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LINES OF NEUTRAL HELIUM IN O- AND B-TYPE STARS

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ABSTRACT

The effect of ultraviolet line blanketing on predicted departures from LTE is investigated. Previous conclusions suggesting that departures are small for stars later than B3 are not altered when ultraviolet blanketing is included in model calculations.

New descriptions of line broadening for the He I diffuse triplet λ4471 and the diffuse singlet λ4922 have been used in conjunction with model atmospheres to investigate the behavior of these lines for O and B stars. Qualitative agreement with the observed behavior of these lines is found for a wide range of spectral types and luminosities.

For stars later than B3, He abundances deduced from the observed strength of the strong triplet line λ4471 are found to agree extremely well with those observed by Hyland from the weak triplet λ4713. This strengthens the belief that departures from LTE are probably not significant in describing He line formation in this range of spectral types. A spectroscopic He abundance of about 0.10 ± 0.02 by number fraction is found to be representative for B stars of Population I. This value is in good agreement with the value recently suggested by Morton on the basis of his analysis of the mass-luminosity relation for B stars and with analyses of gaseous nebulae.

It now seems possible to obtain reliable He abundances from observation of λ4471. This means that even low-dispersion spectroscopic material can be used in estimating stellar He abundances.

I. INTRODUCTION

Many years ago, Struve (1928, 1931) investigated the behavior in O and B stars of the spectral lines arising from the levels 2^1S, 2^1P, 2^3S, 2^3P in neutral helium. He claimed, from eye estimates of the strength of the singlet line λ4388 (2^1P–5^1D) and the strong triplet line λ4471 (2^3P–$4D$), that the ratio of equivalent widths W_{4388}/W_{4471} increased from spectral types B9 to B7 and decreased markedly from B2 to O5. Further observations (Rudnick 1936; Williams 1936; Underhill 1966) have strengthened Struve's conclusions concerning the singlet/triplet behavior in the early B and O stars. The most recent quantitative confirmation of Struve's conclusion is that of Norris (1969). He defines an observed ratio that involves the sum of the equivalent widths of selected singlet and triplet lines and concludes that the singlets weaken relative to the triplets from spectral types B3 to B9 and B1 to O5.

Another aspect of the singlet/triplet behavior is provided by the recent observations of Sargent and Searle (1968). They observed a marked decrease of the singlet/triplet ratio for the high-gravity subdwarf O and B stars compared with main-sequence stars of the same $T_{\rm eff}$.

The observed behavior of the singlets and triplets in spectra of O and B stars has not as yet been satisfactorily explained in the context of a model-atmosphere analysis. Struve and Wurm (1938) were the first to suggest that the observed behavior might result from the nonequilibrium-level population for the metastable levels 2^1S and 2^3S. Goldberg (1939) claimed, on the basis of a single-layer model atmosphere and an LTE line-formation theory, that the different relative positions of the singlet and triplet He lines on the curve of growth were responsible for the observed behavior of the singlet/triplet ratio. Recent work by Mihalas and Stone (1968) and by Johnson and Poland (1968) now suggests that the effects of departures from LTE are small for B stars less luminous than

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class III. We strengthen the argument against the importance of non-LTE effects by ruling out significant changes in the level populations that might be brought about by the effects of strong lines on the ultraviolet radiation field.

Since most of the observational data available are for the diffuse series of He I, we next examine in detail the effects of pressure broadening on the predicted line strengths. The calculations presented here, based on recent theoretical investigations of the broadening theory for selected neutral He lines, seem to provide a satisfactory explanation for most aspects of the singlet/triplet behavior.

Finally, we discuss the reliability of spectroscopic determinations of He abundances in B stars from measurements of the strong He I λ4471 line. Perhaps the most significant conclusion of this paper is that accurate estimates of He abundances can be made from λ4471, which can be observed readily by use of moderate spectral resolution.

II. ULTRAVIOLET LINE BLANKETING

Recently, Mihalas (1967*a*, *b*), Mihalas and Stone (1968), and Kalkofen (1966, 1968), among others, have considered the effects of departures from LTE on atomic-level populations in H and He. Except for supergiants, the effects of departures on the model structure were found to be unimportant for stars cooler than $T_{\rm eff} \sim 25000°$ K (i.e., for stars later than B1 or B2). Moreover, the results of Mihalas and Stone (1968) and Johnson and Poland (1968) suggest that the He I level populations for those stars cooler than $T_{\rm eff} = 25000°$ K are not significantly affected by departures from LTE in the regions where the He I lines are formed ($\tau_{4000} > 10^{-3}$). It is important to note that Johnson and Poland solved the problem of computing the level populations quite generally. In addition to the effects of bound-bound and bound-free collisions and photoionizations, they incorporated the effects of transfer of radiation in the lines in their solution of the equations of statistical equilibrium. To the extent that the temperature structure and radiation field of existing models of B stars are correct, the Johnson and Poland level populations are the most accurate available estimates.

