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FUNDAMENTAL STELLAR PHOTOMETRY FOR STANDARDS OF SPECTRAL TYPE ON THE REVISED SYSTEM OF THE YERKES SPECTRAL *ATLAS*[*]

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ABSTRACT

A system of photoelectric photometry is outlined which utilizes the revised zero point of the visual magnitude scale of the North Polar Sequence and which returns to the original definition for the zero point of color indices in terms of main-sequence stars of class A0; the interval A0–gK0 is 1 mag. The revised Yerkes *Atlas* system (MK) of spectral classification is taken as standard. The latter is described briefly, and a list of standard stars is included.

Magnitudes and color indices from measures in three wave-length bands are given for stars selected by spectral type and luminosity class to be representative of the principal regions of the H-R diagram. A few white dwarfs are also included.

A standard main sequence is defined for the new color–absolute magnitude diagram by the use of stars of large parallax, together with the galactic clusters NGC 2362, the Pleiades, the Ursa Major nucleus, and Praesepe. A standard main sequence is also defined for the relationship between the two systems of color index.

A purely photometric method for determining spectral types and space reddening for B stars in galactic clusters is described.

TERMINOLOGY

y. Deflection through yellow filter, corrected for sky.

b. Deflection through blue filter, corrected for sky.

u. Deflection through ultraviolet filter, corrected for sky.

C_y. Observed blue-yellow color index, reduced to outside the earth's atmosphere.

C_u. Observed ultraviolet-blue color index, reduced to outside the earth's atmosphere.

V. Observed magnitude through yellow filter, reduced to outside the earth's atmosphere. This is approximately equivalent to the photovisual magnitude on the International System.

B. Observed magnitude through blue filter, reduced to outside the earth's atmosphere and including a zero-point correction to satisfy the condition

$$B - V = 0$$

for main-sequence stars of class A0 on the MK system.

U. Observed magnitude through ultraviolet filter, reduced to outside the earth's atmosphere and including a zero-point correction to satisfy the condition

$$U - B = 0$$

for main-sequence stars of class A0 on the MK system.

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[*] *Contributions from the McDonald Observatory, University of Texas,* No. 216.

E_y. Color excess on $B - V$ system.
E_u. Color excess on $U - B$ system.
MKK. The system of spectral classification outlined in: W. W. Morgan, P. C. Keenan, and Edith Kellman, *An Atlas of Stellar Spectra.*
MK. The revised MKK system. The MK system is outlined in the present paper.

INTRODUCTION

Because of nonlinear (and sometimes multivalued) relationships between various systems of color indices,[1] the definition of a fundamental system of magnitudes and colors becomes difficult; in particular, for regions like that of the North Polar Sequence, where no early-type stars are available, a system for stars bluer than class A0 (and for reddened B stars in general) can hardly be considered to exist. The principal difficulty here is that it is not justifiable to extrapolate a color equation determined from A–K stars to those of class B; in addition, the spectrum of a reddened B star does not have the same energy distribution as does that of a later-type star;[2] therefore, a different color equation may be necessary for reddened and unreddened stars.

A fundamental photometric system for stars should therefore include:

1. Magnitudes and color indices for unreddened stars from all parts of the H-R diagram; these should include white dwarfs and subdwarfs, as well as supergiants, giants, and main-sequence stars.
2. The same photometric data for stars having interstellar reddening and of known spectral type and luminosity class.
3. A series of color indices extending from the ultraviolet to the infrared, so that reductions to the standard color system can be made by a process of interpolation rather than extrapolation; the "six-color photometry" of Stebbins and Whitford satisfies this condition extremely well.
4. A determination of the zero point of the color indices in terms of a certain *kind* of star which can be accurately defined spectroscopically; that is, in terms of a kind of star whose spectral energy distribution can be predicted accurately from its spectral type and luminosity class; in addition, the stars used for the zero point should be plentiful.

The above requirements cannot be satisfied by using small selected regions of the sky; the standard stars are, of necessity, scattered over the sky, and many of them must be very bright if condition 1 is to be satisfied.

It is, therefore, of importance to supplement the scattered standards with regional secondary standards which fulfil some of the conditions and which are located in a small region. The most useful of the regional standards would be accurately observed main-sequence stars in open clusters, together with some yellow giants.

An observing program was arranged to include a number of bright and near-by stars to satisfy most of conditions 1, 2, and 4, and also several open clusters for defining a standard main sequence. The observations of the bright and near-by stars are included herewith. Three open clusters (Praesepe, the Pleiades, and IC 4665) were selected as regional secondary standards; the measures for Praesepe have been published (*Ap. J.*, **116**, 640, 1952), the Pleiades are given in the present paper, and IC 4665 has yet to be completed. All the photometric observations were made by Johnson at the McDonald Observatory in the winter of 1950–1951 and the summer of 1951.

THE PHOTOELECTRIC OBSERVATIONS

The photometer that was used during the winter season has been described in detail by Johnson and Morgan.[3] Several modifications were made in preparation for the

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[1] *Ap. J.*, **116**, 272, 1952.

[2] See Frances Sherman and W. W. Morgan, *Ap. J.*, **89**, 515, 1939; Joel Stebbins and A. E. Whitford, *Ap. J.*, **98**, 20, 1943.

[3] *Ap. J.*, **114**, 522, 1951.

summer season. They are: (1) provision for moving (by means of a screw) the entire photometer with respect to the telescope (this device makes it convenient to obtain sky corrections simply by moving back and forth between star and sky); (2) the 1P21 photomultiplier (the same tube that was used during the winter season) was refrigerated with dry ice; (3) the amplifier that was borrowed from the Washburn Observatory was returned, and a similar one, constructed in the Yerkes Observatory electronics shop, was substituted; and (4) the balsam-cemented quartz-fluorite field lens was replaced by a single-element crystalline quartz lens. In all other respects the photometer was unchanged.

The Washburn Observatory amplifier had been calibrated thoroughly in Madison with a Leeds and Northrup Students' Potentiometer owned by the Washburn Observatory. The McDonald amplifier was calibrated in the laboratory at the McDonald Observatory with a Central Scientific Company Students' Potentiometer. The calibrations for summer and winter are, therefore, entirely independent. These laboratory checks have shown that both amplifiers are linear and that the calibrations are stable. The differences between calibration runs on a given amplifier are, at most, a few tenths of 1 per cent, and both amplifiers are capable of measuring the output of the 1P21 within a fraction of 1 per cent. The range over which the gain of the amplifiers can be varied is 17.5 mag.; the use of deflections as small as 20 per cent of full scale for faint stars gives a total useful range for the amplifiers of 19 mag. This extreme range, however, has not been required for the present investigation.

A short description of the calibration of the Brown potentiometers used for recording the observations has been given.[3] No significant deviations from linearity have been found.

The observations were made in the manner described earlier,[3] with the exception that during the summer the sky corrections were made by the use of the back-and-forth motion. A reading on the standard source was taken after each observation, except during work on cluster stars. There is evidence that the particular radium-paint standard source used, while entirely satisfactory over a whole night, varies a total of about ±0.1 mag. over a period of several weeks.

In planning the observing program, an attempt was made to reduce the systematic errors in various regions of the sky by observing only a portion of the stars in a given region on a particular night. For example, the two stars π^3 Ori and π^4 Ori, which are close together in the sky, were never observed on the same night. A single zero point for each of the observed quantities, a mean value determined from the standard stars, has been used for each night. No regional standards have been used, except in the galactic clusters. All stars, even those within a small angular distance of a standard star, have been compared with the mean of all standard stars observed on that night. Except for comparisons between the standard stars themselves, there are no direct comparisons between any two stars. This procedure increases the scatter between values for stars near by in the sky above that which could be obtained, but it insures that regional systematic errors will be minimized.

The reductions for extinction were made in the manner described.[3] The extinction corrections for the ultraviolet color, $C_u = 2.5 \log_{10} b/u$, were made in the same manner as those for C_y, except that the extinction coefficient for C_u turns out to be practically independent of the color of the star. A correction to U, amounting to as much as 0.25 mag. for DS Peg, the reddest star observed, was necessary to allow for the infrared leak of the ultraviolet filter.

All the photometry has been referred to a list of standard stars, now ten in number. During the winter season the six standards listed[3] were used, while during the summer season four more—τ Her, β Lib, α Ser, and ϵ CrB—were added. The closing errors, for a complete circuit around the sky starting and ending with η Hya and β Cnc, are less than 0.01 mag. These standard stars were then compared with the North Polar Sequence, as described.[3]

Twenty-seven stars were observed in both summer and winter seasons to make the tie-in between the two seasons. These same observations may also be used for a check on the scales for the two seasons, since a different amplifier and calibration were used for each season. A comparison, illustrated in Figure 1, between the magnitudes in the two seasons reveals no significant difference between the two scales over the range of observed magnitudes, 0–13. The fact that the two scales agree so well is strong evidence for the correctness of the amplifier calibrations. Many of these stars are represented by only one observation in the summer season; this accounts for the relatively large scatter in Figure 1.

A critical check on the linearity of the entire photometer is available from a comparison of the magnitudes and colors obtained with the 82-inch and the 13-inch telescopes. This comparison is illustrated in Figure 2, which shows that there is no significant trend of the residuals for $1.5 < B < 12.8$, either in magnitude or in color. Since the ratio of the light-gathering powers of the 13-inch and 82-inch telescopes is about 4 mag., and

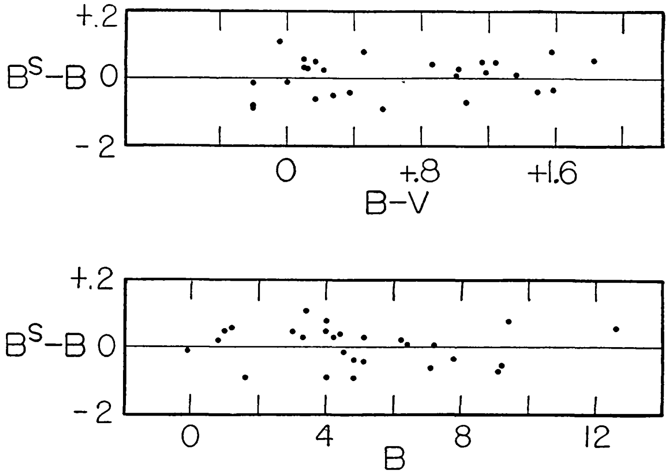

FIG. 1.—Comparison of blue magnitudes in summer (B^s) and in winter (B). Residuals are plotted against color (*above*) and winter magnitudes (*below*).

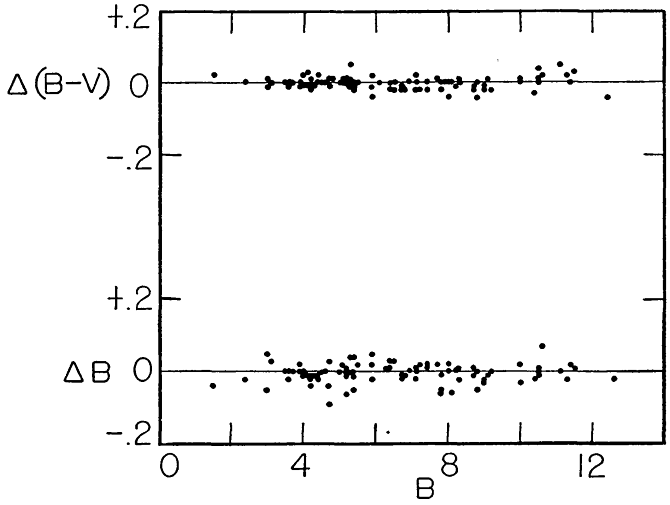

FIG. 2.—Comparisons between the colors and magnitudes obtained with the 82-inch and 13-inch reflectors. The differences are in the sense 82-inch *minus* 13-inch.

1953ApJ...117..313J

the intensities measured by the photometer and the 13-inch telescope range from $B = -2.5$ ($B = 1.5$ with the 82-inch) to $B = 12.8$, it is evident that the response of the photometer is linear over this 15-mag. range. Stars brighter than $B = 1.5$ were measured only with the 13-inch, while stars fainter than $B = 12.8$ were measured only with the 82-inch. We conclude from Figures 1 and 2 that the measured magnitudes are on the Pogson scale over the range $-2.5 < B < 16.8$. This exceeds the range of magnitudes reported here.

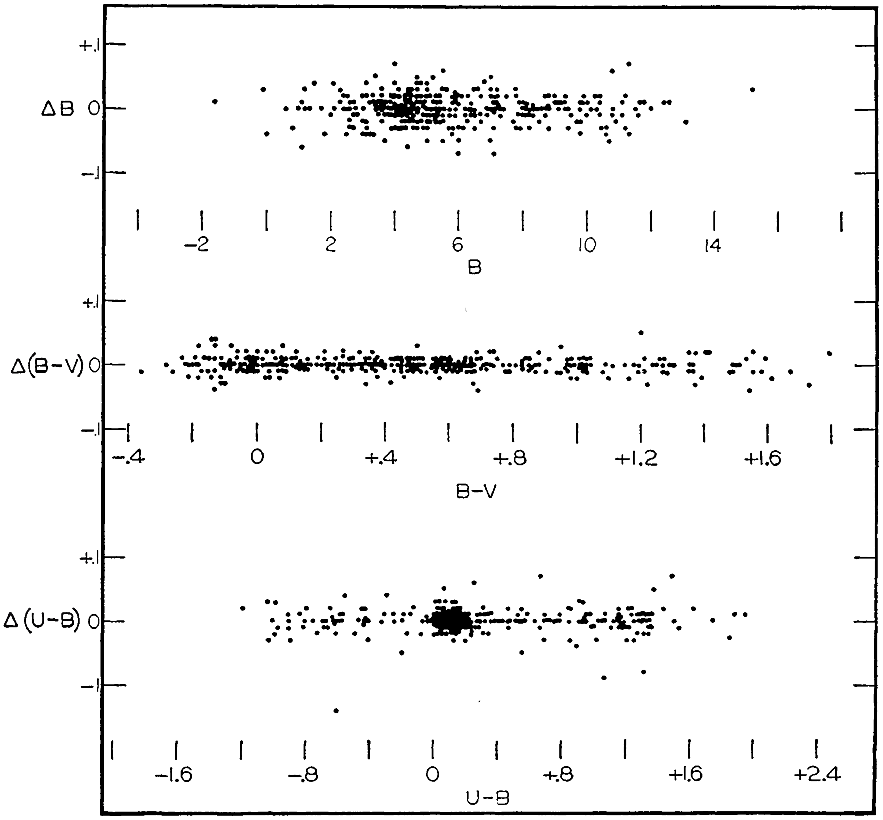

FIG. 3.—Comparison of one observation chosen at random with the mean, for stars for which two or more observations were made.

An idea of the accuracy of the observations can be obtained from a comparison of one observation chosen at random with the mean, for stars for which two or more observations were taken. These comparisons are illustrated in Figure 3.

The internal probable errors may be computed from these comparisons. Let us consider $B - V$ and compute for each star the average deviation from the mean reduced to the zenith,

$$(\text{A.D.})_{\text{zenith}} = \frac{\text{A.D. (obs.)}}{\overline{\sec Z}}, \tag{1}$$

where $\overline{\sec Z}$ denotes the mean of the values of the secant of the zenith distance for each star. It is assumed that the errors of observation are proportional to $\sec Z$. The average probable error at the zenith for a single observation of $B - V$ may then be computed. It is:

$$(\text{p.e.})_{\text{zenith}} = \pm 0.010 \text{ mag.} \tag{2}$$

This value is larger than that given[3] from rather limited data; the value here is to be preferred. Let us now define a quantity, ϵ, so that

$$\epsilon = \frac{10 \times \overline{\sec Z}}{\sqrt{n}}, \tag{3}$$

where n is the number of observations on a particular star. The quantity $0^{\mathrm{m}}.001\,\epsilon$ is the average probable error of $B - V$ for each individual star; it is a much better criterion (when n is small) of the quality of the observations of an individual star than is the average deviation of the observations of that star from the mean.

Similar computations lead to the probable errors for the other observed quantities in terms of ϵ given in Table 1. The mean values for all stars are also given in the table.

TABLE 1

PROBABLE ERRORS OF THE PHOTOMETRY (P.E., MAG.)

	Individual	Mean for All Stars
V	$\pm 0^{\mathrm{m}}.002\epsilon$	$\pm 0^{\mathrm{m}}.017$
$B-V$	$\pm\ .001\epsilon$	$\pm\ .009$
$U-B$	$\pm 0.002\epsilon$	± 0.017

It has been found, from data given for the North Polar Sequence,[3] that

$$V = IPv + 0.000 + 0.002\,(B - V) \pm 0.006 \pm 0.005\ (\text{p.e.})\,, \tag{4}$$

in which V (the magnitude obtained directly from the yellow filter) is therefore very close to the visual magnitude on the International System. In what follows, it will be assumed that V is exactly the International visual magnitude. It is a fortunate circumstance that the magnitudes determined directly from the yellow filter have no color correction to the International Photovisual system, as defined by the nine stars NPS 6, 10, 4r, 2r, 13, 16, 19, 8r, and 12r and the values given by Stebbins, Whitford, and Johnson.[4]

THE REVISED *Atlas* SYSTEM OF SPECTRAL CLASSIFICATION (MK)

In the course of the ten years that have elapsed since the publication of the Yerkes *Atlas of Stellar Spectra* certain changes of a minor nature have been incorporated into the system as used by Morgan. The test of continued use now indicates that further major changes are unlikely. The definitions of the photometric system described in the present paper are referred to the spectral types and luminosity classes of the standard stars; that is, the accuracy of the photometric system depends to a certain extent on the systemic accuracy with which the standard stars are classified. A short outline of the changes from the *Atlas of Stellar Spectra* to the revised system is given below:

1. *O5–O8.* No change.
2. *O9–B5.* Luminosity class I has been subdivided into I*a* and I*b*. Luminosity class IV has been redefined, since an investigation by A. Blaauw indicates that there is no difference in luminosity between classes IV and V as defined in the *Atlas.* The reason for this will be discussed in the revised edition of the *Atlas.* Luminosity classes at B0.5 and B1 have been redefined because of some earlier ambiguity.

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[4] *Ap. J.*, **112**, 469, 1950.

3. *B8–A2.* No systemic changes.

4. *A3–F0.* There appears to be an inescapable indeterminateness between luminosity classes IV and V at type A7 for stars whose lines are very broad. A luminosity class of IV, V is therefore used for such broad-line stars as α Cephei; this notation means that the star so classified is of luminosity class either IV or V.

5. *F2–F8.* A systematic change has been made in the definition of luminosity classes III and IV. It has been noticed for some time that in this spectral range stars of class III resemble much more nearly those of class V than those of class I*b*. *Atlas* standards of class III have therefore been moved to class IV, and stars of class IV have been moved to class IV–V. A few stars which appear to be located (by their spectral appearance) midway between classes I*b* and V have been assigned luminosity class III.

6. *G0–K2.* The giants in this interval did not show a satisfactorily smooth relationship with color equivalent in the *Atlas* system. Classes G5 III, G8 III, and K0 III have been redefined in terms of new criteria which are more closely correlated with temperature.

7. *K2–M5.* The single subdivision between K5 V and M0 V in the *Atlas* has been denoted by K7 V—instead of K6 V—to indicate that it is about midway between classes K5 V and M0 V. A few standard M dwarfs have been reclassified with the fixed point that Barnard's star is set at M5 V.

Table 2 lists a sufficient number of standards to define the MK system over the range O9–M2. All spectrograms were obtained with the 40-inch refractor and have dispersions of either about 100 A/mm, or 50 A/mm, at $H\delta$. The system defined by these standards is of higher accuracy than the original MKK system—with regard to both luminosity class and spectral type—and forms a precise frame of reference for photometric observations, as well as for the derivation of spectroscopic absolute magnitudes and parallaxes.

