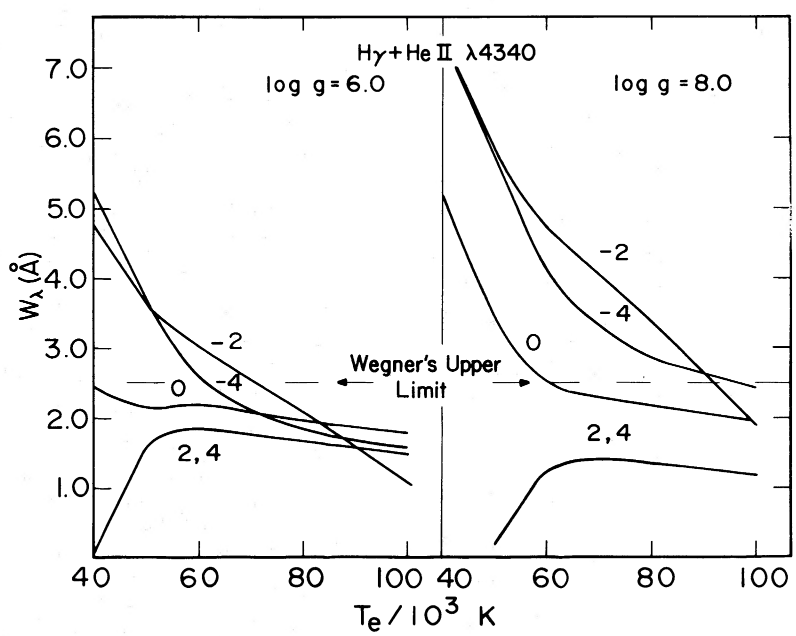

FIG. 4.—Theoretical equivalent width of Hγ + He II λ4340 as a function of effective temperature for gravities log g = 6.0 and 8.0. The curves are labeled by the value of log (N_{He}/N_H). Wegner's (1978) upper limit on the strength of this feature is also shown.

helium abundance of HD 149499 B, since even pure helium models at log $g = 8.0$ generally have a peak strength of He II $\lambda4686$ lower than this upper limit (Wesemael 1981).

Clearly, our analysis would have greatly benefited from additional high-quality optical spectra of the degenerate component. Koester, Liebert, and Hege (1979) and Liebert *et al.* (1981) have demonstrated the usefulness of the He I and He II lines in the optical spectrum to help determine atmospheric parameters for DO stars. Unfortunately, much of that information is lacking in the case of HD 149499 B.

ii) *The Energy Distribution*

To support our conclusions based upon line strengths, a fit of the complete energy distribution was attempted. For our analysis, we extend the baseline of fluxes from the *IUE* range to the *UBV* by using the photometry of Wegner (1978). For a K0 V star, $(B-V) = +0.82$ and $(U-B) = +0.47$ (Johnson 1966). Furthermore, the mean of Rossiter's (1955) two visual estimates of ΔM_{AB} is 2.95 ± 0.15, and Wegner's (1978) composite V, B, and U magnitudes are $+8.693$, $+9.379$ and $+9.254$, respectively. Thus for the white dwarf alone we have $V = +11.70$, $B = +11.31$, and $U = +9.96$. In the analysis of WPH, the V magnitude was used but not the U and B measures. Wegner's U magnitude did not fit their derived high temperatures, and this inconsistency was ascribed to an unexpectedly large flux contribution of the A component in the ultraviolet down to near 2200 Å. *However, we regard the U magnitude for the hotter component to be the best determined quantity based upon Wegner's photometry, since at this wavelength the hot star contributes more to the total light.* We thus normalize our model atmosphere fits to the U flux of Wegner. An attempt was made to remove the flux contribution of the A component in the LWR wavelength range by using the mean of *IUE* fluxes for G8 to K2 stars provided by Baliunas (1981). The fluxes were normalized to Wegner's combined V flux which is essentially due to the K star alone. The *UBV* magnitudes were converted to absolute fluxes using the recent calibration of Hayes (1979). The K star fluxes were subtracted from our combined *IUE* fluxes in the LWR spectrum of HD 149499 AB, a procedure which yields the long wavelength flux due to the white dwarf HD 149499 B alone. Shortward of 2000 Å, the K star contributes less than 1% of the total light so that the SWP fluxes are essentially those of the white dwarf alone. Despite the flux subtraction, we still found an extra flux between 2200 Å and 3200 Å. The composite energy distribution from the *IUE* fluxes and the U, B, and V fluxes derived above is shown in Figure 1*a*. A model atmosphere with parameters $T_e = 60{,}000$ K, log $g = 8$, and log $(N_{\mathrm{He}}/N_{\mathrm{H}}) = 0.0$ normalized to the U ($\lambda = 3660$ Å) flux provides a fit which appears too hot, and the continuum fluxes of hotter models give worse disagreement when normalized to the U flux. On the other hand, a model at $T_e = 40{,}000$ K, the same gravity and helium abundance, and normalized in the same way, fits out IUE continuum fluxes but yields absorption-line depths which are far too deep compared to the observed line depths. We note that if our model atmospheres are normalized to the *IUE* fluxes, the models between 40,000 K and 100,000 K all have essentially the same slope which thus provides no usable temperature discriminant. The model fluxes in the optical region lie within the error bars of the *UBV* fluxes of the white dwarf when normalizing in this way.

