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THE HELIUM-WEAK STARS

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ABSTRACT

In an extensive investigation of spectral classification, the class of helium-weak stars is described. Their spectra are found to resemble the Bp-type stars with the distinction that the helium-weak group does not have the profuse and strongly enhanced metal lines characteristic of the Bp stars. In a quantitative analysis using model atmospheres, several helium-weak stars are found to have apparent helium deficiencies ($N_{\rm He}/N_{\rm H} \approx 0.02$). On the other hand, HD 37129, HD 36629, and HD 37807, previously classified as "helium-weak," appear to be normal early B-type stars—a conclusion which was also found by Norris.

I. INTRODUCTION

In recent years attention has been drawn by several investigators (Sargent and Strittmatter 1966; Bernacca 1968; Garrison 1967; Jaschek, Jaschek, and Arnal 1969) to a group of Population I B-type stars with helium lines too weak for their colors. A prototype of the helium-weak group is described by Keenan, Slettebak, and Bottemiller (1969), who call attention to the peculiar B-type star HD 191980. Assigning a spectral type to this star is difficult because certain spectral features yield different classifications. The Balmer lines give B5; C II λ4267, B3; the ratio He I λ4471/Mg II λ4481, B8; He I λ4026, B7. In addition to these peculiarities, HD 191980 has the colors of a B3 V star or slightly later. If this anomalous star were classified according to its helium lines, the star would have colors too blue for the spectral type. Conversely, if HD 191980 were classified according to its colors, it would have helium lines too weak for the classification; hence, a "helium-weak" star. Stars like HD 191980 strongly resemble the Bp-type (hot Ap) stars which also have spectrum-color anomalies; however, the helium-weak stars *at classification dispersions* (>60 Å mm^{-1}) do not show the strong peculiar metal lines which characterize the Bp–Ap stars.

This investigation of the helium-weak stars is in two parts. The first examines the peculiar group through spectral classification to define qualitatively the class and search for new members. It will be necessary to define the "helium-weak" anomaly which apparently changes in meaning with different investigators. In § II the spectral-classification program is described, with the results containing several new members and a description of this class.

The second part of this work quantitatively examines several of the known helium-weak stars which include some members not investigated by Norris (1971*a*). In § III the observations are given, including scanner data of the stellar continua and coudé spectra for equivalent widths and hydrogen line profiles. These data are used in § IV for a model-atmosphere analysis, to obtain the effective temperatures and gravities. In addition, an abundance determination is made for helium and several metals. The results and implications of this work are discussed in §§ V and VI.

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II. SPECTRAL CLASSIFICATION

Upon investigating the helium-weak stars, one finds that the class has not been defined and that there is considerable confusion as to what constitutes a helium-weak star. This problem is magnified in view of the fact that the Bp stars also exhibit the helium-weak phenomenon (Hyland 1967). Thus, in defining the helium-weak stars it also must be determined whether these stars constitute a truly unique class.

In this work the helium-weak stars were compared with normal and peculiar (Bp) stars in order to make an extensive and thorough investigation. The program stars consisted of MK standards to define the classes, other normal stars for comparison, Bp stars such as silicon stars, and known helium-weak stars. In addition to these objects, suspected new helium-weak stars were included. The *Catalog of Bright Stars* (Hoffleit 1964) was searched for stars with spectrum-color discrepancies such that the observed $B - V$ indicated a star abnormally too blue. The spectral class inferred from the color had to be earlier by two-tenths of a spectral type. This criterion for spectrum-color discrepancy avoids the intrinsic scatter in the colors of a given class. The program list contained about 90 stars.

Five nights were granted by Kitt Peak National Observatory to use the Cassegrain spectrograph on the No. 1 36-inch (91 cm) telescope. A grating ruled with 830 lines mm^{-1} was used in second order to give 63 Å mm^{-1} dispersion with Hγ centered on the plate. The spectra were widened to 1.2 mm with a projected slit width of $\sim$10 μ (1''.75). The unbaked IIa-O plates containing three spectra each were developed in D-76 for 13 minutes and fixed in rapid hypo for 3 minutes. The densities of the spectra for the program and standard stars were kept uniform by using an exposure meter on the spectrograph.

The various program stars were classified and compared by superposing plates. Several MK criteria were judged in assigning a temperature class such as (*a*) the strength of the Ca II K-line; (*b*) He I λ4471/Mg II λ4481; (*c*) strength of He I λ4144 and C II λ4267. The luminosity class was based upon the profiles of the Balmer lines and the He I λ4120/He I λ4144 (triplet: singlet) ratio. An object showing the presence of any abnormal line strengths of metals, such as silicon or strontium, was noted as peculiar. Most of these stars were classified at least four times, and the finally adopted classification is given in table 1 along with any pertinent comments. The photometry in this table is from Crawford (1963) and Blanco *et al.* (1968). S_Q is the photometric classification derived from the Q-method (Johnson and Morgan 1953). This is given to show spectrum-color discrepancies.

