A STUDY OF THE ORION AGGREGATE OF EARLY-TYPE STARS. II*

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Received June 30, 1953

ABSTRACT

Ultraviolet photoelectric colors of 184 members of the Orion aggregate are given, and spectral types are derived from the photometric data.

In Paper I photoelectric colors and magnitudes of a number of early-type stars in Orion were discussed.[1] These were obtained at the McDonald Observatory during November and December, 1951, with the 13 and 82-inch telescopes. Ultraviolet measures were obtained for these stars at the same time, and the results are given here.

The method of reducing the ultraviolet observations was similar to that described earlier,[1] with the exception that the ultraviolet color extinction coefficients were assumed to have no color dependence. A zero-point difference of 0.018 mag. in the color was found to exist between observations made with the two telescopes, and that correction was applied to the 82-inch observations. The observed color, C_u, was related to the $\boldsymbol{U}-\boldsymbol{B}$ system[2] by means of the transformation

$$\boldsymbol{U}-\boldsymbol{B}=E+FC_u\,.$$

From one to five observations of each of thirty-six of the standard stars of Johnson and Morgan[2] were obtained. From a least-squares solution it was found that $E=-0.683\pm 0.003$ and $F=+0.964\pm 0.003$.

The observed colors, C_u, and the values of $\boldsymbol{U}-\boldsymbol{B}$ computed from the above coefficients for the standard stars, as well as the values given by Johnson and Morgan, are listed in Table 1. A comparison of the two sets of values is shown in Figure 1. The internal probable error of C_u was computed on the basis of those Orion stars which were observed two or more times. The probable error of one observation of C_u was found to be ± 0.009 mag.

It has been shown by Johnson and Morgan[2] that a function, Q, of the colors $\boldsymbol{U}-\boldsymbol{B}$ and $\boldsymbol{B}-\boldsymbol{V}$ can be defined which is independent of interstellar reddening, where

$$Q=(\boldsymbol{U}-\boldsymbol{B})-0.72(\boldsymbol{B}-\boldsymbol{V})\,.$$

They have shown that Q is related to spectral type for stars between B0 and A0 and that the color excesses of stars in this spectral range can be obtained from the expression

$$E_y(Q)=(\boldsymbol{B}-\boldsymbol{V})-0.337Q+0.009\,.$$

The coefficient, 0.72, in the first expression is confirmed, within the observational errors, by the colors of the Orion stars given here and in Paper I. This coefficient is the mean ratio of the ultraviolet and yellow color excesses. It is therefore evident that within the range of wave length covered by the two colors the curvature of the relation

* *Contributions from the McDonald Observatory, University of Texas*, No. 231.

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[1] *Ap. J.*, **116**, 251, 1952.

[2] H. L. Johnson and W. W. Morgan, *Ap. J.*, **117**, 313, 1953.

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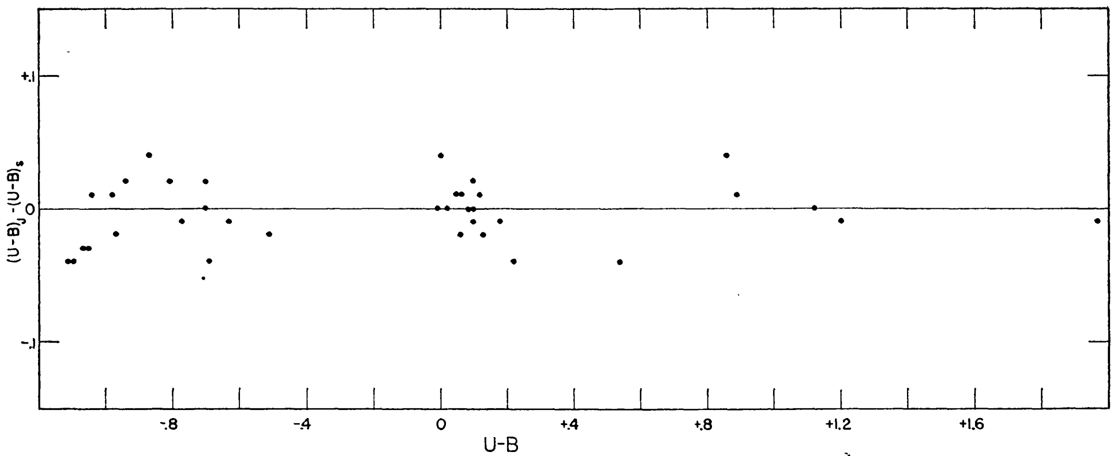

FIG. 1.—A comparison between the colors of standard stars obtained by Johnson and those obtained by the author.