Before we can rule out conclusively the possibility of significant departures from LTE, it is of some importance to investigate the changes in level population that might result from the alteration of the ultraviolet radiation field brought about by line blanketing. Several investigators (Avrett and Strom 1964; Morton 1965; Mihalas and Morton 1965; Adams and Morton 1968; Hickok and Morton 1968) have demonstrated that ultraviolet line blanketing can have an appreciable effect on the temperature structure and emergent flux for atmospheres of O and early B stars. Following Avrett and Strom (1964), we approximated the effects of line blanketing by idealizing the ultraviolet metal lines as a series of lines having infinite opacity. These idealized spectrum lines were assumed to be distributed uniformly over a given frequency region; the fraction of the region occupied by these lines was assumed to be equal to the fraction of the emergent flux removed by the lines. The predicted radiation field from our idealized models was then used in computing the departure coefficients.

The validity of the above simplified treatment of line blanketing was tested by comparing a model atmosphere ($T_{\rm eff} = 21914°$ K, log $g = 4$, and N(He)/N(H) = 0.15) constructed by the above methods with a similar model of Mihalas and Morton (1965) in which the absorption coefficients of approximately 200 lines were explicitly incorporated. The extent of the line blanketing was based on an estimate of the flux removed by the lines in the Mihalas and Morton model—82 percent from λλ911–1038 and 37 percent from λλ1038–1351. The temperature structures of the Mihalas and Morton model and of our simplified model are very similar below $\tau \simeq 10^{-3}$. For $\tau < 10^{-3}$ the strong lines become optically thin and, consequently, the outer layers cool as a result of the escaping radiation in the line frequencies. Since our idealized lines are assumed to have infinite opacity at all τ, we expect and find that our temperatures near the surface are too high.

In the range $30000° \geq T_{\rm eff} \geq 10000°$ K, estimates of the depth of formation of various parts of the strongest He I lines suggest that only a small fraction (at most 14 percent at $T_{\rm eff} = 20000°$ K) of the equivalent width of these lines is contributed by portions of the line formed above $\tau = 10^{-3}$. Hence, our treatment of line blanketing is adequate for the purposes of this investigation. The results were fairly similar for all temperatures and surface gravities: only unrealistically large amounts of blanketing had any appreciable effect on the predicted departures from LTE.

III. LINE BROADENING

Until very recently, the complications of linear Stark broadening and of interacting forbidden components precluded an adequate discussion of pressure broadening for strong He I diffuse lines (such as λλ4471 and 4388). However, during the past year, two theoretical descriptions of He I line broadening have appeared: the Griem (1968) treatment for He I λ4771 and the calculations of Barnard, Cooper, and Shamey (1969, hereinafter referred to as BCS), which treat He I λλ4471 and 4922. These authors have provided tables of the normalized line-absorption coefficient $\phi(\lambda)$ as a function of temperature and electron density for $10^{14} \leq N_e \leq 3 \times 10^{17}$ and $5000° \leq T \leq 40000°$ K. However, in order to apply their results to cases of astrophysical interest, we were faced with the problem of extending the profile tabulations farther into the line wings and to electron densities lower than those tabulated by these authors.

For $N_e < 10^{14}$, the Griem and BCS theories suggest that Voigt profiles can be used to approximate the profile function for the permitted components. They estimate values of the electron-impact half-widths, which are then used as the damping parameters for a Voigt profile. However, in B-star atmospheres the forbidden components of both lines ($2P$–$4F$ transitions shifted about 1.5 Å to the blue of the permitted component in the case of both lines) are also important contributors to the equivalent widths of the line. Nicolas (private communication) of Griem's group has suggested that we approximate the contribution of the forbidden component by a Gaussian profile. Furthermore, we assume that the ratio of the peak intensities of the forbidden and permitted components is linearly proportional to the electron density. This same relation obtains for the detailed calculations in the N_e range between 10^{14} and 10^{15} cm^{-3}. For He I λ4471, we also note that the observed line profile results from a combination of the profile for the permitted component centered at 4471.48 Å and the same profile function shifted 0.21 Å to the red (accounting for the J-splitting of the 2^3P level) and weighted by a factor $\frac{1}{8}$ relative to the central component. Line profiles computed from these approximations correspond very well to the detailed profiles predicted by both theories at the lowest tabulated values of N_e (10^{14} cm^{-3} for BCS and 3×10^{13} cm^{-3} for Griem). The profile for He I λ4471, $N_e = 3 \times 10^{13}$, was calculated with Griem's computer program, which was made available to us by Nicolas.

