OBSERVATIONAL CONFIRMATION OF A THEORY OF STELLAR EVOLUTION*

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ABSTRACT

A "standard" main sequence for age zero has been computed from the observed Hyades, Praesepe, and Pleiades main sequences. The computations were made on the basis of a recent theory of stellar evolution. This "standard" main sequence turns out to be the lower envelope of the near-by stars in the color-magnitude diagram. New distance moduli are given for three clusters. They were obtained by fitting the cluster main sequences to our standard main sequence. A comparison of the luminosities of the brighter cluster stars with the values for these same stars that were obtained from other investigations confirms the evolutionary corrections to the main sequence.

INTRODUCTION

The problem of the determination of the absolute magnitudes of the stars of the higher luminosities is difficult to solve. The low density of such stars in space precludes the use of trigonometric parallaxes because of the large distances. The three principal methods that have been used in the determination of the absolute magnitudes of the higher luminosity stars are: (1) statistical parallaxes, determined through proper motions and radial velocities (and assumed galactic-rotation constants); (2) cluster parallaxes, determined from the group motions of clusters fairly near the sun; and (3) cluster parallaxes, determined by fitting the fainter cluster members to values obtained from stars near enough for direct distance determinations.

In this paper we discuss the applications of the third method and the systematic corrections that should be made on the basis of the current theory of stellar evolution. We apply this method to the determination of the distances of three galactic clusters containing stars of the higher-luminosity classes. We fit the cluster main sequences to a standard main sequence, whose position on the color-luminosity diagram we derive on the basis of present evolutionary theory and observations of near-by stars and clusters. The reliability of this computed standard main sequence may be judged by the degree of agreement between the values obtained herein for stars of the higher luminosities and the previous luminosity calibrations, such as that of Keenan and Morgan (1951). We do not attempt here to give a luminosity calibration more precise than is needed for the present purpose, to check the conceptions of evolution used in the determination of the standard main sequence.

THE STANDARD MAIN SEQUENCE

Before we can fit the cluster main sequence to a standard main sequence, we must determine the position of such a main sequence in the color-luminosity diagram. Johnson and Morgan (1953) gave a "standard" main sequence, derived from their photometry of several galactic clusters and of near-by stars. On the basis of recent theories of stellar evolution and observational confirmation of them, there is now reason to believe, however, that a standard main sequence so derived will necessarily lead to higher luminosities for stars of a given color than one would expect to find for main-sequence stars in galactic clusters containing high-luminosity or O-type stars. The reason is the following: According to present ideas on stellar evolution (Schönberg and Chandrasekhar 1942;

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Sandage 1954; Johnson and Sandage 1955), an evolving star changes its position in the color-luminosity diagram by moving up and to the right, away from the main sequence, the speed of evolution being greater for the higher-luminosity stars. This evolutionary motion in the color-luminosity diagram has two important consequences here: First, the near-by stars that in the past have been designated as "main-sequence" stars, are not, in general, stars whose evolution is zero (age zero) but are, in fact, a mixture of stars of various ages. This means that, for stars of sufficiently high luminosity and age for the evolutionary effects to be significant, the "average" main-sequence stars will be brighter than an unevolved star of the same color (Johnson and Knuckles 1955) and, second, that the brighter end of a cluster main sequence will evolve faster than the

TABLE 1

STANDARD MAIN SEQUENCE FOR AGE ZERO

MK	$B-V$	M_v	MK	$B-V$	M_v	MK	$B-V$	M_v
B8....	−0 09	+0 5	A7 .	+0.19	+2.7	G5 .	+0.68	+5.3
B9. . .	− .05	+1 0	F0.....	+ .30	+3 2	G8 .	+0.70	+5.5
A0...	.00	+1 6	F2 . . .	+ .37	+3.6	K0 .	+0 82	+6.1
A1....	+ .05	+1 8	F5. .. .	+ .44	+4 0	K2	+0.86	+6.3
A2 .	+ .07	+2 0	F8	+ .53	+4 5	K3 .	+1.01	+6.8
A3 .. .	+ .09	+2.2	G0 .	+ .60	+4.9	K5 .	+1.18	+7.5
A5 . .	+0.15	+2.5	G2. .	+0.64	+5.1	K7. .	+1.37	+8.4

TABLE 2

DISTANCE MODULI OF THE THREE CLUSTERS

Cluster	Apparent Modulus	True Modulus	True Distance (Parsecs)
NGC 2362 ..	11.2	10.9	1510
h and χ Persei .. .	13.4	11.8	2290
Orion.	... ..	8.0	400

fainter end, and, as a result, the brighter parts of cluster main sequences tend to be brighter than the initial main sequence for age zero. This effect has been noted observationally by Trumpler (1930) and others.

