RED AND INFRARED MAGNITUDES FOR 138 STARS OBSERVED AS PHOTOMETRIC STANDARDS*

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Received June 2, 1953

ABSTRACT

Red and infrared magnitudes were determined photoelectrically for 138 stars, some groups in a uniformly distributed series of Harvard Standard C and D regions and others at random in declination approximately $-15°$ to $+15°$. The C and D region stars may be used for magnitude zero-point standards and for limited-range color standards. The randomly distributed individual stars were picked to represent an extremely wide color range, for use in color standardization on photometric programs requiring wide, stable color ranges. All the stars are situated in the sky so that they can be observed with precision from a large percentage of all the observatories in both hemispheres. Every effort was made to reduce the systematic and random errors to as small a size as practicable.

I. INTRODUCTION

This paper is a report on an extension of photometric work, already published,[1] on photoelectric red and infrared magnitudes. Late in 1950 the senior author decided to extend to the entire sky a Lick Observatory program for the measurement of red and infrared magnitudes of near-by stars. This decision required a journey to the Southern Hemisphere and the establishment of standards of magnitude in two colors suitable for stabilization of a two-color magnitude system to be used over the whole sky with maximum feasible precision. It was decided that the magnitude zero-point standards should be stars in uniformly distributed small areas zigzagging across the equatorial region of the sky and that the color standards should be individual stars selected for color characteristics and randomly distributed in the declination belt included by the zero-point standard areas.

II. THE PHOTOMETER

The photometer used was the same one described elsewhere,[1, 2] with cell CE25 A/Be. The grid resistor, however, was changed from one of 2.5×10^{13} ohms to one of 5.0×10^{13} ohms, and the unnecessary increase in the signal resulting from this change was reduced by decreasing the gas-multiplying factor of the photocell from 24 to 6 during 1951, and to 10 in 1952–1953; the last value was found to give about optimum signal-to-noise ratio. The reduction in the gas-multiplying factor increased the magnitude range for which the photometer was useful. The range was further increased by adding 1 mag. to the range of the attenuation control of the power amplifier. This change resulted in signals as high as 25 volts appearing across the grid resistor for bright stars. Although the manufacturer states that the resistor will have no voltage coefficient up to 50 volts, the rather high signal voltage we sometimes used, plus the change in the grid resistor itself, made necessary a new linearity check for bright stars. This check was accomplished by measuring the extinction factor of the three neutral screens used for magnitude-scale extension throughout the program. There was no evidence that the screen extinction factors, as

* *Contr. Lick Obs.*, Ser. II, No. 49.

[1] G. E. Kron and J. L. Smith, *Ap. J.*, **113**, 324, 1951; *Contr. Lick Obs.*, Ser. II, No. 34.

[2] G. E. Kron, *Ap. J.*, **115**, 1, 1952; *Contr. Lick Obs.*, Ser. II, No. 38.

measured with the photometer, depended upon star brightness. We take this result as convincing indication that the photometer response is linear for bright stars, and it is justifiable to assume that the response will be linear for faint stars on the basis of previous experience. The sensitivity steps built into the electronic equipment were checked, at reasonable intervals, for constancy to 0.2 per cent of their ratios. In general, the same standards of precision of the photometer described in the previous paper[1] have been maintained throughout the work.

III. COLOR SYSTEMS

The infrared magnitudes were obtained with the same Wratten 88A gelatin filter cemented between glass. The red magnitudes, however, unlike the previous work, were obtained with a new filter, which rejected the blue with a piece of Schott OG-1 filter glass and which excluded the infrared with a 13-film interference filter. This filter was made by J. Lynn Smith,[3] who has described its construction and determined its transmission-curve, which shows sharp cutoffs at both ends of the passband and high maximum transmission. It is designated OG1-74 in this work. The new photoelectric color system was reduced to the ***R, I*** system of red and infrared magnitudes by observing 59 stars in common with the old system. The system used in the Southern Hemisphere in 1951 and that in the Northern Hemisphere in 1952–1953 were brought into agreement by observation of 68 stars common to both.