THE ZERO POINT FOR THE COLOR INDICES

The original zero point of the International System was set by the condition that the color index be zero for A0 stars near the sixth magnitude.[5] Various circumstances resulted in the observed mean values for main-sequence A0 stars ranging from around −0.14 to −0.04.[6]

Recently, the magnitudes and colors of nine stars of the North Polar Sequence as determined by Stebbins, Whitford, and Johnson[4] have been adopted as standards for photoelectric work. Since we here adopt a different zero point for the color systems, some justification would appear to be called for.

For this, it is necessary to anticipate some of the results of the present paper and a following one. The fundamental conclusion arrived at is that, to specify a photometric system with the highest accuracy, it is necessary to know the spectral types and luminosity classes of the stars concerned, as well as the photometric data. We cannot reduce one system of colors to another by a single relation, unless we are satisfied to make a sacrifice in accuracy. For two color systems, where the observations are affected by hydrogen absorption, we will usually have one relation for main-sequence stars, another for the yellow giants, and still another for reddened O and B stars. Examples of these relations will be found in a later paper.

This complexity in ordinary blue-yellow color systems makes imperative the definition of a zero point for colors in a more specific way than is afforded by the nine standard Polar Sequence stars. Two of the highly accurate color systems have adopted different zero points. The "six-color photometry" of Stebbins and Whitford has a zero point set by the mean of ten main-sequence stars of types G and K, and averaging G6. The Greenwich gradients depend for zero point on nine specified stars of HD type A0. We have

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[5] *Trans. I.A.U.*, **1**, 79, 1922.

[6] W. W. Morgan and W. P. Bidelman, *Ap. J.*, **104**, 245, 1946.

TABLE 2

STANDARDS OF MK SYSTEM

Class I*a*		
O9.5	I*a*	α Cam
O9.5	I*a*	195592
B0	I*a*	ϵ Ori
B0	I*a*	15 Sgr
B0.5	I*a*	κ Ori
B0.5	I*a*	194839
B1	I*a*	κ Cas
B1	I*a*	216411
B1.5	I*a*	190603
B1.5	I*a*	194279
B2	I*a*	14143
B2	I*a*	χ^2 Ori
B3	I*a*	14134
B3	I*a*	o^2 CMa
B3	I*a*	55 Cyg
B5	I*a*	13267
B5	I*a*	η CMa
B5	I*a*	167838
B6	I*a*	15497
B7	I*a*	183143
B8	I*a*	14542
B8	I*a*	β Ori
B8	I*a*	199478
B9	I*a*	17088
B9	I*a*	21291
A0	I*a*	223960
A0	I*a*	21389
A1	I*a*	12953
A1	I*a*	14433
A2	I*a*	9 Per
A2	I*a*	α Cyg
A2	I*a*	ν Cep
A5	I*a*	17378
A5	I*a*	164514
F0	I*a*	φ Cas
F2	I*a*	89 Her
F5	I*a*	10494
F5	I*a*	17971
F5	I*a*	231195
F8	I*a*	δ CMa
F8	I*a*	+31°3907
G0	I*a*	18391
G0	I*a*	HR 2974
G0	I*a*	HR 8752
M1	I*a*	6 Gem
M2	I*a*	μ Cep

Class I*ab*		
B5	I*ab*	χ Aur
B9	I*ab*	σ Cyg
B9	I*ab*	4 Lac
F5	I*ab*	44 Cyg
K3	I*ab*	o^1 CMa
M0	I*ab*	ψ^1 Aur
M2	I*ab*	α Ori

Class I*b*		
O9	I*b*	210809
O9.5	I*b*	ζ Ori
O9.5	I*b*	19 Cep
B0	I*b*	69 Cyg
B0.5	I*b*	192422
B1	I*b*	ζ Per
B1	I*b*	ρ Leo
B1	I*b*	190919
B1.5	I*b*	193183
B2	I*b*	13841
B2	I*b*	13866
B2	I*b*	9 Cep
B2.5	I*b*	3 Gem
B5	I*b*	9311
B5	I*b*	67 Oph
B8	I*b*	53 Cas
B8	I*b*	13 Cep
B9	I*b*	35600
A0	I*b*	13 Mon
A0	I*b*	η Leo
A2	I*b*	207673
A3	I*b*	210221
A5	I*b*	59612
F0	I*b*	α Lep
F2	I*b*	ν Aql
F5	I*b*	α Per
F5	I*b*	35 Cyg
F8	I*b*	γ Cyg
G0	I*b*	μ Per
G0	I*b*	β Cam
G0	I*b*	β Aqr
G2	I*b*	ζ Mon
G2	I*b*	22 Vul
G2	I*b*	α Aqr
G5	I*b*	25 Gem
G5	I*b*	9 Peg
G8	I*b*	ϵ Gem
G8	I*b*	HR 8374
K1	I*b*	ζ Cep
K2	I*b*	ϵ Peg
K3	I*b*	η Per
K5	I*b*	ξ Cyg
K5	I*b*	HR 8726
M2	I*b*	119 Tau

Class II		
O9	II	16 Sgr
O9.5	II	δ Ori
B0	II	43818
B1	II	1383
B1	II	199216
B2	II	ϵ CMa
B3	II	ι CMa
B3	II	194779
B8	II	γ CMa
B9	II	43836
A5	II	19 Aur
F0	II	HR 1242
F2	II	22 And
F2	II	ν Her
F5	II	ν Per
F5	II	41 Cyg
G0	II	ϵ Leo
G0	II	α Sge
G2	II	β Dra
G5	II	ω Gem
G5	II	β Sct
G8	II	56 UMa
G8	II	ζ Cyg
K0	II	θ Lyr
K1	II	HR 2334
K1	II	θ Her
K2	II	56 Ori
K3	II	ι Aur
K3	II	π Her
K3	II	γ Aql

Class III		
O9	III	ι Ori
O9	III	193443
B0	III	1 Cam(br)
B0	III	48434
B0.5	III	κ Aql
B1	III	o Per
B1	III	σ Sco
B2	III	π^4 Ori
B2	III	γ Ori
B2	III	12 Lac
B3	III	21483
B5	III	δ Per
B5	III	τ Ori
B5	III	ι Aql
B6	III	17 Tau
B7	III	η Tau
B7	III	β Tau
B8	III	27 Tau
B9	III	γ Lyr

1953ApJ...117..313J

TABLE 2—*Continued*

Class III—*Continued*	
B9.5 III	δ Cyg
A0 III	α Dra
A3 III	β Eri
A3 III	θ Gem
A5 III	β Tri
A5 III	α Oph
A7 III	θ^2 Tau
A7 III	γ Boo
A9 III	γ Her
F0 III	ζ Leo
F2 III	14 Ari
F2 III	16 Per
F4 III	36 Per
G0 III	31 Com
G5 III	HR 1327
G8 III	η Psc
G8 III	ο Tau
G8 III	κ Gem
G8 III	δ Boo
G8 III	η Dra
G8 III	β Her
G8 III	ε Dra
K0 III	γ Tau
K0 III	δ Tau
K0 III	ε Tau
K0 III	θ^1 Tau
K0 III	δ Aur
K0 III	β Gem
K0 III	α UMa
K0 III	τ CrB
K0 III	κ Cyg
K0 III	ε Cyg
K2 III	α Ari
K2 III	ι Dra
K2 III	κ Oph
K2 III	β Oph
K2 III	ξ Dra
K3 III	δ And
K3 III	51 And
K3 III	ρ Boo
K4 III	β Cnc
K4 III	β UMi
K5 III	α Tau
K5 III	γ Dra
M0 III	β And
M0 III	υ Gem
M0 III	λ Dra
M2 III	χ Peg
M2 III	α Cet
M2 III	π Leo
M2 III	83 UMa

Class IV	
B2 IV	γ Peg
B2 IV	δ Cet
B5 IV	τ Her
B7 IV	16 Tau
A0 IV	γ Gem
F0 IV	μ Cet
F0 IV	ε Cep
F2 IV	β Cas
F2 IV	υ UMa
F6 IV	α Tri
F6 IV	40 Leo
F6 IV	θ UMa
F7 IV	σ Peg
F8 IV	υ Peg
G0 IV	η Boo
G0 IV	ζ Her
G5 IV	μ Her
G8 IV	β Aql
K0 IV	δ Eri
K0 IV	η Cep
K1 IV	γ Cep

Class V	
O9 V	46202
O9 V	52266
O9 V	57682
O9 V	14 Cep
O9 V	10 Lac
O9.5 V	34078
O9.5 V	σ Ori
O9.5 V	ζ Oph
B0 V	υ Ori
B0 V	δ Sco
B0 V	τ Sco
B0 V	206183
B0 V	207538
B0.5 V	8965
B0.5 V	40 Per
B0.5 V	ε Per
B1 V	7252
B1 V	24131
B1 V	ω^1 Sco
B2 V	ζ Cas
B2 V	ξ Cas
B2 V	ο Cas
B2 V	β Sco(ft)
B2 V	22 Sco
B2 V	191746
B2 V	208947
B2 V	218440

Class V—*Continued*	
B3 V	6300
B3 V	35 Ari
B3 V	η Aur
B3 V	ν Ori
B3 V	η Hya
B3 V	η UMa
B3 V	178849
B3 V	191263
B3 V	16 Peg
B3 V	218537
B5 V	4142
B5 V	ν And
B5 V	14372
B5 V	ρ Aur
B5 V	κ Hya
B5 V	λ Cyg
B5 V	ψ^2 Aqr
B6 V	19 Tau
B6 V	30 Sex
B7 V	α Leo
B8 V	18 Tau
B8 V	21 Tau
B8 V	ζ Peg
B8 V	ι And
B9 V	α Del
B9.5 V	ω^2 Aqr
A0 V	4 Aur
A0 V	HR 3314
A0 V	γ UMa
A0 V	109 Vir
A0 V	α CrB
A0 V	HR 5859
A0 V	HR 6070
A0 V	γ Oph
A0 V	α Lyr
A1 V	HR 875
A1 V	HR 1046
A1 V	ι Ser
A1 V	39 Dra
A1 V	HR 7784
A1 V	ε Aqr
A2 V	θ And
A2 V	θ Leo
A3 V	λ Gem
A3 V	β Leo
A3 V	α PsA
A4 V	δ Leo
A5 V	δ Cas
A5 V	β Ari
A5 V	80 UMa
A7 V	θ Cas
A7 V	ι UMa

TABLE 2—*Continued*

Class V—*Continued*			Class V—*Continued*			Class V—*Continued*		
A7	V	21 LMi	F7	V	χ Dra	K0	V	54 Psc
F0	V	ρ Gem	F8	V	β Vir	K0	V	124752
F0	V	γ Vir(A+B)	F8	V	υ And	K0	V	σ Dra
F2	V	78 UMa	G0	V	β Com	K0	V	70 Oph(A)
F2	V	σ Boo	G0	V	β CVn	K2	V	ϵ Eri
F3	V	46 Tau	G0	V	η Cas	K2	V	109011
F5	V	ι Peg	G1	V	115043	K3	V	110463
F5	V	45 Boo	G2	V	HR 483	K3	V	128165
F6	V	110 Her	G2	V	16 Cyg(pr)	K3	V	219134
F6	V	γ Ser	G2	V	Sun	K5	V	61 Cyg(A)
F6	V	π^3 Ori	G5	V	κ Cet	K7	V	+56°1458
F7	V	ι Psc	G5	V	16 Cyg(fol)	K7	V	61 Cyg(B)
F7	V	θ Per	G8	V	61 UMa	M0	V	147379
F7	V	θ Boo	G8	V	ξ Boo(A)	M2	V	95735

followed a procedure similar to the latter; the zero point of the present color systems has been set by the mean values for six stars of class A0 V on the MK system; the stars are: α Lyr, γ UMa, 109 Vir, α CrB, γ Oph, and HR 3314. For the mean of these stars

$$U-B=B-V=0\,.$$

The color indices were derived from the observed colors by the following formulae:

$$B-V=C_y+1.040\,,\qquad U-B=C_u-1.120\,. \tag{5}$$

After the zero point for $B-V$ has been set according to the above definition, it is found that, for the K0 III stars listed in Table 3, $B-V=+1.01\pm 0.007$ (p.e.). Therefore, both the zero point and the scale for $B-V$ satisfy the original definition of the International System.

The color indices, magnitudes, and spectral types are listed in Table 3. The columns give: (1) a serial number; (2) the number in the *Henry Draper Catalogue;* (3) the name, or BD number; (4 and 5) the co-ordinates for 1900; (6) the number of observations; (7) the value of ϵ (defined on p. 318), to be used in the computation of the individual probable errors; (8) the yellow magnitude V, as defined on p. 318; (9) the blue-yellow color index, $B-V$, as defined on p. 322; (10) the ultraviolet-blue color index, $U-B$, as defined on p. 322; and (11) the spectral type on the MK system. The types prefixed by "d" are from Kuiper (*Ap. J.*, **95**, 201, 1942) reduced to the MK system according to Table 4.

SOME SUPPLEMENTARY REGIONAL STANDARDS

A number of stars were observed on the U, B, V system in each of four galactic clusters: Praesepe, the Pleiades, M 36, and NGC 2362. In all clusters, at least one star, and usually more, were chosen as standards for the cluster. All other cluster stars were then referred to these standard stars, while the latter were included in the regular program of stars scattered over the entire sky. Certain comments on these cluster observations follow.

THE PLEIADES

Most of the observations of V and $B-V$ given in Table 5 have already been given[3] in terms of $\boldsymbol{P}$ and $\boldsymbol{P-V}$, derived from a linear transformation to the NPS. Small

1953ApJ...117..313J

TABLE 3
PHOTOMETRIC OBSERVATIONS

No.	HD	Name or BD	α (1900)	δ	n	ε	V	B–V	U–B	Sp
1	432	β Cas	$0^{h}03^{m}.8$	+58°36′	2	9	2.25	+0.35	+0.09	F2 IV
2	1013	χ Peg	0 09.4	+19 39	4	9	4.80	+1.58	+1.92	M2 III
3	1280	θ And	0 11.9	+38 08	2	8	4.60	+0.06	+0.02	A2 V
4*	1326	+43°44 A	0 12.7	+43 27	4	7	8.07	+1.56	+1.22	M1 V
5*	....	+43°44 B	0 12.7	+43 27	4	7	11.04	+1.80	+1.38	M6 V
6	2905	κ Cas	0 27.3	+62 23	2	9	4.15	+0.15	–0.80	B1 Ia
7	3651	54 Psc	0 34.2	+20 43	2	8	5.84	+0.86	+0.56	K0 V
8	4614	η Cas	0 43.0	+57 17	2	9	3.45	+0.58	+0.00	G0 V
9	....	v Maanen 2	0 43.9	+04 55	1	11	12.37	+0.56	0.00	.....
10	4727	ν And	0 44.3	+40 32	1	12	4.52	–0.15	–0.57	B5 V
11*	....	+61°195	0 56.3	+61 48	4	7	9.57	+1.50	+1.21	dM 1.5
12*	....	Wolf 47	0 57.0	+61 50	2	11	13.66	+1.68	+0.79	dM 7
13	6582	μ Cas	1 01.6	+54 26	2	9	5.12	+0.69	+0.09	G5 Vp
14	6961	θ Cas	1 05.0	+54 37	2	9	4.32	+0.17	+0.11	A7 V
15	7927	φ Cas	1 13.8	+57 42	2	8	4.95	+0.68	+0.44	F0 Ia
16	8538	δ Cas	1 19.3	+59 43	2	9	2.67	+0.14	+0.10	A5 V
17	9270	η Psc	1 26.1	+14 50	2	8	3.61	+0.98	+0.79	G8 III
18	9826	50 And	1 30.9	+40 54	3	7	4.08	+0.54	+0.06	F8 V
19	9927	51 And	1 31.9	+48 07	2	8	3.56	+1.28	+1.46	K3 III
20	10307	HR 483	1 35.7	+42 07	3	7	4.94	+0.63	+0.12	G2 V
21	10476	107 Psc	1 37.1	+19 47	2	8	5.20	+0.84	+0.48	K1 V
22	10700	τ Cet	1 39.4	–16 28	2	10	3.49	+0.72	+0.18	G8 Vp
23	10780	HR 511	1 40.5	+63 22	3	9	5.63	+0.81	+0.40	dK2
24	11415	ε Cas	1 47.2	+63 11	.	..	.....	.....	.....	B2p
25	11636	β Ari	1 49.1	+20 19	2	8	2.62	+0.14	+0.10	A5 V
26	12929	α Ari	2 01.5	+22 59	std	3	1.99	+1.153	+1.12	K2 III
27	13161	β Tri	2 03.6	+34 31	2	9	3.00	+0.13	+0.08	A5 III
28	13974	δ Tri	2 10.8	+33 46	4	7	4.87	+0.61	+0.02	G0 V
29	14633	+40°501	2 16.7	+41 02	3	8	7.47	–0.21	–1.09	O8
30	15318	ξ^2 Cet	2 22.8	+08 01	2	9	4.27	–0.04	–0.15	B9 III
31	16160	HR 753 A	2 30.6	+06 25	2	11	5.82	+0.99	+0.77	dK4
32	.....	HR 753 B	2 30.6	+06 25	2	11	11.66	+1.62	+1.09	dM6
33	16895	θ Per	2 37.4	+48 48	2	8	4.12	+0.48	–0.01	F7 V
34	17094	μ Cet	2 39.5	+09 42	2	9	4.25	+0.31	+0.05	F0 IV
35	17378	HR 825	2 42.2	+56 40	3	8	6.25	+0.89	+0.48	A5 Ia
36	17584	16 Per	2 44.3	+37 54	2	8	4.22	+0.34	+0.06	F2 III
37	18331	HR 875	2 51.6	–04 07	std	3	5.17	+0.085	+0.05	A1 V
38	19373	ι Per	3 01.8	+49 14	2	8	4.04	+0.60	+0.10	G0 V
39	20630	κ Cet	3 14.1	+03 00	5	6	4.82	+0.68	+0.18	G5 V
40	20902	α Per	3 17.2	+49 30	2	8	1.80	+0.48	+0.34	F5 Ib
41	21120	ο Tau	3 19.4	+08 41	2	8	3.57	+0.89	+0.64	G8 III
42	21291	HR 1035	3 21.0	+59 36	2	9	4.23	+0.40	–0.26	B9 Ia
43	21447	HR 1046	3 22.4	+55 06	2	9	5.06	+0.05	+0.04	A1 V
44	22928	δ Per	3 35.8	+47 28	2	8	3.03	–0.14	–0.52	B5 III
45	23180	ο Per	3 38.0	+31 58	2	8	3.82	+0.06	–0.76	B1 III
46	24398	ζ Per	3 47.8	+31 35	2	8	2.83	+0.13	–0.77	B1 Ib
47	24760	ε Per	3 51.1	+39 43	2	8	2.88	–0.17	–0.98	B0.5 V
48	27371	γ Tau	4 14.1	+15 23	2	8	3.61	+0.99	+0.84	K0 III
49	27697	δ Tau	4 17.2	+17 18	2	8	3.73	+0.98	+0.84	K0 III
50	28305	ε Tau	4 22.8	+18 58	2	8	3.55	+1.03	+0.87	K0 III
51	29139	α Tau	4 30.2	+16 19	2	8	0.78	+1.51	+1.81	K5 III
52	30652	π^3 Ori	4 44.4	+06 47	3	7	3.16	+0.46	0.00	F6 V
53	30836	π^4 Ori	4 45.9	+05 26	4	7	3.69	–0.17	–0.81	B2 III
54	32630	η Aur	4 59.5	+41 06	3	7	3.16	–0.17	–0.68	B3 V
55	33111	β Eri	5 02.9	–05 13	3	8	2.77	+0.12	+0.09	A3 III
56	34085	β Ori	5 09.7	–08 19	2	13	0.08	–0.03	–0.69	B8 Ia
57	34411	λ Aur	5 12.1	+40 01	1	20	4.71	+0.67	+0.10	G0 V
58*	34578	19 Aur	5 13.4	+33 52	2	10	5.03	+0.27	+0.44	A5 II
59	35299	–0°936	5 18.6	–00 15	2	9	5.71	–0.21	–0.87	B2 V
60	35497	β Tau	5 20.0	+28 31	3	7	1.64	–0.13	–0.48	B7 III