Thus when one fits the Pleiades main sequence to the near-by stars, as Johnson and Morgan (1953) did, one makes a systematic error due to the first effect above. Because the Pleiades stars are younger than the average near-by "main-sequence" stars and therefore have evolved less than the average near-by stars, this fit yields a distance modulus for the cluster that is too large (Johnson and Knuckles 1955) and luminosities for the cluster stars that are too high. When one, following Johnson and Morgan (1953), fits the fainter end of the NGC 2362 main sequence to the brighter end of the Pleiades main sequence, one commits systematic error because of the second effect noted. The Pleiades is an older cluster than NGC 2362, and its stars, in the region of the fitting around A0, are more luminous than the corresponding main-sequence stars of NGC 2362. These systematic errors combine to produce a systematic error of about 0.5 mag. at A0 in the "standard" main sequence of Johnson and Morgan.

The position of the main sequence for age zero may be computed in the manner of Johnson and Knuckles (1955), using the Pleiades main sequence to extend the computations to earlier spectral types than is permitted by the Hyades and Praesepe clusters. The position of this new standard main sequence depends basically upon the geometrical distance of the Hyades cluster by van Bueren (1952). The computations of the main sequence for age zero depend upon the theory of Harrison (1944). However, they are performed differentially, starting from the observed Hyades-Praesepe main sequence, and the theory probably is satisfactory for this purpose. The new values obtained by this procedure for the standard main sequence (age zero) are given in Table 1. We estimate that the uncertainty of the position of this main sequence for age zero corresponds to a

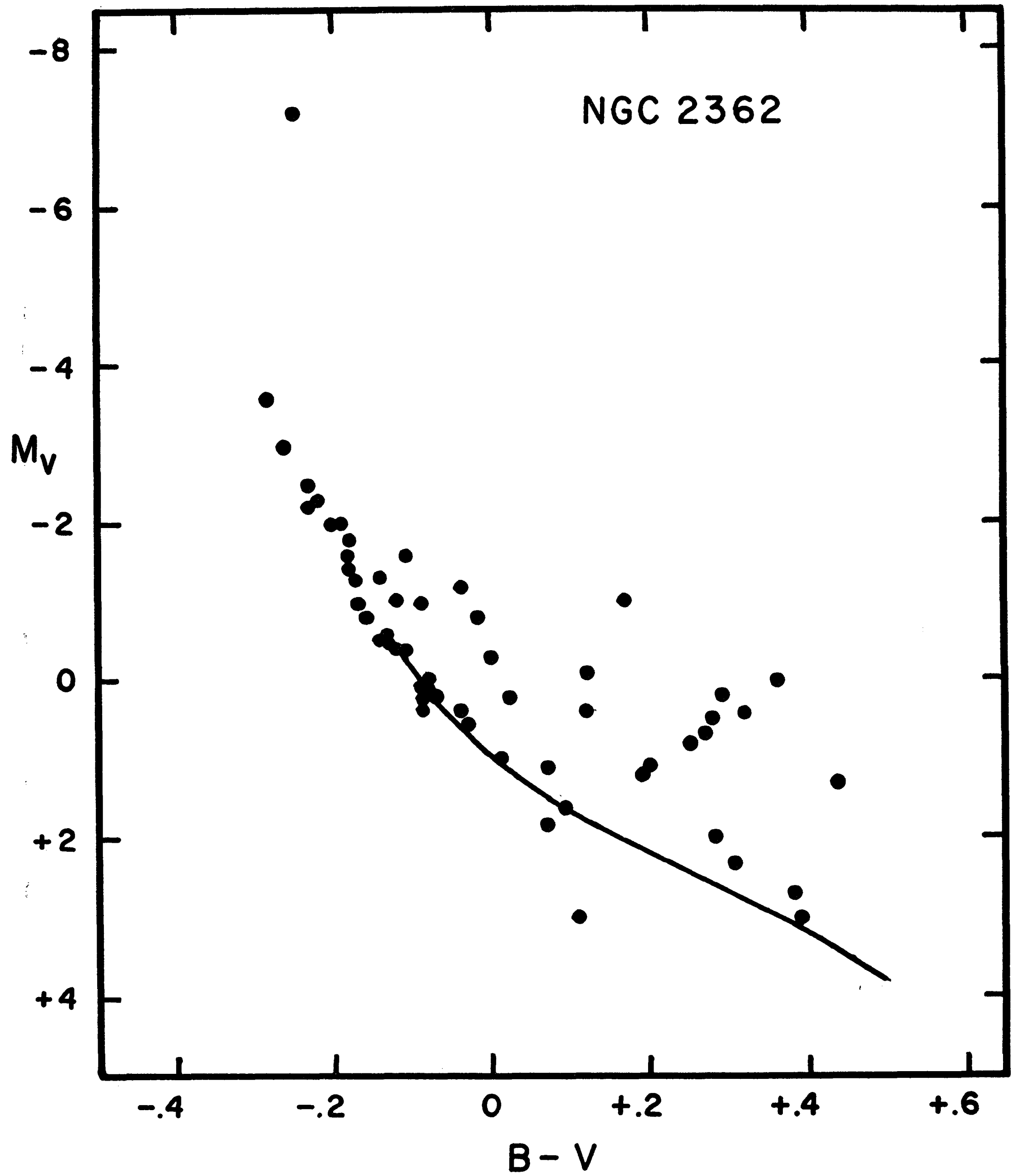

FIG. 1.—Color-luminosity diagram for NGC 2362, corrected for interstellar absorption and reddening. The solid line represents the standard main sequence of Table 1.