In the case of the line wings, we used Griem's approximation formulas for λ4471:

$$\phi(\lambda) = \frac{w}{\pi \Delta\lambda_2{}^2} + \frac{0.81 \times 10^{-16} N_e}{(\Delta\lambda_i)^{5/2}} \left(\frac{\Delta\lambda_i}{\Delta\lambda_i + 1.44}\right)^{4i-5/4},$$

where

$$\Delta\lambda_i = \lambda - 4471.48\,, \quad i = 2\,, \qquad \text{for} \qquad \lambda \geq 4471.6\,,$$

and

$$\Delta\lambda_i = 4470.4 - \lambda\,, \quad i = 3\,, \qquad \text{for} \qquad \lambda \leq 4469.9\,.$$

The same weighting procedure was adopted to take account of J-splitting. (Values of w are given by Griem as a function of temperature.) For λ4922, we assumed that the line-absorption coefficient diminishes as $(\Delta\lambda)^{-5/2}$ from the last tabulated values in the BCS tables. The calculations of Pfennig and Trefftz (1966) show that the Stark effect of He is linear for $\Delta\lambda \geq 2$ Å; for large $\Delta\lambda$, the quasi-static approximation should therefore be valid.

There are no substantial differences between the Griem and BCS theories for electron densities less than 10^{16} cm^{-3}. Hence, for the conditions that obtain for main-sequence and higher-luminosity stars ($N_e \leq 10^{15}$ cm^{-3} in the region of line formation), the predicted profiles are essentially the same for both theories. In models of O and B subdwarfs where $\log g \geq 5$ and $N_e \geq 10^{16}$, we expect that the line profiles derived from the two theories will differ.

We emphasize that the broadening theories used in our calculations do not depend in any way on existing observations of He lines in B stars; they are entirely quantum mechanical in nature. Therefore, we feel that the observational tests of these broadening theories presented in the following sections provide an important and independent test of their validity.

IV. RESULTS AND DISCUSSION

We have computed He-line profiles for model atmospheres having a variety of temperatures and surface gravities, using the methods outlined in Strom and Avrett (1964). Opacity sources included in the model calculations were H, He I, He II, electron scattering, and Rayleigh scattering. Flux constancy of several tenths of a percent was achieved in all regions revelant to the calculation of line strengths. The line source function was in all cases set equal to the Planck function. In view of the discussion in § II, this assumption seems quite justified for B stars later than about B3. The numerical results are presented in Tables 1 and 2. In Table 1 we give the equivalent widths for $\lambda\lambda$4471 and 4922 as computed for the indicated models from the Griem and/or BCS theories. The notation under Model Parameters represents $T_{\rm eff}$, $\log g$, He abundance by number fraction, and broadening theory. We should note that the continuum level was assigned at 10 Å from line center. The computations presented in Table 1 were made for several specific problems, some not directly concerned with the main purpose of this work. However, in the interest of making the data generally available, we decided to publish all our results. For several models in Table 1, the values of W_{4471} predicted for the Griem and BCS theories can be compared. For $\log g \lesssim 4.5$, the two theories yield values of W_{4471} that differ by less than 5 percent. For larger gravities, up to $\log g \sim 6$, the difference amounts to about 10 percent. In Table 2 we present the λ4471 profiles predicted by the BCS theory for some representative model atmospheres. The values tabulated are residual intensities as functions of $\Delta\lambda$, the distance from line center. In assessing the general applicability of our predictions, it is of some importance to note that the work of Hyland (1967) indicates that the He I line strengths will not be affected significantly by stellar rotation.

