COLOR-MAGNITUDE DIAGRAM FOR THE DISK GLOBULAR CLUSTER NGC 6356 COMPARED WITH HALO CLUSTERS

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ABSTRACT

The color-magnitude diagram for the strong metallic-line globular cluster NGC 6356 has been obtained by using photographic plates and a photoelectric magnitude sequence made with the 200-inch Hale telescope The photometric limit of the data is $V = 19.2$, $B = 20.2$ The diagram shows a well-defined giant sequence, a stubby horizontal branch confined to stars redder than $(B-V)_0 = +0.3$, and the beginning of a subgiant branch. From a study of B and A stars in the cluster neighborhood, the interstellar reddening in front of the cluster is estimated to be $E(B-V) = +0.5$ Comparison of the C-M diagram of NGC 6356 with the diagram of halo clusters shows that the giant branch of 6356 is fainter than that of M3 (which has weak to nearly normal metallic-line strength compared with the sun) and is fainter still than that of M92 (which has very weak metal lines) Further comparison shows that the giants in NGC 6356 are brighter than those in M67 (which have normal metallic-line strengths) These results hold, whether the horizontal branches of M3, M92, and NGC 6356 are put at $M_v = 0.00$ or are placed more reasonably at $M_v = +0.4$ for M92, $M_v = +0.6$ for M3, and $M_v = +0.9$ for 6356. Reasons for the second possibility are discussed

Confirmatory evidence that the brightness of giant stars in globular clusters depends on chemical composition comes from a comparison of sixteen clusters for which we have accurate photometric data. Globular clusters with high metal abundance (47 Tuc, NGC 6356, NGC 6838) have giant branches which are at least 0.8 mag. fainter than clusters with a pronounced weakening of their Fraunhofer lines This dependence of M_v on metal abundance makes invalid those methods of distance determination which depend upon assigning a constant absolute magnitude either to the top of the giant branch or to the nth brightest star.

The photometric data for NGC 6356 suggest a true distance modulus of 15.3, a diameter of 11 pc, and an absolute magnitude of $M_{pg} = -7.1$ This diameter is small compared with normal halo clusters and again suggests the action of a tidal force due to the galactic nuclear bulge which limits the cluster size.

I. INTRODUCTION

In classifying the integrated spectra of globular clusters, N. U. Mayall (1946) noted that several clusters had metallic lines of considerably later type than did the majority of the others. This distinction was later amplified and discussed by W. W. Morgan (1956) on the basis of Mayall's original spectrograms plus additional spectrograms obtained with the 82-inch telescope at McDonald. In his original paper, Morgan (1956) isolated ten clusters with strong metallic lines. Eight of these are located in the direction of the galactic center, and it is distinctly possible that they are imbedded in the nuclear bulge itself. Morgan (1959) has recently revised his basic list and has shown that the metallic-line intensity of globular-cluster spectra is a continuous variable ranging from very strong lines, as in NGC 6553 and NGC 6528, to moderately strong lines, as in NGC 6356, through the intermediate systems like M10 and M13, to the very weak-lined clusters, such as M15 and M92.

NGC 6356 is the most favorably placed of the moderate- to strong-lined clusters for observation from the Northern Hemisphere. At culmination it is about 40° above the Mount Palomar horizon and can be observed for at least 2 hours on either side of the meridian. From the theory of stellar structure, there is reason to suspect that the color-magnitude diagrams for strong- and weak-lined clusters will differ. We therefore undertook a photometric study of NGC 6356. The cluster ($l^{\mathrm{I}} = 334°$, $b^{\mathrm{I}} = +9°$) is located

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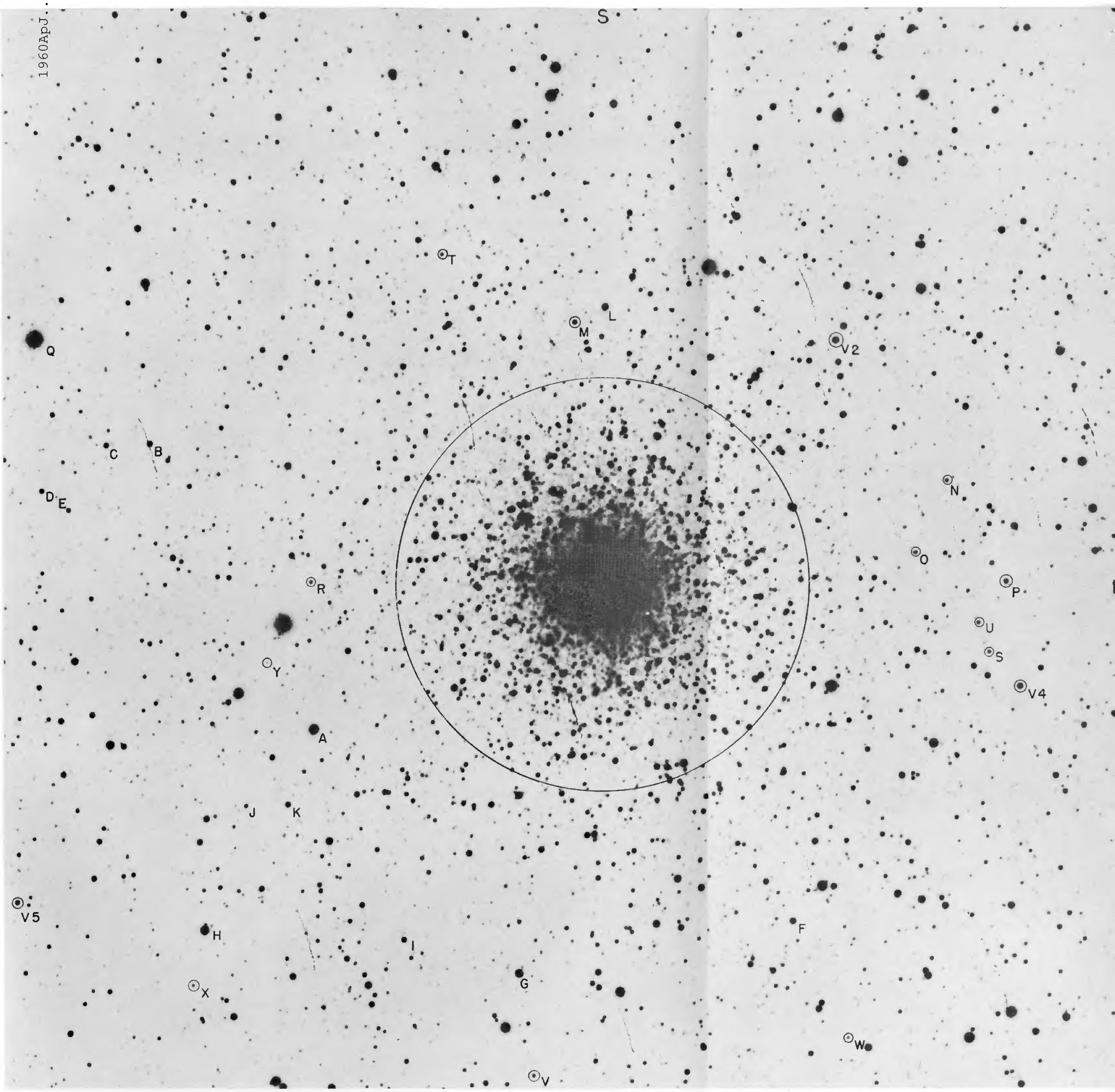

FIG. 1.—The identification chart for the photoelectric standards of Table 1. The radius of the circle is 94 seconds of arc. Variable stars V2, V4, and V5 of Mrs. Hogg's list (1955) are shown.