IV. OBSERVING TECHNIQUE

The results for 1951 were obtained with the 29-inch Reynolds reflecting telescope at the Commonwealth Observatory, Mount Stromlo, Australia, and the 1952–1953 observations were made with the 36-inch refractor of the Lick Observatory. The Reynolds was used at its Newtonian focus with a focal-plane aperture 35 seconds of arc in diameter. The 36-inch refractor was used with a 30-second aperture, and a focus 20 mm inside the focus determined visually through the red filter (placed inside the focus) with a knife-edge test. The observing pattern of deflections was the same as described previously.[1]

The range of sensitivity under electrical control was too small to permit working on the full brightness range of all stars on our program without some additional means of sensitivity control. Following Seares and Stebbins, we adopted screens for reduction of the bright stars to increase the magnitude range. An objective screen of extinction 1.94 mag. was used with the Reynolds in 1951, and the Crossley reflector objective screen of extinction 2.43 mag. was used with the 36-inch in 1952. The use of an objective screen with a large refractor is inconvenient, so on January 22, 1953, we changed to a double thickness of a nickel screen of 1000 meshes per inch, diameter $1\frac{1}{2}$ inches, placed 10 inches inside the focus.[4] This remarkable screen material, when doubled, gave an extinction of 3.99 mag. and was neutral. All visible light diffracted away from the optic axis appeared well clear of the focal-plane aperture, even at the short distance of 10 inches. The rather fragile screen material was supported by clamping it between two pieces of UV transparent glass, each 2 mm thick. This screen unit makes a permanent, very stable, practical method of extending a magnitude range without resort to additional electrical control, with its attendant possibility of overillumination of the photocell.

As usual, the sensitivity of the photometer was monitored by means of an artificial source made from a luminescent radioactive mixture.[1, 5] The luminescent mixture was tested for temperature coefficient and showed no significant effect.

[3] *Pub. A.S.P.*, **63**, 91, 1951.

[4] We are indebted to W. A. Hiltner for calling our attention to the existence of such screen material and for furnishing us with the material.

[5] Joel Stebbins and J. Lynn Smith, *Pub. A.S.P.*, **63**, 203, 1951.

The Harvard Standard Regions, the color standards, and the near-by stars were all observed on the same program. The zero point of the Standard Regions was twice carried completely around the sky from one region to the next in the order of right ascension, once in 1951 in the Southern Hemisphere and once in 1952 in the Northern Hemisphere.

V. REDUCTIONS

As before, we used the general method of reduction employed by Eggen, except that we employed mean extinction coefficients. During the first 12 nights of observing at Mount Stromo we determined extinction coefficients for this site by following a C region to large zenith distances. The mean values for extinction coefficients so obtained, however, were 0.12 and 0.07 mag. in the red and infrared, respectively, which are the same as those used before and after 1951 at Mount Hamilton. Throughout this work we had no trouble with extinction for normal skies either at Mount Hamilton or at Mount Stromlo. Although Mount Stromlo has an elevation of only 2600 feet, it has nearly the same extinction in the red and infrared as Mount Hamilton, elevation 4200 feet. It is of interest to note that if all observations of the present program were made at zenith