From this comparison of spectral classification, one can make several observations about the helium-weak stars. The first is that these stars do not share the distinguishing characteristic of the Bp stars, namely, abnormally enhanced metal lines such as Si, Sr, or Mn. Here a distinction must be drawn between the slightly enhanced Si II λλ4128–4130 lines in HR 1063, a well-known helium-weak star, and the strongly enhanced lines in a silicon star such as θ Aur. It also should be noted that no other peculiar lines are seen at the 63 Å mm^{-1} dispersion used in this work; however, this does not preclude the possibility that peculiar lines may be found at higher dispersion.

In comparing the helium-weak stars with normal stars, further conclusions are drawn. Although these anomalous stars are usually classified as late B giants, the helium-weak stars are very different from any late B-type star. A salient feature of the helium-weak spectrum is the profile of the hydrogen lines, which is indicative of the spectral type inferred from the intrinsic colors. Garrison (1971) further notes that these profiles are perhaps not truly normal for an early main-sequence B star, as found in this work, but that the wings may show an abrupt cutoff. In addition to the hydrogen lines, the Ca II K-line, Si III λ4552, and C II λ4267 are also indicative of an early B star rather than a late B star.

A helium-weak star can thus be described by the following criteria: (*a*) there must

TABLE 1

SPECTRAL CLASSIFICATION

HR	NAME	HD	B-V	U-B	S_Q	MK	COMMENTS
123	14 λCas	2772	-0.10	-0.33	B8	B8 V	1
345	32 Cas	6972	.10	.29	B8	B9 IV	1
364	87 Psc	7374	.07	.42	B7	B9 III	
477	53 τAnd	10205	.10	.41	B7	B8 III	
548	46 ωCas	11529	.09	.41	B7	B8 III	
677		14272	.10	.40	B7	B8 III	
746		16004	.10	.34	B8	B9.5 IIIp	Hg?
838	41 Ari	17573	.11	.35	B8	B8 V	
950		19736	.09	.57	B4	B4 V	3
1063		21699	.10	.57	B4	B9 III	helium-weak
1144	18 Tau	23324	.07	.36	B7	B8 V	standard
1149	20 Tau	23408	.07	.40	B7	B7 III	
1165	25 ηTau	23630	.09	.33	B8	B7 III	standard
1178	27 Tau	23850	.08	.36	B7	B8 III	standard
1315		26793	.08	.35	B7	B8 Vn	
1415		28375	.11	.54	B5	B5 V	3
1510		30085	.08	.25	B9	B9 III	
1696	3 ιLep	33802	.10	.43	B8	B8 V	
1753		34798	.13	.58	B5	B5 V	1,2,3
1754		34797	.12	.44	B7	B8 III	2
1791	112 βTau	35497	.13	.48	B6	B7 III	standard
1944		37643	.12	.41	B7	B8 V	1
1945		37646	.11	.39	B7	B8 V	1
1956	αCol	37795	.12	.45	B6	B8 Vn	1
1957		37808	.16	.53	B6	B9.5 III	1
2095	37 θAur	40312	.08	.14	B9.5	B9 Vp	silicon
2130	64 Ori	41040	.11	.44	B7	B8 III	
2139		41269	.08	.30	B8	B9 Vp	Sr-Cr
2167		42035	.04	.20	B9	B9 V	
2193	68 Ori	42509	.06	.15	B9.5	B9.5 V	
2223	72 Ori	43153	.16	.47	B7	B7 V	
2248		43526	.14	.50	B6	B8 V	
2306		44953	.15	.65	B4	B8 III	helium-weak
2309		44996	.08	.64	B3	B5 Ve	3
2433		47247	.11	.55	B5	B5 V	3
2461		47964	.09	.34	B8	B9 III	
2519	33 Gem	49606	.12	.52	B5	B9 III	helium-weak
2605	40 Gem	51688	.08	.51	B5	B8 IV	helium-weak
2613		51892	.10	.48	B6	B7 V	
2669		53744	.09	.26	B8	B8 V	1
2676		53929	-0.14	-0.46	B7	B9.5 III	1
2760		56446	.12	.40	B7	B8 Vn	1
2801		57608	.10	.26	B9	B9 IV	1
2809		57742	.09	.20	B9	B9 V	1
2844		58661	.10	.42	B7	B9 IIIp	1 Sr
3059	13 ζCMi	63975	.12	.46	B7	B9 III	
3201		68099	.12	.41	B7	B8 III	
3470		74604	.11	.41	B7	B8 V	
3479		74824	.16	---	--	B2 III	3
3652	36 Lyn	79158	.14	.46	B7	B9 IIIp	silicon
3656		79241	.12	---	--	B6 V	3
3665	22 θHya	79469	.06	.12	B9.5	A0 Vp	(weak-lines)
3683	24 Hya	79931	.05	.34	B7	B9 V	
3745		81753	.11	.60	B4	B6 V	3
3774		82327	.10	.34	B8	B9 V	
4468	21 θCrt	100889	.06	.20	B9	B9 V	
4494	o Hya	101431	.08	.21	B9	B9 V	
4552	β Hya	103192	.10	.32	B8	B9 IIIp	silicon
4612		105078	.08	---	--	B8 V	
4662	4 γCrv	106625	.11	.36	B7	B8 III	
4696	5 ζCrv	107348	.11	.39	B7	B8 Vn	
4787	5 κ Dra	109387	.13	.55	B5	B7 Vne	1
4857		111226	.04	.46	B5	B8 III	1
4943	14 CVn	113797	.08	.20	B9	B9 V	1
4967	15 CVn	114376	.10	.50	B5	B7 III	1
5250	47 Hya	121847	.10	.40	B7	B8 Vp	1 shell
5313		124224	.11	.38	B7	B9 IVp	1 silicon
5597		133029	.07	.26	B8	Ap	silicon
5653		134837	.08	---	--	B8 V	
5685	27 βLib	135742	.11	.37	B7	B8 V	
5731		137389	.07	.15	B9.5	B9 V	
5778	4 θCrB	138749	.13	.55	B5	B6 Vn	
5931		142763	.09	.46	B6	B7 III	
5938	4 Her	142926	.12	.42	B7	B8p	shell
5941	48 Lib	142983	.09	.53	B5	B6p	shell
6079	19 UMi	146926	.15	.46	B7	B8 III	
6396	22 ζDra	155763	.11	.42	B7	B7 III	
7073		173936	.12	.41	B7	B6 V	3
7118		175132	.09	.32	B8	B9 IIIp	silicon
7174		176318	.17	.52	B6	B7 V	
7224		177410	.15	.54	B5	B9.5 IIIp	silicon
7381		182691	.08	.37	B7	B9 IV	
7401		183339	.15	.54	B5	B8 IV	1 helium-weak
7437	9 Vul	184606	-0.12	-0.42	B7	B7 V	1
7452		184961	.04	.30	B7	B9 IVp	1 silicon
7457	11 Cyg	185037	.10	.42	B7	B8 Vn	1
7721		192276	.12	.46	B6	B8 III	
8535		212454	.12	.56	B5	B8 IIIp	Hg II 3984 Å
8770		217833	.08	.56	B4	B9 III	helium-weak

