SOME CHARACTERISTICS OF COLOR SYSTEMS*

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ABSTRACT

Relations between various color systems are investigated. Systemic reductions are given in terms of interstellar reddening, a normal main sequence, and the yellow giants. As would be expected from the work of W. Becker and the "Six-Color Photometry" of Stebbins and Whitford, different relations are found for the three groups of stars. The ratios of reddening to total visual absorption are found to be:

$$A_{\text{vis}} = 0.96E_{[V-I]}\ ; \qquad A_{\text{vis}} = 3.0E_{(B-V)}\ ; \qquad A_{\text{vis}} = 6.1E_1\ .$$

TERMINOLOGY

(U, B, V) system: The photometric system described by Johnson and Morgan.[1]
$[V - I]$, $[U - B]$, etc.: The colors of Stebbins and Whitford, "Six-Color Photometry."[2]
C_1: The color system of Stebbins, Huffer, and Whitford as defined in "733 B Stars" and "1332 B Stars."[3] The present dicussion does not apply to other investigations utilizing the same symbol.
E_1: Color excesses on the C_1 system as defined above.
$E_{(B-V)}$, $E_{[V-I]}$, etc.: Color excesses on the $(B - V)$ and $[V - I]$ systems.
A_V: Interstellar absorption on the V magnitude system.[1]
MK: The classification system of the Yerkes revised spectral atlas.
"Impartial line": See *Ap. J.*, **102**, 366, 1945. Probable errors are used throughout.

INTRODUCTION

It is possible to note certain general features of the relation between two color systems, one of which is more strongly affected by Balmer-line absorption and continuum than the other. Figure 1 gives a schematic description of two such systems: the one more strongly affected by hydrogen absorption is plotted as the ordinate; the positions of the (unreddened) main sequence and yellow giants are shown, together with the path followed by O stars affected by varying degrees of interstellar reddening. In general, the O reddening path (or O path) is located above the main sequence, and the yellow giants are below. These effects have been described by W. Becker[4] and in Parts I and III of the Stebbins-Whitford "Six-Color Photometry."

For the most accurate determination of the reddening path it is important to include only stars of similar intrinsic color; the O stars are probably the most useful group for the purpose, since their range in intrinsic color is small and they can be classified with ease. The greatest range in reddening, however, has been observed for the early B supergiants of luminosity class I*a;* the group B0 I*a*–B2 I*a* allows the most accurate determination of the reddening path to be made. In general, only a slight zero-point correction is needed to reduce this relation to that for the O stars; when there is an appreciable difference of zero point, the slope is determined from the B0 I*a*–B2 I*a* group.

* *Contributions from the McDonald Observatory, University of Texas*, No. 224.

[1] *Ap. J.*, **117**, 313, 1953.

[2] *Ap. J.*, **102**, 318, 1945.

[3] *Pub. Washburn Obs.*, Vol. **15**, Part 5, 1934; *Ap. J.*, **91**, 61, 1940.

[4] For references see *Ap. J.*, **107**, 278, 1948.

THE REDDENING PATHS FOR $(B - V)$ AND VARIOUS COMBINATIONS

Observational data are given in Table 1 for the intercomparison of several color systems. The selection includes the following, which are contained in the investigation of Johnson and Morgan[1] (Table 3) or in the "Six-Color Photometry"[2, 5] of Stebbins and Whitford: (*a*) all unreddened stars of luminosity class V (MK system) earlier than M0; (*b*) stars B0 I*a*–B2 I*a*, inclusive; (*c*) all stars having spectral types earlier than B0 (white dwarfs and subdwarfs have been omitted); (*d*) stars of classes G8 III–K5 III, inclusive. To these have been added values of C_1 for stars in the above-mentioned list.[3]

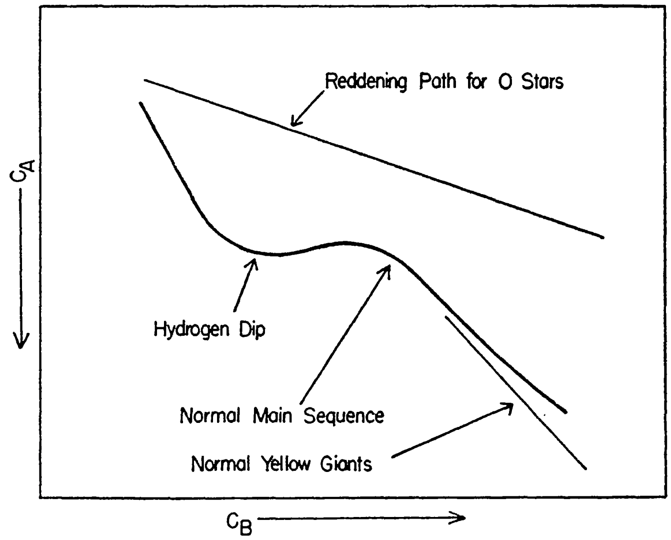

FIG. 1.—Schematic diagram showing two-color relations for unreddened main sequence, unreddened G8 III–K5 III stars and reddening path for O stars. Color C_A is more strongly affected by hydrogen absorption than C_B.

Figure 2 gives the relation between color indices $(B - V)$ and $(U - B)$ for the stars in Table 1. The reddening line for the B0 I*a*–B2 I*a* supergiants is

$$\begin{gathered} U - B = -0.910 + 0.886(B - V), \\ \pm 0.006 \pm 0.008 \end{gathered} \tag{1}$$

from a least-squares solution ("impartial line").

The relation between $(B - V)$ and C_1 is shown in Figure 3. The "impartial" reddening line for the O stars and B0 I*a*–B2 I*a* is

$$\begin{gathered} C_1 = -0.144 + 0.483(B - V). \\ \pm 0.006 \pm 0.015 \end{gathered} \tag{2}$$

There are no main-sequence stars common to the two series later than A7; for the range B1–A7 a linear relation represents the unreddened main sequence satisfactorily:

$$\begin{gathered} C_1 = -0.103 + 0.568(B - V). \\ \pm 0.005 \pm 0.027 \end{gathered} \tag{3}$$

[5] We are greatly indebted to Dr. Stebbins for permission to use and publish a number of six-color observations not included in "Six-Color Photometry." These have strengthened the weight of the reductions greatly.

