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THREE-COLOR PHOTOMETRY IN THE GLOBULAR CLUSTER M3*

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ABSTRACT

New three-color photometric data are presented for about 225 stars in the globular cluster M3. These stars permit conversion of the older m_{pg}, m_{pv} magnitude in M3 to the well-defined B, V system. A new color-magnitude diagram in V and $B-V$ is given. An ultraviolet excess exists for the giant, subgiant, and main-sequence stars. This excess ranges from about $\Delta(U-B) = 0.20$ mag. for the giants at $B-V = 1.0$ to $\Delta(U-B) = 0.55$ mag. for main-sequence stars at $B-V = 0.6$. As in M13, the M3 stars along the blue-end horizontal branch appear to have an ultraviolet deficiency which may be due to the effect of low surface gravity on the Balmer jump. The difference in the energy distributions for the M3 stars compared with the nearby stars makes any identification of sequences dubious at this time.

I. INTRODUCTION

A photometric study in three colors of about 225 stars in M3 is reported. The present work is an extension and revision of the earlier two-color study of this cluster (Sandage 1953), hereafter referred to as "Paper I." A combination of photoelectric and photographic techniques was used. Photoelectric observations in U, B, and V of 35 standard stars were made with the 82-inch telescope at the McDonald Observatory. These standards range from $V = 9.9$ to $V = 21.9$ and embrace the entire magnitude interval covered by the older photographic material. New photographic plates were obtained in three colors with the 100-inch Hooker telescope and the 200-inch Hale telescope at the Mount Wilson and Palomar Observatories. These new data are used to convert the m_{pg} and m_{pv} values of Paper I to the B, V system. Furthermore, the new observations give the $U-B$ versus $B-V$ relation for the cluster stars from $M_v = -3$ to $M_v = +5$.

II. THE PHOTOELECTRIC OBSERVATIONS

The three-color photoelectric observations were all made with the 82-inch telescope of the McDonald Observatory during March and April, 1954, and February, 1956. The 1954 observations were made with the same filters and 1P21 that were used to establish the U, B, V system (Johnson and Morgan 1953; Johnson 1955). The 1956 observations were made with the same filters, but the photomultiplier was an extremely sensitive, nineteen-stage tube made for the Lowell Observatory by Dr. A. Lallemand, of the Paris Observatory. In both seasons an integrator-type D.C. amplifier (Gardiner and Johnson 1955) was used; however, this amplifier was torn down, rebuilt, and recalibrated between the two observing seasons, and we may consider that two distinct amplifiers (of the same type) were used.

The photoelectric observations are listed in Table 1. The designation system is that of Paper I, with the exception of the faintest stars, F-1 to F-12. These additional stars are identified in Figure 1. The estimated probable errors in magnitude range from $\pm 0.010(V)$, $\pm 0.010(B-V)$, and $\pm 0.020(U-B)$ for the brightest stars, to $\pm 0.08(V)$, $\pm 0.11(B-V)$, and $\pm 0.14(U-B)$ for the stars between $V = 20$ and $V = 21.5$.

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Because of the relatively short time of exposure ($1\frac{1}{2}$ hours) on the faintest star, its probable errors are $\pm 0.2(V)$ and $\pm 0.3(B - V)$. All the stars brighter than $V = 18$ and about half of those between $V = 18$ and $V = 20.5$ were observed in 1954 with the 1P21. The rest of the faint stars were observed in 1956 with the Lallemand tube. There is sufficient overlap between the two seasons, during which different photomultipliers and amplifiers were used, to establish the equality of the two scales. This may be regarded as confirmation of the linearity of both the amplifiers and the photomultipliers, since it does not seem likely that all would be in error by the same amount in the same direction. The 1P21 was used with a multiplication of about 1.4×10^6, while the Lallemand tube was used at a multiplication of about 1×10^7.

TABLE 1

PHOTOELECTRIC STANDARDS

Star	V	$B-V$	$U-B$	Star	V	$B-V$	$U-B$
206. ..	9 86	+1 15	+1 04 Std.	I-II-4......	15.86	+0.08	−0.03
1397..... .	12 65	+1 56	+1 63	I-IV-18...	15.95	− .01	− .02
1402... ..	12 66	+0 63	+0 08 Std.				
I-III-28....	12.81	+1.37	+1 26	I-II-9......	16.74	+ .71	+ .05
297.....	12 87	+1.44	+1.42	a	16 86	+ .75	− .01
				I-VI-4... .	17.00	+ .71	+ .07
216..	14 05	+1 00	+0 68	F-1.......	17.75	+ .70	− .04
I-II-18 .	14.09	+0 94	+0 49	F-2	18 38	+ .60	− .12
237	14 09	+0 65	+0 10				
193 .	14 76	+0 90	+0 35	F-3.......	18 39	+ .71	+ .20
I-II-57... .	14 93	−0 27	−1 11	F-4*.... ..	18 46	+ .48	− .22
				F-5	18 99	+ .41	− .27
180	15 23	+1 11	+1.03	F-6	19.18	+ .44	− .35
I-III-9... .	15 58	+0.51	−0.03	F-7........	19.76	+ .56	− 31
I-II-6.	15 61	+0 08	+0 14				
I-II-11....	15 68	+0 42	−0.03	F-8	20.09	+ 36	− .44
I-VI-14 .	15 68	+0 72	+0 20	F-9.	20.11	+ .58	− .16
				F-10. .. .	20.44	+ .63	−0.34
182. ...	15 69	+0 09	+0 10	F-11	21.32	+ .74	....
I-VI-18	15 70	+0 16	+0 05	F-12.......	21.9	+0.5	....
235	15.76	+0.08	+0.13				

* Star F-4 is double. Measures refer to combined light.

Laboratory checks on the linearity have also been made, and no significant deviations from linearity have been found. These tests were made with light-intensities covering the range corresponding to $V = 10$ to $V = 22$ with the 82-inch telescope.

The sensitivity of the 1P21 that was used in 1954 is such that, with the yellow filter on a star of visual magnitude $V = 21.40$ in the 82-inch, the photoemission from the cathode is about 3×10^{-19} amp. Under the same conditions the photoemission from the Lallemand tube is about 7×10^{-19} amp. Since a current of 1 electron/sec corresponds to 1.60×10^{-19} amp, the first two rows in Table 2 follow immediately. The third row contains data computed from Table II of Baum's (1954) study of M13. In his table Baum gives the average number of counts at $V = 21.40$ as 390/100 sec. The data in Table 2 are only approximate, but they show clearly that the photometer used at the 82-inch in 1956 is sufficiently more sensitive than Baum's photometer to make up the difference in the light-gathering powers of the two telescopes.

