Notes on the magnitude scale of the Pleiades

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Notes on the magnitude scale of the Plejades, by *Ejnar Hertzsprung*.

1. In *V. J. S.* **50**, 81, 1915 K. GRAFF remarks that the fainter objects of my list of photographic magnitudes of stars in the central region of the Plejades (*A. N.* 4767, **199**, 251, 1914) have been given at least one magnitude too faint.

Later (*Astronomische Abhandlungen der Hamburger Sternwarte in Bergedorf*, Bd. 2, Nr. 3, 1920) GRAFF has published visual magnitudes of 600 stars in the group of the Plejades down to about the 14th magnitude and discussed the differences between his visual and my photographic magnitudes (*l. c.* p. 23).

Finally GRAFF recently (*A. N.* 5158, **215**, 435, 1922) derived the corrections $-^{m}\cdot1$ at 11^{m}, $-^{m}\cdot3$ at 12^{m}, $-^{m}\cdot6$ at 13^{m} and $-^{m}\cdot8$ at 14^{m} to be applied to my photographic magnitudes in order to reduce them to the normal scale, the original assertion of GRAFF thus having been somewhat moderated. *)

The validity of GRAFF's conclusion may now be tested with the aid of the new photographic magnitudes of 821 stars in the Plejades publisheid by HARLOW SHAPLEY and MYRTLE L. RICHMOND in *Ap. J.* **54**, 323, 1921, *Contrib. from the Mount Wilson Obs.* No. 218. Although the individual catalogue magnitudes are not very accurate — the mean error will not be considerably below $\pm^{m}\cdot2$ — their great number makes them fit for a comparison of scales. An advantage is that the magnitudes of SHAPLEY and RICHMOND have been determined by a direct connection of the Plejades with the North Polar Sequence. Besides the comparison between two photographic scales is much more reliable than between a photographic and a visual one, when — as is here the case — there is a systematic change of the colours of the stars with the apparent magnitude. For evidently it is difficult to separate the effect of this change from the effect of scale differences, when pairs of stars of the same magnitude but of considerable differencc in colour are rare.

From the figures given in Table 1 it is seen, that the magnitudes of SHAPLEY and RICHMOND agree with mine near the beginning and the end of the interval examined, viz. at 12^{m} and at 15^{m}, while in between these two magnitudes there is indicated a maximum difference of $^{m}\cdot22$ at about 14^{m} on my scale. Taken as a whole my magnitudes are $^{m}\cdot12 \pm ^{m}\cdot03$ (m. e.) greater than those of SHAPLEY and RICHMOND.

TABLE 1.

Number of stars	10	10	21	21	11	10
	m	*m*	*m*	*m*	*m*	*m*
m_{pg} (SHAPLEY and RICHMOND	11.42	12·44	13·16	13·78	14·27	14·96
m_{pg} (HERTZSPRUNG	11.36	12·47	13·32	14·01	14·47	14·98
SH and RI minus HE	+·06	—·03	—·17	—·22	—·20	—·02
m. e	±·06	±·06	±·04	±·04	±·06	±·06
Corr. according to GRAFF	—·15	—·43	—·67	—·80		
diff.	·21	·40	·50	·58		

A comparison of this result with the corrections to my magnitudes derived by GRAFF tends to show that GRAFF's conclusion as to the error of my scale is exaggerated by four or five tenths of a magnitude.

2. In visual photometry the equality between the real and the artificial star is generally effected by submitting the last to a measurable change. The question as to the influence of the Purkinje phenomenon on measures of this kind is therefore of particular interest. Thus the visual magnitudes by GRAFF mentioned above have been determined within considerable intervals of brightness by adjusting the artificial star. Further they have been carried down to the faintest stars measurable which form the one end of the interval, where the Purkinje phenomenon asserts itself.

For an investigation of this kind it is necessary to take account of the colours of the stars. Now for the Plejades I am in possession of good colour equivalents down to about 14^{m}, mainly based on my measures of effective wavelengths on plates taken with the 60 inch reflector at Mount Wilson.

First I compared the visual magnitudes of GRAFF $m_{v,Gf}$ with my photographic ones $m_{pg,He}$ of the central Plejades (*l. c.*) using as colour equivalent the effective wavelength converted into colourindex $I\lambda$ which was intended to correspond to the scale I_H of the Göttingen-Actinometry. The fainter stars, for which $I\lambda$ is uncertain, were combined to pairs or groups. Thus 57 equations of condition were formed covering the interval between $10^{m}\cdot00$ and $14^{m}\cdot11$ on GRAFF's scale. A least square solution gave the formula

$$m_{pg,He} - 10 = -\cdot245 + 1\cdot211\ (m_{v,Gf} - 10) + 1\cdot392\ I\lambda - \cdot247\ (m_{v,Gf} - 10)\ I\lambda.$$

The coefficient $-\cdot247$ is nearly 5 times its mean error $\pm\cdot050$. It indicates a Purkinje effect between the two series compared and its sign is as to be expected,

*) A remark of GRAFF (*l. c.* p. 431) causes me to state that I am not of opinion that the discrepancies found can only be explained by a Purkinje effect in the visual measures, but that the sign found for the Purkinje coefficient invites us to look for the error in the visual magnitudes. Neither do I think that GRAFF's eyes show the Purkinje phenomenon to an extraordinary degree — we have in fact hardly anything else to compare with. The measures of GRAFF perhaps offer the first opportunity to test this important question earnestly by comparison with photovisual magnitudes, the colours of the stars here considered being reasonably well known.

when the effect has its cause in the visual measures. Still I do not wish to lay much stress on this result, as the number of stars treated is only small.