probable error of approximately +0.2 mag., unless there is some unforeseen, but unlikely, error in the evolutionary theory. It should be understood that by the term "main sequence for age zero" we mean the locus in the color-luminosity diagram of stars which have completed their gravitational contraction but which have not yet begun their evolutionary motion caused by changing chemical composition.

If we use the evolutionary theory of Ledoux (1949) instead of that of Harrison (1944), we find the standard main sequence from B8 to F0 to be about 0.1 mag. fainter than given in Table 1. This difference is negligible for the purposes of this paper.

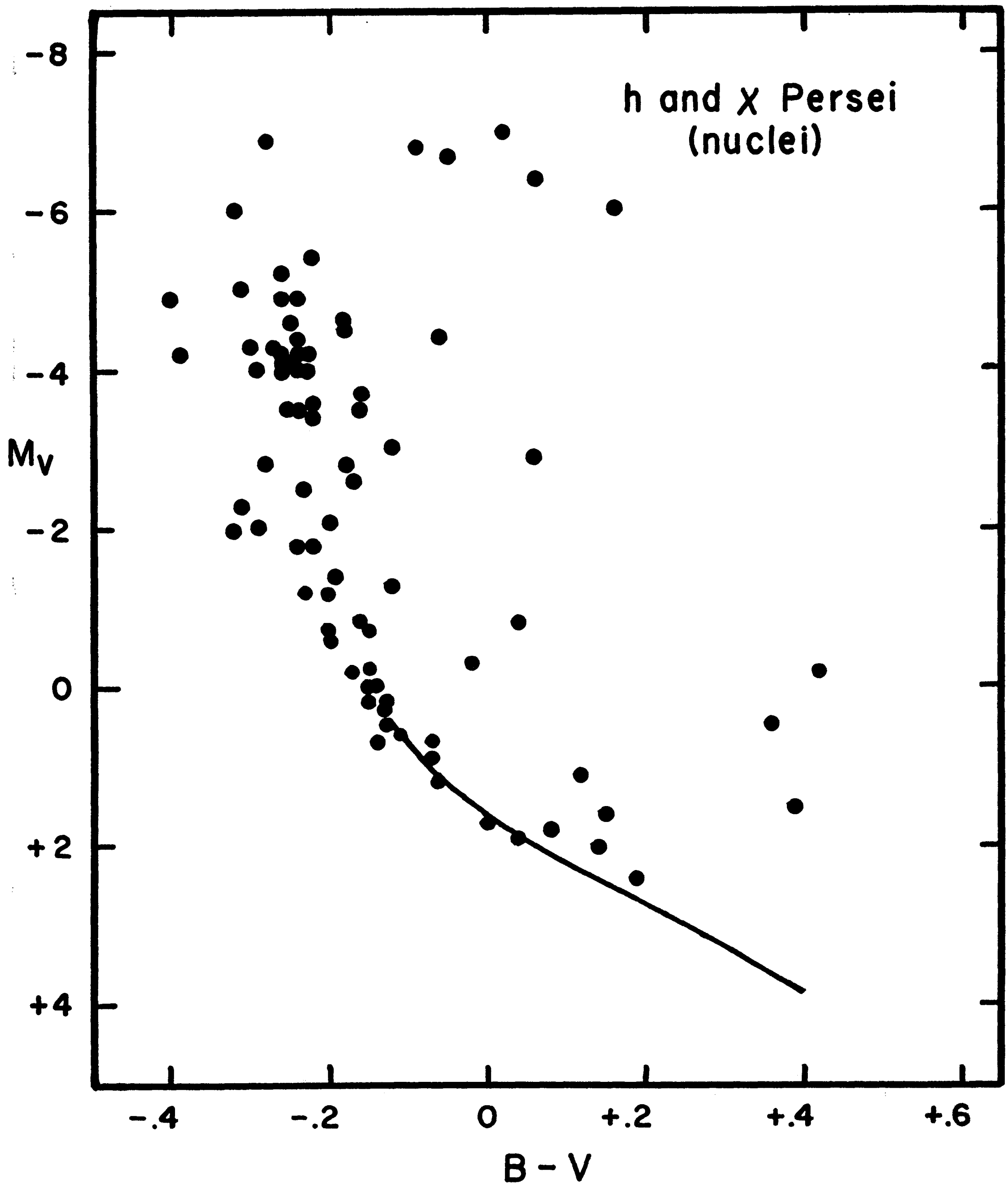

FIG. 2.—Color-luminosity diagram for the nuclear regions of h and χ Persei, corrected for interstellar absorption and reddening. The solid line represents the standard main sequence of Table 1.