All observations on all stars, including the standard stars, were made with a focal-plane diaphragm 7″ in diameter. This size diaphragm is large enough to minimize the systematic corrections for seeing that Baum (1954) found to be necessary; furthermore

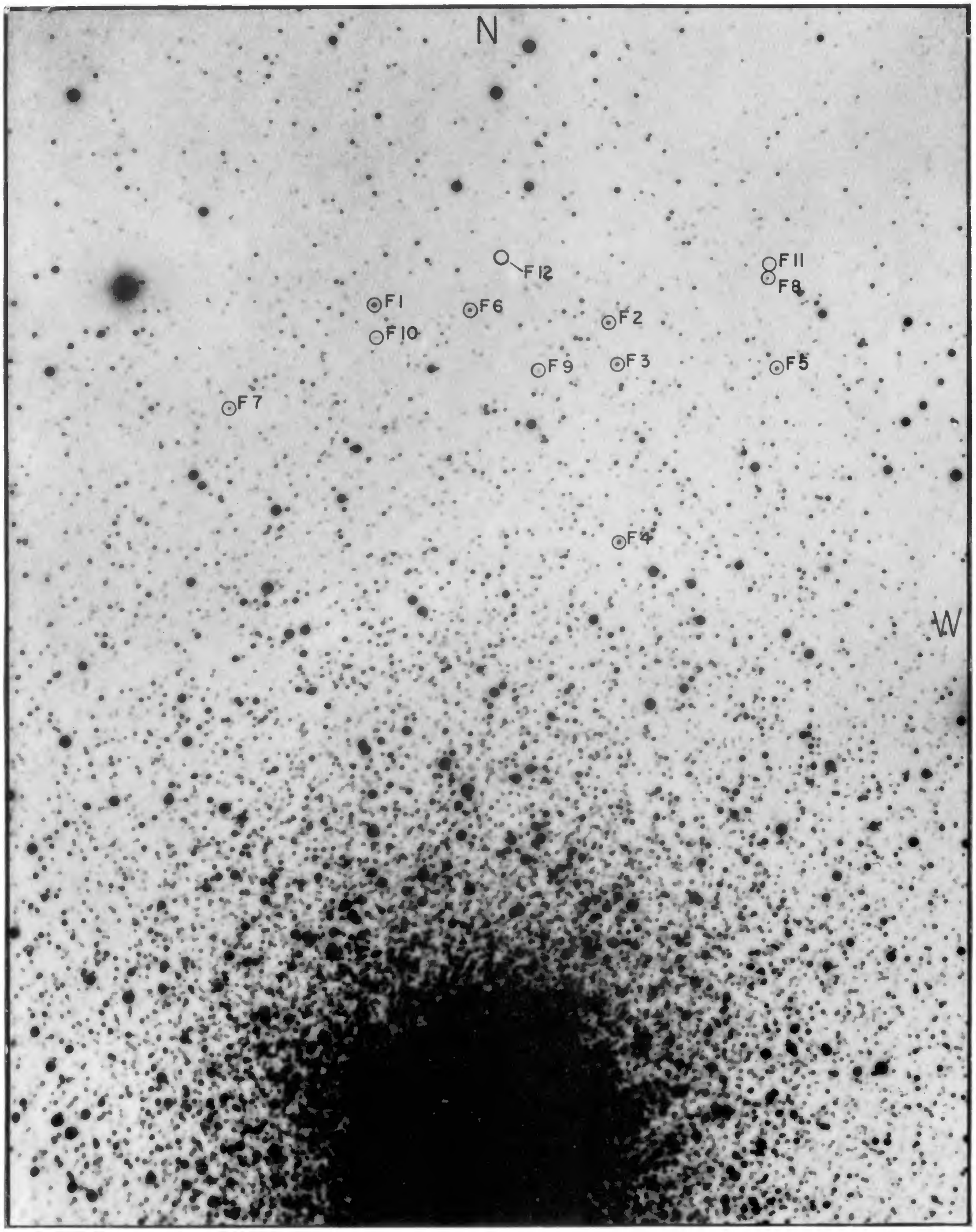

FIG. 1.—Identification chart for the 12 faint standard stars of Table 1. The remaining photoelectric standards were identified on charts in Paper I.

since the standard stars were observed with the *same diaphragm* at intervals of 1–1½ hours, all remaining systematic errors should cancel out.

A rough measurement of the scattered light at various distances from a bright star indicates that, at a distance of 6′ from the center of the cluster (nearly the outer limit of the photographic photometry for the color-magnitude diagram), systematic errors at $V = 21.4$ of as much as 0.3 mag. in V and 0.1–0.3 mag. in $B - V$ and $U - B$ may be made. This error would be made if, because of crowding by other stars, the comparison-sky position would have to be taken along the radius vector from the cluster center. This scattered-light problem can be avoided by taking the sky measurement on a line perpendicular to the radius vector from the cluster center, but this restriction so severely limited our choice of faint stars for photoelectric standards that all the faint stars were located about 12′ north of the cluster and the magnitude scale was transferred inward by special photographic plates. All sky measures were taken at right angles to the direction of the cluster center, and sometimes two sky measures, one on each side of the star, were taken.

Stars fainter than $V = 16.5$ were found by means of offsets measured from 100- and 200-inch plates. The 100-inch plates, taken at the Newtonian focus, were used directly

TABLE 2

ELECTRON COUNTS AT $V = 21.40$ (YELLOW FILTER)

Tube	Telescope	Electrons per Second
1P21-Y	82-inch	1 9
Pierette V (Lallemand)	82-inch	4 4
EMI (Baum)	200-inch	3 9

(except for a scale change) for the 82-inch Cassegrain offsets. The 200-inch plate was taken with the Ross corrector, and a correction for the field distortion produced by this lens has been applied. After this correction has been made, the computed offsets for the stars present on plates taken with both telescopes are in very satisfactory agreement. The two faintest stars that were measured with the 82-inch telescope are too faint to be photographed with the 100-inch, and they could not have been measured if the 200-inch plate had not been available.