1953ApJ...117..313J

TABLE 3 (Continued)
PHOTOMETRIC OBSERVATIONS

No.	HD	Name or BD	α (1900)	δ	n	ε	V	B−V	U−B	Sp
61	36395	Cin 705	$5^h26^m.4$	−03°42′	1	12	7.96	+1.48	+1.20	dM1
62	36512	υ Ori	5 27.1	−07 23	2	9	4.59	−0.27	−1.11	BO V
63	36591	−1°935	5 27.7	−01 40	2	9	5.36	−0.20	−0.97	B1 V
64	36673	α Lep	5 28.3	−17 54	2	11	2.56	+0.21	+0.22	FO Ib
65	37043	ι Ori	5 30.5	−05 59	2	9	2.74	−0.25	−1.11	09 III
66	37128	ε Ori	5 31.1	−01 16	2	9	1.71	−0.20	−1.06	BO Ia
67	38771	κ Ori	5 43.0	−09 42	2	9	2.04	−0.18	−1.06	BO.5 Ia
68	38899	134 Tau	5 43.9	+12 37	2	8	4.91	−0.07	−0.20	B9 IV
69	40035	δ Aur	5 51.3	+54 17	2	10	3.69	+0.99	+0.86	KO III
70	41117	χ^2 Ori	5 58.0	+20 08	2	8	4.63	+0.27	−0.70	B2 Ia
71	43112	HR 2222	6 09.5	+13 53	3	8	5.90	−0.24	−0.96	B1 V
72	43384	9 Gem	6 10.8	+23 46	2	8	6.28	+0.44	−0.40	B3 Ia
73	46106	+5°1279	6 26.3	+05 05	2	8	7.93	+0.14	−0.77	B1 V
74	46149	+5°1282	6 26.6	+05 06	2	8	7.59	+0.16	−0.80	08
75	46150	+5°1283	6 26.6	+05 00	2	8	6.75	+0.12	−0.85	06
76	46202	+5°1286	6 26.9	+05 03	2	8	8.19	+0.17	−0.76	09 V
77	46223	+5°1302	6 27.0	+04 53	3	7	7.27	+0.21	−0.78	05
78	47105	γ Gem	6 31.9	+16 29	2	8	1.95	0.00	+0.01	AO IV
79	48434	+4°1414	6 38.3	+04 02	2	9	5.91	−0.02	−0.89	BO III
80	48915	α CMa	6 40.7	−16 35	2	12	−1.47	+0.01	−0.08	A1 V
81	50019	θ Gem	6 46.2	+34 05	3	8	3.59	+0.10	+0.13	A3 III
82	51309	ι CMa	6 51.7	−16 55	2	12	4.36	−0.07	−0.70	B3 II
83	56537	λ Gem	7 12.3	+16 43	2	9	3.57	+0.10	+0.09	A3 V
84	58946	ρ Gem	7 22.7	+31 59	2	8	4.16	+0.31	−0.04	FO V
85	61421	α CMi	7 34.1	+05 29	2	9	0.34	+0.40	−0.01	F5 IV−V
86	62345	κ Gem	7 38.4	+24 38	3	8	3.57	+0.93	+0.68	G8 III
87	62509	β Gem	7 39.2	+28 16	5	6	1.15	+1.00	+0.84	KO III
88	64145	φ Gem	7 47.4	+27 01	2	8	4.95	+0.10	+0.08	
89	69267	β Cnc	8 11.1	+09 30	std	3	3.53	+1.478	+1.77	K4 III
90	71155	HR 3314	8 20.7	−03 35	2	9	3.89	−0.01	0.00	AO V
91	74280	η Hya	8 38.0	+03 46	std	3	4.31	−0.196	−0.74	B3 V
92	76644	ι UMa	8 52.4	+48 26	2	8	3.12	+0.18	+0.06	A7 V
93	76943	10 UMa	8 54.2	+42 11	2	10	3.95	+0.43	+0.06	F5 V
94	78154	σ^2 UMa	9 01.6	+67 32	2	11	4.78	+0.48	+0.01	F7 IV-V
95	82885	11 LMi	9 29.7	+36 16	2	10	5.47	+0.75	+0.44	G8 IV−V
96	87696	21 LMi	10 01.5	+35 44	2	8	4.47	+0.16	+0.07	A7 V
97	87901	α Leo	10 03.0	+12 27	2	9	1.33	−0.12	−0.38	B7 V
98	88230	Gmb 1618	10 05.3	+49 58	2	10	6.59	+1.38	+1.28	dMO
99	89021	λ UMa	10 11.1	+43 25	2	10	3.46	+0.01	+0.06	A2 IV
100*	.....	AD Leo	10 14.2	+20 22	4	8	9.43	+1.54	+1.06	M4.5: V
101	89449	40 Leo	10 14.3	+19 59	2	10	4.83	+0.44	−0.01	F6 IV
102*	.....	36 UMa C	10 21.4	+56 52	2	10	8.22	+0.92	+0.70	KO IV
103	90839	36 UMa A	10 24.2	+56 30	2	10	4.82	+0.51	0.00	F8 V
104*	.....	36 UMa B	10 24.2	+56 30	2	12	8.69	+1.36	+1.26	K7 V
105	94264	46 LMi	10 47.7	+34 45	2	9	3.84	+1.03	+0.91	KO III−IV
106	95689	α UMa	10 57.6	+62 17	3	8	1.79	+1.06	+0.90	KO III
107	95735	Lal 21185	10 57.9	+36 38	2	9	7.47	+1.51	+1.13	M2 V
108	96833	ψ UMa	11 04.0	+45 02	3	8	3.01	+1.13	+1.10	K1 III
109	98262	ν UMa	11 13.1	+33 38	2	8	3.48	+1.38	+1.56	K3 III
110*	.....	+66°717	11 14.8	+66 23	3	9	9.32	+1.42	+1.08	M1 V
111	101501	61 UMa	11 35.8	+34 46	2	9	5.33	+0.69	+0.27	G8 V
112	102647	β Leo	11 44.0	+15 08	2	9	2.12	+0.09	+0.04	A3 V
113	102870	β Vir	11 45.5	+02 20	7	6	3.63	+0.54	+0.10	F8 V
114	103095	Gmb 1830	11 47.2	+38 26	3	8	6.49	+0.75	+0.17	G8 Vp
115	103287	γ UMa	11 48.6	+54 15	4	7	2.43	0.00	+0.01	AO V
116	106591	δ UMa	12 10.5	+57 35	2	9	3.27	+0.08	+0.07	A3 V
117	109358	β CVn	12 29.0	+41 54	3	8	4.29	+0.59	+0.05	GO V
118	111631	Cin 1633	12 45.6	−00 13	2	8	8.49	+1.41	+1.27	MO.5 V
119	112412	α CVn B	12 51.4	+38 51	2	9	5.60	+0.34	−0.03	FO V
120*	112413	α CVn A	12 51.4	+38 51	2	9	2.89	−0.12	−0.32	Ap

1953ApJ...117..313J

TABLE 3 (Continued)
PHOTOMETRIC OBSERVATIONS

No.	HD	Name or BD	α (1900)	δ	n	ε	V	B-V	U-B	Sp
121	......	Wolf 457	$12^{h}55^{m}.1$	+04°02'	1	16	15.90	+0.64	-0.09	.....
122	113139	78 UMa	12 56.4	+56 54	5	6	4.93	+0.37	0.00	F2 V
123	114710	β Com	13 07.2	+28 23	5	6	4.30	+0.56	+0.05	G0 V
124	115617	61 Vir	13 13.2	-17 45	2	12	4.74	+0.70	+0.26	G6 V
125*	116658	α Vir	13 19.9	-10 38	4	7	0.98	-0.26	-0.94	B1 V
126	116842	80 UMa	13 21.2	+55 30	5	6	4.01	+0.16	+0.08	A5 V
127	117176	70 Vir	13 23.5	+14 19	2	8	4.98	+0.71	+0.24	G5 V
128*	......	+11°2576	13 24.9	+10 55	3	8	9.04	+1.51	+1.26	M1 V
129	......	Wolf 489	13 31.8	+04 13	1	15	14.71	+0.95	+0.37	......
130	120136	τ Boo	13 42.5	+17 57	2	8	4.51	+0.48	+0.04	F7 V
131	120315	η UMa	13 43.6	+49 49	6	6	1.86	-0.20	-0.68	B3 V
132	121370	η Boo	13 49.9	+18 54	3	7	2.70	+0.59	+0.20	G0 IV
133	122408	τ Vir	13 56.6	+02 02	7	6	4.26	+0.10	+0.12	......
134	123299	α Dra	14 01.7	+64 51	3	8	3.64	-0.05	-0.09	A0 III
135	124674	κ Boo B	14 09.9	+52 15	2	9	6.69	+0.39	-0.04	F2 V
136	124675	κ Boo A	14 09.9	+52 15	3	8	4.54	+0.20	+0.14	......
137	124897	α Boo	14 11.1	+19 42	6	6	-0.06	+1.23	+1.26	K2 IIIp
138	126660	θ Boo	14 21.8	+52 19	3	8	4.06	+0.50	+0.01	F7 V
139	127665	ρ Boo	14 27.5	+30 49	2	8	3.57	+1.29	+1.44	K3 III
140	127762	γ Boo	14 28.1	+38 45	2	9	3.03	+0.19	+0.12	A7 III
141	130109	109 Vir	14 41.2	+02 19	2	10	3.75	-0.01	-0.03	A0 V
142	......	L1126-68	14 45.9	+07 59	1	13	15.47	+0.02	-0.67	......
143*	135722	δ Boo A	15 11.5	+33 41	2	8	3.50	+0.95	+0.69	G8 III
144*	......	δ Boo B	15 11.5	+33 41	2	8	7.84	+0.59	+0.01	G0 V
145	135742	β Lib	15 11.6	-09 01	std	3	2.62	-0.111	-0.37	B8 V
146*	136202	5 Ser A	15 14.2	+02 09	5	7	5.06	+0.54	+0.06	F8 IV-V
147*	......	5 Ser B	15 14.2	+02 09	2	25	10.11	+1.34	.....	......
148	137391	μ Boo	15 20.7	+37 44	2	8	4.30	+0.30	+0.08	......
149	137759	ι Dra	15 22.7	+59 19	2	15	3.26	+1.17	+1.22	K2 III
150*	139006	α CrB	15 30.5	+27 03	6	6	2.23	-0.02	-0.02	A0 V
151*	140159	ι Ser	15 37.1	+20 00	2	10	4.52	+0.04	+0.04	A1 V
152	140573	α Ser	15 39.3	+06 44	std	3	2.66	+1.165	+1.24	K2 III
153*	141003	β Ser A	15 41.6	+15 44	4	6	3.67	+0.07	+0.09	A2 IV
154*	......	β Ser B	15 41.6	+15 44	2	8	9.95	+0.99	+0.81	......
155	141004	λ Ser	15 41.6	+07 40	4	7	4.43	+0.60	+0.11	G0 V
156	142373	χ Her	15 49.2	+42 44	3	7	4.60	+0.56	+0.01	F9 V
157	142860	γ Ser	15 51.8	+15 59	3	7	3.85	+0.48	-0.02	F6 V
158	143107	ε CrB	15 53.4	+27 10	std	3	4.15	+1.227	+1.28	K3 III
159	......	Ross 808	15 57.7	+37 06	1	11	14.36	+0.17	-0.56	......
160*	144217	β Sco A	15 59.6	-19 32	3	9	2.63	-0.08	-0.88	B0.5 V
161*	144218	β Sco C	15 59.6	-19 32	3	9	4.92	-0.02	-0.70	B2 V
162	144284	θ Dra	16 00.0	+58 50	3	8	4.01	+0.53	+0.11	F8 IV-V
163	147379	Cin 2184 A	16 16.5	+67 29	4	7	8.60	+1.41	+1.27	M0 V
164	......	Cin 2184 B	16 16.5	+67 29	2	9	10.69	+1.51	+1.18	......
165	147394	τ Her	16 16.7	+46 33	std	3	3.89	-0.155	-0.56	B5 IV
166	147547	γ Her	16 17.5	+19 23	2	10	3.74	+0.26	+0.13	A9 III
167*	148478-9	α Sco AB	16 23.3	-26 13	2	15	0.92	+1.84	+1.30	Comp
168*	150680	ζ Her	16 37.5	+31 47	3	7	2.82	+0.64	+0.21	G0 IV
169	151288	Cin 2238	16 41.4	+33 41	3	7	8.11	+1.37	+1.29	K7 V
170	154363	CC 1017	16 59.8	-04 54	3	9	7.74	+1.16	+1.05	K5 V
171*	......	+4°4226	17 00.0	-04 55	3	9	10.07	+1.44	+1.09	M3.5:V
172	156164	δ Her	17 10.9	+24 57	4	6	3.14	+0.08	+0.08	A3 IV
173	......	Wolf 672 A	17 13.6	+02 04	1	12	14.34	+0.10	-0.55	......
174	......	Wolf 672 B	17 13.6	+02 04	1	12	14.03	+1.52	+1.30	......
175	157214	72 Her	17 16.9	+32 36	3	7	5.39	+0.62	+0.07	G0 V
176	157881	Cin 2322	17 20.8	+02 14	3	8	7.54	+1.36	+1.27	K7 V
177*	159181	β Dra	17 28.2	+52 23	(2)	..	(2.9)	(+0.95)	(+0.70)	G2 II
178*	159541	ν^1 Dra	17 30.2	+55 15	2	9	4.86	+0.25	+0.06	Am
179*	159560	ν^2 Dra	17 30.3	+55 14	2	9	4.84	+0.28	+0.10	Am
180*	160269	26 Dra	17 34.0	+61 57	3	8	5.23	+0.61	+0.10	G1 V

TABLE 3 (Continued)
PHOTOMETRIC OBSERVATIONS

No.	HD	Name or BD	α (1900)	δ	n	ε	V	B–V	U–B	Sp
181	160762	ι Her	$17^{h}36^{m}.6$	+46°04′	5	5	3.80	−0.18	−0.69	B3 V
182*	......	+68°946	17 37.0	+68 26	5	7	9.15	+1.50	+1.08	M3.5 V
183	161096	β Oph	17 38.5	+04 37	3	8	2.78	+1.16	+1.24	K2 III
184*	161797	μ Her A	17 42.5	+27 47	6	6	3.42	+0.75	+0.39	G5 IV
185*	......	μ Her BC	17 42.5	+27 47	3	7	9.78	+1.49	+1.03	dM4
186	161868	γ Oph	17 42.9	+02 45	3	10	3.72	+0.04	+0.06	A0 V
187	163506	89 Her	17 51.4	+26 04	4	10	5.46	+0.35	+0.25	F2 Ia
188*	......	+4°3561	17 52.9	+04 25	5	7	9.53	+1.74	+1.29	M5 V
189	164058	γ Dra	17 54.3	+51 30	3	8	2.22	+1.52	+1.86	K5 III
190	164259	ζ Ser	17 55.2	−03 41	3	9	4.62	+0.38	+0.00	F3 V
191	165908	99 Her	18 03.2	+30 33	4	8	5.04	+0.52	−0.10	F7 V
192	166620	HR 6806	18 06.3	+38 27	4	6	6.40	+0.87	+0.59	K2 V
193*	166865	40 Dra	18 07.6	+79 59	2	11	6.04	+0.51	−0.01	......
194*	166866	41 Dra	18 07.6	+79 59	2	11	5.68	+0.50	−0.01	......
195	168723	η Ser	18 16.1	−02 55	3	8	3.26	+0.94	+0.65	K0 III-IV
196	......	Ross 137	18 21.6	+04 01	1	12	13.98	+0.02	−0.59	......
197	170153	χ Dra	18 22.9	+72 41	3	8	3.58	+0.50	−0.07	F7 V
198	172167	α Lyr	18 33.6	+38 41	8	6	0.03	0.00	−0.01	A0 V
199*	173648	ζ Lyr A	18 41.3	+37 30	2	9	4.37	+0.18	+0.17	Am
200*	173649	ζ Lyr B	18 41.4	+37 30	2	9	5.74	+0.28	+0.06	F0 IV
201	173667	110 Her	18 41.4	+20 27	3	7	4.20	+0.48	0.00	F6 V
202	173739	ADS 11632 A	18 41.8	+59 27	3	7	8.90	+1.54	+1.11	dM3.5
203	173740	ADS 11632 B	18 41.8	+59 27	3	7	9.69	+1.59	+1.14	dM4
204*	175638	θ Ser A	18 51.2	+04 04	2	10	4.59	+0.15	+0.09	......
205*	175639	θ Ser B	18 51.2	+04 04	2	10	4.99	+0.20	+0.07	......
206	176437	γ Lyr	18 55.2	+32 33	4	8	3.23	−0.05	−0.10	B9 III
207	......	AC+70°8247	19 01.1	+70 30	1	12	13.18	+0.05	−0.86	......
208*	179957	HR 7293	19 09.5	+49 40	2	9	6.75	+0.64	+0.17	......
209*	179958	HR 7294	19 09.5	+49 40	2	9	6.57	+0.65	+0.21	......
210	180617	CC 1143	19 12.1	+05 03	4	7	9.12	+1.50	+1.15	M3.5 V
211	......	LDS 678 A	19 15.2	−07 51	1	14	12.36	+0.02	−0.86	......
212	......	LDS 678 B	19 15.2	−07 51	1	14	12.75	+1.31	+1.10	......
213*	183912	β Cyg A	19 26.7	+27 45	2	8	3.07	+1.12	+0.62	Comp
214*	183914	β Cyg B	19 26.7	+27 45	2	8	5.11	−0.10	−0.32	B8 V
215	185144	σ Dra	19 32.6	+69 29	3	8	4.68	+0.79	+0.39	K0 V
216*	186408	16 Cyg A	19 39.2	+50 18	2	8	5.96	+0.64	+0.19	G2 V
217*	186427	16 Cyg B	19 39.2	+50 17	2	8	6.20	+0.66	+0.20	G5 V
218	......	L1140–73	19 39.5	+08 40	1	11	13.84	+0.70	−0.06	......
219*	187013	17 Cyg A	19 42.6	+33 30	2	8	4.99	+0.46	0.00	F5 V
220*	225732	17 Cyg B	19 42.6	+33 30	2	8	8.56	+1.04	+0.95	......
221*	187642	α Aql	19 45.9	+08 36	6	7	0.75	+0.23	+0.07	A7 IV, V
222*	188293	57 Aql A	19 49.2	−08 29	2	10	5.70	−0.08	−0.49	......
223*	188294	57 Aql B	19 49.2	−08 30	2	10	6.48	−0.04	−0.27	......
224	188512	β Aql	19 50.4	+06 09	9	6	3.70	+0.86	+0.49	G8 IV
225*	191570	θ Sge A	20 05.5	+20 37	2	8	6.48	+0.38	−0.04	......
226*	......	θ Sge B	20 05.5	+20 37	2	8	8.89	+0.76	+0.34	......
227*	194093	γ Cyg	20 18.6	+39 56	(2)	..	(2.2)	(+0.68)	(+0.53)	F8 Ib
228	194765	ADS 13868 A	20 22.3	−02 26	2	9	6.70	+0.52	−0.02	......
229	194766	ADS 13868 B	20 22.3	−02 26	2	9	7.50	+0.52	−0.02	......
230	195593	44 Cyg	20 27.2	+36 36	3	12	6.17	+1.02	+0.73	F5 Iab
231	......	Wolf 1346	20 30.1	+24 44	1	10	11.53	−0.06	−0.87	......
232	196867	α Del	20 35.0	+15 34	4	8	3.77	−0.06	−0.23	B9 V
233	197345	α Cyg	20 38.0	+44 55	6	7	1.26	+0.09	−0.25	A2 Ia
234*	197963	γ Del B	20 42.0	+15 46	3	7	5.14	+0.49	+0.08	......
235*	197964	γ Del A	20 42.0	+15 46	3	7	4.27	+1.04	+0.97	......
236	197989	ε Cyg	20 42.2	+33 36	5	7	2.45	+1.03	+0.87	K0 III
237	198001	ε Aqr	20 42.3	−09 52	3	8	3.77	+0.02	+0.06	A1 V
238	198149	η Cep	20 43.3	+61 27	3	8	3.43	+0.92	+0.62	K0 IV
239	198478	55 Cyg	20 45.5	+45 45	1	10	4.82	+0.40	−0.46	B3 Ia
240	199305	Cin 2707	20 51.3	+61 48	1	11	8.50	+1.49	+1.24	dM0.5

