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Four-Color and Hβ Photometry of Open Clusters. I. The Hyades*

D. L. CRAWFORD AND C. L. PERRY
Kitt Peak National Observatory,† *Tucson, Arizona*

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Photoelectric photometry is presented for 132 member stars of the Hyades moving cluster. Five parameters are used, two color indices $(b-y)$ and $(u-b)$, a metallic-line strength index m_1, a Balmer discontinuity index c_1, and an Hβ absorption line strength index β. These indices are compared to similar parameters used by other observers. Standard relations between our indices are derived, valid for the Hyades stars. These are given in Table III and are shown in the figures. The position of the metallic-line stars in these relations is discussed in detail. Two weak-line stars are possible members and are deserving of further study.

I. INTRODUCTION

THE Hyades open cluster has long been the standard cluster against which other open clusters and field stars have been compared. It is an excellent choice for a standard cluster, because of several distinctive features, as follows:

First, it is the prime example of a moving cluster. Such clusters (and they are few in number) enable one to accurately determine individual absolute magnitudes by a study of the proper motions and radial velocities of the member stars. The Hyades moving cluster has been studied by many authors during the past 70 yr or more. Probably the most comprehensive study of recent years was that of Van Bueren (1952), who considered 132 stars as definite members of the cluster and a number of other stars as possible members. Van Bueren determined an accurate convergent point and space velocity for the cluster. He also gives references to much of the earlier work on this open cluster.

A more recent identification of cluster members based on new proper motions for a limited region of the sky containing most of the Hyades cluster has been made by Heckmann and Johnson (1956). They derived an accurate color–magnitude diagram, based on previous *UBV* photometry of Johnson and Knuckles (1955), and the proper motions of their own study.

Accurate individual absolute magnitudes derived in these studies enable one to use the observed Hyades main sequence as a starting point for absolute magnitude calibrations involving other clusters: the so-called "buildup" of cluster main sequences. A number of papers by Johnson (1954, 1957) are excellent examples of this type of work. Essentially all the cluster main sequence buildups have started with the zero point defined by the Hyades cluster.

A by-product of the nearness of the Hyades, a fact which makes it a moving cluster, is that the cluster members are reasonably bright and one can observe them to a considerable range down the main sequence—that is, to late-type main sequence stars.

Other authors have considered the Hyades to be the nucleus of a much more extended moving group of stars scattered over the sky. Eggen (1960, 1963a) has summarized these particulars in recent papers. He considers many stars throughout the sky as being extended members of this Hyades moving group. The Praesepe open cluster is also considered to be a member of this moving group, and it will be discussed in a later paper of this series.

A second feature of the Hyades cluster, which stamps it as a standard cluster against which others are compared, is that the spectra of its stars appear to have as strong metallic line blanketing as any observed in A- and F-type stars (Strömgren 1964; Abt 1963). Therefore, ultraviolet excesses and iron-to-hydrogen ratios generally have been determined relative to the Hyades stars.

As a result of the natural features of this cluster, a considerable body of literature has developed and very high weight data are available. In particular, excellent *UBV* photometry has been done by Johnson and Knuckles (1955), and extended by Johnson, Mitchell, and Iriarte (1962) to faint limiting magnitudes; also, very accurate MK spectral classifications are now available through the work of Morgan and Hiltner (1965). Observations in this paper are compared to this existing high-quality work.

A number of years ago Strömgren (1956a,b, 1958a,b, 1963), in a series of papers, reported development of a number of narrow and intermediate band photometric parameters that provide astrophysically meaningful indices of high accuracy and usefulness. They may be considered a natural extension of MK classification and *UBV* photometry. His papers considered indices giving a measure of the blanketing effect in stellar spectra, and indices that would correlate well with intrinsic color and with absolute magnitude. He showed that for A- and F-type stars accurate absolute magnitudes can be predicted, and that high-accuracy intrinsic colors could be derived. It was on the basis of this earlier work that the present four-color system (*uvby*) was developed, and it has been used extensively recently by Strömgren and by a number of observers at Kitt Peak. This system has been described in detail by Strömgren (1963) and by Crawford (1965), and we do not dwell on its features, *per se*, any further here.

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Recently, Strömgren and Perry (1965) have completed four-color photometry for most of the A- and F-type stars brighter than visual magnitude 6.5 in the northern hemisphere—the so-called "Strömgren–Perry Catalogue." A discussion of the data in this catalogue is now underway by Strömgren. Many of the data will be compared with the standard relations derived in this paper for the Hyades cluster. One point of interest is that few, if any, A- and F-type stars have stronger metallic-line strengths than the stars of the Hyades cluster. Preliminary observations in the Hyades cluster were discussed recently by Crawford and Strömgren (1965), who compared them with similar photometry for the Coma and Pleiades open clusters. These authors confirmed earlier work, by means of MK spectral classifications and *UBV* photometry, that the Coma

TABLE Ia. Hyades observations.