TABLE 1

ULTRAVIOLET COLORS OF STANDARD STARS

STAR	SP.	$\overline{C_u}$	*U−B* Johnson and Morgan	*U−B* Sharpless	No.
β Cas	F2 IV	+0.798	+0.09	+0.09	2
50 And	F8 IV–V	+0.759	+0.06	+0.05	5
HR 483	G2 V	+0.823	+0.12	+0.11	5
β Ari	A5 V	+0.788	+0.10	+0.08	5
α Ari	K2 III	+1.865	+1.12	+1.12	18
δ Tri	G0 V	+0.729	+0.02	+0.02	3
16 Per	F2 III	+0.788	+0.06	+0.08	2
HR 875	A1 V	+0.745	+0.05	+0.04	18
ι Per	G0 V	+0.822	+0.10	+0.11	5
κ Cet	G5 V	+0.908	+0.18	+0.19	4
ϵ Eri	K2 V	+1.326	+0.54	+0.60	4
ζ Per	B1 I*b*	−0.081	−0.77	−0.76	4
ϵ Per	B0.5 V	−0.319	−0.98	−0.99	4
π^3 Ori	F6 V	+0.670	0.00	−0.04	22
π^4 Ori	B2 III	−0.155	−0.81	−0.83	20
β Eri	A3 III	+0.800	+0.09	+0.09	2
β Ori	B8 I*a*	+0.037	−0.69	−0.65	1
τ Ori	B5 III	+0.204	−0.51	−0.49	2
HD 35299	B1 V	−0.237	−0.87	−0.91	2
HD 35899	B5 V	+0.063	−0.63	−0.62	2
HD 36591	B1 V	−0.277	−0.97	−0.95	2
Cin 705	M1 V	+1.962	+1.20	+1.21	18
υ Ori	B0 V	−0.403	−1.11	−1.07	18
α Lep	F0 I*b*	+0.975	+0.22	+0.26	1
ι Ori	O9 III	−0.406	−1.11	−1.07	2
ϵ Ori	B0 I*a*	−0.361	−1.06	−1.03	1
κ Ori	B0.5 I*a*	−0.358	−1.06	−1.03	1
δ Aur	K0 III	+1.564	+0.86	+0.82	2
χ^2 Ori	B2 I*a*	−0.014	−0.70	−0.70	1
ι CMa	B3 II	−0.038	−0.70	−0.72	2
β Cnc	K4 III	+2.560	+1.77	+1.78	15
η Hya	B3 V	−0.082	−0.74	−0.76	13
10 Lac	O9 V	−0.382	−1.04	−1.05	20
HR 8832	K3 V	+1.620	+0.89	+0.88	20
υ Peg	F8 IV	+0.862	+0.13	+0.15	1
ι Psc	F8 V	+0.695	−0.01	−0.01	2