III. THE PHOTOGRAPHIC OBSERVATIONS

Plates in three colors were taken with the 100-inch telescope diaphragmed to 58 inches. These plates were centered on the cluster and were used for stars brighter than $V = 17.0$. The plate and filter combinations were: ultraviolet, Eastman 103*a*-O + 2-mm Schott UG2; blue, Eastman 103*a*-O + 2-mm Schott GG13; yellow, Eastman 103*a*-D + 2-mm Schott GG11. These combinations are known to give negligible color equations to the U, B, V system (Johnson and Sandage 1955; Johnson, Sandage, and Wahlquist 1956). For stars fainter than $V = 17.0$, plates were obtained with the 200-inch telescope. These were centered midway between the faint standards and the stars of series III, sector II, which are identified in Paper I. Negligible distance corrections were encountered for plates centered in this way. One ultraviolet plate was obtained with the 200-inch with the Ross corrector lens removed (since the ultraviolet transmission of the $f/3.67$ lens is very small) and with the mirror diaphragmed to 120 inches. A second faint ultraviolet plate, exposed for 90 minutes in good seeing, was obtained with the 100-inch diaphragmed to 58 inches.

About 200 stars were chosen for measurement from the photometric catalogue of Paper I. They were picked to cover adequately the interval from $V = 12.7$ to $V = 20.8$, so that conversion curves from the m_{pg}, m_{pv} system to the B, V system would be well determined.

Six plates in each of the three colors were measured for stars brighter than $V = 17.0$. Two plates in each of the three colors were used for stars fainter than this limit. The resulting colors and magnitudes are given in Table 3, where the identifying notation is that of Paper I. The internal probable errors are of the order of ± 0.02 for the final magnitudes and ± 0.03 for the colors for stars brighter than $V = 17$, and about twice these values for stars fainter than this limit.

Data for the photoelectric standards, read back through the calibration-curves, are also given in Table 3. Comparison of these data with those of Table 1 gives the color and magnitude equations for the remaining data. Figures 2 and 3 show these comparisons. The sense of the plotted differences is photoelectric *minus* photographic. The residuals are all satisfactorily small and show no systematic trend with either V or $B - V$. We conclude that all data of Table 3 are on the U, B, V system to within the errors of the determination.

Table 3 compared with Tables II and VI of Paper I gives the conversion functions relating m_{pg} and m_{pv} to B and V. These are shown in Figure 4. The visual magnitudes of Paper I are nearly on the V system for stars brighter than $V = 17.0$. For stars fainter than this, a systematic error exists in m_{pv} which reaches 0.40 mag. at $m_{pv} = 21.2$. The fact that the divergence begins with stars as bright as $V = 17.0$ and continues to faint magnitudes probably means that the two faintest photoelectric standards of Paper I, which are stars c and d (Baum 1952; Sandage 1953) are too faint compared with the present system and that the extrapolation of the scale used in Paper I beyond $m_{pv} = 19.0$ continued the error to the photographic limit. The same systematic difference exists in $B - m_{pg}$, and this circumstance leaves the color difference between CI and $B - V$ nearly constant over the entire range. The mean difference in the color systems of about 0.12 mag. is primarily a result of the change in zero point of $B - V$ compared with the International system (Johnson and Morgan 1953; Johnson 1955). The effect of these magnitude corrections on the luminosity function (Sandage 1954) will be discussed in a separate paper.

IV. THE COLOR-MAGNITUDE DIAGRAM

All magnitudes in Paper I have been converted to B and V by the relations of Figure 4, and the resulting color-magnitude diagram is shown in Figure 5. The diagram is very similar to that previously given, but several changes in detail should be noted. (1) The bluest stars on the extension of the horizontal branch now reach only to $B - V = -0.40$ instead of to $CI = -0.80$. This large change is, of course, a result of the cutoff of the blue filter at 3800 A, which is characteristic of the U, B, V system. (2) The color boundaries of the variable-star domain are well defined at $B - V = +0.17$ and $B - V = +0.39$. (3) The change in the slope of the subgiant branch from $V = 16$ to $V = 18$ is evident. In the diagram of Paper I, this sequence was nearly vertical, whereas Figure 5 shows a slight blueward slope for faint magnitudes.

The apparent visual magnitude of the RR Lyrae domain is $V = 15.67$. This is the apparent modulus of M3 on the assumption that $\bar{M}_v = 0.00$ for the RR Lyrae stars. The break point from the main sequence occurs at about $V = 19.0$, which corresponds to $M_v = +3.3$. This is about 0.2 mag. brighter than was given by the old diagram. The difference is a result of the corrections to the magnitudes shown in Figure 4. The age of the stars in M3, computed in the manner of Paper I, becomes about 20 per cent smaller. However, it has become increasingly clear that stellar models of a more detailed nature than those of Schönberg and Chandrasekhar (1942) are needed before a precise age can be obtained for the globular-cluster stars. Recent models by Hoyle and Schwarzschild (1955) and by Hoyle and Hazelgrove (1956) are a step in this direction. The new data of Figure 5, together with Hoyle and Hazelgrove's models, give an age of about 6×10^9