The behavior of W_{4471} and W_{4922} as a function of temperature, gravity, and He abundance is plotted in Figures 1, 2, and 3. The BCS theory was used to compute the equivalent widths plotted in these figures. It is apparent that both λ4471 and λ4922 reach their maximum intensity for $T_{\rm eff} = 22000°$ K (at about spectral type B2). Furthermore, the maximum is much more pronounced for B subdwarfs ($\log g \sim 5.0$) and main-sequence B stars, and much flatter for giants. This prediction is in qualitative agreement with the observational results of Rudnick (1936) and Williams (1936).

V. THE SINGLET/TRIPLET RATIO

The predicted behavior of the singlet/triplet ratio is presented in Figure 4. We emphasize that the lines used in making these predictions are $\lambda\lambda$4471 (2^3P–4^3D) and 4922 (2^1P–4^1D). Because of the paucity of published λ4922 equivalent widths, we are unable to compare our predicted ratio directly with observations. We therefore regard

TABLE 1

THEORETICAL EQUIVALENT WIDTHS FOR HE LINES IN B STARS (mÅ)

Model Parameters	W_{4471}	W_{4922}	Model Parameters	W_{4471}	W_{4922}
12000, 2.5, 0.1, G	280		23000, 4, 0.1, BCS	1465	854
12000, 2.5, 0.1, BCS	260	106	24000, 4, 0.1, BCS	1416	828
15000, 2.5, 0.1, BCS	610	248	25000, 4, 0.1, BCS	1398	818
20000, 2.5, 0.1, BCS	563	287	27500, 4, 0.1, BCS	1247	743
			30000, 4, 0.1, BCS	1064	640
12000, 3, 0.1, BCS	245	92	40000, 4, 0.1, BCS	238	148
15000, 3, 0.1, BCS	636	283	49900, 4, 0.1, BCS	57	28
20000, 3, 0.1, BCS	904	419			
			20000, 4.3, 0.1, BCS	1549	904
12000, 3.5, 0.1, BCS	229	83	20000, 4.6, 0.1, G	1725	
15000, 3.5, 0.1, BCS	657	309			
20000, 3.5, 0.1, BCS	1226	649	12000, 5, 0.1, BCS	313	73
22000, 3.5, 0.1, BCS	1205	635	12000, 5, 0.01, BCS	61	10
25000, 3.5, 0.1, BCS	1012	550	15000, 5, 0.1, BCS	964	390
			15000, 5, 0.01, BCS	314	81
20500, 3.7, 0.1, G	1370		17500, 5, 0.1, BCS	1416	664
			17500, 5, 0.01, BCS	530	166
11000, 4, 0.1, G	150		20000, 5, 0.1, G	1766	
11000, 4, 0.075, G	127		20000, 5, 0.1, BCS	1950	1070
11000, 4, 0.055, G	105		20000, 5, 0.01, BCS	837	332
12000, 4, 0.1, G	220		21000, 5, 0.1, BCS	2087	1191
12000, 4, 0.1, BCS	209	68	21000, 5, 0.01, BCS	916	387
12000, 4, 0.075, G	183		22000, 5, 0.1, BCS	2198	1289
12000, 4, 0.05, G	161		22000, 5, 0.01, BCS	970	429
12000, 4, 0.03, G	129		24000, 5, 0.1, BCS	2290	1383
12000, 4, 0.01, G	67		24000, 5, 0.01, BCS	999	465
13000, 4, 0.1, BCS	334	125	25000, 5, 0.1, BCS	2350	1418
14000, 4, 0.1, BCS	485	203	25000, 5, 0.01, BCS	1016	470
15000, 4, 0.125, BCS	741	347	30000, 5, 0.1, BCS	1946	1161
15000, 4, 0.1, BCS	678	315	30000, 5, 0.01, BCS	768	346
15000, 4, 0.075, BCS	603	269	35000, 5, 0.1, BCS	1421	828
15000, 4, 0.05, BCS	476	200	35000, 5, 0.01, BCS	500	215
15000, 4, 0.025, BCS	366	147			
15000, 4, 0.01, BCS	220	80	20000, 5.2, 0.1, BCS	2065	1143
16000, 4, 0.1, BCS	856	423			
17000, 4, 0.1, BCS	1039	542	12000, 6, 0.1, BCS	170	30
18000, 4, 0.1, BCS	1209	658	12000, 6, 0.01, BCS	27	4
18200, 4, 0.1, G	1330		15000, 6, 0.1, BCS	765	233
19000, 4, 0.1, BCS	1348	756	15000, 6, 0.01, BCS	194	38
20000, 4, 0.3, BCS	2275	1460	17500, 6, 0.1, BCS	1543	635
20000, 4, 0.1, BCS	1449	826	17500, 6, 0.01, BCS	498	127
20000, 4, 0.05, BCS	1052	626	20000, 6, 0.1, BCS	2355	1192
20000, 4, 0.01, BCS	479	268	20000, 6, 0.01, BCS	983	311
21000, 4, 0.1, BCS	1484	859	22500, 6, 0.1, BCS	2650	1487
22000, 4, 0.1, BCS	1501	872	22500, 6, 0.01, BCS	1117	384
			25000, 6, 0.1, BCS	3025	1845
			25000, 6, 0.01, BCS	1375	528