1954ApJ...119..200S

TABLE 2

OBSERVATIONS OF STARS IN THE ORION AGGREGATE

Star	$U-B$	ϵ	Q	S_Q	$E_y(Q)$	Star	$U-B$	ϵ	Q	S_Q	$E_y(Q)$
30836[a]	−0.83	2	−0.71	B2	+0.08	36487	−0.54	9	−0.46	B5	+0.05
31237[b]	−0.84	5	−0.70	B2	+0.05	36512[i]	−1.07	2	−0.88	O–B0	+0.04
−3°1013	+0.03	6	−0.14	B9	+0.30	36513	−0.11	9	−0.13	B9	+0.08
33647	−0.36	6	−0.32	B7	+0.07	36527	+0.10	9	0.00	A0	+0.15
34179	−0.47	6	−0.45	B5	+0.13	36540	−0.49	9	−0.52	B3	+0.23
34317	−0.01	6	+0.01	A0	−0.01	36541	−0.45	9	−0.39	B7	+0.06
34511	−0.69	6	−0.62	B3	+0.12	36559	−0.22	3	−0.19	B8	+0.02
34748	−0.78	6	−0.70	B2	+0.15	36560	−0.41	9	−0.34	B7	+0.03
34959	−0.53	6	−0.45	B5	+0.05	36591	−0.95	6	−0.81	B1	+0.09
34989	−0.90	6	−0.80	B1	+0.15	36607	−0.16	9	−0.13	B9	+0.01
35007	−0.67	6	−0.59	B3	+0.09	36627	−0.54	6	−0.47	B5	+0.06
35008	−0.32	9	−0.23	B8	−0.02	36629	−0.68	9	−0.69	B2	+0.26
35039[c]	−0.82	6	−0.71	B2	+0.09	36655	−0.27	3	−0.24	B8	+0.05
35079	−0.53	6	−0.51	B5	+0.15	36670	−0.05	9	−0.04	A0	+0.01
35203	−0.50	9	−0.43	B5	+0.06	36695[j]	−0.92	6	−0.80	B1	+0.11
35298	−0.59	6	−0.49	B5	+0.03	36697	−0.04	9	−0.08	B9	+0.10
35299	−0.91	6	−0.75	B1	+0.04	36741	−0.79	6	−0.65	B2	+0.03
35407	−0.64	6	−0.53	B3	+0.03	36779	−0.81	6	−0.68	B2	+0.05
35411[d]	−0.93	6	−0.79	B1	+0.09	36783	−0.11	9	−0.12	B9	+0.06
35439[e]	−0.92	6	−0.77	B1	+0.06	−3°1140	+0.11	9	−0.07	B9	+0.29
35501	−0.40	6	−0.36	B7	+0.07	36824	−0.72	6	−0.61	B3	+0.07
35502	−0.54	6	−0.52	B3	+0.15	36842	−0.51	9	−0.43	B5	+0.04
35575	−0.73	6	−0.61	B3	+0.05	36865	−0.43	9	−0.38	B7	+0.07
35588	−0.77	6	−0.64	B2	+0.05	36867	−0.16	9	−0.15	B9	+0.04
35640	−0.23	3	−0.20	B8	+0.03	36883	−0.47	9	−0.41	B5	+0.07
35673	−0.23	6	−0.23	B8	+0.09	36898	−0.43	6	−0.37	B7	+0.06
35715[f]	−0.94	6	−0.77	B1	+0.04	36899	−0.02	9	−0.06	B9	+0.08
35718	+0.01	6	−0.02	A0	+0.04	36916	−0.58	9	−0.50	B5	+0.08
35730	−0.69	6	−0.58	B3	+0.05	36917	+0.03	6	−0.09	B9	+0.20
35762	−0.73	6	−0.60	B3	+0.03	36936	−0.58	9	−0.50	B5	+0.07
35777	−0.75	6	−0.62	B3	+0.04	36938	−0.20	9	−0.25	B8	+0.16
35792	−0.64	6	−0.53	B3	+0.05	36939	−0.28	9	−0.29	B8	+0.12
35834	−0.37	6	−0.33	B7	+0.07	36954	−0.66	6	−0.60	B3	+0.12
35881	−0.50	6	−0.43	B5	+0.06	36957	−0.05	9	−0.08	B9	+0.09
35882	−0.48	9	−0.43	B5	+0.09	36958	−0.61	9	−0.56	B3	+0.13
35899	−0.62	6	−0.52	B3	+0.04	36959	−0.93	9	−0.77	B1	+0.05
35901	−0.14	9	−0.13	B9	+0.03	36960	−1.04	6	−0.86	B1	+0.05
35910	−0.55	6	−0.48	B5	+0.07	36981	−0.59	6	−0.52	B3	+0.08
35912	−0.75	6	−0.62	B3	+0.04	−3°1143	+0.04	9	−0.08	B9	+0.21
36012	−0.65	6	−0.58	B3	+0.10	36982	−0.62	9	−0.70	B2	+0.37
36013	−0.65	6	−0.56	B3	+0.07	36983	−0.20	9	−0.20	B8	+0.08
36120	−0.36	6	−0.34	B7	+0.09	36998	−0.21	9	−0.21	B8	+0.08
36133	−0.60	9	−0.54	B3	+0.10	36999	−0.45	6	−0.39	B7	+0.05
36151	−0.57	9	−0.48	B5	+0.04	37000	−0.67	6	−0.58	B3	+0.08
36166	−0.86	6	−0.71	B2	+0.05	37001	−0.27	9	−0.23	B8	+0.03
36219	−0.35	6	−0.31	B7	+0.05	37016	−0.69	9	−0.57	B3	+0.03
36234	−0.39	6	−0.34	B7	+0.05	37017	−0.79	9	−0.69	B2	+0.10
36285	−0.86	9	−0.74	B2	+0.09	37018[k]	−0.94	6	−0.80	B1	+0.08
36324	+0.05	9	−0.01	A0	+0.09	−4°1181	−0.43	9	−0.66	B2	+0.55
36351[g]	−0.84	6	−0.71	B2	+0.07	37019	−0.03	9	−0.06	A0	+0.07
−3°1119	+0.13	9	−0.02	A0	+0.23	37020[l]	−0.92	9	−0.96	O–B0	+0.39
36366	−0.02	9	−0.11	B9	+0.17	37021[m]	−0.49	9	−0.66	B2	+0.47
36392	−0.67	6	−0.57	B3	+0.06	37022[n]	−0.97	5	−1.01	O–B0	+0.41
36411	+0.05	9	−0.02	A0	+0.12	37023[o]	−0.64	5	−0.92	O–B0	+0.43
36429	−0.64	6	−0.54	B3	+0.06	37025	−0.63	6	−0.55	B3	+0.07
36430	−0.77	9	−0.66	B2	+0.08	37040	−0.71	9	−0.61	B3	+0.08
36486[h]	−1.07	6	−0.92	O–B0	+0.11	Bond 669	−0.35	9	−0.53	B3	+0.44

