PHOTOELECTRIC MEASURES OF COMPARISON STARS IN SEVEN VARIABLE STAR FIELDS

RICHARD H. STANTON
217 Starlane Drive
La Canada, CA 91011

Abstract

Photoelectric measures with filters intended to match the response of the dark-adapted eye show substantial differences from the values on preliminary AAVSO charts. A mean error of $0.^{m}61$, and a standard deviation of $0.^{m}22$, were measured. These differences do not depend strongly on apparent magnitude or color.

* * * * *

With a 16-inch Cassegrain telescope located at an altitude of 3500 feet, and a home-built photon counter, I have measured the comparison stars in seven fields suggested to me by Clinton Ford. This is a report on the results, including a comparison between the magnitudes on the AAVSO charts and my photoelectric measurements.

Before comparing visual and photoelectric magnitudes, it is important to address differences in color response between the eye and the photoelectric system. As discussed by previous authors (Landis 1977, Howarth 1977), the spectral response of the dark-adapted eye differs considerably from that of the standard photoelectric V (of UBV). This disparity leads to a systematic difference between V and v (visual magnitude) that is a function of star color. Landis, by averaging the estimates of seven experienced observers, showed that this difference is greatest for red stars. The eye consistently underestimates the brightness of a red star relative to a blue star with the same V. Howarth reached qualitatively the same conclusion by doing a least-squares fit of catalogued data.

Since I was interested in finding a filter set that would permit direct photoelectric measurement of v values, I pursued yet a third approach. One can calculate the difference between v and V (vs. star color) once the spectral sensitivity of the eye and appropriate stellar irradiance curves are known. This was done (Figure 1) using eye response functions tabulated by Teele (1965) and stellar irradiance data of Forbes and Mitchell (1970).

There are several curves in Figure 1 since the spectral sensitivity of the human eye is not fixed, but varies as a function of the surrounding luminance (light intensity). This is not surprising since it is well known that the properties of the eye change as one becomes dark adapted. However, I was very much surprised to find that, at least according to several authorities (RCA Handbook, 1970), the eye is not completely dark adapted even under a clear moonless sky. As can be seen from the curves (Fig. 1), there is a slightly different color correction for a clear starlit sky (approximately 10^{-3} candela/m^2) than for total dark adaptation (less than 3×10^{-5} cd/m^2) and a considerably different correction for fairly bright moonlight (10^{-2} cd/m^2). As a result, the color difference between v and V for an individual observer is probably a function of his observing environment and whether or not the moon is up.

All of this is rather discouraging for one attempting to define a single curve representing the difference between v and V. Further complications arise due to differences between individual observers and, at least in the case of very red stars, differences between stars. However, these differences are usually small, implying that it should be possible to define a filter set to match the conditions under which most AAVSO observers work.

I selected a Schott GG4 filter for the purpose. The result of combining this filter with an S-11 photocathode (I have an EMI 9789B) matches closely the response of a fully dark-adapted eye (Figure 2). I call it "VIS" to distinguish it from either V or v). Since the VIS response does not quite match the eye under visual observing conditions, it is still necessary to apply a small correction which is a function of color (B-V). This correction is easily made as long as the color of each star is measured. In the final analysis, the validity of this, or any other color system attempting to match the eye, must rest on careful visual observations made by a number of qualified observers. For this reason, I have undertaken the measurement of comparison stars for charts currently being prepared and tested by the Chart Committee. If this experiment proves successful, it should be possible to bring comparison star magnitudes for AAVSO charts up to photoelectric standards.

The results of measuring magnitudes and colors for 47 existing comparison stars on seven* AAVSO charts are plotted in Figures 3, 4 and 5. Other surrounding stars were also measured, but since these had no corresponding AAVSO magnitudes they are not discussed here. To my knowledge, all of these charts are still preliminary, implying that the comparison star magnitudes are probably not as accurate as those on charts that have been finally approved. At any rate the data plotted in the figures represents differences between the comparison star magnitudes on the chart and my photoelectric measurements.

Perhaps the most significant aspect of these results is that the photoelectric magnitudes were almost always <u>significantly</u> higher than the values shown on the charts. Figure 3 is a plot of the difference between my measured visual magnitude (vis + small correction) and those shown on the chart. It is interesting to note that there seems to be no significant correlation between magnitude and measured difference.