TABLE 1

COLORS FROM (U, B, V), SIX-COLOR, AND C_1 SYSTEMS

HD	Name	MK	$B-V$	$U-B$	No. of Obs.*	$[B-R]$	$[U-B]$	$[V-G]$	$[V-I]$	C_1†
116658‡..	α Vir	B1 V	−0.26	−0.94	4	−1.12	−1.56	−1.13	−2.49	−0.23
120315...	η UMa	B3 V	− .20	− .68	6	−1.10	−1.28	−1.06	−2.40	− .23
74280...	η Hya	B3 V	− .20	− .74	Stand.	......	......	......	......	− .23
160762...	ι Her	B3 V	− .18	− .69	5	......	......	......	......	− .20
32630...	η Aur	B3 V	− .17	− .68	3	......	......	......	......	− .20
4727...	ν And	B5 V	− .15	− .57	1	−1.05	−1.13	−1.02	−2.23	− .18
87901...	α Leo	B7 V	− .12	− .38	2	......	......	......	......	......
135742...	β Lib	B8 V	− .11	− .37	Stand.	......	......	......	......	......
196867...	α Del	B9 V	− .06	− .23	4	......	......	......	......	......
222661...	ω^2 Aqr	B9.5 V	......	......	......	−0.95	−0.49	−0.83	−1.88	......
139006...	α CrB	A0 V	− .02	− .02	6	......	......	......	......	......
130109...	109 Vir	A0 V	− .01	− .03	2	......	......	......	......	......
71155...	HR 3314	A0 V	− .01	.00	2	......	......	......	......	......
172167...	α Lyr	A0 V	.00	− .01	8	−0.93	−0.37	−0.88	−1.85	......
103287...	γ UMa	A0 V	.00	+ .01	4	......	......	......	......	......
161868...	γ Oph	A0 V	+ .04	+ .06	3	......	......	......	......	......
95418...	β UMa	A1 V	− .02	.00	H4	......	......	......	......	......
48915...	α CMa	A1 V	+ .01	− .08	2	......	......	......	......	......
198001...	ε Aqr	A1 V	+ .02	+ .06	3	......	......	......	......	......
140159...	ι Ser	A1 V	+ .04	+ .04	2	......	......	......	......	......
21447...	HR 1046	A1 V	+ .05	+ .04	2	......	......	......	......	......
18331...	HR 875	A1 V	+ .09	+ .05	Stand.	......	......	......	......	......
116656...	ζ UMa (br)	A2 V	+ .02	+ .01	H3	......	......	......	......	......
1280...	θ And	A2 V	+ .06	+ .02	2	......	......	......	......	......
40183‡..	β Aur	A2 V	......	......	......	−0.88	−0.32	−0.79	−1.77	......
106591...	δ UMa	A3 V	+ .08	+ .07	2	......	......	......	......	......
102647...	β Leo	A3 V	+ .09	+ .04	2	......	......	......	......	......
56537...	λ Gem	A3 V	+ .10	+ .09	2	......	......	......	......	......
8538‡..	δ Cas	A5 V	+ .14	+ .10	2	−0.70	−0.17	−0.63	−1.45	......
11636...	β Ari	A5 V	+ .14	+ .10	2	......	......	......	......	− .03
116842...	80 UMa	A5 V	+ .16	+ .08	5	......	......	......	......	......
87696...	21 LMi	A7 V	+ .16	+ .07	2	......	......	......	......	0.00
6961...	θ Cas	A7 V	+ .17	+ .11	2	......	......	......	......	......
76644...	ι UMa	A7 V	+ .18	+ .06	2	......	......	......	......	......
187642...	α Aql	A7 IV, V	+ .23	+ .07	5	−0.61	−0.24	−0.61	−1.30	......
203280...	α Cep	A7 IV, V	+ .23	+ .10	2	−0.62	−0.21	−0.58	−1.24	......
58946...	ρ Gem	F0 V	+ .31	− .04	2	......	......	......	......	......
110379...	γ Vir (AB)	F0 V	+ .34	− .05	H6	......	......	......	......	......
112412...	α CVn (ft)	F0 V	+ .34	− .03	2	......	......	......	......	......
91480...	37 UMa	F1 V	+ .32	− .01	H4	......	......	......	......	......
113139...	78 UMa	F2 V	+ .37	.00	5	−0.35	−0.30	−0.40	−0.86	......
124674...	κ Boo (B)	F2 V	+ .39	− .04	2	......	......	......	......	......
129798...	....	F2 V	+ .39	.00	H5	......	......	......	......	......
164259...	ζ Ser	F3 V	+ .38	.00	3	......	......	......	......	......
76943...	10 UMa	F5 V	+ .43	+ .06	2	......	......	......	......	......
210027...	ι Peg	F5 V	+ .44	− .05	7	......	......	......	......	......
111456...	....	F5 V	+ .46	− .03	H5	......	......	......	......	......
187013...	17 Cyg (A)	F5 V	+ .46	.00	2	......	......	......	......	......
30652...	π^3 Ori	F6 V	+ .46	.00	3	......	......	......	......	......
173667...	110 Her	F6 V	+0.46	0.00	3	......	......	......	......	......

* When no letter precedes the number, the observer is Johnson; the prefix "H" refers to Harris.

† The C_1 colors are from *Ap. J.*, **91**, 20, 1940, and *Pub. Washburn Obs.*, Vol. **15**, Part 5, 1934.

‡ Unpublished six-color observations, kindly communicated by Dr. Stebbins.

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TABLE 1—*Continued*

HD	Name	MK	$B-V$	$U-B$	No. of Obs.*	$[B-R]$	$[U-B]$	$[V-G]$	$[V-I]$	C_1†
142860...	γ Ser	F6 V	+0.48	−0.02	3	......	......	......	......	......
184960...	....	F7 V	+0.47	−0.03	H5	......	......	......	......	......
16895...	θ Per	F7 V	+0.48	−0.01	2	......	......	......	......	......
120136...	τ Boo	F7 V	+0.48	+0.04	2	......	......	......	......	......
126660...	θ Boo	F7 V	+0.50	+0.01	3	......	......	......	......	......
170153...	χ Dra	F7 V	+0.50	−0.07	2	......	......	......	......	......
222368...	ι Psc	F7 V	+0.51	−0.01	3	......	......	......	......	......
165908...	99 Her	F7 V	+0.52	−0.10	4	......	......	......	......	......
90839...	36 UMa	F8 V	+0.51	0.00	2	......	......	......	......	......
9826...	50 And	F8 V	+0.54	+0.06	3	......	......	......	......	......
102870...	β Vir	F8 V	+0.54	+0.10	7	......	......	......	......	......
142373...	χ Her	F9 V	+0.56	+0.01	3	−0.08	−0.28	−0.18	−0.31	......
114710...	β Com	G0 V	+0.56	+0.05	5	−0.14	−0.20	−0.14	−0.37	......
4614...	η Cas	G0 V	+0.58	0.00	2	......	......	......	......	......
109358...	β CVn	G0 V	+0.59	+0.05	3	−0.09	−0.21	−0.13	−0.30	......
JM 144§..	....	G0 V	+0.59	+0.01	2	......	......	......	......	......
19373...	ι Per	G0 V	+0.60	+0.10	2	......	......	......	......	......
141004...	λ Ser	G0 V	+0.60	+0.11	4	......	......	......	......	......
13974...	δ Tri	G0 V	+0.61	+0.02	4	......	......	......	......	......
157214...	72 Her	G0 V	+0.62	+0.07	3	......	......	......	......	......
34411...	λ Aur	G0 V	+0.67	+0.10	1	......	......	......	......	......
115043...	....	G1 V	+0.60	+0.10	H5	......	......	......	......	......
160269...	26 Dra	G1 V	+0.61	+0.10	3	......	......	......	......	......
10307...	HR 483	G2 V	+0.63	+0.12	3	−0.07	−0.18	−0.12	−0.24	......
186408...	16 Cyg (A)	G2 V	+0.64	+0.19	2	......	......	......	......	......
224930...	85 Peg	G2 V	+0.66	+0.04	1	......	......	......	......	......
186427...	16 Cyg (B)	G5 V	+0.66	+0.20	2	......	......	......	......	......
20630...	κ Cet	G5 V	+0.68	+0.18	5	......	......	......	......	......
6582...	μ Cas	G5 Vp	+0.69	+0.09	2	......	......	......	......	......
117176...	70 Vir	G5 V	+0.71	+0.24	2	......	......	......	......	......
115617...	61 Vir	G6 V	+0.70	+0.26	2	......	......	......	......	......
111395...	....	G7 V	......	......	......	0.00	−0.04	−0.02	−0.06	......
101501...	61 UMa	G8 V	+0.69	+0.27	2	......	......	......	......	......
152391...	....	G8 V	......	......	......	0.00	+0.04	+0.07	+0.15	......
10700...	τ Cet	G8 Vp	+0.72	+0.18	2	......	......	......	......	......
154345...	....	G8 V	......	......	......	+0.04	+0.03	+0.01	0.00	......
103095...	Gr 1830	G8 Vp	+0.75	+0.17	3	......	......	......	......	......
185144...	σ Dra	K0 V	+0.79	+0.39	3	......	......	......	......	......
10780...	HR 511	K0 V	+0.81	+0.40	3	......	......	......	......	......
124752...	....	K0 V	+0.83	+0.52	H5	......	......	......	......	......
3651...	54 Psc	K0 V	+0.86	+0.56	2	+0.09	+0.32	+0.19	+0.32	......
10476...	....	K1 V	+0.84	+0.48	2	......	......	......	......	......
166620...	HR 6806	K2 V	+0.87	+0.59	4	+0.23	+0.41	+0.21	+0.43	......
3765...	....	K2 V	......	......	......	+0.22	+0.55	+0.34	+0.63	......
109011...	....	K2 V	+0.94	+0.63	H5	......	......	......	......	......
110463...	....	K3 V	+0.94	+0.73	H5	......	......	......	......	......
219134...	HR 8832	K3 V	+1.01	+0.89	Stand.	......	......	......	......	......
128165...	....	K3 V	......	......	......	+0.43	+0.78	+0.51	+0.98	......
154363...	....	K5 V	+1.16	+1.05	3	......	......	......	......	......
201091‡..	61 Cyg (A)	K5 V	+1.19	+1.10	4	+0.74	+1.14	+0.62	+1.36	......
JM 104§..	....	K7 V	+1.36	+1.26	2	......	......	......	......	......
157881...	....	K7 V	+1.36	+1.27	3	......	......	......	......	......
151288...	....	K7 V	+1.37	+1.29	3	+1.03	......	+0.86	+1.88	......
201092‡..	61 Cyg (B)	K7 V	+1.38	+1.23	4	+1.02	+1.30	+0.93	+2.01:	......
37128...	ϵ Ori	B0 I*a*	−0.20	−1.06	2	−1.04	−1.62	−1.06	−2.37	−0.20