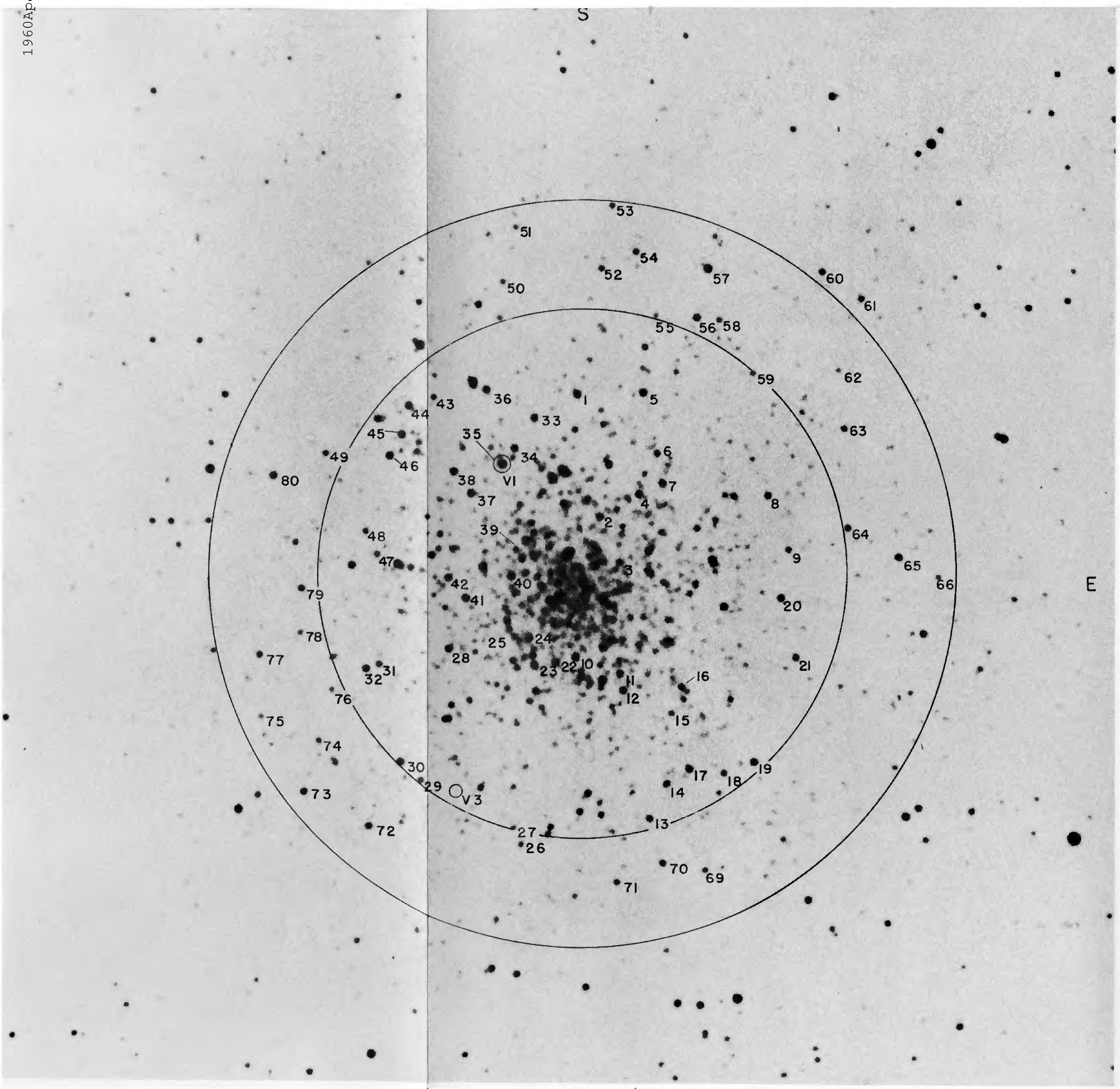

FIG. 2.—The identification chart for stars 1–80 of Table 2. The radius of the inner circle is 54 seconds of arc. The radius of the outer circle is 77 seconds of arc. Variable stars 1 and 3 of Mrs. Hogg's list (1955) are shown. Variable star V1 is the same as star 35 of Table 2.

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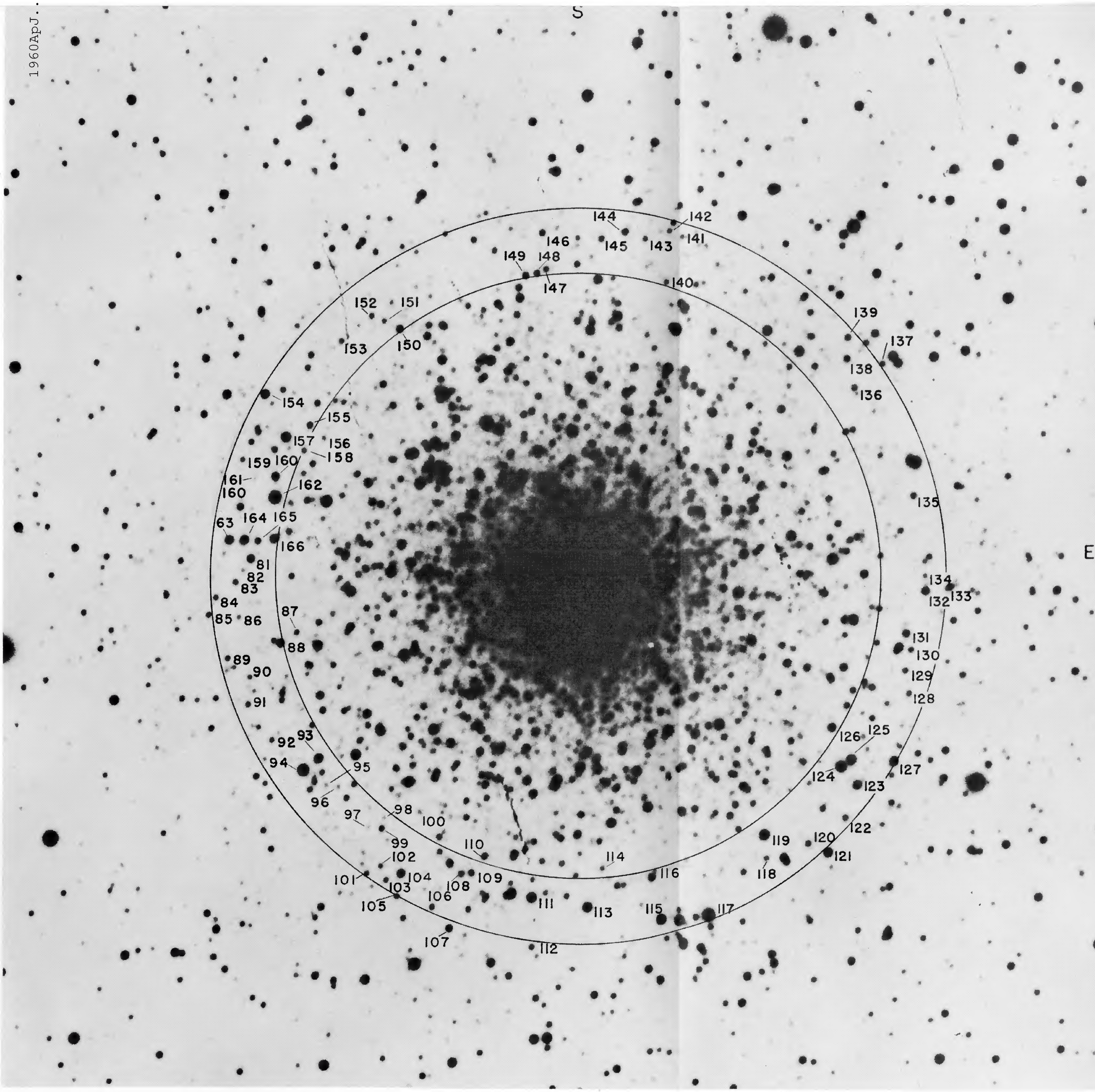