COMMENTS TO TABLE 1

1. These stars were classified only twice, so their MK types are less reliable than the others which are classified at least four times.
2. The correct photometry from Blanco *et al.* (1968) is given.
3. The HD type was B8 or B9.

be at classification dispersions no enhanced or peculiar metal lines as in the Si or Mn-Hg stars; (*b*) the hydrogen line profiles and metal line strengths such as Ca II K, Si III λ4552, and C II λ4267 are indicative of the intrinsic colors; and (*c*) the spectral type according to the helium lines is later by at least two-tenths than the type inferred from the colors. Using this definition, several new helium-weak stars were found. These are HR 2306, 2519, 2605, 7401 and 8770.

20 Tauri, HD 37807, HD 37129, and HD 36629, which have been reported as helium-weak, do not fit this definition. McNamara and Larsson (1962) pointed out that HD 37807 and HD 36629 have helium lines too weak for their colors. Sharpless (1952) noted that HD 37129 has weak helium lines, although no inference was made about the star's colors. The peculiarities of 20 Tau have been described by Huang and Struve (1956). This investigation, however, finds 20 Tau to be a late B giant with many faint metal lines, and the other stars are apparently normal early B stars. These stars will be further discussed below.

In searching for new helium-weak stars, it was noted that a number of stars with late-B HD types are early B stars (B2–B5). Some of these include HR 950 (B4 V); HR 1415 (B5 V); HR 1753 (B5 V); HR 2309 (B5 Ve); HR 2433 (B5 V); HR 3479 (B2 III). Finding so many of these stars may be noteworthy; the implications of this will be discussed later.