TABLE 3

MAGNITUDES OF SELECTED STARS IN M3 DETERMINED PHOTOGRAPHICALLY

Star	V	B-V	U-B
STANDARDS OF TABLE 1			
1397	12 70	+1 69	+1 57
I-III-28	12 79	+1 37	+1 28
297	12 87	+1 46	+1 37
216	14 04	+1 00	+0 58
I-II-18	14 15	+0 89	+0 45
237	14 13	+0 59	+0.14
193	14 76	+0 88	+0 28
I-II-57	15 06	-0 40	-1 10
180	15 10	+1 22	+1 04
I-III-9	15 62	+0 47	-0 08
I-II-6	15 59	+0 08	+0 11
I-II-11	15 69	+0 42	-0 05
I-VI-14	15 57	+0 82	+0 21
182	15 71	+0 11	+0 08
I-VI-18	15 70	+0 16	+0 11
235	15 67	+0 17	+0 12
I-II-4	15 95	+0 01	0 00
I-IV-18	15 92	+0 05	+0 01
I-II-9	16 80	+0 72	+0 02
a	16 79	+0 82	+0 05
I-VI-4	16 90	+0 82	-0 01
F 1	17 74	+0 69	-0 02
F 2	18 43	+0 60	-0 16
F 3	18 37	+0 81	0 00
F 4	18 47	+0 43	-0 20
F 5	18 93	+0 44	-0 24
F 6	19 07	+0 44	-0 19
F 7	19 80	+0 57	-0 36
F 8	19 92	+0 52	-0 35
F 9	20 30	+0 69	-0 41
F 10	20 56	+0 59	-0 47
F 11	21 27	+0 74	-
A J , 58, 61, 1953 Table II			
B	13 56	+0 67	+0 25
D	15 08	+0 86	+0 25
E	16 37	+0 83	+0 13
G	16 12	+0 85	+0 14
H	14 91	+0 90	+0 29
L	15 15	+0 83	+0 22
M	16 00	+0 81	+0 23
N	16 87	+0 70	-0 09
O	16 75	+0 71	-0 09
P	16 29	+0 87	+0 08
R	16 70	+0 64	-0 12
S	14 11	+0 95	+0 69
T	14 62	+0 77	+0 29
U	13 53	+1 11	+0 90
V	14 87	+0 70	+0 19
W	15 62	+0 88	+0 63
X	16 81	+0 80	+0 02
Y	16 34	+0 88	+0 01
Z	15 77	+0 02	+0 14
AA	12 69	1 57	1 56
AB	16 40	+0 80	+0 11
AC	14 82	+0 87	+0 36
AE	13 85	+0 98	+0 61
AF	15 66	+0 12	+0 13
AG	15 78	+0 91	+0 04
AH	13 74	+1 08	+0 90
AI	16 06	+0 80	+0 16
AJ	16 26	+0 77	+0 14
AM	15 02	+0 51	-0 03
AN	15 97	-0 05	+0 06
AO	14 70	+0 72	+0 30
AQ	15 68	+0 48	-0 06
AR	15 63	+0 37	+0 01
AT	15 60	+0 75	+0 15
AU	15 79	+0 76	+0 10
AV	14 01	+1 04	+0 63
AW	14 80	+0 76	+0 16
AX	15 57	+0 13	+0 11
AZ	15 92	+0 77	+0 21
BB	14 73	+0 82	+0 34
BC	13 84	+1 05	+0 79
BF	13 62	+1 16	+0 75
BG	14 24	+0 92	+0 47
BH	14 63	+0 78	+0 23
BI	14 11	+1 03	+0 58
A J , 58, 61, 1953. Tab II (Cont'd)			
BJ	15 47	+0 83	+0 17
BK	16 85	+0.78	+0.15
BL	15 42	+0 88	+0 20
155	14 51	+0 98	+0 48
167	15 12	+0 84	+0 17
179	14 76	+0 62	+0 06
1331	15 23	+0 87	+0 16
SERIES I			
I, 2	15.47	+0 89	+0 17
21	13 05	+1 37	+1 10
30	15 79	0 00	+0 04
34	14 65	+0 91	+0 36
36	16 03	+0 80	+0 16
39	14 44	+0 91	+0 37
46	13 82	+1 06	+0 74
55	15 54	+0 54	-0 07
58	17 08	-0 23	-0 59
65	15 50	+0 54	-0 05
71	15 42	+0 54	0 00
72	14 59	+0 87	+0 48
77	15 56	+0 43	-0 01
78	15 23	+0 53	+0 10
80	15 35	+0 48	+0 08
91	15.60	+0 18	+0 11
97	15 77	+0 05	+0 06
103	15 53	+0 14	+0 11
II, 1	15 98	+0 57	-0 14
2	16 64	+0 75	+0 09
3	15 23	+0 89	+0.10
5	16 01	+0 77	+0 09
7	15 48	+0 84	+0 16
8	15 73	+0 14	+0 07
12	15 57	+0 71	+0 19
13	15 72	+0 08	+0 13
15	15 62	+0 45	-0 05
22	16 48	+0 82	+0 12
24	17 04	+0 72	-0 06
26	16 84	+0 75	-0 03
28	16 54	+0 74	+0 09
32	15 86	+0 81	+0 22
34	17 00	+0 67	+0 06
35	16 31	+0 72	+0 12
39	16 66	+0 80	+0 02
40	16 98	+0 62	+0.06
42	14 78	+0 63	+0.31
43	15 76	+0 66	+0 20
45	15 61	+0 15	+0 10
47	15 59	+0 47	+0 04
48	16 87	+0 71	+0 05
50	16 88	+0 70	+0.01
52	16 77	+0 65	-0 01
53	15 68	+0 40	+0.03
54	15 13	+0 75	+0 23
56	17 00	+0 76	+0 04
58	16 66	+0 69	+0 04
63	15.72	+0 08	+0 12
III, 6	15 69	+0 12	+0 13
8	15 40	+0 84	+0 19
10	15 93	+0.79	+0.09
12	15 73	+0 08	+0.15
15	15 18	+0 80	+0 21
19	15 46	+0 46	-0 04
32	15 40	+0 59	+0 01
33	14.40	+0 90	+0.56
43	15.48	+0 55	+0 03
51	15 56	+0 43	-0 01
56	14.68	+0.67	+0 27
57	16 65	-0.15	-0 37
71	14 93	+0 77	+0.36
72	15 47	+0 18	+0 10
74	14 94	+0.57	+0 13
77	13 30	+1 15	+1 16
87	17 60	-0 38	-1.04
IV, 7	15.51	+0.62	0 00
25	13 60	+1 13	+0 87
IV, 27	13 99	+1 00	+0 75
29	15.54	+0 56	0.00
33	15 67	+0 44	-0 02
50	15 58	+0 45	-0 01
56	15 65	+0.15	+0 12
82	13 46	+1 23	+1 26
86	15 62	+0 18	+0.12
92	15 62	+0 18	+0 10
98	15 61	+0 43	+0 01
101	13.26	+1 30	+1.19
V, 41	13.79	+0 88	+0 55
75	15 66	+0 12	+0 12
VI,54	17 39	-0 21	-0 68
74	15 40	+0 16	+0 11
85	15 43	+0.12	+0 14
SERIES II			
II, 10	17 88	+0 72	-0 10
12	18 56	+0 46	-0 20
58	17 90	+0 20	+0 05
III, 23	17 73	+0 49	-0 14
25	16 97	+0 70	+0 07
26	17 45	+0 71	-0 07
27	18 40	+0 60	-0 11
33	17 78	+0 61	-0 11
SERIES III			
II, 4	20 30	+0 62	-
5	19 51	+0 51	-0 42
8	20.30	+0 61	-0.28
10	20 09	+0 64	-0 75
11	19 63	+0 61	-0 40
15	20 13	+0 72	-
18	18 24	+0.20	-0 01
19	19 37	+0 56	-0 27
21	20 59	+0 81	-
22	20 53	+0 77	-
23	20 74	+0 73	-
24	20 58	+0 74	-
25	19 50	+0 56	-0.40
31	20 46	+0 62	-
32	19 54	+0 46	-
35	19 31	+0 51	-0 28
90	18 76	+0 43	-0 15
92	18 77	+0 41	-0 22
93	19 81	+0 62	-0 43
95	19 86	+0.57	-
100	18 77	+0 82	-0 14
108	17 28	+0 64	-0 04
113	19 50	+0 48	-0 31
122	20.47	+0 58	-
126	17 13	+0 72	-0 03
127	20 12	+0 85	-
141	20 00	+0 61	-0 40
143	20 68	+0 63	-
154	19 30	+0 44	-
155	18 92	+0 37	-0 16
164	18 97	+0 40	-0.21
167	18 49	+0 45	-0 18
181	17 95	+0 74	-0 12
195	18.82	+0 40	-0 26
199	18 90	+0.41	-0.23
217	18.22	+0.92	-
230	18 65	+0 43	-0 27
232	18.77	+0 43	-0 09
239	18.89	+0 43	-0.31
251	19.13	+0 39	-0.26
254	19 37	+0 39	-0 32
258	18.70	+0 40	-0 23
267	20 20	+0.65	-0.35
275	18 84	+0 42	-0.29
299	18.03	+0 62	-0 03
306	17 32	+0.69	-0 08
325	17.82	+0 69	-0 12
332	19.27	+0 38	-
344	18.82	+0 39	-0.36

