A PHOTOMETRIC SYSTEM

by Harold L. Johnson
(Lowell Observatory, Flagstaff, Arizona, U. S. A.)

Abstract. — *The usefulness of the International System of magnitudes and of the North Polar Sequence for the standardization of accurate photometry is discussed. Further evidence of the ambiguity of the International System is presented.*

The substitution of the U, B, V *system of* Johnson *and* Morgan *for the ambiguous International System is recommended and a complete catalogue of the standard stars of the* U, B, V *system is given. A number of suggestions regarding transformations to the* U, B, V *system are made.*

Автор разсматривает вопрос о использовании интернациональной системы звездных величин и северного полярного ряда в точной фотометрии. Приводятся новые доказательства двойственности интернациональной системы.

Автор рекомендует замен двойственной интернациональной системы, системой U, B, V. Johnson'a-Morgan'a, и дает полный каталог звездных стандартов в системе U, B, V. Он вводит несколько новых замечаний по поводу перехода к системе U, B, V.

I. Introduction.

It has now become common knowledge among photometric observers that the International System of magnitudes and colors as defined by the stars of the North Polar Sequence is too poorly defined for the standardization of highly accurate photometry. Transformations to the International System of Photographic Magnitudes of the NPS stars are ambiguous and must always remain so for the following reasons : (1) The International Photographic Magnitudes, I_{pg}, contain an unknown amount of ultraviolet radiation on the violet side of 3 800 A that has been shown [1] to have a detrimental effect upon the precision of transformation, and (2) the number of types of stars in the NPS is entirely too small to permit transformations of sufficient accuracy for modern photometry.

The ultraviolet radiation in I_{pg} and the very limited number of types of stars in the NPS make it forever impossible to transfer unambiguously the International Photographic Magnitudes to other regions of the sky. The difficulties involved are illustrated in Table 1, which lists, for different amounts of ultraviolet response in the blue filter, the colors of a number of stars on the International System. It is plain that the International System of Photographic Magnitudes is defined only for the rather peculiar selection of reddened stars available in the NPS.

This lack of definition for stars of types other than those available in the NPS makes it clear that any attempt to transfer the International System to stars, or objects, of a more general character than those in the NPS is really a redefinition of the International System, not in terms of the NPS stars, but in terms of the other stars, or objects that were observed. This is a very important point that has not been given the consideration it deserves. There have been photometric investigations of the magnitudes and colors of O and B stars, of white dwarfs, and of globular clusters and external galaxies, which have their results given on the " International System ".

It should be made clear that each new investigations of objects of a kind that is not included in the list of photometric standards may well lead to a new definition of the system for these objects. In many cases, photometric values, all supposed to be on the International System, that have been obtained by different observers have not been in very good agreement.

There is even considerable disagreement on the exact definition of the International System *for the NPS stars, themselves*. As an example of such disagreement, let us consider the following six transformation equations :

(1($(P - V)_J = - .18 + 1.09\,(B - V)$

(2) $(P - V)_E = - .12 + 1.04\,(B - V)$

(3) $C_p = - .08 + 0.97\,(B - V)$

(4) $(P - V)_W = - .13 + 1.06\,(B - V)$

(5) $FI^H = - .13 + 1.02\,(B - V)$

(6) $C_{int} = = .09 + 0.95\,(B - V)$.

These equations relate colors on the B-V system of JOHNSON and MORGAN (1953) with colors on the " International System ". The descriptions and methods of derivation of these equations follow :

Eq. (1) is the equation from Cy to P-V given by JOHNSON and MORGAN [2] with $Cy = (B\text{-}V) - 1.040$ [3] substituted.

Eq. (2) is Equation (6) of EGGEN [4].

Eq. (3) arises from the combination of Eq. (2), above, and Eq. (11) of EGGEN [4]. This equation is, then, the relation between B-V and EGGEN's early colors, C_p.

Eq. (4) is the linear transformation between B-V [5] and WEAVER's [6] observations for the Coma Berenices star cluster.

Eq. (5) is the linear transformation between B-V [5] and BAHNER and MICZAIKA's [7] observations for the Coma Berenices star cluster.

Eq. (6) arises from the combination of two equations. One, $C_{int} = + 0.575 + 0.760(V\text{-}G)$, is the linear transformation of STEBBINS and WHITFORD's [8] colors, V-G, and C_{int} read from their Table 10. The other is Eq. (5) of MORGAN, HARRIS and JOHNSON [9] with the second-order term omitted. The omission of this second-order term has little effect upon the color system of Eq. (6), but does affect the zero-point.

Each of the authors of the data on which the first five equations are based has stated that the color system of his colors is on the " International System ". The transformations to the NPS in the sixth equation was made in the same manner as for the other five.

The B-V colors have been used on the right side of all equations principally as a matter of convenience in putting all equations on a common basis. Any other system of colors that includes the necessary stars could be used instead.

These six systems of colors " on the International System " differ greatly in color system ; the color term ranges from 0.95(B-V) to 1.09(B-V), with the mean at 1.02(B-V). All six equations are derived from photoelectric observations of NPS stars, although the selection of stars chosen to represent the International System differs somewhat among the several observers. Similar disparities are to be expected for all other systems of photometry, whether photographic or photoelectric, that are supposed to be on the International System.

A comparison of Eqs. (1)-(6) shows clearly some of the difficulties that are involved in the use of the NPS stars as photometric standards. There seems to be no reason to prefer one of the transformed " International Systems " to any other. On the basis of Eqs. (1)-(6), they are all valid approximations to the International System.

Recently, EGGEN [4] has published a list of observations on 833 stars. In his paper he states with regard to his observations. " This system, which we shall call the $(P\text{-}V)_E$ system, may be thought of as one comparable to the International System freed of the ultraviolet ". But, of course, any of the systems represented by Eqs. (1)-(6) may also be thought of as being *comparable* to the International System and the majority are also freed of the ultraviolet. In this connection, it should be pointed out that the color system of B-V, itself, may also be thought of as one *comparable* to the International System freed of the ultraviolet, since a color term of 1.00(B-V) lies within the range of color terms in Eqs. (1)-(6). Note that the color system of B-V lies between the systems of EGGEN's two transformations, Eqs. (2) and (3). As a matter of fact, all of the systems discussed here (including B-V) are consistent with the rather ambiguous definition of the International System.

It is my opinion that the International System and the North Polar Sequence should be abandoned forthwith as a system for the standardization of photometry and that a new, well-defined system should be substituted. The abandonment of the International System will not jeopardize the previous work that has been tied in with the NPS because (1) the range of color systems shown by Eqs. (1)-(6) and by Table 1 indicates that this previous photometry (most of which is photographic and, therefore, of rather lower weight) is *by no means* a homogeneous mass of data and (2) it is entirely possible to choose a new color system that will be consistent with the older data within the accuracy of these data.

