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TWO-DIMENSIONAL SPECTRAL CLASSIFICATION BY NARROW-BAND PHOTOMETRY FOR B STARS IN CLUSTERS AND ASSOCIATIONS*

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ABSTRACT

Photoelectric observations of the intensity of the Hβ line have been made with the 36-inch reflector of the McDonald Observatory for B stars with available MK spectral types and for B stars in several clusters and associations. The various filter systems used are discussed, and the measures are transformed to a standard system. The color index $(U-B)$ of the U, B, V system, when corrected for interstellar reddening, is used with the Hβ intensities to define a two-dimensional spectral classification system Evolutionary effects on this classification system are discussed, and relative ages for the Scorpio-Centaurus cluster, the Orion association, the ζ Persei association, the α Persei cluster, and the field stars are estimated. Mean absolute magnitudes are computed for the B8 V and B9 V stars in the Scorpio-Centaurus cluster, and a comparison with the α Persei cluster yields a minimum distance modulus for it of 6 4 mag

I. INTRODUCTION

Most of the current investigations on luminosity determinations for B stars have used either visual two-dimensional spectral classification, such as the MK system, or photographic determinations of hydrogen-line intensities, together with some type of estimates for spectral type. These methods have given fundamental results in galactic structure and other fields of astronomy. However, the success of narrow-band photometry for the F stars by B. Strömgren suggests that such methods would be quite useful for the B stars as well.

The MK system is well reviewed and references to earlier work on spectral type determination are given in a publication by Johnson and Morgan (1953) and in the *Atlas of Stellar Spectra* by Morgan, Keenan, and Kellman (1943). Only a few remarks will be noted here.

The system depends on visual estimates of certain criteria for both spectral type and luminosity. The end-result is that the star receives a definite spectral type and luminosity class, which, for an experienced classifier and a good spectrum, is accurate to about one subdivision in either spectral type or luminosity The empirical criteria vary, depending on the approximate class, but an attempt has been made to achieve the best correlation possible for visual estimates with effective temperature and absolute magnitude. The system itself is defined by a network of standard stars with well-determined types classified by Morgan.

The correlation of the spectral type thus obtained with the star's intrinsic color is remarkably good, and hence this intrinsic color is often used as a measure of spectral type. This has the advantage of giving a wider range for the spectral-type parameter and is more of a continuous variable than the definite spectral types of the MK system The most widely used color index for this purpose has been the $(B - V)$ of the U, B, V system of Johnson and Morgan (1953). They have also derived a quantity Q, which is a parameter calculated from both $(U - B)$ and $(B - V)$ and which is independent of interstellar reddening. It is an example of the color-difference method suggested by Becker (1938, 1948). This Q is also an accurate indicator of spectral type.

However, since $(U - B)$ has the widest range of values throughout the B stars, it would seem to be a good index of spectral type for use in the B stars alone. This has

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been done to some extent by Johnson and Morgan and was used by Morgan and Harris (1956) for their study of M29.

Lindblad (1922, 1925, 1926) used methods based on spectrophotometry from low-dispersion photographic plates to achieve a two-dimensional classification. He measured the intensity of relatively strong features in objective-prism spectra. This work showed the value of the strength of the hydrogen lines as a luminosity criterion.

Another method that has achieved good results is the system used by Chalonge and Divan (1952) and their associates. This consists of measuring, from photographic plates, the amount and position of the Balmer discontinuity. They show that the relation between these two parameters and MK types is very good.

Hack (1953) has amplified this method by utilizing the central depth of Hδ measured on the same plates as those used by Chalonge and Divan and using it with the amount of the Balmer discontinuity to define a spectral type and luminosity class. This again is well correlated with MK type.

Strömgren (1951, 1952, 1956*a*, *b*) has investigated the possibility of the extension of these methods by the use of photoelectric photometry. He found that, over the range from the early B stars to the late F stars, the measure of the total intensity of Hβ and the amount of the Balmer discontinuity give a high accuracy for determining spectral type, color index, and absolute magnitude. He estimated that the accuracy for B stars should be as follows: in spectral type, ± 0.01 of a type; in $(B - V)$, ± 0.005 mag.; and in M_V, ± 0.22—all for one observation. (Mean errors are used throughout this paper.) These were derived from the photometric accuracy alone and do not include the effects of cosmic scatter, if any. These photoelectric methods take advantage of the high accuracy inherent in photoelectric photometry. It is possible also to cover a wide range in apparent magnitude, which is of great value in problems of galactic structure.

II. THE OBSERVATIONS

Several systems of photoelectric measurement of the strength of Hβ have been developed at Yerkes and McDonald Observatories, in addition to the original l system of Strömgren (1956*b*). This l system used three interference filters employed in a conventional refrigerated photoelectric photometer. The Hβ filter itself had a half-width of 35 A and a maximum transmission of about 75 per cent. The two comparison filters had half-widths of about 90 A. Their transmission peaks were centered about 4700 A and 5000 A. The index l is defined by

$$l = 2.5 \{[\log I(4700) + \log I(5000)] - \log I(4861)\} + \text{constant},$$

where $I(4700)$, $I(5000)$, and $I(4861)$ denote the intensity measured through the two comparison filters and the Hβ filter, respectively. As the average wave length of the comparison filters is close to that of Hβ, the influence of interstellar reddening on the index is very small. This index, together with a measure of the Balmer discontinuity, was used by Strömgren (1956*a*) in his work on the F stars. For them he achieved an accuracy in spectral type of ± 0.03 and in absolute magnitude of ± 0.3 mag.

In an effort to secure a larger range in the parameter measuring Hβ, a narrower Hβ interference filter was tried in place of the 35 A filter of the l system. The filter used had a half-width of 15 A. This should cut out most of the continuum contribution in the neighborhood of Hβ that passed through the 35 A filter. All other equipment, including the comparison filters, was the same as for the l system. It turned out that the range of the new index, called L, is a factor of 2 greater than in the l system. The standard L system will be discussed in a publication by Strömgren and Crawford, but details relative to the B stars will be given here.

The transformation between l and L is given in Figure 1 for the B stars. The transformation mean error for the linear part is ± 0.0067 mag. in l. The values of L for the standard stars used in this work are given in Table 1. The internal mean error of one observation is ± 0.0048 mag., as determined from observations of the standard stars of different nights.

In hopes of improving observing efficiency, a method whereby the measure of Hβ itself and the comparison in the nearby continuous spectrum could be observed simultaneously was initiated by Strömgren. The original photometer, sketched in Figure 2, utilizes a 15 A Hβ filter. The light passing through this filter is received by the first photocell; the light reflected from it is collected by a small spherical mirror and passed through a second Hβ filter, about 90 A wide, and into the second photocell. Both cells are refrigerated 1P21's. This second filter yields an apparent double-peaked transmission-curve, the peaks being located in the continuum on either side of Hβ, as the central Hβ part has been subtracted out by the first filter. The outputs from the photocells are ampli-

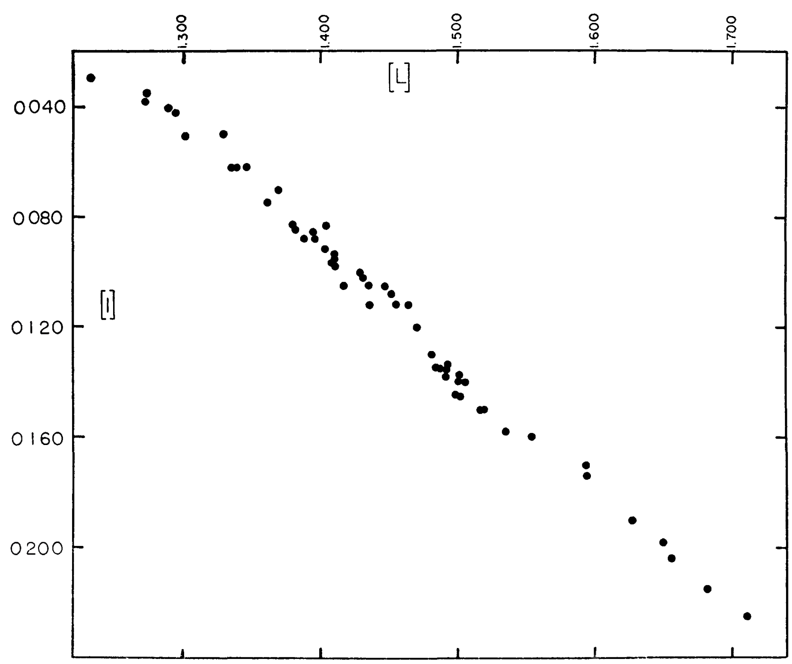


FIG 1.—Transformation between the L and l systems for the B stars

fied and integrated and then recorded on a Brown recorder chart, the whole process being controlled by a suitable programmer unit. The integrators used are the Mark VI type, designed and built by R. Weitbrecht (1957). For a given integration time they have a range of 10 mag. The integration time is variable from 10 to 100 seconds, thus giving an additional range of 2.5 mag. The limit for bright stars with the 36-inch reflector of the McDonald Observatory is about $V = 1.75$ mag. With observing times of about 5 minutes, 12.0 mag. was obtained with an accuracy of ± 0.010.

