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A SPECTROSCOPIC STUDY OF THE PLEIADES

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ABSTRACT

A spectroscopic study of 78 stars of the Pleiades has been made. Spectra of 59 members are combined with the photoelectric observations of Johnson. After eliminating the effects of interstellar absorption, a two-color diagram and an H-R diagram were constructed. The discontinuity in the color index $(B - V)$ shown by the near-by stars is not present in the Pleiades. The F stars in the Pleiades appear, on the average, to be relatively fainter in the ultraviolet than stars of similar type and luminosity in the neighborhood of the sun

Measures of color indices in the (U, B, V) system for near-by stars by Johnson and Harris (cf. Johnson and Morgan 1953; Morgan, Harris, and Johnson 1953) show a deficiency of stars with $(B-V)$ color index in the interval from +0.20 to +0.30 mag. Strömgren (1956) has discussed this problem. The $(B-V)$ color-index observations of the Pleiades (Johnson and Morgan 1953) do not indicate any conspicuous discontinuity between +0.20 and +0.30 mag. in $(B-V)$. The present paper is an investigation of the combined photoelectric and spectroscopic material of members of the Pleiades cluster, to eliminate the effects of interstellar absorption for each star individually.

Spectra of 78 members of the Pleiades were taken with the one-prism spectrograph attached to the 40-inch telescope of the Yerkes Observatory. The dispersion is about 125 A/mm at $H\gamma$. All plates were taken during the fall and winter of 1953–1954 and the fall and winter of 1954–1955. Spectral types and luminosity classes were assigned to these stars according to the criteria of the Yerkes revised atlas system (MK type) outlined by Morgan (see Johnson and Morgan 1953). Among these spectra, 59 are the cluster members studied photoelectrically by Johnson (*ibid.*). The remaining 19 stars were taken from Hertzsprung's catalogue (1947) of the Pleiades region. In this catalogue they are marked as cluster members according to their proper motions.

The results of the spectroscopic observations are summarized in Tables 1 and 2. The columns of Table 1 give, first, the Hertzsprung number (see Hertzsprung 1923); second, third, and fourth, the values of V, $(B-V)$, and $(U-B)$, from Johnson's photoelectric observations (*ibid.*); fifth, the type on the MK system; sixth, the value of $(B-V)_0$, the intrinsic color index; seventh, the value of $(U-B)_0$, the intrinsic color index; eighth, the value of V_0, the V magnitude corrected for interstellar absorption; ninth, Remarks.

The first, fourth, and fifth columns of Table 2 are similar to the first, fifth, and sixth columns of Table 1. The second column of Table 2 gives m, the photographic magnitude (see Binnendijk 1946); the third column lists $(B-V)_c$, the computed color index (see below).

The star Hz 146, which may be a borderline metallic-line star, has been considered to have the photometric characteristics of an A8 star. The star Hz 225 shows a weaker G band than other stars of the cluster of similar spectral type. The star Hz 310 was classified as a giant by Schwassmann (1930). Our plate indicates a spectrum fainter than luminosity class IV.

The intrinsic color indices $(B-V)_0$, which have been used for stars in Table 1, are given in Table 3. Because of the discontinuity in $(B-V)$ observed near the gap in the case of the near-by stars, the intrinsic colors in this region are uncertain; the procedure adopted was as follows: between B6 and A4, $(B-V)_0$ was taken from Table 3 of the