VB	Star	HR	HD	BD	Sp	M_v	VB	Star	HR	HD	BD	Sp	M_v
1			20430	7° 493	(F8)	4.2	74	79 Tau	1414	28355	12° 598	(A5)	2.1
6		1201	24357	16° 523	(dF1)	3.1	75			28363	15° 633	(F8)	3.5
8		1233	25102	9° 524	(dF3)	3.9	77			28394	17° 731	F7 V	4.0
10			25825	15° 582	(G0)	5.0	78			28406	17° 732	F6 V	4.0
11, 12		1279	26015	14° 657	F3 V	3.2	80	80 Tau	1422	28485	15° 636	(A6n)	2.5
13			26345	18° 594	(F8)	3.5	81			28483	19° 731	F6 V	3.8
14	45 Tau	1292	26462	5° 601	(dF4)	3.2	82		1427	28527	15° 637	A6 Vn	1.8
16			26737	22° 657	(F2)	3.4	83	81 Tau	1428	28546	15° 639	Am	2.5
19			26784	10° 551	(F5)	4.2	84	83 Tau	1430	28556	13° 690	F0 Vn	2.4
20	48 Tau	1319	26911	15° 603	F3 V	3.4	85			28568	15° 640	F5 V	3.9
24	51 Tau	1331	27176	21° 618	(dA8)	2.3	86			28608	10° 588	(F5)	4.2
29	55 Tau		27383	16° 579	F8 V	4.0	88			28635	13° 691	F9 V	4.8
30	57 Tau	1351	27397	13° 663	F0 V	2.6	89	85 Tau	1432	28677	15° 645	F2 Vn	3.0
31			27406	18° 623	G0 V	4.6	90		1436	28736	5° 674	(dF4)	3.6
32		1354	27429	18° 624	F2 V	3.1	94			28911	12° 608	F5 V	3.9
33	58 Tau	1356	27459	14° 682	A9 V	2.2	95	86 ρ Tau	1444	28910	14° 720	A8 Vn	1.7
34		1358	27483	13° 665	F6 V	3.2	98			···	27° 667		5.8
35			27524	20° 740	F5 V	3.6	100		1459	29169	23° 715	(dF2)	3.3
36			27534	18° 629	F6 V	3.6	101			29225	15° 656	F5 V	3.7
37			27561	14° 687	F4 V	3.7	102			29310	14° 728	G1 V	4.6
38	60 Tau	1368	27628	13° 668	Am	2.7	103	89 Tau	1472	29375	15° 661	F0 V	2.7
40			27691	14° 690	G0 V	3.9	104	90 Tau	1473	29388	12° 618	A6 Vn	1.3
44			27731	24° 654	(F5)	3.8	105			29419	22° 721	(F5)	5.0
45	63 Tau	1376	27749	16° 586	Am	2.6	107		1480	29499	7° 681	(A5 V)	2.2
47	64 Tau	1380	27819	17° 714	A7.5 V	1.8	108	92 σ^2 Tau	1479	29488	15° 666	A5 Vn	1.3
48			27808	21° 641	F7 V	4.2	111		1507	30034	10° 621	(dA6)	2.6
49			27835	16° 589	(G0)	4.8	112		1519	30210	11° 646	(Am)	1.8
50			27836	14° 693	G1 V	4.8	113			30311	8° 759	(F5)	4.4
51			27848	16° 591	F6 V	3.7	118			30589	15° 686	(F8)	4.5
52			27859	16° 592	G1 V	4.9	119			30676	16° 657	(F8)	4.3
53		1385	27901	18° 633	F4 Vn	3.0	121			30738	15° 692	(F8)	4.4
54	65 κ Tau	1387	27934	21° 642	A7 V	1.0	122			30810	10° 654	(F5)	4.2
55	67 Tau	1388	27946	21° 643	(A5n)	2.4	123	97 Tau	1547	30780	18° 743	(dA5)	1.9
56	68 Tau	1389	27962	17° 719	A3 V	1.3	124			30869	13° 728	(F5)	3.8
57	70 Tau	1391	27991	15° 621	F7 V	3.5	125			···	22° 769		5.6
59			28034	15° 624	F8 V	4.6	126		1566	31236	19° 811	(dF0)	2.8
60	69 υ Tau	1392	28024	22° 696	A8 Vn	1.2	128	101 Tau		31845	15° 713	(F5)	4.0
61			28069	4° 690	(F5)	4.3	129	102 ι Tau	1620	32301	21° 751	(A7 V)	1.3
62			28033	21° 644	F8 V	4.2	130	16 Ori	1672	33254	9° 743	(Am)	2.3
65			28205	15° 627	F8 V	4.4	131		1670	33204	27° 732	(Am)	2.8
66			28237	11° 614	(F8)	4.8	28	54 γ Tau	1346	27371	15° 612	K0 III	0.7
67		1403	28226	21° 647	Am	2.5	41	61 δ Tau	1373	27697	17° 712	K1 III	0.7
68	76 Tau	1408	28294	14° 702	F0 V	3.0	70	74 ϵ Tau	1409	28305	18° 640	K1 III	0.6
72	78 θ^2 Tau	1412	28319	15° 632	A7 IVn	0.4	71	77 θ^1 Tau	1411	28307	15° 631	G9 III	0.7

NOTES

Various Sources: SB1—Spectroscopic Binary, one spectrum.
SB2—two spectra.

VB	Note
1	ADS 2451
11, 12	ADS 2999; SB1?
29	ADS 3135
30	SB1
32	SB
33	SB1
34	SB2
38	SB1
40	ADS 3169; A component is SB1
45	SB1
47	SB
56	ADS 3286
57	Visual binary IDS 04199 N 1543
60	SB1
62	SB1
68	SB2
72	SB1

VB	Note
75	Variable radial velocity
77	SB1?
80	ADS 3264; A component is SB1
82	Variable radial velocity?
89	SB1?
95	SB2
98	Nonmember, or "subdwarf"
104	SB1
112	SB1?
122	ADS 3475
124	ADS 3483, SB1?
125	Nonmember, or "subdwarf"
131, 132	ADS 3730
28	SB1
71	SB1?
72	SB1

Table Ib.