To remove any effect due to drift in the relative sensitivity of the two photocells, an ordinary small light bulb was observed after each star to furnish a standard ratio. The variation of this ratio was negligible over wide ranges in the bulb's intensity. In addition, at the telescope the bulb was run from a regulated voltage supply.

The observing procedure was as follows: Four or more deflections were made on each star and one or more on the sky. Then one or more deflections were made on the standard light-source. Standard stars from the L system were observed about every five stars and entirely on some nights. The total observing time, including moving the telescope

TABLE 1

STANDARD STARS

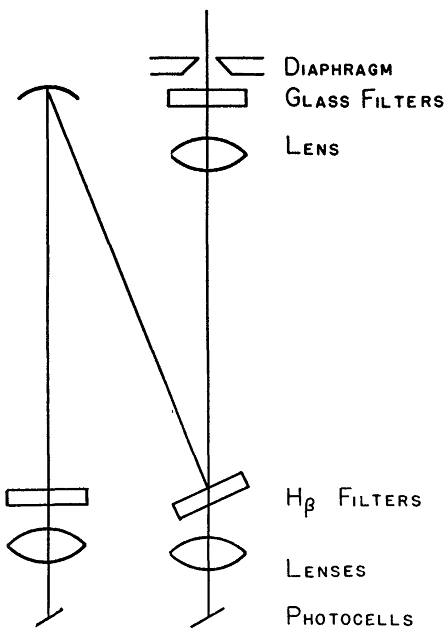
Standard Stars	L	β_c	β	β (Adopted)	n	MK Type
γ Peg	. ...	. .	2 628	2 628	1	B2 IV
ζ Cas	1 382	2 628	2 625	2 627	6	B2 V
π And	1 453	2 688	. .	2 688	1	. .
ξ Cas	. . .	.	2 662	2 662	1	B2 V
o Cas	1 428	2 667	2 664	2 665	7	B2 V
1 Per	. ...	. .	2 639	2 639	2	B2 V
53 Cas	1 329	2 584	2 604	2 594	2	B8 I*b*
35 Ari	1 453	2 688	2 691	2 690	13	B3 V
HR 1034			2 709	2 709	14	B3 V
HR 1035			2 578	2 578	1	B9 I*a*
o Per	. . .	. . .	2 597	2 597	3	B1 III
16 Tau	1 519	2 743	2 753	2 748	2	B7 IV
18 Tau	1 518	2 742	2 755	2 750	5	B8 V
19 Tau			2 716	2 716	1	B6 V
20 Tau			2 678	2 678	1	B7 III
21 Tau	. .	.	2 790	2 790	1	B8 V
27 Tau	1 462	2 696	2 700	2 699	4	B8 III
π^4 Ori	1 356	2 606	2 605	2 605	8	B2 III
η Aur	1 455	2 690	2 691	2 691	4	B3 V
103 Tau	1 408	2 650		2 650	1	B2 V
ρ Aur	1 493	2 722	. .	2 722	2	B5 V
υ Ori	. ....		2 606	2 606	1	B0 V
χ^2 Ori	1 233	. ..	. .	. .	2	B2 I*a*
ξ Ori	1 431	2 670	2 676	2 672	3	B3 V
γ CMa	1 454	2 689		2 689	1	B8 II
β CMa	1 506	2 733	. ..	2 733	1	B8 V
δ Hya	1 656	2 860	2 854	2 857	3	. ..
η Hya	1 411	2 653	2 661	2 655	5	B3 V
κ Hya	1 471	2 704	2 708	2 706	3	B5 V
ρ Leo	1 272	2 535	2 556	2 545:	5	B1 I*b*
β UMa	1 690	2 887		2 787	4	A1 V
γ UMa	1 679	2 875		2 875	3	A0 V
109 Vir	1 640	2 846		2 846	2	A0 V
β Lib	1 478	2 709		2 709	3	B8 V
π Sco	1 363	2 612		2 612	11	B1 V
δ Sco	1 342	2 594		2 594	4	B0 V
τ Her	1 478	2 710		2 710	3	B5 IV
22 Sco	1 429	2 668		2 668	7	B2 V
ι Her	1 423	2 663		2 663	7	B3 V
γ Oph	1 714	2 908		2 908	7	A0 V
67 Oph	1 331	2 585	. ..	2 585	4	B5 I*b*
γ Lyr	1 538	2 760	2 747:	2 758	13	B9 III
ζ Aql	1 674	2 874	2 863	2 869	13	. .. .
κ Aql	1 302	2 560	2 566	2 563	14	B0 5 III
ι Aql	1 484	2 714	2 703	2 709	11	B5 III
δ Cyg	1 600	2 812	. ..	2 812	2	B9 5 III
α Del	1 595	2 808	2 798	2 803	18	B9 V
55 Cyg	1 260	2 525	2 535	2 530	17	B3 I*a*
σ Cyg	1 324	2 579	2 577	2 578	12	O9 I*ab*
9 Cep	1 289	2 550	2 539	2 545	4	B2 I*b*
ν Cep	1 339	2 592	2 605	2 597	3	A2 I*a*
19 Cep	1 291	2 551	... ...	2 551	3	O9 5 I*b*
γ Aqr	....	.. . ...	2 853	2 853	1	B9 III
α Lac	1 714	2 908	2 907	2 908	16	. . .
10 Lac	1 335	2 588	2 580	2 584	19	O9 V
ζ Peg	1 555	2 774	2 784	2 779	6	B8 V
12 Lac	1 361	2 610		2 610	2	B2 III
o Peg	1 682	2 881		2 881	1	.
ρ Peg	1 711	2 900	. ...	2 900	1	.. . ..
α Peg	1 651	2 856	2 857	2 857	4	B9 V
ι And	1 502	2 729	2 733	2 731	16	B8 V
κ And	1 628	2 836	2 833	2 834	14	.. . .

and setting up on the star, averaged about $4\frac{1}{2}$ minutes per star. The transmission of the filter and the sensitivity of the cells were such that the second integrator operated with 2 mag. less gain than the first for a given star. The resulting ratio,

$$\beta' = 2.5\,[\log I(90\text{ A filter}) - \log I(15\text{ A filter})] + \text{constant}\,,$$

was taken as the measure of Hβ.

As both filters and the resultant transmission-curves have the same effective wave length, no corrections should be necessary for interstellar reddening. In addition, as the measures of Hβ and the comparison are made simultaneously, atmospheric extinction should be negligible. This means that no correction is necessary for observations through different air masses and also that observations in non-photometric conditions should



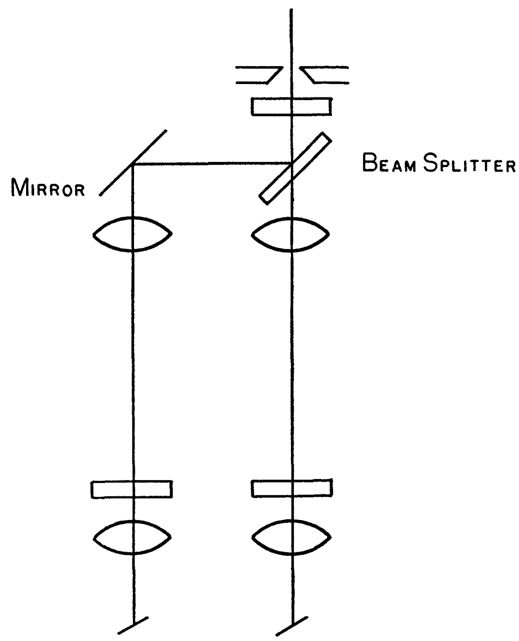


FIG. 2.—Sketch of the original simultaneous Hβ photometer

FIG. 3 —Sketch of the second simultaneous Hβ photometer

be possible. This was found to be the case, as no variation occurred in the observed ratio over a range of about four air masses or in observation through clouds amounting to an extinction of as much as 3 mag.

However, a systematic effect was observed which appeared to be a function of hour angle and declination in a rather irregular way. This was thought to be due to flexure within the photometer itself. It could be corrected for, however, utilizing the many standard stars observed as checks. The resultant measures have, as a result, a higher internal mean error. It is $\pm 0\,011$ mag. This equipment was used during the winter of 1956–1957 with the 40-inch refractor of the Yerkes Observatory and during the spring of 1957 with the 36-inch reflector at the McDonald Observatory.

In an effort to eliminate the troublesome flexure effect, a second model designed by Strömgren was built of somewhat different structure and more rigid in every respect. It preserves the advantage of simultaneous observations. It is sketched in Figure 3. Here the incoming light is split into parts by a 30/70 beam splitter. The 70 per cent fraction passes through the 15 A filter, while the 30 per cent fraction passes through a

150 A Hβ filter. The second filter, of course, passes the Hβ line also, but its effect relative to the continuum contribution should be small. The outputs of the cells were treated in the same way as those of the previous model. As an additional check, it is possible to remove the beam splitter and observe during photometric weather with one cell only. In this method, measures are made through the 15 A and the 150 A filters in succession. These measures are on the same system as above, with a change in zero point, because the filters are the same.