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TABLE 1

OBSERVATIONS OF THE PLEIADES

Hz	V	$(B-V)$	$(U-B)$	MK	$(B-V)_0$	$(U-B)_0$	V_0	Remarks
28	8 24	+0 235	+0 14	A7 V	+0 20	+0 11	8 13	
43	8 05	+ .197	+ 15	A5 V	+ 15	+ 12	7 91	
88	9 06	+ 458	+ 10	F2 V	+ 38	+ 04	8 83	
92	8 16	+ 265	+ 09	A8 V	+ 23	+ 06	8 06	
108	9 82	+ 537	+ 05	F9 V	+ 56	+ 07	9 89	
117	5 45	− 046	− 33	B7 IV	− 12	− 38	5 23	Celaeno
126	3 69	− 107	− 41	B6 III	− 14	− 43	3 59	Electra
133	10 37	+ 627	+ 13	G0 V	+ 60	+ 11	10 29	
146	8 57	+ 331	+ 16	A m ?	+ 23	+ 09	8 27	
150	5.64	− 075	− 36	B8 V	− 09	− 37	5 60	18 Tau
156	4 29	− .106	− 46	B6 V	− 14	− 48	4 19	Taygeta
169	8 98	+ 439	+ 08	F3 V	+ 41	+ .06	8 89	
187	8 02	+ 216	+ .18	A3 V	+ 09	+ 09	7 64	
206	8 58	+ 352	+ 11	A9 V	+ 27	+ 05	8 33	
213	10 12	+ .602	+ 13	F9 V	+ 56	+ 10	9 99	
216	7 16	+ 159	+ 08	A1 V	+ .03	− 01	6 77	
219	9 70	+ 548	+ 05	F9 V	+ 56	+ 06	9 74	
227	9 43	+ 520	+ 11	F5 V	+ 45	+ 06	9 22	
242	3 86	− 068	− 40	B7 III	− 12	− 44	3 70	Maia
251	7 84	+ 192	+ 16	A2 V	+ 06	+ 06	7 44	
255	5 75	− .044	− 23	B8 V	− 09	− 26	5 61	Asterope
265	6 41	− 028	− 15	B9 V	− 06	− 17	6 31	
323	4 16	− 056	− 43	B6 IV nn	− 14	− 49	3 91	Merope
329	10.42	+ .640	+ 15	G0 V	+ 60	+ 12	10 30	
341	7 34	+ .097	+ 12	A2 V	+ 06	+ 09	7 23	
371	8 09	+ .353	+ 28	A0 V	00	+ 03	7 03	
385	10 20	+ .724	+ 31	G6 V	+ 70	+ 29	10 13	
388	9 28	+ .457	+ 03	F4 V	+ 42	00	9 17	
428	10 52	+ .638	+ 16	G0 V	+ 60	+ 13	10 43	
436	6 80	+ .025	− 07	B9 5 V	− 03	− 11	6 63	
457	8 38	+ .294	+ .08	A9 V	+ 27	+ 06	8 31	
468	9 44	+ .468	+ .02	F6 V	+ 46	+ 01	9 42	
510	6 98	+ .030	+ 05	A1 V	+ 03	+ 05	6 98	
513	7 64	+ .206	+ 12	A4 V	+ 12	+ 06	7 38	
520	7 26	+ .035	+ 05	A2 V	+ 06	+ 07	7 34	
534	7 76	+ .153	+ 12	A3 V	+ 09	+ 07	7 57	
540	6.80	+ 063	+ 02	A0 V	00	− 03	6 61	
542	2 86	− .090	− 33	B7 III	− 12	− 35	2 77	Alcyone
620	9 86	+ 540	+ 11	F8 V	+ 53	+ 10	9 84	
681	9 24	+ 548	+ .12	F6 V	+ 46	+ 06	8 88	
693	8 25	+ .361	+ 11	A9 V	+ 27	+ 04	7 98	
695	9.12	+ 470	+ 07	F4 V	+ 42	+ 03	8 97	
708	10 09	+ 558	+ .07	F9 V	+ 56	+ 07	10 10	
722	5 44	− 072	− .32	B8 V	− .09	− 33	5 39	HR 1172
736	10 02	+ .556	+ .09	F8 V	+ 53	+ 07	9 96	
742	6 94	+ .125	+ 09	A1 V	+ .03	+ 02	6 66	
760	10 34	+ 614	+ .13	G0 V	+ .60	+ 12	10 30	
792	8 36	+ .284	+ 13	A8 V	+ .23	+ 11	8 20	
870	3 62	− 085	− 36	B8 III	− .09	− 36	3 60	Atlas
878	5 08	− 078	− .28	B8 pec	− 09	− 29	5 04	Pleione
885	8 11	+ .22	+ .13	A7 V	+ 20	+ 12	8 05	
891	7 51	+ .097	+ .11	A2 V	+ 06	+ 08	7 40	
910	6 59	− 028	− .12	B9 5 V	− 03	− 12	6 58	
924	7 96	+ 175	+ 13	A3 V	+ 09	+ 07	7 70	
948	9 08	+ 434	+ 02	F3 V	+ .41	00	9 01	
977	6 16	− 052	− 19	B9 V	− 06	− 20	6 14	HR 1183
996	7 53	+ 077	+ 08	A2 V	+ 06	+ 07	7 48	
1129	6 92	+ 086	+ 03	A2 V	+ 06	+ 01	6 84	
1184	8 81	+0 384	+0 05	F2 V	+0 38	+0 05	8 80	

