

## TRANSFORMATION OF PHOTOGRAPHIC MAGNITUDES

HALTON ARP

Mount Wilson and Palomar Observatories  
Carnegie Institution of Washington, California Institute of Technology*Received November 7, 1960*

## ABSTRACT

Transformation equations are determined semi-empirically between the  $B$  system and photographic magnitudes obtained: (1) with 103a-O plates and aluminized reflectors, using only the atmosphere as an ultraviolet cutoff filter; (2) with 103a-O plates taken with the 48-inch Schmidt corrector plate as a filter (Sky Survey photographic system); (3) 103a-O plates with a WG2 or equivalent GG1 filter (a system used after the introduction of aluminized reflectors to approximate the original international photographic system).

## INTRODUCTION

It has been demonstrated (Johnson 1952) that inclusion of light bluer than 3800 Å in a photographic magnitude system makes the transformation to  $B$  magnitudes non-linear and multivalued. Despite the resulting loss of accuracy in transforming such magnitudes to the  $B$  system, it is sometimes necessary to use old observations or observations not on the  $B$  system for some other reason. Therefore, the following calculations have been made to determine as accurately as possible the transformation to the  $B$  system of (1) the extreme case of ultraviolet admission, viz., a 103a-O plate taken with an aluminized reflector; (2) 103a-O plates taken with the Palomar 48-inch Schmidt telescope, where only the correcting plate and the atmosphere limit the ultraviolet admission; and (3) 103a-O plates taken with aluminized reflectors and with either a GG1 or WG2 filter. These latter two filters were introduced by Baade about 1938 to return aluminized reflectors to the old international photographic system of silvered mirrors with no filter. It turns out that system 3 allows slightly more ultraviolet light in than either the old international photographic system or the photoelectric,  $P$ , approximation to it. Therefore, the equations commonly found in the literature relating  $P$  and  $B$  magnitudes are less strong than the three cases treated here. For example, Paul Wild (unpublished) compares Johnson's final  $B$  magnitudes in the Pleiades with his first published  $P$  magnitudes and finds

$$(a) \quad B - P = 0.17 - 0.09 (B - V) .$$

Allen (1955, p. 180) gives an almost identical transformation between the  $P$  system and the  $B$ ,  $V$  system:

$$(b) \quad B - P = 0.18 - 0.10 (B - V) .$$

Present-day photographic photometry, of course, is done with a GG13 filter whenever possible, and the measured magnitudes are then automatically  $B$  magnitudes. Color equations with 103a-D plates are negligible for a wide range of yellow filters, so that photovisual magnitudes are all considered to be on the  $V$  system.

It should be noted that  $m_{pg}$  has been used in the present paper to designate a generalized photographic magnitude. This has been customary in the literature. That is, any of the cases 1, 2, and 3, as well as intermediate cases, are usually loosely called " $m_{pg}$ ." Some workers, however, use  $m_{pg}$  consistently to refer to some one system. For example, Arp and Sandage, whenever they have used the symbol  $m_{pg}$  in the past, have always referred strictly to case 3.

It would be best to determine the transformations for the above cases completely empirically by measuring groups of stars with each system and correlating their magnitude residuals with  $B - V$ . The corrections are small, however, and special effort have to be made to bring the quantities above the measuring error. Even worse is the fact that it is impossible to find a localized field of stars having a large enough range in color index and luminosity class. It was therefore decided to compute the energy in the photographic band pass of each system by operating on stars of known intensity distribution with the filter cutoff of each system.

## SENSITIVITY OF FUNCTIONS

Table 1 lists the adopted sensitivity functions of each photographic magnitude system. The ultraviolet cutoff is taken for clear air on Mont Ventoux (Baum and Dunkelman 1955) with a scale height of 7.9 km. This means that, for less clear observing conditions and at zenith distances greater than  $\sec z = 1$ , the ultraviolet atmospheric extinction will be somewhat greater than that used in Table 1. The color sensitivity of 103a-O emulsion is taken from the *Kodak Photographic Plates* (7th ed., 1953). The red cutoff could be read only approximately, and the blue sensitivity was assumed to hold at 100

TABLE 1  
SENSITIVITY FUNCTIONS

$\lambda$	103a-O +atmosphere	Schmidt corr. +103a-O+at- mosphere	WG2+103a-O	2-mm GG13 +1-mm BG12 (B) +130a-O
2800	0 037			
2900	0 148			
3000	0 328			
3100	0.615			
3200	0 665			
3300	0 691	0.042		
3400	0 720	0 257	0.029	
3500	0 778	0 444	.210	
3600	0 852	0.630	.481	0
3700	0 968	0.828	.706	0.09
3800	0 978	0 911	.802	.33
3900	0 989	0 974	.840	.54
4000	1 000	1 000	.860	.66
4100	1 000	1 000	.860	.73
4200	0 950	0 950	.825	.76
4300	0.900	0.900	.783	.76
4400	0 850	0 850	.743	.75
4500	0 800	0.800	.702	.72
4600				.68
4700	0 630	0 630	.553	.60
4800	0 500	0 500	.439	.48
4900	0.330	0 330	.290	.35
5000	0 250	0 250	0.219	.23
5100				.15
5200				.08
5300				.04
5400				.02
5500				.03
5600				.04
5700				.03
5800				.01
5900				0 00