TABLE 1

OBSERVING SCHEDULE

Reynolds Reflector		36-Inch Refractor	
Date	Program*	Date	Program
May 9, 1951	C6, D6, C8, extinction	Mar. 20, 1952	C4, D6, color
May 10	C6, D6, C8, extinction	Mar. 26	C4, D6, color
May 11	C6, D6, extinction	Apr. 2	C4, D6, color
May 12	C6, D6, extinction	Apr. 15	C4, D6, C6, C8
May 16	C6, D6, extinction	May 10	D6, C6, C8, color
May 17	D6, C8, extinction	May 14	D6, C6, color
May 30	D6, C8, extinction	May 21	C6, C8, color
May 31	D6, C8, extinction	May 26	C6, C8, color
June 1	D6, extinction	June 18	C6, C8, D10, color
June 2	D6, extinction	July 15	C8, D10, color
June 29	C8, D10, extinction	Aug. 14	C8, D10, color
July 1	C8, D10, extinction	Aug. 23	D10, C12, color
July 10	D10, C12	Aug. 24	D10, C12, color
July 28	C8, D10, C12	Aug. 25	D10, C12, color
July 29	C8, D10	Sept. 20	C12, D2, color
Aug. 27	D10, C12, D2	Sept. 21	C12, color
Oct. 4	C12, D2, color	Oct. 24	C12, D2, C4, color
Oct. 9	C12, D2, color	Oct. 25	C12, D2, C4, color
Oct. 15	C12, D2, color	Nov. 18	C12, D2, color
Nov. 17	D2, C4, color	Nov. 25	C12, color
Nov. 20	D2, C4, color	Jan. 29, 1953	C4, color
Dec. 6	D2, color	Feb. 16	C4, color
Dec. 12	C4, C6, color	Mar. 3	C6, color
		Mar. 5	C4, color
		Mar. 15	C4, color
		Apr. 1	C6, color
		Apr. 14	C4, color

* The word "color" appearing in this column means that color standards were observed on the indicated night.

TABLE 2

MAGNITUDES OF THE ZERO-POINT STANDARDS

Star	R	A.D.	$(R-I)$	A.D.	No. of Nights 1950, 1951, 1952
			Area D2 ($3^{\mathrm{h}}04^{\mathrm{m}}$, $-14°$)		
A......	$5^{\mathrm{m}}70$	2	$+0^{\mathrm{m}}42$	1	0, 7, 3
B......	6.73	2	+ .22	2	0, 7, 3
G......	7.34	3	+ .36	2	0, 7, 3
C......	7.54	2	+ .14	2	0, 7, 3
H......	7.75	2	+ .31	2	0, 7, 3
E......	8.39	3	− .03	2	0, 6, 3
K......	9.01	3	+0.13	3	0, 7, 3
			Area C4 ($7^{\mathrm{h}}02^{\mathrm{m}}$, $+15°$)		
D......	6.59	2	+0.33	1	4, 3, 5
F......	6.92	2	+ .38	1	3, 3, 6
A......	7.23	2	− .15	1	5, 3, 6
B......	7.50	2	− .02	1	5, 3, 6
E......	7.58	2	+ .19	1	2, 2, 6
K......	8.01	1	+ .38	1	5, 2, 3
G......	8.99	3	− .08	3	1, 2, 3
L......	9.21	3	+0.20	2	2, 2, 3
			Area C6 ($11^{\mathrm{h}}00^{\mathrm{m}}$, $+15°$)		
K......	6.40	1	+0.80	1	6, 4, 7
A......	7.00	2	− .10	2	6, 5, 7
D......	7.11	2	+ .18	1	6, 5, 7
G......	7.24	1	+ .34	1	6, 5, 7
M......	7.70	1	+ .45	2	6, 5, 5
F......	7.85	1	+0.14	1	6, 5, 6
			Area D6 ($11^{\mathrm{h}}05^{\mathrm{m}}$, $-16°$)		
Q......	7.45	2	+0.58	1	0, 10, 6
G......	7.59	1	+ .19	1	0, 11, 6
F......	7.81	2	+ .13	1	0, 11, 6
M......	8.01	2	+ .34	2	0, 9, 6
I......	8.14	1	+ .17	2	0, 9, 6
K......	8.85	2	+ .04	2	0, 6, 3
S......	8.97	1	+ .39	1	0, 5, 0
N......	9.26	2	+0.17	2	0, 4, 6
			Area C8 ($15^{\mathrm{h}}00^{\mathrm{m}}$, $+15°$)		
D........	$6^{\mathrm{m}}14$	2	$+0^{\mathrm{m}}46$	1	0, 9, 9
C........	6.49	2	+ .33	1	0, 9, 9
F........	6.67	1	+ .40	2	0, 9, 9
A........	6.78	2	+ .20	1	0, 9, 9
B........	7.27	3	− .01	1	0, 7, 7
E........	8.07	2	+ .06	3	0, 3, 6
N........	8.36	1	+0.42	2	0, 4, 4
			Area D10 ($19^{\mathrm{h}}10^{\mathrm{m}}$, $-15°$)		
M........	*	.....	+1.42	2	0, 6, 6
H........	6.26	1	+ .56	1	0, 6, 6
O........	6.70	1	+ .82	1	0, 6, 6
E........	7.47	1	+ .17	2	0, 6, 6
C........	7.88	1	− .05	2	0, 6, 6
Q........	8.16	1	+ .52	2	0, 6, 5
F........	8.38	1	−0.08	2	0, 6, 6
			Area C12 ($23^{\mathrm{h}}00^{\mathrm{m}}$, $+15°$)		
D........	5.99	1	+0.45	1	7, 10, 7
E........	6.66	1	+ .37	1	4, 10, 7
A........	6.94	3	− .10	1	7, 10, 7
C........	7.44	2	− .02	1	3, 10, 7
I........	7.47	2	+ .45	1	3, 10, 7
+15°4733.	7.58	1	+ .88	1	7, 6, 7
M........	7.86	1	+ .53	2	3, 5, 7
F........	8.19	1	+0.08	2	6, 5, 7