These large offsets prompted me to re-evaluate my photon counter calibration and to look for possible sources of response error. Since I use bright stars ($V \sim 5$) as standards using the Naval Observatory Catalog (Pub. Nav. Obs., 1970), it was conceivable that significant nonlinearity was occurring when mapping from 5^m to 15^m. Factors such as counter-chain errors, dead-time, background subtraction, atmospheric calibration, etc., were all considered. After all of these effects were carefully studied, I reached the conclusion that the photon counter system has no important sources of systematic error over the complete range mentioned above. As a check of this conclusion, one of the standard photoelectric fields (Pub. Naval Obs. Vol XX) was examined down to magnitude 16.1. The results (also plotted in Figure 3) agreed very well within the expected noise range. Although this check only verified the calibration with respect to V (of UBV) it is significant that the agreement was better than ±.1 magnitude over an 11 magnitude range.

The residuals plotted in Figure 3 do not give the entire picture of the measured magnitude differences. Since data from seven separate fields are plotted, much of the scatter is due to the fact that some comparison sequences are consistently faint, while others are consistently bright, relative to the mean. This type of residual is not as serious as star-to-star errors within a single field. The latter can degrade a variable's light curve while field-to-field errors ~~nearly~~ merely shift the entire curve up or down by a few tenths of a magnitude.

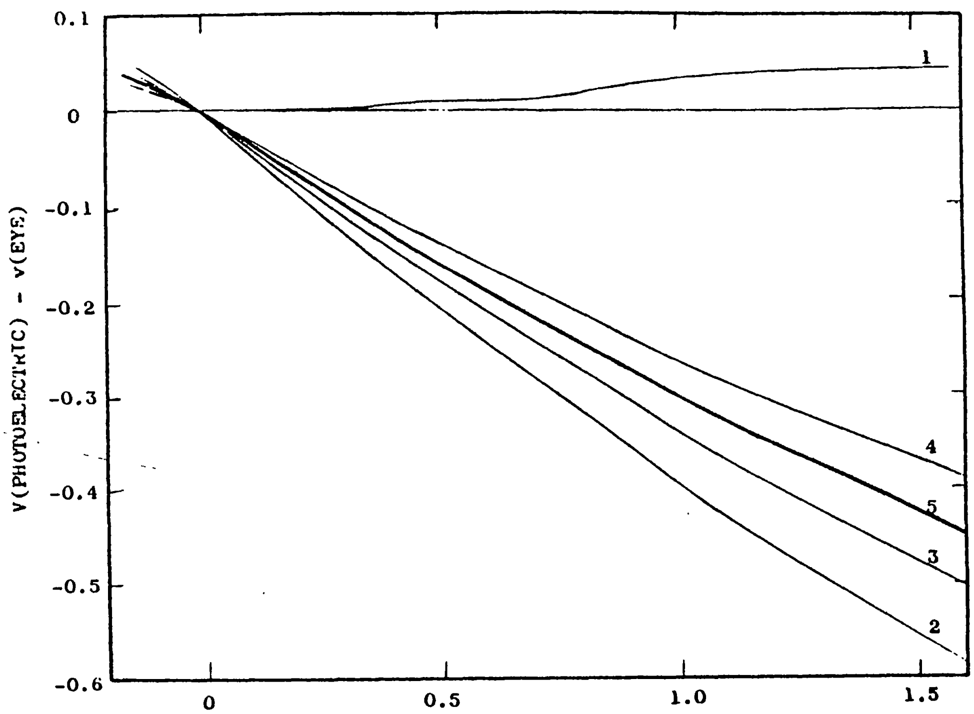

Figure 1. Calculated difference between photoelectric V and the eye's response (v) vs star color (B-V) for a variety of background light levels: (1) 3 candela/m^2 (photopic vision), (2) 10^{-5} cd/m^2 (full dark-adaptation), (3) 10^{-3} cd/m^2 (clear night sky), (4) 10^{-2} cd/m^2 (fairly bright moonlight). A compromise between curves (3) and (4) was selected for the magnitude reported here (curve 5)).