per cent out to the ultraviolet atmospheric cutoff. The transmission of the 48-inch Schmidt is as measured by Pettit (unpublished). The transmission-curves for WG2 and the GG13 + BG12 photoelectric  $B$  filters are from filters available at Mount Wilson and Palomar Observatories.

Energy-curves for six stars (Preliminary Monochromatic Magnitudes of Bright Stars, Washburn Observatory, 1955) were operated on by the sensitivity functions in Table 1. The computed energy admitted by the  $B$  band pass was taken as unity, and the excess in magnitudes for the remaining three photographic systems are computed in Table 2. The results are plotted in Figure 1 as a function of color index. The one filled symbol in each case represents the Ia supergiant  $\alpha$  Cyg.

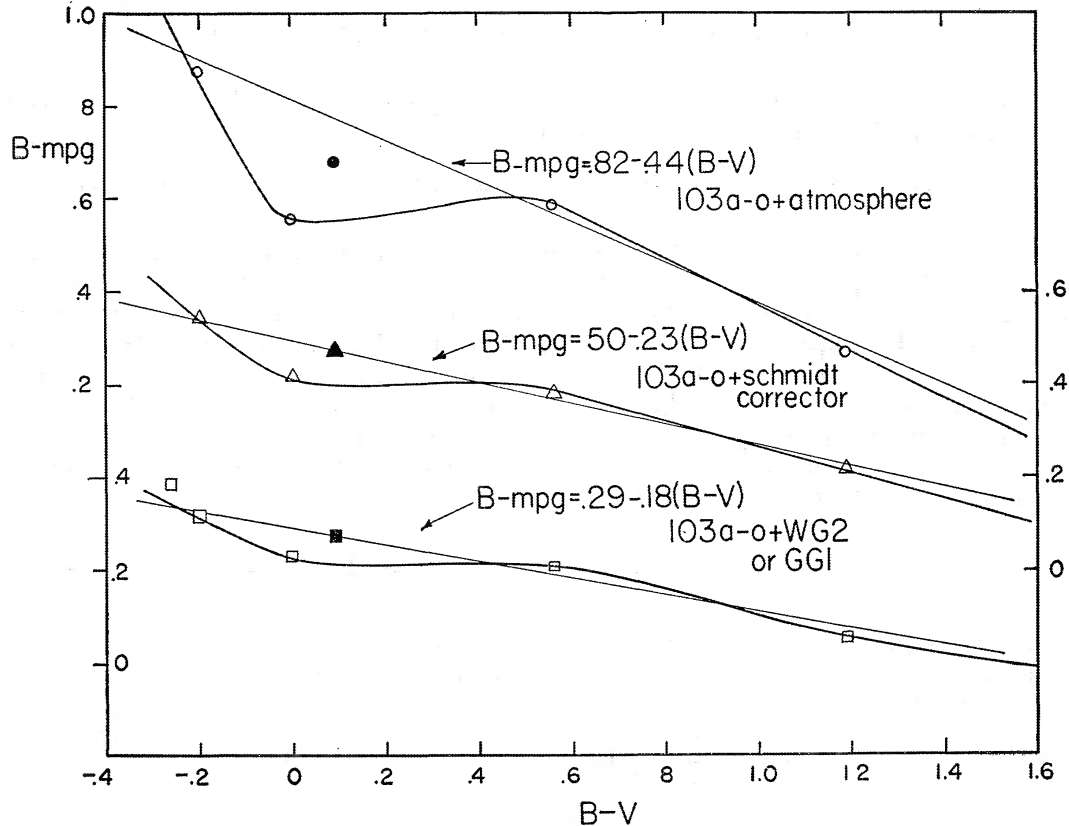


FIG. 1.—Corrections ( $B - m_{pg}$ ) to be applied to various photographic magnitude systems in order to derive  $B$  magnitudes. Open symbols represent luminosity class V stars; filled symbols, luminosity class I.

TABLE 2

RELATIVE ENERGY BENEATH PHOTOGRAPHIC BAND PASS (MAG.)

