AN ATTEMPTED EXPLANATION OF THE HORIZONTAL BRANCH

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The purpose of the work reported here has been to determine whether the horizontal branch in globular clusters might be explained on the hypothesis that at the time of the helium flash or subsequently, globular cluster stars become completely mixed and then evolve across the HR diagram from left to right. To this end the evolution of an initially homogeneous star, representing the hypothetical post-mixing stage of a globular cluster star, was computed in detail. As will be seen, the result was to make the hypothesis of complete mixing appear quite unlikely.

As a reasonable estimate for the mass of a horizontal branch star, a value $\boldsymbol{m} = \boldsymbol{m}_\odot$ was chosen. Also, a heavy element content $Z = 0.001$ was adopted. With this choice of $\boldsymbol{m}$ and Z, the initial homogeneous state must consist mainly of helium if the luminosity is to come out comparable to that of the globular cluster horizontal branches. Various values for the hydrogen content X were tried; the value for which the computations were carried furthest and for which results are given here was $X = 0.25$.

The method used to compute the evolution was essentially that of Larson and Demarque,[1] with the following improvements:

1) Radiation pressure has been included.
2) Recent opacity tabulations by Cox and Stewart[2] have been used, including the effect of conduction by degenerate electrons.
3) A subroutine that inserts more points in the thin hydrogen-burning shell of advanced evolutionary stages has been incorporated to keep numerical errors within a specified tolerance.
4) A modified transformation of variables has been em-

ployed. The variable that Larson and Demarque call "p" ($\equiv 10\ P/T^{2.5}$) is unsuitable for luminous stars with no convective envelope because it becomes extremely small close to the surface in such a way that numerical accuracy is poor unless many points are used. Instead the variable $p^{1/\nu}$ has here been used, where $\nu = \sigma - 2.5$ in the notation of Larson and Demarque. It can be shown that the new dependent variable $p^{1/\nu}$ is a nearly linear function of the independent variable x close to the surface, so that we still get good numerical accuracy with only a moderate number of points.

Computation of an evolutionary sequence of models was carried out with the Caltech IBM 7094 computer. A total of 80 models were computed, covering a time interval of 1.68×10^8 years. Some properties of selected models in the evolutionary sequence are given in Table I. The evolutionary track in an

TABLE I

EVOLUTION OF A STAR WITH $m = m_\odot$, $X = 0.25$, $Z = 0.001$

t (10^8 yr)	$L/L_\odot$	$R/R_\odot$	T_c (10^7 °K)	ρ_c (gm/cm³)	M_{bol}	$\log T_e$
0	28.5	.747	2.72	1.37×10^2	1.12	4.189
.4	31.7	.792	2.79	1.41	1.01	4.188
.8	35.9	.852	2.92	1.51	0.87	4.186
1.0	38.6	.885	3.01	1.60	0.80	4.185
1.2	42.6	.888	3.29	2.01	0.69	4.195
1.25	45.0	.841	3.54	2.57	0.63	4.213
1.2602	49.7	.817	3.59	3.80	0.52	4.230
1.2656	54.3	.850	3.14	5.72	0.42	4.231
1.3375	63.4	.911	2.91	8.84×10^2	0.25	4.233
1.4375	75.3	.979	2.95	1.24×10^3	0.07	4.236
1.5250	92.7	1.09	3.07	1.90	−0.16	4.236
1.5937	121	1.30	3.39	3.52	−0.44	4.225
1.6344	159	1.71	4.07	6.86×10^3	−0.74	4.196
1.6547	197	2.29	4.84	1.14×10^4	−0.98	4.155
1.6672	232	3.09	5.57	1.66	−1.15	4.108
1.6758	264	4.25	6.22	2.22	−1.29	4.053
1.6809	286	5.56	6.67	2.66×10^4	−1.38	4.004

M_{bol}, $\log T_e$ diagram is plotted in Figure 1, with times marked along the track in units of 10^8 years. Also plotted for comparison are the zero-age main sequence[3] and the horizontal branch of M 3, based on normal points given by Sandage[4] with the revised distance modulus of 15.40.[5] Bolometric corrections and effective temperatures have been taken mainly from Harris.[6]

It is immediately apparent from Figure 1 that the computed track gives no hope of representing the globular cluster horizontal branches. The increase in luminosity is much too great, and furthermore there is the difficulty that the star spends most of its time near the beginning of its track, where few if any stars are observed. One could alter the position of the computed track somewhat by trying different values for the mass and initial composition, but it seems unlikely that its general shape could be greatly altered, and one would still be left with both of the difficulties mentioned. The hypothesis of complete mixing during or after the helium flash thus appears to be ruled out, and one will have to consider more complicated unmixed models to obtain an explanation of the horizontal branch. In this connec-

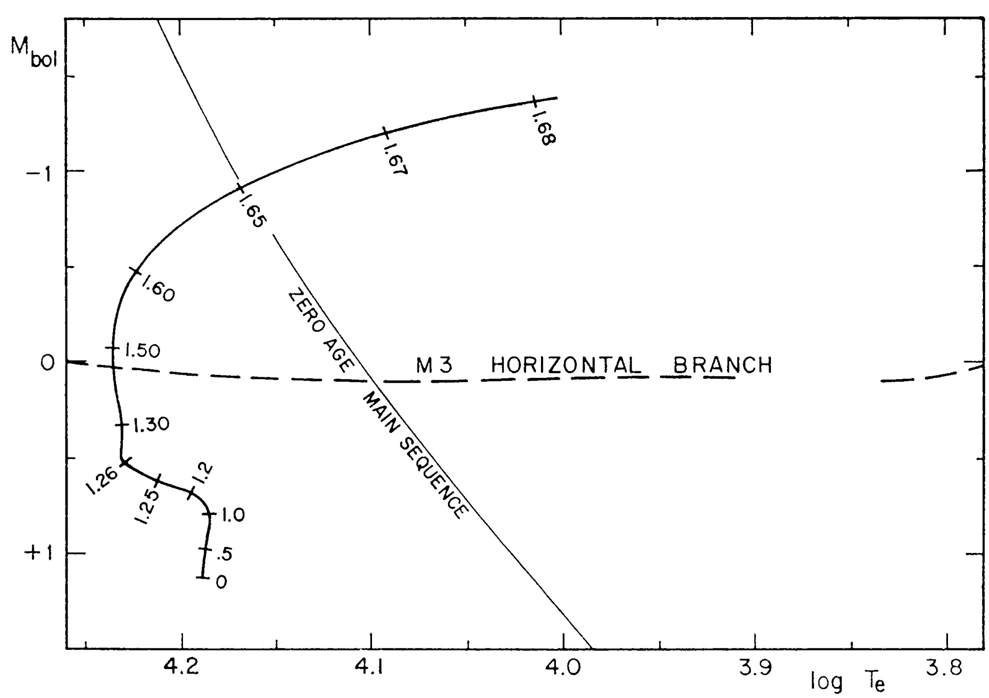

FIG. 1.—Evolutionary track for an initially homogeneous star with $m = m_\odot$, $X = 0.25$, $Z = 0.001$. Times are marked along the track in units of 10^8 years.

tion the helium-burning models studied by Hayashi, Hoshi, and Sugimoto[7] show more promise. Helium core models with a hydrogen-burning shell source are presently under investigation by John Faulkner at Caltech.

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[3] A. Sandage, *Ap. J.*, **125**, 435, 1957.

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[5] *The Observatory,* **84**, 245, 1964.

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[7] C. Hayashi, R. Hoshi, and D. Sugimoto, *Prog. Theor. Phys. Supplements* No. 22, 1962.