TABLE 1

Colors of Stars on the International System

STAR	P_0-V*	$P_{0,5}$V-*	$P_{1,0}$-V-*	$P_{1,7}$V*	Sp.	C_p(SWJ)
—	—	—	—	—	—	—
NPS 6	+ 0.02	+ 0.03	+ 0.04	+ 0.06	....	+ 0.06
NPS 10	+ 0.14	+ 0.13	+ 0.13	+ 0.13	....	+ 0.12
NPS 16	+ 0.35	+ 0.33	+ 0.33	+ 0.31	....	+ 0.32
NPS 19	+ 0.45	+ 0.43	+ 0.42	+ 0.40	....	+ 0.41
NPS 2r	+ 1.54	+ 1.55	+ 1.55	+ 1.56	....	+ 1.56
NPS 4r	+ 0.98	+ 1.01	+ 1.01	+ 1.02	....	+ 1.02
NPS 8r	+ 1.02	+ 1.03	+ 1.03	+ 1.03	....	+ 1.02
α Lyr	— 0.17	— 0.16	— 0.14	— 0.11	A0 V	.....
α Aql	+ .08	+ .08	+ .09	+ 0.10	A7 IV, V	.....
α Cyg	— .07	— .11	— .13	— 0.13	A2 Ia	.....
9 Cep	+ .15	+ .04	— .02	— 0.10	B2 Ib	.....
λ Cep	+ .10	— .06	— .14	— 0.24	O6f	.....
β Ori	— .20	— .33	— .38	— 0.44	B8 Ia	.....
τ CMa	— .34	— .54	— .62	— 0.70	O9 III	.....
HD 14 633	— .41	— .64	— .72	— 0.80	O8	.....
ι Ori	— .45	— .68	— .77	— 0.84	O9 III	.....
υ Ori	— .47	— .70	— .78	— 0.86	B0 V	.....
BD + 28°4 211	— 0.56	— 0.83	— 0.93	— 1.01	Op	.....

* For an explanation of these symbols see JOHNSON [1].

If a new fundamental system is to be unambiguous, it must include magnitudes and color-indices for unreddened stars from all parts of the H-R diagram ; it must include white dwarfs and subdwarfs, as well as supergiants, giants and main-sequence stars. This list of standard stars must also include stars of known spectral type and luminosity class having different amounts of interstellar reddening. The standard photometric values should also be extended beyond the minimum two colors on the International System, preferably to a system comparable with the " 6-color photometry " of STEBBINS and WHITFORD [8]. Such a list of standard stars, and the standard photometric values for them, should make it possible for any observer to transform his observations to the fundamental system. In addition, it is desirable that the new system be consistent, so far as possible, with the present two-color International System of the NPS.

In the May, 1953 issue of the *Astrophysical Journal*, H. L. JOHNSON and W. W. MORGAN [2] proposed a new fundamental photometric system that seems to meet many of these conditions. This is a three-color system, called the U, B, V system. The V magnitudes are very close to the International Photovisual Magnitudes ; B-V is a color index which, as we have seen, is not inconsistent (except for a zero-point difference of about 0.12 mag.) with the present ill-defined

International System ; and U-B is a new color index involving the ultraviolet that partially satisfies the requirement for more than two colors. The effective wavelengths of U, B, and V are, approximately, 3 500 A, 4 350 A, and 5 550 A, respectively. The zero-point and scale of B-V are those specified for the original definition of the International System.

The U, B, V system has the advantage that it is an *observed* system, that is, it is essentially a single homogeneous set of measures made with a single instrument. The observed values for the list of standard stars are, therefore, a definition, in terms of the stars, of the physical characteristics of the photometric apparatus and its performance when it is used to measure stars. When an observer transforms his observed values to the U, B, V system by means of its standard stars and values, he obtains values which (if he makes an adequate transformation) are very close to those that would have been obtained with the apparatus that was used to set up the U, B, V system.

It is the purpose of this paper to suggest that this new photometric system is a logical substitue for the ambiguous International System and to collect in one place lists and catalogues of the standard stars that define the U, B, V system.

The values given for these standard stars define the performance of the photometric apparatus that was used to set up the system and should be regarded as a device by which other photometric apparatus (including photographic plates) can be calibrated in terms of the original apparatus. The U, B, V system is, therefore, an *instrumental system* (a necessity if one is to set up a single, homogeneous photometric system) and the values for the standard stars cannot be combined with values obtained with different apparatus without changing the definition of the system.

It is for this reason that the list of standard stars must include all kinds of stars and it is also for this reason that the list must contain nearly 400 stars. In this respect one would wish to describe the physical construction of the standard apparatus so thoroughly that anyone could duplicate its performance, but this is not possible from a practical standpoint and the only remaining method is to give standard values for an adequate number of standard stars. The choice of the initial apparatus is largely arbitrary but sufficient data concerning its performance must be available to permit accurate calibrations (or transformations).

II. The Fundamental Photometric System.

The observations on which the U, B, V system is based have been made with a filter-photomultiplier combination that has the spectral response characteristics in the three wave length bands that is given in Table 2 and Figure 1. These measured values do not include the effect of the two aluminized-surface mirrors in each

TABLE 2. — *Response of Photometer* *.

λ	Corning 9 863 (Ultraviolet)	Corning 5 030 + Schott GG13 (Blue)	Corning 3 384 (Yellow)
—	—	—	—
2 983	0.51	0.00	....
3 190	3.51	....	....
3 410	5.49	....	....
3 630	5.86	0.02	....
3 780	4.64	0.48	....
3 864	2.58	1.96	....
3 959	0.80	4.74	....
4 058	0.11	....	....
4 157	0.00	....	....
4 257	....	5.42	....
4 459	....	4.94	0.00
4 872	....	....	0.25
4 977	....	2.10	1.27
5 082	....	....	2.81
5 187	....	....	3.87
5 292	....	....	4.29
5 500	....	0.05	3.95
6 015	....	....	1.65
6 500	....	....	0.21
7 020	....	....	0.05

* Equal energy at all wave lengths.

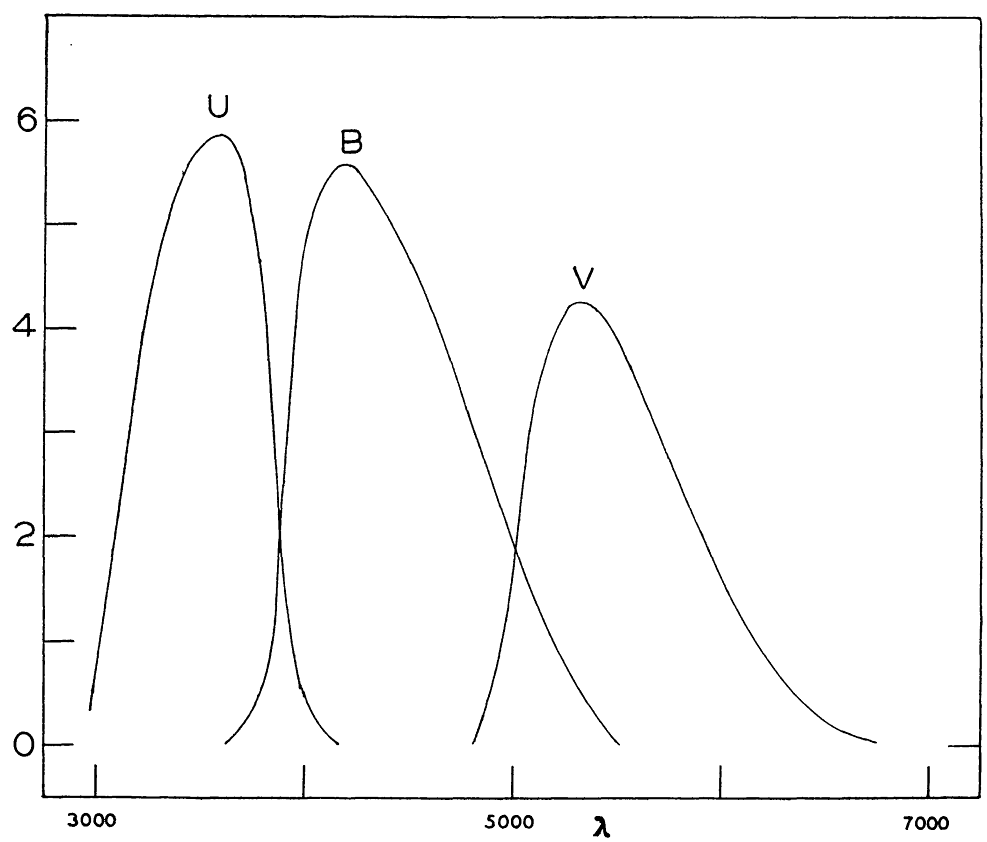

Fig. 1. — The relative response of the photometer to equal energy at all wavelengths.

telescope, but, according to STRONG [10], the reflectivity of aluminium is practically constant over the range of wave lengths involved here. The aluminium coats were all fairly new and were always in good condition.