paper by Morgan, Harris, and Johnson (1953). From it the color excesses, $E_{(B-V)}$, follow. These color excesses were plotted on a chart of the Pleiades to obtain $E_{(B-V)}$ for stars with spectra later than A4 and earlier than F2; the $E_{(B-V)}$ of each star in this spectral range is defined as the mean color excess of the neighboring stars. This determination is based only on stars with accurately defined intrinsic colors, e.g., the late B- and early A-type stars.

TABLE 2

PLEIADES STARS WITH COMPUTED $(B-V)$

Hz	m	$(B-V)_c$	MK	$(B-V)_0$	Hz	m	$(B-V)_c$	MK	$(B-V)_0$
8	9 91	+0 48	F5 V	+0 45	313	8 18	+0 25	A7 V	+0 20
27	8 18	+ 37	A9 V	+ 31	396	9 ·81	+ 41	F5 V	+ 45
29	10 03	+ 47	F5 V	+ 45	447	8 61	+ 37	A9 V	+ 31
44	10 21	+ 56	F6 V	+ 46	484	9 12	+ 48	F3 V	+ 41
123	9 37	+ 36	F3 V	+ 41	501	8 48	+ 24	A7 V	+ 20
145	9 31	+ 39	F2 V	+ 38	508	6 19	+ 03	A0 V	00
176	10 15	+ 48	F5 V	+ .45	757	9 52	+ 49	F4 V	+ 42
225	10 16	+ 60	G0 V*	+ 60	975	8 28	+ 19	A7 V	+ .20
248	6 54	+ 27	A0 V	00	1003	6 74	+0 03	A0 V	0 00
310	9 19	+0 56	G0 V	+0 60					

* Weak G band.

TABLE 3

INTRINSIC COLORS

MK	$(B-V)_0$	MK	$(B-V)_0$	MK	$(B-V)_0$	MK	$(B-V)_0$
B6	−0 14	A1	+0 03	A8	+0 23	F5 . .	+0 45
B7	− 12	A2	+ 06	A9	+ 27	F6 . .	+ 46
B8	− 09	A3	+ 09	(A9	+ 31)*	F8 . .	+ 53
B9	− 06	A4	+ 12	F2	+ 38	F9	+ 56
B9 5	− 03	A5	+ 15	F3	+ 41	G0	+ .60
A0	0 00	A7	+0 20	F4	+0 42	G6. .	+0 70

* This star is included in Table 2

The intrinsic color index, $(U-B)_0$, was computed from the formula

$$(U-B)_0 = (U-B) - 0.72E_{(B-V)}\ , \tag{1}$$

where

$$\frac{E_{(U-B)}}{E_{(B-V)}} = 0.72 \tag{2}$$

is the slope of the reddening path. This value has been taken from Johnson and Morgan (1953). For stars of Table 2 the procedure was as follows: The color indices, $\overline{CI}$, of Binnendijk's catalogue were compared with stars of known $(B-V)$ and MK type; this permitted the determination of computed values of $(B-V)$, which have been labeled $(B-V)_c$. When corrected for local values of $E_{(B-V)}$, the quantity $(B-V)_0$ was determined for stars having no directly observed (U, B, V) photometry. The intrinsic color of the A9 stars is poorly determined. In Table 2 the value of +0.31 mag. is used for class A9.