FIG. 3.—The identification chart for stars 81–166 of Table 2. The radius of the inner circle is 77 seconds of arc. The radius of the outer circle is 94 seconds of arc.

within 11° of the direction of the galactic center. It is in a region of very uniform star density, and no differential absorption is expected across the field.

II. THE PHOTOMETRIC DATA

Photoelectric magnitudes have been determined in two colors for twenty-three stars in the vicinity of NGC 6356. Both the 100-inch and the 200-inch telescopes were used. The photometer at each telescope used a refrigerated 1P21 photomultiplier, together with the standard *U*, *B*, *V* filters (2 mm of Corning 9863, 0.7 mm of Schott BG12 plus 1.3 mm of Schott GG13, 2 mm of Schott GG11). Direct d.c. readout was employed. The photoelectric sequence was tied to the *B*, *V* system on a total of 11 nights. The sequence stars are identified in Figure 1, and the magnitudes are listed in Table 1.

TABLE 1

PHOTOMETRIC STANDARDS IN NGC 6356

Star	Photoelectric Values				Photographic Values	
	V	*B−V*	100″ (*n*)	200″ (*n*)	*V*	*B−V*
A	13 72	1 56	3		13 73	1 50
B	15 73	0 97	2		15 78	0 90
C	16 10	1 00	2		16 44	0 98
D	16 78	1 40	2		16 78	1 44
E	17 11	1 20	2		17 12	1 00
F	15 73	1 50	3	.	15 74	1 54
G	14 60	1 39	3	1	14 53	1 50
H	14 04	1 29	2		14 09	1 29
I	16 20	1 26	3		16 24	1 17
J	17 18	1 10	2		17 56	0 67
K	16 21	1 71	1		16 22	1 65
L.	15 24	(1 79)	2		15 25	1 80
M	16 82	1 00	1		16 70	1 21
N	17 16	0 92	1		17 48	0 87
O	17 65	0 96	2		17 59	0 89
P	16 72	1 49		2	16 88	1 35
Q*	11 77	1 32	7	8	. .	. . .
R†	18 02:	1 40:		1	17 65:	1 17:
S					17 70	0 72
T	.	. . .		.	17 76	0 74
U	17 66	1 01		1	17 62	1 26
V.	17 52	1 02		1	17 79	0 86
W	18 51	0 91		1	18 51	0 88
X	18 29	0 85		2	18 31	0 70
Y	19 39	0 88		2	19 40	0 88

* $U - B = 1\ 20$ † Probably variable

Although the internal error of several measures on a single star is only a few hundredths of a magnitude, the possible presence of faint companions can introduce systematic errors in the magnitude of a faint star which cannot be entirely eliminated. Long-exposure plates (30 min.), taken at the 200-inch telescope, were examined carefully for the presence of companions to the standards. Although most of the standards chosen had no visible companions less than 2.5 mag. fainter than the standards, we cannot claim an accuracy of greater than ± 0.10 mag. for stars fainter than $V = 18.0$, $B = 19.0$. In spite of our precautions, faint companions occur to standards N and P. These companions were measured on the photographic plates, and the necessary corrections were made to the photoelectric magnitudes given in Table 2 before plotting the final calibration-curves. Standard star R showed considerable scatter in both the photoelectric and the photographic magnitudes and is presumably a variable star. It was not used for calibrating the photographic plates.

The photographic plates to be measured were taken at the prime focus of the 200-inch Hale telescope with the Ross F3.67 correcting lens. The plate and filter combinations

TABLE 2

MAGNITUDES AND COLORS OF 166 STARS IN AND NEAR NGC 6356

Star No	V	$B-V$	Star No	V	$B-V$	Star No	V	$B-V$	Star No	V	$B-V$
1	15 30	1 88	41	15 32	2 12	81	16 53	1 46	121	16 00	1 01
2	15 47	1 74	42	15 48	1 77	82	18 58	0 99	122	17 65	0 96
3	15 60	1 69	43	16 45	1 43	83	17 59	0 96	123	16 28	1 46
4	15 42	2 13	44	15 36	1 99	84	17 63	1 35	124	15 22	2 01
5	15 35	2 05	45	15 32	2 05	85	17 65	1 09	125	15 74	1 75
6	16 05	1 76	46	15 35	2 22	86	18 29	1 16	126	16 62	1 12
7	15 54	1 88	47	16 23	1 39	87	17 71	1 33	127	16 09	1 44
8	15 68	1 84	48	16 35	1 32	88	16 50	1 04	128	17 78	0 86
9	16 12	1 52	49	16 48	1 33	89	17 72	0 96	129	17 73	1 04
10	15 11	1 99	50	16 66	1 22	90	18 02	1 23	130	17 67	1 18
11	15 66	1 52	51	16 70	0 72	91	17 71	1 05	131	17 00	1 20
12	15 70	1 62	52	16 18	1 52	92	17 75	1 15	132	16 62	1 22
13	15 68	1 70	53	16 33	1 36	93	16 02	1 49	133	17 20	0 74
14	15 96	1 51	54	16 05	1 64	94	14 95	1 55	134	18 75	1 12
15	16 48	1 26	55	17 05	1 11	95	18 60	0 93	135	17 59	1 15
16	15 76	1 72	56	15 56	1 78	96	18 57	1 19	136	17 45	0 80
17	15 44	2 11	57	15 06	1 46	97	19 06	0 86	137	17 59	1 17
18	16 18	1 42	58	16 43	1 55	98	18 84	1 08	138	17 17	1 26
19	15 40	1 87	59	16 59	1 33	99	18 76	1 12	139	17 33	1 24
20	15 62	1 63	60	15 93	1 28	100	18 40	1 07	140	17 91	1 12
21	15 84	1 42	61	15 88	1 69	101	17 65	1 17	141	18 22	0 83
22	15 23	2 07	62	15 97	1 19	102	17 92	1 41	142	17 91	1 20
23	15 13	1 84	63	16 18	0 77	103	17 69	0 98	143	17 91	1 11
24	15 04	2 04	64	15 89	1 47	104	16 32	1 65	144	17 19	1 27
25	15 72	1 79	65	15 45	1 80	105	17 61	0 99	145	17 57	1 10
26	16 46	1 44	66	16 68	1 30	106	18 80	1 24	146	17 31	1 27
27	16 82	1 12	67	15 47	1 83	107	16 84	1 39	147	17 56	0 87
28	15 46	1 97	68	15 40	2 02	108	17 33	1 14	148	17 26	0 94
29	16 13	1 59	69	16 35	1 42	109	17 16	0 88	149	17 07	1 23
30	15 40	2 03	70	15 92	1 62	110	17 09	1 31	150	16 78	1 40
31	16 02	1 62	71	16 10	1 52	111	15 67	1 76	151	18 01	0 81
32	15 49	1 13	72	15 62	1 92	112	17 55	1 13	152	17 78	1 00
33	15 58	1 89	73	15 59	1 70	113	15 77	1 66	153	17 76	0 84
34	15 52	1 94	74	16 34	1 55	114	18 09	1 12	154	16 22	1 64
35	14 87	2 00	75	16 74	1 32	115	18 10	1 75	155	17 41	1 22
36	15 54	1 76	76	16 74	1 21	116	16 76	1 26	156	18 27	1 14
37	15 23	2 04	77	15 90	1 70	117	14 46	1 67	157	15 88	1 49
38	15 36	1 98	78	16 62	1 19	118	17 93	1 21	158	17 78	1 22
39	15 18	1 71	79	15 97	1 56	119	15 60	1 93	159	17 91	1 25
40.	14 90	2 14	80	15 36	2 02	120	17 59	0 79	160	16 58	0 74
			161	19 24	0 95	163	16 24	1.66	165	17 17	1 19
			162	14 72	1 13	164	16.09	1 71	166	16 22	1 59