The catalogue of standard stars and standard values on the U, B, V system is given in Table 3. Unreddened stars from all regions of the H-R diagram are

EKPLANATION OF TABLE 3

Column 1. — The H. D. or B. D. numbers of the stars, except in the cluster VI Cyg, where the numbers are those of JOHNSON and MORGAN [16].

An ,, s '' following the star number indicates that the declination is south of + 30 degrees and that the star is available to observers in the southern hemisphere.

Column 2. — The spectral types on the MK system as classified by W. W. MORGAN, except as follows : The types in parenthesis for the M-supergiants are those given by BIDELMAN [17], The types in parenthesis for the M-dwarfs are from KUIPER as quoted by JOHNSON and MORGAN [2].

Column 3. — The visual magnitudes, *V*.

Column 4. — The blue-yellow color indices, *B-V*.

Column 5. — The ultraviolet color indices, *U-B*.

Column 6. — The number of independent observations on each star.

TABLE 3*a*

O-Stars

STAR		*Sp*	*V*	*B-V*	*U-B*	*n*
—		—	—	—	—	—
+ 28° 4 211	S	Opec	10.54	— .34	— 1.26	6
			O5			
HD 12 993		O5	9.01	+ .19	— .81	3
46 223	S	O5	7.25	+ .22	— .76	4
242 908		O5	9.05	+ .27	— .72	3
193 682		O5	8.41	+ .51	— .48	3
VI Cyg 9		O5f	10.80	+ 1.93	+ .65	4
			O6			
48 099	S	O6	6.36	— .05	— .94	3
54 662	S	O6	6.21	+ .03	— .88	2
42 088	S	O6	7.54	+ .05	— .89	4
5 005		O6	7.76	+ .09	— .83	4
46 150	S	O6	6.72	+ .13	— .82	4
14 434		O6	8.50	+ .16	— .79	2
36 879	S	O6	7.58	+ .18	— .79	4
206 267		O6	5.62	+ .21	— .74	2
210 839		O6f	5.04	+ .25	— .74	4
242 926		O6	9.35	+ .32	— .66	3
215 835		O6	8.58	+ .32	— .66	3
15 558		O6	8.79	+ .57	— .50	3
VI Cyg 8A		O6f	8.98	+ 1.29	+ .14	4
VI Cyg 11		O6f	10.04	+ 1.43	+ .25	3
VI Cyg 7		O6f	10.50	+ 1.44	+ .30	3

TABLE 3*a* (*continued*)

Star		*Sp*	*V*	*B-V*	*U-B*	*n*
			O7			
47 839	S	O7	4.65	− .25	−1.06	3
24 912		O7	4.03	+ .01	− .92	4
34 656	S	O7	6.79	+ .02	− .90	4
46 573	S	O7	7.92	+ .35	− .66	4
217 086		O7	7.64	+ .62	− .44	3
193 514		O7f	7.42	+ .45	− .52	3
			O8			
14 633		O8	7.47	− .21	−1.09	3
36 861	S	O8	3.39	− .19	−1.03	4
53 975	S	O8	6.47	− .10	− .98	2
46 966	S	O8	6.84	− .04	− .92	3
47 129	S	O8	6.04	+ .04	− .87	3
48 279	S	O8	7.84	+ .15	− .78	3
46 149	S	O8	7.56	+ .17	− .78	4
46 056	S	O8	8.19	+ .18	− .76	2
35 619		O8	8.55	+ .24	− .71	4
46 485	S	O8	8.24	+ .32	− .68	4
41 997	S	O8	8.40	+ .39	− .63	4
216 532		O8	8.00	+ .55	− .48	3
VI Cyg 4		O8	10.22	+1.17	+ .09	3
VI Cyg 6		O8	10.67	+1.22	+ .18	3
			O9			
37 043	S	O9 III	2.77	− .25	−1.08	5
214 680		O9 V	4.88	− .20	−1.04	std
57 061	S	O9 III	4.39	− .14	− .99	7
149 757	S	O9.5 V	2.56	+ .02	− .86	10
210 809		O9 Ib	7.56	+ .04	− .88	3
209 481		O9 V	5.56	+ .07	− .86	3
46 202	S	O9 V	8.17	+ .17	− .74	4
207 198		O9 II	5.96	+ .31	− .64	3
24 431		O9 IV-V	6.72	+ .37	− .61	3
193 443		O9 III	7.23	+ .39	− .52	2
19 820		O9 IV	7.08	+ .51	− .47	3
VI Cyg 1		O9 V ?	11.09	+1.42	+ .31	3
VI Cyg 10		O9 Ia	9.88	+1.52	+ .40	3

TABLE 3*b*

Supergiants of Luminosity Classes Ia, Ib, II

STAR		*Sp*	*V*	*B-V*	*U-B*	*n*
			B0			
37 128	S	B0 Ia	1.70	— .19	— 1.04	6
38 771	S	B0.5 Ia	2.04	— .18	— 1.06	2
13 402		B0.5 I	8.06	+ .60	— .42	2
229 239		B0.5 I	—	+ .85	— .15	3
194 839		B0.5 Ia	—	+ .96	— .06	3
			B1			
91 316		B1 Ib	3.85	— .14	— .95	6
24 398		B1 Ib	2.83	+ .13	— .77	2
47 240	S	B1 Ib	6.15	+ .14	— .73	3
2 905		B1 Ia	4.15	+ .15	— .80	2
+ 56° 473		B1 II :	9.08	+ .26	— .66	2
13 854		B1 Iab	6.49	+ .28	— .65	2
16 310		B1 II :	8.07	+ .66	— .35	2
15 690		B1.5 Ib	8.00	+ .66	— .27	2
194 279		B1.5 Ia	—	+ 1.01	— .02	3
VI Cyg 2		B1 Ib ?	10.61	+ 1.15	+ .13	3
			B2			
13 841		B2 Ib	7.40	+ .24	— .66	2
41 117	S	B2 Ia	4.63	+ .27	— .70	2
206 165		B2 Ib	4.72	+ .30	— .52	2
14 818		B2 Ia	6.25	+ .31	— .62	15
14 357		B2 II	8.53	+ .32	— .53	2
14 520		B2 II	9.15	+ .33	— .55	2
14 443		B2 Ib	8.05	+ .34	— .55	2
14 143		B2 Ia	6.66	+ .51	— .45	2
14 956		B2 Ia	7.22	+ .72	— .29	2
			B3			
43 384	S	B3 Ia	6.28	+ .44	— .40	2
14 134		B3 Ia	6.55	+ .47	— .37	2
			B5			
13 267		B5 Ia	6.39	+ .33	— .43	2
			B6			
15 497		B6 Ia	7.03	+ .78	— .07	2