* Variable; mean $5^{\mathrm{m}}75$; amplitude $0^{\mathrm{m}}24$.

distances of such size that air mass 1.5 was never exceeded and if all results were reduced to the mean air mass 1.25, instead of to air mass zero, then the largest error, even if extinction corrections were completely neglected, would be only 0.03 mag. for the red and less than 0.02 mag. for the infrared. Throughout most of this work an effort was made to observe with an air mass less than 1.5, which was done in all but a small percentage of the observations. It is probable that some of the systematic errors made in extinction corrections applied to stars observed in the Standard Regions will cancel or partly cancel in the combination of the data from the two hemispheres.

No appreciable color-closure error was found in the closed circuits around the sky in either the 1951 or the 1952 series of data, a result indicating that the ability of the photometer to carry the color was good. Closure errors in magnitude were found for both years, in the sense that the end-season results indicated fainter magnitudes than those found at the beginning. The closure errors were 0.030 mag. for 1951 and 0.006 mag. for 1952. For both years these errors were assumed to be uniformly distributed throughout

TABLE 3

SYSTEMATIC MEAN SEASONAL DIFFERENCES FOR COLOR AND MAGNITUDE

Region	(O−C) (Unit = 0^m01)					
	1950		1951		1952	
	Mag.	Color	Mag.	Color	Mag.	Color
D2	....	....	+1.4	−0.2	−3.7	+0.2
C4	−0.8	−0.1	+1.8	+0.5	−0.2	−1.1
C6	+ .3	− .1	−0.8	−0.3	+0.1	+0.7
D6	....	....	−0.5	+1.0	+0.4	−1.0
C8	....	....	−1.3	−0.9	+1.0	+0.6
D10	....	....	+0.2	+0.4	−0.2	−0.9
C12	+0.1	+0.8	+0.2	−0.5	−0.2	−0.9
Mean	−0.1	+0.2	+0.2	±0.0	−0.4	−0.3

seven transfers made in the closed circuit, and corrections were made accordingly. A comparison between the 1951 magnitudes and the independently determined 1952 values, after both sets had been corrected for closure errors, indicated such close agreement that no further work to investigate these errors seemed necessary.

VI. THE OBSERVATIONS

The schedule of observing is given in Table 1, and Table 2 contains the magnitudes and colors for the seven Harvard Standard Regions. The headings of the columns are self-explanatory. Three Standard Regions—C4, C6, and C12—are common with the earlier work, and the results therefore represent improvements based on additional observing. The tabulated values for R and $(R - I)$ are means for all nights on each star after reduction of each season independently to the R, I system. The average deviations, formed from these means, thus contain the effects of any season-to-season systematic differences present in the data, and for this reason they are in some cases larger than average deviations given for the same stars in the relatively lower-weight results previously published.[1] Mean values for each star for each season were also formed from the night-to-night data, and we have computed, from these seasonal means, the systematic mean seasonal differences for color and magnitude given in Table 3. These mean seasonal differences were obtained by subtracting the magnitudes and colors for each star for

