

THE EFFECTIVE TEMPERATURES OF WOLF-RAYET STARS AS DERIVED FROM THEIR *UBV* COLOR INDICES CORRECTED FOR EMISSION*

DIANE M. PYPER

Lick Observatory, University of California, Mount Hamilton, California

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ABSTRACT

The *UBV* color indices and the contributions to them from emission lines (based on calibrated slit spectrograms) have been determined for a number of Wolf-Rayet stars. When reddening corrections are applied, a comparison of the intrinsic color indices of the Wolf-Rayet stars with normal main-sequence stars indicates that the WN stars as a group are hotter than the WC stars by about 15000° K.

I. INTRODUCTION

Of the many unsolved problems concerning the Wolf-Rayet stars (henceforth called W-R stars), the determination of their temperatures is one of the most basic. Attempts have been made to find temperatures by use of the excitations and intensities of the emission lines (Zanstra and Weenen 1950; Miyamoto 1952), and from the spectrophotometric gradients (for further references see Underhill [1960]). No definite conclusion can be drawn from these results as regards the relative temperatures of the subclasses WN and WC.

A method not previously used for the temperature determination is to measure the *UBV* color indices of the W-R stars and correct for the effect of the emission lines. The positions of the WN and WC stars in the *UBV* two-color diagram, compared with the main-sequence stars, then should indicate whether any large temperature difference between the two groups exists. This paper reports on observations undertaken with such an objective in view.

II. OBSERVATIONS

The program stars were selected from the Roberts (1962) catalogue of W-R stars. These include all stars north of $\delta \cong -20^\circ$ and brighter than $V = 13.0$ mag. for which finding charts are available. Star designations and positions are given in Table 1, columns (1)–(4). Stars having only a number in the Roberts catalogue are preceded by the letters "R.C."

UBV colors were obtained with the 24-inch and 36-inch Crossley reflectors at the Lick Observatory for thirty-four of these stars. The photometric equipment used with the Crossley is described by Smak (1964) and that of the 24-inch by Sturch (1966). Average values for the extinction were used and transfers to the *UBV* system were made from photoelectric standard stars observed each night. Internal accuracy for each telescope is ± 0.01 mag. for the color indices.

UBV colors are available in the literature for about two-thirds of the stars listed in Table 1 (Hiltner and Iriarte 1955; Hiltner 1956; Hiltner, Schild, and Jackson 1964; Demers and Fernie 1964; Feinstein 1964). We have found systematic differences to exist (see Table 2) between the results of the present paper and those of the two other major observers of W-R stars (Hiltner 1956; Demers and Fernie 1964). In order to determine the causes of these differences, a thorough study of the methods and instruments used by all observers would be necessary. Until such a study is made, we suggest the following explanation as the most probable. Various filter-photometer systems with slightly dif-

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TABLE 1
SPECTRAL TYPES OF WR STARS

Sp.T.						
(1)	(2)	(3)	(4)	(5)	(6)	(7)
HD	Star	(1900)	(1900)	R C.	D. P.	Remarks
4004		0 ^h 37.5 ^m	+64°14'	WN 6	WN 6	Like HD 191765
16523		2 33.9	+56 18	WC 6	WC 6	Like HD 165763
17638		2 44.8	+56 31	WC 6	WC 6-7	
50896		6 50.0	-23 48	WN 5	WN 5 pec.	Variable spectrum, Sp. B.?
	R. C. 82	17 58.9	-21 12	WC 7	WC 8 + O;	Probably Sp. B.
165688		18 02.1	-19 25	WN 5	WN 5	Very broad lines
165763		18 02.5	-21 16	WC 6	WC 6	
168206	CV Ser	18 13.5	-11 40	WC 7 + B0;	WC 7 + B 0;	
169010		18 17.5	-13 46	WC 6	WC 6	Like HD 165763
	R. C. 87	18 19.8	-14 42	WR	WN 6 + O	Like CQ cep.
177230		18 57.8	-04 28	WN 8	WN 8	Sp. B. *
	R C. 93	19 24.0	+19 23	WR	WC 6 + O	Rather like HD 193793
186943		19 42.2	+28 01	WN 5	WN 5 + O	Like V444 Cyg
187282		19 44.1	+17 57	WN 5	WN 5 + O	Like HD 193077
	Ton. 50 **	19 55.7	+31 39	.	WN 7	Possible Sp. B., not in R. C.
	R. C. 97	19 56.4	+32 59	WR	WN 6-7 + O	
190002		19 57.8	+32 18	WC 6	WC 6-7	
190918		20 02.2	+34 31	WN 5+O9.5III	WN 5 + O9g	
191765		20 06.5	+35 53	WN 6	WN 6	Broad lines
192103		20 08.1	+35 54	WC 7	WC 7	
192163		20 08.4	+38 03	WN 6	WN 6	
192641		20 10.8	+36 21	WC 6	WC 6-7 + B0;	
193077		20 13.3	+37 07	WN 5	WN 5 + B0;	
228766		20 13.8	+37 00	WN 7	WN 7 + O6	
193576	V444 Cyg	20 15.8	+38 25	WN 5 + B1;	WN 5 + B0;	
193793		20 17.1	+43 32	WC 6 + O6	WC 6 + O5	Very broad lines
193928		20 17.8	+36 36	WN 5 +	WN 5	Sp. B. †
195177		20 24.7	+38 17	WC	WC 6	Possible Sp. B.
197406		20 38.4	+52 14	WN 5	WN 6-7 + O	
	CX Cep	22 06.1	+57 13	WN 5	WN 5 + O	
211853		22 15.0	+55 37	WN 5 + B0 :I:	WN 5 + O	
214419	CQ Cep	22 32.9	+56 23	WN 6 + O7	WN 6 + O	
219460		23 10.8	+59 55	WN 5	WN 5 + O	
	MH _α 217-9	23 38.7	+61 23	WR	WN 7	Possible Sp. B.