§ Serial number from Table 3 of Johnson and Morgan, "Fundamental Stellar Photometry."

TABLE 1—*Continued*

HD	Name	MK	$B-V$	$U-B$	No. of Obs.*	$[B-R]$	$[U-B]$	$[V-G]$	$[V-I]$	C_1†
38771...	κ Ori	B0.5 I*a*	−0.18	−1.06	2	......	......	......	......	−0.16
2905...	κ Cas	B1 I*a*	+0.15	−0.80	2	−0.65	−1.34	−0.73	−1.50	− .09
41117...	χ² Ori	B2 I*a*	+0.27	−0.70	2	......	......	......	......	− .02
216411...	....	B1 I*a*	......	......	......	−0.02	−0.69	−0.21	−0.09	+ .15
229239...	....	B0.5 I	+0.85	−0.15	H3	......	......	......	......	......
169454...	....	B1 I*a*	......	......	......	+0.61	−0.27	+0.26	+1.04	+ .29
194839...	....	B0.5 I*a*	+0.96	−0.06	H3	+0.61	−0.21	+0.33	+1.14	+ .34
194279...	....	B1.5 I*a*	+1.01	−0.02	H3	+0.71	−0.14	+0.33	+1.28	+ .33
229059...	....	B1.5 I*ap*	+1.50	+0.43	H4	......	......	......	......	......
37043...	ι Ori	O9 III	−0.25	−1.11	2	......	......	......	......	− .23
14633...	....	O8	−0.21	−1.09	3	−1.10	−1.74	−1.14	−2.55	− .30
36486...	δ Ori	O9.5 II	......	......	......	−1.11	−1.69	−1.10	−2.52	− .23
214680...	10 Lac	O9 V	−0.20	−1.04	Stand.	−1.11	−1.73	−1.11	−2.49	− .23
57061...	τ CMa	O9 III	−0.14	−0.99	6	......	......	......	......	− .25
37742...	ζ Ori	O9.5 I*b*	......	......	......	−1.07	−1.67	−1.07	−2.43	− .22
1337‡...	....	O9 III	......	......	......	−0.97	−1.64	−1.01	−2.24	− .20
188209...	....	O9.5 III	......	......	......	−0.92	−1.58	−0.94	−2.08	− .17
203064...	68 Cyg	O8	......	......	......	−0.76	−1.57	−0.87	−1.82	− .16
24912...	ξ Per	O7	......	......	......	−0.76	−1.49	−0.86	−1.80	− .14
149757...	ζ Oph	O9.5 V	+0.01	−0.86	H5	......	......	......	......	− .13
199579...	....	O6	......	......	......	−0.73	−1.42	−0.81	−1.70	− .12
209975...	19 Cep	O9.5 I*b*	......	......	......	−0.71	−1.39	−0.77	−1.62	− .12
193322...	....	O8	......	......	......	−0.66	−1.33	−0.71	−1.57	− .07
37022...	θ¹ Ori‖	(O9)	......	......	......	−0.56	−1.35	−0.76	−1.30	− .02
46150...	....	O6	+0.12	−0.85	2	......	......	......	......	− .04
46149...	....	O8	+0.16	−0.80	2	......	......	......	......	− .09
46202...	....	O9 V	+0.17	−0.76	2	......	......	......	......	− .10
46223...	....	O5	+0.21	−0.78	3	......	......	......	......	− .04
210839...	λ Cep	O6 f	+0.26	−0.73	2	−0.47	−1.25	−0.60	−1.17	− .04
207198...	....	O9 II	......	......	......	−0.38	−1.13	−0.53	−1.03	+ .03
192639...	....	O8 f	......	......	......	−0.34	−1.07	−0.47	−0.87	+ .03
192281...	....	O5 f	......	......	......	−0.22	−1.06	−0.42	−0.80	+ .07
193443...	....	O9 III	+0.38	−0.53	H3	−0.28	−0.99	−0.43	−0.78	+ .03
193514...	....	O7 f	+0.43	−0.50	H3	−0.12	−0.88	−0.36	−0.48	+ .10
195592...	....	O9.5 I*a*	......	......	......	+0.39	−0.32	+0.09	+0.75	+ .30
229234...	....	O9.5 III	+0.76	−0.20	H3	......	......	......	......	......
166734...	....	O8 f:	......	......	......	+0.81	−0.29	+0.35	+1.46	+ .39
216131‡..	μ Peg	G8 III	......	......	......	+0.22	+0.60	+0.33	+0.56	......
21120...	ο Tau	G8 III	+0.89	+0.64	2	......	......	......	......	......
148387‡..	η Dra	G8 III	+0.91	+0.64	H4	+0.24	+0.58	+0.29	+0.47	......
148856...	β Her	G8 III	+0.91	+0.66	H4	......	......	......	......	......
62345...	κ Gem	G8 III	+0.92	+0.68	3; H1	......	......	......	......	+ .49
133208...	β Boo	G8 III	+0.95	+0.72	H5	+0.29	+0.65	+0.36	+0.56	......
135722...	δ Boo	G8 III	+0.96	+0.68	2; H2	+0.32	+0.61	+0.37	+0.65	......
9270...	η Psc	G8 III	+0.98	+0.79	2	+0.16	+0.54	+0.27	+0.51	......
180711‡..	δ Dra	G9 III	+1.00	+0.78	H2	+0.34	+0.75	+0.44	+0.74	......
181276...	κ Cyg	K0 III	+0.95	+0.74	H2	......	......	......	......	......
27697‡..	δ Tau	K0 III	+0.98	+0.84	2	+0.26	+0.80	+0.41	+0.63	......
27371...	γ Tau	K0 III	+0.99	+0.84	2	......	......	......	......	......
40035...	δ Aur	K0 III	+0.99	+0.86	2	......	......	......	......	......
62509...	β Gem	K0 III	+1.00	+0.84	5	......	......	......	......	+0.52
145328...	τ CrB	K0 III	+1.02	+0.85	H4	+0.38	+0.83	+0.43	+0.77	......
28305‡..	ε Tau	K0 III	+1.03	+0.87	2	+0.30	+0.91	+0.45	+0.70	......
197989...	ε Cyg	K0 III	+1.03	+0.87	5	......	......	......	......	......
95689...	α UMa	K0 III	+1.06	+0.90	3; H1	......	......	......	......	......

‖ The MK types of the Trapezium stars, in order of decreasing brightness, are: O6 p, B0.5 p, B0.5 p, and B3 p. The mean type weighted by magnitude is near O9.