TABLE 4

COLOR STANDARDS

STAR	1900 POSITION		SPECTRAL TYPE	R	A.D.	$(R-I)$	A.D.	n
	R.A.	Dec.						
γ Peg	00^h08^m1	+14° 38′	B2 IV	3^m06	1	-0^m22	1	4
η Psc	1 26.1	+14 50	G8 III	3.23	3	+0.32	1	5
τ Cet	1 39.4	−16 28	G8 V	3.16	2	+0.26	1	5
−18°359	2 00.1	−18 06	....	9.00	1	+1.02	2	4
+2°348	2 07.4	+03 10	....	9.02	3	+0.86	1	4
ξ^2 Cet	2 22.8	+08 01	B9 III	4.45	3	−0.13	1	3
HR 753B	2 30.6	+06 25	....	10.26	3	+1.28	2	6
HR 875	2 51.6	−04 07	A1 V	5.26	2	−0.04	1	3
κ Cet	3 14.1	+03 00	G5 V	4.57	4	+0.22	1	8
o Tau	3 19.4	+08 41	G8 III	3.28	1	+0.32	1	4
ϵ Eri	3 28.2	−09 48	K2 V	3.33	2	+0.30	1	4
o^2 Eri A	4 10.7	−07 49	....	4.07	3	+0.31	2	3
γ Tau	4 14.1	+15 23	K0 III	3.30	1	+0.34	1	4
δ Tau	4 17.2	+17 18	K0 III	3.41	1	+0.34	1	4
π^3 Ori	4 44.4	+06 47	F6 V	3.05	2	+0.16	2	5
π^4 Ori	4 45.9	+05 26	B2 III	3.86	3	−0.19	1	4
β Eri	5 02.9	−05 13	A3 III	2.82	3	−0.01	2	5
HD 35299	5 18.6	−00 15	B2 V	5.91	2	−0.23	1	4
γ Ori	5 19.8	+06 16	B2 III	1.84	3	−0.25	1	4
−3°1123	5 26.4	−03 42	....	6.87	2	+0.84	1	5
υ Ori	5 27.1	−07 23	B0 V	4.84	3	−0.25	1	5
HD 36591	5 27.6	−01 40	B1 V	5.53	2	−0.20	2	4
ι Ori	5 30.5	−05 59	O9 III	2.95	3	−0.24	1	4
ϵ Ori	5 31.1	−01 16	B0 Ia	1.88	2	−0.20	1	4
ζ Lep	5 42.4	−14 52	A3 V	3.61	2	−0.05	1	4
134 Tau	5 43.9	+12 37	B9 IV	5.04	1	−0.14	1	4
Ross 614AB	6 24.3	−02 44	....	9.42	2	+1.38	2	5
+17°1320	6 31.5	+17 38	....	8.64	2	+0.74	1	4
γ Gem	6 31.9	+16 29	A1 IV	2.02	2	−0.09	1	4
γ CMa	6 59.2	−15 29	B8 II	4.24	1	−0.16	1	3
λ Gem	7 12.3	+16 43	A3 V	3.64	3	−0.05	2	5
Luyten's Star	7 22.0	+05 31	....	8.40	3	+1.19	1	6
Ross 882	7 39.4	+03 48	....	9.76	4	+1.40	3	6
β Cnc	8 11.1	+09 30	K4 III	2.77	1	+0.52	1	4
C Hya	8 20.7	−03 35	A0 V	4.03	2	−0.14	1	4
η Hya	8 38.0	+03 45	B3 V	4.47	1	−0.21	2	4
θ Hya	9 09.2	+02 44	A0p	4.01	1	−0.15	1	6
−12°2918	9 26.4	−13 03	....	8.84	1	+1.04	1	3
α Leo A	10 03.3	+12 27	B7 V	1.48	3	−0.17	1	3
ρ Leo	10 27.5	+09 49	B1 I	4.01	2	−0.19	1	7
Wolf 359	10 51.6	+07 37	....	11.28	1	+1.85	1	3
Ross 128	11 42.6	+01 23	....	9.55	1	+1.30	1	5
β Leo	11 44.0	+15 08	A3 V	2.18	2	−0.06	1	4
β Vir	11 45.5	+02 20	F8 V	3.39	1	+0.16	1	8
γ Crv	12 10.7	−16 59	B8 III	2.72	2	−0.16	2	3

