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THE INTENSITY OF CERTAIN LINES OF *He* I IN THE B STARS

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ABSTRACT

The behavior of the *He* I lines λλ 4471, 4387, and 4144 is investigated in connection with spectral types determined on the system of the Yerkes spectral atlas for main-sequence stars and for supergiants. In the main-sequence stars the results are similar to those found earlier by Struve, Williams, and Rudnick; in the supergiants, however, the behavior is strikingly different for λ 4471, which appears to reach its maximum intensity near O9–B0.

Attention is called to the peculiar spectrum of the O9 star HD 93521; its spectral peculiarities and large distance from the galactic plane suggest a connection with Baade's Population II.

The behavior of the lines of *He* I with respect to spectral type and luminosity in the O and B stars has been described by—among others—Struve,[1] Williams,[2] and Rudnick.[3] Their results can be summarized as follows:

Struve found that with increasing temperature the singlets (λ 4387 and λ 4009) fade out more rapidly in the giants than in the dwarfs. For the cooler stars he found little, if any, difference in the ratio of triplets to singlets between giants and dwarfs; he placed the maximum intensity at about type B2 for both triplets and singlets. In connection with Harvard spectral types he found a null effect in the intensity of *He* I for the hottest stars; near maximum (B2) he found the *He* I lines to be systematically stronger in the giants than in the main-sequence stars.

Williams found the maximum intensity near type B3 and an absolute-magnitude effect opposite in sign to that found by Miss Payne[4] and Struve; he states: "An absolute magnitude effect similar in sign to that found for the H lines extends from the earliest types (within which the helium criterion is capable of distinguishing giants from dwarfs, although hydrogen intensity is not) to type B5 at least. . . ."[5]

Rudnick found the maximum to occur at B2 for both singlet and triplet systems, with the maximum sharper and better defined for the singlets than for the triplets. The asymmetry found by Struve[6] was confirmed. He found that λ 4471 fades out more slowly on either side of maximum in giants than in the main-sequence stars. For the singlet line λ 4387 the same is true for the later types; but in the range B2–O the situation is reversed, in that the intensities in giants drop faster than those in dwarfs. At class B2 Rudnick found that both λ 4471 and λ 4387 are about 50 per cent stronger in dwarfs than in giants; that is, he found a pronounced negative luminosity effect; he found this effect to be present as early as type B0. The results of Rudnick and Williams therefore agree that the strongest *He* I lines in the ordinary photographic region are enhanced in main-sequence stars over supergiants in the spectral range B0–B5.

It would seem to be of interest to investigate the behavior of these same lines on the

[1] *Ap. J.*, **78**, 73, 1933.

[2] *Ap. J.*, **83**, 109, 1936.

[3] *Ap. J.*, **83**, 439, 1936.

[4] *The Stars of High Luminosity* (Cambridge, Mass.: Harvard College Observatory, 1930), p. 268.

[5] The differences in the results from visual estimates and from the microphotometric measures can be accounted for by consideration of the inclusion of more of the wings of the lines in the latter than in the former. When very low dispersion is used, the visual intensity of strong lines is probably closer to the measures.

[6] *Ap. J.*, **78**, 82, 1933.

system of spectral classification described in the Yerkes spectral atlas.[7, 8] For this purpose the results of Rudnick were used, since a better selection of stars of different luminosity is possible than in the case of the measures of Williams. The spectral types were determined from plates taken with the parallax spectrograph attached to the 40-inch refractor of the Yerkes Observatory; they are on what will be described as the "revised Yerkes system." This system is very close to that of the Yerkes *Atlas of Stellar Spectra;* the changes are slight revisions in spectral type which have been possible because of the improved quality of spectrograms obtained during the past few years. For the main sequence the stars included are those in Rudnick's list of luminosity classes IV and V; the supergiants are those of luminosity classes I*a* and I*b*. Table 1 gives the

TABLE 1

EQUIVALENT WIDTHS (A) FOR MAIN SEQUENCE (RUDNICK)