VB	$b-y$	m_1	c_1	n	β	n	$u-b$	δc_1	δm_1
1	0.364	0.198	0.403	4	2.611	4	1.527	+.069	+.001
6	.221	.166	.610	22	2.712	16	1.384	+.007	+.012
8	.273	.170	.479	4	2.670	7	1.365	−.001	.000
10	.374	.209	.325	5	2.606	4	1.492	.000	−.002
11, 12	.261	.171	.539	4	2.693	4	1.403	+.034	−.001
13	.277	.169	.470	3	2.675	3	1.362	.000	.000
14	.231	.163	.592	17	2.694	6	1.380	+.015	+.012
16	.273	.170	.476	3	2.676	3	1.362	−.004	.000
19	.330	.184	.398	4	2.636	4	1.426	−.019	−.004
20	.259	.175	.524	6	2.690	6	1.392	+.015	−.005
24	.175	.186	.787	9	2.768	8	1.509	+.059	+.012
29	.352	.194	.371	4	2.621	3	1.463	+.023	−.004
30	.170	.198	.770	4	2.767	7	1.506	+.029	−.002
31	.357	.186	.367	3	2.623	3	1.453	+.025	+.008
32	.240	.171	.588	4	2.693	7	1.410	+.034	+.002
33	.126	.208	.868	4	2.812	7	1.526	+.030	−.002
34	.292	.177	.437	4	2.655	3	1.375	−.007	−.007
35	.286	.161	.464	3	2.655	5	1.358	+.009	+.009
36	.279	.173	.439	3	2.671	3	1.343	−.029	−.004
37	.267	.167	.482	3	2.674	3	1.350	−.010	+.003
38	.196	.204	.719	5	2.757	7	1.519	+.048	−.017
40	.362	.199	.359	3	2.626	4	1.481	−.023	−.002
44	.296	.180	.437	3	2.663	3	1.389	.000	−.009
45	.180	.237	.738	10	2.783	10	1.572	+.023	−.044
47	.081	.210	.981	8	2.857	7	1.563	+.057	+.003
48	.337	.179	.375	4	2.626	3	1.407	+.007	+.004
49	.369	.217	.345	5	2.610	4	1.517	+.016	−.015
50	.386	.200	.325	3	2.589	3	1.497	+.009	+.018
51	.294	.164	.458	4	2.659	5	1.374	+.017	+.006
52	.384	.204	.327	4	2.606	5	1.503	+.009	+.012
53	.242	.176	.600	4	2.705	8	1.436	+.051	−.003
54	.070	.200	1.054	11	2.864	10	1.594	+.112	+.014
55	.149	.193	.840	13	2.784	9	1.524	+.049	+.008
56	.021	.191	1.046	7	2.889	8	1.470	+.045	+.031
57	.314	.181	.390	4	2.644	4	1.380	−.015	−.007
59	.349	.187	.364	6	2.635	3	1.436	+.013	+.001
60	.165	.175	.947	3	2.753	8	1.627	+.193	+.022
61	.329	.174	.388	5	2.633	3	1.394	+.007	+.001
62	.338	.191	.388	4	2.628	3	1.446	+.021	−.008
65	.347	.176	.380	4	2.620	4	1.426	+.026	+.012
66	.356	.190	.355	3	2.621	3	1.447	+.012	+.003
67	.164	.213	.770	4	2.775	8	1.524	+.014	−.016
68	.206	.170	.701	4	2.747	7	1.453	+.058	+.013
72	.100	.202	1.013	47	2. 30	Std	1.617	+.123	+.008
74	.1 4	.225	.912	11	2.831	7	1.590	+.050	−.017
75	.342	.187	.381	4	2.636	3	1.439	+.020	−.002
77	.324	.171	.396	3	2.637	3	1.386	+.007	+.007
78	.298	.162	.435	3	2.656	3	1.355	+.001	+.009
80	.196	.197	.716	4	2.740	9	1.502	+.035	−.010
81	.307	.175	.411	3	2.654	3	1.375	−.008	−.003
82	.088	.217	.965	3	2.856	8	1.575	+.052	−.005
83	.142	.233	.795	4	2.809	11	1.545	−.011	−.030
84	.154	.201	.814	11	2.797	6	1.524	+.027	−.001
85	.281	.171	.468	5	2.680	4	1.372	+.149	−.002
86	.309	.174	.395	3	2.656	3	1.361	−.019	−.001
88	.342	.194	.366	3	2.635	3	1.438	+.005	−.009
89	.215	.175	.658	5	2.725	6	1.438	+.039	+.005
90	.271	.177	.483	4	2.670	7	1.379	−.001	−.007
94	.277	.170	.456	3	2.663	3	1.350	−.016	−.001
95	.144	.205	.823	8	2.797	12	1.521	+.021	−.003
98	.309	.129	.500	5	2.700	4	1.376	+.086	+.044
100	.244	.180	.570	3	2.709	7	1.418	+.026	−.008
101	.286	.176	.462	3	2.681	4	1.386	+.007	−.006
102	.384	.214	.331	5	2.605	3	1.527	+.013	+.002
103	.191	.188	.740	3	2.754	9	1.498	+.053	+.001
104	.067	.197	1.048	3	2.870	8	1.576	+.102	+.018
105	.345	.206	.359	3	2.612	3	1.461	+.002	−.020
107	.150	.222	.827	3	2.811	8	1.571	+.038	−.021
108	.088	.193	1.014	3	2.852	8	1.576	+.101	+.019
111	.149	.195	.814	4	2.791	6	1.502	+.023	+.006
112	.091	.253	.955	7	2.844	7	1.643	+.048	−.041
113	.360	.190	.350	4	2.619	3	1.450	+.012	+.006
118	.370	.194	.359	3	2.618	5	1.487	+.031	+.009

TABLE Ib (*continued*)

VB	$b-y$	m_1	c_1	n	β	n	$u-b$	δc_1	δm_1
119	.356	.195	.353	3	2.617	3	1.455	+.004	−.002
121	.328	.176	.389	3	2.642	3	1.397	+.007	+.003
122	.351	.180	.364	3	2.615	3	1.426	+.015	+.010
123	.122	.207	.900	5	2.813	10	1.558	+.054	.000
124	.324	.180	.444	5	2.648	3	1.452	+.055	−.002
125	.342	.142	.304	7	2.605	3	1.272	−.057	+.043
126	.178	.190	.739	3	2.739	7	1.475	+.019	+.004
128	.288	.174	.436	4	2.655	3	1.360	−.016	−.004
129	.079	.204	1.030	23	2.847	11	1.596	+.102	+.009
130	.138	.245	.840	13	2.820	7	1.606	+.026	−.042
131	.149	.245	.803	3	2.796	8	1.591	+.012	−.044
28	.596	.428	.388	30					
41	.599	.433	.405	5					
70	.612	.447	.422	5					
71	.581	.384	.387	12					

cluster has an ultraviolet excess relative to the Hyades and hence its stars are weaker in metals than the Hyades ones. The metallic-line index used by Crawford and Strömgren is essentially independent of the stars' luminosity; this is not the case for the ultraviolet excesses determined on the *UBV* system.

In this paper, we attempt to derive standard relations valid for the Hyades cluster, against which observations on other clusters and field stars may be compared in detail, particularly with respect to evolutionary effects, metallic line strength, and so forth.

II. OBSERVATIONS

Table I lists those stars that have been observed on the present program. Column 1 gives the identification number as taken from van Bueren (1952), and the next four columns give the star's name, its number in the *Bright Star Catalogue* (Hoffleit 1964) and the HD and BD number. Column 6 gives the spectral type as recently published by Morgan and Hiltner (1965); for those stars not classified by Morgan, the spectral type is taken from the *Bright Star Catalogue* and it is given in parenthesis. The next column gives the value of the absolute magnitude as determined by Heckmann and Johnson (1956). For stars not in their list, we have computed M_V with the same convergent point and mean space motion that they used and with the V magnitude of Johnson and Knuckles (1955).