Figure 1 is a plot of $(U-B)_0$ of the Pleiades (*upper part*) and the near-by stars (*lower part*). In the upper part, filled circles refer to stars of Table 1 and open circles those of Table 2; for the latter the ordinates are arbitrary. For the near-by stars the observed colors are taken to be equal to the intrinsic colors. Some values provided by Dr. Harris in advance of publication were included. These values differ very slightly from those used to define the color index listed in Table 3. The diagram indicates that there is no gap between +0.20 and +0.30 mag. in the $(B-V)_0$ color index for the Pleiades.

The stars with $(B-V)_0$ greater than +0.4 mag. and smaller than +0.6 mag. show a remarkable difference when compared with the near-by stars; the Pleiades members have, on the average, fainter $(U-B)_0$ than the near-by stars. In the former the stars tend to be below the line $(U-B)_0 = 0.00$ mag.; in the latter they are, in general, above this

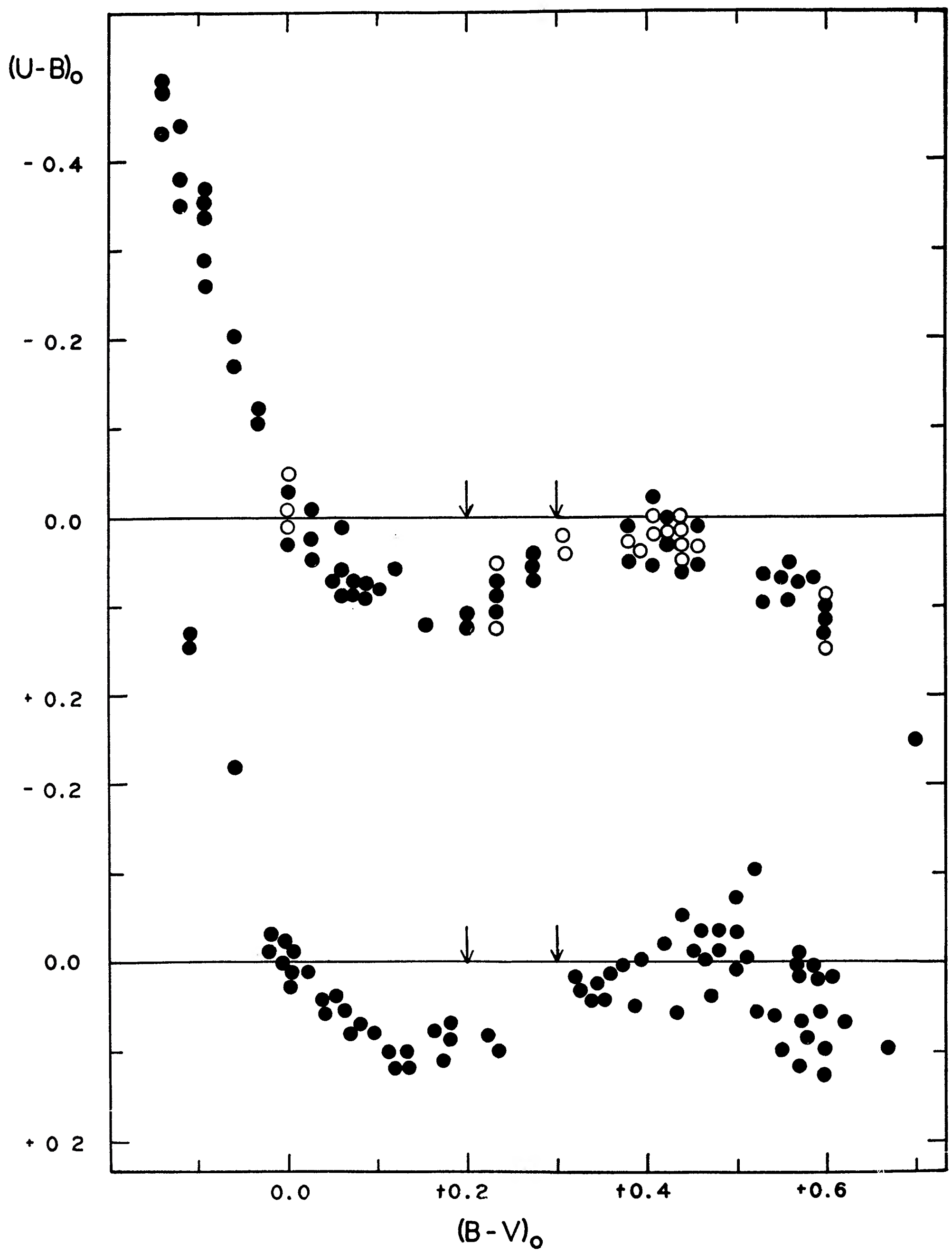

FIG. 1.—Two-color diagram of the Pleiades (*upper*) and the near-by stars (*lower*). For the Pleiades, filled circles refer to stars of Table 1 and open circles to those of Table 2.