Star	Sp. (RYS)*	λ 4471	λ 4387	λ 4144
ξ Per	O7	0.59	0.20	0.12
S Mon	O7	0.51	.21	.14
λ Ori	O8	0.61	.21	.11
10 Lac	O9 V	0.81	.32	.19
τ Sco	B0 V	1.07	.60	.37
ε Per	B0.5 V	1.41	.80	.53
γ Peg	B2 IV	1.42	.92	.69
δ Cet	B2 IV	1.36	.91	.76
θ Oph	B2 IV	1.13	.71	.59
ζ Cas	B2 V	1.42	.97	.78
102 Her	B2 V	1.14	.81	.58
η Aur	B3 V	1.06	.59	.55
η UMa	B3 V	1.08	.64	.47
ι Her	B3 V	1.18	.82	.66
π And	B5 V	0.84	.54	.45
λ Cyg	B5 V	0.74	.50	.35
2 Lac	B6 IV	0.69	27	.26
ζ Peg	B8 V	0.29	.18	.05
ι And	B8 V	0.26	.25	.13
α Del	B9 V	0.34	0.30	0.14

* Revised Yerkes system.

data for the main-sequence stars and Table 2 those for the supergiants. The columns list the name of the star, the spectral type on the revised Yerkes system, and the equivalent width in angstroms of the diffuse triplet λ 4471 and of the diffuse singlets λ 4387 and λ 4144. The results are plotted in Figure 1, *a*, where the open circles refer to the supergiants and the closed circles to main-sequence stars.

The following conclusions can be drawn from an inspection of Figure 1, *a:*

a) There is a well-defined maximum for λ 4387 and λ 4144 at class B2 for the main-sequence stars and a less well-defined maximum near the same point for the supergiants.

b) The maximum for λ 4471 is also near B2 or slightly earlier.

c) The behavior of λ 4471 in the supergiants is quite different from that of λ 4387 and λ 4144, in that the intensity appears to increase with increasing temperature as far as the earliest supergiants plotted—of spectral type O9.5. At this spectral type there is probably a slight enhancement of λ 4471 with increasing luminosity.

[7] W. W. Morgan, P. C. Keenan, and E. Kellman, *An Atlas of Stellar Spectra* (Chicago: University of Chicago Press, 1943).

[8] See also W. W. Morgan and N. G. Roman, *Ap. J.*, **112**, 362, 1950.