III. OBSERVATIONS FOR ATMOSPHERIC ANALYSIS

The University of Wisconsin rapid scanner mounted on the 36-inch telescope was used to obtain continuum energy distributions and equivalent widths of Hβ and Hγ for several of the brighter program stars. Table 2 lists the program stars selected from the literature as being "helium-weak" plus HR 8770, a new helium-weak star, and HR 8535, a Bp star, were added from the spectral classification investigation of this work. HR 8535 was included because its spectrum is remarkably similar to helium-weak stars, except for the presence of the conspicuous Hg II line at 3984 Å.

The continuum scans covered 3300–4660 Å at 20 Å resolution. Oke (1964) standard stars were used for extinction and for the instrumental transformation. The data were reduced relative to 4176 Å by averaging over five data points (40 Å) centered on each wavelength. These results are given in table 3, where *n* signifies the number of nights

TABLE 2

SCANNER PROGRAM STARS

Star	V	$(B-V)_0$	$(U-B)_0$	$E(B-V)$	MK	Source
HD 191980...	8.04	−0.22	−0.67	0.02	B8 p	Keenan *et al.* 1969
HR 8770.....	6.38	−0.13	−0.63	0.10	B9 III	Crawford 1963
HR 8535.....	6.16	−0.14	−0.59	0.04	B8 IIIp	Crawford 1963
HR 1063.....	5.46	−0.14	−0.62	0.07	B9 III	Crawford 1963
20 Tau.......	3.86	−0.13	−0.44	0.06	B7 III	Blanco *et al.* 1968
HD 37129....	7.13	−0.20	−0.79	0.07	B2 V	Sharpless 1962
HD 37807....	7.92	−0.15	−0.73	0.11	B2 V	Sharpless 1962
HD 36629....	7.66	−0.23	−0.86	0.25	B2 V	Sharpless 1962
HD 36919....	10.6	−0.11	−0.51	0.01	B8 III	Morgan and Lodén 1966

TABLE 3

MONOCHROMATIC MAGNITUDES $m(1/\lambda)$

STAR	n	λ(Å) 3390	3448	3509	3571	3636	3704	4032	4167	4255	4464	4566
HD 191980....	3	0.33	0.24	0.35	0.32	0.33	0.35	−0.03	0.00	0.03	0.06	0.09
		±0.05	±0.03	±0.03	±0.03	±0.01	±0.01	±0.01		±0.01	±0.01	±0.01
HR 8535......	3	0.41	0.38	0.42	0.42	0.42	0.44	−0.04	0.00	0.00	0.04	0.05
		±0.01	±0.01	±0.01	±0.01	±0.01	±0.01	±0.01		±0.01	±0.01	±0.01
HR 8770......	3	0.35	0.37	0.36	0.39	0.40	0.41	−0.05	0.00	0.00	0.01	0.03
		±0.01	±0.03	±0.01	±0.01	±0.02	±0.01	±0.01		±0.01	±0.01	±0.02
HR 1063......	6	0.36	0.36	0.39	0.40	0.41	0.43	−0.03	0.00	0.00	0.02	0.03
		±0.01	±0.02	±0.02	±0.02	±0.01	±0.01	±0.01		±0.01	±0.01	±0.01
20 Tau........	5	0.61	0.63	0.64	0.65	0.66	0.57	−0.01	0.00	0.00	0.02	0.03
		±0.02	±0.01	±0.01	±0.01	±0.01	±0.02	±0.01		±0.01	±0.01	±0.01
HD 36919.....	3	0.57	0.52	0.48	0.51	0.44	0.49	−0.04	0.00	0.00	0.05	0.05
		±0.03	±0.02	±0.03	±0.04	±0.03	±0.02	±0.01		±0.01	±0.01	±0.03
HD 36629.....	2	0.30	0.28	0.28	0.26	0.23	0.29	0.00	0.00	0.00	0.03	0.03
		±0.05	±0.01	±0.01	±0.04	±0.02	±0.01	±0.01		±0.01	±0.01	±0.01
HD 37807.....	2	0.34	0.40	0.35	0.37	0.34	0.35	−0.03	0.00	0.00	0.02	0.05
		±0.06	±0.05	±0.02	±0.03	±0.02	±0.02	±0.01		±0.01	±0.02	±0.02
HD 37129.....	2	0.30	0.26	0.23	0.25	0.23	0.26	0.02	0.00	0.00	0.07	0.06
		±0.01	±0.02	±0.01	±0.01	±0.01	±0.01	±0.02		±0.01	±0.01	±0.01

the star was scanned. Five of these program stars were also scanned for equivalent widths of Hβ and Hγ at a resolution of 20 Å. Sampling was done at every 5 Å for smoothing of the data. Table 4 gives these scanner equivalent widths with several comparisons for Hγ from coudé spectra in this investigation and from other sources. In the model-atmosphere analysis the coudé equivalent widths were used, if available, rather than the less accurate scanner equivalent widths.