TABLE 3 (Continued)
PHOTOMETRIC OBSERVATIONS

No.	HD	Name or BD	α (1900)	δ	n	ε	V	B–V	U–B	Sp
241*	200905	ξ Cyg	$21^{h}01^{m}.3$	$+43^{\circ}32'$	(2)	..	(4.1)	(+1.64)	(+1.89)	K5 Ib
242*	201091	61 Cyg A	21 02.4	+38 15	4	8	5.19	+1.19	+1.10	K5 V
243*	201092	61 Cyg B	21 02.4	+38 15	4	8	6.02	+1.38	+1.23	K7 V
244*	203280	α Cep	21 16.2	+62 10	2	11	2.41	+0.23	+0.10	A7 IV, V
245*	203504	1 Peg A	21 17.5	+19 23	2	9	4.09	+1.10	+1.05	K1 II^{T}
246*	......	1 Peg B	21 17.5	+19 23	2	9	9.14	+0.86	+0.52	......
247	......	Ross 198	21 23.3	+54 47	1	11	14.66	+0.15	–0.68	......
248*	204867	β Aqr	21 26.3	–06 01	(3)	..	(3.0)	(+0.83)	(+0.60)	G0 Ib
249	206165	9 Cep	21 35.2	+61 38	2	10	4.72	+0.30	–0.52	B2 Ib
250*	206570	DS Peg	21 37.8	+35 03	1	10	6.11	+2.52	+3.67	C6$_3$
251*	206778	ε Peg	21 39.3	+09 25	(2)	..	(2.4)	(+1.58)	(+1.76)	K2 Ib
252*	206859	9 Peg	21 39.8	+16 53	(2)	..	(4.4)	(+1.18)	(+1.05)	G5 Ib
253*	206936	μ Cep	21 40.4	+58 19	4	7	3.99	+2.41	+2.40	M2 Ia
254	207826	ADS 15366 A	21 46.8	+66 19	2	9	6.45	+0.39	+0.05	......
255	......	ADS 15366 B	21 46.8	+66 19	1	15	10.53	+0.91	+0.57	......
256	......	$+28^{\circ}4211$	21 47.0	+28 27	4	7	10.53	–0.34	–1.26	Op
257*	209750	α Aqr	22 00.6	–00 48	(2)	..	(3.1)	(+1.00)	(+0.82)	G2 Ib
258	209942	ADS 15571 A	22 01.9	+82 23	2	11	6.98	+0.52	–0.02	......
259	209943	ADS 15571 B	22 01.9	+82 23	2	11	7.49	+0.70	+0.17	......
260	210027	ι Peg	22 02.4	+24 51	7	6	3.76	+0.44	–0.05	F5 V
261	210839	λ Cep	22 08.1	+58 55	2	10	5.00	+0.26	–0.73	O6f
262	210884	ADS 15719 A	22 08.4	+69 38	2	10	5.50	+0.38	–0.04	......
263	......	ADS 15719 B	22 08.4	+69 38	2	10	8.62	+0.86	+0.49	......
264	211336	ε Cep	22 11.4	+56 33	4	9	4.19	+0.28	+0.03	F0 IV
265*	......	Kr 60 AB	22 24.4	+57 12	1	10	9.59	+1.65	+1.27	dM4 + dM
266*	214167	8 Lac B	22 31.4	+39 07	2	10	6.45	–0.14	–0.83	B2 V
267*	214168	8 Lac A	22 31.4	+39 07	2	10	5.72	–0.16	–0.91	B1 (V)e
268	214238	ADS 16097 A	22 31.8	+56 35	2	11	7.63	+0.68	+0.17	......
269	......	ADS 16097 B	22 31.8	+56 35	2	11	9.71	+0.81	+0.42	......
270	214680	10 Lac	22 34.8	+38 32	std	3	4.87	–0.200	–1.04	O9 V
271	215182	η Peg	22 38.3	+29 42	2	12	2.96	+0.84	+0.51	G2 II-II
272	215648	ξ Peg	22 41.7	+11 40	3	8	4.19	+0.50	–0.03	F7 V
273	......	$-15^{\circ}6290$	22 47.9	–14 47	3	9	10.16	+1.60	+1.15	dM5
274	216735	ρ Peg	22 50.2	+08 17	2	11	4.89	+0.01	0.00	......
275	216899	CC 1392	22 51.8	+16 02	4	8	8.66	+1.51	+1.17	dM2
276	217014	51 Peg	22 52.6	+20 14	3	8	5.53	+0.68	+0.20	......
277	217476	HR 8752	22 55.9	+56 25	3	9	4.99	+1.29	+1.00	G0 Ia
278	218329	55 Peg	23 02.0	+08 52	2	15	4.50	+1.56	+1.81	M2 III
279	219134	HR 8832	23 08.5	+56 37	std	3	5.56	+1.013	+0.89	K3 V
280	219175	ADS 16611 A	23 08.8	–09 29	2	10	7.56	+0.56	–0.04	......
281	......	ADS 16611 B	23 08.8	–09 29	2	10	8.19	+0.69	+0.09	......
282	220657	υ Peg	23 20.4	+22 51	2	9	4.38	+0.61	+0.13	F8 IV
283	222107	λ And	23 32.7	+45 55	3	9	3.88	+1.02	+0.68	G8 III-I
284	222368	ι Psc	23 34.8	+05 05	3	8	4.13	+0.51	–0.01	F7 V
285	222404	γ Cep	23 35.2	+77 04	2	11	3.22	+1.03	+0.92	K1 IV
286	222439	κ And	23 35.5	+43 47	2	11	4.13	–0.07	–0.27	......
287	......	$+1^{\circ}4774$	23 44.0	+01 52	4	7	8.98	+1.49	+1.08	M2 V
288	224930	85 Peg	23 56.9	+26 33	1	15	5.75	+0.66	+0.04	G2 V
289	225009	ADS 1 A	23 57.5	+65 32	1	15	5.86	+1.09	+0.91	......
290	225010	ADS 1 B	23 57.5	+65 32	2	11	7.34	+0.08	+0.05	......

NOTES TO TABLE 3

$\left.\begin{matrix}4\\5\end{matrix}\right\}$ ADS 246 = Gmb 34AB.

11 Wolf 46.

12 This star "flared" during observation.

58 The observations are accordant, but the ultraviolet is peculiar.

100 +20°2465 = Cin 1244.

102 +57°1266. This star has common proper motion (Vyssotsky and Ruyl, *Pub. A.S.P.*, **54**, 263, 1942) and radial velocity (Popper, *Ap. J.*, **98**, 210, 1943) with No. 103, 36 UMa A. The absolute magnitude determined from *V* and the trigonometric parallax for 36 UMa A is that of a subdwarf about 1 mag. below the main sequence, in contradiction to the spectroscopic luminosity classification as a subgiant. Because of this lack of agreement, the star has not been used in any discussions in this paper. An additional trigonometric parallax for this star is desirable.

104 +56°1458. Observations discordant; the individual values are:

V	*B*−*V*	*U*−*B*
8.76	+1.42	+1.29
8.65	+1.33	+1.25

The first observation is definitely poor on the original tracing and has been given half-weight.

110 Cin 1383.

120 Variable star.

125 Eclipsing variable.

128 CC 782.

$\left.\begin{matrix}143\\144\end{matrix}\right\}$ ADS 9559.

$\left.\begin{matrix}146\\147\end{matrix}\right\}$ ADS 9584. 5 Ser B is discordant. The individual values are:

V	*B*−*V*	*U*−*B*
10.13	+1.39	+0.89
10.09	+1.29	+0.41

The discordance is due to the great difficulty in making corrections for scattered light from the bright star.

150 Eclipsing variable.

151 ADS 9744; $\Delta m \cong 0.0$ mag. Measured as one star.

$\left.\begin{matrix}153\\154\end{matrix}\right\}$ ADS 9778.

$\left.\begin{matrix}160\\161\end{matrix}\right\}$ ADS 9913.

167 Variable.

168 ADS 10157.

171 CC 1018.

177 The colors given are transformed by means of relations from the six-color photometry (Stebbins and Whitford, *Ap. J.*, **102**, 273, 1945). The magnitude given there has been corrected by −0.1 mag., the correction from the HR magnitudes to *V*, and entered as *V*.

$\left.\begin{matrix}178\\179\end{matrix}\right\}$ ADS 10628.

180 ADS 10660.

182 Cin 2354.

$\left.\begin{matrix}184\\185\end{matrix}\right\}$ ADS 10786.

188 CC 1069, Barnard's proper-motion star.

$\left.\begin{matrix}193\\194\end{matrix}\right\}$ ADS 11061.

$\left.\begin{matrix}199\\200\end{matrix}\right\}$ ADS 11639.

$\left.\begin{matrix}204\\205\end{matrix}\right\}$ ADS 11853.

$\left.\begin{matrix}208\\209\end{matrix}\right\}$ ADS 12169.

$\left.\begin{matrix}213\\214\end{matrix}\right\}$ ADS 12540.

$\left.\begin{matrix}216\\217\end{matrix}\right\}$ ADS 12815.

$\left.\begin{matrix}219\\220\end{matrix}\right\}$ ADS 12913.

221 The broad lines of this star preclude accurate luminosity classification. The symbol IV, V indicates that the luminosity class may be anywhere from IV to V, inclusive.

$\left.\begin{matrix}222\\223\end{matrix}\right\}$ ADS 13087.

$\left.\begin{matrix}225\\226\end{matrix}\right\}$ ADS 13442.

227 See note for No. 177.

$\left.\begin{matrix}234\\235\end{matrix}\right\}$ ADS 14279.

241 See note for No. 177.

$\left.\begin{matrix}242\\243\end{matrix}\right\}$ ADS 14636.

244 See note for No. 221.

$\left.\begin{matrix}245\\246\end{matrix}\right\}$ ADS 14909.

248 See note for No. 177.

250 Variable star.

251 See note for No. 177.

252 See note for No. 177.

253 Variable star.

257 See note for No. 177.

265 ADS 15972. An estimate of the magnitudes and colors for each component can be made on the basis of Kuiper's spectral types and the known difference in visual magnitude, as follows:

Star	V	$B-V$	$U-B$	Sp.
Kr 60A.........	9.85	+1.62	+1.23:	dM4
Kr 60B.........	11.3	+1.8	+1.3	dM6

$\left.\begin{matrix}266\\267\end{matrix}\right\}$ ADS 16095.

TABLE 4

APPROXIMATE REDUCTION OF KUIPER'S SPECTRAL TYPES TO MK SYSTEM

Kuiper's Type	Reduced	Kuiper's Type	Reduced	Kuiper's Type	Reduced
K0..........	K0	K5.........	K7	M0.........	M0.5
K1..........	K2	K6.........	K7	M0+.......	M0.5
K2..........	K3	K7.........	M0	>M0+.....	No change*
K3..........	K4	K8.........	M0		
K4..........	K5	K9.........	M0		

* Kuiper's "+" types are counted as "0.5" types; i.e., M3+=M3.5.

systematic night corrections to C_v, omitted from the reductions reported, have now been included, as well as additional observations on all but one of the stars for which but a single observation was previously available. The values of $U - B$ were observed at the same time but are reported now for the first time.

The cluster standards were observed on eight different nights, which give, for the zero points only, $\epsilon = 3.5$. The relative probable errors within the cluster are: V, $\pm 0^{\mathrm{m}}.007$; $B - V$, $\pm 0^{\mathrm{m}}.005$; $U - B$, $\pm 0^{\mathrm{m}}.010$ for one observation.

1953ApJ...117..313J

TABLE 5
THE PLEIADES

Hertzsprung No.	n	V	B-V	U-B	Sp	M_V	Remarks
28	2	8.24	+0.235	+0.14	....	+2.3	
43	2	8.05	+0.197	+0.15	....	+2.2	
88	2	9.06	+0.458	+0.10	....	+3.2	
92	2	8.16	+0.265	+0.09	....	+2.3	
108	2	9.82	+0.537	+0.05	....	+3.9	
117	6	5.45	-0.046	-0.33	B7 IV	-0.5	16 Tau
126	3	3.69	-0.107	-0.41	B6 III	-2.2	17 Tau
133	2	10.37	+0.627	+0.13	....	+4.5	
146	2	8.57	+0.331	+0.16	....	+2.7	
150	6	5.64	-0.075	-0.36	B8 V	-0.3	18 Tau
156	4	4.29	-0.106	-0.46	B6 V	-1.6	19 Tau
169	2	8.98	+0.439	+0.08	....	+3.1	
187	2	8.02	+0.216	+0.18	....	+2.1	
206	2	8.58	+0.352	+0.11	....	+2.7	
213	2	10.12	+0.602	+0.13	....	+4.2	
216	3	7.16	+0.159	+0.08	....	+1.3	
219	2	9.70	+0.548	+0.05	....	+3.8	
227	2	9.43	+0.520	+0.11	....	+3.5	
242	4	3.86	-0.068	-0.40	B7 III	-2.0	20 Tau
251	2	7.84	+0.192	+0.16	....	+1.9	
255	3	5.75	-0.044	-0.23	B8 V	-0.2	21 Tau
265	3	6.41	-0.028	-0.15	B9 V:	+0.5	22 Tau
323	3	4.16	-0.056	-0.43	B6 IV nn	-1.7	23 Tau
329	2	10.42	+0.640	+0.15	....	+4.5	
341	2	7.34	+0.097	+0.12	....	+1.4	
371	std	8.09	+0.353	+0.28	A0:	....	Reddened
385	2	10.20	+0.724	+0.31	....	+4.3	
388	2	9.28	+0.457	+0.03	....	+3.4	
428	2	10.52	+0.638	+0.16	....	+4.6	
436	std	6.80	+0.025	-0.07	B9 V:	+0.9	
457	2	8.38	+0.294	+0.08	....	+2.5	
468	2	9.44	+0.468	+0.02	....	+3.5	
510	2	6.98	+0.030	+0.05	....	+1.1	
513	3	7.64	+0.206	+0.12	....	+1.7	
520	2	7.26	+0.035	+0.05	....	+1.4	
534	4	7.76	+0.153	+0.12	....	+1.9	
540	3	6.80	+0.063	+0.02	....	+0.9	
542	std	2.86	-0.090	-0.33	B7 III	-3.0	η Tau
569	1	7.68	+1.24	+1.10	....	....	non-member
597	1	8.77	+1.17	+0.81	....	....	non-member
620	2	9.86	+0.540	+0.11	....	+4.0	
669	std	6.43	+1.702	+2.00	....	....	non-member
681	2	9.24	+0.548	+0.12	....	+3.3	
693	3	8.25	+0.361	+0.11	....	+2.4	
695	2	9.12	+0.470	+0.07	....	+3.2	
708	2	10.09	+0.558	+0.07	....	+4.2	
722	7	5.44	-0.072	-0.32	B8 V	-0.5	HR 1172
736	2	10.02	+0.556	+0.09	....	+4.1	
742	4	6.94	+0.125	+0.09	....	+1.0	
760	2	10.34	+0.614	+0.13	....	+4.4	
792	2	8.36	+0.284	+0.13	....	+2.5	
870	4	3.62	-0.085	-0.36	B8 III	-2.3	27 Tau
878	6	5.09	-0.078	-0.28	Pec	-0.8	28 Tau; var.
885	1	8.11	+0.22	+0.13	....	+2.2	
891	2	7.51	+0.097	+0.11	....	+1.6	
910	3	6.59	-0.028	-0.12	A0 V:	+0.7	
924	3	7.96	+0.175	+0.13	....	+2.1	
948	2	9.08	+0.434	+0.02	....	+3.2	
977	2	6.16	-0.052	-0.19	B9 V	+0.3	HR 1183
993	2	9.14	+0.162	+0.15	....	....	non-member

TABLE 5 (Continued)
THE PLEIADES

Hertzsprung No.	n	V	B-V	U-B	Sp	M_V	Remarks
996	3	7.53	+0.077	+0.08	....	+1.6	
1069	3	7.41	+0.134	+0.12	....	....	non-member
1129	2	6.92	+0.086	+0.03	....	+1.0	
1184	2	8.81	+0.384	+0.05	....	+2.9	

The numbers of the stars are those of Hertzsprung.[7] The absolute magnitudes on the V system, M_V, are computed on the basis of an apparent distance modulus of 5.9 mag., as derived below.

M 36

The cluster standards were observed on a total of five nights, corresponding for the zero points to $\epsilon = 4.5$. The relative probable errors within the cluster are the same as for the Pleiades.

The observations are given in Table 6, where the numbers of the stars are those of Bodèn.[8] The quality of the spectrograms (taken at McDonald) is not so high as that of the Yerkes spectrograms; as a result, the accuracy of the spectral types is considerably lower than for those in Table 3. Furthermore, most of the stars in M 36 have very broad lines, making classification difficult. The stars designated as nonmembers have been so classified on the basis of the results of photometry.

NGC 2362

NGC 2362 is quite far south (−25°), and the determination of the zero points of the magnitudes and colors is more uncertain than for the other clusters discussed in this paper. Sec Z is always greater than 1.75 for this cluster; furthermore, any systematic differences in the extinction toward the south from that for the rest of the sky will be reflected in systematic errors in the zero points. In general, the differential manner in which the colors are determined reduces their errors considerably by comparison with the magnitudes. The zero points for this cluster were determined on six different nights, by the use of No. 46 as the cluster standard. The colors, both $B - V$ and $U - B$, are as accordant as could be expected for the low altitude, but there is more scatter in the magnitudes than seems normal. We estimate that the probable errors for the three zero points are as follows: V, ± 0.025; $B - V$, ± 0.008; $U - B$, ± 0.020. The relative probable errors within the cluster are: V, ± 0.012; $B - V$, ± 0.008; $U - B$, ± 0.016, all for a single observation.

The new observations given in Table 7 may be compared with those made by Johnson[9] at Mount Wilson Observatory; the comparison is exhibited in Figure 4. The Mount Wilson values were transformed to the present system by means of the linear NPS transformations given earlier.[3] It should be kept in mind that the transformations are linear and not universally valid. The solid lines represent these linear transformations.

There appears to be a difference of zero point in V between the two series of observations, amounting to about 0.05 mag. A difference of this size is perhaps not unexpected; the sum of the probable errors of the magnitude zero points is 0.05 mag. We shall use the zero point as determined from the McDonald observations; the zero point will, in either case, be sufficiently accurate for the purposes of this paper.

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[7] *Effective Wavelengths of Stars in the Pleiades* (Copenhagen, 1923).

[8] *Uppsala Astr. Obs. Ann.*, Vol. **3**, No. 4.