We feel that the energy distribution fits, when normalized to the U flux, strengthen our contention that the effective temperature of HD 149499 B lies between 50,000 K and 60,000 K, with the most likely temperature being near 55,000 K. It must be remembered that agreement between the model atmosphere calculations and the observations is very sensitive to both the assigned spectral class (and luminosity class) of the A component and Rossiter's visual estimates of the magnitude difference between the A and B components. For example, if the magnitude difference is larger than our adopted mean of 2.95, a cooler temperature is implied for the white dwarf. If the spectral class of the A component is earlier than K0, a cooler energy distribution fit will also result. The MKK spectral classes are accurate to within two subclasses only.

We strongly urge southern observers to obtain a parallax measurement of the pair, additional uncontaminated optical spectra of the white dwarf, and new measurements of the separation, position angle, and, most importantly, the visual magnitude difference between the pair.

IV. CONCLUSION

For a normal K0 V star, $(B-V) = +0.82$ which, combined with Wegner's photometry, yields $V = 8.76$ for the A component. The spectroscopic absolute magnitude is $M_v = +6.0$, giving a distance to the system of ~ 36 pc. If we adopt the mean of Rossiter's two visual estimates $\Delta M_{\mathrm{AB}} = 2.95$ and the bolometric correction (B.C. = 4.56) from our model atmospheres, $M_v(\mathrm{WD}) = +8.95$ and $M_{\mathrm{bol}}(\mathrm{WD}) = +4.39$. Thus, with log $(L/L_\odot) = 0.14$ and an effective temperature of 55,000 K, we obtain log $(R/R_\odot) = -1.89$ which implies $M \approx 0.53\, M_\odot$ for a white dwarf with a carbon core (Hamada and Salpeter 1961).

Thus, on the basis of our analysis of the line strengths and of the continuum energy distribution, we adopt the following parameters for HD 149499 B: $T_e \approx 55{,}000$ K, log g near 8, and log $(N_{\mathrm{He}}/N_{\mathrm{H}})$ of at least 0 but possibly as high as 4. Coupled with Wegner's suggested detection of He II $\lambda4686$, these properties confirm the classification of HD 149499 B as a DO white dwarf. Our analysis also strengthens the evidence for a large spread in the helium to hydrogen ratio in the atmospheres of hybrid white dwarfs above $T_e \sim 50{,}000$ K. How the mixed-composition atmospheres characterizing the DO stars evolve into the chemically pure atmospheres of the DB white dwarfs needs to be investigated. Mechanisms involving expulsion or dilution of the remaining hydrogen may have to be invoked to comply with the stringent hydrogen abundance constraints set by the DB white dwarfs below $T_e \sim 25{,}000$ K. We wish to point out that we may have now identified at least one star which, we believe, will evolve into a DB white dwarf without going through a phase of cannibalistic evolution in a short period binary system, as is thought to be the case for HZ 29 and G61-29 (Nather, Robinson, and Stover 1981).

Finally, Holberg (1981) has kindly provided us with a flux value at $\lambda 1008$ for HD 149499 B obtained by the ultraviolet spectrometer aboard the *Voyager 2* spacecraft. The *Voyager 2* flux value of 1.39 photons cm^{-2} s^{-1} is consistent with the expected flux at our derived temperature based upon normalizing the continuum to the *U* band flux.

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