years for the M3 stars (Hoyle 1956). This is probably the best available estimate at the present time.

Mean points obtained from the data of Figure 5 are given in Table 4. Here n is the number of stars used in forming the means. The mean points, together with the photoelectric data of Table 1, are plotted in Figure 6. Shown also is the relation of the M3 diagram to the main sequence of unevolved stars as defined by the faint members of the Hyades and Pleiades clusters. The geometrical modulus for the Hyades of 3.03 given by van Bueren (1952) is adopted, and the M3 modulus is assumed to be $m - M = 15.67$. The main sequence of M3 is very close to the initial sequence as defined by the Hyades

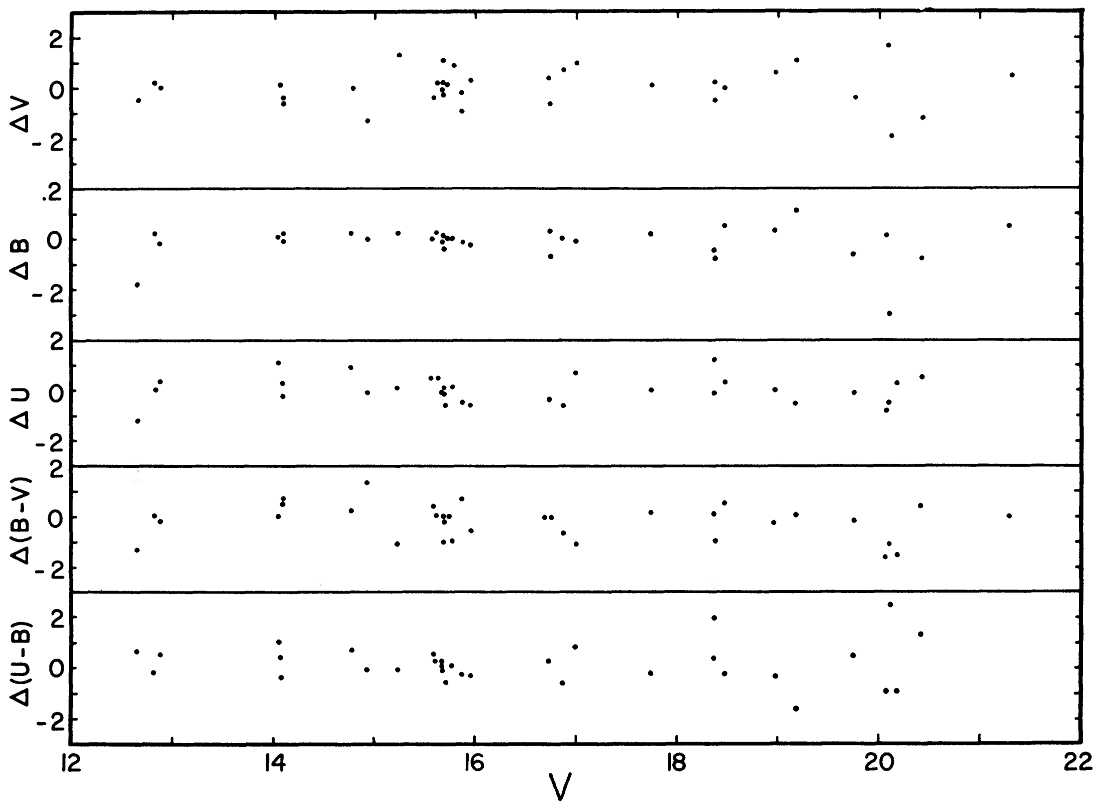

FIG. 2.—The residuals for the standard stars in the sense photoelectric *minus* photographic data. Data are from Tables 1 and 3. These relations define the magnitude equations.

and the Pleiades. However, the discussion of the two-color diagram in the next section shows that the stars in M3 are fundamentally different in their energy-distribution-curves from stars in the solar neighborhood; hence the comparison shown in Figure 6 may have only formal significance. At the present stage it seems highly dubious to fit globular-cluster main sequences to any known sequence of the nearby stars in order to determine an absolute magnitude for the RR Lyrae stars, as has been suggested (Baade 1948). It also seems premature to compare the present M3 diagram with those of other globular clusters until additional and independent photometry is completed on M13, M92, and other clusters.

V. THE TWO-COLOR DIAGRAM

The data of Tables 1 and 3 give the $U - B$ versus $B - V$ relation for the M3 stars. Mean points have been computed from the data of Table 3 for stars lying on the giant,