[a] π^4 Ori. [b] π^5 Ori (var.). [c] 22 Ori. [d] η Ori.
[e] 25 Ori. [f] ψ Ori. [g] 33 Ori. [h] δ Ori (var.).
[i] υ Ori. [j] VV Ori (var.). [k] 42 Ori. [l] θ'(A) Ori = Bond 619.
[m] θ'(B) Ori = Bond 624. [n] θ'(C) Ori = Bond 628. [o] θ'(D) Ori = Bond 640.

TABLE 2—*Continued*

Star	$U-B$	ϵ	Q	S_Q	$E_y(Q)$	Star	$U-B$	ϵ	Q	S_Q	$E_y(Q)$
37041[p]...	−0.94	9	−0.91	O–B0	+0.27	37397....	−0.75	6	−0.64	B2	+0.08
37042....	−0.93	9	−0.90	O–B0	+0.26	37411....	+0.11	9	0.00	A0	+0.17
37043[q]...	−1.07	6	−0.90	O–B0	+0.06	37428....	−0.23	9	−0.34	B7	+0.27
37055....	−0.63	9	−0.54	B3	+0.07	37468[s]...	−1.05	9	−0.88	O–B0	+0.07
37056....	−0.37	6	−0.32	B7	+0.06	−6°1273.	−0.05	9	−0.27	B8	+0.41
37057....	−0.14	9	−0.15	B9	+0.08	37469....	0.00	9	−0.16	B9	+0.28
37058....	−0.74	6	−0.62	B3	+0.06	37470....	−0.27	9	−0.32	B7	+0.18
37059....	−0.24	9	−0.22	B8	+0.06	37480....	−0.06	9	−0.07	B9	+0.04
37060....	−0.07	9	−0.09	B9	+0.06	37481....	−0.92	3	−0.76	B1	+0.04
37061....	−0.64	9	−0.85	B1	+0.59	37490....	−0.84	6	−0.80	B1	+0.22
37062....	−0.47	9	−0.51	B5	+0.23	37526....	−0.56	3	−0.47	B5	+0.05
−5°1328.	+0.02	9	−0.04	A0	+0.11	37547....	−0.10	9	−0.10	B9	+0.04
37114....	−0.12	9	−0.09	B9	0.00	37606....	−0.34	6	−0.29	B8	+0.04
37115....	−0.57	6	−0.52	B3	+0.12	37641....	−0.39	9	−0.35	B7	+0.08
37128[r]...	−1.03	9	−0.90	O–B0	+0.13	37663....	−0.09	9	−0.08	B9	+0.02
37129....	−0.73	9	−0.63	B3	+0.08	37700....	−0.48	6	−0.41	B5	+0.06
37130....	−0.11	9	−0.23	B8	+0.25	37742[t]...	−1.05	6	−0.90	O–B0	+0.10
37150....	−0.82	6	−0.69	B2	+0.05	37744....	−0.91	6	−0.75	B1	+0.03
37151....	−0.40	9	−0.34	B7	+0.04	37745....	−0.07	9	−0.08	B9	+0.06
37174....	−0.14	9	−0.11	B9	+0.02	37756....	−0.85	6	−0.70	B2	+0.03
37187....	−0.25	6	−0.24	B8	+0.08	37776....	−0.86	6	−0.76	B1	+0.13
−3°1154.	−0.09	9	−0.11	B9	+0.07	37807....	−0.65	9	−0.58	B3	+0.11
37209....	−0.93	9	−0.76	B1	+0.04	37887....	−0.11	6	−0.10	B9	+0.03
37210....	−0.41	9	−0.36	B7	+0.06	37888....	−0.05	9	−0.08	B9	+0.09
37232....	−0.85	6	−0.73	B2	+0.08	37903....	−0.63	9	−0.70	B2	+0.34
37273....	+0.04	9	−0.08	B9	+0.20	38051....	−0.31	9	−0.58	B3	+0.58
37303....	−0.96	9	−0.81	B1	+0.08	38088....	+0.05	9	−0.07	B9	+0.19
37321....	−0.55	6	−0.49	B5	+0.09	38120....	−0.06	9	−0.09	B9	+0.08
37322....	+0.01	9	−0.04	A0	+0.09	38239....	+0.01	9	−0.03	A0	+0.08
37330....	−0.56	6	−0.53	B3	+0.14	38563A[u].	−0.03	5	−0.48	B5	+0.79
37334....	−0.77	9	−0.64	B2	+0.06	38563B[v].	+0.36	5	−0.53	B3	+1.42
37342....	−0.55	5	−0.46	B5	+0.04	38755....	−0.52	6	−0.44	B5	+0.05
37357....	+0.01	9	−0.08	B9	+0.16	38771[w]...	−1.03	9	−0.92	O–B0	+0.16
37373....	−0.41	9	−0.35	B7	+0.04	39291[x]...	−0.87	6	−0.73	B2	+0.07
37390....	−0.09	9	−0.21	B8	+0.25	39777....	−0.82	6	−0.68	B2	+0.05