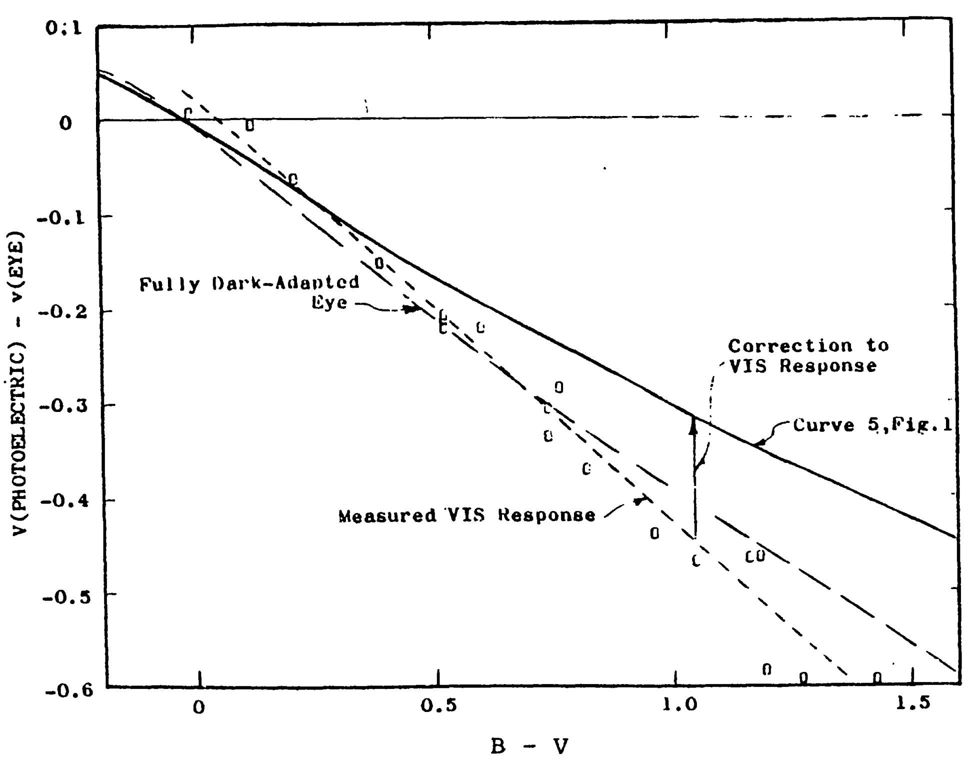

Figure 2. The measured response of my photometer (using a Schott GG-4 filter) is plotted along with the compromise curve from Figure 1. Unfortunately, this filter overcompensates the color difference between V and v so it is necessary to apply the correction indicated.

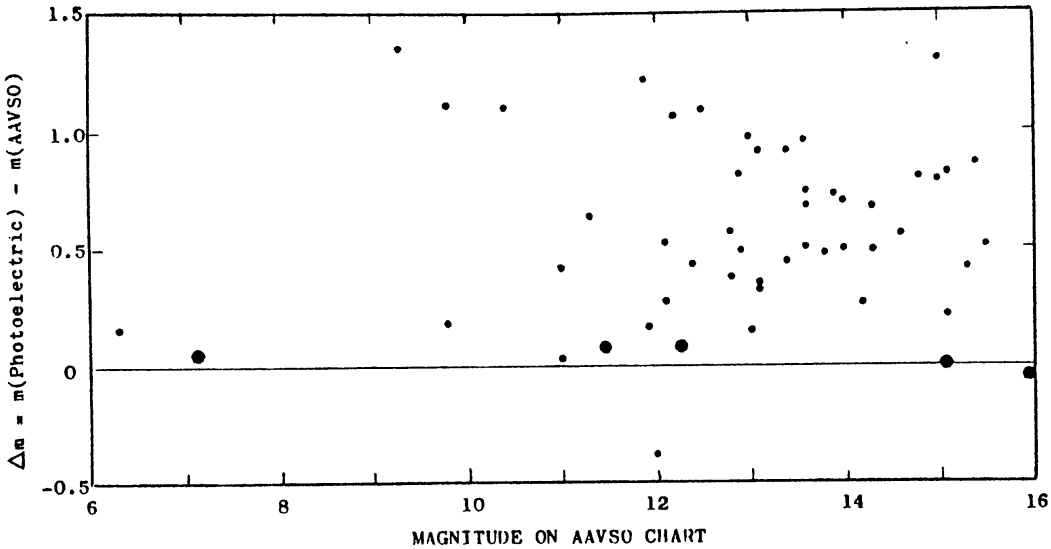

Figure 3. Magnitude difference between corrected photoelectric magnitudes and values appearing on seven preliminary AAVSO charts. The average offset is $0\overset{m}{.}61$ with a standard deviation of $0\overset{m}{.}361$. The large dots are measurements of a photoelectric sequence in a selected area (US Naval Obs. 1974).