* Wilson (1948)

** Star 50, Iriarte and Chavira (1956)

† Hiltner (1945)

ferent responses were used by each of the observers. The strong emission lines in the spectra of the W-R stars may make different contributions to these various systems, thereby causing the observed differences in color. It was therefore decided, in order to preserve homogeneity, not to use color indices determined by other observers in the present study.

Spectrograms for a number of W-R stars brighter than $V = 9.0$ mag. were kindly obtained by Dr. G. W. Preston with the coudé spectrograph of the 120-inch telescope. They are in the wavelength region $\lambda\lambda$ 3100–6300 at a dispersion of 48 Å/mm. For some of the stars these were supplemented by grating spectrograms from the 36-inch refractor in the visual region ($\lambda\lambda$ 4600–6300) at a dispersion of 88 Å/mm. For all of the W-R stars on the program, prism spectrograms were obtained with the Crossley nebular spectrograph (430 Å/mm at H γ) in the blue region.

III. SPECTRAL CLASSIFICATION

All of the Crossley spectrograms were examined and classified according to the IAU criteria for the classification of W-R stars (Beals 1938). Both microphotometer intensity tracings and visual inspection were used to determine the classes. The program stars for which only the general types WN, WC, or W-R were previously available have here been given more precise classifications.

TABLE 2
SYSTEMATIC COLOR DIFFERENCES

	$B - V$	$U - B$
Crossley minus 24-inch .	0 00 ₅ ± 0 01	0 00 ₅ ± 0 01
Hiltner minus Lick	03 ± 01	00 ± 01
Demers and Fernie minus Lick	0 04 ± 0 03	0 03 ± 0 03

In the case of the WC stars, it was necessary to add another subdivision, WC 6–7, which includes stars having lines intermediate in width between those of classes WC6 and WC7. This intermediate classification is confirmed for one “WC6–7” star (HD 192641) for which higher dispersion spectrograms show intermediate excitation as well as intermediate line width. There are also two stars which appear to be intermediate between the Beals types WN6 and WN7.

Several of the brighter stars were confirmed as spectroscopic binaries from the presence of hydrogen absorption lines in the high-dispersion spectrograms. An estimate of the spectral type of the companion has been made in each case. The classification of the fainter stars as binaries or single stars has been made on the basis of the intensity above the continuum of the line λ 4686 Å (He II) for the WN stars and of the blend λ 4650 Å (C III, C IV) for the WC stars. For each star the parameter IW was obtained from the Crossley spectrograms. This parameter is a function of the width and intensity of the line, as is explained in § IV. For the single WN stars it was found that the values of IW range from 5.0 to 7.0. The known W-R binaries all have values of IW less than 2.5. There is a greater spread in the WC stars, the range of IW being 8.0 to 18.0 for the single stars and less than 6.0 for the known binaries. The WC6 stars can be clearly differentiated from the WC7 stars on the basis of the IW values, the WC6 stars all having values of over 13.0, while those of the WC6–7 and WC7 stars are all less than 11.0. The WC6 star HD 195177 is an exception, however, as it has an IW of 8.8, compared to an average value of 14.9 for the other WC6 stars. This star may therefore be a binary, as has been remarked in Table 1. All other possible binaries have also been noted in Table 1. None of the fainter stars have IW values which lie outside the above groups and thus they

were classified as binaries or single stars according to these values. No estimate could be made of the spectral type of the companion in these cases, so they are listed as "W-R + O."

It should be emphasized that the separation of the stars into binaries and single stars has been made on the basis of line intensity alone. The stars HD 192103 and HD 192163 were studied in detail by Miss Underhill (1959). She found no evidence that either star is a binary. Nevertheless there may be stars among those considered here to be single which are spectroscopic binaries but whose companions are too faint to contribute to the spectrum. Such a star is HD 193928, for which a velocity curve was determined by Hiltner (1945) but whose emission lines are as strong as those of the two stars mentioned above. In the treatment of these stars, the assumption that the continuum is that of the W-R component is considered to be reasonable. It is impossible to determine whether the two stars classified as WN7 are binaries or not, as they were too faint for high dispersion spectrograms to be obtained. They are assumed to be single stars in this study. The main purpose of these classifications was to find single W-R stars. The binaries, although they have been included in the tables and illustrations, are not discussed with reference to the temperatures of the W-R stars, since the observed continua in these stars are the result of contributions by both the W-R and O components.

