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THE BLUE HORIZONTAL-BRANCH STARS OF NGC 6752

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ABSTRACT

We show that the wide horizontal-branch gap, discovered in NGC 6752 by Cannon and Lee, lies at the same value of effective temperature (log $T_{\rm eff}$ = 4.33) as gap 2 of the high-latitude faint blue star samples discussed by Newell and Newell and Graham. The properties of the NGC 6752 gap support the hypothesis that the field-star gaps are a characteristic of the $T_{\rm eff}$ distribution of the field horizontal-branch stars.

We demonstrate also that the bluest stars in NGC 6752 have $\langle T_{\rm eff}\rangle \approx$ 27,000 K and log $\langle L/L_\odot\rangle \approx 1.25$, consistent with membership in an extended horizontal branch, and suggesting that these objects are the cluster analogs of the spectroscopically defined field subdwarf B stars. The large number of possible sdB stars in NGC 6752 (there are at least 15 stars below the horizontal-branch gap) is difficult to explain by using the hypothesis that the sdB stars are binaries.

Subject headings: clusters: globular — stars: evolution — stars: horizontal-branch

I. INTRODUCTION

The H-R diagram derived for the globular cluster NGC 6752 by Cannon and Lee (1973; see Lee 1976) revealed the presence of a remarkable horizontal branch (HB). It was already known, from the work of Alcaino (1970, 1972) and Cannon and Stobie (1973), that the HB in NGC 6752 was confined to the blue horizontal-branch (BHB) region, and that it sloped down steeply toward the blue. Cannon and Lee's new measurements penetrated to much fainter limiting magnitudes ($V \sim 19.3$ mag) than the earlier studies, and they discovered that the BHB sequence extended to $V \approx 17.8$ mag ($M_v \sim +4.6$ mag) and that it displayed a wide gap ($\Delta V \sim 1.0$ mag) centered at $V \approx 16.3$ mag ($M_v \sim +3.0$ mag). Wesselink (1974) also demonstrated the extreme blueness of the NGC 6752 BHB sequence, although his measurements were not dense enough to show the gap.

The unusual BHB distribution seen in NGC 6752 provides a unique opportunity to investigate several problems in post–red-giant evolution. First, we can study the properties of the stars below the HB gap. If they are faint because they are hot (and hence have large bolometric corrections), then they may be globular cluster subdwarf B (sdB) stars (Sargent and Searle 1968). Baschek and Norris (1975) have shown that the majority of the field sdB stars are members of the Galaxy's disk population; the large collection of possible sdB's in NGC 6752 (there are 15 BHB stars below the gap in Cannon and Lee's H-R diagram) could provide a means for greatly extending our understanding of halo (Population II) sdB's.

Second, we can test the hypothesis, advanced by Newell (1973, hereafter Paper I) and Newell and Graham (1976, hereafter Paper II), that the gaps seen in the effective temperature ($T_{\rm eff}$) distribution of the high-latitude faint blue stars are a horizontal-branch phenomenon. One of the difficulties in testing this hypothesis, as pointed out in Paper I, is that there are few cluster BHB stars known that have $T_{\rm eff} \geqslant 4.33$ (the effective temperature of gap 2—the hotter of the two field-star gaps discussed in Papers I and II); NGC 6752 affords us an opportunity to remove this limitation.

In this paper we report an initial investigation of the NGC 6752 BHB sequence. We base our study on *UBV* photometry (§ II) of a small sample of BHB stars; the sample contains objects from above and below the gap. In § III we examine the distribution of our program stars in the (log L, log $T_{\rm eff}$)-diagram and show that (i) their properties are consistent with membership of an extended BHB, and (ii) the stars below the gap have properties like those observed for sdB stars. In § IV we use our observations to derive a (V, $T_{\rm eff}$)-calibration for the NGC 6752 BHB stars and, via this calibration, use the Cannon and Lee (1973) photometry to derive the $T_{\rm eff}$ boundaries of the gap. We show that the NGC 6752 BHB gap is similar to gap 2 in the field BHB sequence.

II. *UBV* OBSERVATIONS

Program stars were selected on the basis of unpublished finding charts and photometry kindly made available by Dr. R. D. Cannon. Offsets were determined for each star, and for several sky regions near each star; care was taken, by examining each field on a deep photograph of the cluster, to ensure that no obvious contaminating stars were present in the regions selected for observation.