An important problem in reducing the scanner observations of the continuum distributions is the correction for interstellar extinction. If there was no other means to calculate the color excess, the Q-method was used (Johnson 1958). For HD 191980, however, the color excess was derived by Keenan *et al.* (1969), who used a normal star in the same field to derive the reddening. For HD 37129, HD 37807, and HD 36629 the average color excess derived from the cluster is used (Sharpless 1962). There is good agreement for these stars between the $E(B - V)$ derived from the cluster and that from the Q-method; e.g., for HR 1063 in the α Persei cluster, the $E(B - V)$ from S_Q is 0.07 and the mean for the cluster is 0.08 (Mitchell 1960). These $B - V$ color excesses, for which the scanner data were corrected, are given in table 2 along with the colors and sources. The scans were also corrected to the Oke and Schild (1970) system of relative fluxes for α Lyr.

Coudé spectrograms for all but the first three stars in table 2 were taken on the Kitt Peak National Observatory 84 inch telescope to obtain equivalent widths and profiles of Hγ. Unbaked IIa-O plates were developed in D-76. The usable wavelength range was 3800–4600 Å. For maximum efficiency in taking spectra, a dispersion of 8.9 Å mm^{-1} was used for stars brighter than 6 mag and 13.5 Å mm^{-1} was used for fainter stars.

The plates were reduced at Kitt Peak on the Hilger-Watts transmission microphotometer. The works of Hack (1969) and Wright *et al.* (1964) were used for line identifications. The latter work was also used for a comparison of equivalent widths using γ Gem as a standard star. The graph in figure 1 shows the equivalent widths of this work compared with those of Wright *et al.*, indicating that the continuum in this investigation was placed lower than theirs giving values smaller by 10–15 percent. The important line equivalent widths and identifications for the program stars are presented in table 5; a complete list can be obtained from the author. A "P" signifies that the line is present but too weak to be measured or blended with other lines, and a "P?" indicates that the identification of the line is in question.

IV. MODEL-ATMOSPHERE ANALYSIS

The corrected scanner data were used to determine the size of the Balmer discontinuity. Ordinarily, the difference of the two continua extrapolated to 3647 Å determines this parameter, but in this work the difference between the two continua at 3647 Å and 4142 Å was used to define the magnitude of the Balmer discontinuity:

$$m_{\rm B} = m(1/3647) - m(1/4142) .$$

TABLE 4

SCANNER EQUIVALENT WIDTHS (Å)

Star	Hβ	Hγ	Hγ	Comparison Source
HD 191980....	...	7.3	7.2	Keenan *et al.* 1969
HR 8770......	6.1	6.9	...	
HR 8535......	5.9	6.7	...	
HR 1063......	6.1	7.0	6.77	This work (coudé)
20 Tau........	5.9	6.4	6.28	Huang and Struve 1956
			6.36	This work (coudé)

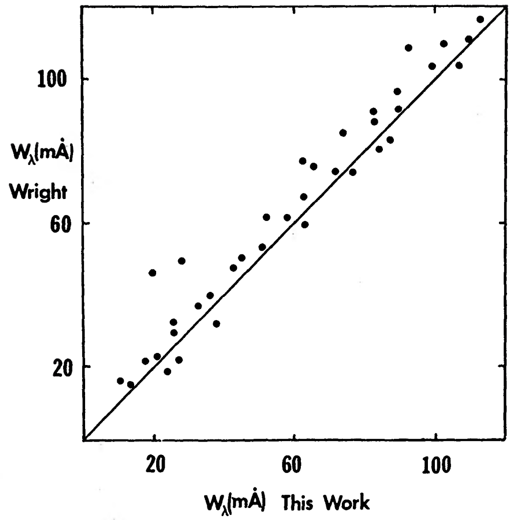

FIG. 1.—Comparison of equivalent widths for γ Gem from Wright *et al.* (1964) and this investigation

TABLE 5

EQUIVALENT WIDTHS (mÅ)

λ	Atom and Multiplet	HR 1063	20 Tau	HD 36919	HD 37129	HD 37807	HD 36629
4552.65.....	Si III, 2	038	...	...	059	034	110
4481.23.....	Mg II, 4	230	175	241	241	219	244
4471.53.....	He I, 14	390	158	361	1580	1220	1370
4437.54.....	He I, 50	P?	034	030	189	114	174
4387.93.....	He I, 51	...	064	190	860	603	819
4340.47.....	Hγ, 1	6770	6360	6500	5030	5400	5000
4267.15.....	C II, 6	115	079	076	200	197	242
4200.78.....	Si II, ...	055	...	...	...	...	...
4143.76.....	He I, 53	P	150	030	695	526	690
4130.88.....	Si II, 3	172	074	130	116	112	026
4128.05.....	Si II, 3	194	064	075	066	075	026
4120.90.....	He I, 16	100	036	046	269	230	249
4101.74.....	Hδ, 1	6430	6190	6610	4780	5390	4330