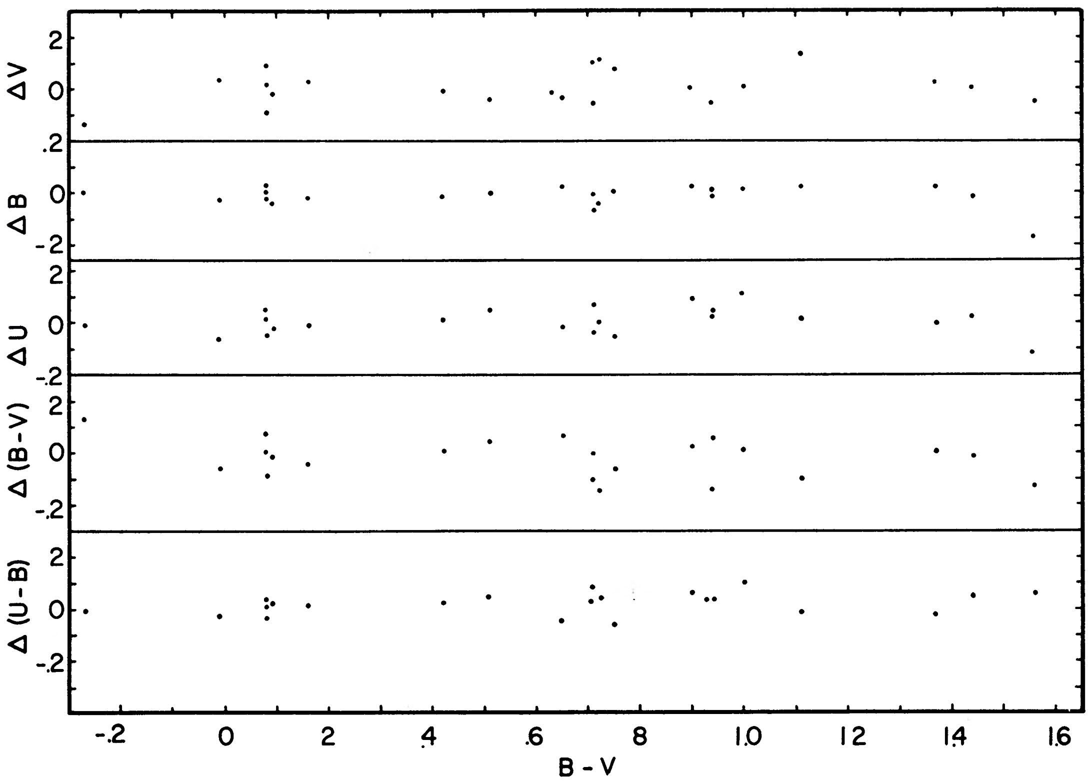

FIG. 3.—Same as Fig. 2 plotted against $B - V$. These relations define the color equations

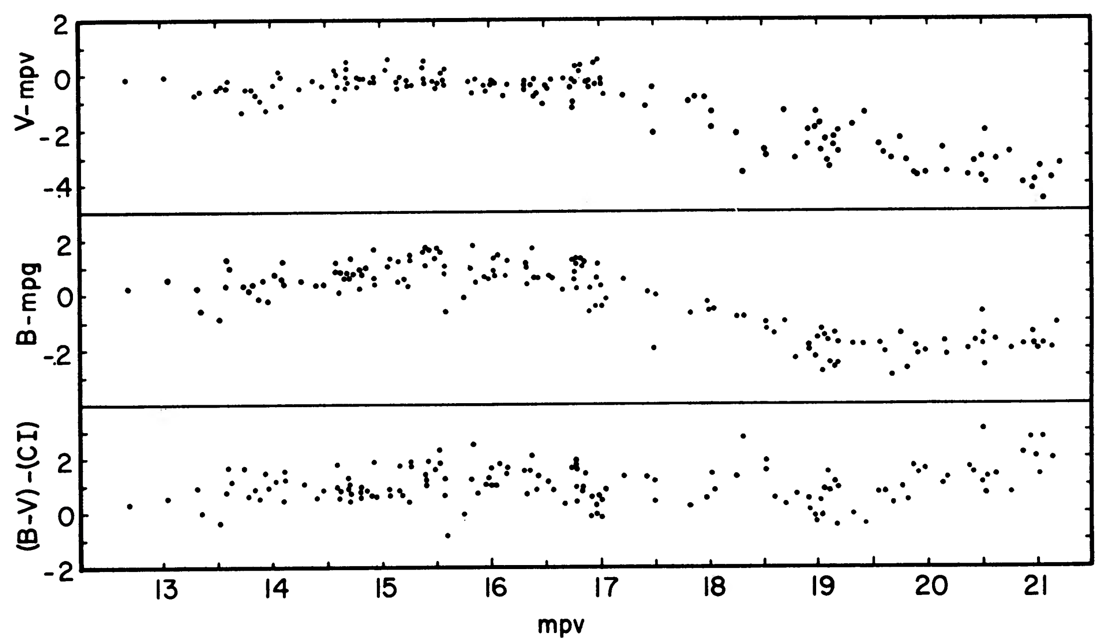

FIG. 4.—Magnitude and color correction-curves to convert m_{pg}, m_{pv}, and CI from Paper I to B, V, and $B - V$.