THE DISTANCE MODULI OF THE THREE CLUSTERS

We now proceed to fit the main sequences of the three clusters to our new standard main sequence in the range of spectral types from B8 to A0. The resultant moduli are listed in Table 2. The data for the cluster stars are from Johnson and Morgan (1953, 1955) and Sharpless (1952, 1954). Except for Orion, the clusters were assumed to be uniformly reddened, and the true distance moduli were computed from the apparent ones by means of the value of the ratio of total to selective absorption, $A_v/E_{(B-V)} = 3.0$ (Morgan, Harris, and Johnson 1953). For Orion, the value of $A_v/E_{(B-V)} = 6.0$ (Sharpless 1952) has been used, and, because of the variable reddening, individual corrections for absorption were made for each star. No apparent modulus is given for Orion. The moduli for h and χ Persei apply to main-sequence stars in the nuclear regions.

TABLE 3

ABSOLUTE MAGNITUDES OF STARS IN NGC 2362

Star	MK	M_v	Star	MK	M_v	Star	MK	M_v
9	B3 V	−1 4	26	B5 V	−0 8	39	B2 V	−1 4
14	B2 V	−1 6	27	B3 V	−1 0	48	B3 V	−1 7
20	B2 V	−2 4	30	B1 V	−3 0	50	B5 V	−1 0
23	O9 III	−6 8	31	B2 V	−1 9			

TABLE 4

ABSOLUTE MAGNITUDES OF STARS IN h AND χ PERSEI (INNER REGION)

Star	MK	M_v	Star	MK	M_v
3	B2 I*b*	−5 8	1899	B2 II	−5.0
16	B1 I*ab*	−6 9	2139	B2 V	−1 9
146	B1 IV	−3 9	2172	O6	−4.7
612	B1 II	−4 9	2178	A1 I*a*	−7 1
662	B1 I*b*	−5 3	2185	B3 V	−2 5
864	B1 V	−3.6	2227	B2 I*b*	−5 5
950	B2 V	−2 3	2232	B2 V	−2.2
978	B1 5 V	−3 1	2246	B2 III	−3 6
1057	B3 I*a*	−7 2	2251	B3 V	−1.8
1078	B1 V	−3 8	2488	B1 V	−3 4
1162	B2 I*a*	−7 3	2541	B2 II	−4 3
1187	B2 IV	−2 9	2589	A2 I*ap*	−6 4
1268	B0 5 V	−4 4	2621	B8 I*a*	−6 9
1586	B1 III	−4 5			

In the fitting of the cluster main sequences to our standard "age-zero" main sequence, we must be sure that the cluster stars used in the fit are neither *too old* nor *too young* for our standard main sequence. For both NGC 2362 and h and χ Persei, the maximum age of the clusters, based upon the value of $M_v = -6.5$ for the brightest cluster stars and equation (24) of Strömgren (1952), is about 3×10^6 years. The minimum age of these two clusters, based upon the observed fact that the faintest members of each cluster are of spectral class approximately A0 and Table 1 of Henyey, Le Levier, and Levée (1955), is about 2×10^6 years. Thus all the stars of these two clusters must be about the same age, and we can be certain that the fainter main-sequence stars just above the lower limit of the cluster main sequences are comparable with our standard main sequence. Figures 1 and 2 illustrate these points. Some of the fainter stars to the right of the standard main sequence may be in the process of gravitational contraction.

The situation for Orion is not so clear cut as for the other two clusters, since Sharpless' (1954, Fig. 2) observations do not show the lower limit of the main sequence. However, since the brightest stars in Orion are about the same age as those in the other two clusters, it seems reasonable to assume that the fit to the cluster stars, B8–A0, is valid.

The absolute magnitudes of a number of stars in these three clusters are given in Tables 3–6. These magnitudes have been computed with the distance moduli of Table 2. A large number of higher-luminosity stars within 3 degrees of the double cluster are

TABLE 5

ABSOLUTE MAGNITUDES OF STARS IN h AND χ PERSEI (OUTER ASSOCIATION)