The information on spectral types is included in Table 1. For comparison, the previous classifications as listed in the Roberts catalogue are given in column (5). The classifications by the author and some remarks are given in columns (6) and (7).

IV. CORRECTIONS OF THE *UBV* COLOR INDICES

In order to compare the *UBV* color indices of W-R stars with those of normal upper main-sequence stars, it is necessary to correct the observed $B - V$ and $U - B$ indices for the effects of the emission lines. This procedure could only be carried out directly for the eleven stars for which the higher-dispersion spectrograms were available. The assumption is made that the emission arises in an envelope that is optically thin at all wavelengths except those of the emission lines. This implies that the continuum observed is that of the surface of the star. Even if there is an electron-scattering envelope for all W-R stars, such as that observed in V444 Cyg (Kron and Gordon 1950), this would have no effect upon the colors, as the scattering due to free electrons is independent of wavelength.

For each star, microphotometer intensity tracings were made in the region $\lambda\lambda$ 3100–6300. For some of the stars, two exposures were required in order to obtain both the very strong lines and the weak lines. These tracings were reduced as outlined below.

The total flux in the lines (modified by a filter response), F_L , may be written as

$$F_L = \int_0^\infty \frac{\mathfrak{F}_L(\lambda) - \mathfrak{F}_C(\lambda)}{\mathfrak{F}_C(\lambda)} F(\lambda) S(\lambda) d\lambda, \quad (1)$$

where $\mathfrak{F}_L(\lambda)$ is a parameter (derived from spectrophotometry) proportional to the flux in the line plus continuum at a wavelength λ , $\mathfrak{F}_C(\lambda)$ is the corresponding parameter for the continuum alone at the same λ , $F(\lambda)$ is the absolute flux in the continuum at λ , and $S(\lambda)$ is the value of the instrumental response function (the *U*, *B*, or *V* band in this case) at λ . The values of $\mathfrak{F}_L(\lambda)$ and $\mathfrak{F}_C(\lambda)$ are obtained from the microphotometer tracings.

The quantity $F(\lambda)$ is approximated by the Planck function, $B_\lambda(T)$, for a temperature of 30000° K (McDonald 1955). In the recent literature, estimates of the temperatures of W-R stars are in the range 14000°–50000° K. In order to check the sensitivity of the color corrections to temperature, a sample calculation was performed. For the temperature of 14000° K, $F(\lambda)$ was taken from the models of de Jager and Neven (1957) and for 50000° K, from McDonald (1955). The differences between the resulting corrections were not greater than 0.02 mag. This insensitivity of the emission-line corrections both to

temperature and to the form of $F(\lambda)$ suggests that the corrections would not be significantly different within the above temperature range if the continuous energy distribution approximates that of a black body or a normal main-sequence star. To the extent that this inference is correct, the use of $F(\lambda) = B_\lambda(30000^\circ \text{K})$ is justified even though the true $F(\lambda)$ for W-R stars is unknown.

The values of $S(\lambda)$ are those of Johnson (1955) modified to take into account the transmission of the Earth's atmosphere, that is,

$$S(\lambda) = S_J(\lambda)T(\lambda), \quad (2)$$

where $S_J(\lambda)$ is taken from Johnson (1955) and $T(\lambda)$ is the atmospheric transmission taken from Allen (1963). Sample calculations show that the color-index corrections are insensitive to any change in atmospheric transmission with air mass.

If F_s is the continuum flux observed through a given filter, then

$$F_s = \int_0^\infty F(\lambda) S(\lambda) d\lambda, \quad (3)$$

and the correction due to the presence of emission lines is given by

$$\Delta S = 2.5 \log \left(\frac{F_L + F_s}{F_s} \right). \quad (4)$$

For the UBV system, ΔS becomes ΔU , ΔB , or ΔV and

$$\Delta(U - B) = \Delta U - \Delta B, \quad \Delta(B - V) = \Delta B - \Delta V. \quad (5)$$

The IBM 7094 electronic computer at the University of California, Berkeley, was used to perform the numerical integrations of equations (1) and (3). A program to determine the UBV corrections in the case of ordinary blanketing was available, and this was modified so that it would apply to emission lines instead of absorption lines. A check on the validity of the method used in the computer program was made by reducing the spectrogram of the star HD 192103 independently. The results were the same to within 0.02 mag.