TABLE 1—*Continued*

HD	Name	MK	$B-V$	$U-B$	No. of Obs.*	$[B-R]$	$[U-B]$	$[V-G]$	$[V-I]$	C_1†
203504. . .	1 Peg	K1 III	+1.10	+1.05	2	. . . . . .	. . . . . .	. . . . . .	. . . . . .	. . . . . .
96833. . .	ψ UMa	K1 III	+1.13	+1.11	3; H1	. . . . . .	. . . . . .	. . . . . .	. . . . . .	. . . . . .
153210. . .	κ Oph	K2 III	+1.14	+1.18	H5	. . . . . .	. . . . . .	. . . . . .	. . . . . .	. . . . . .
12929‡. .	α Ari	K2 III	+1.15	+1.12	Stand.	+0.48	+1.21	+0.64	+1.16	. . . . . .
140573. . .	α Ser	K2 III	+1.16	+1.24	Stand.	. . . . . .	. . . . . .	. . . . . .	. . . . . .	. . . . . .
161096. . .	β Oph	K2 III	+1.16	+1.24	3; H2	. . . . . .	. . . . . .	. . . . . .	. . . . . .	. . . . . .
137759. . .	ι Dra	K2 III	+1.17	+1.22	3; H2	. . . . . .	. . . . . .	. . . . . .	. . . . . .	. . . . . .
163588. . .	ξ Dra	K2 III	+1.18	+1.23	H5	. . . . . .	. . . . . .	. . . . . .	. . . . . .	. . . . . .
143107. . .	ε CrB	K3 III	+1.23	+1.28	Stand.	. . . . . .	. . . . . .	. . . . . .	. . . . . .	. . . . . .
127665. . .	ρ Boo	K3 III	+1.28	+1.44	2; H2	. . . . . .	. . . . . .	. . . . . .	. . . . . .	. . . . . .
216446‡. .	. . . .	K3 III	. . . . . .	. . . . . .	. . . . . .	+0.69	+1.47	+0.79	+1.46	. . . . . .
9927. . .	51 And	K3 III	+1.28	+1.46	2	. . . . . .	. . . . . .	. . . . . .	. . . . . .	+0.74
98262. . .	ν UMa	K3 III	+1.38	+1.57	2; H3	. . . . . .	. . . . . .	. . . . . .	. . . . . .	+ .81
131873‡. .	β UMi	K4 III	+1.46	+1.75	H4	+0.93	+2.00	+1.03	+1.91	. . . . . .
69267. . .	β Cnc	K4 III	+1.48	+1.77	Stand.	. . . . . .	. . . . . .	. . . . . .	. . . . . .	+0.89
29139. . .	α Tau	K5 III	+1.51	+1.81	2	+1.10	+2.09	+1.18	+2.38	. . . . . .
164058‡. .	γ Dra	K5 III	+1.52	+1.87	3; H2	+1.03	+2.16	+1.13	+2.18	. . . . . .

The five yellow giants in common have a markedly different relation:

$$C_1 = -0.196 + 0.731(B - V). \tag{4}$$
$$\pm 0.026 \pm 0.021$$

The relation between $(B - V)$ and the $[B - R]$ index of the "Six-Color Photometry" is shown in Figure 4. Here $(B - V)$ is considered as the ordinate, since the effect of hydrogen absorption on $[B - R]$ is probably slight; $H\alpha$ is within the sensitivity range of the $[R]$-point, and $H\beta$–$H\delta$ are included in $[B]$; the higher members of the Paschen series which are within the range of the $[R]$-point[6] would tend toward balancing the hydrogen effect on the two filter combinations. A single reduction formula is not satisfactory; the O reddening path, the main sequence, and the yellow giants all require different relations if an accurate reduction is desired. At $[B - R] \sim +0.7$, there is a difference of the order of 0.3 mag. in $B - V$ between the O reddening path and the yellow giants; the K-type main-sequence stars lie in an intermediate position. There is also a trace of the hydrogen dip in the main sequence.

Figure 5 gives the relation between $(B - V)$ and $[V - G]$. This comparison is of special interest because of the similarity in the effective wave lengths of the two systems. Since $[V]$ includes more ultraviolet light than B, $(B - V)$ is selected as the abscissa.

In spite of the similar instrumentation, traces of some of the systematic effects already noted persist; the stars of classes O and B0 I*a*–B2 I*a* lie systematically above the main sequence by a small amount, and the yellow giants lie slightly below the main sequence. At $(B - V) = +1.0$ the difference between the O reddening path and the yellow giants is around 0.1 mag. in $[V - G]$. While a mean relation for all three kinds of stars might be considered satisfactory for some purposes, an appreciable sacrifice in the accuracy of the observations would result. The relation for the main sequence is not linear; a quadratic interpolation curve computed by least squares is

$$B - V = +0.703 + 0.803[V - G] - 0.044[V - G]^2. \tag{5}$$
$$\pm 0.005 \pm 0.005 \qquad \pm 0.007$$

[6] See transmission curves in *Ap. J.*, **98**, 23, 1943.