In observing, a series of four or more deflections were made for each star besides a deflection on the sky. The integration times varied from 10 to 40 seconds, depending on the star's magnitude. In addition, two or more deflections were then made, where a 150 A filter, cut from the same piece as the other one, was moved into the place of the narrow filter. This ratio should be the same for all stars and was hence used to eliminate the cell drift instead of any kind of standard lamp. The relative sensitivity of the system was such that the second integrator operated at about 2.5 mag. less than the first one when using the 15 A filter.

Observations were made on 13 nights during October, 1957, with this equipment on the McDonald 36-inch reflector. The resultant index, after small night corrections had been applied to put the measures on the same system, has been called $\boldsymbol{\beta}$:

$$\boldsymbol{\beta} = 2.5\,[\log I(150\text{ A filter}) - \log I(15\text{ A filter})] + \text{constant}\,.$$

The internal mean error, as determined from the measures of different nights, was ± 0.006 mag. for one observation. The average number of observations on each standard for this observing session was 4.5. The total range of the parameter from early B supergiants to the strongest hydrogen absorption observed was about 0.4 mag.; hence the error of one observation is 1.5 per cent. This is to be compared with that achieved in photographic determinations of line intensity, which is about 5 per cent for an average of over two plates per star.

The values of $\boldsymbol{\beta}$ for the standard stars are given in Table 1. For use, all measures on the L and $\boldsymbol{\beta}'$ systems were transformed to the $\boldsymbol{\beta}$ system. The transformations used were

$$(\boldsymbol{\beta} - 2.000) = -0.021 + 1.00\,\boldsymbol{\beta}'\,,$$

$$(\beta - 2.000) = +0.306 + 0.843\,(L - 1.000)\,.$$

The final adopted values of $\boldsymbol{\beta}$ are given in Table 1 for the standard stars.

There are many photographically determined values for hydrogen-line strengths in the literature. Petrie (1953, 1956*a*, *b*) and Petrie and Maunsell (1949) have done considerable work on Hγ, in order to determine values of the absolute magnitude of early-type stars. In Figure 4 his measured values for Hγ are plotted against the photoelectric values of $\boldsymbol{\beta}$. The deviation from linearity in the region of strong Hβ intensities is probably due to the line wings becoming important in the region outside the 15 A filter. The transformation in the linear region (where most of the stars are) is $W = -16.7 + 34\,(\beta - 2.000)$, with a transformation mean error in W of ± 0.8. Figure 5 shows a similar relation between $\boldsymbol{\beta}$ and the values given for Hβ by Williams (1936). The transformation is $W = -19.1 + 38\,(\boldsymbol{\beta} - 2.000)$, with a mean error of $\pm 0\ 6$. Hack (1953) measured the "apparent central intensity" for Hδ on low-dispersion plates, and her values are plotted against $\boldsymbol{\beta}$ in Figure 6. The transformation mean error is ± 0.011 from $(\beta - 2.000) = 2.451 + 1.040$ Hδ. Comparison of $\boldsymbol{\beta}$ with other measured values of hydrogen-line strengths were also made, but, as they were all similar in appearance to those given above, individual treatment is of little value. Williams' and Hack's values have the least transformation mean error of any treated.

The advantage of the method lies not only in the higher accuracy possible through the photoelectric method but also in the increased observing efficiency over photographic

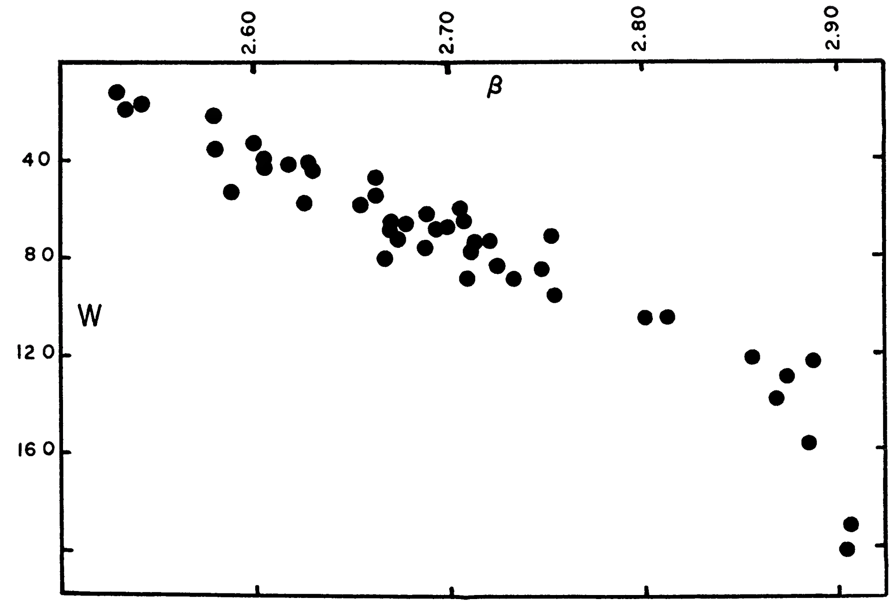


FIG 4

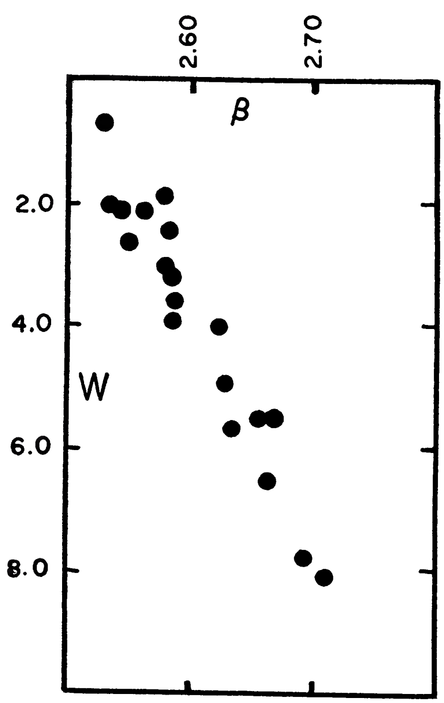


FIG 5

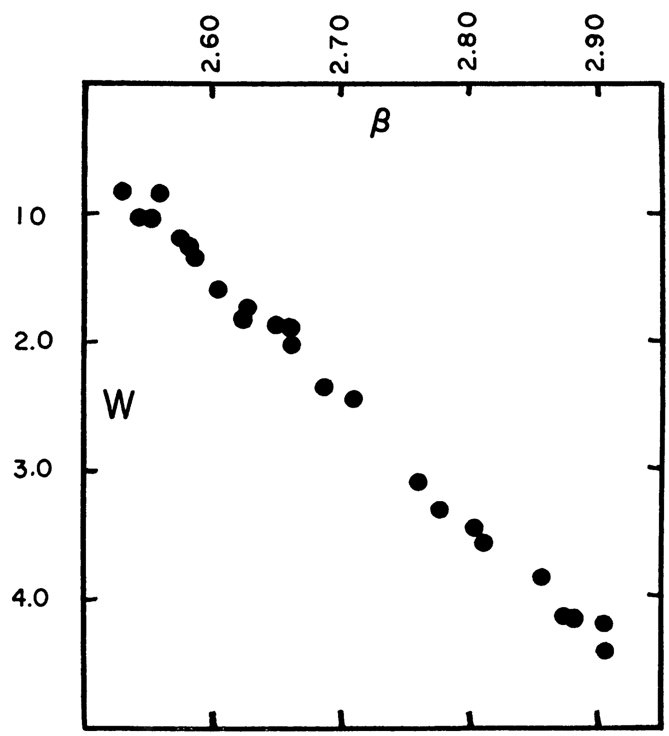


FIG 6

FIGS 4–6.—Fig. 4, transformation between β and Petrie's Hγ values (W); Fig. 5, transformation between β and Williams' Hβ values (W); Fig. 6, transformation between β and Hack's Hδ values work. The total time to obtain a measure with an accuracy of ± 0.004 is under 5 minutes for stars brighter than the ninth magnitude. In addition, the reduction of the observations is simple, especially since no corrections need be made for atmospheric extinction.

III. THE DETERMINATION OF SPECTRAL TYPE FROM U, B, V PHOTOMETRY AND β

It has been shown by several authors that some type of measure of the Balmer discontinuity is an excellent indicator of spectral type along the main sequence (see, e.g., Strömgren 1956*b* and references given there). Any photometric measure of this quantity for the B stars should be quite sensitive to changes in the discontinuity, so that a high percentage accuracy will be obtained. It should be independent of the effects of interstellar reddening, if possible. An advantage also is that criteria based on hydrogen alone are rather insensitive to changes in relative chemical composition of the stars.

Chalonge and his associates in their work (Chalonge and Divan 1952) have measured the discontinuity directly from low-dispersion photographic plates. Their index, D, is of sufficient accuracy to enable them uniquely to determine the spectral type. One would hope, however, to achieve somewhat better accuracy, and a fainter limiting magnitude from photoelectric measures. Strömgren (1956*b*), in fact, has measured an ultraviolet color difference (his index c), well correlated with the Balmer discontinuity, which achieves these ends. He estimates a resultant accuracy in spectral type of about one-hundredth of a spectral class.