In order to extend the corrections to the fainter stars on the program, the microphotometer intensity tracings of the Crossley spectrograms were used. In all but two spectrograms, which were overexposed, the $\lambda 4686$ feature in WN stars and the $\lambda 4650$ feature in WC stars were used as criteria for color corrections. As these are the most intense emissions in the blue region, the $U - B$ correction is almost entirely determined by their widths and intensities. This is also true of the $B - V$ correction in WN stars, as there are no strong emission lines in the wavelength range of the V band in these stars. (The $B - V$ correction is small for all WC stars due to the strong emissions from $\lambda\lambda 5700-5800$.) For each star the quantity IW was formed, where I is the central intensity of $\lambda 4686$ or $\lambda 4650$, and W is the width in arbitrary linear units at the half-intensity point. This parameter was plotted against $\Delta(U - B)$ and $\Delta(B - V)$ for the stars for which corrections had already been obtained (Figure 1). The best straight line in each case was drawn through the points and then corrections were read off for each of the fainter stars. For HD 187282 and HD 193928, the spectrograms of which were overexposed, intensities of several of the fainter emission features were used in comparison with the same features in the standard stars in order to determine a correction. No calibration at high dispersion was available for types WN7, WN8, or WC8. These types were included, nevertheless, on the assumption that their corrections also fall on the straight lines obtained. A colon has been placed by the corrections for these stars, however, to indicate that there is some uncertainty involved. The information on the colors and their corrections is given in Table 3. The first column gives the name of the star;

the next four columns contain the V magnitude, the colors before correction for emission, and the number of observations made. The sixth column contains the quantity IW ; the seventh and eighth columns, the corrections to the colors due to removal of the emission; and the last two columns, the corrected colors. Figures 2 and 3 show the color-color diagram before and after correction for emission.

V. THE REDDENING CORRECTIONS

It is possible to project the stars back onto the main-sequence curve in the $U - B$, $B - V$ diagram if the slope of the reddening line, $\delta(U - B)/\delta(B - V)$, is known. The assumption that W-R stars are main-sequence objects is justified by the fact that the $U - B$, $B - V$ curve for intrinsic colors is the same for both dwarfs and giants in the OB region, and that the existing information on luminosities indicates that these stars are not extremely overluminous, i.e., supergiants (see § VI).

It was assumed that there is no curvature in the slope of the reddening correction and also that the value of $\delta(U - B)/\delta(B - V)$ is dependent on galactic longitude (Wampler 1961). The stars were thus corrected according to their galactic coordinates.

The results of these corrections are illustrated in Figure 4. It will be noted that all of