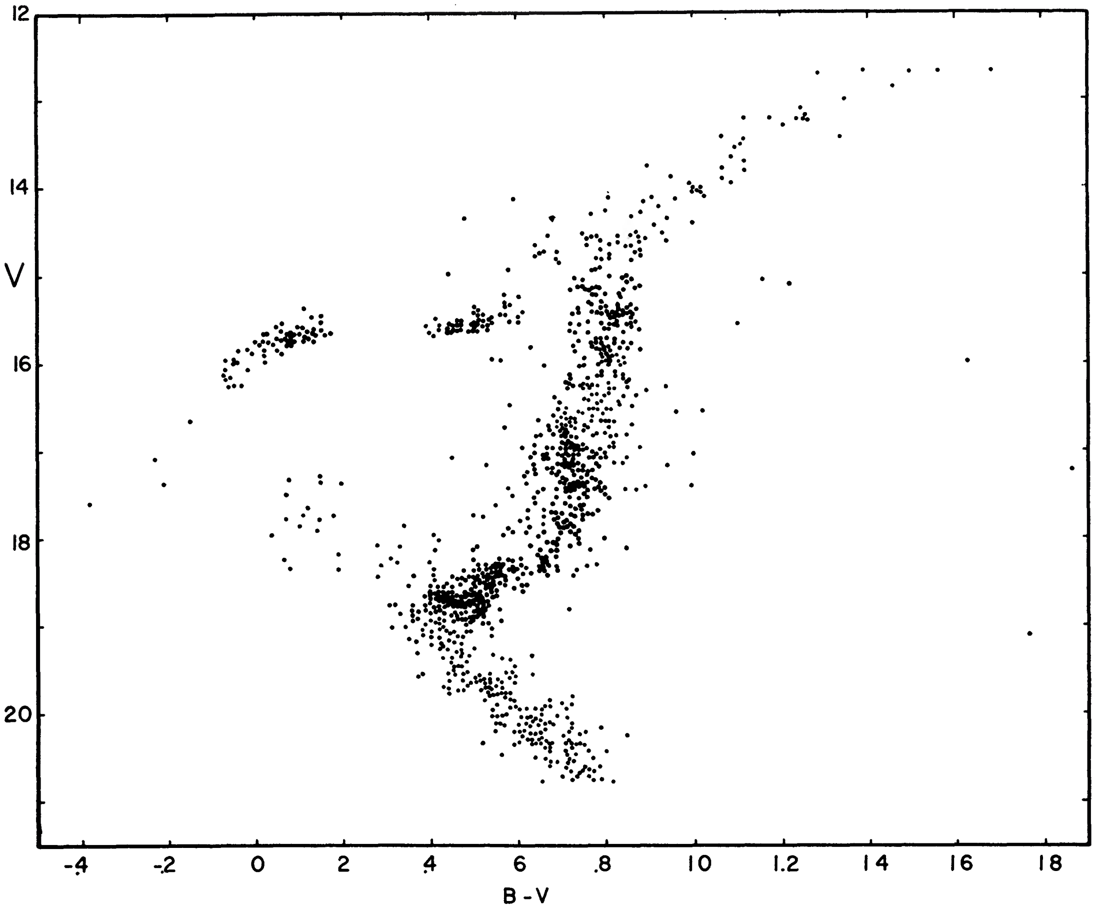

FIG. 5.—Color-magnitude diagram for M3 stars in the arguments V and $B - V$

TABLE 4

MEAN COLOR-MAGNITUDE DIAGRAM FOR M3

GIANTS AND HORIZONTAL-BRANCH STARS			SUBGIANTS AND MAIN SEQUENCE		
V	$B-V$	n	V	$B-V$	n
12 68	+1 70	1	15 29	0 80	54
12 70	+1 60	1	15 77	80	58
12 75	+1 50	1	16 26	77	51
12 90	+1 40	3	16 77	74	86
13 10	+1 30	5	17 24	72	91
13 32	+1 20	5	17 75	70	59
13 75	+1 07	8	18 32	60	84
14 25	+0 95	14	18 75	47	142
14 75	+0 86	18	18 95	42	
15 50	+0 55	27	19 24	45	46
15 59	+0 45	24	19 73	54	69
15 61	+0 15	18	20 25	65	68
15 75	+0 05	26	20 64	0 73	26
16 09	−0 05	16			

transition, subgiant, and main sequences, and these are tabulated in Table 5. Again, n is the number of stars forming each mean. These data are plotted as triangles in Figure 7. The individual photoelectrically measured stars, with data taken from Table 3, are plotted as crosses. The curve through the points traces out the giant to main-sequence stars in order of decreasing luminosity as we go from the lower right to the upper left. The bend in the curve at $B - V = +0.4$ occurs at the junction of the subgiants with the main sequence at $V = 19.0$. Also plotted in this figure are the individual stars on the horizontal branch. The solid curve is the normal relation for the main sequence and the

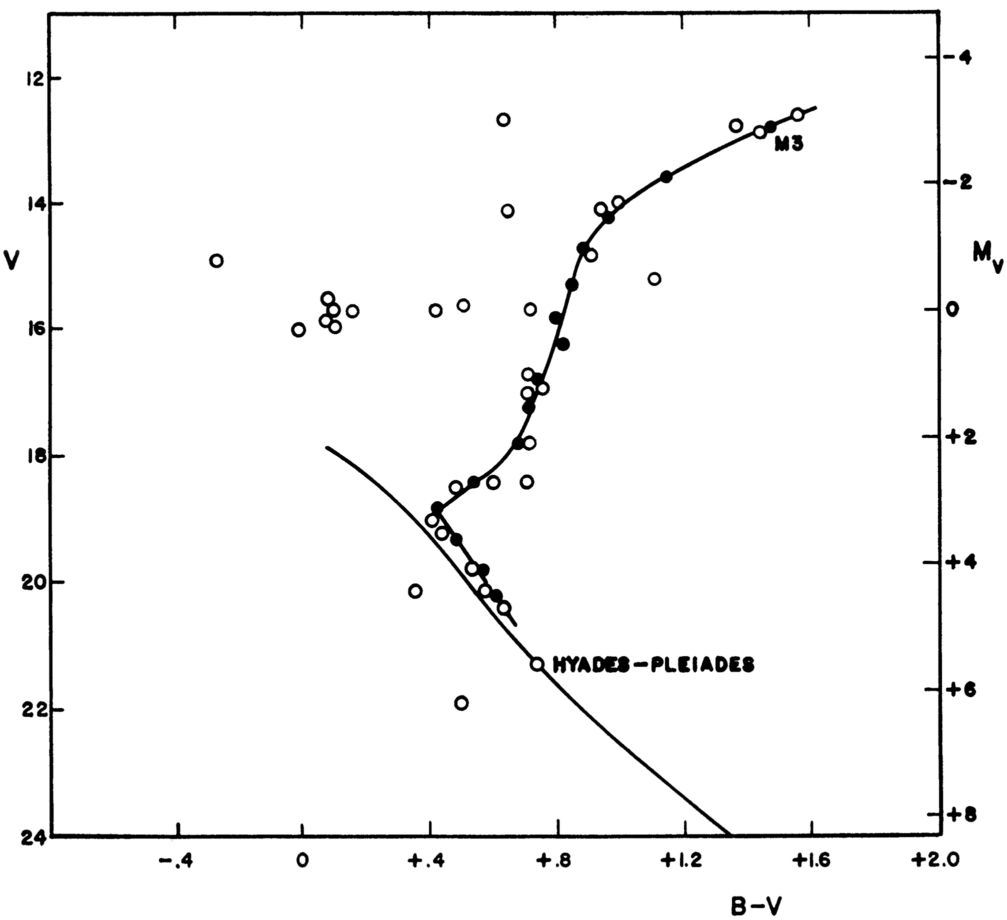

FIG. 6.—Color-magnitude diagram for M3 defined from the photoelectric standards of Table 1 (*open circles*) and from the mean points of Table 4 (*closed circles*). The main sequence from the Hyades and Pleiades stars is shown. See text.

yellow giants, defined by the nearby stars and by several of the brighter galactic clusters (Johnson and Morgan 1953). As in M13 (Arp and Johnson 1955), there appears to be an ultraviolet deficiency for these horizontal-branch stars. The explanation of this deficiency may lie in the effect of the low surface gravity on the Balmer discontinuity.