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TABLE 1

TEST OBSERVATIONS OF BLUE FIELD STARS

Star	Spectral Type	V	B-V	U-B	Source
Feige 107	B	10.13	-0.13	-0.59	Klemola (1962)
		10.13	-0.14	-0.59	Present Study
Feige 108	sdB	12.90	-0.28	-1.06	Eggen & Greenstein (1965)
		12.97	-0.24	-1.04	Present Study
Feige 110	sdO	11.8:*	-0.31	-1.18	Feige (1958)
		11.86	-0.33	-1.19	Klemola (1962)
		11.50	-0.30	-1.20	Eggen & Greenstein (1965)
		11.83	-0.31	-1.16	Present Study
HD 205805	sdB	10.22	-0.21	-0.95	Newell (1969)
		10.19	-0.24	-0.95	Present Study

* the value quoted by Feige is m_{pg} = 11.5 which is equivalent to $\underline{V}$ ~ 11.8.

The observations were made with the Cerro Tololo 91 cm and 1.5 m telescopes, using a 1P21 pulse-counting photometer and standard *UBV* filters. Red-leak measurements were made, but corrections were found to be unnecessary for our blue stars. Extinction was measured each night; night-to-night variations were insignificant, so mean values were computed and used throughout the reductions.

We standardized the photometry via observations of (i) isolated field stars selected from the lists of Cousins and Stoy (1963), and (ii) stars in the open cluster NGC 6087 (Fernie 1961). The transformations to the *UBV* system were well determined and could be adequately represented by linear relations.

As a check on the reliability of our photometry of extreme BHB stars, we observed a set of field stars that were expected to be similar to the NGC 6752 program stars. The test stars are identified in Table 1; in column (2) of this table we give spectral types according to Sargent and Searle (1968; HD 205805) and Greenstein and Sargent (1974; Feige 107, 108, and 110). In the subsequent columns of Table 1 we present our *UBV* observations plus any previously published photometry; the sources of the photometry are listed in the final column. There is good agreement between our data (NS) and the mean of the previous measurements. At most there is a small shift in $(U - B)$; the average algebraic difference being $\langle\Delta(U - B)\rangle = +0.013$ mag (in the sense NS − other). This effect in $(U - B)$ is not significant in the context of the present investigation.

Our results for the 10 NGC 6752 BHB stars are presented in Table 2. In column (1) we give identification numbers according to Cannon and Lee (1973); columns (2), (3), and (4) contain the *UBV* data; and in column (5) we list the number of nights on which each star was observed.

The stars in Table 2 can be divided into a *bright group* (six stars that lie above the BHB gap) and a *faint group* (four stars that lie below the gap). Approximately 40% of the observations of the members of the bright group, and two measurements of star 3565 in the faint group, were made with the 91 cm telescope; the rest of the data were obtained with the 1.5 m reflector.

We list the standard errors of our photometry in Table 3A. The errors were computed by using small sample statistics in the manner recommended by Keeping (1962); we show the results obtained for the bright and faint groups separately.

All of our program stars have been observed, either photoelectrically or photographically, in *B* and *V* by Cannon and Lee (1973), and they have also observed the four brightest stars (1007, 1065, 1091, and 1118) photoelectrically in *U*. In Table 3B we show the results of a comparison between our photometry and that of Cannon and Lee (CL): the quantities tabulated are the mean values of the differences $(m_{NS} - m_{CL})$. The two sets of colors agree reasonably well; there appear to be systematic differences $\Delta(B - V) \sim +0.014$ mag and $\Delta(U - B) \sim -0.03$ mag. More serious for our present study is the possibility of a scale difference in the *V* measurements. Cannon (1977) has suggested that,

TABLE 2

UBV OBSERVATIONS OF BHB STARS IN NGC 6752

Star (1)	*V* (2)	*B − V* (3)	*U − B* (4)	*n* (5)
1007.....	14.25	+0.00	−0.03	6
1056.....	14.96	−0.07	−0.35	5
1065.....	14.47	−0.02	−0.09	4
1083.....	15.37	−0.14	−0.60	4
1091.....	14.25	+0.02	+0.01	4
1118.....	14.45	−0.02	−0.15	5
3299.....	17.47	−0.22	−0.90	3
3507.....	17.55	−0.22	−0.93	2
3565.....	17.31	−0.13	−0.98	5
III-118...	17.79	−0.25	−1.03	2

TABLE 3

A. INTERNAL ERRORS OF OUR PHOTOMETRY

	Bright Group (mag)	Faint Group (mag)
$\epsilon(V)$..........	± 0.018	± 0.040
$\epsilon(B - V)$.......	± 0.018	± 0.033
$\epsilon(U - B)$.......	± 0.022	± 0.025

B. COMPARISON WITH CANNON AND LEE'S PHOTOMETRY

	Bright Group (mag)	Faint Group (mag)
$\langle \Delta V \rangle$..........	$+0.007$	$+0.113$
$\langle \Delta(B - V) \rangle$....	$+0.018$	$+0.010$
$\langle \Delta(U - B) \rangle$....	-0.033*	...