were Eastman 103*a*-O behind 2 mm of Schott GG 13 glass for blue and Eastman 103*a*-D behind 2 mm of Schott GG 11 glass for yellow plates. It has already been shown (Johnson and Sandage 1955) that no color equation is needed to relate these combinations to the B, V system. Exposures of approximately $\frac{1}{2}$, 2, 6, and 30 minutes were taken. The longest exposures were used only in the choice of photoelectric standards, as previously described.

Four blue and three yellow plates were measured on the Eichner astrophotometer. The photoelectric standards were used to draw the relationship between photometer reading and magnitude in the usual way, and the magnitudes of 166 stars within a radius of 94 seconds of arc of the cluster center were read from the calibration-curves. Usually each star was measured on two plates, although some were measured three times, and the faintest stars were measured only once. The magnitudes of the photoelectric standards were also read back through the final calibration-curves and are listed in the final section of Table 1. The program stars are identified in Figures 2 and 3, and their magnitudes and colors are listed in Table 2.

Inspection of Figures 2 and 3 shows only too clearly that our photographic observations are beset by grave crowding difficulties. On the shortest exposures, stars as close to the cluster center as it was possible to go were measured. For succeedingly longer exposures, an increasingly larger area about the cluster center had to be omitted because of crowding, until finally, on the 6-minute exposure, only stars within a narrow ring were sufficiently uncrowded for measurement. If plates of still longer exposure had been measured, the crowding would have forced us entirely out of the cluster.

III. THE COLOR-MAGNITUDE DIAGRAM

The color-magnitude (C-M) diagram for NGC 6356 is shown in Figures 4 and 5. Stars 1–80 from Table 2 are plotted in Figure 4. The limit of this diagram is $V = 17$. Fainter than this, stars 81–166 from Table 2 are plotted in Figure 5. The limit of our measures is $V = 19.2$, $B = 20.2$. These two figures show the following, almost unique, features: (1) The red giant branch is well defined but is much less steep than in halo globular clusters such as M2, M3, M13, M15, and M92. The giant sequence in NGC 6356 can be represented by a straight line with a gradient of $\Delta V/\Delta(B-V) \simeq 1.8$. In contrast, the giant sequence in halo clusters is not linear, and in M3 the change in V for a change in color index from $B-V = 1.7$ to $B-V = 0.7$ is $\Delta V = 2.9$, which is considerably greater than 1.8. (2) In NGC 6356 the magnitude difference between the top of the giant branch and the stubby horizontal branch is $\Delta V \simeq 2.25$ mag., whereas for a normal halo cluster $\Delta V \simeq 3.0$ mag. (3) A short, stubby horizontal branch is present in Figure 5, beginning at $V = 17.7$, $B-V = 1.1$ and ending at $V = 17.7$, $B-V = 0.8$. If bluer stars had been present, they would have been found. This type of horizontal branch, which is devoid of stars blueward of the RR Lyrae star gap, is known in only a few other clusters. (4) Below the junction of the horizontal and red giant branches, we note a poorly determined subgiant branch. Although the observations may well be affected by both random and systematic errors below $V = 18.0$, there is a sufficient grouping of stars in Figure 5 to suggest the reality of the separation of the horizontal and subgiant sequences.

To assess the theoretical implications of Figures 4 and 5, it is necessary to compare NGC 6356 with the C-M diagrams of the halo clusters of low metal abundance. Before this can be done, it is necessary to estimate the interstellar reddening in front of NGC 6356.

IV. THE INTERSTELLAR REDDENING

Because the horizontal branch does not show a region containing RR Lyrae stars, it is not possible to determine the reddening by assuming knowledge of the colors of the variable-star gap. Furthermore, there are no RR Lyrae stars known in the cluster. Mrs. Hogg has searched the field (1953) and lists five variables (1955). These stars are identified in

Figures 2 and 3 as V1–V5. We have also blinked our 200-inch plates, but no new variables were found. The five stars listed by Mrs. Hogg are either long-period or irregular variables. They are definitely not RR Lyrae variables.

Examination of the Palomar Sky Survey plates indicates that any irregularity of the absorption within several degrees of NGC 6356 is small. Therefore, to obtain an approximate value for the reddening, we have observed early-type stars within about 1° of the cluster. Photoelectric measures on the *U*, *B*, *V* system were made at the 60- and 100-inch telescopes. Spectra were taken with the 60-inch cassegrain spectrograph at a dispersion of 80 A/mm. These were classified by comparison with standards on the MK system (Johnson and Morgan 1953) taken with the same instrument. Four stars more distant than a degree from the cluster were later added to the program. Two of these

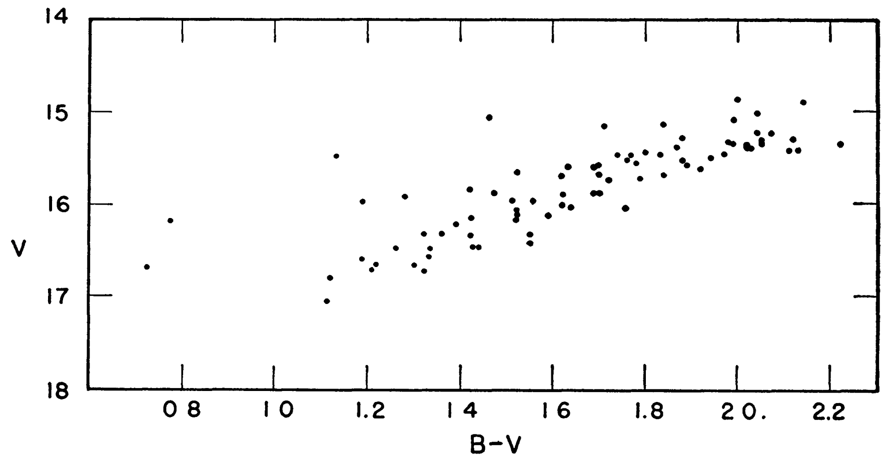

FIG. 4.—The color-magnitude diagram of NGC 6356 for stars brighter than $V = 17\,0$ Stars 1–80 of Table 2 are plotted.