[9] *Ap. J.*, **112**, 240, 1950.

TABLE 6
M 36

Bogen No.	n	V	B-V	U-B	Sp	Remarks
3	2	10.72	+0.097	-0.25	....	
8	2	9.36	+0.020	-0.58	B2 V	
9	2	9.13	-0.002	-0.66	B2 V	
11	2	11.24	+0.104	-0.30	....	
13	2	10.80	+0.126	-0.28	B8: nn	
14	2	10.68	+0.092	-0.38	B8: III-IV	
16	2	8.86	-0.001	-0.66	B2 V	
18	2	10.78	+0.077	-0.37	....	
21	2	9.76	+0.012	-0.60	B2.5 V	
23	2	8.96	+0.006	-0.68	B3 V	
27	2	9.58	+0.020	-0.58	B2:: nn	
30	2	12.03	+0.142	-0.14	....	
33	2	11.87	+0.124	-0.12	B9: V:	
38	2	9.92	+0.054	-0.49	....	
41	2	12.38	+0.189	+0.04	....	
44	2	11.33	+0.090	-0.29	B8: III-IV	
46	2	12.32	+0.282	+0.15	....	
47	2	10.44	+0.120	-0.25	B8 ?	
48	2	9.52	+0.061	-0.46	B3 V	
50	2	11.61	+0.202	-0.12	B9 ::	
55	2	11.62	+0.102	-0.30	....	
56	1	12.42	+0.44	+0.24	....	non-member
57	2	11.76	+0.123	-0.12	....	
61	2	9.14	+0.010	-0.66	B2 V:	
69	1	12.43	+0.20	-0.38	....	non-member
71	2	12.16	+0.158	-0.05	....	
77	1	12.11	+0.16	0.00	....	
79	1	11.93	+0.12	-0.12	....	
81	2	10.01	+0.024	-0.57	B2 III	
85	2	11.30	+0.145	-0.27	....	
86	2	10.65	+0.060	-0.24	B8:: III-IV	
87	2	10.65	+0.068	-0.40	B6: V	
91	2	10.37	+0.038	-0.47	....	
92	2	10.96	+0.048	-0.44	....	
101	std	9.23	+0.050	-0.69	B2 Ve	
109	2	10.70	+0.080	-0.41	....	
110	2	11.98	+0.204	-0.07	....	
112	2	12.30	+0.212	+0.04	....	
113	2	10.54	+0.106	+0.03	....	non-member
114	1	11.82	+0.30	-0.06	....	non-member
123	2	11.53	+0.106	-0.25	....	
126	2	11.00	+1.005	+0.68	....	non-member
127	2	11.34	+0.418	-0.40	....	non-member
138	2	9.04	+0.022	-0.60	B3: V:	
145	1	12.07	+0.36	+0.10	....	non-member
152	2	11.26	+0.022	-0.39	....	non-member
184	std	9.98	+0.970	+0.60	....	non-member
196	2	9.91	+1.262	+1.04	....	non-member
197	3	9.62	+0.045	-0.43	....	
252	1	9.12	.00	-0.36	....	non-member

TABLE 7
NGC 2362

Johnson No.	n	V	B-V	U-B	Sp	M_V	Remarks
1	3	11.39	0.00	-0.28	......	-0.5	
2	3	11.18	-0.02	-0.38	......	-0.7	
3	3	11.05	+0.09	-0.15	......	-0.8	
4	2	12.44	+0.08	+0.02	......	+0.5	
5	3	10.78	-0.06	-0.52	B5 V:	-1.1	
6	2	12.88	+0.18	.....	......	+1.0	Mt. W.
7	2	13.44	+0.20	.....	......	+1.5	Mt. W.
8	2	12.51	+0.38	.....	......	....	Mt. W. non-member.
9	3	9.84	-0.08	-0.61	B3 V	-2.1	
10	2	12.04	+0.40	.....	......	....	Mt. W. non-member.
11	2	11.92	+0.03	.....	......	0.0	Mt. W.
12	3	10.03	-0.07	-0.57	B3: nn	-1.9	
13	2	10.48	+0.11	+0.07	......	-1.4	member?
14	3	9.80	-0.12	-0.73	B2 V	-2.3	
15	3	11.76	+0.03	-0.14	B9 V:	-0.1	
16	3	10.57	+0.07	-0.20	B9 V:	-1.3	member?
17	2	12.30	+1.13	.....	......	....	Mt. W. non-member.
20	4	8.78	-0.15	-0.87	B2 V	-3.1	
21	3	10.44	-0.07	-0.51	......	-1.5	
22	2	11.93	+0.02	.....	......	0.0	Mt. W.
23	7	4.39	-0.14	-0.99	09 III	-7.5	not plotted. τ CMa
24	2	11.02	-0.05	-0.42	B7 nn	-0.9	
25	1	10.79	-0.01	-0.44	......	-1.1	member?
26	3	10.43	-0.07	-0.52	B5 V	-1.5	
27	3	10.17	-0.07	-0.58	B3 V	-1.7	
28	2	12.05	+0.02	.....	......	+0.1	Mt. W.
29	1	11.34	-0.02	-0.33	......	-0.6	
30	5	8.21	-0.17	-0.91	B1 V	-3.7	
31	3	9.32	-0.12	-0.76	B2 V	-2.6	
32	1	10.77	+0.28	+0.23	......	....	non-member.
34	2	10.49	-0.03	-0.49	......	-1.4	
35	2	12.98	+0.30	.....	......	....	Mt. W. non-member.
36	3	10.76	+0.02	-0.48	B7: nn	-1.1	
37	2	12.56	+0.36	.....	......	....	Mt. W. non-member.
38	2	12.76	+0.12	.....	......	+0.8	Mt. W.
39	3	9.78	-0.09	-0.87	B2 V	-2.1	
40	2	12.86	+0.31	.....	......	....	Mt. W. non-member.
41	2	13.13	+0.55	.....	......	....	Mt. W. non-member.
42	2	11.33	-0.03	.....	......	-0.6	Mt. W.
43	2	14.75	+0.50	.....	......	....	Mt. W. non-member.
44	2	14.81	+0.22	.....	......	....	Mt. W. non-member.
46	std	6.80	-0.17	-0.73	B2 IV	....	non-member.
47	2	13.82	+0.39	.....	......	....	Mt. W. non-member.
48	3	9.54	-0.11	-0.89	B3 V	-2.4	
49	1	12.30	+0.39	+0.02	......	....	non-member.
50	3	10.20	0.00	-0.36	B5 V	-1.7	
51	2	12.23	+0.43	.....	......	....	Mt. W. non-member.
52	2	11.93	+0.03	.....	......	....	Mt. W. non-member.
53	2	13.58	+0.18	.....	......	+1.8	Mt. W.
54	2	14.13	+0.42	.....	......	....	Mt. W. non-member.
55	2	14.49	+0.49	.....	......	....	Mt. W. non-member.
56	2	12.01	+0.13	.....	......	+0.1	Mt. W.
57	2	12.16	+0.02	-0.12	......	+0.3	
58	2	12.23	+0.07	-0.04	A0 V:	+0.3	
59	2	12.21	+0.23	.....	......	....	Mt. W. non-member.
64	2	11.80	+0.47	.....	......	....	Mt. W. non-member.
65	2	11.67	+0.23	.....	......	....	Mt. W. non-member.
66	2	11.44	-0.01	-0.33	......	-0.5	

The difference in the colors as determined at the two observatories can best be explained as the result of using a linear transformation where a nonlinear one is needed. It has already been pointed out[1] that the difference in ultraviolet transmission of the two blue filters used is sufficient to cause such discordances, and the result for this cluster is additional confirmation of this fact. For the redder stars ($B - V > +0.1$) the zero points seem to be very nearly the same; they do not differ by as much as the estimated probable error of the Mount Wilson zero point (±0.025 mag.).[9]

That the additional ultraviolet response of the Mount Wilson photometer has a very real effect is demonstrated in Figure 4 by the positions of No. 23, τ CMa (*open circle*), the cluster main sequence (*filled circles*), and No. 46 (*plus sign*). In Table 7, τ CMa has the strongest ultraviolet, No. 46 the weakest, while the main-sequence stars (No. 20 and No. 30, for example) lie between. Since the Mount Wilson observations contain more ultraviolet than the McDonald ones, we would expect τ CMa to be bluer at Mount Wilson than at McDonald compared to the main-sequence stars, Nos. 20 and 30; and No. 46 to be redder. This is exactly the situation in Figure 4, *b*. Furthermore, a significant amount of the scatter among the other cluster stars can be explained on this same basis.

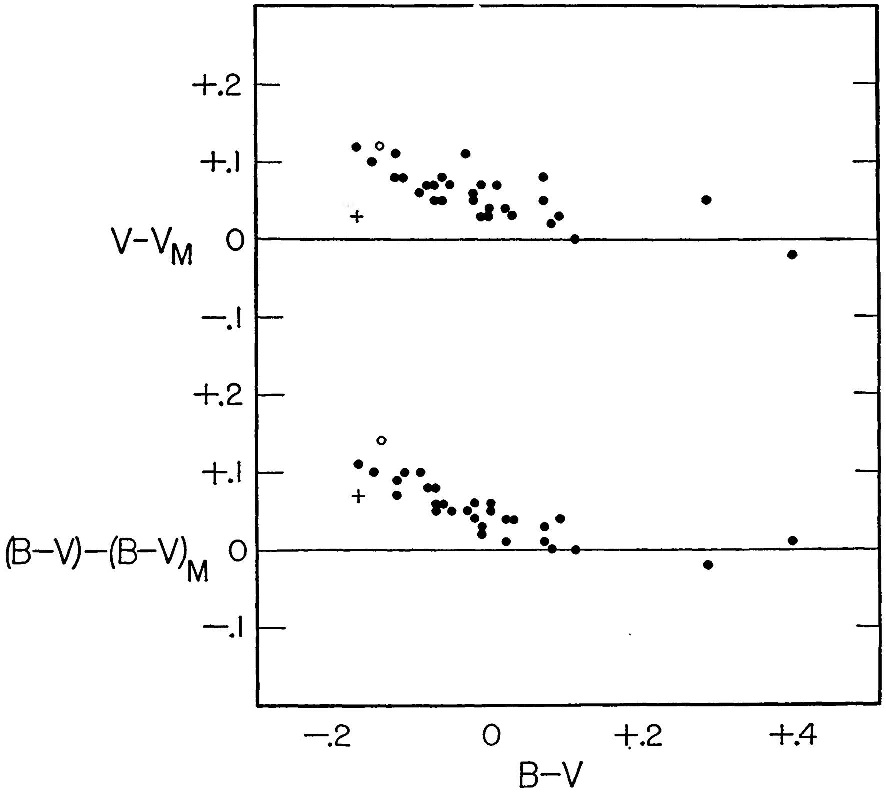

FIG. 4.—Comparisons between the magnitudes and colors for stars in NGC 2362 obtained at McDonald and Mount Wilson Observatories. Subscripts M refer to observations made at Mount Wilson. The open circle represents No. 23, τ CMa; the plus sign, No. 46.

We conclude that, since the results obtained at Mount Wilson agree well with those at McDonald, the zero points of the McDonald colors are substantially correct. We shall adopt them for this paper.

Not all the stars observed at Mount Wilson were also observed at McDonald, and Mount Wilson values have been transformed to the (B, V) system for those stars not observed at McDonald; they are designated by "Mt. W." in the "Remarks" column.

1953ApJ...117..313J

TABLE 8
STARS HAVING ACCURATE TRIGONOMETRIC OR CLUSTER PARALLAXES

No.	Name	π, (p.e.)	M_V, (p.e.)
4	+43°44A	″.284 ± .005	+10.34 ± .04
5	+43°44B	.285 ± .005	+13.30 ± .04
7	54 Psc	.104 ± .006	+ 5.9 ± .1
8	η Cas	.182 ± .005	+ 4.74 ± .06
9	v Maanen 2	.243 ± .006	+14.30 ± .03
11	+61°195	.101 ± .007	+ 9.6 ± .2
12	Wolf 47	.101 ± .007	+13.7 ± .2
13	μ Cas	.130 ± .006	+ 5.7 ± .1
21	107 Psc	.132 ± .006	+ 5.8 ± .1
22	τ Cet	.301 ± .007	+ 5.90 ± .05
23	HR 511	.111 ± .007	+ 5.9 ± .1
31	HR 753A	.144 ± .005	+ 6.62 ± .06
32	HR 753B	.144 ± .005	+12.46 ± .06
39	κ Cet	.106 ± .005	+ 5.0 ± .1
48*	γ Tau	.0257 ± .0005	+ 0.66 ± .05
49*	δ Tau	.0244 ± .0005	+ 0.66 ± .05
50*	ϵ Tau	.0253 ± .0005	+ 0.56 ± .05
51*	α Tau	.046 ± .004	− 1.0 ± .2
52	π^3 Ori	.128 ± .005	+ 3.7 ± .1
61	Cin 705	.168 ± .004	+ 9.08 ± .05
80	α CMa	.373 ± .002	+ 1.40 ± .03
85	α CMi	.291 ± .004	+ 2.67 ± .03
87	β Gem	.100 ± .010	+ 1.2 ± .2
98	Gmb 1618	.220 ± .008	+ 8.31 ± .08
100	AD Leo	.193 ± .008	+10.9 ± .1
107	Lal 21185	.388 ± .006	+10.40 ± .03
110	+66°717	.120 ± .005	+ 9.72 ± .09
111	61 UMa	.109 ± .009	+ 5.5 ± .2
113	β Vir	.101 ± .007	+ 3.8 ± .2
114	Gmb 1830	.108 ± .004	+ 6.68 ± .08
115*	γ UMa	.042 ± .003	+ 0.5 ± .2
116*	δ UMa	.044 ± .003	+ 1.5 ± .2
117	β CVn	.108 ± .006	+ 4.5 ± .1
121*	Wolf 457	.076 ± .008	+15.3 ± .2
122*	78 UMa	.043 ± .003	+ 3.1 ± .2
123	β Com	″.134 ± .010	+ 5.0 ± .2
124	61 Vir	.129 ± .007	+ 5.3 ± .1
126*	80 UMa	.043 ± .003	+ 2.2 ± .2
128	+11°2576	.123 ± .010	+ 9.5 ± .2
129	Wolf 489	.130 ± .009	+15.3 ± .2
132	η Boo	.112 ± .011	+ 2.9 ± .2
137*	α Boo	.085 ± .004	− 0.3 ± .1
168	ζ Her	.110 ± .005	+ 3.0 ± .1
169	Cin 2238	.113 ± .006	+ 8.4 ± .1
176	Cin 2322	.124 ± .005	+ 8.02 ± .09
182	+68°946	.213 ± .005	+10.78 ± .05
184	μ Her A	.109 ± .006	+ 3.6 ± .1
185*	μ Her BC	.109 ± .006	+10.0 ± .1
188	+4°3561	.545 ± .003	+13.23 ± .03
197	χ Dra	.119 ± .008	+ 4.0 ± .2
198	α Lyr	.121 ± .004	+ 0.44 ± .07
202	ADS 11632A	.282 ± .004	+11.17 ± .04
203	ADS 11632B	.282 ± .004	+11.95 ± .04
207*	AC + 70°8247	.065 ± .011	+12.2 ± .4
210	CC 1143	.170 ± .004	+10.28 ± .05
215	σ Dra	.191 ± .004	+ 5.98 ± .05
221	α Aql	.208 ± .005	+ 2.34 ± .05
231*	Wolf 1346	.074 ± .007	+10.9 ± .2
240	Cin 2707	.138 ± .005	+ 9.20 ± .08
242	61 Cyg A	.299 ± .003	+ 7.57 ± .03
243	61 Cyg B	.299 ± .003	+ 8.39 ± .03
265A*	Kr 60A	.258 ± .004	+11.9 ± .1
265B*	Kr 60B	.258 ± .004	+13.3 ± .2
273	−15°6290	.231 ± .012	+12.0 ± .1
275	CC 1392	.161 ± .007	+ 9.7 ± .1
279	HR 8832	.146 ± .006	+ 6.37 ± .09
287	+1°4774	.167 ± .006	+10.11 ± .08

Notes

48, 49, 50 . . Cluster parallax by H. G. van Buren, B.A. N. No. 432

51 . . The parallax is smaller than 0″.100 but the star has been included because of the scarcity of late-type giants having appreciable parallaxes.

115, 116 . . Cluster parallax by Miss Roman (Ap. J., 110, 205, 1949). She has estimated (private communication) that the probable errors of these cluster parallaxes are ± 0″.003.

121 . . Parallax determined at Mt. Wilson. The parallax is smaller than 0″.100, but the star has been included to illustrate the position of the white dwarfs.

122, 126 . . See footnote for No. 115.

157 . . See footnote for No. 51.

185 . . The absolute magnitude is for the two stars together.

207 . . See footnote for No. 121.

231 . . See footnote for No. 121.

265A, 265V . . The absolute magnitudes are determined from the visual magnitude estimated in the footnote to Table 3.

1953ApJ...117..313J

The absolute magnitudes, M_V, are computed on the basis of an apparent distance modulus of 11.9.

PRAESEPE

The observations for this cluster have been published elsewhere.[10]

COLOR-MAGNITUDE DIAGRAMS

A number of the stars listed in Table 3 have accurately known parallaxes, through which the absolute magnitudes may be determined. Table 8 contains all the stars in Table 3 having trigonometric parallaxes of $0''.100$ or greater; three yellow giants from the Hyades cluster and four A and F stars from the Ursa Major cluster for which accurate cluster parallaxes are known; α Boo and α Tau, the two yellow giants later than K0 having the largest parallaxes; and all the degenerate stars (white dwarfs) contained in Table 3 for which parallaxes have been measured. The first two columns of Table 8 contain the same serial numbers and names of the stars as Table 3; the third, the parallax; and the fourth the absolute visual magnitude. The parallaxes are, in general, from the Yale 1935 catalogue.

We can construct a color-luminosity diagram from these stars, but the number of bluish stars having accurately known absolute magnitudes is very small, and no stars earlier than A0 can be included. We cannot, therefore, form any idea about the main sequence earlier than A0, and much of the detail for later-type stars is lost, especially in the A to G stars. We can, however, fill in many of the gaps by using the color-magnitude diagrams from galactic clusters to interpolate between and extrapolate beyond the stars with known absolute magnitudes. In this way we can show the slope and some of the details of the main sequence. We do, of course, make the assumption that the main sequences of the clusters may legitimately be fitted to near-by stars.

For these processes of interpolation and extrapolation we shall use the following galactic clusters: The Pleiades (we omit the brighter stars, which have luminosity classes III and IV, and a strongly reddened A star); Praesepe;[11] and NGC 2362. The spectral types of the stars in these clusters range from B1 to M0, and adequate fits to the near-by stars are possible. Two of the clusters (the Pleiades and NGC 2362) are reddened, while the third is not. We shall correct the Pleiades for +0.04 mag. reddening and NGC 2362 for +0.11 mag. (on the $B - V$ scale); the determination of these values is described later.

We first fit the Pleiades to the near-by stars (correcting for +0.04 mag. reddening in the process) over the range of spectral type A0 to G0, corresponding to $0.00 < B - V < +0.60$. The resultant apparent distance modulus is $5^{\rm m}.9 \pm 0^{\rm m}.1$ (p.e.), and there is no significant systematic difference in shape between the main sequence of the Pleiades and that of the near-by stars. When we correct for the ratio of total to selective absorption, we find that the true distance modulus of the Pleiades is $5^{\rm m}.8 \pm 0^{\rm m}.1$ (p.e.), corresponding to a distance of 144 ± 7 (p.e.) parsecs.