Star	MK	M_v	Star	MK	M_v
HD 15558	O6	−6.5	HD 16778	A2 *Ia*	−6.6
BD+60°503	B1 5 V	−4 6	HD 16808	B0 5 *Ib*	−5.7
HD 15570	O5 f	−6 8	HD 17088	B9 *Ia*	−6.9
HD 15620	B8 *Iab*	−6 5	HD 17114	B1 V	−4 9
HD 15629	O5	−5 6	HD 17145	B8 *Ia*	−6.4
HD 15642	B0 IV	−4 4	HD 17378	A5 *Ia*	−7.8
HD 15690	B1 5 *Ib*	−6 5	HDE 237007	B0 V	−4.2
BD+60°512	O6	−4.6	HD 17505	O7	−6 9
HD 15752	B0 III	−5 5	HD 17520	O8 V	−5 4
HD 15785	B1 *Iab*	−5 9	HD 17603	O7 f:	−6.2
BD+58°488	B0 5 V	−4 8	BD+59°562	O8 V	−4.4
HDE 236971	B1 IV	−4.5	BD+60°586	O7	−5.2
BD+62°424	O8	−5 3	HD 17857	B8 *Ib*	−6.7
HD 16429	O9 5 III	−6 9	No. 18325§	B1 V	−3 6
HD 16691	O5 f	−5 5	BD+60°594	O9 V	−4 5
HD 13338	B1 V	−4 3	HD 14818	B2 *Ia*	−7.2
HD 13476	A3 *Iab*	−6.8	HD 14899	B8 *Ib*	−6.0
BD+57°513	B1 III	−3.9	HD 14947	O6 f	−6.2
BD+57°520	B1 II	−4.1	HD 14956	B2 *Ia*	−7.5
HD 13494	B1 III	−3.8	No. 10*	B2 IV	−3.3
HD 13544	B0.5 IV	−3.7	BD+56°549	B1 V	−3.8
BD+54°490	B1 V	−3.4	No. 11*	B1 III	−4.2
HD 13621	B0.5 IV	−4.7	HD 15316	A3 *Iab*	−6.6
HD 13659	B1 *Ib*	−5.7	HD 15325	B1 IV	−5.3
HD 13716	B0.5 III	−5.4	BD+57°579	B1 V	−4.0
BD+59°451	B1 II	−5.5	BD+60°493	B0.5 *Ia*	−6.6
HD 13744	A0 *Iab*	−6.4	BD+60°498	O9 V	−4.4
HD 13745	B0 III	−5.3	BD+60°501	O6.5	−4.6
HD 13758	B1 V	−4.6	HD 15497	B6 *Ia*	−7.5
No. 8*	B0.5 V	−4.1	HD 15548	B1 V	−4.3
HD 12301	B8 *Ib*	−7.6	HD 13831	B0 IV	−4.7
BD+59°388	B3 II	−4.6	HD 13841	B2 *Ib*	−5.8
HD 12323	O9 V	−3 8	HD 13866	B2 *Ib*	−5.5
BD+61°370	O9 V	−4.8	BD+59°456	B0.5 V	−4.4
HDE 232588	B1.5 III	−4 1	HD 14014	B0.5 V	−4.3
HD 12509	B1 III	−6 5	HD 14092	B1 V	−4.2
BD+61°375	B0.5 IV	−4 8	BD+59°461	B1 II	−4 1
HD 12567	B0.5 III	−5.5	HD 14322	B8 *Ib*	−6.2
HD 12727	B2 III	−3 7	HD 14331	B0 III	−4.8
BD+60°435	B2 III	−5.2	HD 14442	O5.5	−4.8
HD 12867	B1 V	−3 6	BD+56°589	B1 III	−4 4
HD 12953	A1 *Ia*	−7 9	BD+60°470	O8 V	−5.0
HD 12993	O5	−4 4	No. 19316†	B1 V	−3.4
HD 13267	B5 *Ia*	−6.9	HD 14489	A2 *Ia*	−7 6
HD 13268	O8 Vnn	−5 0	BD+57°558	B0 5 III	−4.4

* Gonzalez, Graciela, and Gonzalez, Guillermina. 1953, *Bol Obs Tonanzintla y Tacubaya*, **7**, 3–10, Table 4.
† Vatican Observatory Zone + 57°, Pl. No. 252, No 19316.
§ Vatican Observatory Zone + 59°, Pl. No. 494, No. 18325.

included. For these stars, individual corrections for reddening and absorption were made on the basis of the spectral types and $A_v/E_{(B-V)} = 3.0$, and it was assumed that the distance modulus of this outer association is the same (11.8) as of the nuclear regions of the double cluster. The photometric data upon which values are based for stars not in the lists of Johnson and Morgan (1953) or of Sharpless (1952, 1954) are given in Table 7.

The absolute magnitudes of the M-type supergiants in the region of the double cluster, listed in Table 8, are computed on the same basis, except that the absorption was read from a graph, determined from the early-type stars, of the mean absorption as a function of galactic latitude and longitude. The spectral types are those given by Bidelman (1948).