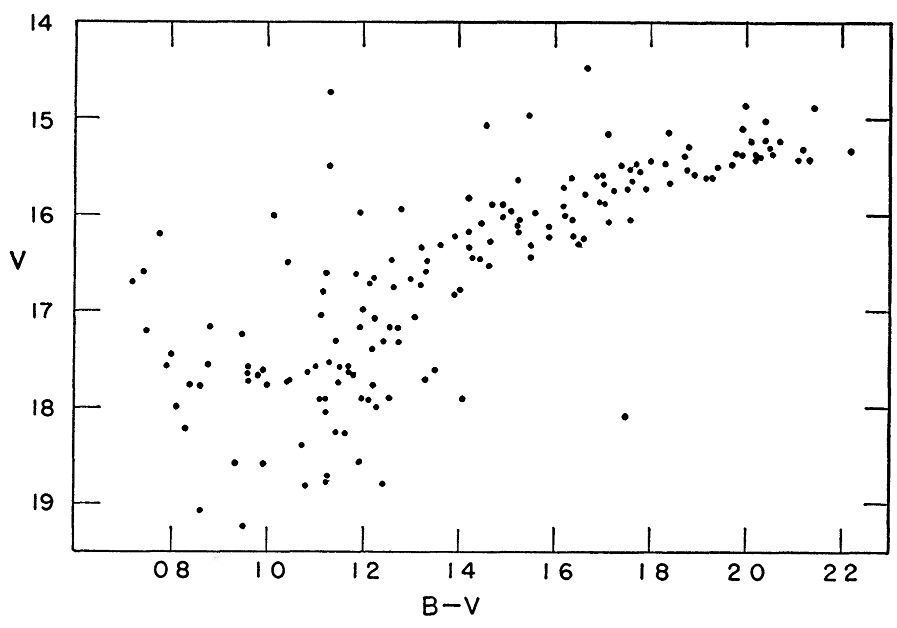

FIG. 5.—The color-magnitude diagram of NGC 6356 to the limit of the present study All stars of Table 2 are plotted

stars, HD 159864 and HD 160186, were observed by Hiltner (1956). These stars are about 4° distant from the cluster center. Two additional high-luminosity stars, HD 158661 and HD 162064, were taken from the list of Morgan, Code, and Whitford (1955). HD 158661 is only 2° from the cluster. Its apparent modulus is 14.2, and this star is the most distant in the list that can give information about the reddening of the cluster itself. HD 162064 is about 6° from the cluster, is near to the galactic plane, and is in a region of highly irregular and dense absorbing clouds. The $E(B-V)$ of 0.90 derived for this star is a generous upper limit for the reddening of 6356 itself.

The spectroscopic and photometric data for the twelve stars in the list are given in Table 3. The color excess as a function of apparent distance modulus is plotted in Figure 6. Here the apparent moduli were determined from our apparent magnitudes, together with the absolute magnitudes from Morgan and Keenan's (1950) calibration of the

TABLE 3

EARLY-TYPE STARS NEAR NGC 6356

HD	BD	Sp	V	$B-V$	$U-B$	$(m-M)_{app}$	$E(B-V)_{Sp}$	$E(B-V)_c$
156779	−18°4494	B2 V	9 32	0 12	−0 52	11 9	0 36	0 33
156974	−17°4783	A0 V	9 40	14	+ 05	9 1	14	14
157170	−17°4789	A0 IV	7 97	14	+ 07	7 7	14	12
157184	−17°4790	A1 V	9 44	23	+ 12	8 6	18	
157201	−20°4748	A4 V	8 22	12	+ 21	6 2	12	
157546	−18°4516	A0 Vnn	6 37	00	− 09	6 1	00	03
157860	−17°4805	A0 V	10 27	21	+ 13	10 0	21	
157897	−17°4808	B9 5 V	9 84	23	+ 19	9 6	25	. .
158661	−17°4834	B0 5 I*b**	8 23	16	− 70	14 2	36	31
159864	−17°4864	B0 5 II*	8 59†	24	− 72	13 8	50	54
160186	−18°4598	B0 5 V*	9 05†	19	− 73	12 6	47	50
162064	−19°4713	B0 I*a**	9 26	0 68	−0 34	16 0	0 90	0 85

* Spectral types from W W Morgan, A D Code, and A E Whitford 1955, *Ap J Suppl*, **2,** No 14, 41
† Photometry from W A Hiltner, 1956, *Ap J Suppl*, **2,** No 24, 389

Yerkes luminosity classes. The three stars more distant than 4° from the cluster (HD 159864, HD 160186, and HD 162064) are plotted as crosses. Since these stars are closer to the galactic plane than NGC 6356, they probably indicate greater reddening (at their apparent moduli) than should be applied to NGC 6356. The minimum permissible reddening for NGC 6356 is $E(B-V) = 0.36$, the value for HD 158661. The reddening of the cluster is probably greater than 0.36 mag. but is probably less than 0.90 mag., as given by HD 162064. As we shall see in the last section, the apparent modulus for 6356 is close to $m-M = 16.8$. Extrapolation of the trend in Figure 6 to this distance gives an estimate of $E(B-V) = 0.5 \pm 0.1$ for the cluster itself. We adopt this value in the following discussion.