The four-color system (*uvby*) has been described in some detail by Strömgren (1963) and by Crawford (1965). The observations given in this paper were obtained with the original set of four-color filters, and the observing was done with the 36- and 16-in. telescopes of the Kitt Peak National Observatory. Mean extinction coefficients were used in the reductions, except for a few nights where the use of individual coefficients was deemed necessary. The mean values used are: $0^m.068$ for $(b-y)$, $0^m.058$ for m_1, and $0^m.187$ for c_1. Night corrections were obtained for each night by means of observations of standard stars. Table I lists the derived indices; they are on the standard system. The columns give $(b-y)$, m_1, c_1, $[m_1=(v-b)-(b-y)$, $c_1=(u-v)-(v-b)]$, and the number of observations obtained for each star. The mean error of a single observation, as determined from the internal scatter, is $\pm 0^m.009$ in $(b-y)$, $\pm 0^m.013$ in m_1, and $\pm 0^m.013$ in c_1 (mean errors are used throughout this paper). Strömgren and Perry (1965) have observed a number of the same Hyades stars, and the agreement of our values with those in their catalogue is good. The average difference in $(b-y)$, m_1, and c_1 is $-0^m.001$, $+0^m.004$, $-0^m.004$, respectively. Their values were therefore averaged with ours; the weighted mean is given in the table. The table also includes at the end the four-color measures for the four red giant stars that are cluster members.

Figure 1 shows the relation between the observed $(b-y)$ values and the $(B-V)$ values taken from Johnson's photometry. Table II gives the smoothed $(b-y)$ versus $(B-V)$ relation. If one omits the residuals for stars VB 98, VB 105, and VB 125, the rms scatter about the mean relation, in $(B-V)$, is $\pm 0^m.008$. VB 98 and VB 125 are weak-line stars and are discussed later. This small scatter shows that $(b-y)$ can be

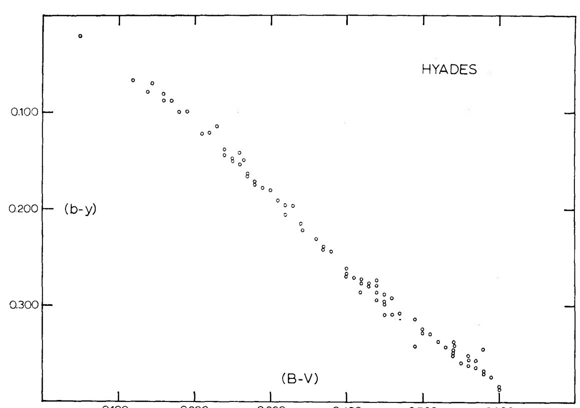

FIG. 1. The relation between the $(B-V)$ values of the *UBV* system and the $(b-y)$ values of this paper.

TABLE II. The $(b-y)$ versus $(B-V)$ relation for the Hyades stars.

$(b-y)$	$(B-V)$	$(b-y)$	$(B-V)$
0.02	0.050	0.22	0.346
.04	.085	.24	.373
.06	.119	.26	.400
.08	.152	.28	.428
.10	.184	.30	.460
.12	.213	.32	.494
.14	.241	.34	.530
.16	.268	.36	.566
.18	.294	.38	.602
0.20	0.320	0.40	0.674

accurately transformed to the $(B-V)$ values of the UBV system for stars of the same chemical composition.

Figure 2 shows the relation between $(B-G)$ values of the six-color photometry (Breckinridge 1965) and observed $(b-y)$ values. Again, a smooth transformation curve would fit the data quite well.

Figure 3 shows the relation between values of the Balmer discontinuity index D observed by Berger (1962) and the observed values of c_1. Deviations from the line given by the equation $D=-0.101+0.562c_1$ yield an rms scatter of ± 0.020 in D. c_1 is, of course, an excellent measure of the discontinuity. In Fig. 4, c_1 is plotted versus an index C formed from the six-color photometry in a similar manner to that by which c_1 is defined $(C=U+B-2V)$. Again, a rather smooth relation exists. Two stars, each with only one six-color measure, deviate from the mean relation. Figure 5 shows the relation between m_1 and an index M formed in a manner similar to the way in which m_1 is formed on the four-color system $(M=V+G-2B)$. There is no apparent correlation between the two indices, perhaps because of the wide bandwidths of the V filter.

The four-color indices were compared to indices derived by Golay (1964) from his seven-color photometry. The $(b-y)$ correlates well with (B_2-G), c_1 rather well with Δ, and m_1 poorly with g. Metallic-line stars deviate in the c_1 versus Δ relation.

The Hβ system used at Kitt Peak has been described in detail by Crawford (1960). The system has now undergone a slight revision due to a change of filters (Crawford and Mander 1966), and has been extended to stars of spectral types A and F. The values of β given in this paper are on the revised system. The number of observations per star as observed for the Hyades is large enough so that these stars may be used as secondary standards for Hβ photometry. Table I gives the observed β values and the number of observations per star. The mean error of a single observation of β is $\pm 0^{m}.012$.

In the next column in Table I are listed values of $(u-b)$ on the four-color system. These values were computed from the observed indices by the equation $(u-b)=c_1+2(b-y)+2m_1$. The remaining columns are discussed in the next section.

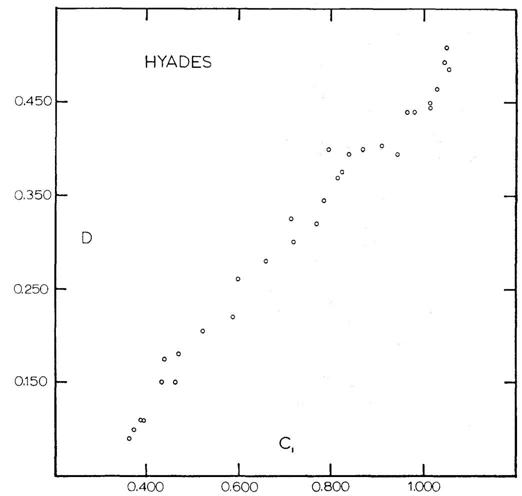

FIG. 3. The relation between the Balmer discontinuity values D of Berger (1962) and the c_1 values of this paper.

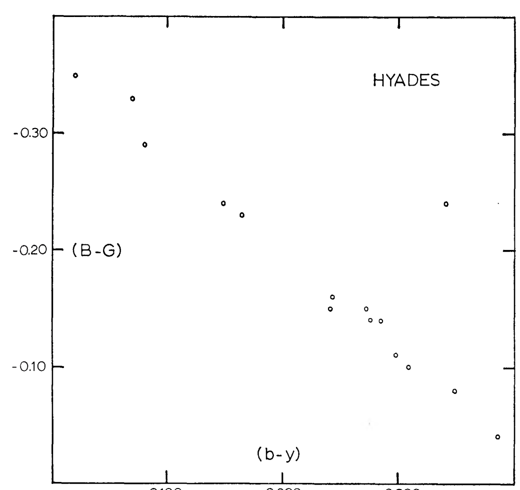

FIG. 2. The relation between the $(B-G)$ values of six-color photometry and the $(b-y)$ values of this paper.