TABLE 2

LINE PROFILES FOR He I λ4471

MODEL PARAMETERS	Δλ (Å)													
	−5.0	−3.0	−2.0	−1.5	−1.25	−1.0	−0.6	−0.2	0.0	+0.2	+0.6	+1.0	+3.0	+5.0
20000, 3.0, 0.1, BCS.....	0.993	0.972	0.917	0.801	0.880	0.934	0.870	0.585	0.492	0.544	0.804	0.883	0.983	0.995
20000, 3.5, 0.1, BCS.....	0.984	0.944	0.867	0.752	0.838	0.895	0.823	0.586	0.574	0.666	0.869	0.922	0.991	0.998
12000, 4.0, 0.1, BCS.....	0.998	0.994	0.982	0.960	0.985	0.989	0.979	0.923	0.805	0.864	0.954	0.976	0.996	0.999
14000, 4.0, 0.1, BCS.....	0.994	0.980	0.954	0.904	0.955	0.967	0.944	0.840	0.670	0.760	0.900	0.939	0.987	0.995
16000, 4.0, 0.1, BCS.....	0.987	0.958	0.912	0.836	0.910	0.932	0.893	0.744	0.561	0.660	0.835	0.890	0.970	0.989
18000, 4.0, 0.1, BCS.....	0.979	0.935	0.870	0.773	0.862	0.897	0.843	0.654	0.523	0.585	0.776	0.840	0.953	0.983
20000, 4.0, 0.1, BCS.....	0.974	0.919	0.837	0.729	0.822	0.869	0.802	0.597	0.541	0.561	0.732	0.802	0.942	0.979
22000, 4.0, 0.1, BCS.....	0.974	0.917	0.828	0.716	0.808	0.863	0.790	0.593	0.517	0.563	0.720	0.791	0.941	0.979
25000, 4.0, 0.1, BCS.....	0.978	0.927	0.842	0.734	0.821	0.877	0.806	0.580	0.489	0.655	0.827	0.889	0.984	0.996
30000, 4.0, 0.1, BCS.....	0.986	0.950	0.884	0.788	0.866	0.915	0.857	0.617	0.563	0.594	0.785	0.855	0.967	0.989

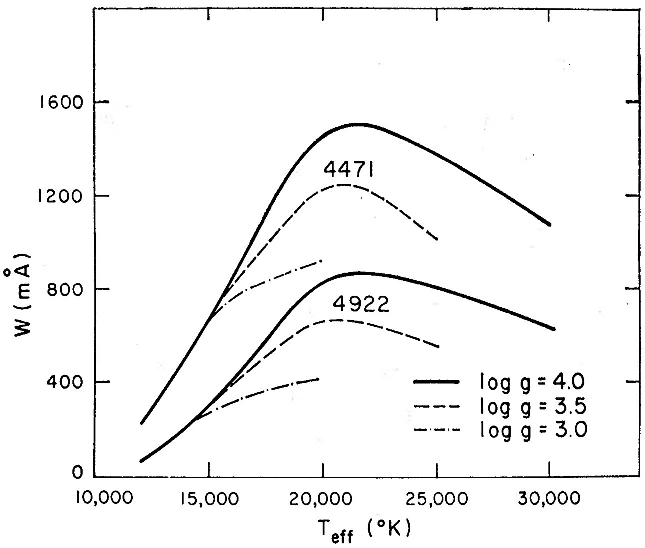

FIG. 1.—Predicted relations between the equivalent widths of He I λ4471 (triplet) and λ4922 (singlet) and effective temperature for the indicated values of surface gravity. He abundance is $N(\mathrm{He}) = 0.10$.