We next fit the Praesepe main sequence to the Pleiades main sequence for $+0.30 < B - V < +0.60$. Since there is no systematic difference between the Pleiades main sequence and that of the near-by stars, this process is equivalent to fitting Praesepe to the near-by stars over the same range of color. The resultant distance modulus is $6^{\rm m}.2 \pm 0^{\rm m}.1$ (p.e.), corresponding, since Praesepe is not reddened, to a distance of 174 ± 8 (p.e.) parsecs. As a check, let us fit the Praesepe main sequence to the near-by stars for $B - V > +0.60$, the range of color that was not used in the above fit. We find, after rounding off to the nearest tenth, the same distance modulus as before—6.2 mag. In this computation Gmb 1830 has been omitted because it is known to lie well below the main sequence. As in the case of the Pleiades, there is no significant systematic

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[10] *Ap. J.*, **116**, 640, 1952.

[11] Only main-sequence and yellow giant stars are used.

difference in shape between the main sequence of Praesepe and that of the near-by stars.

Finally, we fit NGC 2362 to the upper portion of the Pleiades main sequence, taking into account the reddening of +0.11 mag. The fit is not so certain as the other two, because of the appreciable width of the Pleiades main sequence in this region and the lack of any method, independent of the photometry, for choosing cluster members for NGC 2362. We find an apparent distance modulus of $11^{m}.9 \pm 0^{m}.2$ (p.e.). When we correct for the ratio of total to selective absorption, we find a true distance modulus of $11^{m}.6 \pm 0^{m}.2$ (p.e.), corresponding to a distance of 2090 ± 190 (p.e.) parsecs.

This last distance, 2090 parsecs, seems rather large for the amount of reddening, +0.11 mag., of the cluster. A satisfactory check on the reliability of the distance modulus for NGC 2362 can be had by comparing the absolute magnitudes from Table 7 with those given by Keenan and Morgan[12] for the same spectral types. This comparison is shown in Table 9, where it is evident that the agreement of the cluster magnitudes with the independent ones of Keenan and Morgan is quite good. The discordance at B9 V can be removed if NGC 2362, No. 16, which lies far above the main sequence of the cluster, is omitted.

TABLE 9

COMPARISON OF ABSOLUTE MAGNITUDES FOR B STARS

Sp.	M_V (NGC 2362)	No. of Stars	M_V (Keenan and Morgan)*	Sp.	M_V (NGC 2362)	No. of Stars	M_V (Keenan and Morgan)*
B1 V..........	−3.7	1	−3.3	B7 V........	−1.0	2	−0.9
B2 V..........	−2.6	4	−2.7	B9 V........	−0.7	2	−0.1
B3 V..........	−2.0	4	−2.1	A0 V........	+0.3	1	+0.2
B5 V..........	−1.4	3	−1.4				

* The magnitudes of Keenan and Morgan have been corrected by −0.1 mag. to correct from the HR magnitudes to the visual magnitudes of this paper.

We are now prepared to plot the composite color-magnitude diagram given in Figure 5, which shows the main sequence from B1 V to M6 V, the yellow giant branch from K0 III to K5 III, and a few white dwarfs. Several stars that fall somewhat below the main sequence (as defined by the Praesepe stars) will be noted around $B - V = +0.7$. In order to avoid confusing the diagram with too many points, the Praesepe stars bluer than $B - V = +0.60$ have been omitted. The Pleiades stars adequately represent this portion of the diagram.

Values of $U - B$ are available for all the stars plotted in Figure 5; we can therefore plot Figure 6, M_V versus $U - B$. Again we have the main sequence from B1 V to M6 V, the yellow giant branch from K0 III to K5 III, and the white dwarfs. Those few stars that fall below the main sequence of Figure 5 deviate even farther from the main sequence of Figure 6. The stars involved are: μ Cas, Gmb 1830, τ Cet, and χ Dra. The other two stars below the main sequence are in Praesepe. The dip due to the hydrogen absorption in the A stars is very marked.

Some of the scatter to the right of the hydrogen dip is due to Pleiades stars that apparently are reddened considerably more than the average (+0.04 mag.) for the cluster. Such an effect is not surprising, considering the reflecting nebulosity associated with the cluster. This differential reddening within the cluster does not affect Figure 5 significantly, since the absorption/reddening line is very nearly parallel to the main sequence. In Figure 6, the absorption/reddening line is perpendicular to the main sequence in the region of the hydrogen dip, and the effects of internal reddening in the cluster are considerable.

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[12] *Astrophysics*, ed. J. A. Hynek (New York: McGraw-Hill Book Co., Inc., 1951), p. 23.

1953ApJ...117..313J

THE RELATIONS BETWEEN $U - B$ AND $B - V$

For the discussion of the relations between $U - B$ and $B - V$, all the main-sequence stars in Table 3 that can reasonably be expected to be unreddened, the Praesepe stars, and the stars in NGC 2362 have been used. The Pleiades have been omitted because of the differential reddening within the cluster. Also we have assumed that reddening in $U - B$ is 0.72 of that in $B - V$, as will be shown below. Corrections for the reddening of NGC 2362 can therefore be made in both colors.

The mean relation for the main sequence as defined by the stars mentioned above is shown in Figure 7. Again the dip caused by the hydrogen absorption in the A stars is evident. The few stars falling above the main sequence (as defined by the Praesepe stars) at $B - V \sim +0.7$ are the same stars—μ Cas, Gmb 1830, τ Cet, and χ Dra—that fell below the main sequence in Figures 5 and 6. It may be, therefore, that there is a luminosity effect here, in the sense that stars below the main sequence in luminosity have stronger ultraviolet than do main-sequence stars. If this effect is universal, it would seem

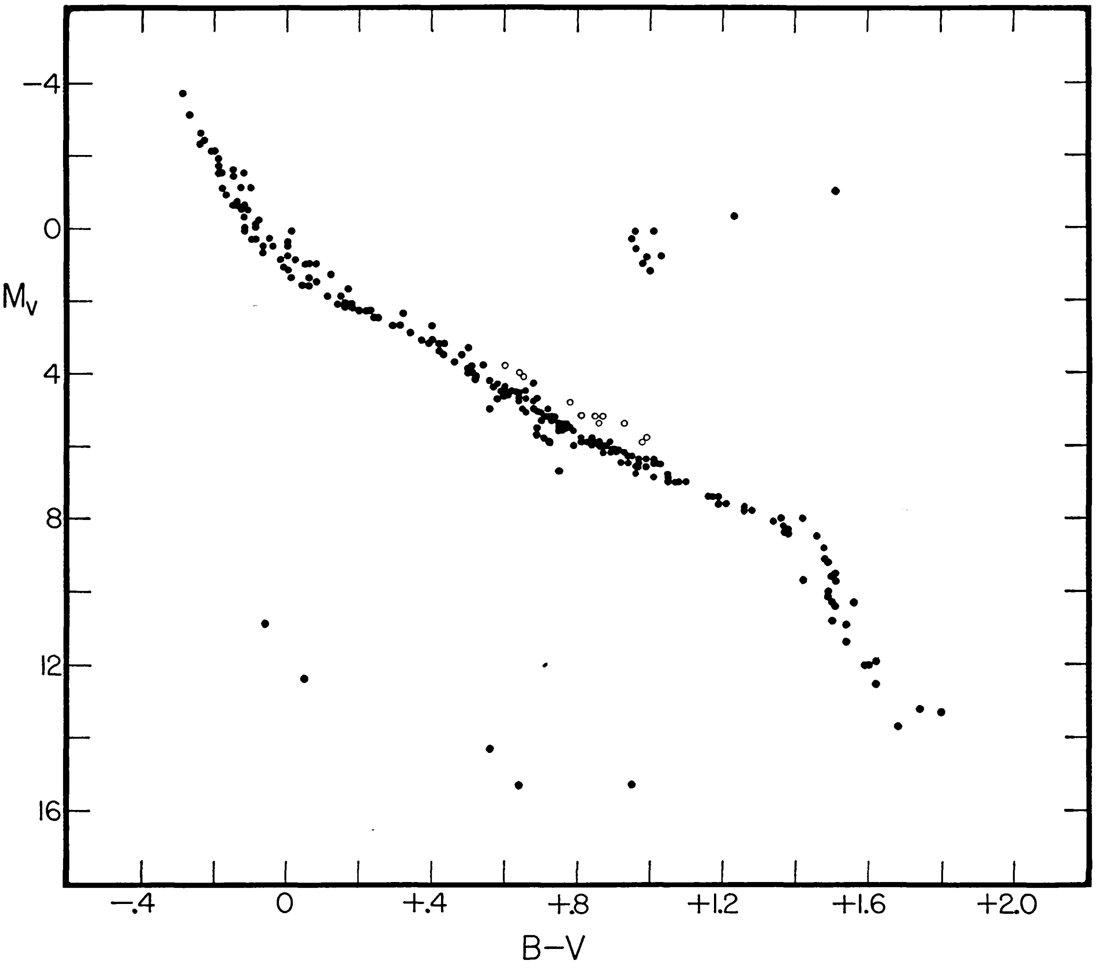

FIG. 5.—A standard main sequence for the color system $B - V$ and the absolute-magnitude system M_V. The stars plotted include main-sequence objects: (*a*), which have trigonometric parallaxes $\geqslant 0''.100$; (*b*) the Pleiades, corrected for a mean interstellar reddening (one highly reddened A star omitted); (*c*) Praesepe; (*d*) NGC 2362 corrected for a mean interstellar reddening. In addition, five white dwarfs, three yellow giants from the Hyades, and several other yellow giants of large parallax are included. The open circles refer to a few stars lying above the main sequence in Praesepe which may be binaries.

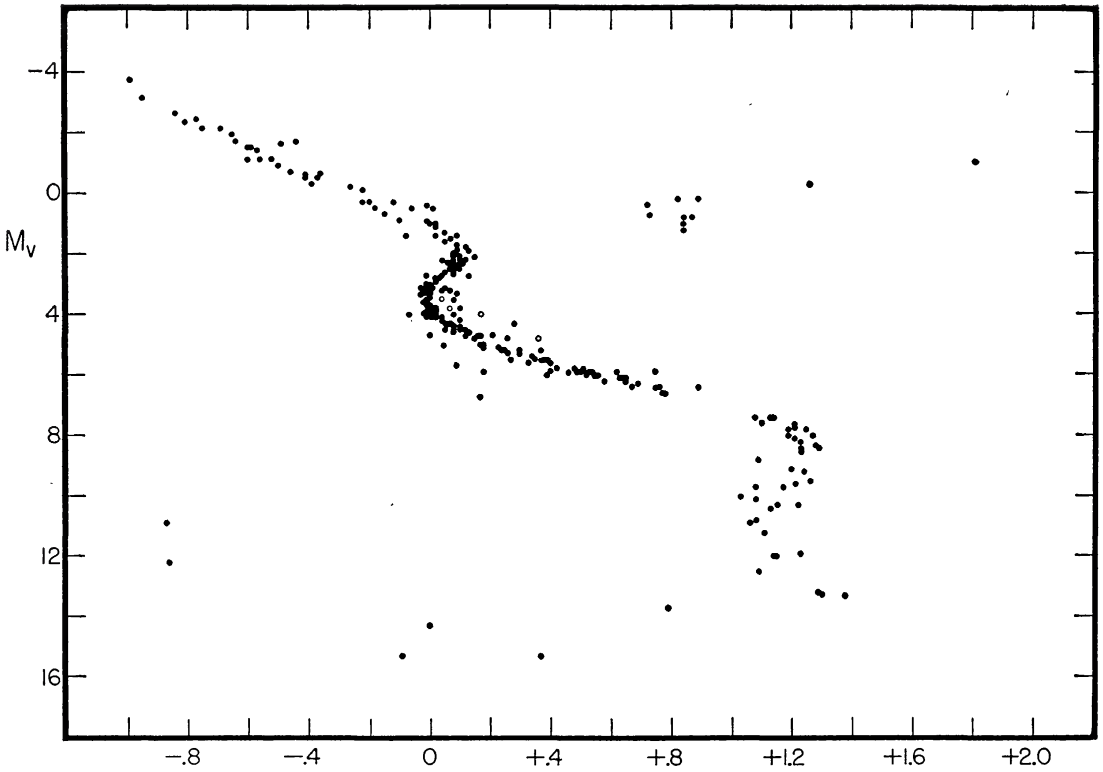

FIG. 6.—A standard main sequence for the color system $U - B$ and the absolute-magnitude system M_V. The selection of stars and notation are the same as for Fig. 5.

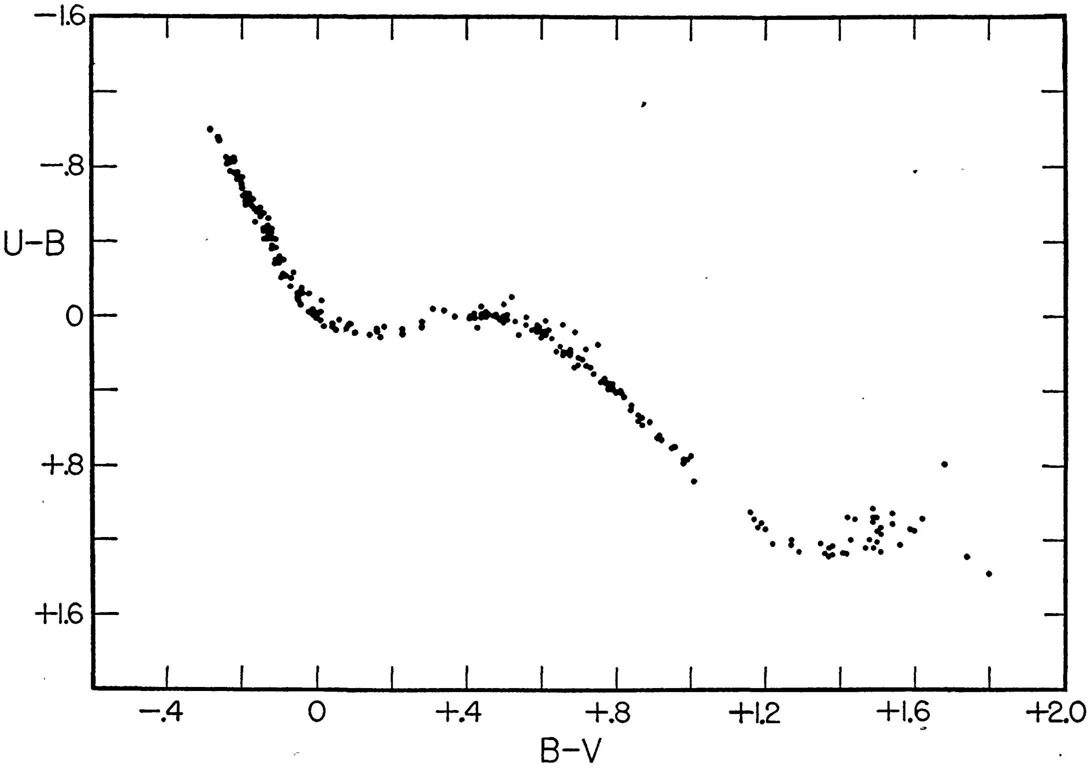

FIG. 7.—The relation between the color systems $U - B$ and $B - V$ for unreddened main-sequence stars.

1953ApJ...117..313J

to remove from cluster membership the five stars below the main sequence in Praesepe,[10] since all five stars fall along with the main-sequence stars in Figure 7.

Larger scatter among the M dwarfs ($B - V > +1.40$) is evident. This scatter is much too large to be explained by observational errors. There appears to be some correlation between $U - B$ and the strength of hydrogen emission in these stars: Wolf 47[13] has extremely strong hydrogen emission lines on a spectrogram obtained at the McDonald Observatory by W. P. Bidelman, and it also has the strongest ultraviolet of all the M dwarfs observed. Barnard's star and Gmb 34B have no appreciable emission and have the weakest ultraviolet of the M dwarfs observed.

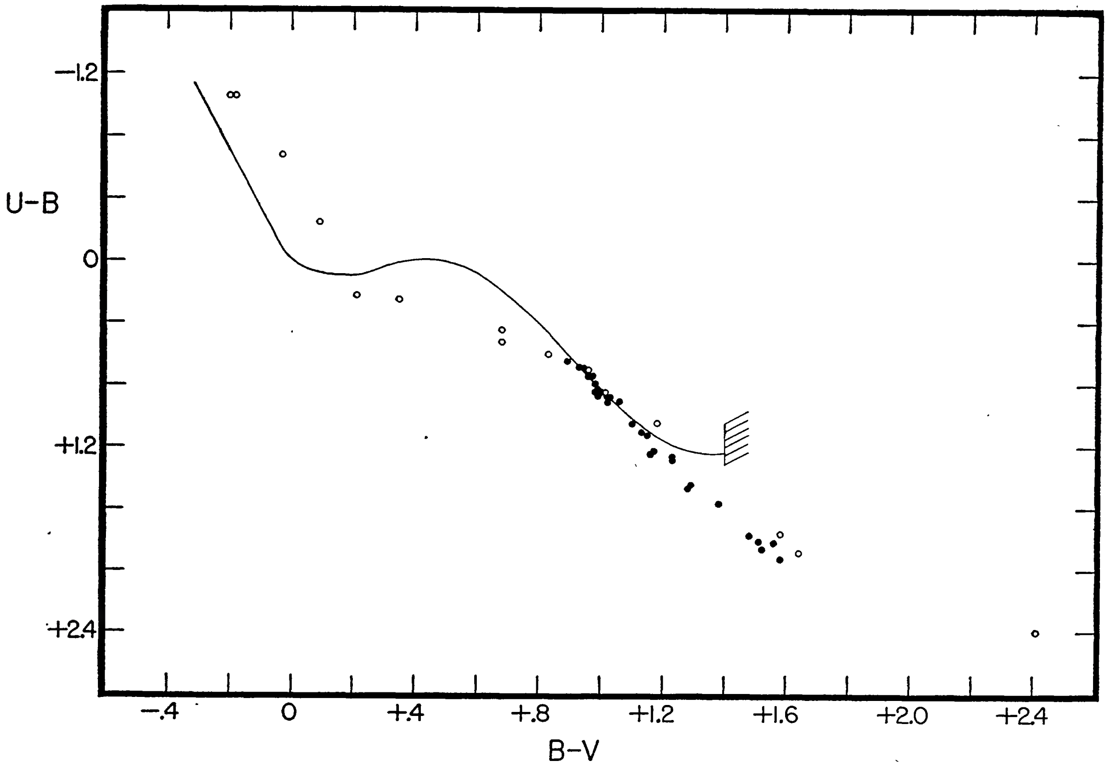

FIG. 8.—The relation between $U - B$ and $B - V$ for little-reddened supergiants (*open circles*) and yellow giants (*filled circles*). The solid line represents the main sequence of Fig 7.

Figure 8 shows the plot of $U - B$ and $B - V$ for the supergiants having little interstellar reddening (*open circles*) and ordinary yellow giants (*filled circles*). The solid line represents the main sequence of Figure 7. One notices immediately that the early-type supergiants have systematically stronger ultraviolet than do the main-sequence stars with the same values of $B - V$; in addition, the hydrogen absorption in the early A supergiants is not so pronounced as in the main-sequence stars. The K and M giants and supergiants ($B - V > +0.80$) appear to run pretty well together, both deviating systematically in $U - B$ from the dwarfs among the late K and M stars ($B - V > +1.40$).

Figure 9 shows the plot of $U - B$ and $B - V$ for the white dwarfs. As in Figure 8, the solid line represents the main sequence of Figure 7. The open circle represents BD+28°4211, a subluminous O star. It is evident that the white dwarfs for which $B - V \sim 0$ have much stronger ultraviolet than do the main-sequence stars of the

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[13] Wolf 47 "flared" during one of the observations.

same color. This fact makes the identification of white dwarfs easy, since the ultraviolet deflection is so much larger than for a normal star that, if the possibility of the star's being a supergiant can be eliminated, one knows immediately whether or not a white dwarf is being observed. Among the later-type white dwarfs the same systematic excess in the ultraviolet compared with the normal stars appears, although here it is not so pronounced. In the case of the white dwarfs, there appears to be little or no continuous hydrogen absorption.