TABLE 6

ABSOLUTE MAGNITUDES OF STARS IN THE ORION ASSOCIATION

Star	MK	M_v	Star	MK	M_v	Star	MK	M_v
HD 30836	B2 III	−4 7	HD 36166 .	B1 5 V	−2 5	HD 37042	B1 V	−2 9
HD 31237	B2 III	−4 5	HD 36285.	B1 5 V	−2 3	HD 37043.	O9 III	−5 7
HD 34511	B5 V	−1 0	HD 36351	B1 5 V	−3 0	HD 37055 .	B3 V	−2 1
HD 34748	B1 5 V	−2 8	HD 36392	B3 V	−0 8	HD 37062	B5 V	−1 0
HD 34989	B1 V	−3 1	HD 36429 .	B5 V	−0 6	HD 37115	B6 V	−1 4
HD 35007	B3 V	−2 9	HD 36430	B2 V	−2 3	HD 37128	B0 I*a*	−7 0
HD 35079 ..	B3 V	−1 9	HD 36486	O9 5 II	−6 4	HD 37150	B3 V	−1.5
HD 35203 .	B6 V	−0 4	HD 36512 ..	B0 V	−3 6	HD 37232	B1 5 V	−2 3
HD 35299 .	B1 V	−2 6	HD 36591...	B1 V	−3 2	HD 37303 ..	B1 V	−2 4
HD 35407 .	B5 V	−0 7	HD 36627	B6 V	−0 7	HD 37321 .	B3 V	−1 6
HD 35411	B1 V	−5 2	HD 36629	B2 V	−1 9	HD 37330 .	B6 V	−1 3
HD 35502	B5 V	−1.4	HD 36695	B1 V	−3 3	HD 37342 .	B5 V	−0 2
HD 35575	B3 V	−1 8	HD 36741	B2 V	−1 6	HD 37397	B3 V	−1 5
HD 35588	B3 V	−2 0	HD 36779	B3 V	−1 8	HD 37468	O9 5 V	−4 7
HD 35762	B2 V	−1 6	HD 36824	B3 V	−1 6	HD 37481 .	B1 V	−2 3
HD 35777	B2 V	−1 7	HD 36954 .	B3 V	−1 8	HD 37526	B3 V	−0 9
HD 35792. .	B3 V	−1.2	HD 36959	B1 V	−2 6	HD 37742	O9 5 I*b*	−6 9
HD 35899	B5 V	−0 6	HD 36960 ..	B0 V	−3 5	HD 37744	B1 V	−2 0
HD 35910	B6 V	−0 7	HD 37016	B3 V	−2 0	HD 38755	B6 V	−0 6
HD 36013	B1.5 V	−1 8	HD 37017	B1 5 V	−3 2	HD 38771	B0 5 I*a*	−6 7
HD 36133 .	B2 V	−1 9	HD 37022	O6	(−5 5)	HD 39777	B2 V	−1.7
HD 36151	B5 V	−1 5	HD 37041	O9 V	−4 6			

DISCUSSION

The data of Table 3 can be used to make a smoothed "luminosity calibration" for some of the spectral types and luminosity classes of the MK system, as in Table 9. This luminosity calibration, which is based upon computed evolutionary effects for main-sequence stars near A0, should not, at the present time, be regarded as a calibration table for use in other investigations. We wish to compare Table 9 with similar tables obtained from other investigations, to see whether observational confirmations of the evolutionary aspects of this paper can be obtained. We shall first compare Table 9 with that given by Keenan and Morgan (1951).

Since in both these investigations the same higher-luminosity stars (those in Orion and the double cluster) were used, we expect that the only difference between Table 9 and the luminosity calibration of Keenan and Morgan is a systematic difference in the zero points of the tables. This systematic difference will arise if the derived distances of Orion and the double cluster are different in the two investigations. Keenan and Morgan base their determination of the distances of Orion and the double cluster partly upon the distances found by Blaauw (1946) from the absolute space motions of the Scorpio-Centaurus group and partly upon mean values of the parallaxes of stars of types B3 V