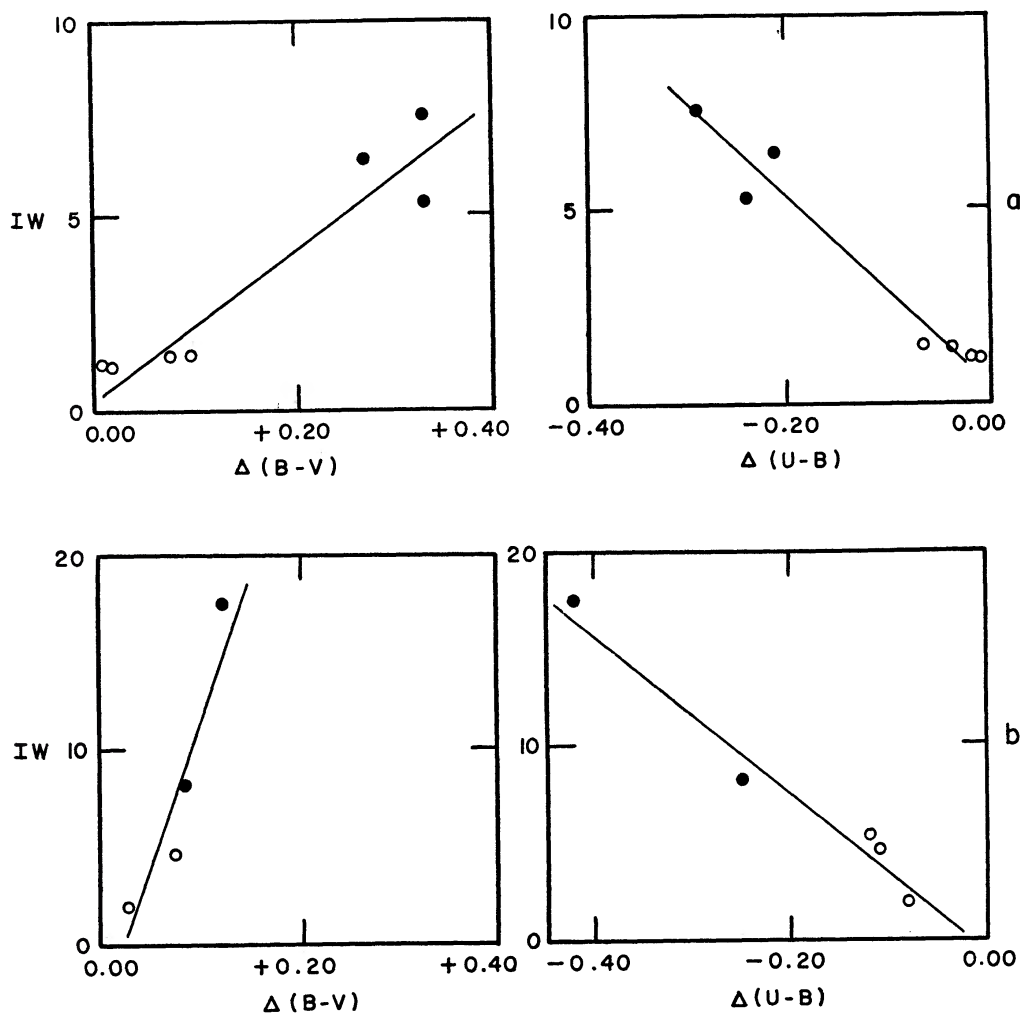


FIG. 1.— IW versus color corrections for (a) WN stars, (b) WC stars. Filled circles indicate single stars and open circles are binaries.

TABLE 3

UBV COLOR INDICES UNCORRECTED AND CORRECTED FOR EMISSION

Star	<u>V</u>	<u>B-V</u>	<u>U-B</u>	<u>n</u>	<u>I W</u>	$\Delta(\underline{B-V})$	$\Delta(\underline{U-B})$	$(\underline{B-V})_{\text{Corr.}}$	$(\underline{U-B})_{\text{Corr.}}$
4004	10.23	+0.37	-0.24	2	5.5	+0.27	-0.20	+0.64	-0.44
16523	10.01	+ .16	- .14	2	13.7	+ .11	- .36	+ .27	- .50
17638	10.46	+ .41	+ .15	2	10.9	+ .10	- .29	+ .51	- .14
50896*	6.90	- .32	- .76	2	5.3	+ .33	- .24	+ .01	-1.00
R C. 82	11.89	+1.20	+ .30	3	1.8	+ .03:	- .06:	+1.23:	+ .24:
165688	9.90	+ .43	+ .15	3	5.9	+ .30	- .24	+ .73	- .09
165763*	7.82	- .28	- .38	3	17.5	+ .12	- .42	- .16	- .80
CV Ser*	9.15	+ .66	- .24	4	2.0	+ .02	- .08	+ .68	- .32
169010	12.08:	+ .92:	+ .55:	1	13.6	+ .11	- .35	+1.03:	+ .20:
R. C. 87	11.84:	+1.18:	+ .36:	1	1.7	+ .06	- .05	+1.24:	+ .31:
177230	11.12	+ .48	- .28	2	2.6	+ .10:	- .09:	+ .58:	- .37:
R. C. 93	12.78	+1.60	+ .59	3	3.7	+ .05	- .10	+1.65	+ .49
186943	10.30	+ .24	- .66	5	1.1	+ .02	- .02	+ .26	- .68
187282	10.50	- .02	- .89	4	-	+ .09:	- .06:	+ .07:	- .95:
Anon. +	12.28	+1.40	+ .39	3	1.5	+ .04:	- .04:	+1.44:	+ .35:
R C. 97	12.08:	+ .97:	- .12:	1	0.9	+ .01	- .01	+ .98:	- .13:
190002	12.67:	+ .75:	+ .41:	1	8.5	+ .08	- .22	+ .83:	+ .19:
190918*	6.79	+ .11	- .77	2	1.2	0.00	- .01	+ .11	- .78
191765*	8.09	- .01	- .50	6	6.2	+ .27	- .21	+ .26	- .71
192103*	8.16	+ .02	- .40	6	8.3	+ .08	- .25	+ .10	- .65
192163*	7.52	- .03	- .44	6	7.0	+ .33	- .29	+ .30	- .73
192641*	7.92	+ .25	- .46	6	4.7	+ .07	- .11	+ .32	- .57
193077*	8.00	+ .28	- .53	6	1.5	+ .09	- .06	+ .37	- .59
228766*	9.13	+ .59	- .38	6	1.1	+ .01	0.00	+ .60	- .38
V444 Cyg*	8.0v	+ .47	- .39	7	1.4	+ .07	- .03	+ .54	- .42
193793*	6.89	+ .37	- .36	3	5.4	+ .05	- .12	+ .42	- .48
193928	9.86	+ .77	+ .08	3	-	+ .27:	- .21:	+1.04:	- .13:
195177	11.46	+1.21:	+ .75:	1	8.8	+ .08	- .24	+1.29:	+ .51:
197406	10.30	+ .55	- .43	3	0.9	+ .01	- .01	+ .56	- .44
CX Cep	12.1v	+ .74	- .21	3	1.9	+ .07	- .06	+ .81	- .27
211853	9.04	+ .38	- .55	2	1.1	+ .02	- .02	+ .40	- .57
CQ Cep	8.8v	+ .38	- .55	4	0.7	0.00	0.00	+ .38	- .55
219460	9.68	+ .60	- .27	2	1.0	+ .02	- .01	+ .62	- .28
MH _{α} 217-9	11.18	+0.90	-0.20	3	1.5	+0.04:	-0.04:	+0.94:	-0.24:

* Standard for color corrections.

+"Anon." is the star Ton. 50 in Table 1.