* Four stars.

because of the paucity of blue standards, a scale error may be present in the photographic measurements of the faintest BHB stars. A plot of $\Delta V = V_{NS} - V_{CL}$ versus V_{CL} shows that the difference between the two sets of observations can be represented by the relation $\Delta V = 0.036 V_{CL} - 0.518$; in the analysis presented in § IV it is essential that the Cannon and Lee photometry be on the same scale as our photoelectric data, and we have used the above $(\Delta V, V_{CL})$-relation to transform their observations onto our system.

The data from Table 2 are plotted in Figure 1. Figure 1*a* shows, schematically, the relationship between the stars of our sample and the complete NGC 6752 horizontal branch (from Cannon and Lee 1973).

In the two-color diagram (Fig. 1*b*) our observations define a tight sequence that runs parallel to the Population I main-sequence relation (Eggen 1965); this is the expected behavior for a BHB sequence (Newell 1970). Star 3565 lies considerably to the red of the other members of the faint group. There are three obvious explanations for this displacement:

i) *Photometric errors.*—This star is the only member of the faint group that was observed with the 91 cm telescope. The mean $(V, B - V, U - B)$-values from the two 91 cm observations are (17.29, −0.05, −0.98 mag), and those from the three 1.5 m observations are (17.33, −0.19, −0.99 mag). If the 1.5 m data are adopted, then star 3565 moves across toward the other members of the faint group; nevertheless, the good agreement between the V and $(U - B)$ measurements indicates that this explanation may be incorrect. Furthermore, there is no indication of systematic, telescope-dependent differences in the photometry of the brighter cluster stars and the four test stars.

ii) *Reddening differences.*—It is possible that the unusual colors of star 3565 reflect larger-than-average reddening. The tightness of the sequence defined by

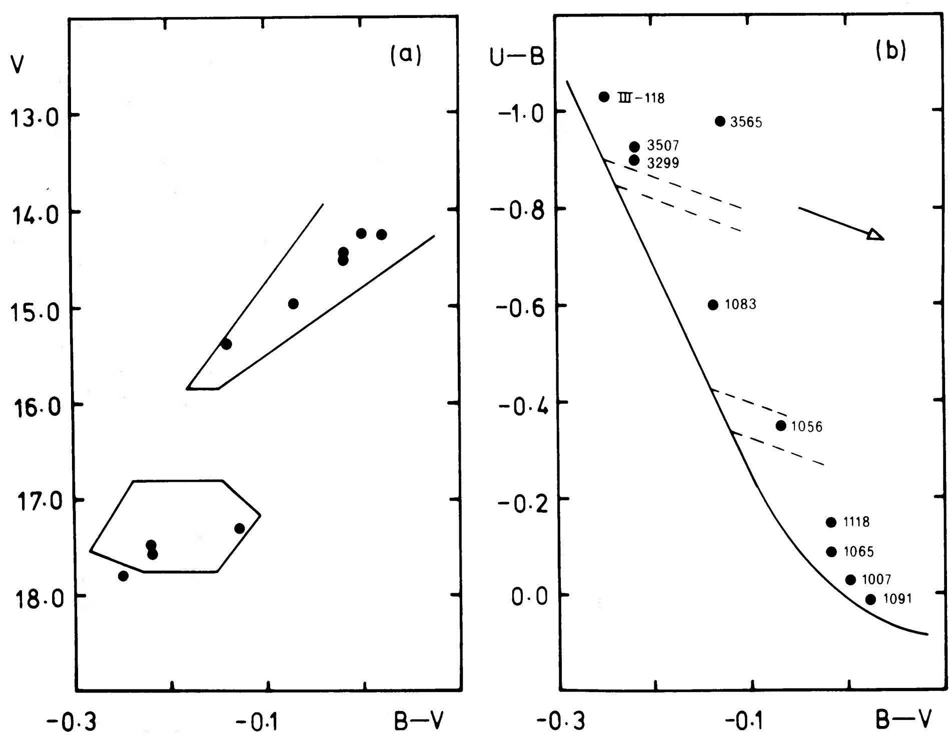

FIG. 1.—(*a*) An H-R-diagram for the NGC 6752 BHB stars observed in this study. *Solid lines* show approximately the boundaries of the BHB star distribution as determined by Cannon and Lee 1973. The gap in the horizontal branch occurs between $V \sim 15.8$ mag and $V \sim 16.8$ mag. (*b*) The NGC 6752 BHB stars in the two-color diagram. The stars are identified using the Cannon and Lee numbers quoted in Table 2. *Solid line*, intrinsic Population I main-sequence two-color relation of Eggen 1965; *arrow*, slope of the reddening trajectory; *dashed lines*, locations of the field star gaps from Newell 1973.

the remaining BHB stars argues against this explanation; the standard error of the mean reddening (see below) is ± 0.006 mag, which indicates that the reddening across NGC 6752 is uniform.

iii) *Composite energy distribution.*—Greenstein and Sargent (1974) have discussed a subgroup of the high-latitude faint blue stars that, spectroscopically, appear to be composite. These composite objects have unusual colors, and Greenstein and Sargent have shown that they may be binaries composed of a hot horizontal-branch subdwarf plus a G or K main-sequence star. If we accept the colors of 3565 as quoted in Table 2, then we find that it lies with the Greenstein and Sargent composites in the two-color diagram.