TABLE 7

OBSERVATIONS NOT PREVIOUSLY PUBLISHED

Star	Sp.	*V*	*B−V*	*U−B*
HD 12301	B8 I*b*	5.58	+0 38	−0.27
BD+59°388	B3 II	9 62	+ .60	− 24
HD 12323	O9 V	8 90	− 21	− 93
BD+61°370	O9 V	10.06	+ 70	− 37
HDE 232588	B1 5 III	8 63	+ 07	− 71
HD 12509	B1 III	7 09	+ .35	− 54
BD+61°375	B0 5 IV	9 55	+ 57	− 44
HD 12567	B0 5 III	8 30	+ 38	− 56
HD 12727	B2 III	9.03	+ 08	− 72
BD+60°435	B2 III	9.68	+ .47	− .38
HD 12867	B1 V	9 41	+ .15	− 67
HD 12993	O5	8.95	+ .20	− .79
HD 13268	O8 Vnn	8 18	+ .13	− 83
HD 13338	B1 V	9.02	+ .25	− 55
BD+57°513	B1 III	9.50	+ 28	− 56
BD+57°520	B1 II	9.62	+ 39	− 51
HD 13494	B1 III	9 30	+ .18	− .65
HD 13544	B0.5 IV	8.88	− 01	− .82
BD+54°490	B1 V	9.52	+ .11	− 67
HD 13659	B1 I*b*	8.65	+ .56	− .41
HD 13716	B0 5 III	8.27	+ .32	− .59
BD+59°451	B1 II	9.30	+ .69	− .29
HD 13758	B1 V	9.05	+ .33	− 53
No. 8*	B0.5 V	10 22	+ .55	− .37
HD 13841	B2 I*b*	7.37	+ .23	− .65
BD+59°456	B0 5 V	9 88	+ 55	− .41
HD 14014	B0 5 V	8.75	+ .14	− .66
HD 14092	B1 V	9 23	+ 23	− .59
BD+59°461	B1 II	10 09	+ 51	− .39
HD 14442	O5 5	9 21	+ .41	− .61
BD+56°589	B1 III	9.46	+ .41	− .48
No. 19316†	B1 V	10 56	+ 41	− .44
BD+60°470	O8 V	9.88	+ .70	− 36
HD 14489	A2 I*a*	5 17	+ 37	− .11
BD+57°558	B0 5 III	9.89	+ .55	− .42
HD 14947	O6 f	7 98	+ .46	− .60
No. 10*	B2 IV	10 49	+ .43	− 41
No. 11*	B1 III	9 86	+ .48	− .44
HD 15325	B1 IV	8 51	+ 42	− 47
BD+57°579	B1 V	10 09	+ 49	− .40
BD+60°493	B0 5 I*a*	8 44	+ .79	− 30
BD+60°498	O9 V	9 92	+ 54	− 46
BD+60°501	O6.5	9.60	+ .46	− .58
HD 15548	B1 V	9.26	+ .28	− .58
HD 15558	O6	7 81	+ 52	− .56
BD+60°503	B1 5 V	9.95	+ 66	− .30
HD 15570	O5 f	8.10	+ .70	− .40
HD 15620	B8 I*ab*	8 35	+ 92	+ .17
HD 15629	O5	8 42	+ 43	− 62
BD+60°512	O6	9 41	+ 50	− .53
HD 15752	B0 III	8 74	+ .49	− 52
HD 15785	B1 I*ab*	8 34	+ .57	− 50
BD+58°488	B0 5 V	9.85	+ 68	− 26
HDE 236971	B1 IV	9.55	+ .50	− .40
BD+62°424	O8	8 83	+ .45	− 57
HD 16429	O9 5 III	7 67	+ 62	− .38
HD 16691	O5 f	8 70	+ .48	− 55
HD 16779	B2 I*b*	8 85	+0 74	−0.26

TABLE 7—*Continued*

Star	Sp.	*V*	*B−V*	*U−B*
HD 16808	B0 5 I*b*	8 60	+0 56	−0 47
HD 17088	B9 I*a*	7 50	+ 82	+ 05
HD 17114 .	B1 V	9 17	+ 50	− 45
HDE 237007	B0 V	9 44	+ 33	− 60
HD 17505	O7	7 06	+ 40	− 64
HD 17520	O8 V	8 27	+ 32	− 68
HD 17603.	O7 f:	8 45	+ 64	− 42
BD+59°562	O8 V	9.73	+ 47	− 53
BD+60°586	O7	8 48	+ .30	− 67
HD 17857.	B8 I*b*	7 66	+ 75	− 02
No. 18325‡.	B1 V	10 66	+ 57	− 34
BD+60°594	O9 V	9 30	+0 36	−0 64

* Gonzalez and Gonzalez, 1953, *Bol Obs Tonanzintla y Tacubaya,* No 7, pp 3–10, Table 4.
† Vatican Observatory Zone +57°, Pl No 252, No 19316.
‡ Vatican Observatory Zone +59°, Pl No. 494, No. 18325.

TABLE 8

M-TYPE SUPERGIANTS OBSERVED IN h AND χ PERSEI

Star	MK	V_0	$(B-V)_0$	M_v
HD 13136	M2 I*b*	6 71	+1.91	−5 1
HD 14142	M2 I*ab*	6 31	+1 64	−5.5
HD 14270	M3 I*ab*	6 13	+1 68	−5 7
HD 14330	M1 I*ab*	6 29	+1 66	−5 5
HD 14404 .	M2 I*b*	5 94	+1 67	−5 9
HD 14469	M3 I*ab*	6 04	+1 61	−5 8
HD 14488	M4 I*ab*	6 63	+1 69	−5 2
HD 14528	M3e I*a*	7 19	+1 97	−4 6
HD 14580	M0 I*ab*	6 74	+1.70	−5 1
HD 14826	M2 I*ab*	6 40	+1 68	−5 4
HDE 236979	M3 I*ab*	6 25	+1 65	−5.6
BD+56°512	M4 I*b*	7 57	+1 87	−4 2
BD+56°595	M0 I*ab*	6 45	+1 65	−5.4

and B5 V computed from their proper motions. Our determination of the distances of these same clusters depends upon van Bueren's (1952) group parallax of the Hyades, corrections to the Hyades and Pleiades main sequences according to the evolutionary models of Harrison (1944), and the fitting of the main sequences in the Orion region and the double cluster to the resultant standard main sequence for age zero. The two distance determinations are, therefore, independent.