TABLE 4—*Continued*

Star	1900 Position		Spectral Type	R	A.D.	$(R-I)$	A.D.	n
	R.A.	Dec.						
Wolf 424 AB	12^h28^m4	+09°34′	....	10^m50	1	$+1^m62$	3	4
+0°2989	12 45.6	−00 13	M0.5 V	7.58	2	+0.66	2	5
α Vir	13 19.9	−10 38	B1 V	1.19	1	−0.26	1	6
70 Vir	13 23.5	+14 19	G5 IV–V	4.68	1	+0.24	2	7
η Boo	13 49.9	+18 54	G0 IV	2.45	2	+0.20	1	4
109 Vir	14 41.2	+02 19	A0 V	3.86	1	−0.10	2	6
α^2 Lib	14 45.3	−15 38	A3 V	2.82	1	−0.03	2	3
β Lib	15 11.6	−09 01	B8 V	2.72	3	−0.14	2	3
−7°4003	15 14.2	−07 21	....	9.26	2	+1.10	1	4
α Ser A	15 39.3	+06 44	K2 III	2.10	1	+0.37	2	4
β Ser A	15 41.6	+15 44	A2 IV	3.74	2	−0.06	2	6
λ Ser	15 41.6	+07 40	G0 V	4.20	1	+0.20	1	6
γ Ser	15 51.8	+15 59	F6 IV	3.67	1	+0.14	3	5
−12°4523	16 24.7	−12 25	....	8.71	3	+1.20	1	4
ζ Oph	16 31.7	−10 22	O9.5 V	2.64	2	−0.07	1	5
−4°4226	17 00.0	−04 55	M3.5: V	8.99	2	+0.91	2	4
+2°3312	17 20.8	+02 14	K7 V	6.67	3	+0.60	2	3
α Oph	17 30.3	+12 38	A5 III	2.10	1	0.00	2	4
β Oph	17 38.5	+04 37	K2 III	2.24	1	+0.39	1	4
γ Oph	17 42.9	+02 43	A0 V	3.84	1	−0.09	1	5
Barnard's Star	17 52.9	+04 25	M5 V	8.09	1	+1.23	2	4
−3°4233	17 59.8	−03 02	....	8.34	2	+0.88	1	4
ζ Aql	19 00.8	+13 43	B9.5 V	3.10	1	−0.07	2	5
Wolf 1055 A	19 12.1	+05 03	M3.5 V	7.90	1	+1.00	2	5
+3°4065	19 28.6	+03 34	....	6.99	1	−0.06	2	5
κ Aql	19 31.5	−07 15	....	5.02	1	−0.09	2	4
α Aql	19 45.9	+08 36	A7 IV, V	0.76	1	+0.02	1	4
β Aql	19 50.4	+06 09	G8 IV	3.35	2	+0.31	1	3
α Del	20 35.0	+15 34	B9 V	3.91	1	−0.11	2	5
ε Aqr	20 42.3	−09 52	A1 V	3.86	1	−0.11	2	5
Wolf 922	21 25.8	−10 14	....	10.43	2	+1.36	2	5
LPM 837	22 33.0	−15 52	....	10.26	2	+1.66	2	5
−15°6290	22 47.9	−14 47	....	8.76	4	+1.22	2	4
74 Aqr	22 48.2	−12 09	....	5.95	2	−0.14	1	5
α Peg	22 59.8	+14 40	B9 V	2.63	2	−0.08	1	3
ι Psc	23 34.8	+05 05	F7 V	3.94	1	+0.19	1	4
+1°4774	23 44.0	+01 52	M2 V	7.95	2	+0.87	1	5

each season from the mean values of all seasons and then forming mean values for each Standard Region for each season.