The possibility that 3565 is a binary deserves further investigation (see discussion in § V). Because of our present uncertainty concerning the interpretation of our colors for this star, we have omitted it from all subsequent analyses.

We derive a reddening estimate for NGC 6752 by measuring the shift required to move the points plotted in Figure 1*b*, with the exception of that for star 3565, onto the Population I main-sequence relation; we find $E(B - V) = 0.05 \pm 0.006$ mag. The error quoted has been derived from the scatter in the nine individual reddening values and is, therefore, an internal error. Our reddening value agrees well with that derived by Cannon and Stobie (1973); Burstein and McDonald (1975) also concluded that the reddening of NGC 6752 is $\sim$0.05 mag.

III. THE NGC 6752 BHB STARS IN THE PHYSICAL H-R DIAGRAM

We begin our analysis by examining the assumption, implicit in the discussion so far, that both groups of blue stars in NGC 6752 are members of a single HB sequence. Our approach to this problem is to study the distribution of our program stars in the ($\log L$, $\log T_{\rm eff}$)-diagram, and to compare this distribution with the predictions of interior theory.

In Table 4 we present Q and $T_{\rm eff}$ values for nine of our program stars: star 3565 has been omitted for the reasons discussed in § II. Here $Q = (U - B) - 0.72$. $(B - V)$ is Johnson and Morgan's (1953) reddening-free $T_{\rm eff}$ parameter; the $T_{\rm eff}$ values were determined by using the (Q, θ_e)-calibration given by Philip and Newell (1975), where $\theta_e = 5040/T_{\rm eff}$ is the reciprocal effective temperature. Because we can expect stellar surface gravity g to increase with $T_{\rm eff}$ along the BHB sequence (see Paper I, § IV), and because Q does display some gravity sensitivity for hot stars, we need to check the validity of our application of a (Q, θ_e)-calibration to a BHB sample. This we did by using the (Q, θ_e)-relation to derive $T_{\rm eff}$ values for several sdB stars that have had model atmosphere analyses made of their spectra and energy distributions; HD 205805 (Baschek and Norris 1970), HD 4539 (Baschek, Sargent, and Searle 1972), and HD 149382 (Baschek and Norris 1975). We found excellent agreement between the $T_{\rm eff}$ values adopted by the authors listed above and those derived via our (Q, θ_e)-calibration:

Luminosities were derived for our program stars from the V magnitudes listed in Table 2. We used a visual absorption $A_V = 3E(B - V) = 0.15$ mag, and we adopted a distance modulus $(m - M)_\odot = 13.20$ mag (Lee 1976); Lee's estimate of the distance modulus is consistent with earlier values quoted by Alcaino [1972; $(m - M)_\odot = 13.5$ mag], Cannon and Stobie (1973; 13.5: mag), and Wesselink (1974; 13.0 mag). We adopted the bolometric-correction (B.C.) scale of Code *et al.* (1976); we list bolometric corrections and bolometric magnitudes in columns (4) and (5), respectively, of Table 4. The luminosities of our program stars, derived assuming $M_{\rm bol,\odot} = 4.72$ mag (Allen 1963), are presented in column (6) of Table 4.

The ($\log L$, $\log T_{\rm eff}$)-distribution of the NGC 6752 stars is shown in Figure 2. The error bars plotted in this diagram include the effect of random errors in the photometry, and the effect of systematic errors in the distance modulus [$\epsilon(m - M) = \pm 0.30$ mag] and in the visual absorption [$\epsilon(A_V) = \pm 0.02$ mag]. Figure 2 also includes representative zero-age horizontal-branch (ZAHB) loci based on computations by Sweigart and Gross (1976). The light lines show constant core-mass ($M_c = 0.475\ M_\odot$) loci for three values of the helium abundance ($Y = 0.2$, 0.3, and 0.4 by mass); all loci were computed for metal abundance $Z = 0.001$. The total mass, M_T, varies along these three ZAHB-sequences, from $M_T = 0.50\ M_\odot$ at $\log T_{\rm eff} \sim 4.35$ to

TABLE 4

PHYSICAL PROPERTIES OF BHB STARS IN NGC 6752

Star* (1)	Q (2)	Log $T_{\rm eff}$ (3)	B.C. (3)	$M_{\rm bol}$ (5)	Log $(L/L_\odot)$ (6)
1007........	−0.03	4.021	−0.37	0.53	1.68
1056........	−0.30	4.134	−1.06	0.55	1.67
1065........	−0.08	4.037	−0.46	0.66	1.62
1083........	−0.50	4.217	−1.62	0.40	1.73
1091........	0.00	4.009	−0.32	0.58	1.66
1118........	−0.14	4.064	−0.60	0.50	1.69
3299........	−0.74	4.380	−2.44	1.68	1.22
3507........	−0.77	4.412	−2.59	1.61	1.24
III-118........	−0.85	4.493	−2.96	1.48	1.30

* Star 3565 omitted from this table; see text.

