THE APPLICATION OF SYNTHETIC SPECTRA TO COLOUR SYSTEM TRANSFORMATIONS—II

The Photographic and Photoelectric UBV Systems

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SUMMARY

Synthetic spectra and the photoelectric and various photographic UBV sensitivity functions are used to compute theoretical colours for F and G dwarfs. Similar calculations are made for hotter stars. It is shown that photographic V magnitudes obtained using 103a-G emulsion and a GG 11 filter will be in better agreement with photoelectric V magnitudes than is the case when the 103a-D emulsion is used. The photographic and photoelectric U and B magnitudes are in good agreement. It is also shown that the use of S20 photocathodes for direct photography with image tubes will introduce large colour corrections terms if V magnitudes are to be measured, unless a BG18 filter is used in addition to the GG 11 filter.

I. INTRODUCTION

The technique used in the previous paper (Bell 1972) to determine the relation between the UBV and RGU colours can also be used to study the relations between the UBV colours measured photoelectrically and photographically. This latter problem arises because the sensitivity functions of the equipment used to obtain UBV colours photoelectrically are different from those used to obtain photographic measurements.

Photographic U, B and V magnitudes are obtained from iris photometer measurements of direct photographs. The iris measurements of a sequence of stars for which U, B and V magnitudes have been measured photoelectrically supplies the calibration necessary to convert the iris measurements of the remaining stars into magnitudes. We refer to these latter magnitudes as photographic ones and denote them by $U_{pg}$, $B_{pg}$ and $V_{pg}$. The absence of a subscript denotes photoelectrically measured magnitudes. The technique of measuring UBV data photographically suggests that the transformation relations should be written as

$$V = V_{pg} + \beta(B-V)$$

(and similarly for U and B) rather than as

$$B-V = \gamma(B-V)_{pg} + \delta(U-B)_{pg}$$

which is of the form used to discuss the relation between different photoelectric systems. The former transformation equation then leads us to the following two points.

Firstly, transformation errors in the photometry will be minimized in a situation where $V$ is correlated with $B-V$, as in observations of the main sequence of a galactic cluster where the fainter stars are also the redder ones. The colour effects
will then be absorbed in the curve relating $V$ to iris photometer reading. Conversely, the influence of colour effects will be largest when $V$ and $B-V$ are not correlated as will occur, for example, when discussing the HR diagram of a sample of stars in the Magellanic Clouds.

Secondly, if the $V$ magnitude of a particular star of the photoelectric sequence is erroneous then all the photographic measures which rely on that star for calibration will be erroneous. This will then produce an error in $B-V$ which will exist over a range in $V$. Similar errors can occur in $U$ and $B$ and are particularly serious in $B$ as erroneous values of $\delta(U-B)$ will be derived. This second problem is mentioned for completeness, particularly because it occurs in practice and has not always been correctly identified.

2. COLOUR CALCULATIONS

The sensitivity functions of the plate and filter combinations used for photographic photometry, i.e. $V = \text{Kodak 103 a-D+2-mm Schott GG11}$; $B = \text{Kodak 103 a-O+2-mm Schott GG13}$ and $U = \text{Kodak 103 a-O+2-mm Schott UG2}$ and the transmission of the Earth’s atmosphere at the zenith were used to obtain the sensitivity function of the three pass bands. These calculations were carried out by Mr M. Raff. Comparison with the photoelectric sensitivity functions (Matthews & Sandage 1963) shows that the combination of 103a-D emulsion and GG-11 filter is a poor fit to the photoelectric $V$ sensitivity function. A study of the Kodak catalogue shows that the sensitivity of the 103a-G emulsion does not extend to as long wavelengths as does that of 103a-D. The sensitivity function of the GG-11 filter and 103a-G emulsion was consequently calculated to see if this combination would yield closer agreement with the photoelectric $V$ function.

Current image tubes are available with S4 or S20 photocathodes. The former is used in the 1P21 photomultiplier so direct photographs with image tubes with this photocathode should yield $V$ magnitudes without large colour terms. This is not the case for the image tubes using the S20 photocathode, with its greater red sensitivity. The sensitivity function of GG-11 and the S20 photocathode was calculated. The measurements of stars on the $UBVr$ system are carried out using an S20 photocathode and a BG18 filter is used, in addition to the normal GG11, to define the $V$ passband. Calculations using the $UBV$ sensitivity functions of Sandage & Smith (1963) yield $V$ magnitudes and $U-B$, $V-B$ colours in close agreement with the values calculated using the $UBV$ sensitivity functions.