This simple parameter facilitates the model-atmosphere analysis. These wavelengths are given by the model-atmosphere grid ATLAS (Kurucz 1969), and the scanner data were interpolated for these two wavelengths. This parameter is much more temperature sensitive than either of the continuum slopes covered by the scans, and only slightly reddening dependent. Although the slope of the Balmer continuum becomes very sensitive to temperature in the B stars, it is drastically affected by the slightest errors in the color excess. For these reasons the continuum slopes were not included to determine the effective temperatures and gravities; however, they do fit the model solutions determined from the Hγ equivalent width and m_B within the probable errors. These solutions are given in table 6 with the estimated errors.

The Hγ profile using ESW theory (Edmonds, Schlüter and Wells 1967) in the ATLAS grid was computed for four of the program stars from the results of the model analysis and these are shown in figure 2. The profile agreement is good, with the exception of

TABLE 6

DERIVED T_{eff} AND LOG g

Name	$T_{eff} \times 10^{-3}$ ° K	log g
HD 191980....	17.9±0.6	4.0±0.2
HR 8535......	16.6±0.6	3.7±0.2
HR 8770......	17.5±0.6	4.0±0.2
HR 1063......	16.6±0.4	3.9±0.15
20 Tau........	14.0±0.5	3.4±0.15
HD 36919.....	15.6±0.6	3.6±0.2
HD 36629.....	23.3±0.7	4.0±0.2
HD 37129.....	22.7±0.7	4.0±0.2
HD 37807.....	19.0±0.7	3.8±0.2

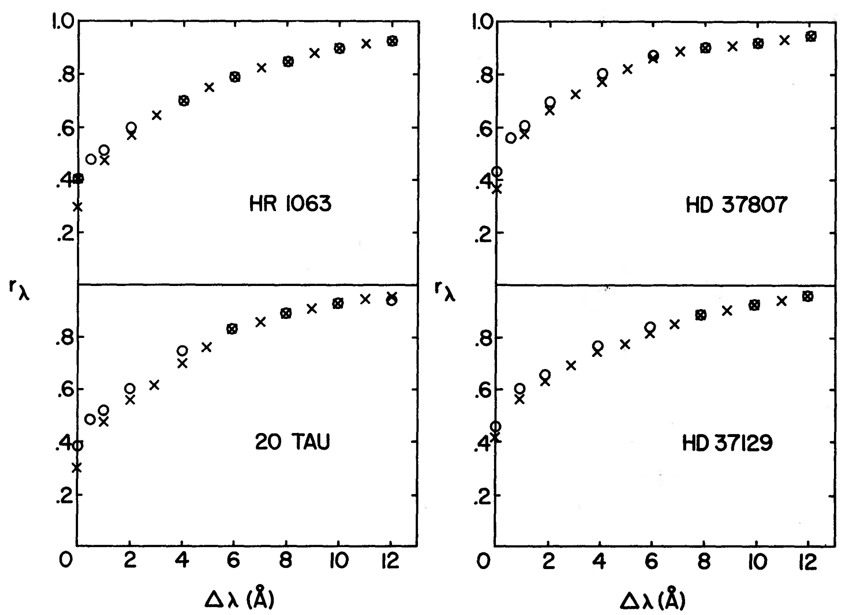

FIG. 2.—Observed (×) Hγ profiles and theoretical (○) profiles from ATLAS using ESW theory

20 Tau for which there is agreement in the wings but not toward the core. No instrumental corrections have been applied; thus, any discrepancies toward the core may be greater. On the other hand, the agreement is good for HR 1063 (B9 III) which indicates that the profile is for an early B star, not a late B giant.

With T_{eff} and log g determined from the model-atmosphere solution, an analysis of the abundances of silicon, carbon, and magnesium was made by using the Mihalas and Henshaw (1966) computed equivalent widths for C II λ4267; Mg II λ4481; Si II λλ4128–4130, 4200; and Si III λ4552. In their analysis, these equivalent widths were calculated for a run of effective temperatures and gravities that had to be extrapolated slightly to accommodate two of the hottest program stars. Although the model analysis in this work was done with ATLAS, the two models do not differ greatly in structure so that the ATLAS solution can be used with the Mihalas and Henshaw equivalent widths without incurring serious error (Molnar 1971). This is further supported by the good agreement between the abundances derived from the Si II and Si III lines, indicating that this analysis is self-consistent. The first part of table 7 lists for each line the logarithm of the abundance relative to a "normal" cosmic abundance (Goldberg, Müller, and Aller 1960) with a probable error of ± 0.3. One should note that microturbulence is not included in these computations for the metal lines, though this is not important for the helium lines whose broadening is dominated by thermal and collisional processes.