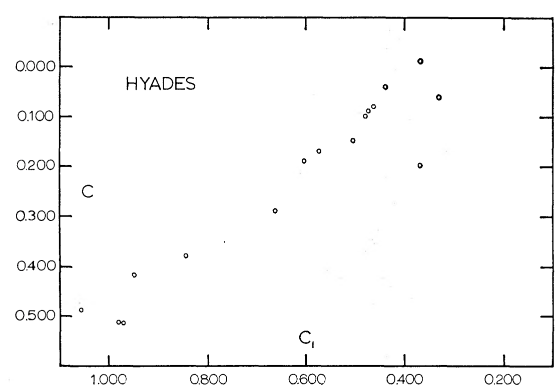

FIG. 4. The relation between $C=U+B-2V$, formed from six-color photometry, and the c_1 values of this paper.

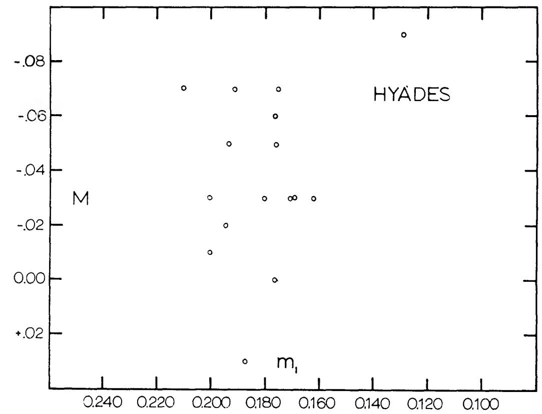

FIG. 5. The relation between $M=V+G-2B$, formed from the six-color photometry, and the m_1 values of this paper.

III. STANDARD RELATIONS FOR THE HYADES

It is our purpose in this paper to define for the Hyades cluster a number of standard relations which may be used as the standard of comparison for other clusters to determine differences relative to the Hyades main sequence.

Figure 6 shows the relation between $(b-y)$ and the recent MK spectral classes of Morgan and Hiltner (1965). The diagram is almost identical to Fig. 2 of their paper. This similarity exists, of course, because of the very close correlation between $(b-y)$ and $(B-V)$. Data for the metallic-line stars and the four red giants are not plotted in the diagram. The point for VB 72, the single luminosity class IV star, is shown in the diagram as an open circle. It appears in a similar place on the diagram of Morgan and Hiltner. As with the case of $(B-V)$, the correlation of $(b-y)$ with MK spectral type is very good.

The relation between the Balmer discontinuity index c_1 and the color index $(b-y)$ for the Hyades stars is shown in Fig. 7. The correlation between the two indices is remarkably good. VB 60, which is 69 v Tauri, has a large c_1 index compared to other cluster stars of the same color, and it is an apparently evolved star lying above the main sequence in a color–magnitude diagram. It is interesting to note that the points for the two weak-line stars, VB 98 and VB 125, lie on different sides of the mean relation for the Hyades. The two other F-type stars whose points lie above the mean relation are VB 124 and VB 1. Both of these stars are known double stars. The smooth relation between c_1 and $(b-y)$ is shown in Table III. The rms scatter in c_1 about the smooth relation, omitting the four stars noted above, is $\pm 0\overset{m}{.}017$.

Strömgren (1963) has shown that evolving stars lie above and to the right of a zero-age line in such a diagram; the zone-age line derived by him is drawn in as a solid line in Fig. 7. It is interesting to see that the Hyades stars bluer than $(b-y)=0.27$ lie consistently above the zero-age main sequence line. The deviation is largest, of course, for the bluest stars. At about $(b-y)=0.27$, the lower envelope of the Hyades stars is identical to the zero-age main sequence. The fact that the Hyades stars redder than $(b-y)=0.30$ lie consistently above the zero-age line is undoubtedly significant. Crawford and Strömgren (1965) have tentatively interpreted this deviation as an effect of the hydrogen-to-helium abundance being somewhat different in the Hyades stars than in normal stars of the solar neighborhood.

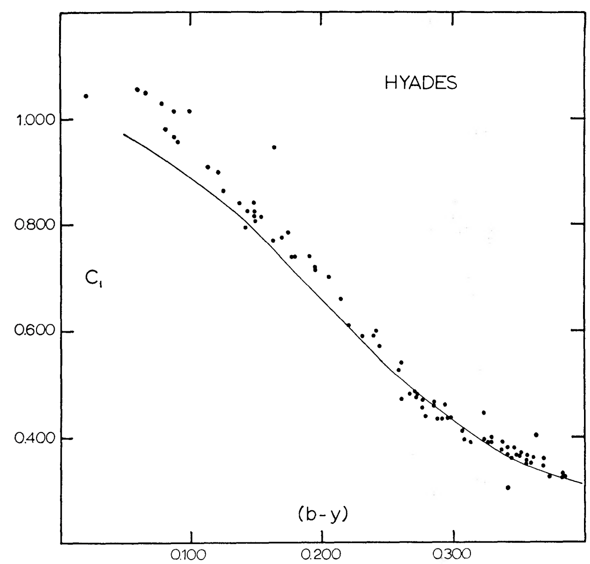

FIG. 7. The relation between c_1 and $(b-y)$ for the Hyades stars. The line gives the zero-age main sequence (Strömgren 1963).

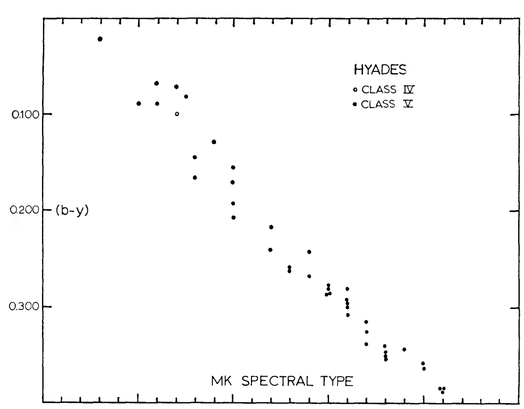

FIG. 6. The relation between $(b-y)$ and the MK spectral types of Morgan and Hiltner (1965).