1953ApJ...118...92M

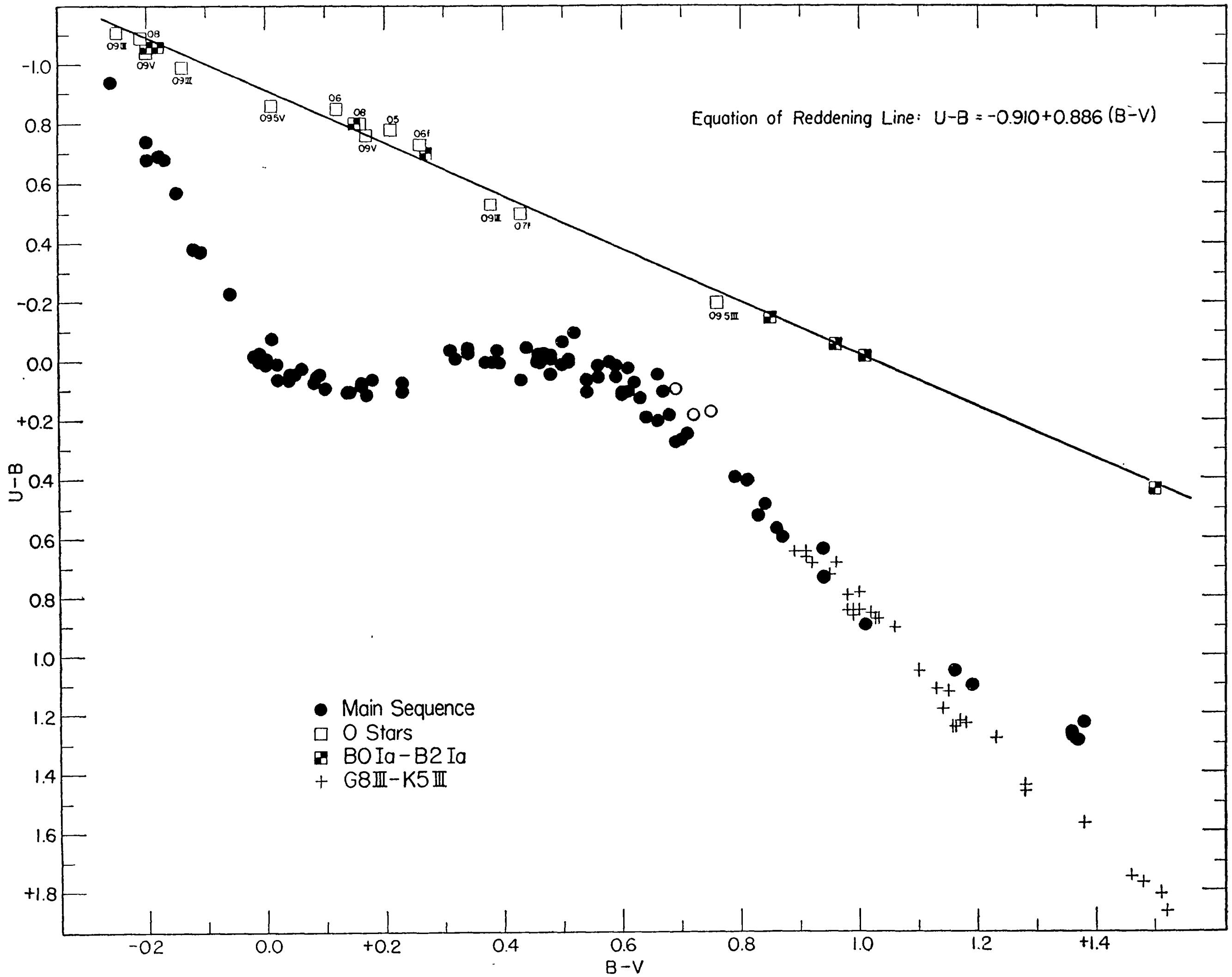

FIG. 2.—The relation between $(B - V)$ and $(U - B)$. The reddening line was determined from the B0 I*a*–B2 I*a* stars. The three open circles refer to μ Cas (G5 Vp), τ Cet (G8 Vp), and Gr 1830 (G8 Vp).

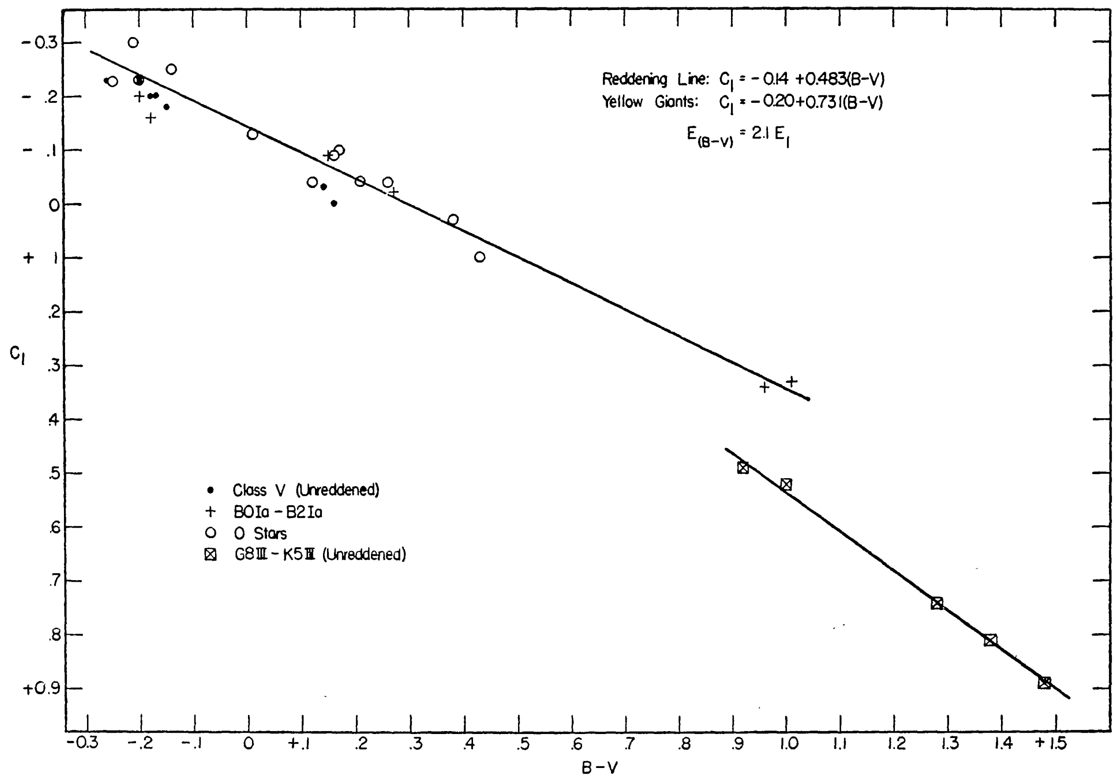

FIG. 3.—The relation between $(B - V)$ and C_1. The reddening line was determined from a combination of O and B0 I*a*–B2 I*a* stars.

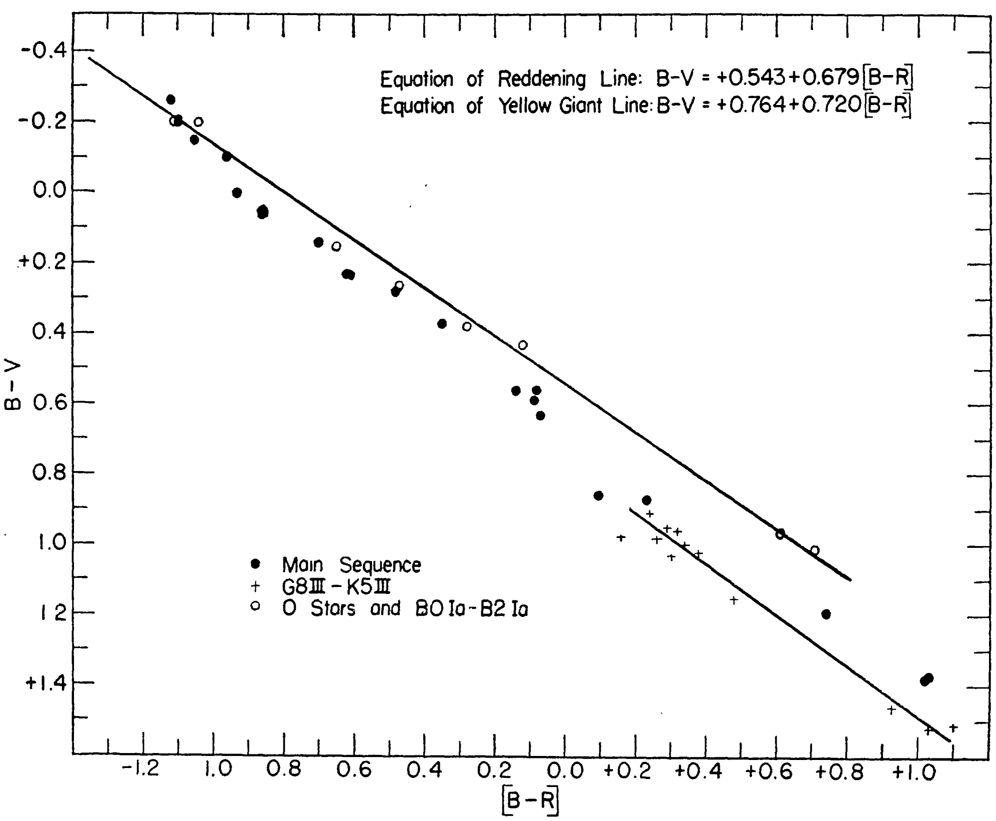

FIG. 4.—The relation between [B − R] and (B − V). The reddening line was determined from the B0 I*a*–B2 I*a* stars.