Star	$\alpha$ Vir	$\eta$ UMa	$\alpha$ Lyr	$\alpha$ Cyg	$\beta$ Com	61 Cyg A
$B-V$	-0.26	-0.20	0.00	0.09	0.56	1.19
Sp.	B1 V	B3 V	A0 V	A2 Ia	G0 V	K5 V
103a-O+atmosphere...	...	-0.88	-0.56	-0.68	-0.58	-0.27
103a-O+Schmidt ...	...	-.54	-.42	-.47	-.38	-.22
103a-O+WG2. ...	-0.39	-0.32	-0.23	-0.27	-0.20	-0.06
B.....	0	0	0	0	0	0

It is clear that a linear transformation equation between  $B$  and these other systems is disturbed most by the strong hydrogen absorption in the A stars. That absorption allows less ultraviolet light through than would be expected on the basis of their  $B - V$  colors. Nevertheless, the straight lines fitted in Figure 1 give the best over-all linear approximation possible and can be used with the understanding that errors of the order shown can be expected for stars with strong absorption in the ultraviolet.

## ALUMINIZED REFLECTOR

$$B - m_{pg} = 0.82 - 0.44 (B - V) \quad 103a\text{-O plate} + \text{atmosphere}, \quad (1)$$

$$B - m_{pg} = 0.50 - 0.23 (B - V) \quad 103a\text{-O} + \text{Schmidt corrector plate}, \quad (2)$$

$$B - m_{pg} = 0.29 - 0.18 (B - V) \quad 103a\text{-O} + \text{WG2 or GG1}. \quad (3)$$

The last equation agrees very well with the completely empirically determined transformation for the same system (Arp 1957):

$$B - m_{pg} = 0.27 - 0.19 (B - V) \quad \text{empirically determined, } 103a\text{-O} + \text{GG1}. \quad (3a)$$

This result gives confidence in the semiempirical determination of equations (1) and (2).

The results in Figure 1 show small differences from Johnson's (1955) results. He identified his  $P_{0.5}$  as near international photographic, which would indicate his transformation equations to be slightly less strong than the bottom relation in Figure 1. His predicted errors for supergiants and blue stars from a linear transformation are near 0.2 mag., whereas the maximum error indicated here is only in the neighborhood of 0.1 mag.

The results in Figure 1 may be roughly checked by an independent calculation. Let  $\delta(U - B)$  denote the ultraviolet excess, at a given  $B - V$  of a star from the normal, luminosity class V,  $U - B$ ,  $B - V$  relation:

$$2.5 \log \frac{I_B}{I_U} \approx (U - B) - 1.4, \quad \text{average transformation for 200-inch}, \quad (3b)$$

where  $I_B$  and  $I_U$  are intensity in  $B$  and  $U$  wave lengths.

If, then, a star, say of luminosity class Ia, has excess ultraviolet radiation of  $\Delta I_U$  relative to class V,

$$2.5 \log \left[ \frac{I_B}{I_U + \Delta I_U} \right] = (U - B) - 1.4 + \delta (U - B), \quad (3c)$$

and, together with (b), this reduces to

$$2.5 \log \left[ 1 + \frac{\Delta I_U}{I_U} \right] = -\delta (U - B), \quad (3d)$$

and we can solve for  $\Delta I_U / I_U$  if given the ultraviolet excess.

At the same time the light that comes through the photographic window of systems 1, 2, and 3 can be written:

$$I_{mpg} = I_B + I'_U + \Delta I_U, \quad (3e)$$

where  $I'_U$  is the additional ultraviolet light which the  $B$  system would not pass. We can then write

$$2.5 \log \frac{I_{mpg}}{I_B} = B - m_{pg} = 2.5 \log \left[ 1 + \frac{I'_U}{I_B} + \frac{\Delta I_U}{I_B} \right]. \quad (3f)$$

At the color of  $\alpha$  Cyg, the relations in Figure 1 predict a certain  $B - m_{pg}$  for unreddened main-sequence stars (where  $\Delta I_U \equiv 0$ ), equation (f) above can then be solved for  $I'_U/I_B$  at this point. For  $B - V = 0.09$ :

$$\frac{I'_U}{I_B} = 0.66, \quad \text{case 1,}$$

$$\frac{I'_U}{I_B} = 0.45, \quad \text{case 2,}$$

$$\frac{I'_U}{I_B} = 0.23, \quad \text{case 3.}$$

Now we can compute for  $\alpha$  Cyg, which has an ultraviolet excess of  $\delta(U - B) = -0.34$  mag., what  $\Delta I_U/I_U$  is from equation (d), substitute this value in equation (f) with the values of  $I'_U/I_B$  just found, and predict the extra correction in  $B - m_{pg}$  for this supergiant as in the accompanying table.

	$B - m_{pg}$ (Case 1)	$B - m_{pg}$ (Case 2)	$B - m_{pg}$ (Case 3)
Predicted by equation (f). . .	0 69	0 52	0 29
Computed semiempirically. . .	0 68	0 48	0 27

The agreement is good and not only checks the transformation shown in Figure 1 but furnishes a method of computing a refined correction for stars with ultraviolet excesses or deficiencies if their  $\delta(U - B)$  is known.

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