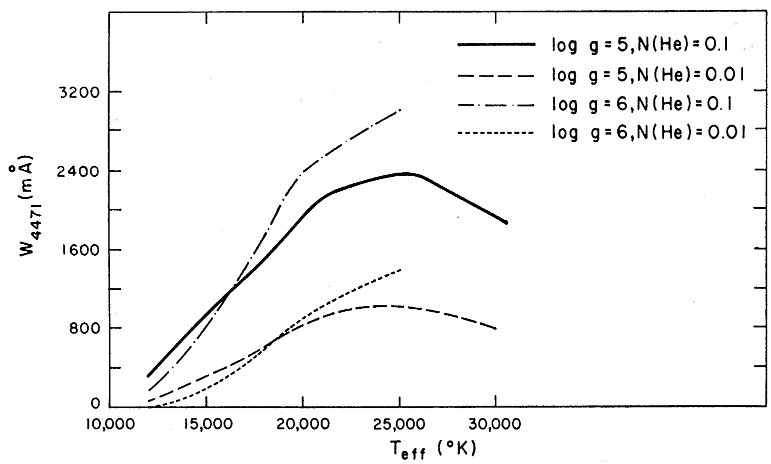

FIG. 2.—Predicted relation between the equivalent width of He I λ4471 (triplet) and effective temperature for the indicated values of surface gravity and He abundance.

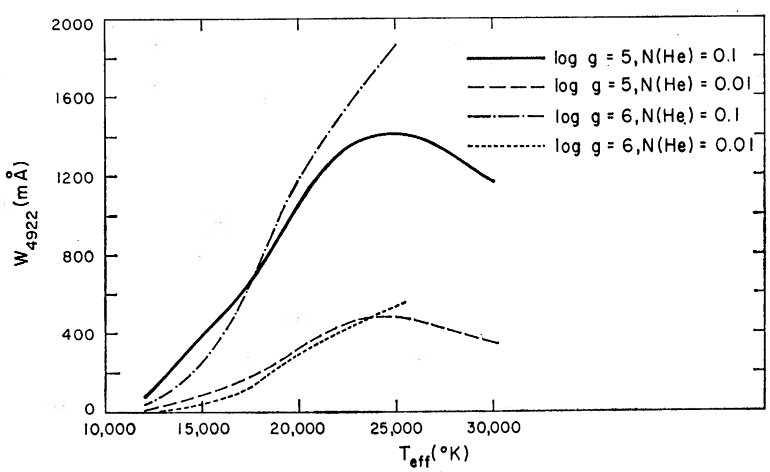

FIG. 3.—Predicted relation between the equivalent width of He I λ4922 (singlet) and effective temperature for the indicated values of surface gravity and He abundance.

the statements made below as *indicative* of the general behavior of the singlet/triplet ratio.[1]

Our calculations predict a decrease in the singlet/triplet ratio from $T_{\text{eff}} = 12000°$ K (i.e., from B3 to B8). From his visual inspection spectra of B stars, Struve concluded that such a decrease does occur for stars later than B3; Norris's (1969) new data provide quantitative confirmation of Struve's observations.

G. Peters of the University of California at Los Angeles (private communication) has measured the ratio W_{4922}/W_{4471} to be 0.52 for the B3 V star ι Her. Using our estimate of $T_{\text{eff}} = 18000°$ K from unblanketed models and the scans by Jugaku and Sargent (1968), we predict a ratio of 0.54. While this provides only one direct comparison, we are very encouraged by the remarkably close agreement of theory and observation.