The reddening path for O and B0 I*a*–B2 I*a* stars can be represented by the line

$$B - V = +0.725 + 0.827[V - G]. \tag{6}$$
$$\pm 0.009 \pm 0.013$$

The least-squares linear solution for the yellow giants is

$$B - V = +0.697 + 0.716[V - G]. \tag{7}$$
$$\pm 0.008 \pm 0.011$$

The relation between $(B - V)$ and $[V - I]$ is illustrated in Figure 6. Here a different effect is observed: the O reddening line crosses the main-sequence relation near $B - V =$

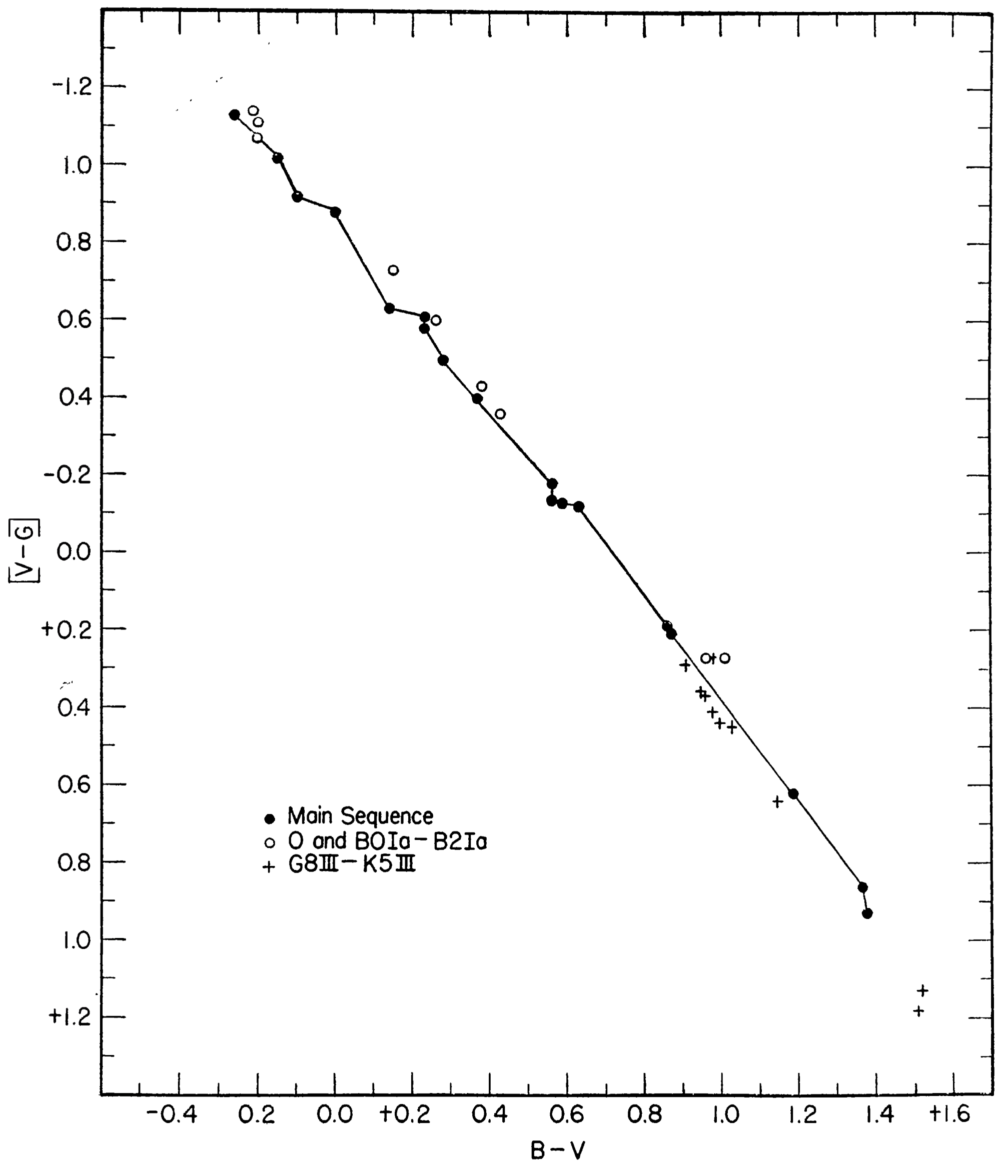

FIG. 5.—The relation between $(B - V)$ and $[V - G]$

+0.1. A possible explanation lies in the characteristics of the $[V - I]$ color index: for the redder stars (both intrinsically redder and space-reddened) the Balmer absorption effect is more marked in $B - V$; we thus find the O reddening line above the main sequence and the yellow giants below. For stars bluer than $B - V = 0$, however, the effect of the Balmer absorption on the $[V]$-point becomes the dominant factor; the blue part of the diagram should therefore be plotted with $B - V$ as the abscissa, to be consistent in sense with earlier diagrams.

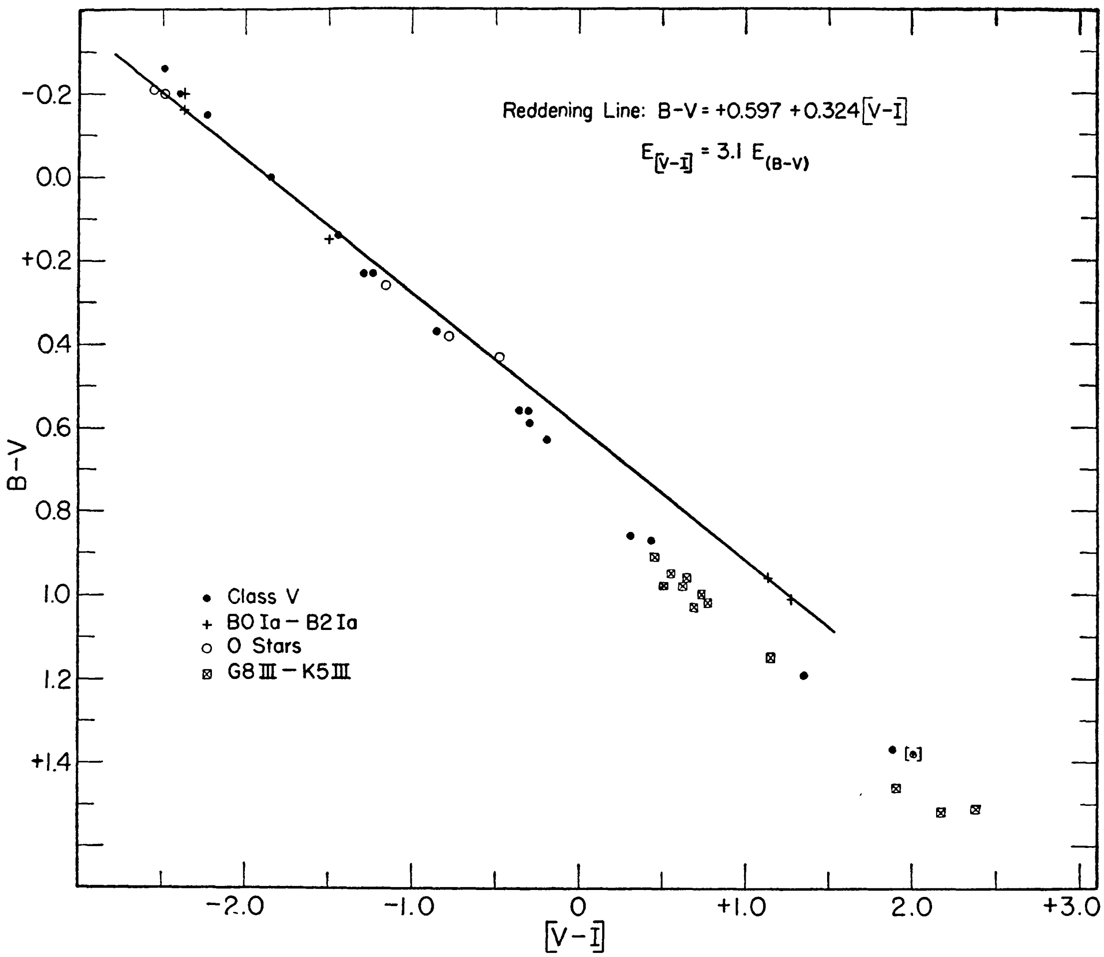

FIG. 6.—The relation between $[V - I]$ and $(B - V)$. The reddening line was determined from the B0 I*a*–B2 I*a* stars.

THE REDDENING PATHS FOR THE SIX-COLOR PHOTOMETRY

We shall now consider certain combinations from the "Six-Color Photometry," together with C_1.