The M3 stars, ranging from the giant sequence to the main sequence, lie from 0.20 to 0.55 mag. above the normal relation. This anomaly, commonly described as an ultraviolet "excess," has also been found in the bright stars of two other globular clusters, NGC 4147 (Sandage and Walker 1955) and M92 (Sandage and Walker 1956), and for certain weak-line F-type stars in the general field (Roman 1954). The excess has been

TABLE 5

MEAN TWO-COLOR DATA FROM TABLE 3 FOR GIANT, SUBGIANT, AND MAIN SEQUENCES

V	$B-V$	$U-B$	$(U-B)_0$	$\Delta(U-B)$	n
12 78	1.47	+1 40	+1.73	0 33	3
13 56	1 15	+0 95	+1 16	21	11
14 19	0 96	+0 55	+0 75	20	7
14 70	0 88	+0 35	+0 60	.25	7
15 29	0 85	+0.18	+0 54	.36	11
15 76	0 80	+0 21	+0 44	.23	10
16 22	0.81	+0 11	+0 46	35	10
16 79	0 74	+0 02	+0.33	.31	16
17.20	0.71	−0.04	+0 27	.31	6
17.83	0 69	−0 09	+0.24	.33	5
18 36	0 54	−0 14	+0 02	.16	5
18 81	0 42	−0 23	−0 01	.22	14
19 32	0 48	−0 29	−0 01	.28	7
19 78	0 57	−0 39	+0 05	.44	6
20 21	0.61	−0 44	+0 11	0 55	5

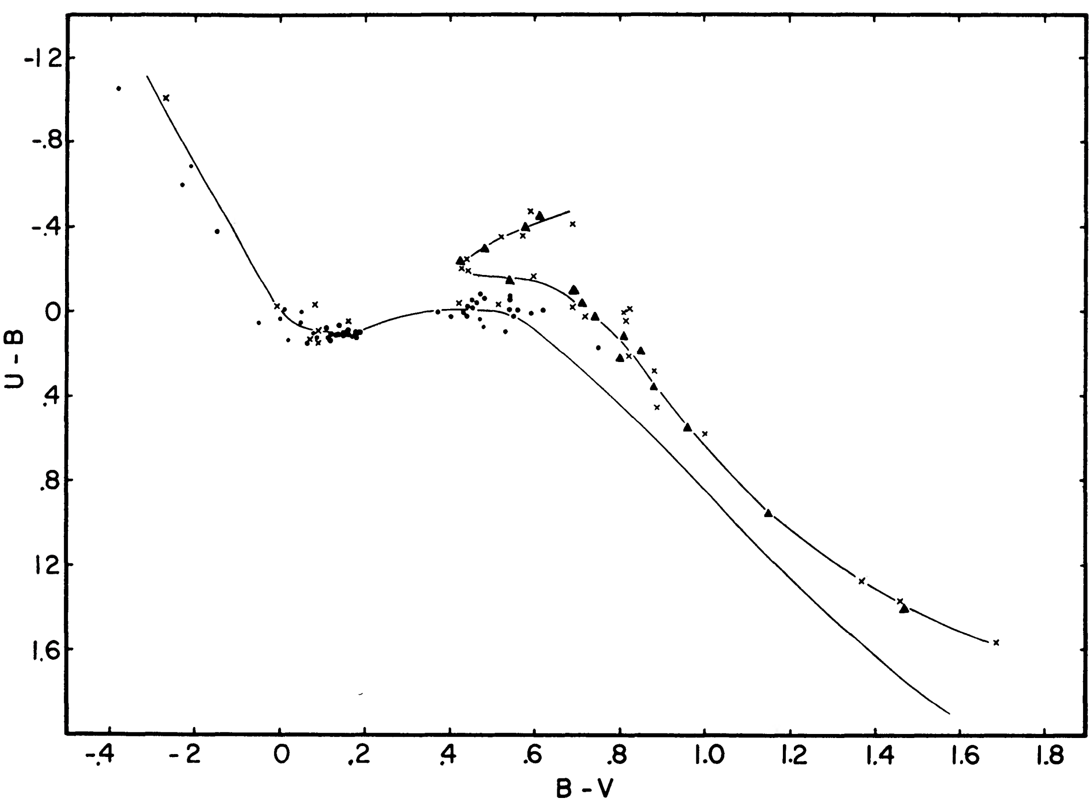

FIG. 7.—The two-color diagram. The triangles are mean points for the M3 giant, subgiant, and main sequences from Table 5. The crosses are the photoelectric standards. Individual stars on the horizontal branch are plotted. The normal relation between $U - B$ and $B - V$ is also shown.

shown to be small, however, in M13 (Arp and Johnson 1955). Our present data show that the anomaly persists for the fainter stars in M3 and may increase until an "excess" of 0.55 mag. is reached for the faintest observed main-sequence stars The last two columns of Table 5 give the normal $U - B$, designated by "$(U - B)_0$" (the "normal" curve of Fig. 7), and the "excess" defined by $\Delta(U - B) = (U - B)_0 - (U - B)_{\text{observed}}$. The dependence of $\Delta(U - B)$ on V is not large until the main sequence is reached, where $\Delta(U - B)$ appears to increase with fainter V. We must point out, however, that the large "excess" of 0.55 mag. for the M3 main-sequence stars may be due partly to observational errors. The mean $U - B$ for the M3 main sequence depends upon photoelectric observation of four stars, for each of which the probable error of $U - B$ is ± 0.14 mag. Furthermore, the scattered-light problem is worst in the ultraviolet. It seems likely, however, that the ultraviolet excess for the M3 main-sequence stars is at least 0.30 mag.

The most plausible explanation for the excess may be that a change in the blanketing of metal lines will cause a change in $U - B$ (a suggestion apparently first made by Strömgren). This suggestion is subject to observational check by a spectrophotometric method such as that used by Schwarzschild, Searle, and Howard (1955). Sufficient numbers of bright field stars with $\Delta(U - B) > 0.20$ mag. are now known (Roman 1954, 1956) to make the spectrophotometric check both feasible and highly desirable. A further check may be available from the stars in M92. If the blanketing suggestion is correct, there should be a difference in the $\Delta(U - B)$ between M3 and M92, since the M92 lines are about 60 per cent weaker than those in M3 (Greenstein 1956). Three-color photometry in M92 is nearly complete, and an answer to this question is forthcoming.

It is interesting to note that among the high-velocity stars observed by Miss Roman (1954, 1956) there are a number with $\Delta(U - B)$ in just the range covered by the M3 stars. Indeed, Miss Roman (1954) foreshadowed the results of Figure 7 by the final comments in her 1954 paper. With the exception of the RR Lyrae stars, these F-type field stars may be the only known cases of stars like those in the globular clusters which have been identified in the general field.

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