[p] θ^2 Ori. [q] ι Ori. [r] ϵ Ori. [s] σ Ori.
[t] ζ Ori. [u] M78 (A). [v] M78 (B). [w] κ Ori.
[x] 55 Ori.

between interstellar absorption and wave length for the Orion stars does not differ appreciably from that for stars in general. It has been shown,[1] however, that the total amount of absorption in this spectral region is somewhat greater in the case of the Orion stars than for other stars of equal reddening.

Spectral types based on the colors alone can now be obtained by means of the values of $U-B$ given here, the values of $B-V$ in Paper I, and the calibration of Q with respect to spectral type given by Johnson and Morgan. The results are listed in Table 2, the columns of which contain (1) the star designation from the *Henry Draper* or *BD* catalogue; (2) the observed value of $U-B$; (3) a quantity ϵ such that the probable error of $U-B$ is $\pm 0^{m}001\epsilon$; (4) the value of Q computed from $U-B$ and $B-V$; (5) the spectral type, S_Q, corresponding to Q; and (6) the color excess, $E_y(Q)$, computed from the relation given above.

From a comparison of the spectral types in Paper I obtained from slit spectrograms and those obtained here from the colors, it is estimated that the probable error of either set of classifications is less than half a spectral subclass. The classifications in Paper I which were obtained from objective-prism spectra have been improved considerably by the new data.

An H-R diagram for the Orion stars based entirely on photoelectric observations can now be constructed. In Figure 2 Q is plotted against the corrected apparent visual magnitude, V_0, that is, V, corrected for interstellar absorption by $6E_y(Q)^1$. This can be compared with Figures 5 and 6 of Paper I, where the H-R diagram is plotted from spectroscopic data. The essential features of the original H-R diagram are preserved here, and the resulting distance modulus of the Orion aggregate is the same in both cases, i.e., $m_0 - M = 8.5$. Two stars, θ^1(A) and θ^1(C) Orionis, have values of Q less than -0.92. These are omitted from Figure 2 because of the insensitivity of Q to intrinsic color in this range.