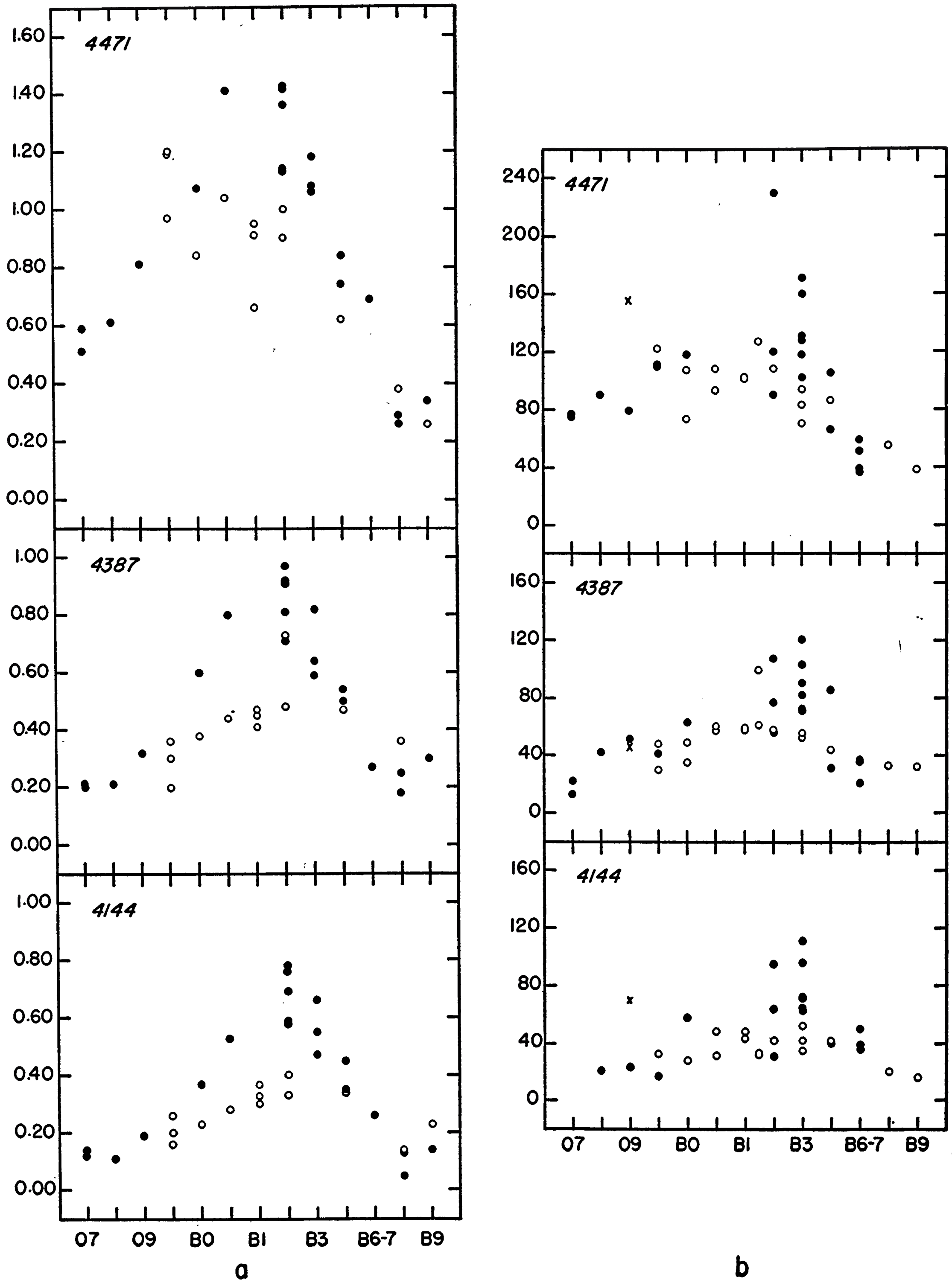

FIG. 1.—*a*, intensities of the *He* I lines λλ 4471, 4387, and 4144 (Rudnick) as a function of spectral type on the revised Yerkes system. Ordinates are equivalent widths in angstroms. Open circles refer to supergiants, filled circles to main-sequence stars. *b*, intensities of the same lines as determined by Williams. The cross refers to the peculiar **O star** HD 93521.