However, since most B stars have already been well observed by many observers on the U, B, V system of Johnson and Morgan and since these color indices can readily be corrected for the influence of interstellar reddening, a parameter derived from the measured colors should be useful, if it is well correlated with the Balmer discontinuity.

The color index $(U - B)_0$, when corrected for interstellar reddening, proves to be a good representation of the Balmer discontinuity. Figure 7 plots this corrected color index, $(U - B)_0$, against D, the index used by Chalonge and Divan. Figure 8 plots it against c, Strömgren's index for the discontinuity. The linear fit is quite good in both cases. The relations are $(U - B)_0 = -1.20 + 2.25D$ for the thirty stars in common, with a transformation mean error of ± 0.036; and $(U - B)_0 = 1.32 + 1.17\,c$ for the forty stars in common, with a transformation mean error of ± 0.030 mag.

Using $(U - B)_0$ also has the advantage that it has to be computed in any case, in order to determine the amount of interstellar reddening. However, in the case of the A and F stars, c is to be preferred, as it is only in the range of the B stars that it is relatively easy to free $(U - B)$ of the effects of interstellar reddening.

In this paper $(U - B)_0$ has been determined by the method of Morgan and Harris (1956) for M29, utilizing, however, an improved relation for the interstellar reddening line. By use of the data given by Hiltner and Johnson (1956) for the O stars and by Hiltner (1956) for the B stars, a best fit was obtained from the main-sequence stars, supergiants, and O stars. Only those stars with normal spectra were used. The relation obtained for the ratio of the color excesses was

$$\frac{E_{(U-B)}}{E_{(B-V)}} = 0.70 + 0.06E_{(B-V)}\,,$$

in excellent agreement with the relation obtained by Johnson and Hiltner from the data on the O stars alone.

The process of calculating $(U - B)_0$ proceeds by successive approximations, the first step using the linear term, $E_{(U-B)}/E_{(B-V)} = 0.70$. Then $(U - B)_o = 1.233\ (U - B) - 0.862\ (B - V)$, and $(B - V)_0 = +0.27\ (U - B)_0$. Then $E_{(B-V)}$ is computed from this $(B - V)_0$. Then $E_{(U-B)}/E_{(B-V)}$ is redetermined, using this $E_{(B-V)}$, the process being gone through again with new coefficients in the equation for the ratio of the color excesses. The $(U - B)_0$'s from the second and third approximations agree except in the cases of highest reddening, so that two stages are all that are usually required.

As an example, take typical values of $(U - B) = -0\ 60$ and $(B - V) = +0.07$. Hence $(U - B)_0 = -0.80$ for the first step. Therefore, $(B - V)_0 = -0.22$, and so $E_{(B-V)} = 0.29$. Then $0.06E_{(B-V)} = 0.02$ and $E_{(U-B)}/E_{(B-V)} = 0.72$. The relation in this case is $(U - B)_0 = 1.242(U - B) - 0.894(B - V)$, which gives $(U - B)_0 = -0.81$. This is the desired value. The star in this example is of class B2 V (HD 23625). The values for the intrinsic color and reddening derived on this system are $(U - B)_0 =$

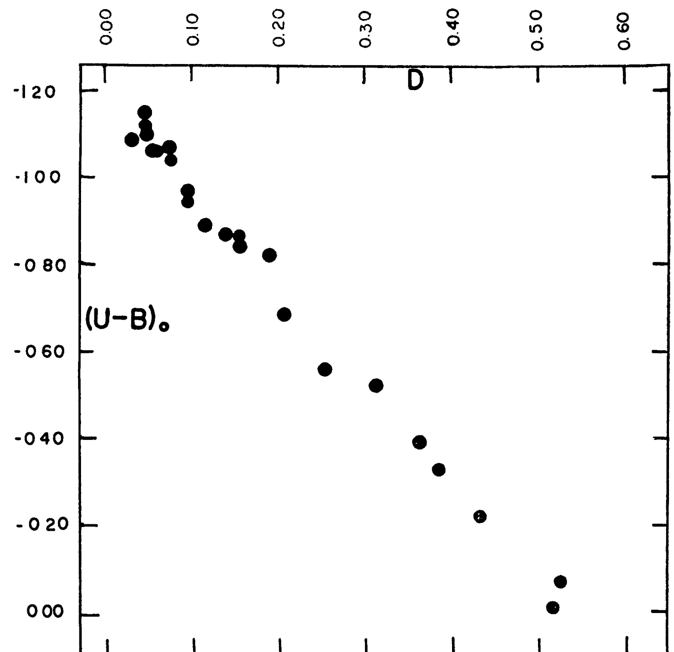


FIG 7

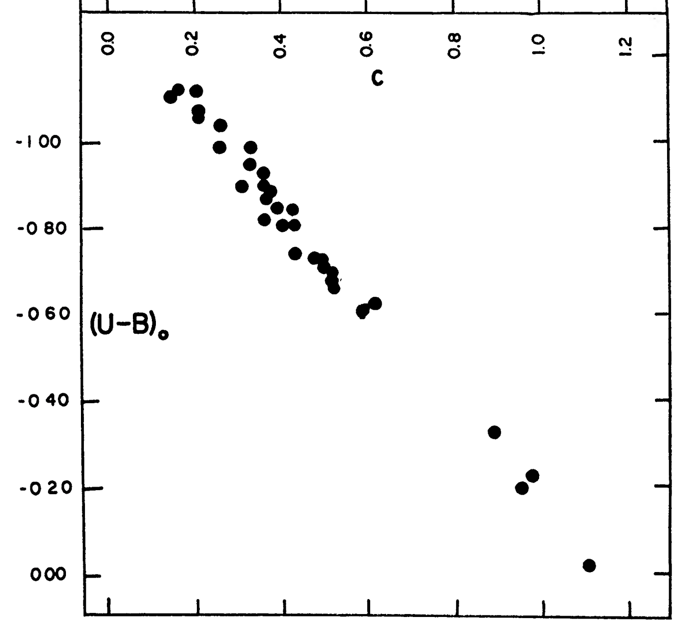


FIG 8

FIGS. 7–8.—Fig. 7, transformation between Chalonge and Divan's index D and $(U - B)_0$ for the B stars; Fig. 8, transformation between Strömgren's index c and $(U - B)_0$ for the B stars.

-0.81, $(B - V)_0 = -0.22$, and $E_{(B-V)} = 0.29$. Taking the MK intrinsic color for a B2 V star, $(B - V) = -0.24$ (note that -0.22 lies within the range of possible values for a B2 V star), $E_{(B-V)} = 0.31$. Using the "Q method" of Johnson and Morgan (1953) (see also Johnson 1957), one gets $Q = (U - B) - 0.72\,(B - V) = -0.65$, which shows that it is a B2 star, and hence its intrinsic color and reddening would be the same as on the MK system. The agreement between these methods is satisfactory.

The good agreement with Chalonge's work and with Strömgren's, for all stars of early and late type, little or heavy reddening, and of high or low luminosity, suggests that there is little or no systematic error involved in the determination of $(U - B)_0$.

Figure 9 plots $(U - B)_0$ and β for the standard stars of Table 1. The solid lines are the dividing lines between the spectral and luminosity classes on the MK system. The solid dots are stars whose photometric type agrees with the MK type, and the open dots are the discordant stars. The triangles are giants, and the crosses, supergiants. It should be noticed that the agreement is quite good. The accuracy of a point on this plot is given by the mean error in β of ± 0.006 mag. and by an estimated mean error in $(U - B)_0$ of about ± 0.015 mag.

The mean values of $(U - B)_0$ for a given MK type along the main sequence are listed in Table 2. These agree well with the standard MK values. The mean error of predicting

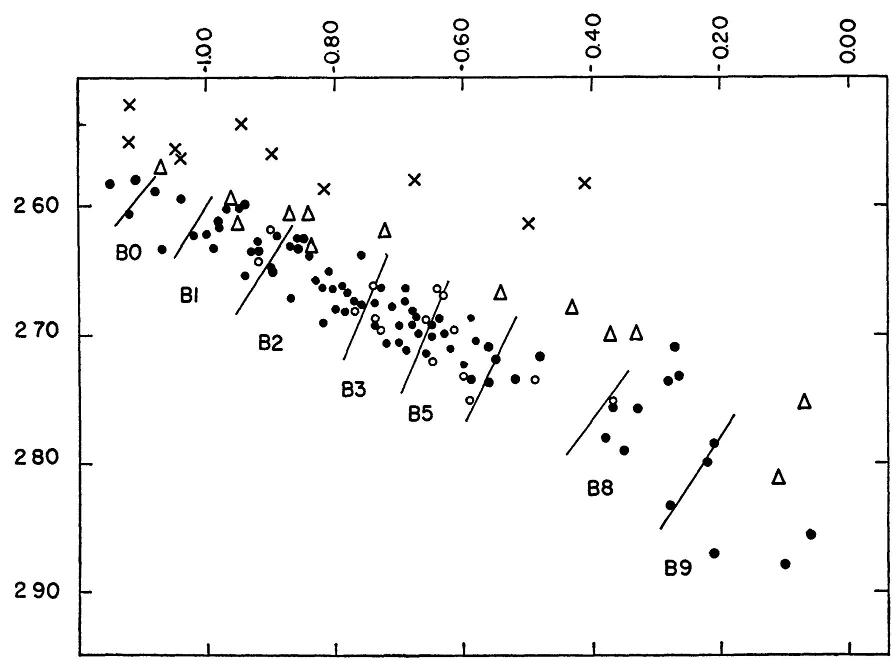


FIG. 9 —The $(U - B)_0$, β diagram for the standard stars of Table 1 Circles indicate main-sequence stars, the lines separating the MK types for these stars The open circles are those stars whose $(U - B)_0$, β type disagrees with the MK type. Triangles indicate luminosity class III stars; crosses indicate the supergiants.