TABLE 3b (*continued*)

Star		Sp	V	B-V	U-B	n
			B8			
34 085	S	B8 Ia	+.08	— .03	— .69	2
14 322		B8 Ib	6.79	+ .32	— .34	15
14 899		B8 Ib	7.40	+ .44	— .11	2
14 542		B8 Ia	7.00	+ .62	— .14	2
17 145		B8 Ia	8.16	+ .82	— .01	2
			B9			
21 291		B9 Ia	4.23	+ .40	— .26	2
			A0			
13 744		A0 Iab	7.60	+ .74	+ .18	2
			A1			
14 433		A1 Ia	6.38	+ .58	+ .02	2
12 953		A1 Ia	5.68	+ .62	— .03	2
			A2			
197 345		A2 Ia	1.26	+ .09	— .25	6
16 778		A2 Ia	7.73	+ .90	+ .34	2
			A3			
13 476		A3 Iab	6.46	+ .59	+ .21	2
15 316		A3 Iab	7.24	+ .77	+ .42	2
			A5			
34 578		A5 II	5.03	+ .27	+ .44	2
17 378		A5 Ia	6.26	+ .89	+ .49	4
			F0			
7 927		F0 Ia	4.95	+ .68	+ .44	2
			F2			
163 506	S	F2 Ia	5.46	+ .35	+ .25	4
			F5			
195 593		F5 Iab	6.17	+ 1.02	+ .73	3
			G0			
217 476		G0 Ia	4.99	+ 1.29	+ 1.00	3

TABLE 3b (*continued*)

STAR	*Sp*	*V*	*B-V*	*U-B*	*n*
		M0 *			
+ 56° 595 S	(M0 Iab)	8.13	+ 2.25	+ 2.45	2
14 580	(M0 Iab)	8.42	+ 2.30	+ 2.59	2
		M1 *			
14 330	(M1 Iab)	7.97	+ 2.26	+ 2.54	2
		M2 *			
13 136	(M2 Ib)	7.76	+ 2.26	+ 2.27	2
14 404	(M2 Ib)	7.83	+ 2.30	+ 2.64	2
14 826	(M2 Iab)	8.26	+ 2.30	+ 2.47	2
14 142	(M2 Iab)	8.38	+ 2.33	+ 2.58	2
206 936	M2 Ia	3.99	+ 2.41	+ 2.40	4
		M3 *			
14 469	(M3 Iab)	7.69	+ 2.16	+ 2.24	2
14 270	(M3 Iab)	7.81	+ 2.28	+ 2.47	2
236 979	(M3 Iab)	8.20	+ 2.30	+ 2.61	2
14 528	(M3 eIa)	9.26	+ 2.66	+ 2.69	2
		M4 *			
14 488	(M4 Iab)	8.31	+ 2.29	+ 2.28	2
+ 56° 512 S	(M4 Ib)	9.25	+ 2.47	+ 2.67	3
		CARBON STARS **			
UX Dra	—	—	+ 2.85	—	2
AX Cyg	—	—	+ 3.78	—	3
DS Peg	—	—	+ 2.52	—	3
TX Psc S	—	—	+ 2.50	—	2
W Ori S	—	—	+ 3.68	—	2
UU Ori S	—	—	+ 3.02	—	2
W CMa S	—	—	+ 2.42	—	2
R CMi S	—	—	+ 3.23	—	2
X Cnc S	—	—	+ 3.24	—	2

* Many of these stars are known variable stars and these values, especially *V*, should not be used individually as standard values. A number of stars must be observed if the effects of variation in the individuals is to be averaged out, and even then the magnitudes will not be reliable.

** These stars were observed by R. HARDIE with the original *U*, *B*, *V* filters and 1P21.

TABLE 3c

Dwarfs, Subgiants, and Giants earlier than G5
(Luminosity Classes, III, IV, V)

Star	*Sp*	*V*	*B-V*	*U-B*	*n*
		B0			
36 512 S	BO V	4.63	— .26	— 1.07	11
24 760	B0.5 V	2.88	— .17	— .98	2
144 217 S	B0.5 V	2.63	— .08	— .88	3
184 915	B0.5 III	4.96	— .01	— .87	6
15 642	B0 III :	8.54	+ .08	— .84	2
46 106 S	B0.5 V	7.90	+ .14	— .74	4
13 745	B0 III	7.88	+ .17	— .78	3
14 331	B0 III	8.45	+ .17	— .76	2
		B1			
43 112 S	B1 V	5.90	— .24	— .96	3
116 658 S	B1 V	0.96	— .23	— .94	7
36 591 S	B1 V	5.35	— .20	— .94	9
23 180	B1 III	3.82	+ .06	— .76	2
13 051	B1 IV : :	8.72	+ .14	— . 72	2
		B2			
886	B2 IV	2.83	— .23	— .87	6
35 468	B2 III	1.64	— .23	— .87	5
35 299 S	B2 V	5.70	— .22	— .87	15
30 836 S	B2 III	3.69	— .17	— .80	9
214 167	B2 V	6.45	— .14	— .83	2
144 218	B2 V	4.92	— .02	— .70	3
		B3			
120 315	B3 V	1.86	— .20	— .68	6
74 280 S	B3 V	4.30	— .195	— .74	std
32 630	B3 V	3.17	— .18	— .67	6
160 762	B3 V	3.80	— .18	— .69	5
		B5			
147 394	B5 IV	3.89	— .152	— .56	std
4 727	B5 V	4.53	— .15	— .58	5
22 928	B5 III	3.03	— .14	— .52	2
		B6			
23 302 S	B6 III	3.69	— .11	— .41	3
23 338 S	B6 V	4.29	— .11	— .46	4
23 480 S	B6 IV nn	4.16	— .06	— .43	3

TABLE 3c (*continued*)

STAR	*Sp*	*V*	*B-V*	*U-B*	*n*
		B7			
35 497 S	B7 III	1.65	— .13	— .49	5
87 901 S	B7 V	1.36	— .11	— .36	7
23 630 S	B7 III	2.86	— .09	— .33	9
23 408 S	B7 III	3.86	— .07	— .40	4
23 288 S	B7 IV	5.45	— .05	— .33	6
		B8			
106 625 S	B8 III	2.60	— .11	— .35	5
135 742 S	B8 V	2.61	— .108	— .37	std
183 914 S	B8 V	5.11	— .10	— .32	2
23 850 S	B8 III	3.62	— .08	— .36	4
23 324 S	B8 V	5.64	— .08	— .36	6
23 753 S	B8 V	5.44	— .07	— .32	7
23 432 S	B8 V	5.75	— .04	— .23	3
		B9			
38 899 S	B9 IV	4.90	— .07	— .18	5
15 318 S	B9 III	4.28	— .06	— .13	5
196 867 S	B9 V	3.77	— .06	— .22	6
176 437	B9 III	3.25	— .05	— .09	10
218 045 S	B9 V	2.49	— .05	— .06	7
23 923 S	B9 V	6.16	— .05	— .19	2
23 441 S	B9 V :	6.41	— .03	— .15	3
23 568 S	B9 V :	6.80	+ .02	— .07	9
		A0			
79 469 S	A0 p	3.88	— .06	— .13	6
123 299	A0 III	3.64	— .05	— .09	3
23 873 S	A0 V :	6.59	— .03	— .12	3
71 155 S	A0 V	3.90	— .02	— .02	5
139 006 S	A0 V	2.23	— .02	— .02	6
103 287	A0 V	2.44	.00	+ .01	6
130 109 S	A0 V	3.74	.00	— .03	7
172 167	A0 V	+ .04	.00	— .01	10
161 868	A0 V	3.75		+ .04	9
		A1			
48 915 S	A1 V	— 1.47	+ .01	— .08	2
198 001 S	A1 V	3.77	+ .01	+ .04	5
140 159 S	A1 V	4.52	+ .04	+ .04	2
21 447	A1 V	5.08	+ .05	+ .03	5
18 331 S	A1 V	5.17	+ .084	+ .05	std