The helium abundances in the second part of table 7 were calculated from the equivalent widths computed by Shipman and Strom (1970) for He I λ4471 using ATLAS models and by Norris and Baschek (1970) for λλ4437 and 4120 using several different models. The agreement between these two investigations is evidently good, and the probable error for N_{He}/N_H is slightly less than ± 0.02. It is assumed, however, that these helium abundances can be represented by a standard LTE abundance determination.

V. SUMMARY OF RESULTS

The Morton and Adams (1968) (T_{eff}, spectral type)-scale for the main sequence was examined to see how this investigation compared with their effective-temperature scale for two normal standard stars, α Leo (B7 V) and η Hya (B3 V). The analysis determined T_{eff} to be 13.8×10^3 ° K for the B7 V star and 19.0×10^3 ° K for the B3 V star, which, according to the Morton and Adams scale, correspond to B7 V and B2 V, respectively. On their temperature scale, a B3 V is 17.9×10^3 ° K. The effective temperatures in this work are slightly too hot relative to Morton and Adams; however, there is agreement to within one-tenth of a spectral type.

Examining the results, one notices that there are apparently two distinct groups of stars. The first includes HD 191980, HR 8770, HR 1063, and HD 36919, which are helium-weak stars, and HR 8535, a Bp (Hg type) star. These stars are characterized by a spectral type which disagrees with the colors and T_{eff} by as much as five-tenths of a spectral type. According to the abundance analysis for the first three of these stars the helium appears to be deficient as indicated by the anomalous late-B spectral type derived from the weak helium lines.

The second group is composed of HD 37129, HD 37807, and HD 36629 which are evidently normal early B-type stars; that is, there is no significant discrepancy between the colors, T_{eff}, Hγ profile, or the spectral type. The results further show that these parameters agree within one-tenth of a spectral type and the helium abundances are not deficient. If these stars are apparently normal early B stars, one wonders why they were called helium-weak. HD 37129 is even used as an MK standard (Abt *et al.* 1968) classified as a sharp-line B2 V. Perhaps this star can be understood to be a "helium-weak" star. Morgan (1969) points out that the He I λ4009 is rather weak for a main-sequence B2 star. This line is a singlet which shows an inverse (weakening) effect at B2 with in-

TABLE 7

ABUNDANCES

	log ($N_{OBSERVED}/N_{COSMIC}$)						He I (N_{He}/N_H)		
			Si II						
NAME	C II λ4267	Mg II λ4481	λ4128	λ4130	λ4200	Si III λ4552	λ4471	λ4437	λ4120
20 Tau......	0.0	−0.6	−0.7	−0.7	...	...	0.01	0.06	0.01
HD 36919...	−0.6	0.0	−0.3	+0.2	...	...	0.03	0.02	0.01
HR 1063....	−0.3	0.0	+0.8	+0.6	0.7	0.7	0.02	0.015	0.03
HD 36629...	−0.3	+0.4	0.0	+0.0	...	0.2	0.10	0.15	0.10
HD 37129...	−0.5	+0.4	+0.3	+0.6	...	0.2	0.11	0.10	0.13
HD 37807...	−0.3	+0.2	0.0	+0.3	...	0.3	0.10	0.11	0.10

creasing luminosity (decreasing log g) compared with the triplets. Otherwise, HD 37129 is a "normal" B2 V with normal colors. Norris (1971*a*), on the other hand, finds a high log g ($\approx$4.45) for HD 37129 and the other Orion "helium-weak" stars and further notes that both singlets and triplets are slightly weak. He, however, concludes that these stars are only slightly helium deficient.

The star 20 Tau appears to be a peculiar case. Unlike a helium-weak star, it has normal colors for its spectral type; however, the apparent helium abundance is low although there is considerable scatter in the analysis. The effective temperature and log g compare with the results of Norris (1971*a*), who finds $T_{\rm eff} = 13600°$ K and log $g = 3.4$. The equivalent widths also agree fairly well with Huang and Struve (1956). 20 Tauri is evidently not a helium-weak star as defined in this work, and it is difficult to conclude anything further about this enigmatic object, which has also been observed to have nonperiodic variations in its helium lines on the order of several hours (Struve *et al.* 1957).

VI. DISCUSSION

From the preceding description and definition of the helium-weak stars, it seems that the sole feature distinguishing this group from Bp stars is the absence of enhanced metal lines. At coudé dispersions some lines are found (Norris 1971*a*); however, at classification dispersions the spectra do not show such peculiarities. There is evidence, though, that the helium-weak stars are related to the Bp stars and are probably a hot extension of the Bp stars.