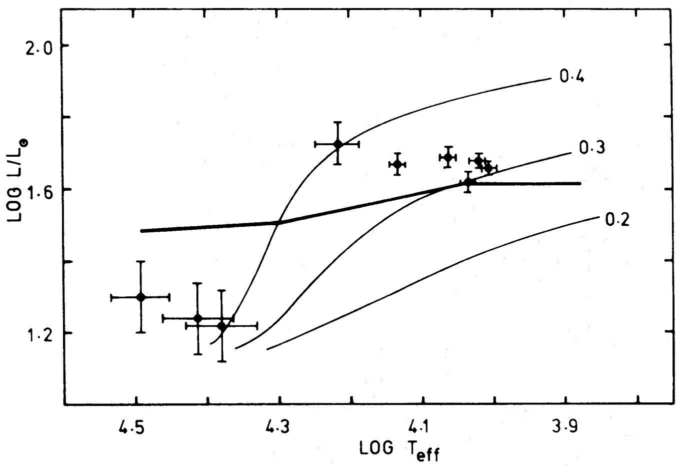

FIG. 2.—The NGC 6752 BHB stars in the physical H-R diagram. Individual stars are represented by *filled circles*; errors were computed as described in the text. The *light lines* represent (constant core-mass, variable total-mass)-ZAHB sequences from the computations of Sweigart and Gross 1976; the curves are labeled with the parameter Y, the abundance (by mass) of helium used in the calculation. The *heavy line* represents a (variable core-mass, constant total-mass)-ZAHB with total mass = 0.58 $M_\odot$, $Y = 0.30$, and metal abundance $Z = 0.001$.

$M_T \sim 0.6\ M_\odot$ at $\log T_{\rm eff} \sim 3.9$. The heavy line shows the shape expected for a constant-M_T ZAHB with $M_T = 0.58\ M_\odot$, $Y = 0.3$, and $Z = 0.001$; M_c varies along this sequence from $M_c = 0.575\ M_\odot$ at $\log T_{\rm eff} \sim 4.5$ to $M_c \sim 0.45\ M_\odot$ at $\log T_{\rm eff} \sim 3.9$.

We can draw several conclusions from the distribution shown in Figure 2:

i) The BHB stars in our sample can be divided into a *hot group* ($\log T_{\rm eff} > 4.3$, $\log \langle L/L_\odot \rangle = 1.25$), and a *cool group* ($\log T_{\rm eff} < 4.3$, $\log \langle L/L_\odot \rangle = 1.68$); these groups correspond, respectively, to the faint and bright groups defined above.

ii) The stars of the hot group are considerably less luminous than those of the cool group. The relationship between the observational points and the theoretical ZAHB sequences shows that the observed luminosity difference is consistent with current theoretical descriptions of the HB. That is, at least one of Sweigart and Gross's (1976) ZAHB sequences (variable-M_T, $Y = 0.3$, $Z = 0.001$) provides a suitable lower envelope to the observed ($\log L$, $\log T_{\rm eff}$)-distribution.

iii) The constant-M_T ZAHB (*heavy line*; Fig. 2) permits only a small decrease in luminosity with increasing $T_{\rm eff}$ and, therefore, appears to be ruled out as the basis for a unified description of the NGC 6752 observations.

iv) According to current theory, an unavoidable consequence of adopting a BHB description of the NGC 6752 blue stars is that the members of the hot group are less massive ($M_T \sim 0.50\ M_\odot$) than those of the cool group ($M_T \sim 0.58\ M_\odot$). If we adopt these ZAHB-based mass estimates, then we can use them, together with the mean luminosities quoted above, to derive estimates of the surface gravities of the stars in each group. We find average atmospheric parameters $\langle \theta_e, \log g \rangle = (0.41, 3.82)$ for the cool group, and $\langle \theta_e, \log g \rangle = (0.19, 5.55)$ for the hot group. The values derived for the cool group agree well with atmospheric parameters obtained previously for cluster and field BHB stars (see Fig. 6 of Paper I); those derived for the stars in the hot group are similar to the values expected for sdB stars (Sargent and Searle 1968; Baschek and Norris 1970, 1975; Baschek, Sargent, and Searle 1972; Greenstein and Sargent 1974).

We conclude that it is likely that the stars of the hot group are true BHB stars (i.e., that they have the same double energy-source structure as cooler HB stars), and that they are cluster analogs of the field sdB stars.