TABLE 3c (*continued*)

STAR	*Sp*	*V*	*B-V*	*U-B*	*n*
		A2			
116 656	A2 V	—	+ .02	+ .01	3
1 280	A2 V	4.61	+ .06	+ .04	6
141 003 S	A2 IV	3.67	+ .06	+ .07	8
		A3			
106 591	A3 V	3.31	+ .08	+ .07	9
102 647 S	A3 V	2.14	+ .09	+ .07	8
50 019	A3 III	3.59	+ .10	+ .13	3
56 537 S	A3 V	3.58	+ .11	+ .10	6
33 111 S	A3 III	2.80	+ .13	+ .10	8
		A5			
8 538	A5 V	2.68	+ .13	+ .12	5
11 636 S	A5 V	2.65	+ .13	+ .10	5
13 161	A5 III	3.00	+ .13	+ .08	2
116 842	A5 V	4.01	+ .16	+ .08	15
		A7			
6 961	A7 V	4.33	+ .17	+ .11	5
28 319 S	A7 III	3.41	+ .18	+ .13	14
76 644	A7 V	3.14	+ .18	+ .07	6
87 696	A7 V	4.48	+ .18	+ .08	7
127 762	A7 III	3.03	+ .19	+ .12	2
187 642 S	A7 IV, V	0.77	+ .22	+ .08	14
203 280	A7 IV, V	2.41	+ .23	+ .10	2
		A9			
147 547 S	A9 III	3.74	+ .26	+ .13	2
		F0			
173 649	F0 IV	5.74	+ .28	+ .03	2
17 094 S	F0 IV	4.25	+ .31	+ .05	2
58 946	F0 V	4.16	+ .32	— .03	6
112 412	F0 V	5.60	+ .34	— .03	2
		F2			
17 584	F2 III	4.22	+ .34	+ .06	2
432	F2 IV	2.25	+ .35	+ .09	2
113 139	F2 V	4.93	+ .36	+ .01	16
124 674	F2 V	6.69	+ .39	— .04	2
73 617 S	F2 V	9.23	+ .39	.00	5

TABLE 3c (*continued*)

STAR	*Sp*	*V*	*B-V*	*U-B*	*n*
		F3-4			
164 259 S	F3 V	4.62	+ .38	.00	3
74 058 S	F4 V	9.23	+ .39	+ .01	2
		F5			
61 421 S	F5 IV-V	0.34	+ .40	— .01	2
76 943 S	F5 V	3.95	+ .43	+ .06	2
210 027 S	F5 V	3.76	+ .44	— .05	7
187 013	F5 V	4.99	+ .46	.00	2
		F6			
89 449 S	F6 IV	4.83	+ .44	— .01	2
73 640 S	F6 V	9.67	+ .44	— .02	5
30 652 S	F6 V	3.19	+ .45	— .01	11
173 667 S	F6 V	4.20	+ .46	.00	3
142 860 S	F6 V	3.85	+ .48	— .03	6
		F7			
16 895	F7 V	4.12	+ .48	— .01	2
78 154	F7 IV-V	4.78	+ .48	+ .01	2
120 136 S	F7 V	4.51	+ .48	+ .04	2
170 153	F7 V	3.58	+ .50	— .07	3
126 660	F7 V	4.06	+ .50	+ .01	3
215 648 S	F7 V	4.19	+ .50	— .03	3
222 368 S	F7 V	4.13	+ .51	.00	8
165 908	F7 V	5.04	+ .52	— .10	4
		F8-9			
90 839	F8 V	4.82	+ .51	.00	2
144 284	F8 IV-V	4.01	+ .53	+ .11	3
9 826	F8 V	4.08	+ .54	+ .06	3
136 202 S	F8 IV-V	5.06	+ .54	+ .06	5
102 870 S	F8 V	3.61	+ .55	+ .10	9
142 373	F9 V	4.60	+ .56	+ .01	3
		G0			
114 710 S	G0 V	4.28	+ .57	+ .07	11
4 614	G0 V	3.45	+ .58	.00	2
121 370 S	G0 IV	2.69	+ .58	+ .19	8
109 358	G0 V	4.29	+ .59	+ .05	3
19 373	G0 V	4.04	+ .60	+ .10	2

TABLE 3c (*continued*)

STAR	*Sp*	*V*	*B-V*	*U-B*	*n*
141 004 S	G0 V	4.43	+ .60	+ .10	7
13 974	G0 V	4.87	+ .61	+ .02	4
157 214	G0 V	5.39	+ .62	+ .07	3
150 680	G0 IV	2.82	+ .64	+ .21	3
		G1-2			
160 269	G1 V	5.23	+ .61	+ .10	3
10 307	G2 V	4.94	+ .63	+ .12	3
186 408	G2 V	5.96	+ .64	+ .19	2
215 182 S	G2 II-III	2.96	+ .84	+ .51	2
		G5-6			
186 427	G5 V	6.20	+ .66	+ .20	2
20 630 S	G5 V	4.82	+ .68	+ .18	7
6 582	G5 Vp	5.12	+ .69	+ .09	2
115 617 S	G6 V	4.75	+ .71	+ .25	5
117 176 S	G5 V	4.98	+ .71	+ .26	8

TABLE 3*d*

Yellow giants and subgiants
(*Luminosity classes III and IV*)

STAR	*Sp*	*V*	*B-V*	*U-B*	*n*
		G8			
188 512 S	G8 IV	3.71	+ .86	+ .48	16
21 120 S	G8 III	3.59	+ .89	+ .62	5
62 345 S	G8 III	3.57	+ .93	+ .68	5
135 722	G8 III	3.50	+ .95	+ .69	2
9 270 S	G8 III	3.62	+ .97	+ .76	5
222 107	G8 III-IV	3.88	+ 1.02	+ .68	3
		K0			
198 149	K0 IV	3.43	+ .92	+ .62	3
168 723 S	K0 III-IV	3.26	+ .94	+ .65	3
73 598 S	K0 III	6.59	+ .96	+ .72	5
73 974 S	K0 III	6.90	+ .96	+ .74	4
27 697 S	K0 III	3.76 :	+ .98	+ .82	6

TABLE 3*d* (*continued*)