Figures 7, 8, and 9 demonstrate very effectively the nonlinear and multivalued relationships between two color systems, one of which contains significantly more ultraviolet short of 3800 A than does the other. Not only is the relationship between the two colors for the main-sequence stars nonlinear, but it obviously does not apply to the supergiants, white dwarfs, and yellow giants.

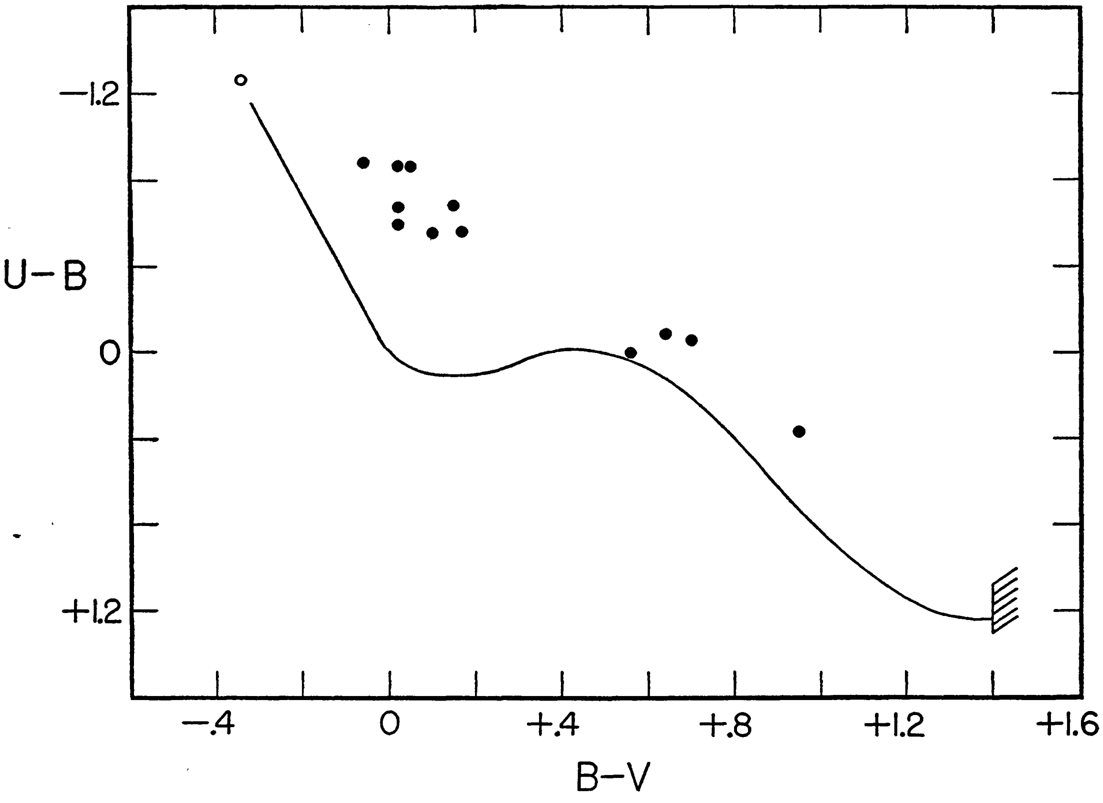

FIG. 9.—The relation between $U - B$ and $B - V$ for white dwarfs (*filled circles*) and BD + 28°4211 (*open circle*). The solid line represents the main sequence of Fig 7.

It will be noticed that in Figure 10 the lines connecting reddened and unreddened stars of the same spectral type have very nearly the same slope. The color excesses for $U - B$ and $B - V$ are, respectively, E_u and E_y; if we compute a quantity $Q = (U - B) - (E_u/E_y)(B - V)$, this quantity will be independent of interstellar reddening. We can therefore separate certain intrinsic properties of the stars, among which are, as we shall show, the spectral type and intrinsic (unreddened) colors. This approach is very nearly the same as W. Becker's[14] "color-difference" method, except that Becker has chosen his effective wave lengths so that the ratio of the color excesses is unity.

The mean ratio of the color excesses, $\overline{E_u/E_y}$, may be determined from the unreddened

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[14] *Ap. J.*, **107**, 278, 1948.

1953ApJ...117..313J

and reddened stars of the same spectral types listed in Table 3. The value so obtained is $\overline{E_u/E_v} = 0.72 \pm 0.03$ (p.e.).

Figure 11 illustrates the relations between Q and $B - V$ for two galactic clusters containing B stars and for certain selected, unreddened bright stars. The cluster stars have been selected from Tables 6 and 7; all stars which fall reasonably near the mean relation have been used, since we have no other way of picking cluster members. It does not seem that the few nonmembers that may be included will affect the results significantly. The selected bright stars, assumed to be unreddened, are listed in Table 10.

A straight line is assumed to be a satisfactory representation for the plotted points, and the slope has been determined from the two clusters, without reference to the bright stars. It is evident that this same slope fits the bright stars well.

We cannot determine the intercept of the straight line at $Q = 0$ from the clusters, since

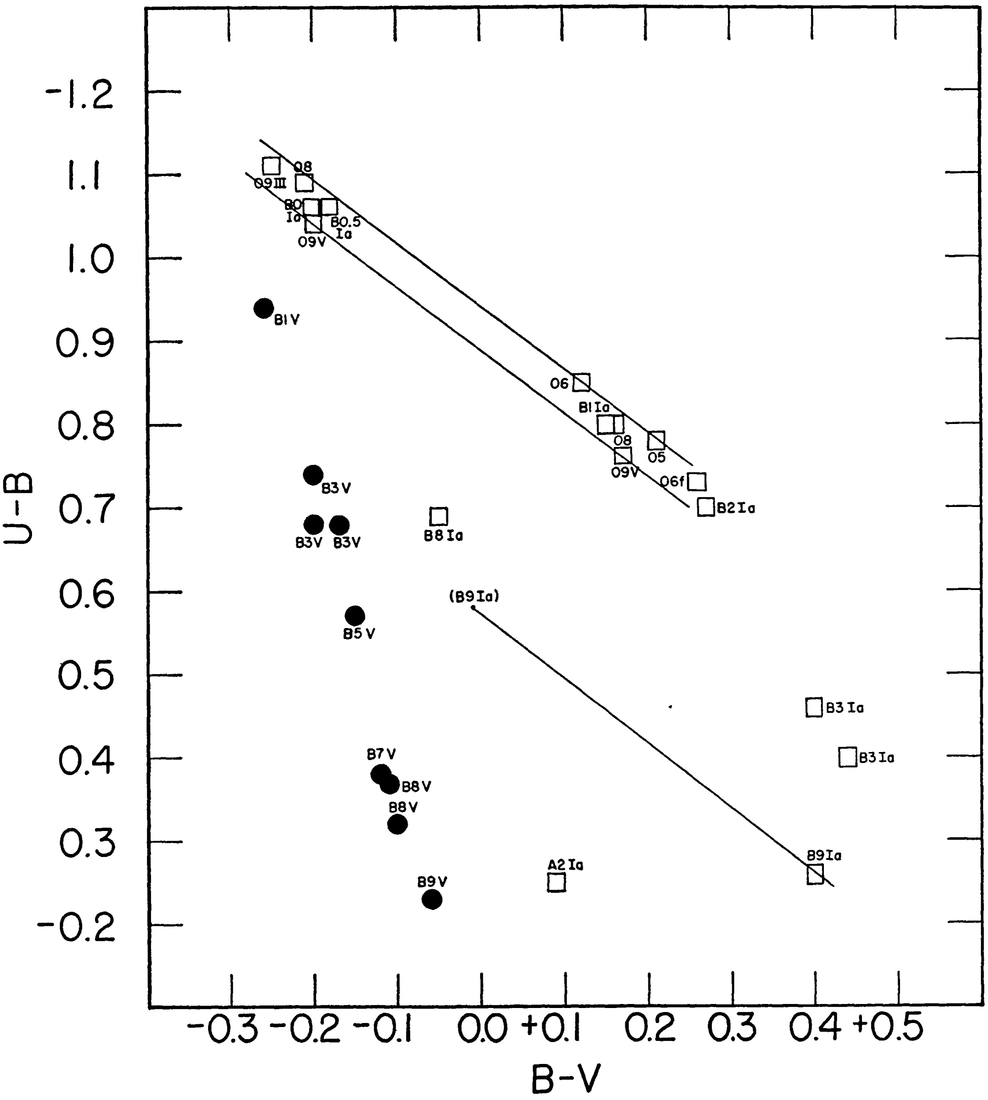

FIG. 10.—Two-color ($B - V$, $U - B$) diagram for main-sequence B1–B9 (*filled circles*), and O stars and B–A2 supergiants (*squares*). The reddening path for the O stars is marked. The point (B9 I*a*) was determined by linear interpolation between the unreddened supergiant values for B8 I*a* and A2 I*a*. The approximate reddening line for B9 I*a* is illustrated.

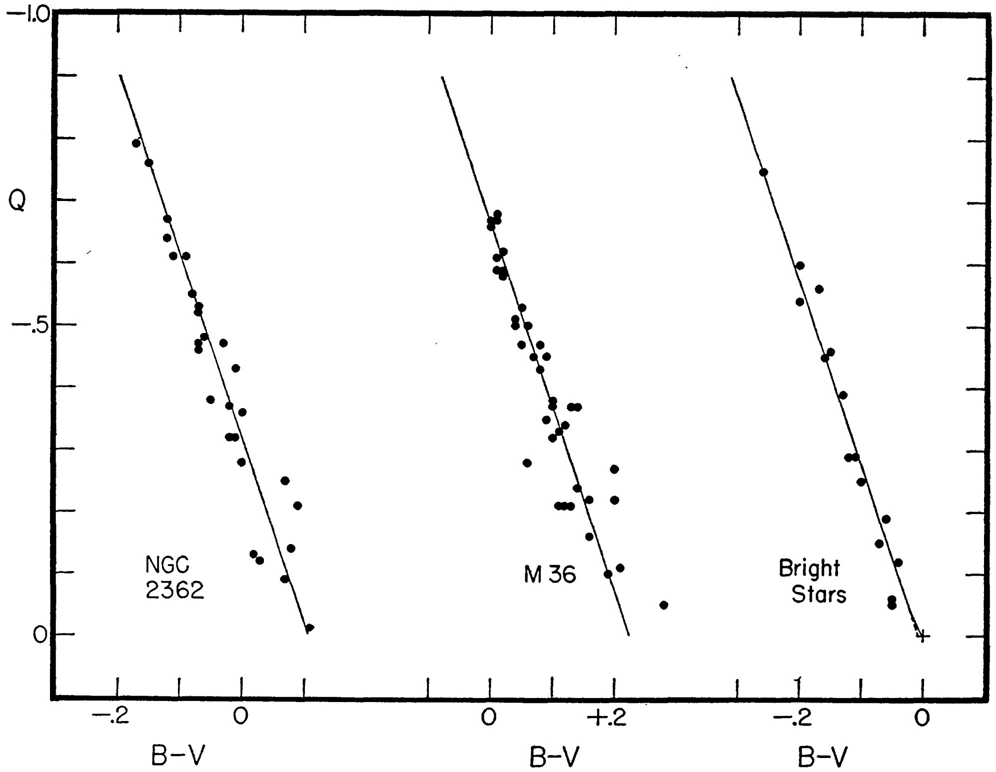

FIG. 11.—The relation between Q and $B - V$ for NGC 2362, M 36, and selected bright stars

TABLE 10

UNREDDENED BRIGHT STARS OF EARLY TYPE

Star	$B-V$	$U-B$	Q	Sp.	Star	$B-V$	$U-B$	Q	Sp.
α Vir.....	−0.26	−0.94	−0.75	B1 V	β Lib.....	−0.11	−0.37	−0.29	B8 V
η Hya.....	− .20	− .74	− .60	B3 V	β Cyg B...	− .10	− .32	− .25	B8 V
η UMa....	− .20	− .68	− .54	B3 V	134 Tau...	− .07	− .20	− .15	B9 IV
η Aur.....	− .17	− .68	− .56	B3 V	α Del.....	− .06	− .23	− .19	B9 V
τ Her.....	− .16	− .56	− .45	B5 IV	γ Lyr.....	− .05	− .10	− .06	B9 III
ν And.....	− .15	− .57	− .46	B5 V	α Dra.....	− .05	− .09	− .06	A0 III
β Tau.....	− .13	− .48	− .39	B7 III	ξ^2 Cet.....	−0.04	−0.15	−0.12	B9 III
α Leo.....	−0.12	−0.38	−0.29	B7 V					

they are reddened by amounts unknown at the present time. We therefore determine this intercept from the bright stars, assuming them to be unreddened. The straight line appears to be quite satisfactory except for a small region near $Q = 0$, as indicated in Figure 11. The straight line is, of course, not valid outside the range of Q and $B - V$ selected.

We find, therefore, for unreddened stars,

$$B - V = -0.009 + 0.337Q . \tag{6}$$

Since the color excess, E_y, is the difference, observed color *minus* intrinsic color, for reddened stars,

$$E_y = (B - V) - 0.337Q + 0.009 . \tag{7}$$

In each case, $B - V$ is the observed color for the particular star. These relations are valid for $-0.80 < Q < -0.05$, which corresponds to spectral types B1–B9 inclusive.

The mean relation between Q and spectral type from O5 to A0 is given in Table 11 and Figure 12. There are no significant systematic differences correlated with luminosity for classes III–V, inclusive, and all stars in the table have been averaged without reference to the luminosity class. A straight line appears to be a quite satisfactory representation of the relationship from spectral type B0 to A0, inclusive.

This relationship may be inverted and spectral types determined from the values of

TABLE 11

THE RELATION BETWEEN Q AND SPECTRAL TYPE

Star	Q	MK	S_Q	Star	Q	MK	S_Q
HD 46223	−0.93	O5	O–B0	ν And	−0.46	B5 V	B5
HD 46150	− .94	O6	O–B0	τ Her	− .45	B5 IV	B5
λ Cep	− .92	O6f	O–B0	δ Per	− .42	B5 III	B5
HD 14633	− .94	O8	O–B0	23 Tau	− .39	B6 IV nn	B7
HD 46149	− .92	O8	O–B0	19 Tau	− .38	B6 V	B7
ι Ori	− .93	O9 III	O–B0	17 Tau	− .33	B6 III	B7
10 Lac	− .90	O9 V	O–B0	β Tau	− .39	B7 III	B7
τ CMa	− .89	O9 III	O–B0	20 Tau	− .35	B7 III	B7
HD 46202	− .88	O9 V	O–B0	α Leo	− .29	B7 V	B8
υ Ori	− .92	B0 V	O–B0	16 Tau	− .29	B7 III	B8
HD 48434	− .88	B0 III	O–B0	η Tau	− .27	B7 III	B8
ε Per	− .86	B0.5 V	B1	27 Tau	− .30	B8 III	B7
β Sco A	− .82	B0.5 V	B1	18 Tau	− .30	B8 V	B7
HD 46106	− .87	B0.5 V	O–B0	β Lib	− .29	B8 V	B8
o Per	− .80	B1 III	B1	26 Tau	− .27	B8 V	B8
8 Lac A	− .79	B1 (V) e	B1	β Cyg B	− .25	B8 V	B8
HR 2222	− .79	B1 V	B1	21 Tau	− .20	B8 V	B8
α Vir	− .75	B1 V	B1	α Del	− .19	B9 V	B8
8 Lac B	− .73	B2 V	B2	BD+23°563	− .15	B9 V	B9
HD 35299	− .72	B2 V	B2	134 Tau	− .15	B9 IV	B9
π^4 Ori	− .69	B2 III	B2	22 Tau	− .13	B9 V:	B9
β Sco C	− .69	B2 V	B2	ξ^2 Cet	− .12	B9 III	B9
η Hya	− .60	B3 V	B3	BD+24°562	− .08	B9 V:	B9
η Aur	− .56	B3 V	B3	γ Lyr	−0.06	B9 III	A0
η UMa	−0.54	B3 V	B3				

MEAN RELATION

Sp.	Q	No. of Stars	Sp.	Q	No. of Stars
O5	−0.93	1	B3	−0.57	3
O6	− .93	2	B5	− .44	3
O8	− .93	2	B6	− .37	3
O9	− .90	4	B7	− .32	5
B0	− .90	2	B8	− .27	6
B0.5	− .85	3	B9	− .13	7
B1	− .78	4	A0	0.00	......
B2	−0.70	3			

1953ApJ...117..313J

Q (see Table 12). Types so determined, designated by S_Q, are given in Table 11 for the stars used in determining the relationship. Despite the fact that some of the stars are moderately reddened while others are unreddened, less than 20 per cent of the types determined from Q differ from the observed spectroscopic types by one subclass, while there are no differences exceeding one subclass. (Part of the discordances are due to the fact that Table 12 lists no type B6 for S_Q.)

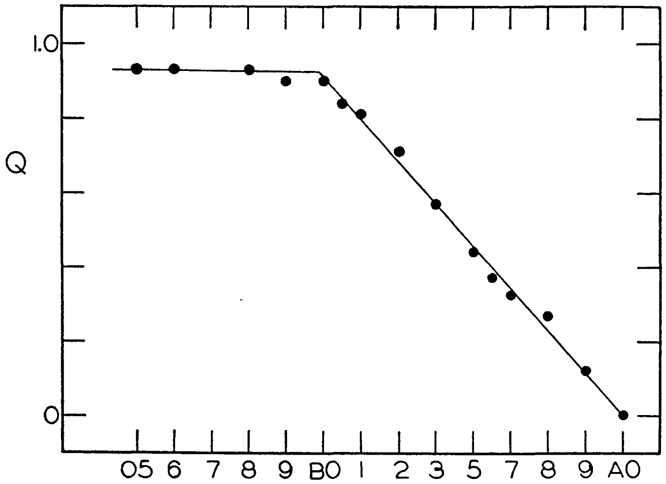

FIG. 12.—Mean values of Q and spectral type on MK system for bright stars whose space reddening ranges from zero to moderate.

TABLE 12

THE DETERMINATION OF SPECTRAL TYPE FROM Q

Q	S_Q	Q	S_Q
$Q<-0.86$	O–B0	$-0.51\leq Q<-0.40$	B5
$-0.86\leq Q<-.74$	B1	$-.40\leq Q<-.29$	B7
$-.74\leq Q<-.63$	B2	$-.29\leq Q<-.17$	B8
$-0.63\leq Q<-0.51$	B3	$-0.17\leq Q<-0.06$	B9

A more independent check on the quality of the types S_Q is afforded by a comparison of S_Q with types determined spectroscopically for the two clusters NGC 2362 and M 36. The spectra obtained for these clusters are of poorer quality than those for the bright stars. Also, the stars in M 36 have very broad lines and are difficult to classify accurately. Nevertheless, Table 13 shows that the same close relationship between S_Q and MK holds; the only discordance of two subclasses occurs for a star (M 36, No. 14) for which the spectroscopic type is quite uncertain. We estimate that the probable error of either MK or S_Q is less than one-third of one subclass.

The relation between Q and $B - V$, discussed above, allows, with the relation between Q and spectral type, the determination of the intrinsic colors of stars in the range of spectral types B1 and B9, inclusive. The values given in Table 14 (intrinsic colors of stars of all spectral types) for these types were determined in this fashion. The value for B0 is an extrapolation from the bluest known value and is therefore somewhat uncertain.