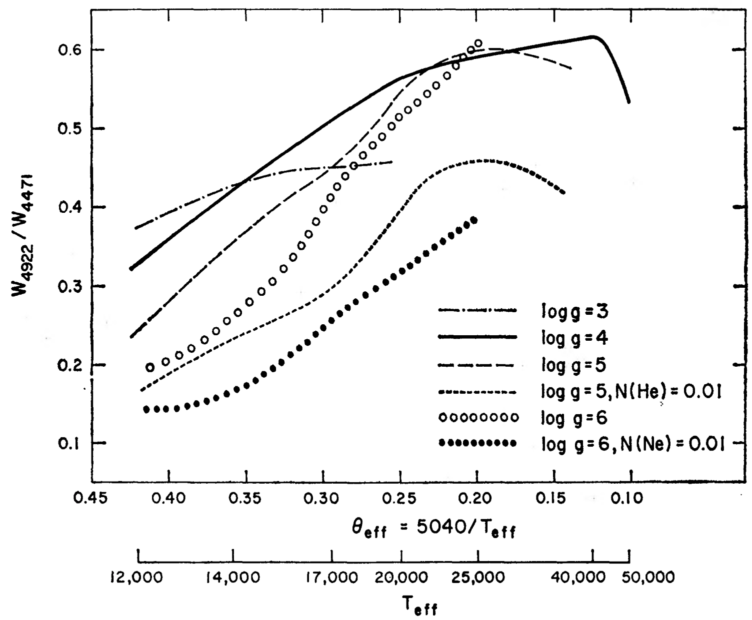

FIG. 4.—Predicted relation between singlet/triplet ratio, W_{4922}/W_{4471}, and effective temperature for the indicated values of surface gravity. All He abundances are 10 percent by number fraction unless otherwise noted.

Reference to Figure 4 shows that the decrease of the singlet/triplet ratio at high T_{eff} begins at $T_{\text{eff}} \simeq 42000°$ K. We are somewhat surprised at this prediction, since we would have expected a decrease at a T_{eff} value closer to 30000° K in view of recent results (Norris 1969). This discrepancy can be explained by (*a*) possible inaccuracies in the T_{eff} scale of O and early B stars or (*b*) the fact that λ4922 is used as the representative singlet line whereas the observational data are generally given for other singlet lines. Further studies of this problem are currently under way that use recently developed descriptions of broadening for λλ4026 and 4388 provided by Cooper and Shamey (private communication).

It is also apparent from Figure 4 that the low singlet/triplet ratio observed by Sargent and Searle (1968) in several horizontal-branch B stars of high gravity and low He abundance is at least qualitatively explained by our theoretical calculations. Reference

[1] After submitting this paper, we received from Dr. J. Norris of Mount Stromlo a copy of his very recent discussion of the singlet/triplet problem. By using the predictions of a semi-empirical broadening theory and new, high-quality observational material, he has presented an impressive explanation of the singlet/triplet behavior in the context of an LTE theory. However, we still feel that it is very useful to present our calculations based on broadening theories that are fully quantum mechanical in nature.

to Table 2 shows that the low ratio observed may arise from a combination of both the high gravity and low He abundance for B subdwarfs.

VI. SPECTROSCOPIC HELIUM ABUNDANCES FOR B STARS

Helium abundances in the young B stars provide an indirect indication of the amount of He that has been synthesized and dispersed into the interstellar medium over the last several billion years. It is therefore of some importance to determine the reliability of spectroscopic determinations. Until recently, abundance estimates based on He I and He II absorption lines ranged from $N(\mathrm{He}) = 0.05$ to $N(\mathrm{He}) = 0.18$. In the past, accurate determination of He abundances from stellar spectra was rendered quite difficult because of a combination of the following: (1) inaccurate model atmospheres and consequent inaccuracies in the T_{eff} and $\log g$ determinations; (2) inaccurate broadening theories for He I and He II lines; (3) uncertainty as to the appropriate approximation for the mechanism of line formation; and (4) the lack of a homogeneous and reliable set of observational data.

Recent work on model atmospheres and improvements in the spectrophotometric data available have resulted in a scale of effective temperatures that seems quite accurate for stars later than B3 (see Morton and Adams 1968; Wolff, Kuhi, and Hayes 1968). Strom and Peterson (1968) and Olson (1968) have demonstrated that use of the Edmonds, Schlüter, and Wells (1967) semi-empirical broadening theory for Balmer lines results in the choice of accurate gravities for B stars.

In the previous sections we have seen that, for stars later than B3, departures from LTE are expected to be small in those depth regions that contribute to over 85 percent of the equivalent width of even the strongest He line, $\lambda4471$. We therefore should be confident in making the LTE simplification.

We also note the success of the new broadening description in predicting at least qualitatively the behavior of the He singlet and triplet line strengths over a wide range of T_{eff} and g. A more rigorous test is afforded by the recent observations of Hyland (1967). He obtained observations of the strengths of the strong triplet line $\lambda4471$ and the weak triplet line $\lambda4713$ for main-sequence B stars in two southern galactic clusters, IC 2391 and IC 2602. The mechanism of quadratic Stark broadening for $\lambda4713$ is well understood; moreover, in late B stars this line is formed at depths sufficiently large so that LTE populations for the relevant levels are a virtual certainty. By choosing values of T_{eff} and g from spectrum scans of Balmer-line profiles, Hyland was able to predict the strength of $\lambda4713$ from the appropriate model atmospheres. His scale of T_{eff} is nearly identical with that of Morton and Adams (1968) and with the empirical scale of Hanbury Brown *et al.* (1967). From the predicted $\lambda4713$ strengths, he obtains a value of $N(\mathrm{He}) = 0.09 \pm 0.02$ for stars in both clusters. We have used Hyland's measurements of $\lambda4471$ equivalent widths and his values of T_{eff} and g to obtain $N(\mathrm{He})$ from our model calculations.