STAR	*Sp*	*V*	*B-V*	*U-B*	*n*
		K0			
73 666 S	K0 III	6.39	+ .98	+ .83	22
27 371 S	K0 III	3.65 :	+ .99	+ .82	6
40 035	K0 III	3.69	+ .99	+ .86	2
62 509 S	K0 III	1.15	+ 1.00	+ .84	5
28 305 S	K0 III	3.54	+ 1.02	+ .88	6
197 989	K0 III	2.45	+ 1.03	+ .87	5
95 689	K0 III	1.79	+ 1.06	+ .90	3
		K1			
222 404	K1 IV	3.22	+ 1.03	+ .92	2
203 504 S	K1 III	4.09	+ 1.10	+ 1.05	2
96 833	K1 III	3.01	+ 1.13	+ 1.10	3
		K2			
12 929 S	K2 III	2.00	+ 1.151	+ 1.12	std
161 096 S	K2 III	2.77	+ 1.16	+ 1.24	10
140 573 S	K2 III	2.65	+ 1.168	+ 1.24	std
137 759	K2 III	3.26	+ 1.17	+ 1.22	2
124 897 S	K2 IIIp	— .06	+ 1.23	+ 1.26	6
		K3			
143 107 S	K3 III	4.15	+ 1.230	+ 1.28	std
9 927	K3 III	3.56	+ 1.28	+ 1.46	2
127 665	K3 III	3.57	+ 1.29	+ 1.44	2
98 262	K3 III	3.48	+ 1.38	+ 1.56	2
		K4-5			
69 267 S	K4 III	3.52	+ 1.480	+ 1.78	std
164 058	K5 III	2.22	+ 1.52	+ 1.86	3
29 139 S	K5 III	0.86 :	+ 1.53	+ 1.90	8
		M2 III			
218 329 S	M2 III	4.50	+ 1.56	+ 1.81	2
1 013 S	M2 III	4.80	+ 1.58	+ 1.92	4

TABLE 3e

Red Dwarfs and Subdwarfs
(Luminosity Class V)

Star		Sp	V	B-V	U-B	n
			G8			
10 700	S	G8 Vp	3.50	+ .72	+ .20	5
103 095		G8 Vp	6.45	+ .75	+ .17	25
82 885		G8 IV-V	5.41	+ .77	+ .45	14
			K0-1-2-3			
185 144		K0 V	4.68	+ .79	+ .39	3
10 476	S	K1 V	5.23	+ .83	+ .50	5
3 651	S	K0 V	5.84	+ .86	+ .56	2
166 620		K2 V	6.40	+ .87	+ .59	4
22 049	S	K2 V	3.73	+ .89	+ .57	6
219 134		K3 V	5.57	+ 1.010	+ .89	std
			K5-7			
154 363	S	K5 V	7.73	+ 1.16	+ 1.05	5
201 091		K5 V	5.19	+ 1.19	+ 1.10	4
157 881	S	K7 V	7.54	+ 1.36	+ 1.26	5
151 288		K7 V	8.11	+ 1.37	+ 1.29	3
201 092		K7 V	6.02	+ 1.38	+ 1.23	4
			M0-1-2			
88 230		(dM0)	6.59	+ 1.38	+ 1.28	2
111 631	S	M0.5 V	8.49	+ 1.41	+ 1.2	5
147 379		M0 V	8.60	+ 1.41	+ 1.27	4
+ 66° 717		M1 V	9.32	+ 1.42	+ 1.08	3
36 395	S	(dM1)	7.97	+ 1.47	+ 1.21	17
+ 1° 4 774	S	M2 V	8.98	+ 1.48	+ 1.09	5
+ 61° 195		(dM1.5)	9.57	+ 1.50	+ 1.21	4
95 735		M2 V	7.47	+ 1.51	+ 1.13	2
+ 11° 2 576	S	M1 V	9.04	+ 1.51	+ 1.26	3
1 326		M1 V	8.07	+ 1.56	+ 1.22	4
			M3-M7			
— 4° 4 226	S	M3.5 V	10.07	+ 1.43	+ 1.09	5
+ 4° 4 048	S	M3.5 V	9.13	+ 1.49	+ 1.16	6
180 617	S	M3.5 V	9.12	+ 1.50	+ 1.15	4
+ 68° 946		M3.5 V	9.15	+ 1.50	+ 1.08	5
+ 20° 2 465	S	M4.5 : V	9.43	+ 1.54	+ 1.06	4

TABLE 3e (continued)

STAR		Sp	V	B-V	U-B	n
173 739		(dM3.5)	8.90	+ 1.54	+ 1.11	3
173 740		(dM4)	9.69	+ 1.59	+ 1.14	3
— 15° 6 290	S	(dM5)	10.17	+ 1.60	+ 1.15	4
HR 753B		(dM6)	11.65	+ 1.61	+ 1.12	3
+ 4° 3 561 *	S	M5 V	9.54	+ 1.74	+ 1.29	9
+ 43° 44B		M6 V	11.04	+ 1.80	+ 1.38	4

* Barnard's proper motion star.

TABLE 3f

White Dwarfs

STAR		V	B-V	U-B	n
O0 # 230 *		13.68	— .12	— .92	2
Wolf 1 346	S	11.53	— .06	— .87	1
LDS 678A	S	12.36	+ .02	— .86	1
L 1 126-68	S	15.47	+ .02	— .67	1
Ross 137	S	13.98	+ .02	— .59	1
AC + 70° 8 247		13.18	+ .05	— .86	1
Wolf 672A	S	14.34	+ .10	— .55	1
Ross 198		14.66	+ .15	— .68	1
Ross 808		14.36	+ .17	— .56	1
v Maanen 2	S	12.37	+ .56	.00	1
Wolf 457		15.90	+ .64	— .09	1
L 1140-73		13.84	+ .70	— 06	1
Wolf 489		14.71	+ .95	+ .37	1

* The number of Oosterhoff (Leiden Annals, Vol. XVII, n° 1).

TABLE 3g

Additional Stars not having Spectral Types on MK System by Morgan

STAR		V	V-B	U-B	n
100 600	S	5.95	— .16	— .64	23
188 293	S	5.70	— .08	— .49	2
216 494	S	5.81	— .08	— .32	6
222 439		4.13	— .07	— .27	2
188 294	S	6.48	— .04	— .27	2

TABLE 3*g* (*continued*)

Star		*V*	*B-V*	*U-B*	*n*
177 724	S	2.99	.00	— .01	6
216 735	S	4.89	+ .01	.00	2
184 279	S	6.82	+ .02	— .83	5
225 010		7.34	+ .08	+ .05	2
38 678	S	3.55	+ .10	+ .06	5
130 841	S	2.75	+ .15	+ .08	8
175 638	S	4.59	+ .15	+ .09	2
124 675		4.54	+ .20	+ .14	3
175 639	S	4.99	+ .20	+ .07	2
137 391		4.30	+ .30	+ .08	2
191 570	S	6.48	+ .38	— .04	2
210 884		5.50	+ .38	— .04	2
207 826		6.45	+ .39	+ .05	2
130 819	S	5.16	+ .41	— .04	7
197 963	S	5.14	+ .49	+ .08	3
166 866		5.68	+ .50	— .01	2
166 865		6.04	+ .51	— .01	2
194 765	S	6.70	+ .52	— .02	2
194 766	S	7.50	+ .52	— .02	2
209 942		6.98	+ .52	— .02	2
219 175	S	7.56	+ .56	— .04	2
179 957		6.75	+ .64	+ .17	2
179 958		6.57	+ .65	+ .21	2
217 014	S	5.53	+ .68	+ .20	3
214 238		7.63	+ .68	+ .17	2
209 943		7.49	+ .70	+ .17	2
197 964	S	4.27	+ 1.04	+ .97	3
+ 2°348	S	10.03	+ 1.44	+ 1.08	3
+ 17°1 320	S	9.63	+ 1.50	+ 1.18	4
+ 1°2 447	S	9.63	+ 1.52	+ 1.19	3
— 18°359	S	10.18	+ 1.53	+ 1.16	3
— 12°2 918	S	10.06	+ 1.53	+ 1.15	2
+ 5°1 668	S	9.82	+ 1.56	+ 1.12	3
— 12°4 523	S	10.13	+ 1.60	+ 1.18	5
— 7°4 003	S	10.56	+ 1.61	+ 1.20	6

included, except that no unreddened M-supergiants are available. Many moderately and heavily reddened O- and B- stars are listed, together with a number of reddened stars of later types. Unfortunately, most of the supergiants included, especially the later types, are north of declination + 30° and, therefore, are not available to southern observers.