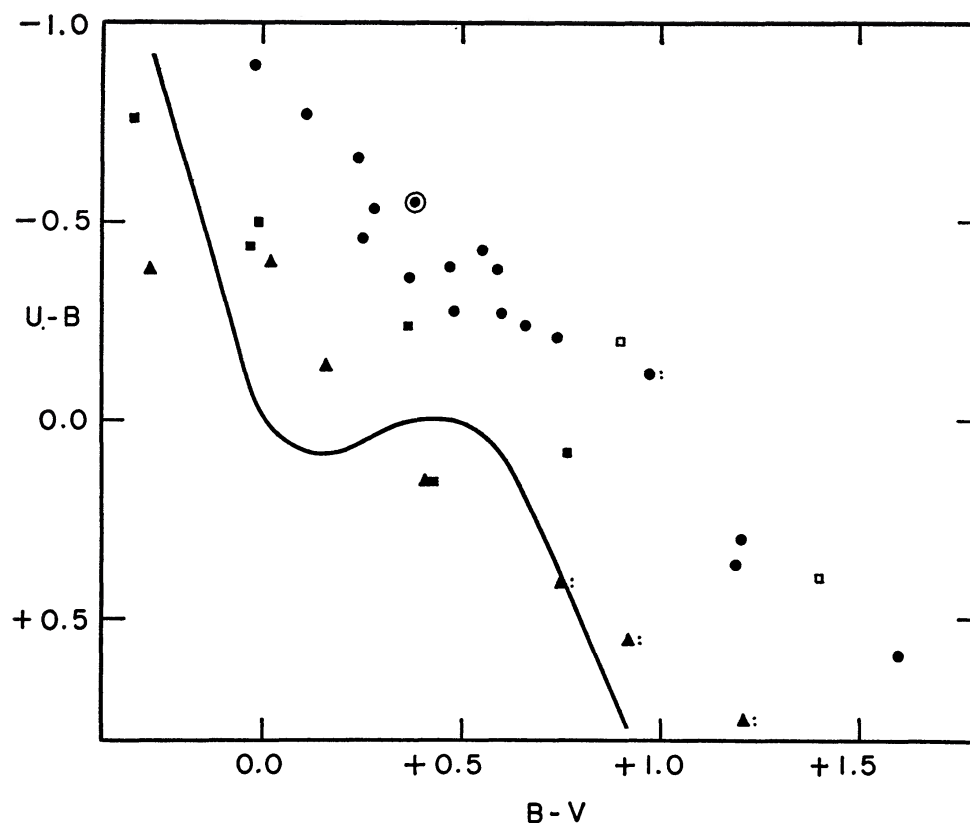


FIG. 2.—Two-color diagram for W-R stars before the emission corrections have been applied. Squares are WN stars, triangles are WC stars, and circles are binaries. The open figures indicate stars which may be binaries. A colon by a figure indicates that only one observation was made for that star. The solid line represents the main sequence.