One similarity between the helium-weak and Bp stars is the apparently weak lines of helium. Osawa (1965) made a study of the Bp stars giving spectral types according to the helium lines, the hydrogen lines, and the Ca II K-line. Many of the stars in his list have spectral types according to their helium lines that are much later than the type inferred from the colors or hydrogen line profiles. As noted earlier, Hyland (1969) also gave evidence that the helium lines in silicon stars appear quite weak for the stars' colors. It is apparent, then, that the helium-weak phenomenon is prominent in the Bp-type stars.

The Bp stars are also known to have magnetic fields; Sargent, Sargent, and Strittmatter (1967) examined two "helium-weak" stars, HD 37058 and HD 36629, and reported that they have strong fields of $+2500$ and ± 300 and $+1400 \pm 300$ gauss, respectively. On the other hand, Conti (1970), using the same equipment with more spectra, found that there is no evidence of magnetic fields in excess of ± 400 gauss for these stars as well as HD 37807 and ι Ori B. These stars with the exception of ι Ori B have been found in this investigation or by Norris (1971*a*) to be normal early B stars. Iota Orionis B is a helium-weak star according to Conti and Loonen (1970) and Norris (1971*a*). It is the only helium-weak star examined for magnetic fields and found to have none; however, more of the peculiar stars will have to be examined for magnetic fields before any conclusions can be drawn.

The Bp–Ap stars are known to be spectrum variables, and there is strong evidence suggesting the helium-weak stars are also spectrum variables. The Si-type stars in particular show variations in the strength of their silicon lines. Jaschek *et al.* (1969) included HR 1121 as a member of the helium-weak stars, and they reported finding weak lines of Si II $\lambda\lambda$4128–4130, though previously Cowley *et al.* (1968) found the lines to be very strong. Coudé plates of HR 1121 in this work, however, showed strong silicon, suggesting that the silicon lines are variable. Another possible example of variable silicon lines is found in HD 144334, a helium-weak star, for which Garrison's (1967) plate shows rather weak Si II $\lambda\lambda$4128–4130 compared with coudé plates in this investigation; the line enhancement seems to be too strong to be attributed to instrumental effects.

An even more striking example of spectral variability is Garrison's (1970) discovery that one possible helium-weak star has apparently changed its spectral type by an enhancement in the strength of its helium lines. HD 37321 has an HD spectral type of B8 and colors of a B3–4 V type, suggesting that this a helium-weak star. Old objective-prism plates verify the B8 classifications; however, at present the star is a B3 V! At this time it is unknown when this change occurred, nor is it known whether this is a periodic phenomenon.

A well-known periodic helium variable that could be related to the helium-weak stars is HD 125823 (a Cen), which changes its spectral type based on its helium line from B7 to B2 in an $8^{d}_{\cdot}8$ period (Norris 1971*b*). When the star is at its late-type phase, it resembles the helium-weak stars because its colors remain fairly constant at values corresponding to the earlier spectral type.

The possibility that the helium-weak stars are helium-line variables cannot be ignored. Even in this work it is striking to find so many stars in table 1 which are unmistakably early-B types, notably B5, when they were given late-B HD types. Although it is possible that HD types taken from objective-prism plates can suffer from atmospheric seeing conditions, appearing as late-B types, the large number found in this work and clustering around B3–B5 V is very suspicious and warrants further investigation. Perhaps some of these stars are spectrum variables like HD 37321 or HD 125823.

Another characteristic common to both Bp and helium-weak stars is their position in the color-color diagram. The Mn-Hg and Si λ4200 stars are the hottest extension of the Bp-type stars; the colors of these stars closely match those of the helium-weak stars. HR 8535 was examined in this work because its spectrum and colors matched the other helium-weak stars remarkably well, with the exception of the line of Hg II λ3984. One is led to conclude from this and the above evidence that the helium-weak stars are an extension of the Bp stars, with the only distinction between the two being the lack of strongly enhanced metal lines in helium-weak stars.

VII. CONCLUSION

HD 37129, HD 36629, and HD 37807 are found not to be "helium-weak" stars; rather, they are normal early-B-type stars. The helium-weak stars have effective temperatures of B3–B5, stars and an abundance analysis indicates an apparent helium deficiency. The weak helium lines give spectral types anomalously too late, making the stars appear to be spectrum-color discrepant. There is also evidence that their spectra show variations in the metal lines and perhaps helium lines. Finally, the similarities between the Bp and helium-weak stars strongly suggest that they are related; the sole distinguishing characteristic is the lack of strongly enhanced metal lines in helium-weak stars.

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