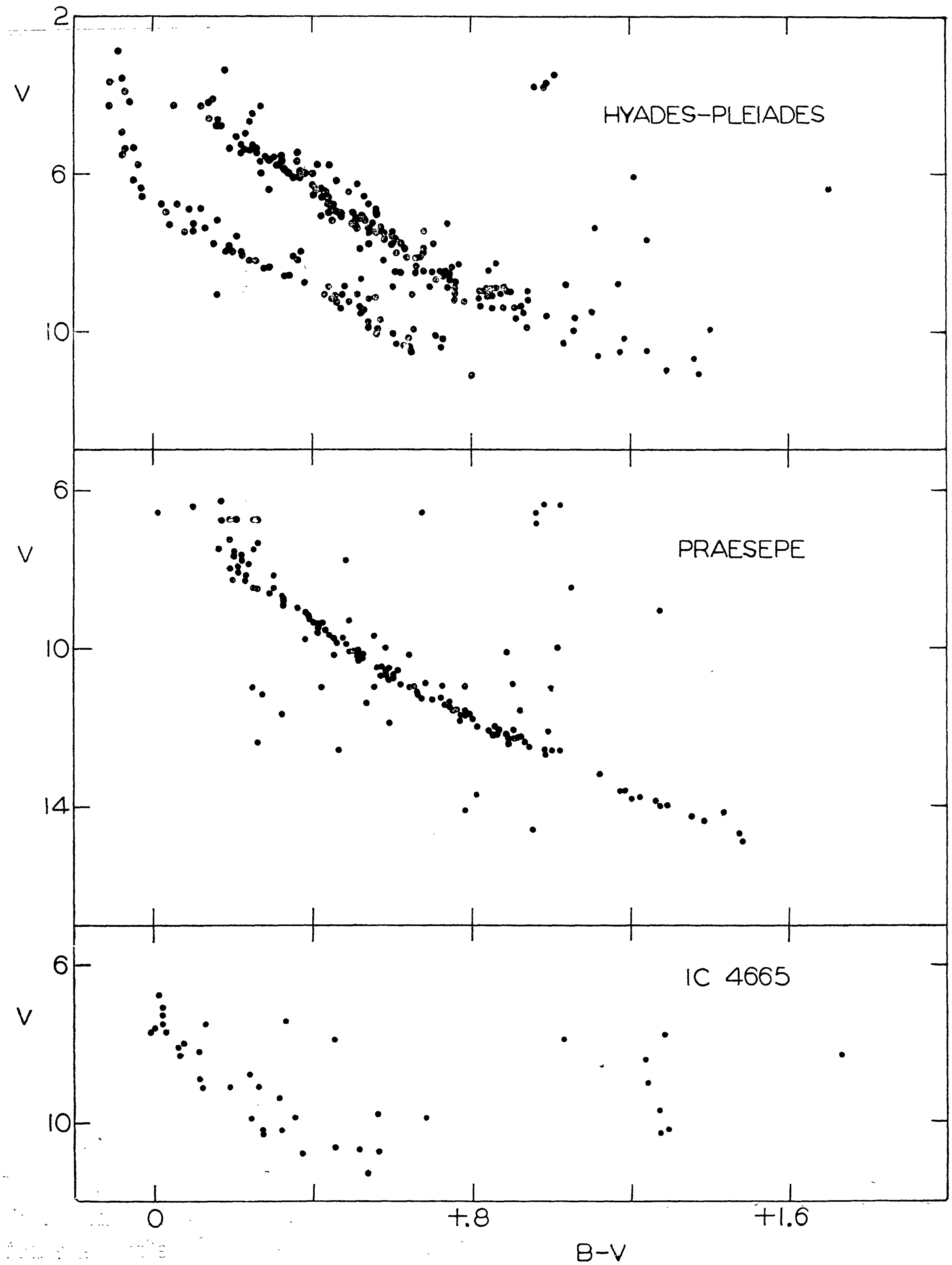

FIG. 2. — The color-magnitude diagrams for the primary standard regions.