TABLE 4

ELEMENTS OBSERVED

Element	I.P.	Fr. Line	Bl. Line	Max. Int.	Notes
1 *H*	13.54	3	...	14	
4 *Be* I	9.28	1	...	0	Probably a chance coincidence
11 *Na* I	5.12	3	5	6	
12 *Mg* I	7.61	4	4	10	
14 *Si* I	8.11	1	...	10	
19 *K* I	4.32	1	1	8	
20 *Ca* I	6.09	15	18	100	
21 *Sc* I	6.7	5	12	8	
Sc II	12.8	5	13	(9)	
22 *Ti* I	6.81	129	222	10	
Ti II	13.6	32	55	9	
23 *V* I	6.71	67	127	10	
V II	14.1	18	31	7	Several chance coincidences
24 *Cr* I	6.74	189	260	20	Some coincidences may be due to chance
Cr II	16.6	16	12	3	The majority are chance coincidences
25 *Mn* I	7.40	34	36	25	
Mn II	15.6	1	...	2	Only a chance coincidence
26 *Fe* I	7.86	442	494	60	Some coincidences may be due to chance
Fe II	16.16	17	24	7	Some coincidences may be due to chance
27 *Co* I	7.84	49	72	10	Some coincidences may be due to chance
28 *Ni* I	7.61	64	81	8	Some coincidences may be due to chance
29 *Cu* I	7.69	...	1	...	Only a chance coincidence
30 *Zn* I	9.35	2	2	3	Chance coincidences?
31 *Ga* I	5.97	...	2	(1)	Chance coincidences?
32 *Ge* I	8.09	1	1	?	Chance coincidences?
38 *Sr* I	5.67	2	5	3	Some coincidences may be due to chance
Sr II	10.98	2	2	12	
39 *Y* I	6.5	11	14	5	
Y II	12.3	5	10	(7)	
40 *Zr* I	6.92	20	39	6	Some coincidences may be due to chance
Zr II	13.97	21	21	7	Several chance coincidences
41 *Cb* I	6.8	3	7	(3)	Some coincidences are due to chance
42 *Mo* I	7.06	1	...	1	Probably a chance coincidence
Mo II	?	1	...	3	Only a chance coincidence
44 *Ru* I	7.5	5	6	1	Several chance coincidences
45 *Rh* I	7.7	...	2	(0)	Chance coincidences
46 *Pd* I	8.30	...	1	(0)	Chance coincidence
55 *Cs* I	3.88	1	1	?	Chance coincidences?
56 *Ba* II	9.96	3	3	8	
57 *La* I	5.59	1	3	(1)	Chance coincidences?
La II	11.38	19	26	5	Several coincidences may be due to chance
58 *Ce* II	?	55	76	4	Several coincidences may be due to chance
59 *Pr* II	?	17	29	4	Some coincidences may be due to chance
60 *Nd* II	?	40	54	7	Some coincidences may be due to chance
62 *Sm* II	11.4	45	68	5	
63 *Eu* I	5.64	...	2	...	Chance coincidences
Eu II	11.21	1	6	9	Some coincidences may be due to chance
64 *Gd* I	6.16	1	1	0	Chance coincidences
Gd II	?	30	44	(4)	Several coincidences are due to chance
65 *Tb* II	?	3	5	...	
66 *Dy* II	?	4	6	...	
67 *Ho* II	?	...	2	...	Chance coincidences?
72 *Hf* II	14.8	11	5	2	Several coincidences are due to chance
74 *W* I	7.94	2	2	(2)	Chance coincidences?
76 *Os* I	8.7	1	3	(1)	Chance coincidences?
82 *Pb* I	7.38	...	1	(8)	

The effects noted above appear to be confirmed by the measures of Williams, although the scatter is rather large. Williams' observations are listed in Tables 3 and 4 and are plotted in Figure 1, *b*.

Especial attention should be called to the star HD 93521, which has an abnormally high intensity of λ 4471 for its spectral type. The intensity of λ 4471 is similar to that in

TABLE 4

EQUIVALENT WIDTHS (A) FOR SUPERGIANTS (WILLIAMS)

HD No.	Sp. (RYS)	λ 4471	λ 4387	λ 4144
30614	O9.5 I*a*	111	30	33
195592	O9.5 I*a*	122	48	(52)*
37128	B0 I*a*	73	35	28
204172	B0 I*b*	107	49	....
38771	B0.5 I*a*	108	57	48
194839	B0.5 I*a*	93	60	31
24398	B1 I*b*	101	59	48
91316	B1 I*b*	102	58	43
190603	B1.5 I*a*	(86)	61	32
194279	B1.5 I*a*	127	99	33
206165	B2 I*b*	108	57	42
14134	B3 I*a*	70	....	52
198478	B3 I*a*	83	52	35
36371	B3 I*b*	94	55	42
164353	B5 I*b*	86	44	42
34085	B8 I*a*	55	33	20
21291	B9 I*a*	38	32	16

* Values in parentheses are of lower accuracy.

main-sequence stars of classes B2 and B3, where the line reaches its greatest strength. It is of interest that HD 93521 is the only O-type star observable in northern latitudes which is located far above the galactic plane; the distance is approximately 800 psc. It thus may have some connection with Baade's Population II, and the spectral peculiarities may be associated with stars of the earliest type belonging to that category.

In conclusion, I wish to express my sincere thanks to Dr. W. W. Morgan for suggesting this problem and for his helpful advice and to Miss Irene Hansen for her kind assistance with the illustration.