It is important to note that Hyland (private communication) has chosen his continuum to be located at distances greater than 15 Å from line center. We have revised our theoretical estimates of the equivalent widths to take into account this choice of continuum. We would urge that in the future observers clearly indicate their choice of continuum, especially in reports of observations of lines with strong wings. Perhaps our published predicted equivalent widths, with a continuum well defined at 10 Å from line center, will start a trend in this direction. The results are presented in Table 3, in which we also list the values of $N(\mathrm{He})$ deduced by Hyland from $\lambda4713$. The essential conclusion is that the strong $\lambda4471$ line and the weaker $\lambda4713$ line give the same He abundances to within ± 0.02.

Helium abundances were also estimated from $\lambda4471$ line strengths for two well-observed field stars, γ Peg (B2 IV) and ι Her (B3 V). The values of T_{eff} were chosen on the basis of spectrum scans by Jugaku and Sargent (1968), renormalized to the absolute calibration of Hayes (1967). For γ Peg we obtained $T_{\rm eff} = 20000° \pm 500°$ K, while for ι Her we derived $T_{\rm eff} = 18200° \pm 500°$ K. These choices of $T_{\rm eff}$ were made on the basis of unblanketed atmospheres. Values of $\log g = 3.7$ and 4.0 were deduced from the Hγ profiles reported by Jacobson *et al.* (1964) for γ Peg and ι Her, respectively. The λ4471 line strengths as measured by Jacobson *et al.* gave values of N(He) = 0.095 for both stars.

It would appear that the value N(He) = 0.10 ± 0.02 is typical for B stars of Population I. This value, deduced spectroscopically, is also in good agreement with the results of Morton (1968), which are based on the mass-luminosity relation for B stars. It also agrees well with values generally found from analyses of gaseous nebulae.

We interpret our results as an indication of the essential validity of the new line-broadening predictions and the reliability of spectroscopic determinations of abundances for B stars. Moreover, we suggest that accurate values of N(He) can now be determined even from relatively low-dispersion material, where only λ4471 can be measured accurately.

TABLE 3

HELIUM ABUNDANCES FROM HYLAND'S (1967) DATA FOR SOUTHERN GALACTIC CLUSTERS

HD	$T_{\rm eff}$ (° K)	log g	W_{4471}(mÅ)	N(He)$_{4471}$	N(He)$_{4713}$
74560........	17700	3.80	1310	0.122	0.09
74196........	15000	3.80	770	0.108	0.095
74071........	16500	3.95	1000	0.105	0.090
93030........	29600	4.05	1330	0.14	0.165
92938........	16500	3.85	1330	0.134	0.145
93607........	18500	4.05	1340	0.088	0.075
93194........	17600	3.95	1220	0.090	0.090
93540........	15500	3.90	850	0.092	0.090
93549........	15300	3.80	745	0.094	0.085

VII. CONCLUSIONS

Earlier conclusions that departures from LTE are unimportant for B stars later than B3 are unaffected when ultraviolet line blanketing is included in model calculations. Even in the regions where strong He I lines are formed, LTE appears to be a good approximation in this spectral-type range.

The predictions of the Griem and BCS pressure-broadening theories for He I λ4471 and He I λ4922 are in general agreement with observations of the dependence of these line strengths on temperature and surface gravity. Our predictions are also in qualitative agreement with the recently observed decrease in the singlet/triplet ratio for subdwarf B stars, although observations of λ4922 would seem advisable in order to provide a direct comparison. We predict a diminution of the ratio W_{4922}/W_{4471} with decreasing temperatures for the late B stars, a prediction in agreement with the recent observations of the singlet/triplet ratio, and also with Struve's original survey data.

Abundances derived from the strong He I λ4471 line are in good agreement with the abundances for B stars in several southern galactic clusters derived by Hyland (1967) from the weak He I λ4713 line.

Detailed comparison of predicted and observed line profiles would be desirable for further confirmation of the validity of the model predictions.

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