Comparison of the values for spectral types B0–B3, inclusive, and all luminosity classes, with the values given by Keenan and Morgan (1951), yields the difference, JH − MK = +0.1 mag. If we omit the main-sequence stars, JH − MK = 0.0 mag.

A comparison of the luminosity calibration for main-sequence stars given in Table 9 and that of Keenan and Morgan (1951) for the same types of stars shows a divergence that reaches a maximum of about 1 mag. around A0. This divergence is in the direction we would expect on the basis of the evolutionary ideas mentioned. The main-sequence calibration of Tables 1 and 9 is supposed to be for very young stars, while the values of Keenan and Morgan are for a mixture of stars of various ages and evolutionary motion in the color-magnitude diagram. The same systematic effect shows for later-type main-sequence stars (see Johnson and Knuckles 1955, Fig. 10).

This systematic effect, due to the aging of stars, will show only for the main sequence, however, since stars move *through* the other luminosities in a more or less continuous stream. The evolutionary effects should not produce a systematic effect for the higher-luminosity classes, and the excellent agreement *in the mean* of the luminosity calibration of Table 5 with that of Keenan and Morgan (1951) for stars other than main-sequence stars is confirmation of the existence and size of the evolutionary effects we have discussed here.

TABLE 9

LUMINOSITY CALIBRATION (MK SYSTEM)

Type	V	IV	III	II	*Ib*	*Iab*	*Ia*
O5–O8	(−5.1)	...	...	...	...	...	...
O9	−4.6	−5.4	−6.4	...	...	...	...
O9.5	−4.4	−5.0	−5.7	−6.2	−6.6	...	...
B0	−4.1	−4.6	−5.0	−5.4	−6.2	...	−6.9
B0.5	−3.6	−4.2	−4.7	−5.2	−5.8	...	−6.9
B1	−3.1	−3.8	−4.4	−4.9	−5.8	−6.5	−6.9
B1.5	−2.6	−3.4	−4.0	−4.8	−5.8	...	−6.9
B2	−2.0	−2.9	−3.6	−4.7	−5.8	...	−6.9
B3	−1.5	−2.5	−3.3	−4.6	−5.8	...	−6.9
B5	−0.9	...	...	...	...	...	−6.9
B6	−0.5	...	...	...	...	...	−6.9
B7	−0.2	...	...	...	...	...	−6.9
B8	+0.5	...	...	...	...	−6.5	−6.9
B9	+1.0	...	...	...	...	−6.5	−6.9
A0	+1.6	...	...	...	...	−6.5	−6.9
A1	+1.8	...	...	...	...	−6.5	−6.9
A2	+2.0	...	...	...	...	−6.5	−6.9
A3	+2.2	...	...	...	...	−6.5	−6.9
A5	+2.5	...	...	...	...	−6.5	−6.9
M0	...	...	...	...	...	−5.3	...
M1	...	...	...	...	...	−5.3	...
M2	...	...	...	...	...	−5.3	...
M3	...	...	...	...	...	−5.3	...
M4	...	...	...	...	...	−5.3	...

We should point out that, in our discussions, we have assumed implicitly that the main sequence for age zero is quite narrow and independent of such differences in chemical composition, for example, as may exist between the several clusters. This assumption is supported by Figure 10 of Johnson and Knuckles (1955) and receives further support from the agreement of the luminosity calibration derived here with that of Keenan and Morgan (1951).

Petrie (1953) has derived absolute magnitudes for B stars of all luminosities that differ from those of Keenan and Morgan (1951) in the average amount, Victoria *minus* MK = +0.7 mag. Since our results agree well with MK, the difference, Victoria *minus* JH = +0.7 mag., for stars other than main-sequence stars. Thus Petrie makes the luminosities of the brighter stars in Orion and the double cluster fainter by 0.7 mag. than we find them. Since we know, from photoelectric observations, the difference in magnitude between the brighter stars and the main-sequence stars in the two clusters, Petrie's luminosities place the cluster main sequences near A0 *fainter* by 0.7 mag. than our derived main sequence for age zero. But, since we have estimated that the probable error of the position of our main sequence for age zero is about 0.2 mag. and, furthermore, since this new standard main sequence represents the *lower envelope* of the near-by stars (Johnson and Knuckles 1955, Fig. 10), it is difficult to see how it could be placed fainter by a further 0.7 mag. This discrepancy of 0.7 mag. is not important in our discussion, since Petrie's results confirm the direction (but not the size) of the evolutionary corrections to the main sequence.

We do not apply our new data to the computations of a new luminosity calibration intended for general use. Such application will be made later in combination with more data from other sources that both confirm the evolutionary corrections we have derived and provide additional data on the luminosities of individual stars.

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