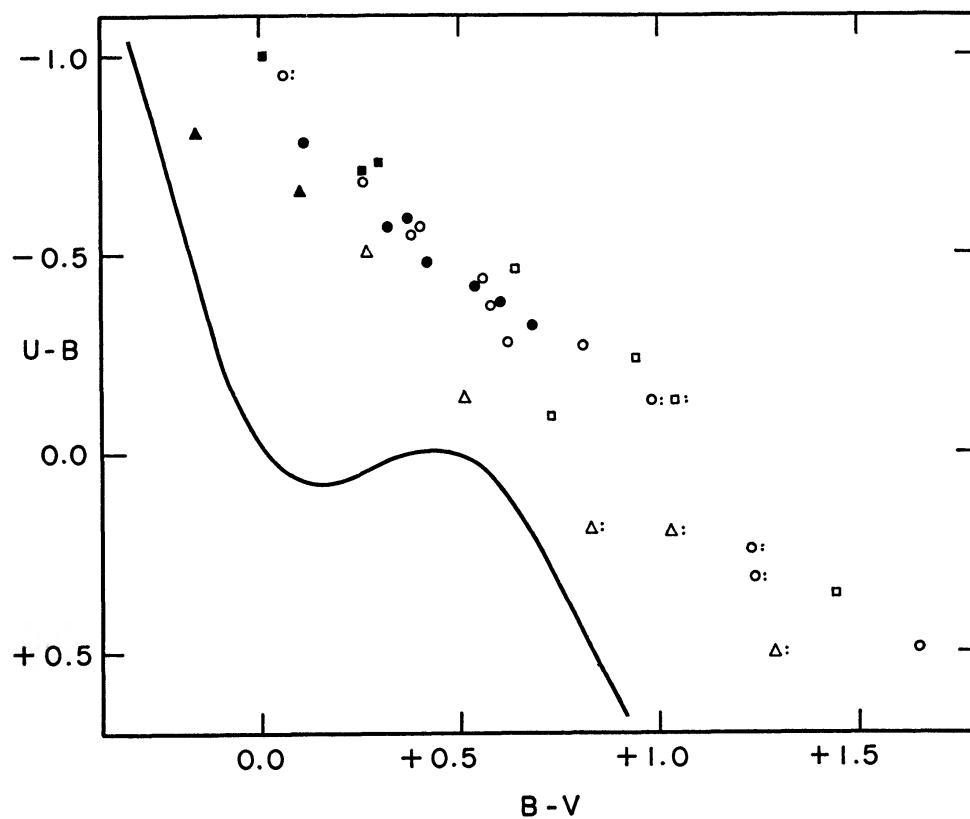


FIG. 3.—Two-color diagram for W-R stars after correction for emission lines. Symbols are the same as in Fig. 2, but here open figures indicate stars with *IW* corrections only and filled figures are stars with computed corrections. Colons again indicate an uncertainty in either the *UBV* colors or in the emission correction.

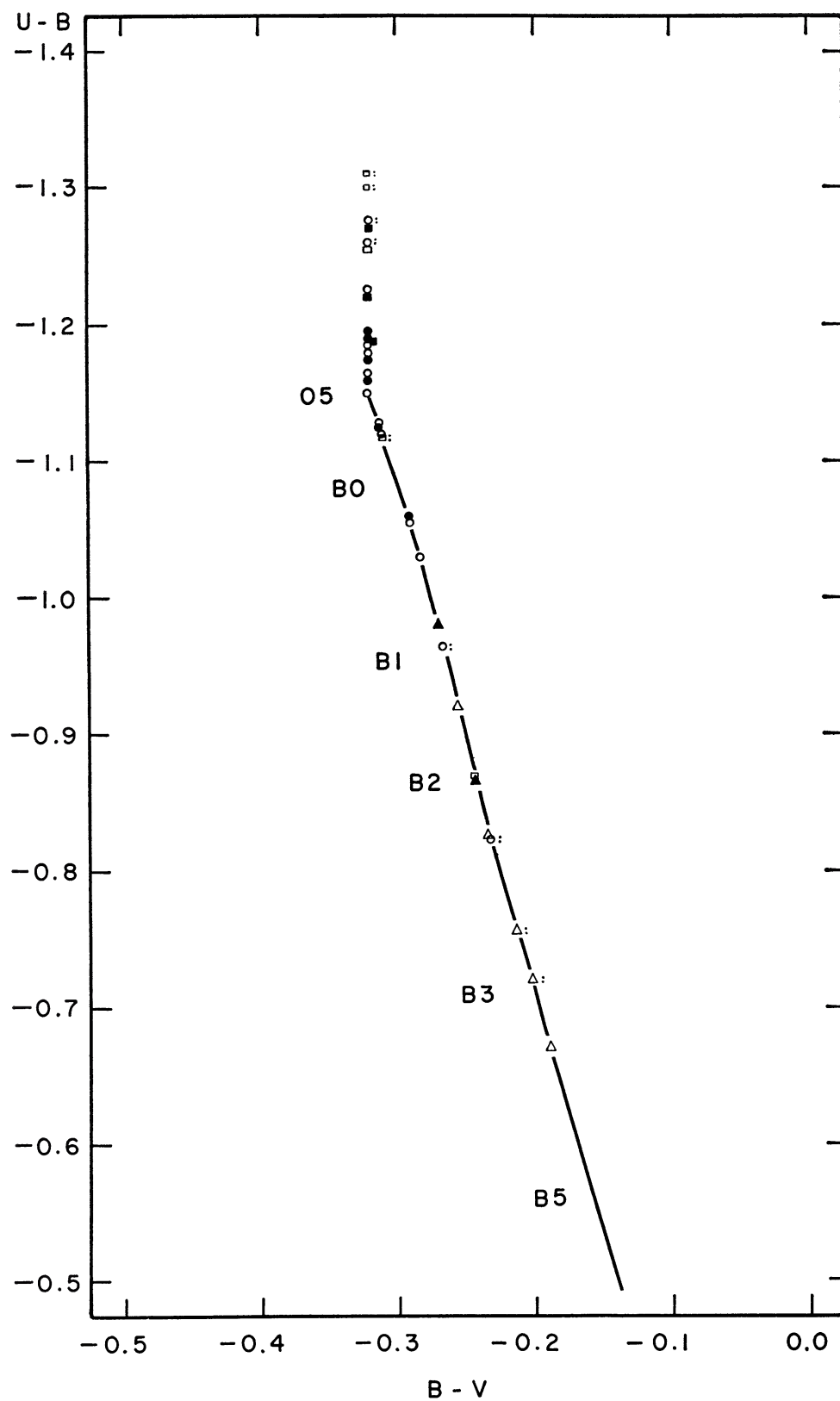


FIG. 4.—Two-color diagram for W-R stars after correction for reddening. Symbols are the same as in Fig. 3. The solid line represents the main sequence.

the WN stars (except HD 165688) have $U - B$ less than -1.10 mag. and that all of the WC stars have $U - B$ greater than -1.00 mag.