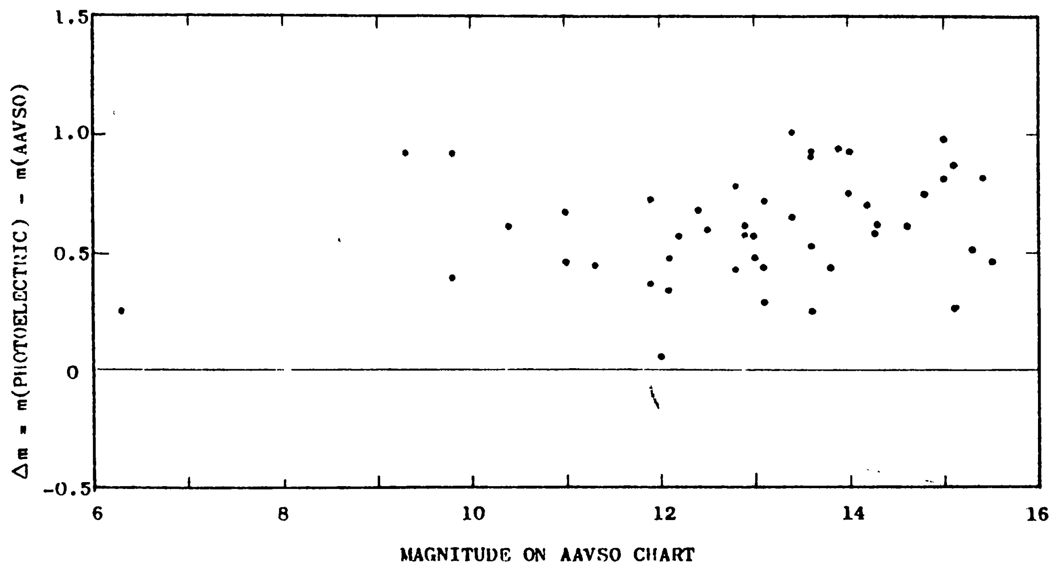

Figure 4. Same data as Figure 3 with field-to-field differences removed. Standard deviation reduced to $0\overset{m}{.}221$.

Figure 4 replots the residuals with field-to-field variations removed. While the scatter is still substantial it is interesting to note that field-to-field variations account for more than half of the total observed variance ($.285^2$ out of $.361^2$). Finally, in Figure 5 are plotted the observed residuals (with field-to-field variations removed) vs. star color (B-V). No systematic trend is evident in this plot.

The standard deviation for data plotted in Figures 4 and 5 ($\sigma = 0.^m22$) while not insignificant, is consistent with what might be expected for a set of comparison star magnitudes generated by non-photoelectric means. This is particularly true considering that these fields were selected as possibly requiring more work. However, the mean offset of $0.^m61$ magnitude is rather surprising since it implies either gross photoelectric errors or substantial errors in the existing sequences. I strongly lean towards this latter interpretation, particularly in view of the large field-to-field variations observed (the mean offset for each of the seven fields varied between .18 and 1.1 magnitudes).

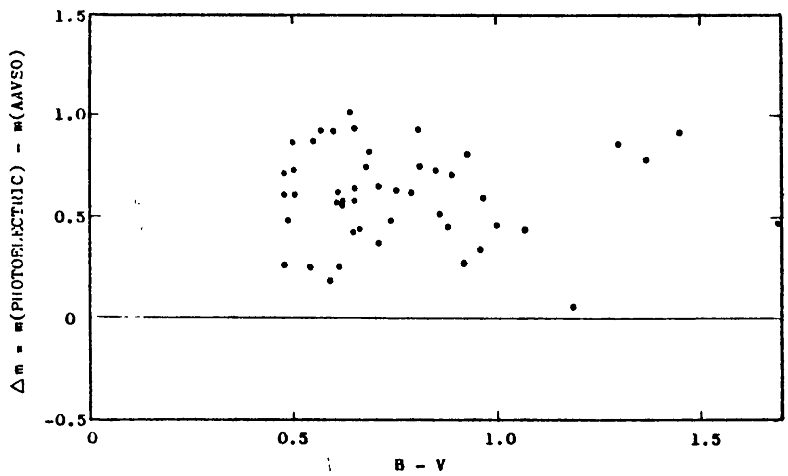

Figure 5. Same data as Figure 4 plotted against star color (B-V). Note absence of correlation between magnitude difference and color.

In summary, it appears from the comparisons discussed above, that at least some of the existing AAVSO sequences can be substantially improved through photoelectric measurements with "homemade" equipment. Evaluation of the proposed method for treating the dark-adapted-eye color response must await careful experimentation by a number of qualified observers.

*RT Boo, WX Ser, AH Ser, V-855 Oph, CH Her, LL Lyr and CY Lyr.

REFERENCES

Landis, L. J. 1977, JAAVSO, 6, 4.

Howarth, I.D. 1977, JAAVSO, 6, 88.

Teele, R. P. 1965, Applied Optics and Optical Engineering, Vol. 1, R. Kingslake Ed, 1.

Forbes, F. F. and Mitchell, R. I., 1970 Ariz. Univ. Comm. Lunar and Planetary Laboratory, Vol. 8.

__________ 1968, RCA Electro-Optics Hdbk, p. 6-6.

__________ 1970, Pub. US Naval Obs., Vol. XXI.

__________ 1974, Pub. US Naval Obs., Vol. XX, Part VII.