The relation between the metallic line index m_1 and the color index $(b-y)$ is shown in Fig. 8. It is important to note that the index $(b-y)$ is essentially free of blanketing effects, unlike $(B-V)$. The metallic-line stars are shown as open circles in this diagram. The smoothed relation between these indices for the Hyades stars, omitting the Am stars and VB 98 and

VB 125, is given in Table III. Strömgren (1963) had previously derived such a Hyades relation from earlier preliminary observations on the cluster. His relation agrees well with the present one.

All the known metallic-line stars have points lying below the average line. Strömgren has defined $\delta m_1 = m_1$ (Hyades)$-m_1$ (observed) as giving the departure from the Hyades relation he derived. We use δm_1 in this paper to denote the deviation from the new relation given in Table III. The average δm_1 for the Am stars is $-0\overset{m}{.}034$. The individual values range from $-0\overset{m}{.}018$ to $-0\overset{m}{.}049$. Two stars whose indices lie in this region (δm_1 of $-0\overset{m}{.}018$ to $-0\overset{m}{.}021$) are not known as metallic-line stars; they are VB 74 and VB 107. They have indices that suggest that they are similar to metallic-line stars. Spectra (120 Å/mm) have been taken of these stars with the 36-in. telescope at Kitt Peak, and visual inspection confirmed the stronger metallic-line character of their spectra with respect to stars located on the average line. That is, the metallic-line strengths of the stars are intermediate between the "normal" metallic-line stars of the type that have been called metallic line by Morgan, and the normal A-type main sequence stars. Morgan (1965) classifies as Am stars only those stars that are extreme in metallic-line strength for a given spectral type. As such, Fig. 8 shows that what Morgan sees by careful visual inspection of spectral plates can easily be detected by the four-color photometry. Other classifiers (e.g., Bidelman 1965)

TABLE III. Hyades standard relations.

$b-y$	m_1	c_1	β	$(u-b)$	MK	$(B-V)$
0.08	0.207	1.020	2.856		A6	0.152
.09	.208	0.991	2.847	1.588	A6	.168
.10	.208	.962	2.838	1.578	A7	.184
.11	.207	.933	2.829	1.568	A7	.199
.12	.206	.904	2.820	1.557	A7	.213
.13	.205	.875	2.811	1.546	A8	.227
.14	.203	.847	2.802	1.535	A8	.241
.15	.201	.821	2.792	1.524	A9	.255
.16	.197	.796	2.782	1.512	A9	.268
.17	.192	.771	2.771	1.500	A9	.281
.18	.188	.746	2.759	1.488	F0	.294
.19	.184	.721	2.748	1.475	F0	.307
.20	.181	.696	2.738	1.462	F0	.320
.21	.178	.669	2.728	1.448	F1	.333
.22	.176	.640	2.718	1.433	F2	.346
.23	.174	.609	2.709	1.418	F2	.359
.24	.172	.576	2.700	1.404	F2	.373
.25	.171	.542	2.692	1.391	F3	.386
.26	.170	.513	2.684	1.378	F4	.400
.27	.170	.488	2.676	1.366	F4	.414
.28	.170	.466	2.668	1.364	F5	.428
.29	.171	.447	2.661	1.366	F5	.444
.30	.173	.430	2.654	1.372	F6	.460
.31	.175	.415	2.648	1.380	F6	.477
.32	.177	.401	2.642	1.398	F7	.494
.33	.181	.388	2.636	1.412	F7	.512
.34	.186	.376	2.630	1.428	F8	.530
.35	.191	.365	2.624	1.446	F9	.548
.36	.196	.354	2.618	1.467	F9	.566
.37	.201	.344	2.612	1.490	G0	.584
.38	.206	.334	2.606	1.514	G1	.602
0.39	0.211	0.324	2.600	1.539		0.638

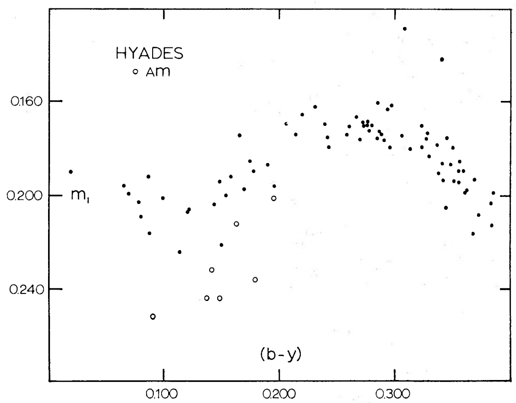

FIG. 8. The relation between m_1 and $(b-y)$ for the Hyades stars. The open circles are known metallic-line stars.

call Am stars those whose metallic-line strengths can be detected as greater than average for stars of the same spectral type. With this criterion, VB 74 and 107 would be called Am stars. In future work with the four-color system, we will call stars of this type "fringe" metallic-line stars

The point for VB 60, which is the somewhat evolved star 69 υ Tauri, lies high in this diagram ($\delta m_1 = +0.020$). If the parameter of interest across the average line is rotational velocity, as suggested by Strömgren (1963), then this star would be a rapid rotator. Kraft (1965) has shown that it is, with $V \sin i = 215$ km/sec.

The two weak-line stars, VB 98 and 125, are obvious from their large values of δm_1 (0.046 and 0.045). Spectra were also obtained of these two stars with the 36-in. telescope, and visual inspection confirms their weak-line character. These stars were not observed by Olin Wilson (1965) in his observations of the possible subdwarfs in the Hyades cluster, as their spectral types were both listed as being earlier than G0; his program was limited to stars of spectral type G and K.

Stars with color indices larger than $(b-y)=0.20$ do not appear to be influenced by the effects giving rise to the large scatter in m_1 in the metallic-line regions. The scatter for these later-type stars in the Hyades is of interest then, for presumably they all have nearly the same metal abundances. Omitting VB 98 and 125, we find that the rms scatter about the mean relation is $\pm 0\overset{m}{.}0069$. This, therefore, is the upper limit, in the Hyades, allowable for "cosmic scatter."