IV. THE NGC 6752 BHB GAP

We compare the NGC 6752 HB gap with the field-star gaps, discussed in Papers I and II, by determining its location in $T_{\rm eff}$. Since we cannot define the gap boundaries on the basis of our small sample of BHB stars, we use our observations instead to calibrate the more extensive photometry of Cannon and Lee (1973). Because $(U - B)$ measurements are not available for the complete sample of BHB stars, and because $(B - V)$ is insensitive to $T_{\rm eff}$ for hot stars, we use apparent V magnitude as our $T_{\rm eff}$ parameter. The rapid falloff in V, as one proceeds along the BHB toward hotter stars, is primarily a reflection of the steep temperature dependence of the bolometric corrections. Thus, provided that we use the results in a statistical sense only (because stars at a constant value of $T_{\rm eff}$ will have a spread in luminosity), we can estimate the $T_{\rm eff}$ properties of the NGC 6752 BHB gap from the observed distribution of V magnitudes by using a (V, $T_{\rm eff}$)-calibration.

The correlation between V and $T_{\rm eff}$, for our sample of BHB stars, is shown in Figure 3. An adequate fit to

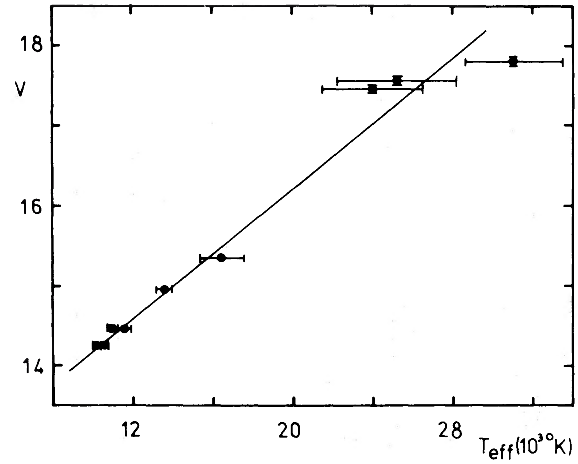

FIG. 3.—The (V, T_{eff})-calibration for the NGC 6752 BHB stars. The abscissa is T_{eff}, in units of 10^3 K, from Table 4. The ordinate is apparent visual magnitude V from Table 2. Error bars are shown on each point; the T_{eff} errors were derived from the individual photometric errors and propagated through the Q calculation and the (Q, θ_e)-calibration. Star 3565 has been omitted (see text).

these data is provided by the linear relation shown in the figure; the equation of this line is $T_{eff} \approx (4.890\,V - 59.260) \times 10^3$ K. The correlation of V with T_{eff} is reasonably tight and, because the scatter about the line is comparable with the expected T_{eff} errors, we see that luminosity effects are not serious for this sample of stars. Our program stars were selected at random from Cannon and Lee's lists, mainly on the basis of freedom from crowding, so the (V, T_{eff})-calibration of Figure 3 should provide adequate T_{eff} estimates for the present investigation.

We use our (V, T_{eff})-calibration as follows: (i) We construct the integral $V(N)$ relation shown in Figure 4.

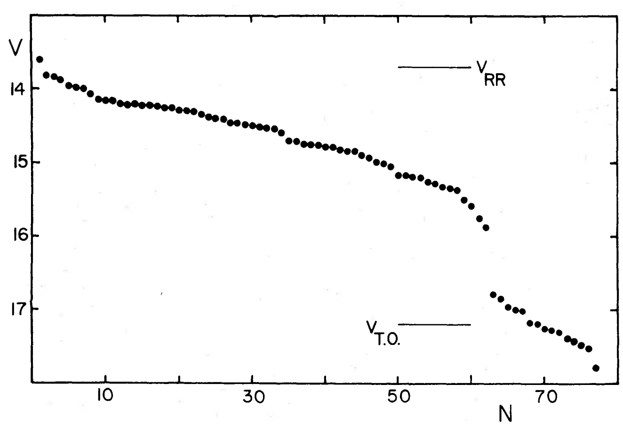

FIG. 4.—The cumulative V distribution, $V(N)$, for the NGC 6752 BHB stars according to the photometry by Cannon and Lee 1973. The *short horizontal lines* labeled V_{RR} and V_{TO} represent, respectively, the apparent magnitude levels expected for the horizontal branch at the position of the RR-Lyrae instability zone, and the apparent magnitude of the NGC 6752 turnoff. The sudden drop in $V(N)$ at $N = 62$ is caused by the HB gap.