TABLE 2

INTRINSIC COLORS OF MAIN-SEQUENCE STARS

MK Type	$(U-B)_0$	MK Type	$(U-B)_0$	MK Type	$(U-B)_0$
B0	−1 06	B3	−0 74	B8	−0 33
B1	−0 96	B5 .	− 63	B9	− 14
B2	−0 86	B6 5	−0 49	A0 ..	0 00

a spectral class is about ± 0.01 of a class. Definite values for the luminosity classes above the main sequence have not been computed because of the small number of stars in each class.

IV. EVOLUTIONARY EFFECTS ON THE $(U - B)_o$, β DIAGRAM

The $(U - B)_0$, β diagram in Figure 9 has been shown to comprise an accurate two-dimensional spectral classification system that agrees well with the MK system. The diagram agrees with those of similar type that have been determined from photographic results based on hydrogen criteria. The inherent accuracy of Figure 9 is, however, higher because of the photoelectric method. This method of two-dimensional classification proposed in Section II depends on objectively determined measures of high accuracy for both the indices used: the $(U - B)_0$ index being closely correlated with spectral type, and the Hβ index with luminosity. The method, therefore, offers a means of investigating, with a precision not previously possible, the population characteristics of galactic clusters and of associations.

For this purpose, member stars of four galactic clusters and associations have been observed. These groups are (1) the northern section of the Scorpio-Centaurus association; (2) the Orion association (excluding the group of stars in and around the Orion Nebula); (3) the ζ Persei association; and (4) the α Persei cluster. For comparison with these groups, a number of non-cluster stars were observed, as well as the ones utilized as standards on the β and L systems. In addition, a few members of the Pleiades cluster have been observed, in order to give an idea of the characteristics of this group.

TABLE 3

THE SCORPIO-CENTAURUS CLUSTER STARS

HD No	Star	V_0	$(U-B)_0$	β	MK Type
142096	λ Lib	4 49	−0 72	2 710	B3 V
142165	HR 5906	4 95	−0 51	2 743	B6 V
142185	HR 5907	4 86	−0 74	2 668	B2 Vnn
142301	3 Sco	5 43	−0 71	2 681	
142315	. . .	6 52	−0 23	2 803	
142378	47 Lib	5 45	−0 65	2 706	. ..
142669	ρ Sco	3 80	−0 91	2 646	B2 V
142990	HR 5942	5 06	−0 73	2 678	. ..
143018	π Sco	2 75	−0 98	2 612	B1 V
143275	δ Sco	1 80	−1 04	2 594	B0 V
143567	.. ...	6 69	−0 23	2 846	
144334	HR 5988	5 60	−0 65	2 708	. .
144844	HR 6003	5 43	−0 50	2 788	...
145482	13 Sco	4 43	−0 80	2 664	B2 5 V
145554		6 97	−0 25	2 837	
145631	.. ....	6 91	−0 21	2 856	
145792	HR 6042	5 74	−0 62	2 718	
146001	HR 6054	5 54	−0 49	2 747	
146029		6 97	−0 16	2 873	
146284		5 91	−0 34	2 753	
146285	.. ...	6 97	−0 32	2 818	
146416	HR 6066	6 36	−0 23	2 832	
147009		7 09	−0 08	2 920	
147010	.	6 59	−0 50	2 755	...
147165	σ Sco	Var.	. ..	2 594	B1 III
147889		4 59	−0 95	2 650	B2 V
148199		6 44	−0 33	2 778	
148579	.	6 29	−0 28	2 881	..
148605	22 Sco	4 54	−0 78	2 668	B2 V
149438	τ Sco	2 77	−1 08	2 588	B0 V
157056	θ Oph	3 22	−0 91	2 632	B2 IV

Table 3 gives the values of V_0, $(U - B)_0$, and β that have been determined for the Scorpio-Centaurus moving cluster. The list contains only the upper part of the group (north of $-30°$ declination), which can be conveniently observed from the latitude of McDonald Observatory. This moving cluster has been discussed by Blaauw (1946, 1957), and the list of members given by him are the stars treated here. The earliest main-sequence stars in this group are B0 V.

The relation between absolute magnitude and Hβ strength is shown in Figure 10 for the Scorpio-Centaurus cluster. The distance modulus is based on Blaauw's results for the upper part of the cluster. No correction has been made for variation due to spectral type, if any, because of the small number of stars in any one class. Most of the stars are located on the main sequence, however, and hence little correction to a mean relation for main-sequence stars would be expected.

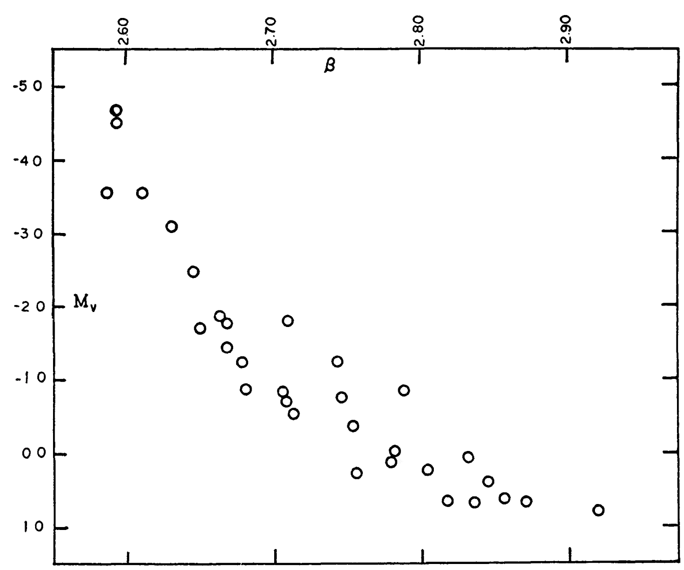


FIG. 10 —Absolute magnitude and Hβ relation for the northern part of the Scorpio-Centaurus cluster

Figure 11 plots the $(U - B)_0$, β relation for the main-sequence stars in this northern part of the Scorpio-Centaurus association. Each of the plotted values for the stars consists of multiple observations, both for U, B, V and for β, and therefore the observed points are of high weight. The scatter in this diagram is small. In such a diagram the effect of unresolved double stars, such as spectroscopic binaries, is such as to change both $(U - B)_0$ and β in the same sense. The secondary star will have a later spectral type, in general, and hence the $(U - B)_0$ index for the combined light will be more positive than for the primary component alone. Likewise, the later-type star will have a stronger Hβ line (except for stars close to the maximum of hydrogen absorption). Hence its β index will be larger than for the primary component alone. The combined effect on these two indices will tend to move the plotted points for double stars off the mean relation for single stars, but, as the direction of the change is the same for both indices, the perpendicular distance of the observed point from the mean line will remain small. If the two stars are of the same spectral type and luminosity, there will be no change in either $(U - B)_0$ or β from the values for either star alone. In fact, one can see that for two stars of nearly equal luminosity the M_V deviation is largest, while the Hβ deviation is the smallest. As the separation in luminosity increases, the M_V deviation decreases, while the Hβ change increases. However, when the Hβ difference is large, the weight of the fainter star to the combined Hβ is small. Any deviations in the total Hβ line due to duplicity are, therefore, expected to be small. The same is true for $(U - B)_0$ as well. This is not true, of course, in an absolute-magnitude–spectral-type diagram (HR diagram). Here, for two stars of equal luminosity, the M_V parameter shifts three-quarters of a magnitude, while the spectral-type parameter remains unchanged. A larger scatter is expected in an Hβ, M_V diagram, such as Figure 10, for the same reason. Therefore, the effect of duplicity on the $(U - B)_0$, β diagram is small, and any rather large deviations from a mean line must be due to other causes.