Figure 7 illustrates the relation between $[V - I]$ and $[U - B]$. There is a qualitative similarity to Figure 2. The reddening line for B0 I*a*–B2 I*a* is

$$[U - B] = -0.678 + 0.410[V - I]. \tag{8}$$
$$\pm 0.009 \pm 0.006$$

1953ApJ...118...92M

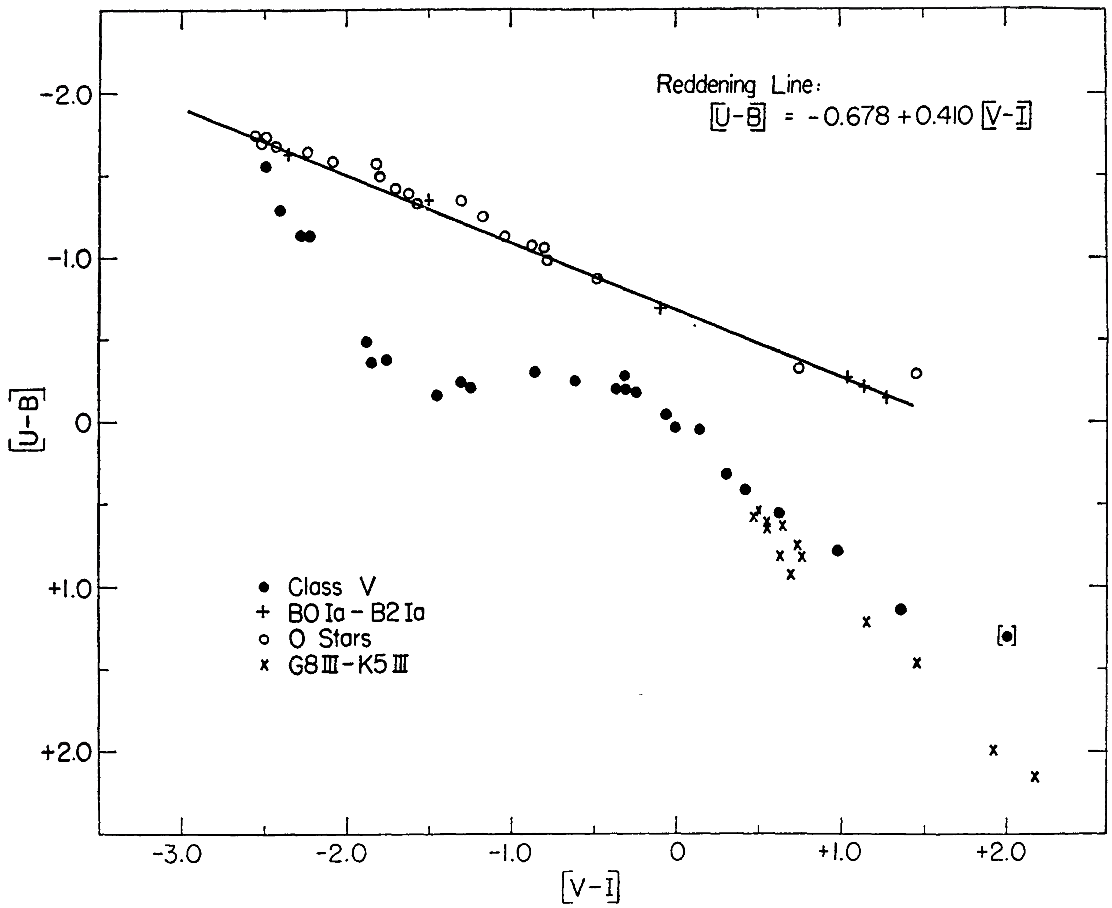

FIG. 7.—The relation between $[V-I]$ and $[U-B]$. The reddening line was determined from the B0 I*a*–B2 I*a* stars.

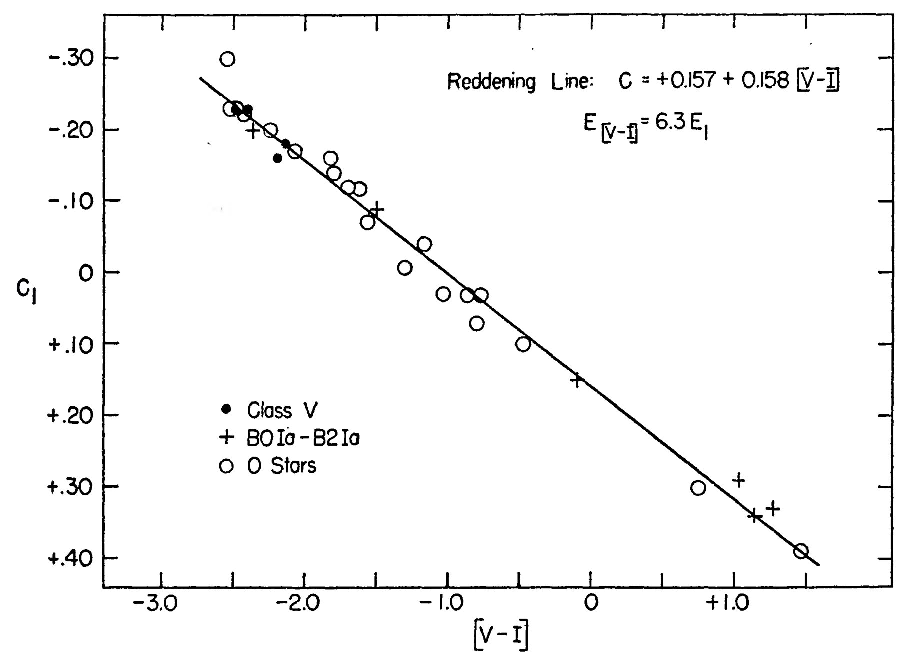

FIG. 8.—The relation between $[V-I]$ and C_1. The reddening line was determined from a combination of the O and B0 I*a*–B2 I*a* stars.

The relation between $[V - I]$ and C_1 is shown in Figure 8. No yellow giants and only four main-sequence stars of Table 1 are common to the two series. However, the reddening path itself is well defined and bears testimony to the good accuracy of the short base-line C_1 colors. The mean relation for O and B0 I*a*–B2 I*a* stars is