V. DISCUSSION

Figure 7 shows the comparison of the C-M diagrams of NGC 6365, M3, and M92 obtained by assigning $M_v = 0.00$ to all three horizontal branches. Also shown for comparison is the diagram for M67 (Johnson and Sandage 1955). It is known from independent evidence (Deutsch 1955, 1959; Morgan 1956, 1959; Helfer, Wallerstein, and Greenstein 1959; Kinman 1959) that the order of the separation of the giant branches of Figure 7 is the same as the order of the abundance of the heavy elements. M92 has the weakest metallic lines of the group, M3 has intermediate-strength metal lines, NGC 6356 has

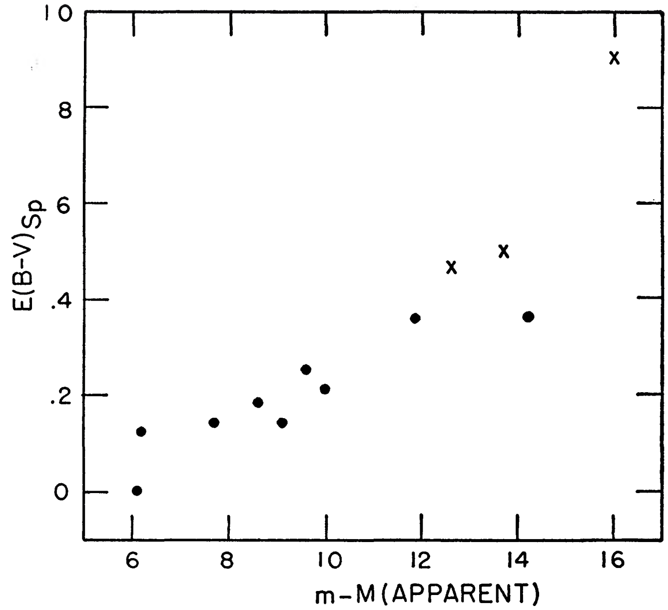

FIG. 6.—The color excess in $B-V$, determined from spectral data, plotted against the apparent distance modulus of B and A stars in the vicinity of NGC 6356. The data are from Table 3. The three crosses represent stars whose reddening is probably greater than should apply to the NGC 6356 field at that modulus

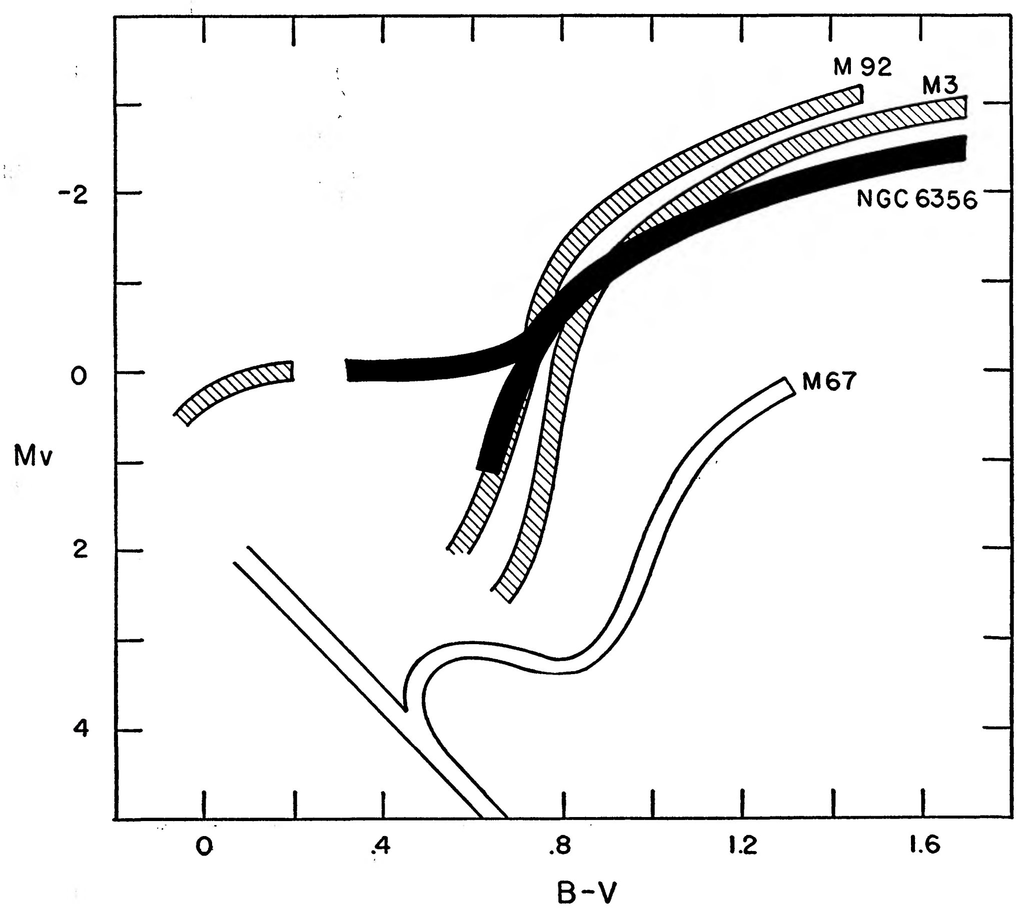

FIG. 7.—Comparison of the diagrams of M92, M3, NGC 6356, and M67 on the assumption that $M_v = 0.00$ for the horizontal branches of the three globular stars. The luminosities of the giant branches at $(B-V)_0 = +1.4$ appear to be correlated with the metal abundances.

almost normal line strengths, while the M67 stars have completely normal spectroscopic features (Popper 1954; Burbidge and Burbidge 1959) when compared with the sun.

The validity of Figure 7 requires that $M_v = 0.00$ for all three horizontal branches. Both this numerical value and the assumption of equality between the clusters is likely to be incorrect. Recent calibration of the absolute magnitude of RR Lyrae itself by the moving-group method (Eggen and Sandage 1959) gives $M_v = 0.65 \pm 0.1$. There it was shown that RR Lyrae may form a kinematical group with Groombridge 1830 and several other high-velocity subdwarfs. If the data on the motions are interpreted in this way, the moving-group parallax method gives the absolute magnitudes of the individual members of the group. In addition to this calibration, Eggen and Sandage applied their resulting C-M diagram of the Groombridge 1830 group to the diagram of M13 (Baum, Hiltner, Johnson, and Sandage 1960) and obtained $M_v = +0.4 \pm 0.1$ for the two M13 RR Lyrae stars. More recently, Arp (1959) has obtained the C-M diagrams of the main sequences of M2 and M5. Fitting these data to the age-zero main sequence, using appropriate blanketing corrections, gave $M_v = +0.8$ for the variables in M5 and $M_v = +1.0$ for those in M2 (Arp 1959). The difference in the values obtained from the above four sources may be significant, i.e., they may represent a real dispersion. Differences in M_v are expected between different clusters according to a hypothesis (Sandage 1958) which ascribes the difference in the mean periods of the RR Lyrae stars in different clusters to a difference in the absolute magnitudes of the horizontal branches. The prediction is that the M3 and M92 horizontal branches should differ by $\Delta M_v \simeq 0.2$ mag. The method cannot be applied directly to NGC 6356 because no RR Lyrae stars are known here. But the character of the horizontal branch is a parameter which seems to be related statistically to the mean periods of the RR Lyrae stars and therefore to M_v. In those clusters which have many more blue stars than red stars on this branch, the mean period of the variables is long ($0^{d}63$). In clusters such as M3 or M5, where the stars are equally distributed along the branch, the mean period of the variables is short ($0^{d}53$). The stubby, red horizontal branch of NGC 6356 suggests that it can be fitted into this progression, at the extreme end beyond the M3 type. If this is so, we should expect the horizontal banch of NGC 6356 to be even fainter than that in M3. The above chain of suppositions must be classed as speculation at present. It can be checked by observations of 47 Tuc and NGC 6838 carried to the main sequence, as will be evident in the next few paragraphs.