The data for the non-cluster main-sequence stars, or field stars, taken from Table 1, are plotted in Figure 11 also. It is of considerable interest to see that, with the exception of the star κ Andromedae, all the field stars have indices smaller than those for the Scorpio-Centaurus cluster stars of the same $(U - B)_0$. This is an important fact, for it

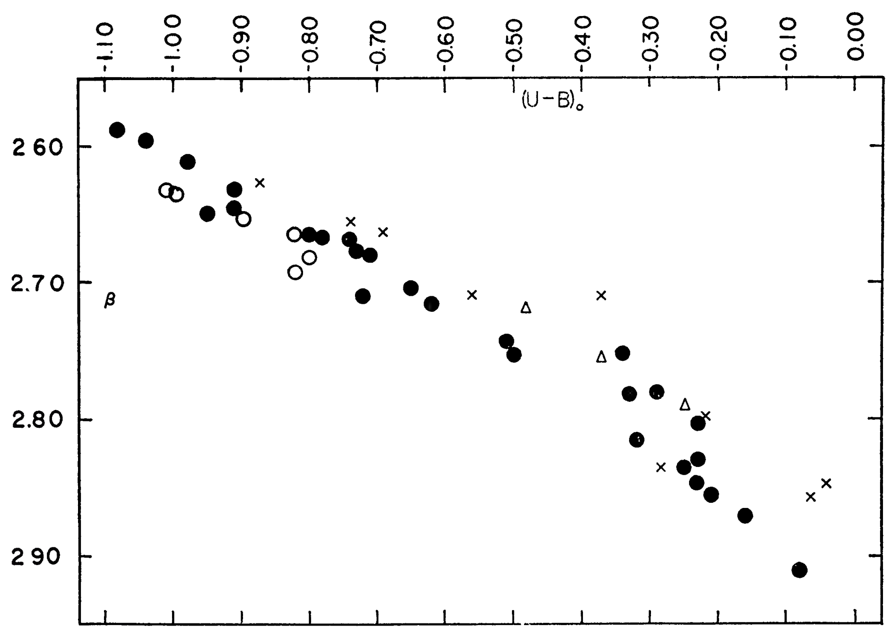


FIG. 11.—The $(U - B)_0$, β diagram for the Scorpio-Centaurus cluster (*filled circles*), the ζ Persei association (*open circles*), the Pleiades (*triangles*), and the field stars of Table 1 (*crosses*).

appears to indicate that an age effect is directly observable in the $(U - B)_0$, β diagram: the index β for main-sequence stars shows an evolutionary effect such that the hydrogen-line absorption at Hβ is weaker for the older stars than for the younger ones.

Two stars are worth checking in more detail. These are the two stars which appear to have stronger Hβ strengths than any of the other Scorpio-Centaurus cluster members. The first is HD 147889, a highly reddened member of this northern part of the association. It is located in the dense dark clouds near ρ Ophiuchi. If the youngest stars in an association are to be found in such locations (as in Orion), then this star would be expected to be among the youngest in the Scorpio-Centaurus cluster. The $(U - B)_0$, β values for this star are -0.95 and 2.650, respectively. Its high relative Hβ strength also indicates that it is younger than the average member. The other star is λ Librae, with $(U - B)_0$ and β values of -0.72 and 2.710, respectively. It appears normal except for its relatively greater Hβ strength.

Figure 11 also contains the plotted data for the six main-sequence stars observed by Harris (1956) which are members of the association II Persei. This is the ζ Persei association. The data for the member stars are contained in Table 4. This cluster is expected to be younger than the Scorpio-Centaurus association. Its earliest-type star is ξ Persei, an O7 star on the MK system. The separation in Hβ index between these stars and the Scorpio-Centaurus cluster stars is well marked; in general, all the main-sequence member stars tend to lie below the Scorpio-Centaurus members for the same $(U - B)_0$.

Table 1 for the standard stars contains three main-sequence stars of the Pleiades cluster. The $(U - B)_0$, β values for these stars are also plotted in Figure 11. The plotted points agree more closely in position with the field stars than with the Scorpio-Centaurus cluster members. From the phenomena of the age effect on Hβ evidenced in the other observed groups, it would appear that the age of the Pleiades cluster is closer to that of the field stars, taken as a group, than to the age of the Scorpio-Centaurus cluster. The earliest main-sequence star in the Pleiades is B6 V, also indicating a considerably older age for the Pleiades than for the Scorpio-Centaurus association members, whose earliest spectral type is B0 V.

Table 5 gives the observed data for the association I Orionis. The U, B, V photometry is that of Sharpless (1952, 1954). The very young stars imbedded in the Orion Nebula

TABLE 4

THE ζ PERSEI ASSOCIATION

HD No	Star	V_0	$(U-B)_0$	β	MK Type
21843	HR 1074	5 42	−0 75	2 618	B3 III
21856		5 25	−1 01	2 634	B1 V
23060		6 25	−0 80	2 682	B2 Vp
23180	*o* Per	2 91	−0 96	2 597	B1 III
23478		5 84	−0 77	2 679	B3 IV
23625	. .	5 71	−0 81	2 664	B2 V
24131	HR 1191	4 97	−1 01	2 632	B1 V
24190		6 60	−0 81	2 691	B2 V
24398	ζ Per	1 65	−1 05	2 563	B1 I*b*
24640	HR 1215	4 87	−0 90	2 650	B2 V
24912	ξ Per	3 08	−1 15	2 581	O7

itself have been treated by Johnson (1957*a*, *b*) and by Strand (1957). Their earliest spectral type is O6. Owing to the effects of the nebula, which is in emission at Hβ, on the observed line strengths for these stars, however, they have been omitted from further discussion here. No stars associated with any nebulosity are included in Table 5. Among the association stars not in the central area (that is, in or around the nebula), the earliest main-sequence stars are of type B0 V. The age of this outer group of the Orion association is therefore probably near to that of the Scorpio-Centaurus association.

Figure 12 shows the $(U - B)_0$, β diagram for these outer Orion association stars. The solid line indicates the mean relation for the Scorpio-Centaurus cluster members. This line fits the Orion data satisfactorily, confirming that the age of these two groups is approximately equal. The larger scatter in the Orion data perhaps indicates that the range of ages of the outer Orion group members is larger than in the Scorpio-Centaurus cluster stars.

Table 6 gives the data for the α Persei cluster, the U, B, V photometry being that of Harris (1956). In this group the earliest main-sequence type is B3 V. Hence this cluster appears to be older than either the Orion association or the northern part of the Scorpio-Centaurus association. However, it would still be younger than the Pleiades cluster. Figure 12 includes the plotted values for these member stars. The position of the stars in the $(U - B)_0$, β diagram would indicate that the cluster is of some age

TABLE 5

ORION ASSOCIATION

HD No	V_0	$(U-B)_0$	β	MK Type
30836	3 49	−0 87	2 605	B2 III
31237	3 61	−0 85	2 592	B2 III
33647	6 56	−0 38	2 779	B8 V
34511	7 15	−0 74	2 689	B5 V
34989	5 48	−0 89	2 624	B1 V
35007	5 47	−0 70	2 692	B3 V
35039	4 51	−0 85	2 628	B2 IV
35079	6 73	−0 60	2 732	B3 V
35299	5 58	−0 92	2 630	B1 V
35407	6 28	−0 64	2 687	B5 V
35411	3 12 (Var)	−0 97	2 601	B0 5V
35502	6 99	−0 62	2 712	B5 V
35575	6 32	−0 74	2 675	B3 V
35588	6 11	−0 77	2 675	B2 V
35640	6 24	−0 21	2 822	B9 V:
35715	4 44	−0 95	2 601	B1 V
35718	8 21	0 00	2 906	. . .
35762	6 68	−0 73	2 663	B2 V
35777	6 54	−0 76	2 637	B2 V
35792	7 11	−0 65	2 720	B3 V
35899	7 43	−0 65	2 701	B5 V
35910	7 46	−0 57	2 714	B6 V
35912	6 29	−0 76	2 676	B2 V
36013	6 76	−0 67	2 681	B2 V
36120	7 78	−0 39	2 777	.
36151	6 65	−0 60	2 723	B5 V
36166	5 67	−0 87	2 629	B2 V
36234	8 55	−0 40	2 796	. .
36285	6 15	−0 90	2 647	B2 V
36392	7 41	−0 69	2 711	B3 V
36429	7 44	−0 66	2 715	B5 V
36430	6 05	−0 80	2 682	B2 V
36487	7 75	−0 57	2 756	. .
36512	4 52	−1 08	2 586	B0 V
36513	9 35	−0 13	2 904	
36541	7 60	−0 49	2 777	
36560	8 28	−0 40	2 768	. .
36591	5 07	−1 00	2 621	B1 V
36607	9 23	−0 14	2 910	. .
36627	7 47	−0 55	2 718	B6 V
36655	8 57	−0 27	2 852	. .
36695	5 04	−0 98	2 626	B1 V
36697	8 43	−0 03	2 902	.
36741	6 82	−0 79	2 661	B2 V
36779	6 15	−0 82	2 664	B2 V
36824	6 54	−0 74	2 691	B2 V
36867	9 27	−0 16	2 912	.
36954	6 65	−0 72	2 707	B3 V
36958	7 06	−0 67	2 700	B3 V
36959	5 58	−0 94	3 634	B1 V
36960	4 62	−1 07	2 598	B0 V
37000	7 34	−0 70	2 715	B5 V
37001	8 89	−0 25	2 835	. .
37209	5 65	−0 94	2 654:	B1 V
37321	6 90	−0 59	2 751	B3 V
37481	5 87	−0 93	2 635	B1 V