Strömgren (1963) has used the c_1 versus $(b-y)$ diagram to derive absolute magnitudes for field stars that are unreddened. An index δc_1, defined as the difference between the observed c_1 value and the value of c_1 for the same color on the zero-age line, is related to the difference in the absolute magnitude between the observed star and the absolute magnitude for a star of the same color on the zero-age main sequence. The predicted accuracy was estimated to be about $\pm 0\overset{m}{.}2$. However, this technique will not work for stars that are reddened, and we must appeal to another

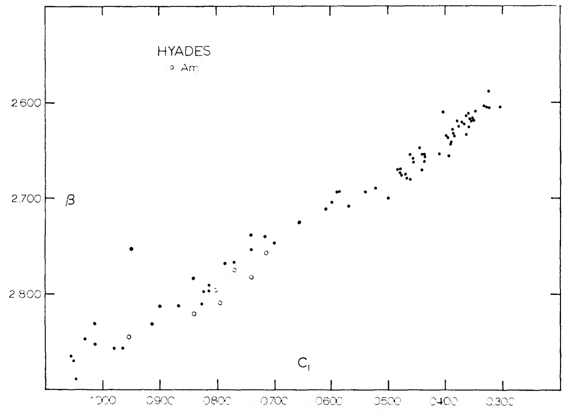

FIG. 9. The relation between β and c_1 for the Hyades stars.

parameter. For A- and F-type stars, the parameter β can be used for this purpose, and a β versus c_1 diagram will enable one to predict the intrinsic color of the star to a high accuracy. Thus, the technique of deriving a δc_1 for a given $(b-y)$ will yield accurate absolute magnitudes. The β versus c_1 diagram for the Hyades stars is shown in Fig. 9. Again, VB 60 deviates from the average values for the Hyades stars, and, hence, it would also differ significantly from the zero-age relation for a β versus c_1 relationship. The luminosity class IV star, VB 72, has the next largest deviation from the average line.

For main sequence stars of spectral type A and F, the color index may be determined solely as a function of the Hβ strength (the index β). Figure 10 shows that the relation between the two indices is essentially linear over the entire range of color observed. Hence one may predict $(b-y)$ from β for most stars, and may ignore any influence of the parameter δc_1. The two largest deviating points in this diagram belong to VB 98 and 125. Again, these two stars deviate in opposite senses. The scatter around the mean β versus $(b-y)$ relation in this diagram is $\pm 0^{m}_{.}0086$ (VB 98 and 125

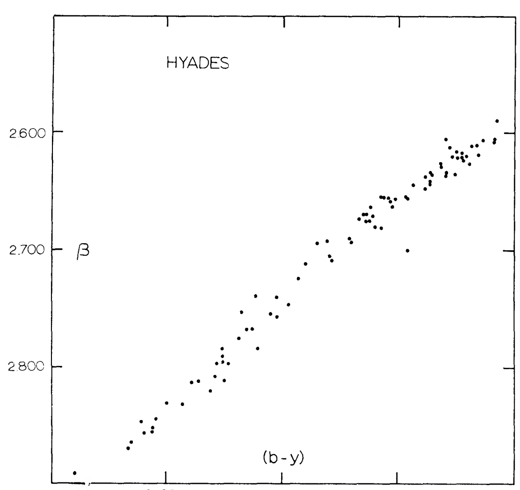

FIG. 10. The relation between β and $(b-y)$ for the Hyades stars.

are omitted). Table III includes the smoothed β versus $(b-y)$ relation

A color index $(u-b)$ on the four-color system may be used in a similar way as the $(U-B)$ color index of the UBV system. The $(u-b)$ values are given in Table I and plotted versus $(b-y)$ in Fig. 11. This diagram looks rather similar to the $(U-B)$ versus $(B-V)$ diagrams of the UBV system, and can be used in a similar way (Wildey, Burbidge, Sandage, and Burbidge 1962) to derive a $\delta(u-b)$ related to differences in chemical composition. (Atmospheric turbulence may also play a role.) This type of argument, either in the *uvby* or UBV system, will be valid only for stars of the same absolute magnitude, that is, for stars which are unevolved. We have derived a smoothed relation between $(u-b)$ and $(b-y)$ for the unevolved Hyades stars, so as to compare the unevolved main sequences of other clusters with this standard relation. Table III includes the relation between $(u-b)$ and $(b-y)$ for the Hyades stars; it is of special interest for those stars whose color index $(b-y)$ is greater than $0^{m}_{.}30$. In

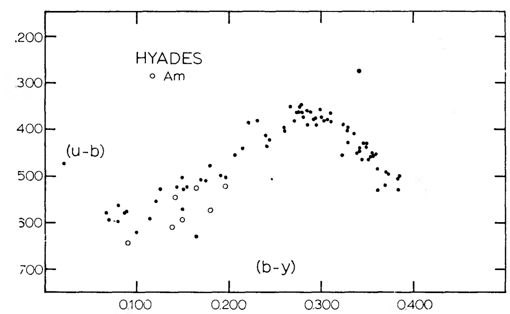

FIG. 11. The relation between $(u-b)$, of the four-color system and $(b-y)$ for the Hyades stars.

Fig. 11 it is interesting to note that the weak line star, VB 98, does not deviate from the average Hyades relation. The other weak line star, VB 125, does deviate in the sense expected; it shows an ultraviolet excess. VB 98 also shows no excess in a $(U-B)$ versus $(B-V)$ diagram.

The color–magnitude diagram plotted from the material given in Table I is shown in Fig. 12. The crosses are the stars noted as visual binaries or spectroscopic binaries. The open circles are the metallic-line stars. Most of the stars lying above the apparent main sequence are seen to be double stars; the width of the scatter above the main sequence can be explained in terms of this duplicity effect. The two stars that do not fit this picture are VB 60 and 72. While both these stars are doubles, they are probably single-line binaries and would not be seen at the observed positions due only to duplicity. They are probably both located at their position in this diagram primarily because they are evolved more than the other cluster stars. VB 72 is the luminosity class IV star, and VB 60 has poor lines and is a "rapid" rotator ($V \sin i = 215$ km/sec).

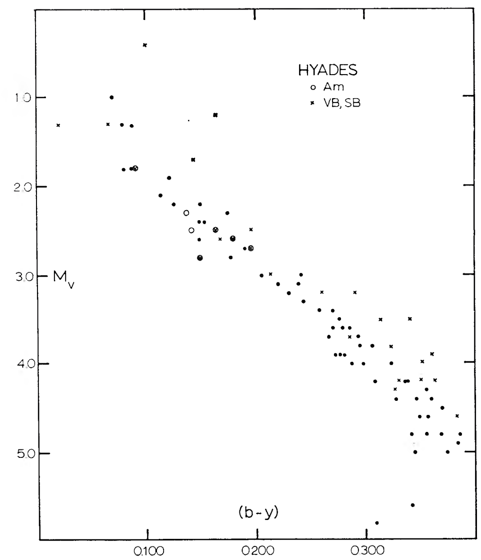

FIG. 12. The color-magnitude for the Hyades stars. The absolute magnitudes are from Table I and are discussed in the text. Known metallic-line stars, visual binaries, and spectroscopic binaries are indicated.