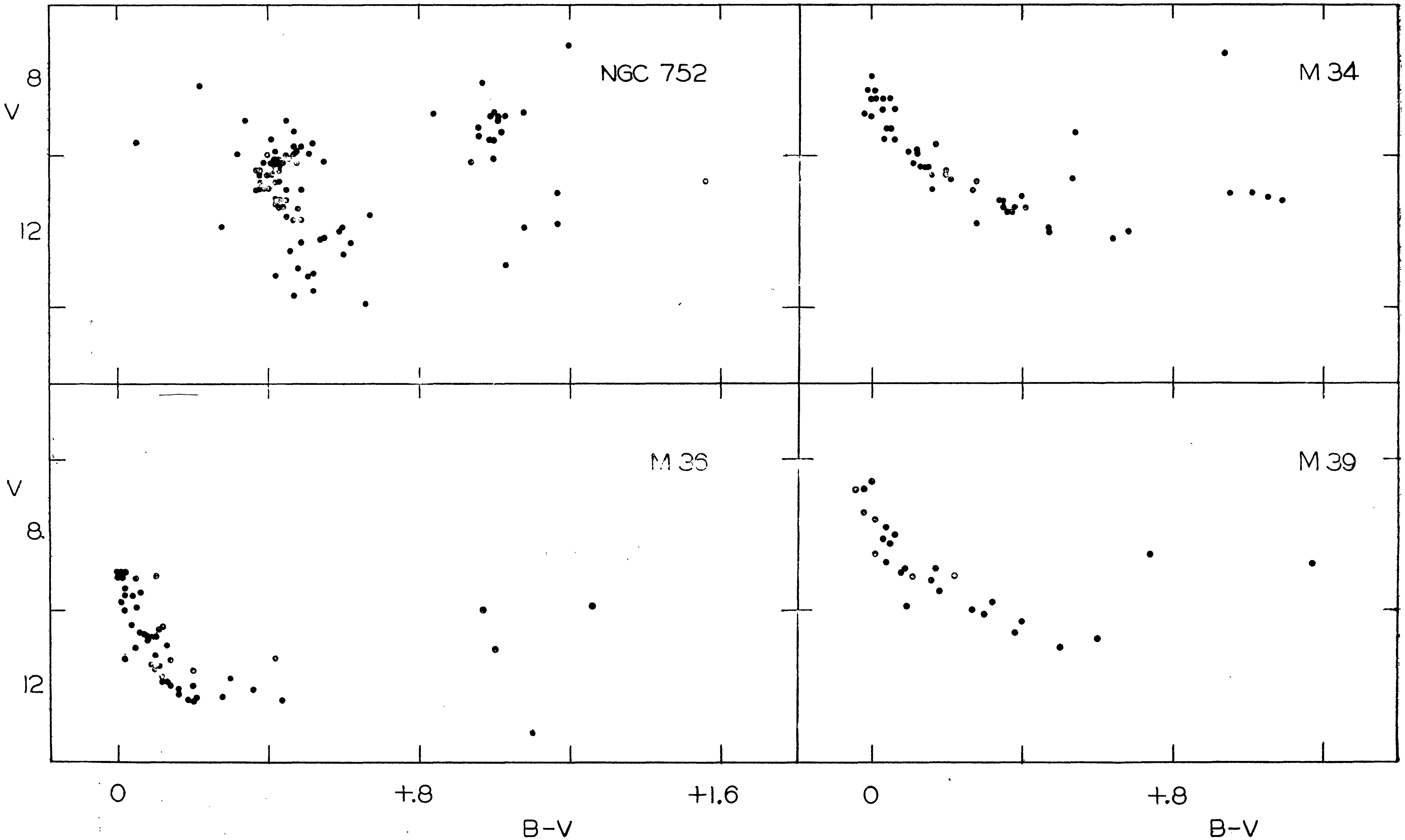

FIG. 3. — The color-magnitude diagrams for the secoundary standard regions.

TABLE 4

The North Polar Sequence

STAR	V	B-V	U-B
NPS 1	4.36	+ .02	+ .02
2	5.27	— .03	— .11
3	5.58	+ .23	+ .13
4	5.79	+ .25	+ .07
5	6.49	+ .10	+ .07
6	7.11	+ .18	+ .08
7	7.51	— .01	— .07
8	8.08	+ .40	— .04
9	8.81	+ .31	+ .11
10	9.06	+ .28	+ .04
13	10.27	+ .34	+ .25
16	11.20	+ .48	+ .07
19	12.22	+ .56	+ .13
1r	5.07	+ 1.63	+ 1.97
2r	6.38	+ 1.57	+ 1.79
3r	7.49	+ 1.44	+ 1.59
4r	8.23	+ 1.06	+ 1.00
8r	10.40	+ 1.09	+ .86
12r	12.50	+ 1.34	—
2s	6.28	+ .35	— .01
3s	6.33	+ .43	— .08

The catalogue should be adequate for the standardization of photoelectric photometry. For photoelectric work we need only a definition of zero-points and color-system ; it is best to establish independently the Pogson scale for the magnitudes. On the other hand, many photographic workers would like to use calibrated magnitudes in a few standard regions. In order to satisfy partially this demand, observations in several standard regions are made available.

The regions surrounding several galactic clusters have been chosen as the standard regions because it is possible, by observing both cluster stars and field stars, to obtain a greater variety of stars than one would expect to find in the general field. The three primary standard regions are those of Hyades-Pleiades, Praesepe and IC 4665. The color-magnitude diagrams for all of the stars that were observed in each region are shown in Figure 2. The standard magnitudes and colors for these stars are given in the following publications :

Hyades	—	Johnson and Knuckles [5].
Pleiades	—	Johnson and Morgan [2].
Praesepe	—	Johnson [11].
IC4 665	—	Johnson [12].

In addition to these primary standard regions, enough cluster and field stars have been observed in the regions of the following clusters to make them useful as secondary standard regions :

NGC 752	—	Johnson [13].
M 34	—	Johnson [14].
M 36	—	Johnson and Morgan [2].
M 39	—	Johnson [15].

The color-magnitude diagrams for these clusters are shown in Figure 3.

A number of stars in the North Polar Sequence have been observed on the U, B, V system. The values for these stars are given in Table 4.

It should be emphasized that *none* of these standard regions is sufficient by itself for the proper standardization of accurate photometry unless one is interested only in the kinds of stars that are known to exist in the standard regions. In general, one should also observe at least 20 stars selected from Table 3.

III. Recommendations for the Use of the U, B, V System.

Experience with the use of the U, B, V system during the past three years permits the following recommendations for its use to be made :

1. If possible, use filters having the same numbers as the ones that were used in defining the U, B, V system (U = Corning 9 863, B = Corning 5 030 + 2 mm Schott GG13, V = Corning 3 384). With such filters, the deviations of the transformations from linearity will be slight. If it is not possible to use these filters, satisfactory substitutes are : U = 2 mm Schott UG2, B = 1 mm Schott BG12 + 2 mm Schott GG13, V = 2 mm Schott GG11.
2. Aluminized reflecting telescopes should be used if possible. Silvered mirrors or refracting telescopes will not affect the transformations to B and V but will introduce non-linear and muti-valued transformations for U. Some photo-multipliers, such as EMI, have somewhat less response in the ultraviolet than do RCA 1P21's and may also affect the U transformations.

3. Regardless of the filters, optics, or photomultipliers, it is recommended to observe a large number of stars of all kinds selected from Table 3. These observations will allow one to check on the quality of transformations. Once the character of the transformations has been established, continued observation of a much smaller number of stars will serve to standardize the observations.
4. Although several standard regions have been supplied for the use of photographic observers, it is always best to use photoelectric transfers to the photographed region and to use a photoelectrically set up standard sequence in the region. One thereby avoids many of the systematic errors that can creep into photographic photometry.
5. Photographic photometry on the U, B, V system is quite satisfactory if the proper filters are used. The recommended photographic filters are : U = Corning 9 863 or 2 mm Schott UG2 with a blue-sensitive plate ; B = 2 mm Schott GG13 with a blue-sensitive plate ; V = 2 mm Schott GG11 with a yellow sensitive plate.

Experience has shown that if these simple precautions are observed, particularly if one observes enough stars, it is possible to transform the observed magnitudes and colors to the U, B, V system without a significant loss in precision. Such transformed values are, then, directly comparable with all the values for the standard stars and with derived relations such as the intrinsic colors and color versus spectral type relation [2], [9].

Manuscrit reçu le 1er *septembre* 1955.

REFERENCES

[1] H. L. Johnson, *Ap. J.*, **116**, 1952, 272.
[2] H. L. Johnson and W. W. Morgan, *Ap. J.*, **114**, 1951, 522.
[3] H. L. Johnson and W. W. Morgan, *Ap. J.*, **117**, 1953, 313.
[4] O. J. Eggen, *A. J.*, **60**, 1955, 65.
[5] H. L. Johnson and C. F. Knuckles, *Ap. J.*, In press, Sept., 1955.
[6] H. F. Weaver, *Ap. J.*, **116**, 1952, 612.
[7] K. Bahner and G. R. Miczaika, *Zs. f. Ap.*, **31**, 1952, 236.
[8] J. Stebbins and A. E. Whitford, *Ap. J.*, **102**, 1945, 273.
[9] W. W. Morgan, D. L. Harris and H. L. Johnson, *Ap. J.*, **118**, 1953, 92.
[10] J. Strong, *Preceedures in Experimental Physics*, Prentice Hall, Inc., New York, 1938, 375.
[11] H. L. Johnson, **116**, 1952, 640.
[12] H. L. Johnson, *Ap. J.*, **119**, 1954, 181.
[13] H. L. Johnson, *Ap. J.*, **117**, 1953, 356.
[14] H. L. Johnson, *Ap. J.*, **119**, 1954, 185.
[15] H. L. Johnson, *Ap. J.*, **117**, 1953, 353.
[16] H. L. Johnson, *Ap. J.*, **119**, 1954, 344.
[17] W. P. Bidelman, *Ap. J.*, **105**, 1947, 492.