In this diagram N is the serial number of each BHB star in a sequence arranged in order of increasing V magnitude; $V(N)$ is based on Cannon and Lee's (1973) data. The gap appears as the sharp drop in $V(N)$ at $N = 62$. (ii) From $V(N)$ we derive the V limits of the HB gap on Cannon and Lee's magnitude system; we find $V_{U,CL} = 15.9$ mag (upper limit) and $V_{L,CL} = 16.8$ mag (lower limit). (iii) The V_{CL} limits are converted to the magnitude scale of our (V, T_{eff})-calibration by using the $(\Delta V, V_{CL})$-relation discussed in § II; this process yields $V_U = 16.0$ mag and $V_L = 16.9$ mag. (iv) Finally, we derive the T_{eff} limits of the gap by using the (V, T_{eff})-calibration. The results are shown in Table 5A; we find that the NGC 6752 gap is approximately 4400 K wide and that it is centered at $T_{eff} = 21{,}180$ K.

A comparison of these results with the data presented in Papers I and II (Table 5B) shows that, while the midpoint of the NGC 6752 gap lies at a slightly lower T_{eff} value than the corresponding field-star gap, it is wide enough to completely overlap the field-star gap. We conclude that the gap seen in NGC 6752 is related to gap 2 in the field-star HB sequence.

Finally, we note that the cooler gap (gap 1 at $\log T_{eff} \sim 4.11$) is not obvious in the $V(N)$-diagram. There is a small jump at $V_{CL} \sim 14.7$ mag (corresponding to $\log T_{eff} \sim 4.1$) but it is not a significant feature of the distribution; additional, more accurate observations are needed before we can assess the status of gap 1 in this cluster.

V. DISCUSSION

There appears to be little doubt that the two field-star gaps, reported in Papers I and II, are a characteristic of the nonuniform T_{eff} distribution of the field BHB stars. Their identification with the horizontal branch depends on their presence in field-star samples that were selected to minimize contamination by non-BHB stars (Greenstein and Sargent 1974; Paper II), and on the existence of gaps, or abrupt changes in stellar number density, at the same values of T_{eff} in globular cluster BHB sequences (Newell 1970; Paper I; the present paper; see also some of the H-R diagrams cataloged by White 1970, especially those for M13

TABLE 5

A. T_{eff} LIMITS OF THE NGC 6752 BHB GAP

Parameter	Upper Limit	Lower Limit
V_{NS}	16.0 mag	16.9 mag
T_{eff}	18,980 K	23,380 K
$\log_{10} T_{eff}$	4.28	4.37

B. COMPARISON WITH FIELD-STAR GAP 2

Gap	$\Delta \log T_{eff}$	$\log T_{eff}$ (center)	Source
Field, gap 2........	0.030	4.33	Paper I
Field, gap 2........	$\sim$0.054	4.34	Paper II
NGC 6752.........	0.091	4.33	This paper

[Arp and Johnson] and M15 [Sandage, Katem and Kristian]). The anomalous Balmer jumps, observed for some M92 BHB stars with log $T_{\rm eff} \sim 4.10$, may be additional evidence for the existence of HB inhomogeneities (Oke, reported by Auer and Demarque 1977).

It is unlikely that the HB gaps are caused by peculiarities of the photometric systems (Greenstein and Sargent 1974; Paper II), or that they are the result of post–ZAHB evolution (Sweigart, Mengel, and Demarque 1974; Paper II; Sweigart and Gross 1976). We are left, therefore, with the conclusion that a clumpy HB implies a multimodal distribution of the physical, or chemical, parameters that determine the location of BHB stars in the H-R and two-color diagrams. The effects may be atmospheric, causing a range of spectral energy distributions for stars with identical values of $T_{\rm eff}$ (Auer and Demarque 1977), or they may involve the interior parameters, causing stars to arrive on the ZAHB at several separate locations (Baschek and Norris 1975; Mengel, Norris, and Gross 1976; Paper II).

Auer and Demarque (1977) have proposed an explanation for gap 1 that is based on the effect of UV absorption by carbon (C) and nitrogen (N). They point out that both C and N can contribute to the UV opacity in the atmosphere of a star with log $T_{\rm eff} \sim 4.1$. If the C, or N, abundance is high enough (greater than 0.10 solar), the additional UV opacity can cause a redistribution of flux in the Balmer continuum; this has the effect of raising the Balmer continuum near the Balmer jump and, since the slope of the Paschen continuum is largely unaffected, it reduces the size of the Balmer jump. Auer and Demarque show that the consequent change in the (Balmer jump, θ_e)-relation, in conjunction with an unchanged (Paschen slope, θ_e)-relation, can cause a low-density region in the two-color diagram. The same mechanism can explain the anomalous Balmer jumps observed by Oke in the spectra of several of the M92 HB stars, provided that we admit that these stars have atmospheric C or N abundances that are $\sim 10^3$ times the values expected in M92.