Figure 8 shows the comparison of the four clusters normalized according to these ideas. The absolute magnitude of the M3 variable gap is put at $M_v = +0.6$, to correspond with RR Lyrae itself (Eggen and Sandage 1959); the gap in M92 is put at $M_v = +0.4$; and the horizontal branch of NGC 6356 is at $M_v = +0.9$. This fit gives a separation of the giant branches according to chemical composition which is greater than in Figure 7.

Figures 7 and 8, as drawn, both suggest that the absolute magnitudes of the giant stars in various clusters depend directly on the metal abundance. Such a dependence has been predicted theoretically by Hoyle and Schwarzschild (1955) and by Kippenhahn, Temesváry, and Biermann (1958). This dependence has been further summarized by Kinman (1959). But we cannot claim with certainty that this prediction is actually borne out by our present data because of the uncertainty in the normalization of the absolute magnitudes. The critical test of the assumptions used in either Figure 7 or Figure 8 will come when the C-M diagrams of clusters like M92 and NGC 6356 are carried to the main sequence, where a more fundamental comparison can be made. The two most important clusters to carry to the main sequence are 47 Tuc (NGC 104), which is known to be metal-rich (Kinman 1959; Feast and Thackeray 1960), and NGC 6838, which is also metal-rich (Morgan 1956). The case of 47 Tuc is especially interesting. Feast and Thackeray (1960) report TiO bands present in the spectra of the individual red giants. None of the stars in well-studied clusters in the Northern Hemisphere are known to have TiO, although the giant stars are certainly cool enough. Because the strength of weak TiO bands goes as the square of the metal abundance, this suggests that the stars in 47 Tuc are richer in the metals than most globular clusters. This is confirmed by the Radcliffe spectra of many individual stars in the cluster (Thackeray 1959).

The difference in the giant branches according to the metal abundance seems to be a general property of globular clusters. Data on sixteen clusters for which we have accurate C-M diagrams are given in Table 4. Column 1 gives the NGC number; 2 gives the Messier number; 3 gives the difference ΔV in the visual magnitude between the horizontal branch and the giant branch read at $(B-V)_0 = +1.4$; columns 4 and 5 give a description of the spectra of individual stars according to Deutsch (1955, 1959) and of

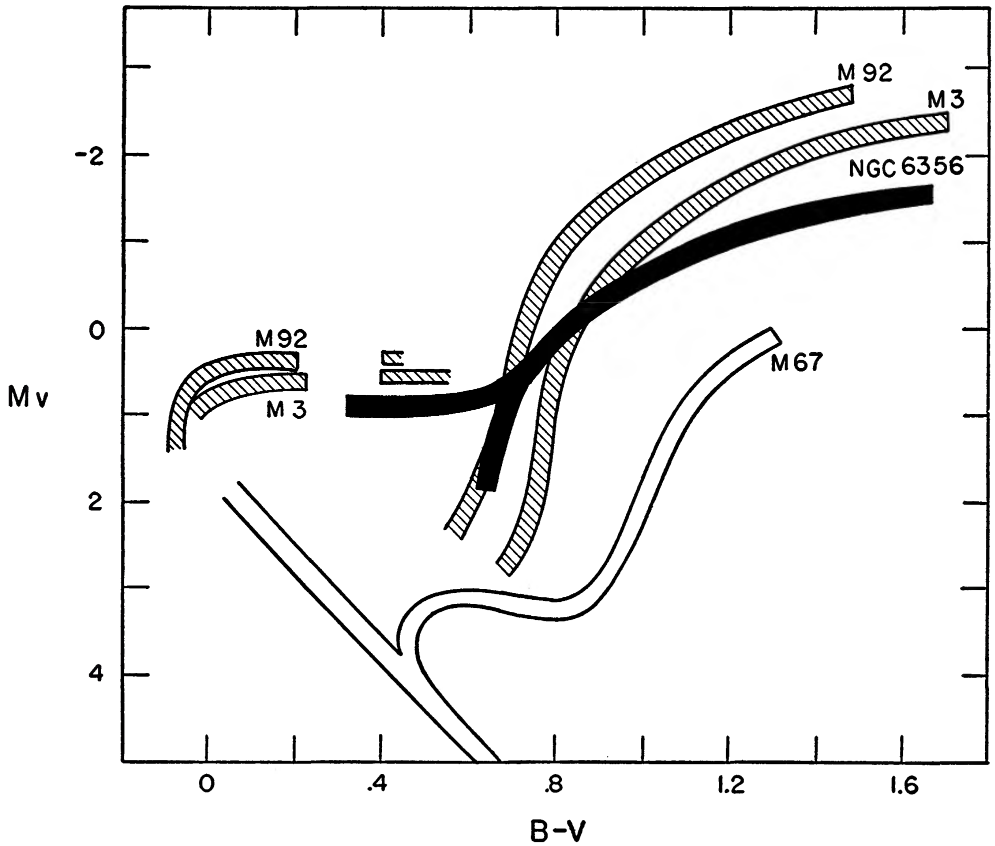

FIG. 8 —Same as Fig 7 except that the horizontal branches of the three globular clusters are assumed to be $M_v = +0.4$ for M92, $M_v = +0\ 6$ for M3, and $M_v = +0\ 9$ for NGC 6356

the integrated light according to Morgan (1959); column 6 gives the mean period of the Bailey-type ab RR Lyrae stars (Hogg 1955); column 7 gives the number of RR Lyrae stars; 8 shows the character of the horizontal branch; and 9 is reference to the source of the color-magnitude diagram. The notation A, B, or C of column 4 gives Deutsch's description of the weakness of the metal lines in individual stars. A means the metallic lines are slightly weaker than in "population I" giants; B means that the metallic lines are definitely weaker; C means that the metallic lines are very much weaker. Morgan's Roman numeral classification (1959) of column 5 refers to the integrated spectrum. Class I clusters have very weak metal lines, while class VIII clusters have normal-strength lines; the intermediate cases range through class II to class VII. The character of the horizontal branch in column 8 is designated by b when most of the stars are on the blue side of the variable-star gap (e.g., M10, M13, M92); by e when nearly equal numbers are on the blue and red sides of the gap (e.g., M3, M5); and by r when most of the stars are redward of the gap (e.g., 47 Tuc, NGC 6356).