The color standards are listed in Table 4, in which the first eight columns are self-explanatory and the last column gives the number of nights on which the star was observed. The spectral types are on the Morgan, Keenan, and Kellman system, or on the Morgan and Keenan system, compiled from various sources.

Figure 1 is a plot of the $(B - V)$ colors of Johnson and Morgan[6] against our $(R - I)$

[6] In press. We are indebted to H. L. Johnson and W. W. Morgan for permitting us to use their data in advance of publication.

colors for 48 stars in common among the color standards. The effects of luminosity are clearly apparent among giants, but less apparent among the dwarf red stars. Except for BD $-$ 4°4226 and Barnard's star,[7] a smooth curve could be drawn through all the points from $(R - I) = +0.6$ to $+1.3$ mag. Barnard's Star is well known as a high-velocity star and as a subdwarf, whereas the BD star, also a high-velocity object, has been classified by Eggen[8] as a subdwarf. The apparent scatter at $(R - I) = +0.18$ mag. is caused by an inherent bifurcation of the color diagram that will be discussed on the basis of definitive data in a forthcoming paper. The correlation of the two sets of data plotted in Figure 1 is very high, even though there may be some unaccountable effects of space reddening, and we conclude that the precision of both sets of data is high. We do not make a quantitative analysis of the residuals in Figure 1 (or in Fig. 2), because we

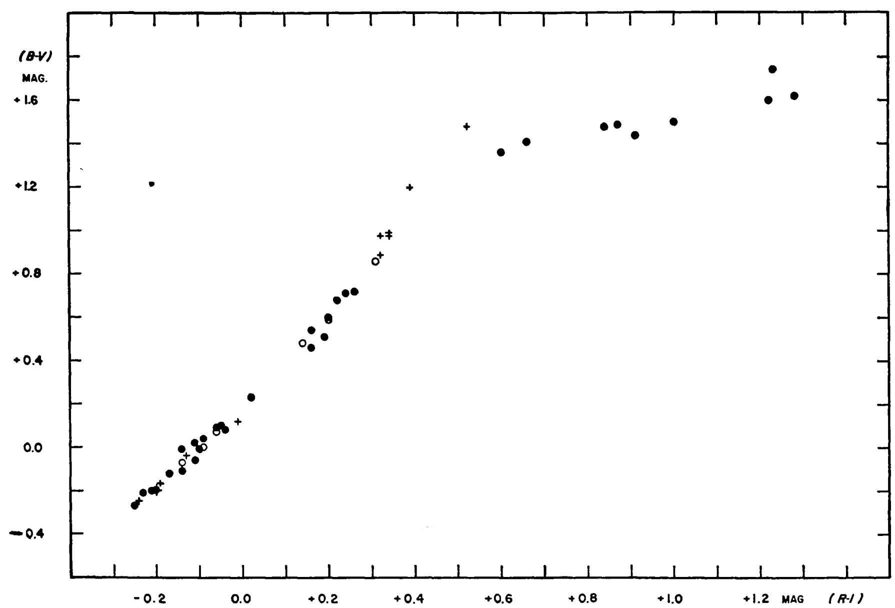

FIG. 1.—Relationship between the $(B - V)$ colors of Johnson and Morgan, and the $(R - I)$ colors for stars in common. Crosses are for stars of luminosity class III, open circles for class IV, and the filled circles for class V.

think the source of these residuals may lie as much in the intrinsic properties of the stars themselves, or in the interstellar medium, as in the properties of the observations. The best quantitative appraisal of the accuracy of the present observations probably can be gained from a study of the average deviations of a single observation given in Tables 2 and 4 and from the systematic mean seasonal differences of the standard regions given in Table 3. The mean average deviation for a single observation of R among the color standards is 0.018 ± 0.0056 (p.e.) mag. and the analogous value for $(R - I)$ is 0.014 ± 0.0038 mag. The average number of nights on which each color standard was observed is 4.5.