line. The Pleiades, on the average, are fainter in the ultraviolet than the near-by stars in the range from F5 to G0.

The results for the Pleiades thus are opposite to the ultraviolet excess found by Johnson and Sandage for certain globular clusters (1955). It appears that the stars in the solar neighborhood are intermediate in this characteristic between the globular clusters, on the one hand, and the Pleiades, on the other. An opposite effect has been found for

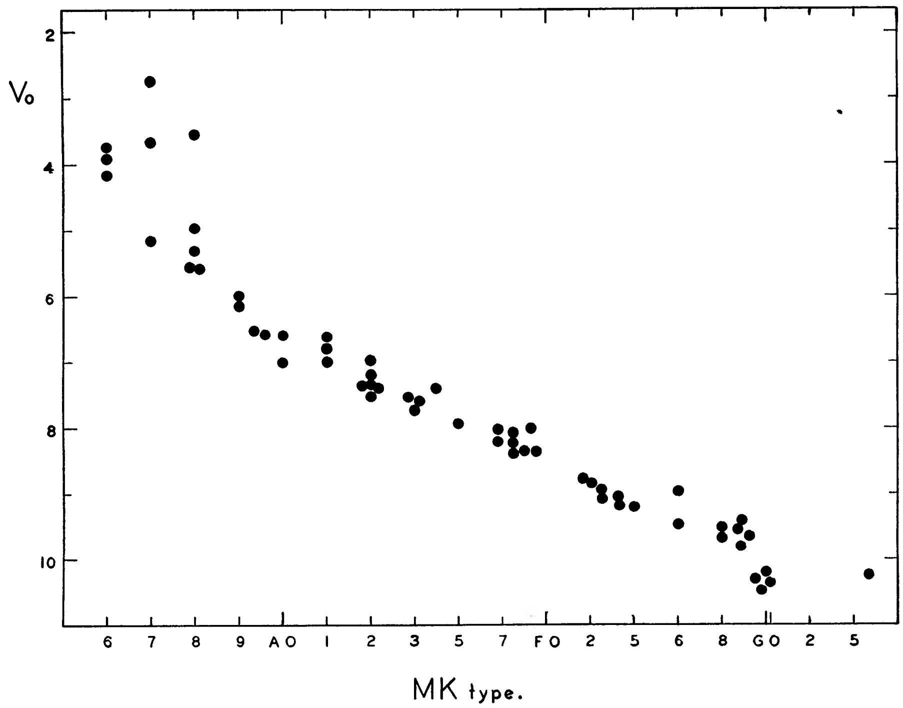

FIG. 2.—Hertzsprung-Russell diagram for the Pleiades. The quantity V_0 is the V magnitude corrected for interstellar absorption.

NGC 752 by Johnson (1953). The latter cluster is probably one of the oldest galactic clusters known. The star Hz 146, a possible metallic-line star, has an intrinsic color which lies in the gap shown by the near-by stars. The H-R diagram is shown in Figure 2. The V magnitudes have been corrected to V_0 by use of a factor of $3.0E_{(B-V)}$.

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