If the two weak-line stars VB 98 and 125 are cluster members, they have absolute magnitudes which place them below the main sequence. If they are weak-line stars mocking membership in the moving cluster, and if they actually have absolute magnitudes equivalent to main sequence stars, then they must be background objects of reasonably high velocity. With the data available at present, it is not possible to decide decisively between these two alternatives. However, if we take an average velocity, appropriate to a star with δm_1 of about $0^m.045$, of 100 km/sec (Strömgren 1964), then, relative to Hyades stars of the same color, VB 98 and VB 125 should have ΔV's of $2^m.0$. VB 98 does, but VB 125 has only about half this value. Remember that VB 98 has no ultraviolet excess. Divan (1957) has discussed these two stars on the basis of λ_1, D, Φ_b photometry. She shows that they are not analogous to subdwarfs of Population II. The δm_1 values agree with this fact, for subdwarfs have δm_1 much larger than these two stars do. However, they are weak lined compared to the other Hyades stars. The D value for VB 98 falls on the mean line in Fig. 3, but the value for VB 125 lies above the curve; this confirms the ultraviolet excess mentioned above. These two stars are deserving of further study.

As a check on the absolute magnitude calibration published by Strömgren, we have computed absolute magnitudes for the Hyades stars with his calibration and the δc_1 values given in Table I. A comparison of these with the absolute magnitudes given in Table I gives an average difference of $+0^m.07$ (Hyades too faint), and an rms scatter (one star) in the difference of $\pm 0^m.21$. Two stars have larger negative residuals than might be expected. They are VB 72 and VB 95; both are doubles, and the deviation is in the sense expected. There are doubles (for example, VB 60) that do not deviate by as much as might be expected.

It is interesting to note in Fig. 12 that the metallic-line stars fall within the main sequence band of the color–magnitude diagram. On the *UBV* system, metallic-line and peculiar A stars generally are located somewhat above the ordinary main sequence of cluster stars. The fact that the color index $(b-y)$ is reasonably unaffected by blanketing makes a natural correction for the blanketing in these stars, and therefore they do not deviate from normal main sequence stars. In other words, their absolute magnitude is normal for their $(b-y)$ color index.

Kraft (1965) has recently discussed the rotational velocities of the stars of the Hyades cluster. He finds that the rotational velocities are essentially the same as for field stars of the same color. He notes that VB 60 and 95, which lie above the observed main sequence in the color–magnitude diagram, both have poor lines and rather large rotational velocities. VB 60 is a single-line spectroscopic binary, and VB 95 is also a binary. He also notes that VB 126 is probably a member star at a greater distance than the average member. We confirm this conclusion, because the absolute magnitude calculated for it either from the Strömgren calibration or from the proper motions and radial velocity places it on the main sequence. Its apparent magnitude is such that it would be a star farther from the sun than the average cluster member. Kraft also calls attention to VB 56, the bluest observed star in the cluster. He notes that Conti (1965) considers this star to be a possible metallic-line star, due to the weakness of scandium lines in the spectrum. However, δm_1 is normal for its color, and Kraft points out that the scanner results of Baschek and Oke (1965) show that no blanketing correction can be allowed for this star. This star has been noted by Babcock (1958) as having a magnetic field, and he states that the spectrum appears intermediate between a peculiar and a metallic-line type. Its color index which is bluer than the "turnoff point" on the Hyades main sequence is still in need of detailed explanation.

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Colors of Stars in the Nucleus of Messier 53*

JAMES CUFFEY
Goethe Link Observatory, Indiana University, Bloomington, Indiana
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The stars in the nucleus of Messier 53, ordinarily not measurable because of interfering background light from unresolved stars, were investigated on plates of very short exposure, between 10 and 30 sec, with the 100-in. reflector. Measures of magnitudes and colors reveal 64 yellow to red giants ordinarily overlooked because of background light, which populate rather uniformly a triangular area above and to the left of the cluster's red giant branch. They show a strong concentration to the nucleus of the cluster and appear to be nearly 100 times more frequent in space there than in the outer regions of the cluster.

ORDINARILY, photographs of globular clusters, exposed to reach faint stars, show an unresolved nucleus in which individual images are too close together to be measured without the interference of background light from myriads of fainter stars. To see whether the brighter stars in the nucleus of M53 could be measured satisfactorily, I made a series of very short exposures with the 100-in. reflector at the Mt. Wilson Observatory and found that with exposures between 10 and 30 sec the background light in the nucleus produced no perceptible fog density on the plates, and that 64 ordinarily unseen stars appeared with images suitable for measurement with the iris photometer. Most of the images were conspicuous enough relative to the fog level so that the background fog contributed at most a relatively small uncertainty in the measurements. Figure 1 contrasts an ordinary 20 min exposure with a 10 sec exposure used in the present series of measures.

Of the short-exposure plates, the six best V plates (103 aD with GG 11 filter), and the six best B plates (103 aO with WG 2 filter) were selected and measured in the iris photometer. For the reductions from iris reading to magnitude, photoelectric and photographic standard stars from a previous study (Cuffey 1958) were used. Table I and the chart in Fig. 2 summarize the results and supplement the data of a previous paper (Cuffey 1965). The B and V magnitudes and the $B-V$ colors are listed, and the F_B and F_V values which indicate the fluctuations of the individual values and may serve to indicate tendency to vary, although in the present series they are mainly a description of the errors and of the difficulty of measurement for some of the images. The values of F_B and F_V are, as before, the average deviations of the individual measures from the mean. The chart in Fig. 2 identifies the stars in Table I using sector, ring, and star number. It supplements without duplication the designation system of a previous paper (Cuffey 1965).

RESULTS

The color–magnitude relation for the bright stars in the nucleus of M53, Fig. 3, displays yellow to red giants exclusively, which populate rather uniformly a triangular area above and to the left of the usual globular cluster red giant branch. Forming a unique group with an unusual distribution in the color–magnitude relation, they also show a remarkably high degree of concentration to the center of the cluster which merits evaluation. In the corresponding region of the color–magnitude relation, a previous investigation (Cuffey 1965) found only seven stars

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