The main sequence later than B1 appears sharply limited on the lower side, with a scattering of somewhat higher luminosity stars (luminosity class IV) above it. Some of the latter may be field stars not physically associated with the aggregate. The spectral

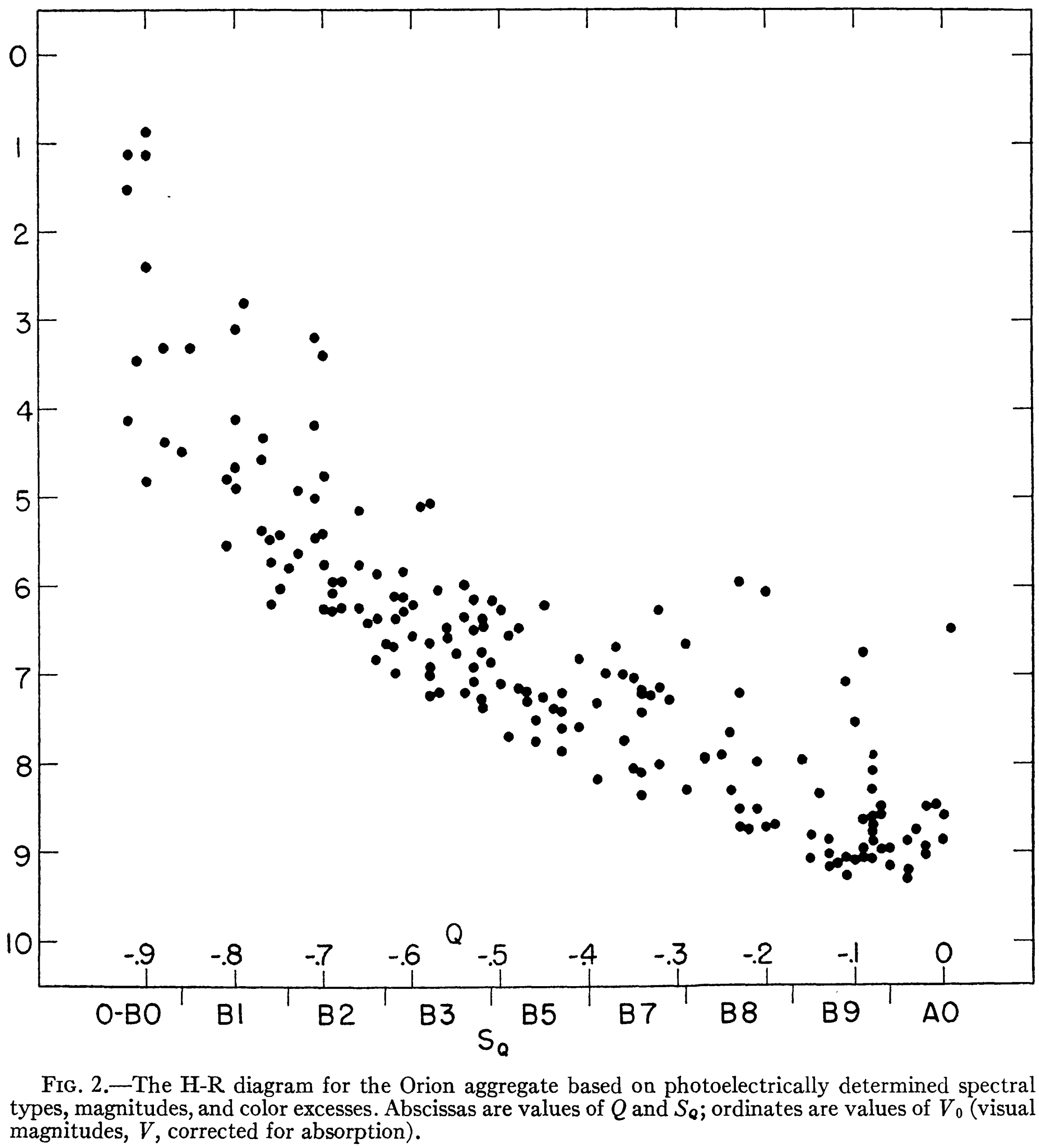

FIG. 2.—The H-R diagram for the Orion aggregate based on photoelectrically determined spectral types, magnitudes, and color excesses. Abscissas are values of Q and S_Q; ordinates are values of V_0 (visual magnitudes, V, corrected for absorption).

types predicted in Table 2 for the supergiants, δ, ϵ, ζ, and κ Orionis, are essentially correct. Their absolute magnitudes, as derived from Figure 2 are, within a tenth of a magnitude, the same as those obtained in Paper I. The width of the main sequence, after correction for observational errors and for the finite depth of the aggregate is approximately 1.2 mag.

The author is indebted to Drs. Johnson and Morgan for the use of some of their photometric results prior to publication.