It is immediately obvious from Table 4 that the sixteen clusters can be divided into three groups, according to the value of ΔV. In general, this same separation also divides the clusters according to (1) metal abundance, (2) mean period of the RR Lyrae stars, and (3) the character of the horizontal branch. The data for the high-metal group are from an unpublished study of 47 Tuc by Wildey, using Wesselink's plates and photoelectric calibration, and from recent work on NGC 6838 by Arp. The value of $\langle \Delta V \rangle$ for this group is 2.17 ± 0.06 (m.e.) mag. The intermediate group is predominantly of Deutsch's class A–B and has $\langle \Delta V \rangle$ = 2.54 ± 0.06 (m.e.) mag. The third group, with spectra of type B–C, with long mean periods for the RR Lyrae stars, and with hori-

TABLE 4

CHARACTERISTICS OF A NUMBER OF GLOBULAR CLUSTERS

Cluster		ΔV*	Spectra		$P_{a,b}$	No of RR Lyr	H B	Reference‡
NGC (1)	M (2)	(3)	Deutsch (4)	Morgan (5)	(6)	(7)	(8)	(9)
104	47 Tuc	2 15	A†	High Met †		2	r	1
6356	.	2 15		VI		0	r	2
6838	71	2 1		VI		0	r	3
		2 17±0 06 (m e)						
4147	.	2 45:	B		0 531	16	?	4
5272	3	2 64	AB	II	.550	201	e	5
5904	5	2 58	A	II	546	99	e	6
6205	13	2 55	A	III	. .	3	b	6, 7
6656	22	2 50	B	II	651	19	b	8
		2 54±0 06						
5024	53	3 10	B	III	642	45		9
5053		. .	C		673	10		10
5466		3 0	C		636	18	be	10
5897	. .	3 10	C	.		4	b	11
6254	10	2 85	B	IV	.	0	b	6
6341	92	2 92	C	I	626	15	b	12
7078	15	3 10	C	I	645	93	be	6
7089.	2	2 98	B	II	0 629	13	b	6
		3 01±0 08						

* Difference between horizontal branch and giant branch read at $(B - V)_0 = +1\ 4$

† Data on spectra of individual stars from T D Kinman, *M N*, **119**, 538, 1959, and from M W Feast and A D Thackeray, *M N* (in press), 1960

‡ Following are the references for C-M diagrams:

1 R L Wildey, unpublished
2. Present study
3 H C Arp, preliminary unpublished
4 A R Sandage and M F Walker, *A J*, **60**, 230, 1955.
5 H L Johnson and A. R Sandage, *Ap J*, **124**, 379, 1956
6 H C Arp, *A J.*, **60**, 317, 1955
7 H C Arp and H. L. Johnson, *Ap J.*, **122**, 171, 1955
8 H C. Arp and W. G. Melbourne, *A J*, **64**, 28, 1959
9. J. Cuffey, *Ap J*, **128**, 219, 1958
10 J Cuffey, unpublished
11 A R Sandage and M Schmidt, 1958, unpublished
12 A R Sandage and M F Walker, 1957, unpublished

zontal branches shifted toward the blue, have $\langle \Delta V \rangle = 3.01 \pm 0.08$ (m.e.) mag. Based on the size of the mean deviations, the difference of the ΔV between the three groups appears to be highly significant. However, the suggested correlations between ΔV, $\langle P_{a,b} \rangle$, and the character of the horizontal branch is spoiled by the two clusters M13 and M22. M13 has always presented somewhat of an anomaly, in that the spectra of its individual stars appear to be metal-rich (Deutsch class A), whereas the character of the horizontal branch simulates that of the very weak-lined group (M15, M92, NGC 5897). But the recent study of M13 by Baum, Hiltner, Johnson, and Sandage (1960), which revised the colors of Baum's original photometry (1954), shows that M13 is younger than M2 or M5 (Arp 1959). Consequently, in addition to chemical composition, the second parameter of age may be affecting the correlations of Table 4. The age difference may change the evolution along the horizontal branch (due to a slight mass difference) and give apparently spurious results in columns 6 and 8 of Table 4 for M13 and M22. Nevertheless, it is clear from both Figures 7 and 8 and from Table 4 that there is a strong correlation between the metal abundance and the difference in absolute magnitude between the horizontal branch read at $(B-V)_0 = +1.4$. This result makes invalid the common practice in distance determinations (e.g., Shapley 1930; Baade 1952) of assigning a unique absolute magnitude to the brightest stars in any globular cluster. Table 4 shows that the upper luminosity limit can vary by at least 0.8 mag. between the clusters of high and of low metallic abundance. This difference will be even greater if the normalization of Figure 8 is valid. The upper limit of luminosity of globular clusters may eventually be used for precise distance determination but only when the parameter of metal abundance is taken into account.

It is of interest to quote the available quantitative estimates of the metal abundances in the three groups of Table 4 The first abundance analysis of the globular cluster giant stars is that by Helfer, Wallerstein, and Greenstein (1959). Their results showed that stars in M13 are deficient in the metals by at least a factor of 20 compared with the sun. Stars in M92 are underabundant in the metals by a factor of at least 100. These authors state that the actual abundance ratios might be even greater—by perhaps an additional factor of 10. Presumably, the stars of NGC 6356 or 47 Tuc have abundance deficiencies of less than a factor of 10. Kinman has also studied the problem of abundances (1959) and concludes that for Deutsch's group A, where the integrated spectral type determined from the G band to Hγ ratio is G5–G0, the underabundance factor is less than 10; for the A group, where the integrated spectrum is G0–F5, the factor is greater than 10; for Deutsch's group B the factor is less than 100, while for group C the factor is greater than 100. This is in excellent agreement with the much more detailed curve-of-growth study by Helfer, Wallerstein, and Greenstein.

VI. DISTANCE, ABSOLUTE MAGNITUDE, AND DIAMETER OF NGC 6356

Figure 6 shows that the apparent modulus of NGC 6356 is $(m-M)_{\text{app}} = 17.7$ if we assume that $M_v = 0.00$ for the horizontal branch. If $M_v = +0.9$, then $(m-M)_{\text{app}} = 16.8$. If we adopt $E(B-V) = 0.5$, then $(m-M)_{\text{true}}$ is either 16.2 or 15.3. The true distance on each hypothesis is $d = 17400$ pc (for $M_v = 0.0$) or $d = 11500$ pc (for $M_v = 0.9$). If we further make the *ad hoc* assumption that NGC 6356 is close to the galactic nucleus (Morgan 1956), then the second value of $d = 11500$ pc is preferred, especially as there is increasing evidence that the distance to the galactic center must be somewhat greater than Baade's value of 8.7 pc (1950). (See, for example, Whitford's discussion of the absorption in front of NGC 6522 which he presented at the A.A.S. meeting in Cambridge, Mass., in May, 1957.) Whitford showed that the best guess of the reddening of NGC 6522 increased the distance to the center to about 12000 pc. However, because we have no a priori knowledge that NGC 6356 is associated with the galactic center, we cannot on this basis choose between the two possible distances.

The absolute magnitude of NGC 6356 is $M_{pg} = -8.0$ if $m-M = 17.7$, or $M_{pg} = -7.1$ if $m-M = 16.8$. These values follow from W. A. Christie's determination (1940) of $m_{pg} = 9.7$.

The linear diameter of NGC 6356 cannot be estimated on the same basis as for the high-latitude halo clusters because the background crowding difficulties prevent the outer regions of the cluster from being seen. However, photometric measurements of the field just outside the marked region of Figures 1 and 3 show that the cluster does not extend far beyond the circle. At the cluster, the diameter of this circle is either 16 pc (for $M_v = 0.0$) or 11 pc (for $M_v = +0.9$). Even if the cluster actually extends to twice the distance of the circle, the resulting diameter is small compared with 50 pc, which applies to M3 (Burbidge and Sandage 1958). This again suggests that the diameters of clusters near the galactic nucleus are systematically smaller than those of halo clusters—presumably because of tidal action of the nuclear regions (von Hoerner 1957).

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