The major objection to the Auer-Demarque hypothesis is that it requires such high C or N abundances. It is difficult to see how these abundances could be elevated, in HB stars, without some effect being apparent in the spectra of the asymptotic–giant-branch stars; in their spectroscopic survey Norris and Zinn (1977) found *no* CH or CN stars in their samples in M13 and M15 (both of which appear to have clumpy horizontal branches; see White's 1970 catalog), or in M92 (where some of the HB stars have anomalous Balmer jumps). An observational study of the (Balmer jump, Paschen slope)-relationship for cluster HB stars may provide a method for attacking this problem: excess scatter, or cluster-to-cluster slope variations, would be expected if Auer and Demarque are right.

An explanation for gap 2 is implicit in the binary mass-transfer mechanism proposed by Mengel, Norris, and Gross (1976) to explain the low masses expected for sdB stars. If the B subdwarfs are BHB stars, then their total masses must satisfy the condition $M_T \approx M_c$ because, for a wide range of abundances, an extremely blue ZAHB location requires a small envelope mass ($M_e = M_T - M_c$); the above condition implies that M_T(sdB) $\approx 0.5\ M_\odot$ (see Sweigart, Mengel, and Demarque 1974; Baschek and Norris 1975; Mengel, Norris, and Gross 1976; and the references quoted in these papers). Following the suggestion that such low masses might result from accelerated mass loss in a binary system (Baschek and Norris 1975), Mengel, Norris, and Gross carried out a theoretical investigation of the mass-transfer process in a Population II binary. They found that, for components with masses 0.80 $M_\odot$ and 0.78 $M_\odot$, there was a restricted range of initial separations (0.6 AU $\leqslant S \leqslant$ 0.9 AU) for which the primary lost essentially all of its envelope by transfer to the secondary as it evolved up the giant branch. If the initial separation exceeded $\sim$0.9 AU, no mass transfer occurred, and the primary could be expected to become a normal HB star. If the initial separation was less than $\sim$0.6 AU, the mass transfer was too rapid for the primary to complete its evolution to the helium-core flash; in this case the star should bypass the HB and evolve directly from the giant branch to the white-dwarf sequence.

Such an on-off mass-loss mechanism provides an attractive explanation for gap 2. Because the ZAHB location of a BHB star depends sensitively on M_e, a bimodal distribution of M_e produces a bimodal $T_{\rm eff}$ distribution of ZAHB stars; the predominantly vertical post-ZAHB evolution expected for BHB stars with log $T_{\rm eff} \geqslant 4.1$ (Sweigart, Mengel, and Demarque 1974) should allow the initial nonuniform distribution to persist in the evolving HB sequence.

The unusual BHB star distribution seen in NGC 6752 poses several problems for the binary mass-transfer hypothesis. First, the overall blueness of the HB indicates that the mean mass of the BHB stars is significantly lower ($M_{\rm BHB} \sim 0.6\ M_\odot$) than the masses expected for stars near the turnoff ($M_{\rm TO} \sim 0.8$–$1.0\ M_\odot$). This conclusion, which is consistent with the masses derived for BHB stars in other clusters (see, for example, Newell 1970 and the references quoted therein), suggests that a pre–helium-flash mass-loss of $\sim$0.2–0.3 $M_\odot$ is a normal occurrence during the evolution of a Population II star. Mengel, Norris, and Gross (1976) point out that, since they assumed that the mass of the binary system was conserved, their calculations may not be reliable if mass is lost from the system as a whole (see Mengel, Norris, and Gross 1976 for a complete discussion).

A more serious problem involves the survival of binaries in a globular cluster environment. As long as few cluster sdB's were known, it was possible to argue that their rarity was a point in favor of the binary mass-transfer mechanism (Mengel, Norris, and Gross 1976). But it is likely that sdB's are *not* rare in NGC 6752—in Cannon and Lee's (1973) H-R diagram there are 15 BHB stars below the HB gap. According to calculations by Renzini, Mengel, and Sweigart (1977), it is difficult for binaries with separations greater than $\sim$0.04 AU to survive in NGC 6752. Furthermore, Renzini, Mengel, and Sweigart suggest that blue stragglers should be present in clusters where binaries can survive; there are no blue stragglers in Cannon and Lee's H-R diagram for NGC 6752. If the extreme BHB stars in NGC 6752 are B subdwarfs, then it is likely that their low masses (and the presence of gap 2 in the BHB sequence) cannot be explained by the binary mass-transfer mechanism.

A more detailed investigation of the NGC 6752 BHB stars would be valuable. In particular, a spectroscopic study of the hot BHB stars (with $\log T_{\text{eff}} > 4.33$) should be made; such an investigation would allow the homogeneity of the group to be investigated (for example: Is star 3565 peculiar? Are there other peculiar objects in the group? Do any of the stars show signs of duplicity?), and should also provide a test of the suggestion that these stars are sdB's. If it can be shown that the hot BHB stars in NGC 6752 are sdB's, then the occurrence of such a large group in one cluster provides an unparalleled opportunity for us to improve our understanding of these enigmatic objects.

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