TABLE 5—*Continued*

HD No	V_0	$(U-B)_0$	β	MK Type
37526	7 55	−0 56	2 737	B5: V:
37606	6 90	−0 33	2 757	B8 V
37700	7 90	−0 49	2 735	B5 V
37744	6 11	−0 92	2 628	B1 V
37756	4 88	−0 85	2 639	B3 III
37776	6 70	−0 92	2 640	B2 V
37807	7 65	−0 70	2 705	
37887	7 67	−0 10	2 870	
37888	9 06	−0 08	2 884	. ..
37889	. .	. .	2 678	B2 V
37903	6 87	−0 84	2 639	B2 V
38051	6 88	−0 69	2 673	. ..
38755	7 62	−0 52	2 733	B5 V
38771	1 66	−1 12	2 549	B0 5 I*a*
39291	5 18	−0 90	2 629	.. ..
39377	6 45	−0 83	2 658	B2 V

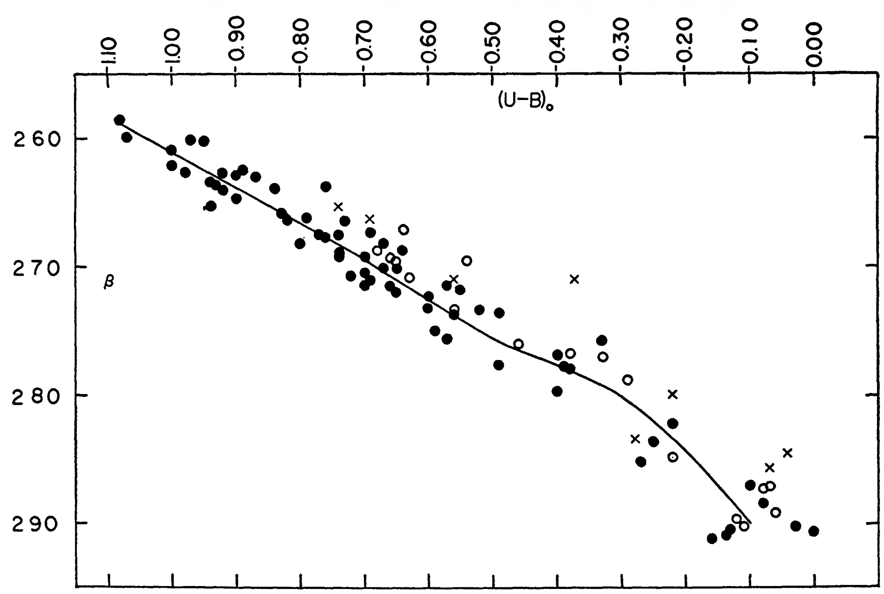


FIG. 12 —The $(U-B)_0$, β diagram for the outer part of the Orion association (*filled circles*), the α Persei cluster (*open circles*), and the field stars (*crosses*). The solid line indicates the mean relation for the Scorpio-Centaurus cluster

intermediate between the field stars and the Scorpio-Centaurus cluster members, but definitely younger than the Pleiades group.

It is interesting to consider the difference in this evolutionary effect between earlier and later B-type stars. In the earlier-type stars the "turnup" effect in the HR diagrams is most evident. Hence an age criterion, such as the Hβ strength, would be expected to separate clusters of various ages better for the earlier-type B stars than for the late-type stars. This is actually seen in Figures 11 and 12. While the range of the parameter β is largest in the late-type B stars, the separation between the groups is not so apparent as it is in the earlier types. It is especially noticeable for the case of the α Persei cluster, where for the earlier types the plotted points tend definitely to lie above the Orion members, but in the later types the points are more intermingled.

Table 7 summarizes the observed data for the five groups discussed above. The order of their decreasing Hβ strength may be taken as an indication of their relative ages The relative ages are also indicated by the earliest main-sequence spectral type observed in the group. The last column lists the ages as determined by von Hoerner (1957). He determined ages for a number of groups and gives a relation between age and the earliest spectral type in the group. The spectral type in Table 7 hence yields the age given in the last column.

Over the entire range of $(U - B)_0$ within a group the member stars define a line which may be taken as a measure of the cluster age relative to other groups or to the field stars in general. The scatter about this mean line may be due to several causes: (1) the accidental errors of the photometry; (2) the varying ages of the stars within the group, for it is not likely that all stars within an association are formed at the same time (the scatter due to this should be more noticeable in an association than in a cluster, which is more likely to consist of stars of about the same ages); (3) the scatter due to duplicity of some of the observed stars; and (4) the effect of actual field stars being included in

TABLE 6

α PERSEI CLUSTER

HD No	Star	V_0	$(U-B)_0$	β	MK Type
20365	29 Per	4 77	−0 68	2 688	B3 V
20391	.	7 64		2 923	A1 V
20418	31 Per	4 67	− 64	2 671	B5 V
20701	. ....	8 06		2 925	A1 V
20809	HR 1011	4 96	− 65	2 696	B5 V
20961	. ..	7 16	− 12	2 896	A0 V
21071	HR 1029	5 85	− 56	2 734	B6 V
21091		7 29	− 11	2 902	A0 V
21181	.. ...	6 60	− 29	2 787	B9 V
21278	HR 1034	4 71	− 63	2 708	B3 V
21362	HR 1037	5 26	− 54	2 695	B6 V
21375		7 17		2 893	A1 V
21398	.	7 13	− 22	2 849	B9 V
21428	34 Per	4 33	− 66	2 694	B3 IV
21479		6 98	.	2 873	A2 V
21481	...	7 32	− 07	2 871	A0 V
21551	HR 1051	5 62	− 38	2 766	B8 IV
21641		6 56	− 33	2 770	B9 V
21672	..	6 39	− 38	2 781	B8 V
21699	HR 1063	5 27	−0 63	2 711	B8 III

TABLE 7

SUMMARY OF EVOLUTIONARY EFFECTS

Association or Cluster	Order in Decreasing Strength of Hβ	Spectral Type of Earliest Main-Sequence Star	Approximate Age (Years)
ζ Persei .	1	O7	1×10^6
Scorpio-Centaurus . .	2	B0	4×10^6
Orion (less nebula cluster)	2	B0	4×10^6
α Persei	3	B3	10×10^6
Pleiades	4	B6	80×10^6
Field stars	5	.	.

the lists of members of a group, for the Hβ values of these field stars would, in general, be less than for the member stars.

Hence the high accuracy with which $(U - B)_0$ and β can be determined enables an evolutionary effect to be shown in such diagrams as Figure 11. By use of this effect, one can estimate the relative ages of different clusters and associations. This effect is independent of any other criteria of age, such as the turnup observed in clusters and associations.

Figure 13 illustrates this phenomenon of varying Hβ strength as a function of age for the five groups discussed above. Mean values for β were taken as a function of $(U - B)_0$ for the main-sequence stars of the groups in Table 7, and the resultant curves were smoothed to a linear relation. The "hump" observed in Figure 11, therefore, has not been taken into account. The question of its reality will have to await observation of more groups.

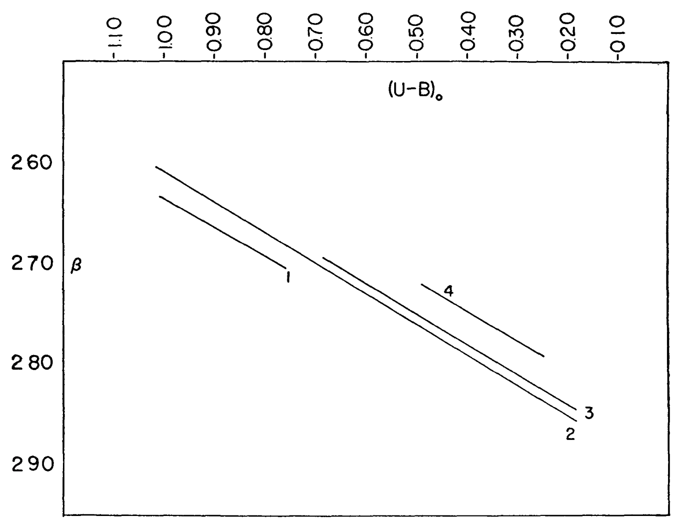


FIG. 13 —The mean $(U - B)_0$, β relation for the groups discussed in this paper The numbers next to the mean lines indicate the order in decreasing Hβ strength, as given in Table 7.

V. DISCUSSION OF THE AGE EFFECT

In the $(U - B)_0$, β diagram, a well-defined relation therefore appears to be present, so that the intensity of the Hβ absorption of a star and the stage of its evolution are well correlated. The strongest hydrogen-line absorption for B stars of a given spectral type are present in those stars which are members of the youngest groups. Of the five groups discussed in Section IV, the ζ Persei group would be judged to be the youngest, owing to the extension of the main sequence to a star of type O7. This group also shows the highest relative strength of the Hβ line in its stars. Those main-sequence stars with the same spectral type—or $(U - B)_0$—in the northern Scorpio-Centaurus group have systematically weaker intensities of the Hβ line, as measured by the index β. The α Persei cluster and the Pleiades stars appear older, for their earliest main-sequence stars are B3 V and B6 V, respectively. They also have increasingly weaker Hβ intensities. The oldest "group" of all—the field stars—have the weakest Hβ intensity of all, with a few exceptions, such as κ Andromedae.