Figure 2 is a plot of $(V - R)$ versus $(R - I)$ for the same stars as in Figure 1. In effect, this diagram shows the correlation between the V magnitudes of Johnson and Morgan and our R magnitudes, and it may be seen that this correlation is again very high. The separation of the luminosity classes is weak, if present at all, probably partly

[7] Barnard's Star, $(B - V) = +1.74$ mag., $(R - I) = +1.23$ mag.; BD $-$ 4°4226, $(B - V) = +1.44$ mag., $(R - I) = +0.91$ mag.

[8] *Ap. J.*, **112**, 160, 1950; *Contr. Lick Obs.*, Ser. II, No. 30, 1950.

from the exclusion from this diagram of any magnitudes made in the blue spectral region and partly from the effect of the relatively small color bases.

Three variable stars were found among those on the program—C12 A, D10 M, and, surprisingly, κ Cet. C12 A is an A-type star that is slowly getting brighter at the rate of 0.03 mag. per year. D10 M probably is an M-type giant, and from the work of Stebbins and Huffer[9] one would expect it to vary. The amplitude is so large that D10 M is useless as a zero-point standard, but we retain it as useful for its color, which apparently remains practically constant. The star κ Cet is a G-type main-sequence star with known parallax

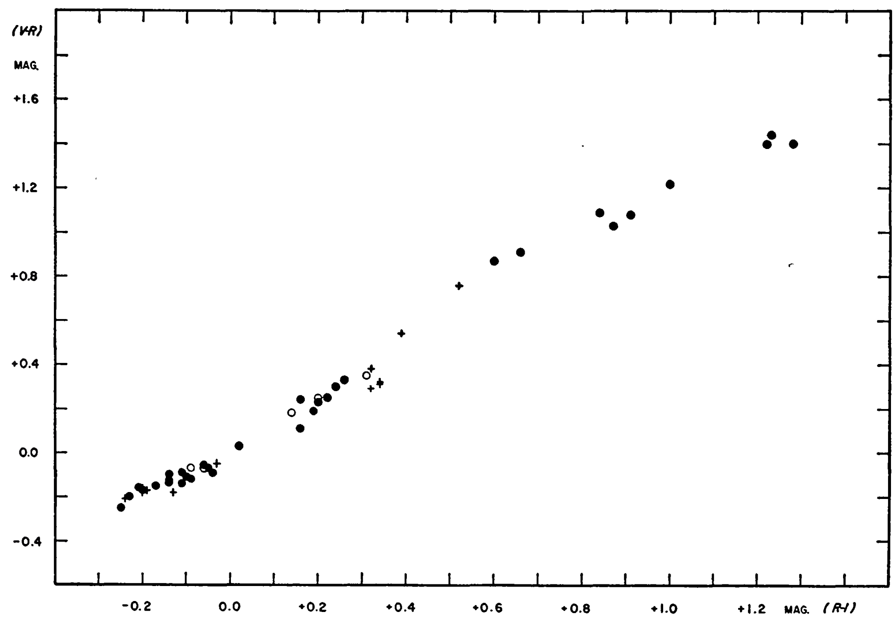

FIG. 2.—Relationship between ($V - R$) and ($R - I$). Coding of the plotted points is the same as for Fig. 1.

and no known or suspected peculiarities. The amplitude of variation is approximately 0.10 mag., as determined from two nights in 1950, four in 1951, and two in 1952. The color remains constant. The variation of this star makes it an interesting object, and it may be profitable to follow it.

We are indebted to J. Lynn Smith for help with the observations and to Joel Stebbins, Olin Eggen, and Harold Johnson for valuable discussion. A grant from the American Philosophical Society and funds from the University of California, which made possible the trip to the Southern Hemisphere,[10] are gratefully acknowledged.

[9] *Pub. Washington Obs.*, **15**, 139, 1930.

[10] Katherine Gordon Kron, *Pub. A.S.P.*, **64**, 165, 1952.