There is very little scatter in the grouping of the WN stars in the two-color diagram, with the exception of the WN5 star HD 165688, which falls in the same region as the WC stars. Only a single Crossley spectrogram is available for this star, but the spectrum appears to be identical with those of the other WN5 stars that have no apparent companions. The central intensity of λ 4686 is about the same or slightly weaker than is the case for the other WN5 and WN6 stars. There is some uncertainty in this intensity due to the high density of the He II line on the plate, but no reasonable correction to our estimate would bring this star up to the position of the other WN stars in Figure 3. There might, however, be an uncertainty in the colors because the star is so far south that relatively small changes in the extinction could cause fairly large changes in the $U - B$ color. As was stated in § II, average extinctions were used, which in general are thought to be better than separate determinations for sites at which there are no large variations in extinction (Hiltner 1956). In the case of stars for which the air mass is never less than 2.0, however, an accurate determination of extinction on each night by use of appropriate standard stars should give better results. This was not done, since there were only three single W-R stars in our program with $\delta \leq -19^\circ$. It should be noted, however, that the other southern stars, HD 165763 (WC) and HD 50896 (WN), show no significant discrepancy in the two-color diagram.

Perhaps HD 165688 is really cooler than the other WN stars, but before this conclusion (and its resulting complications) is finally accepted, a more careful photoelectric and spectroscopic study of this star should be made.

VI. DISCUSSION

The assumption that the envelope of a W-R star is optically thin (see § IV) implies that the observed difference in the colors of the WN and WC stars is due to a difference in effective temperatures. If the W-R stars are compared to ordinary main-sequence stars, the average temperature of a WN star is about 38000° K. On the same scale, the average temperature of a WC star is 20000° K (Aller 1963). As the values of the effective temperatures of early-type stars are extremely uncertain, they are used here simply as a rough criterion for the comparison of the temperatures of the WN and WC stars. Nevertheless, it can be concluded that there is a difference in temperature of at least 10000° and perhaps 20000° K between the two groups of W-R stars. No attempt was made to find a subsequence within the WC and WN groups. This was felt to be unwarranted because of the small number of stars observed and the approximate nature of the corrections to the color indices.

The average $(B - V)_0$ colors for the WN and WC stars are -0.32 and -0.23 mag., respectively (Fig. 4). If these stars are located on the main sequence in the M_V , $B - V$ diagram, the WN stars should be about 3.5 mag. brighter in M_V than the WC stars.

The literature contains a number of papers concerning the luminosities of W-R stars. The determination of the absolute magnitudes of the W-R stars in our Galaxy is made very difficult, however, because they are highly concentrated to the galactic plane and are therefore affected by varying (unknown) amounts of interstellar extinction. The most recent study is that of Rublev (1963), but of the stars considered by him only three are in the group of single stars as classified in § III. Rublev's values of M_V (corrected for emission according to the method outlined in § IV) are listed in Table 4. It is seen that the WC and the two WN stars have almost the same absolute magnitudes but that the WC star is slightly to the red of the age-zero main sequence (Blaauw 1963). Therefore for these data, $\Delta M_V = M_V(\text{WN}) - M_V(\text{WC}) = -0.2$ mag. An earlier study by Onderlička (1958) gives $\Delta M_V = -0.6$ mag. for 3 WN and 3 WC stars.

Absolute magnitudes are also available for a large number of W-R stars in the Large

Magellanic Cloud (Westerlund and Smith 1964). In this paper, $m_V - M_V = 18.7$ is used, in which case the average absolute magnitudes are as follows:

$$\begin{aligned}\bar{M}_V &= -5.2 \text{ mag. for WN stars in associations and clusters} \\ &= -4.2 \text{ mag. for WN stars in the field} \\ &= -5.3 \text{ mag. for all WC stars.}\end{aligned}$$

These magnitudes are uncorrected for emission. According to the high-dispersion data above, the average corrections to M_V are $+0.2$ mag. for WN stars and $+0.6$ mag. for WC stars. Thus the values listed become -5.0 , -4.0 , and -4.7 mag., respectively, and

$$\begin{aligned}\Delta\bar{M}_V &= -0.3 \text{ mag. for association stars} \\ &= +0.7 \text{ mag. for field stars} \\ &= +0.2 \text{ mag. for all stars.}\end{aligned}$$

Thus, it seems likely that the WN and WC stars are of approximately the same luminosity. It should be noted that the WC stars fall 0.08 mag. to the red of the main

TABLE 4
ABSOLUTE MAGNITUDES

Star	Spectral Type	M_V	ΔM_V	$(M_V)_{\text{corr}}$
191765	WN6	-5 2	+0 2	-5 0
192103	WC7	-5 5	+0 5	-5 0
192163	WN6	-5 5	+0 2	-5 3

sequence if $\bar{M}_V = -4.7$ mag. and $\langle(B - V)_0\rangle = -0.24$ mag. This difference is rather larger than can be explained by errors in the colors. It may be that the WC stars are in a slightly more advanced state of evolution than the WN stars.

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