A full explanation of this effect is difficult at the present time, for only in the case of the Scorpio-Centaurus cluster are accurate individual absolute magnitudes available. Therefore, how much fainter the ζ Persei main sequence is than that of Scorpio-Centaurus is not accurately known. The data of the present paper do not permit a new calibration to be made of the absolute magnitudes for the main-sequence B stars, even for the groups illustrated in Figure 13. We can conclude, therefore, that the main-sequence stars of the ζ Persei cluster are fainter than those in the Scorpio-Centaurus cluster and that the main-sequence stars in the α Persei and Pleiades clusters are brighter than those in the Scorpio-Centaurus cluster. But the exact differences cannot be estimated in terms of absolute magnitude.

The uncertainty in absolute-magnitude difference between the groups interferes seriously with any quantitative explanation of the observed evolutionary effect, for we do not have enough available information to allow a calculation of the effects of changes in surface gravity. These changes, however, seem to be the most likely explanation of the observed phenomena. Therefore, any point on the $(U - B)_0$, β plane should depend only on the age and chemical composition of the stars.

A promising attack on the problem should be the investigation of the line intensities in associations where main-sequence stars of different ages might exist. The aim of such a program would be to establish an accurate relation between the observed $(U - B)_0$ and β indices and the absolute magnitudes. The resultant relation would give accurate relative M_V's, which would then be tied into the Scorpio-Centaurus absolute magnitudes for use. This would not be a simple problem but is probably the most straightforward approach.

Another approach which would be used for the tie-ins between various groups and also for a better understanding of the evolutionary phenomena as a whole would be to observe the indices $(U - B)_0$ and β for the A-type members of the groups discussed above. Field stars of spectral type A should also be observed, especially those with significant trigonometric parallaxes. For the A stars the evolutionary effects proceed at a slower rate, and hence the observed age differences in the $(U - B)_0$, β diagram for these stars might not be so apparent as in the case of the B stars. If so, an actual combination of the diagrams would be possible, and therefore accurate relative absolute magnitudes would be determined for all the stars in the different clusters. If such a fit were possible in the A stars, then groups with known distances could be used to give the zero-point correction necessary to apply to the relative M_V's, in order to strengthen the determination from the Scorpio-Centaurus moving cluster alone.

In this connection useful clusters would be those where members are known throughout the spectral range from the late B stars through the A stars and even into the F stars, if possible. Some of the groups which would be particularly useful would be (1) the α Persei cluster, (2) the Pleiades, (3) the Hyades cluster, and (4) the Ursa Major moving cluster. In addition, of course, A- and F-type stars with significant trigonometric parallaxes would be most useful for determining the $(U - B)_0$, β and M_V relation.

The resulting $(U - B)_0$, β, and M_V three-dimensional relation would be of the greatest importance for several reasons. It would enable a physical explanation to be attempted of the evolutionary phenomena discussed in this paper. The information then derived concerning line strength, absolute magnitude, and surface gravity would be of prime importance in the field of stellar evolution for population I stars, especially those of spectral type B, where the phenomenon is most marked due to the rapid evolution. In addition, the relation would furnish an accurate method of determining the galactic distance scale, by means of the individual absolute magnitudes obtainable for the early-type stars and for the galactic clusters. The work now being carried on by Strömgren and associates may make this possible.

VI. SOME APPLICATIONS

In spite of the evolutionary effects discussed in the preceding section, it may be useful to determine the mean absolute magnitudes for the late-type B stars in the Scorpio-Centaurus cluster. These absolute magnitudes should be, in a sense, standard absolute magnitudes for a group of stars whose main sequence extends to B0 V. The absolute magnitudes could then be used, along with the $(U - B)_0$, β diagram, to draw some conclusions about later-type clusters. In this section these standard absolute magnitudes will be derived from the B8 V and B9 V stars in the Scorpio-Centaurus cluster and then applied to the α Persei cluster to obtain a limiting value for its distance modulus.

While the data for the Scorpio-Centaurus association are not extensive, as only the northern part of the whole moving cluster has available $(U - B)_0$, β, and absolute-magnitude data, it is interesting to look into the absolute-magnitude calibration for the main-sequence spectral types having a number of stars available. Table 8 gives the data for the B8 V and B9 V stars in the upper Scorpio-Centaurus group. The computed value of $(U - B)_0$ yields a spectral type for these ten stars, and mean values for V_0 and β have been taken for the B8 and B9 stars separately. No corrections have been made for completeness of the data, for the range in values of V_0 for B9 is about the same as for B8, while the mean value of V_0 for the B8 stars is 0.34 mag. brighter than for the

TABLE 8

B8 V AND B9 V STARS IN THE SCORPIO-CENTAURUS CLUSTER

Spectral Type	β	$(U-B)_0$	V_0	M_V
B8 V	2 753	−0 34	5 91	
	2 818	− 32	6 97	
	2 778	− 33	6 44	
	2 781	− 28	6 29	
Mean B8 V	2 782	− 32	6 42	+0 12
B9 V	2 832	− 23	6 36	
	2 805	− .23	6 52	
	2 846	− 23	6 52	
	2 837	− 25	6 97	
	2 856	− 21	6 91	
	2 873	− 16	6 97	
Mean B9 V	2 841	−0 22	6 74	+0 44

B9 stars. If there was a selection effect in apparent magnitude, the range in the B9's would be less than in the case of the B8's. Also in the original work the stars were selected from the available types in the *Henry Draper Catalogue*, which is certainly complete to fainter apparent magnitudes than the seventh, the approximate magnitude of the faintest B9 star in the upper group of the Scorpio-Centaurus cluster.

The distance modulus of this part of the cluster has been taken as $V_0 - M_V = 6.3$ mag. This value is derived from Blaauw's absolute magnitudes and available U, B, V photometry. It should not be in error by more than ± 0.1 mag.

Using this value, the mean absolute magnitude given in Table 8 was derived from the V_0's for the B8 and B9 stars. These M_V's should be accurate for the main-sequence B8 V and B9 V stars of clusters and associations in which the main sequence extends to B0 V. They will therefore be lower-limit values for B8 V and B9 V stars of groups where the turnoff occurs at later main-sequence types than B0 V. In fact, from an inspection of the $(U - B)_0$, β diagram it is probable that, for the B8 V and B9 V stars, the M_V, β relations may be unique. That is, for stars fainter than $M_V = 0.0$ mag. the dependence on $(U - B)_0$ is slight. For higher luminosities, of course, the $(U - B)_0$ dependence is well marked.

It is interesting to look at the case of the α Persei cluster, using these mean absolute magnitudes. For this group the absolute magnitudes are lower limits, as the turnoff occurs at B3 V. We can therefore compute a minimum value for the distance modulus for this group, using its B8 and B9 main-sequence stars. The data for these stars are given in Table 9. The resultant minimum distance modulus for each type is given in the table.

Blaauw (1956) in his work on the northern O–B5 stars derived a value of $V_0 - M_V =$ 5.52 mag., based on the assumption that the cluster was at the same distance as the Cassiopeia-Taurus stream. The larger value derived from the Hβ considerations is in closer agreement with the distance modulus determined by Mitchell (1957) of 6.1 mag. He obtained U, B, V photometry for the late-type members of this cluster discovered at Hamburg and fitted the F- and G-star part of the main sequence of the cluster with the equivalent parts of other clusters of known distance. These late-type members, not being greatly affected by the evolutionary turnup occurring for B-star members, should give a reliable value for the distance modulus. Hence the low value of absolute magnitudes determined by Blaauw for this cluster are not confirmed. This removes the discrepancy that this cluster, in which the turnup is at B3 V, should have such low absolute magnitudes for its late-B-type members, compared to other clusters of the same age.

TABLE 9

B8 V AND B9 V STARS IN THE α PERSEI CLUSTER

Spectral Type	β	$(U-B)_0$	V_0	Distance Modulus
B8 V	2 787	−0 29	6 60	
	2 770	− 33	6 56	
	2 781	− 38	6 39	
	2 805	− 39	6 59	
B8 V mean	2 788	− 35	6 54	6 42
B9 V	2 849	− 22	7 15	
		− 21	7 04	
B9 V mean	2 849	−0 22	7 08	6 64

VII. SUMMARY

An accurate two-dimensional classification system for B stars has been established, utilizing the two parameters $(U - B)_0$ and β. The parameter $(U - B)_0$, the intrinsic ultraviolet color index on the U, B, V system, is primarily a spectral-type parameter, and β, which measures photoelectrically the intensity of the Hβ line absorption, is a luminosity parameter. Both parameters are inherently of high internal accuracy. Several clusters and associations, as well as a number of field stars, were observed on this system.

From the $(U - B)_0$, β diagrams for these groups, a new phenomenon has been found which appears to be of an evolutionary nature. For main-sequence stars of the same $(U - B)_0$, or spectral type, the Hβ line decreases in intensity with increasing age of the cluster. Hence a simple but accurate method is furnished for arranging galactic clusters in order of evolutionary development. This method of age determination is, of course, applicable also to field stars not assigned to a cluster or association.

When a proper calibration can be made, it appears that the $(U - B)_0$, β classification system should be capable of furnishing accurate absolute magnitudes and hence distances of high precision for clusters and associations.

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