$$C_1 = +0.157 + 0.158[V - I] . \quad (9)$$
$$\pm 0.004 \pm 0.003$$

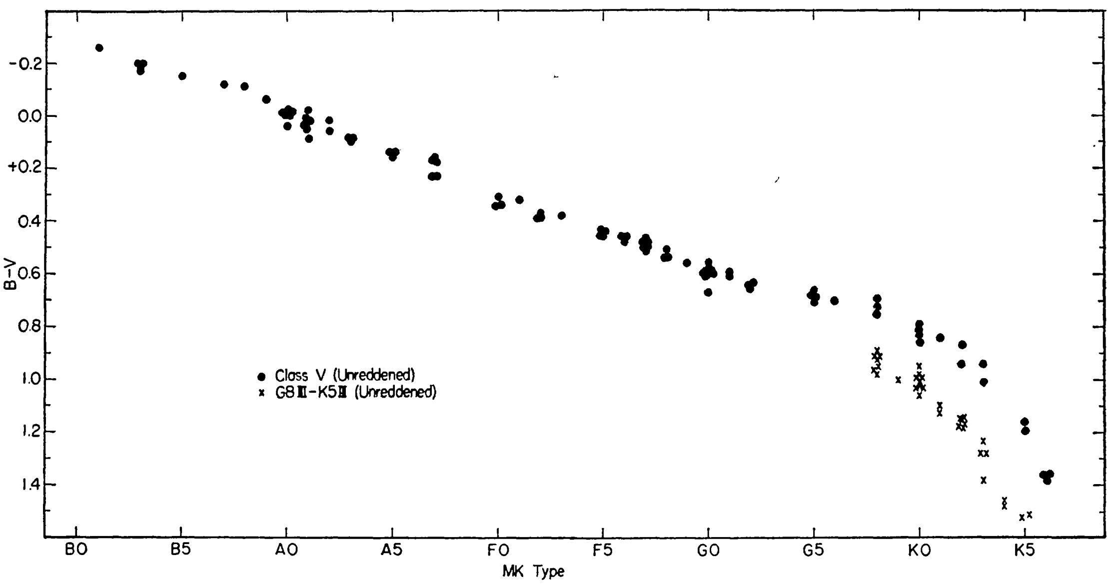

FIG. 9.—The relation between MK spectral type and $(B - V)$

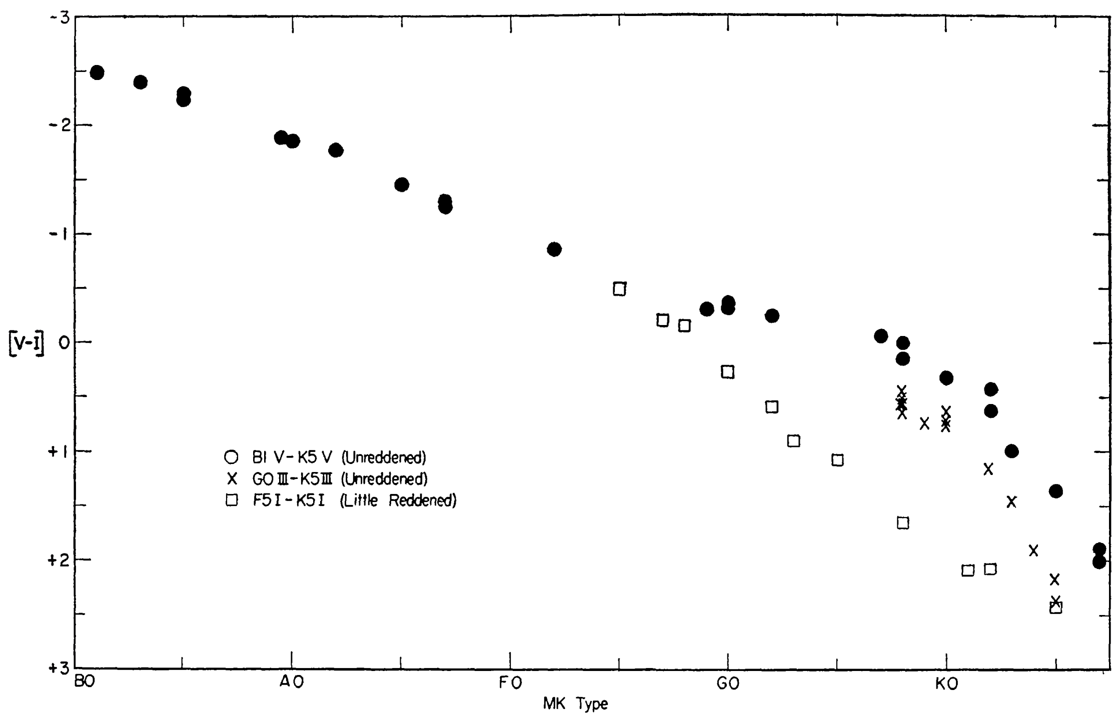

FIG. 10.—The relation between MK type and $[V - I]$

SOME RELATIONS BETWEEN COLOR AND MK TYPE

Figures 9 and 10 illustrate the relations between the normal main-sequence stars and yellow giants, and colors on the $(B - V)$ and $[V - I]$ systems, respectively. In addition, the little-reddened supergiants of classes F5 I–K5 I are shown in Figure 10; the data on the latter are given in Table 2.

TABLE 2

LITTLE-REDDENED F5 I–K5 I STARS

Star	MK	$[V-I]$ (Mag.)	$[U-B]$ (Mag.)	Star	MK	$[V-I]$ (Mag.)	$[U-B]$ (Mag.)
α Per	F5 I*b*	−0.49	+0.20	α^1 Cap	G3 I*b*	+0.90	+0.82
45 Dra	F7 I*b*	− .21	+ .32	9 Peg	G5 I*b*	+1.08	+1.08
γ Cyg	F8 I*b*	− .15	+ .40	ϵ Peg	K2 I*b*	+2.07	+2.02
β Aqr	G0 I*b*	+ .27	+ .49	ξ Cyg	K5 I*b*	+2.43	+2.19
α Aqr	G2 I*b*	+0.62	+0.78				

TABLE 3

INTRINSIC COLORS

MK	$B-V$ (Mag.)	C_1 (Mag.)	MK	$B-V$ (Mag.)	C_1 (Mag.)
O7	−0.32	−0.29	B6	−0.14	−0.18
O8	− .31	− .28	B7	− .12	− .16
O9	− .31	− .27	B8	− .09	− .15
B0	− .30	− .26	B9	− .06	− .14
B0.5	− .28	− .25	B9.5	− .03	− .13
B1	− .26	− .24	A0	.00	− .12
B2	− .24	− .23	A1	+ .03	− .10
B3	− .20	− .22	A2	+0.06	−0.08
B5	−0.16	−0.19			

THE INTRINSIC COLORS

One of the most difficult problems in the assignment of intrinsic colors is that of the O stars. Even in clusters containing O stars, the differential determination of intrinsic colors of the latter is not easy, because of the tendency of reddening material to be concentrated in the immediate neighborhood of the O stars.

Preliminary intrinsic colors for $(B - V)$ and C_1 are listed in Table 3. The values have been smoothed. Some of the stars on which the calibration of the C_1 intrinsic colors was based are listed in Table 4. To the class V stars have been added four F stars of class IV.

SUMMARY OF REDDENING RATIOS AND CONVERSION TO TOTAL ABSORPTION

In a note published separately,[7] D. L. Harris and H. L. Johnson have reinvestigated the problem of the ratio of total to selective absorption, and find:

$$A_V = 0.96E_{[V-I]} . \qquad (10)$$
$$\pm 0.05$$

[7] *Ap. J.*, in press.

This fundamental quantity allows the reduction of the relative values determined earlier. The various fundamental ratios are collected below:

$$E_{[V-I]} = 3.08E_{(B-V)}, \pm 0.06 \quad (11)$$

$$E_{[V-I]} = 6.3E_1, \pm 0.1 \quad (12)$$

$$A_V = 3.0E_{(B-V)}, \pm 0.2 \quad (13)$$

$$A_V = 6.1E_1. \pm 0.4 \quad (14)$$

TABLE 4

STANDARD STARS FOR C_1 COLORS

Star	MK	C_1 (Mag.)	Star	MK	C_1 (Mag.)
α Vir	B1 V	−0.23	o Peg	A1 V	−0.14
η Hya	B3 V	− .23	υ Psc	A2 V	− .10
η UMa	B3 V	− .23	26 UMa	A2 V	− .08
ι Her	B3 V	− .20	θ Peg	A2 V	− .08
η Aur	B3 V	− .20	ϵ Ari	A2 V	− .07
ν And	B5 V	− .18	β Ari	A5 V	− .03
κ Hya	B5 V	− .18	21 LMi	A7 V	.00
ζ Peg	B8 V	− .14	λ Psc	A7 V	.00
θ Hya	B9.5 V	− .14	ρ Psc	F2 V:	+0.10
ρ Peg	B9.5 Vp*	−0.12			

F IV STARS

Star	MK	C_1 (Mag.)	Star	MK	C_1 (Mag.)
δ Gem	F0 IV	+0.07	ι Leo	F2 IV	+0.11
23 UMa	F0 IV	+0.07	40 Leo	F6 IV	+0.18

* The K line is stronger than in α CMa (A1 V); *He* I is as strong as in α Del (B9 V).

From these relations precise corrections for interstellar absorption can be made in investigations of galactic structure—so long as the ratio of total to selective absorption is found not to vary.