It is possible, of course, to determine intrinsic colors from the unreddened stars listed in Table 10. A comparison of the values of $B - V$ determined from the means for these stars with the adopted values is shown in Table 15. The differences between the values

TABLE 13

COMPARISON OF SPECTRAL TYPE WITH S_Q

Star and No.	MK	S_Q	Star and No.	MK	S_Q
NGC 2362:			*M 36:*		
5	B5 V:	B5	8	B2 V	B3
9	B3 V	B3	9	B2 V	B2
12	B3:nn	B3	13	B8:nn	B7
14	B2 V	B2	14	B8:III–IV	B5
15	B9 V:	B9	16	B2 V	B2
16	B9 V	B8	21	B2.5 V	B3
20	B2 V	B1	23	B3 V	B2
24	B7 nn	B7	27	B2::nn	B3
26	B5 V	B5	33	B9:V:	B8
27	B3 V	B3	44	B8:III–IV	B7
30	B1 V	B1	47	B8 ?	B7
31	B2 V	B2	48	B3 V	B5
36	B7:nn	B5	50	B9::	B8
39	B2 V	B3	61	B2 V:	B2
46	B2 IV	B3	81	B2 III	B3
48	B3 V	B3	86	B8::III–IV	B8
50	B5 V	B7	87	B6:V	B5
58	A0 V:	B9	101	B2 Ve	B2
			138	B3:V:	B3

TABLE 14

INTRINSIC COLORS

MAIN-SEQUENCE STARS

Sp.	$B-V$	$U-B$	Sp.	$B-V$	$U-B$	Sp.	$B-V$	$U-B$
B0 V	(−0.32)	(−1.13)	A3 V	+0.09	+0.07	G5 V	+0.68	+0.21
B1 V	− .28	−1.00	A5 V	+ .15	+ .09	G8 V	+0.70	+0.24
B2 V	− .24	−0.86	A7 V	+ .19	+ .08	K0 V	+0.82	+0.48
B3 V	− .20	−0.71	F0 V	+ .30	+ .02	K1 V	+0.86	+0.54
B5 V	− .16	−0.56	F2 V	+ .37	+ .00	K3 V	+1.01	+0.89
B7 V	− .13	−0.47	F5 V	+ .44	+ .00	K5 V	+1.18	+1.12
B8 V	− .09	−0.29	F6 V	+ .47	− .02	K7 V	+1.37	+1.26
B9 V	− .05	−0.16	F8 V	+ .53	+ .02	M1 V	+1.48	+1.21
A0 V	.00	0.00	G0 V	+ .60	+ .06	M3 V	+1.49	+1.10
A1 V	+0.05	+0.05	G2 V	+0.64	+0.16	M5 V	+1.69	+1.24

YELLOW GIANT STARS

Sp.	$B-V$	$U-B$	Sp.	$B-V$	$U-B$	Sp.	$B-V$	$U-B$
G8 III	+0.95	+0.72	K2 III	+1.16	+1.20	K5 III	+1.52	+1.84
K0 III	+1.01	+0.86	K3 III	+1.30	+1.44	M2 III	+1.57	+1.86

TABLE 15

COMPARISON OF ADOPTED INTRINSIC COLORS WITH MEANS FOR UNREDDENED STARS

Sp.	Adopted $B-V$	Mean from Stars $B-V$	No. of Stars	Sp.	Adopted $B-V$	Mean from Stars $B-V$	No. of Stars
B1........	−0.28	−0.26	1	B7.......	−0.13	−0.12	2
B3........	− .20	− .19	3	B8.......	− .09	− .10	2
B5........	−0.16	−0.16	2	B9.......	−0.05	−0.06	4

TABLE 16

REDDENING OF THE CLUSTERS

NGC 2362

Star	Q	$E_y(Q)$	Sp.	E_y (Sp.)
1............	−0.28	+0.103	....	....
2............	− .37	+ .114	....	....
3............	− .21	+ .170	....	....
4............	− .04	+ .102	....	....
5............	− .48	+ .111	B5 V:	+0.10
9............	− .55	+ .114	B3 V	+ .12
12............	− .52	+ .114	B3: nn	+ .13*
13............	− .01	+ .122	....	....
14............	− .64	+ .105	B2 V	+ .12
15............	− .12	+ .079	B9 V	+ .08
16............	− .25	+ .163	B9 V:	+ .12
20............	− .76	+ .115	B2 V	+ .09
21............	− .46	+ .094	....	....
24............	− .38	+ .087	B7 nn	+ .08
25............	− .43	+ .144	....	....
26............	− .47	+ .097	B5 V	+ .09
27............	− .53	+ .118	B3 V	+ .13
29............	− .32	+ .097	....	....
30............	− .79	+ .105	B1 V	+ .09
31............	− .67	+ .115	B2 V	+ .12
34............	− .47	+ .137	....	....
36............	− .49	+ .194	B7: nn	+ .15*
39............	− .61	+ .125	B2 V	+ .15
48............	− .61	+ .105	B3 V	+ .09
50............	− .36	+ .130	B5 V	+ .16
57............	− .13	+ .073	....	....
58............	− .09	+ .109	A0 V:	+0.07
66............	−0.32	+0.107	....	....
Mean	....	+0.116	....	+0.110

* Weight one-half because of inaccurate spectral type.

TABLE 16—*Continued*

M 36

Star	Q	E_y (Q)	Sp.	E_y (Sp.)
3	−0.32	+0.214	....	....
8	− .59	+ .228	B2 V	+0.26
9	− .66	+ .229	B2 V	+ .24
11	− .37	+ .238	....	....
13	− .37	+ .260	B8: nn	+ .22*
14	− .45	+ .253	B8: III–IV	+ .17*
16	− .66	+ .230	B2 V	+ .24
18	− .43	+ .231	....	....
21	− .61	+ .227	B2.5 V	+ .23
23	− .68	+ .244	B3 V	+ .21
27	− .59	+ .228	B2: : nn	....
30	− .24	+ .232	....	....
33	− .21	+ .204	B9: V:	+ .17*
38	− .53	+ .242	....	....
41	− .10	+ .232	....	....
44	− .35	+ .217	B8: III–IV	+ .18*
46	− .05	+ .308	....	....
47	− .34	+ .244	B8 ?	....
48	− .50	+ .238	B3 V	+ .26
50	− .27	+ .302	B9: :	....
55	− .37	+ .236	....	....
57	− .21	+ .203	....	....
61	− .67	+ .245	B2 V:	+ .25
71	− .16	+ .221	....	....
77	− .12	+ .209	....	....
79	− .21	+ .200	....	....
81	− .59	+ .232	B2 III	+ .26
85	− .37	+ .279	....	....
87	− .45	+ .229	B6: V	+ .22*
91	− .50	+ .216	....	....
92	− .47	+ .215	....	....
101	− .73	+ .305	B2 Ve	+ .29
109	− .47	+ .247	....	....
110	− .22	+ .287	....	....
112	− .11	+ .258	....	....
123	− .33	+ .226	....	....
138	− .62	+ .240	B3: V:	+0.22*
197	−0.51	+0.226	....	....
Mean	....	+0.236	....	+0.236

* Weight one-half because of inaccurate spectral type.

TABLE 16—*Continued*

PLEIADES

Star	Q	E_y (Q)	Sp.	E_y (Sp.)
117	−0.30	+0.064	B7 III	+0.08
126	− .33	+ .013	B6 III	+ .04
150	− .31	+ .038	B8 V	+ .02
156	− .38	+ .031	B6 V	+ .04
242	− .35	+ .059	B7 III	+ .06
255	− .20	+ .032	B8 V	+ .05
265	− .13	+ .025	B9 V:	+ .02
323	− .39	+ .084	B6 IV nn	+ .08
436	− .09	+ .064	B9 V:	+ .07
542	− .27	+ .010	B7 III	+ .04
722	− .27	+ .028	B8 V	+ .02
870	− .30	+ .025	B8 III	+ .01
910	− .10	+ .015	A0 V	− .03
977	−0.15	+0.008	B9 V	0.00
Mean		+0.035		+0.037

determined in the two ways are small. The adopted values determined as described in the paragraphs immediately preceding this are, in effect, values from an interpolation formula determined from the cluster stars (presumably having equal reddening), fitted to the few essentially unreddened bright stars available. The adopted values are therefore to be preferred.

Equation (7) can be used for the determination of the color excess for a star, provided that two conditions are fulfilled: (1) that the spectral type is between B1 and B9, inclusive, and (2) that the luminosity class is in the range III to V, inclusive. For an isolated star it cannot be determined without a spectrogram whether or not these conditions are satisfied. For a galactic cluster, we can be reasonably certain of the luminosity classes of stars not too far above the main sequence in the color-magnitude diagram for the cluster, while the approximate spectral types in the cluster can be found from the shape of the plot of $U - B$ versus $B - V$ for the cluster. Furthermore, some selection of cluster members can be made, since no stars should lie far from the main sequence in the latter plot.

A demonstration of this method of determining color excess can be made for the three clusters NGC 2362, M 36, and the Pleiades, for which magnitudes and colors are given in this paper. All three clusters meet the two necessary conditions, and no data other than the observed magnitudes and (two) color indices are necessary to show this. Since we have spectral types for some of the stars in each cluster, we have a check on the precision of the determination of the color excess from Q.

Table 16 contains the individual data for the three clusters. We notice immediately that there is very close agreement between the cluster color excesses determined from Q and those determined from spectral types. With the exception of the observed values of $B - V$ for both the clusters and the bright stars, the two determinations of color excess are independent. It would seem, therefore, that Q can be used without spectral types to obtain color excesses for galactic clusters containing B stars of the lower luminosity classes; the precision should be as good as we would expect from accurate spectral types.

THE RELATIONS BETWEEN THE COLORS AND SPECTRAL TYPE

The mean intrinsic colors for main-sequence stars from B0 to M5 and for yellow giant stars from G8 to M2 are listed in Table 14. The values for spectral types earlier than A0 were determined as described above. For the later types the values are the means for all stars of the various spectral types in Table 3. The relationships between $B - V$ and MK are plotted in Figure 13. For the main sequence the relation is smooth and nearly linear from B0 to K3; in particular, the hydrogen absorption in the A stars has only a minor effect. Among the later types, the well-known difference in color between giant and dwarf stars of the same spectral type is evident.

Figure 14 shows the relationships between $U - B$ and MK spectral types. As in all diagrams in which $U - B$ appears, the strong effect of the hydrogen absorption in the A stars is apparent. We again find a significant color difference between later-type giants and dwarfs of the same spectral type.

An idea of the accuracy of an intrinsic color obtained from an estimate of spectral type can be obtained by noting that the internal probable errors of the difference be-

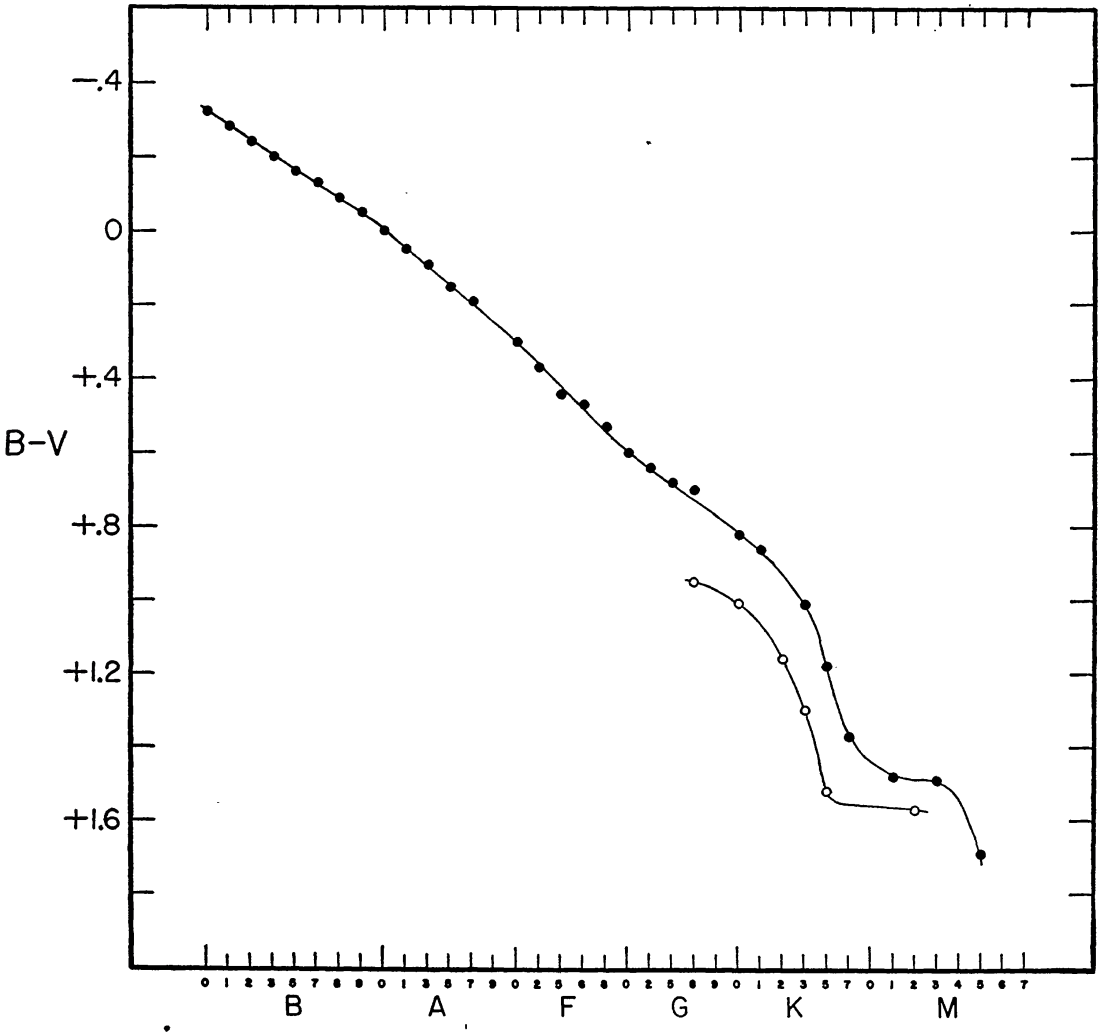

FIG. 13.—Intrinsic colors on $B - V$ system for main-sequence stars (*filled circles*) and yellow giants (*open circles*). The spectral types are on the MK system.

tween the observed $B - V$ colors and the colors predicted from the spectral types by means of Table 14 are: ±0.01 mag. for the main-sequence A stars and ±0.02 mag. for the main-sequence F and G stars. The accuracy of the intrinsic colors determined from spectral types for B stars is about the same as for the A stars.

COMPOSITE STARS

Two stars with composite spectra, β Cyg A and α Sco, are listed in Table 3. β Cyg A consists of a K giant and a B-type main-sequence star; $B - V$ for this star corresponds approximately to spectral type K2 III. For K2 III, $U - B$ is +1.20, while the measured $U - B$ for β Cyg A is +0.62. α Sco consists of an M2 supergiant and a B-type main-sequence star, which may best be compared with ξ Cyg, spectral type K5 I*b*. For α Sco $B - V$ is +1.84, for ξ Cyg, +1.64, while $U - B$ for α Sco is +1.30 and for ξ Cyg, +1.89. In both β Cyg A and α Sco the existence of the blue companion is indicated by the photometry.

SUMMARY

We have presented a system of photoelectric stellar photometry whose visual-magnitude zero point is based upon the revised values of Stebbins, Whitford, and Johnson[4] and which defines the zero point of the color indices in terms of unreddened main-se-

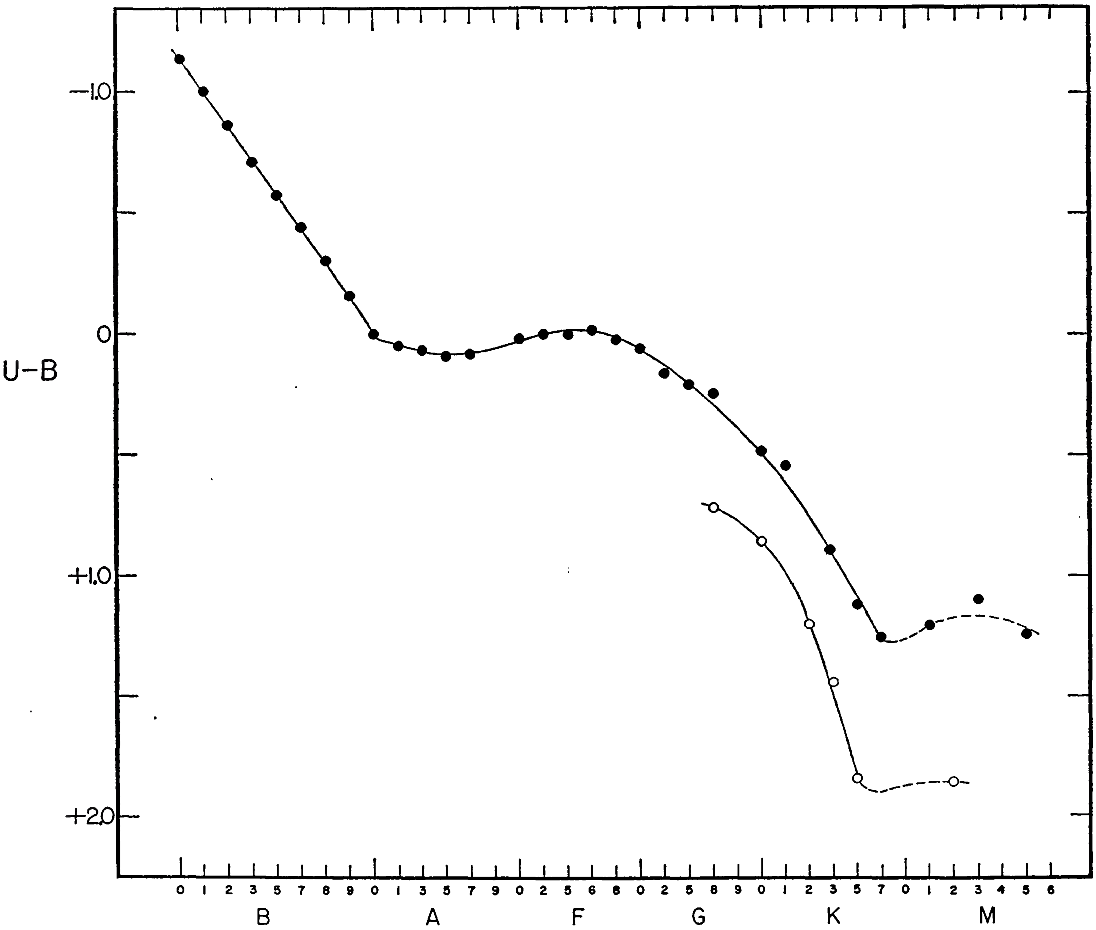

FIG. 14.—Intrinsic colors on the $U - B$ system for main-sequence stars (*filled circles*) and yellow giants (*open circles*). The spectral types are on the MK system.

quence stars of class A0 of the MK system. The accuracy of color indices determined from spectral types around A0 is sufficient to permit the placement of the zero point to about 0.01 mag. We have given sufficient stars of all spectral types to permit accurate transformations to this new system.

The main sequence has been defined in both color-magnitude diagrams from B1 V to M6 V. The positions of the yellow giants and of the white dwarfs in these color-magnitude diagrams are also indicated.

The various relationships between $U - B$ and $B - V$ have been discussed in detail. The position of a standard main sequence on the diagram, $U - B$ versus $B - V$, has been defined, and the positions of the supergiants, yellow giants, and white dwarfs with respect to this standard main sequence have been indicated.

A method by which, for stars in galactic clusters, the spectral types (between B1 and B9, inclusive) and reddening can be determined has been described. The method should be of considerable value in research on the galaxy, since the distances of remote galactic clusters, whose stars are too faint for direct observations of their spectra, can be determined.

We are indebted to Dr. D. L. Harris, both for his generous furnishing of photometric data and for a number of valuable discussions.