A number of the sensitivity functions are plotted in Fig. 1. The sensitivity functions of the various passbands were convolved with the synthetic spectra fluxes and the theoretical colours calculated in the usual way. The colour zero points were obtained in the same way as Paper I, arguing that the solar model should have the solar colours, taken to be $U-B = 0.06$ and $B-V = 0.60$.

The convolution was carried out for the F and G dwarf models Nos 1–5 of Bell (1971), the Balmer-line blanketed models of Mihalas (1966), with $\theta_{\text{eff}} = 0.40$, 0.55 and 0.70 and $\log g = 4.0$, and the model of Bradley & Morton (1969) with $\theta_{\text{eff}} = 0.176$ and $\log g = 3.5$. The results of the convolutions for these models are given in Table I.

The first column of Table I gives the $B-V$ colour of the model. The second column gives the difference between $B-V$ colours obtained using the 103a-D, GG 11 combination and the standard photoelectric $B-V$ colours. The zero point of this
difference has been chosen so that the Sun will have the same colour on both systems. It is clear that there is a significant difference between the two systems in that a hot star is measured to be much bluer on the photographic system. The third

![Graph showing sensitivity functions.](https://academic.oup.com/mnras/article-abstract/159/4/357/2604618)

**Fig. 1.** The solid lines denote the photoelectric UBV sensitivity functions of Matthews & Sandage (1963) and the V sensitivity function, V(S20), when an S20 photocathode is used instead of the S4 photocathode of the 1P21 photomultiplier. The dashed lines represent the photographic sensitivity functions with the V sensitivity function being computed for 103a-G emulsion (V(103a-G)) as well as for the normal 103a-D (V(103a-D)).

<table>
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<tr>
<th>B-V</th>
<th>D(B-V)</th>
<th>D(B-V)</th>
<th>D(B-V)</th>
<th>D(B-V)</th>
<th>D(U-B)</th>
<th>DB</th>
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<td>-0.34</td>
<td>-0.16</td>
<td>-0.02</td>
<td>-0.21</td>
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<td>+0.04</td>
<td>-0.01</td>
<td>-0.02</td>
<td>+0.01</td>
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The first column gives the model B-V colour. The next column gives the difference between photographic B-V, with V being obtained using 103a-D and GG11, and the photoelectric B-V. The third column gives the difference between photographic B-V, V being obtained using 103a-G and GG11, and photoelectric B-V. The fourth column gives the same colour difference, with the photographic B-V being computed using an S20 photocathode response. The fifth column gives the colour difference between B-V of the UBV system, where an S20 surface is used in conjunction with GG11 and BG18 filters, and the standard photoelectric B-V. The sixth column gives the difference between photographic and photoelectric U-B colours and the final column gives the difference between photographic and photoelectric B magnitudes.

The column of Table I gives the B-V differences obtained when the V magnitudes are measured using the 103a-G combination. The colour differences in this case are negligible. The fourth column gives the B-V differences obtained when the V
magnitudes are measured using an image tube with an S20 photocathode. These differences are even larger than in the comparison between the photographic 103a-D, GG 11 colours and the S4 colours. The fifth column gives the colour difference between the natural $B-V$ of the $UBVr$ system and the standard photoelectric $B-V$. It is seen that the use of the BG 18 filter with the S20 photocathode greatly improves the agreement between the colours. The sixth column of Table I gives the difference between photographically and photoelectrically measured $U-B$ colours. The difference is generally small, except at $B-V \sim 0.0$ when it amounts to $0.07$ magnitudes. The seventh and final column gives the difference between photographic and photoelectric $B$ magnitudes.

A comparison of the difference between the $B$ magnitudes of the models shows that the differences in $B-V$ in Table I are caused primarily by differences in $V$. For example, the difference in column 2 at $B-V = -0.12$ is made up of a difference of $0.03$ in $B$ and $0.08$ in $V$. This leads to the conclusion that 103a-G should be the emulsion used to determine photographic $V$ magnitudes. Unfortunately the calculations show that this will require an exposure time increase of a factor of two compared to 103a-D exposure times. The very manner in which $UBV$ colours and magnitudes are obtained photographically, with colour terms possibly occurring in the calibration curve, makes it impossible to prescribe correction equations for any plate-filter combination. This conclusion is reinforced by the possibility of differences between emulsion batches and between melts of glass filters as well as variations in the response curves produced by ageing of aluminium coatings.

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REFERENCES