A better test is afforded by a comparison between visual and photovisual magnitudes, because the difference in colour conception between these is much smaller than between visual and photographic magnitudes.

Photovisual magnitudes of fainter Plejades have been published by G. A. TIKHOFF (*Publ. de l'observatoire central Nicolas*, Sér. 2, Vol. 17, 1912) and (indirectly) by SHAPLEY and RICHMOND (*l. c.*).

TIKHOFF gives on an arbitrary scale monochromatic „magnitudes" for five different wavelengths. I have used the mean „magnitude" corresponding to the two longest of these, viz. 565 and 520 $\mu\mu$, as taken from Table 16 on page 31—36 *l. c.* This mean „magnitude" was first approximately reduced to the usual magnitude scale by means of the formula

$$m_{pv,Tf} = 10{\cdot}4 + {\cdot}25\,\big(10 - Tf(565) - Tf(520)\big).$$

Using 180 stars between 9^m and $12{\cdot}^m5$ on GRAFF's scale and assuming a linear relation between the photovisual magnitudes of TIKHOFF and magnitudes on the normal scale, a least square solution gave the following formula:

$$\begin{array}{l} m_{pv,Tf} - 10 = +{\cdot}086 + \\ +{\cdot}862\,(m_{v,Gf} - 10) + {\cdot}032\,I\lambda - {\cdot}048\,(m_{v,Gf} - 10)\,I\lambda \\ \pm{\cdot}016 \qquad\qquad \pm{\cdot}031 \quad \pm{\cdot}024 \qquad \text{(m. e.)}. \end{array}$$

The coefficient —·048 is twice its mean error and its sign indicates a Purkinje phenomenon in the usual direction. For $I\lambda = 0$ and $I\lambda = 1$ the proportion between the two scales of TIKHOFF and GRAFF is found to be $\Delta\, m_{pv,Tf} / \Delta\, m_{v,Gf} = {\cdot}862$ and ·862 —·048 = ·814 respectively. Assuming the photovisual scale to be independant of the colour of the stars, the proportion between GRAFF's scales for $I\lambda = 0$ and $I\lambda = 1$ is found to be ·862/·814 = 1·059 ± 030 (m. e.).

The photovisual magnitudes determined by SHAPLEY and RICHMOND may be easily calculated from the differences between the photographic magnitudes and the colour indices given (*l. c.*). A least square solution using 327 stars between $10^m{\cdot}24$ and $13^m{\cdot}94$ on GRAFF's scale gave the formula

$$\begin{array}{l} m_{pv,\,Sh\text{ and }Ri} - 10 = -{\cdot}167 + 1{\cdot}090\,(m_{v,Gf} - 10) + \\ \qquad\qquad + {\cdot}140\,I\lambda - {\cdot}1065\,(m_{v,Gf} - 10)\,I\lambda. \end{array}$$

The mean error of the Purkinje coefficient is ±·036, or about one third of its value. For $I\lambda = 0$ and $I\lambda = 1$ the proportion between the two scales is found to be $\Delta m_{pv,\,Sh\text{ and }Ri} / \Delta m_{v,Gf} = 1{\cdot}090$ and 1·090 —·1065 = ·9835 respectively. Assuming again the photovisual scale to be independent of colour the proportion between GRAFF's scales for $I\lambda = 0$ and $I\lambda = 1$ is here found to be 1·090/·9835 = 1·108 ± ·036. We now have two values of this proportion. viz. from comparison of GRAFF with the photovisual magnitudes of

TIKHOFF.....	1·059	± ·030 (m. e.)
SHAPLEY and RICHMOND...	1·108	± ·036
combined....	1·079	± ·023

This corresponds to a difference of 7·9 ± 2·3 (m. e.) percent in the scale of GRAFF for stars of spectra *A* and *K*.

The evidence for the presence of a Purkinje effect in the visual magnitudes of GRAFF is therefore rather strong, but more material is needed to settle the question definitively.

3. In *Ap. J.* **47**, 38, 1918 HARRIET MC WILLIAMS PARSONS publishes photovisual magnitudes of 110 stars in the Plejades down to about 11^m*). A comparison with the visual magnitudes of GRAFF (*l. c.*) reveals a considerable systematic difference between the photovisual magnitudes of Table I and Table II (*l. c.*). Omitting $BD + 23°555$ = GAULTIER 205, which is the variable *SY* Tauri, the mean photovisual magnitudes of the 10 last stars of Table I and the 10 first stars of Table II are respectively $10^m{\cdot}22$ and $10^m{\cdot}20$. The corresponding mean visual magnitudes of GRAFF are $10^m{\cdot}53$ and $11^m{\cdot}25$ respectively, the difference between the two being $^m{\cdot}74$ greater than between the two mean photovisual magnitudes of HARRIET MC WILLIAMS PARSONS.

*) On p. 42, 3d line from bottom, for 23°549 read 23°534. The star VI is not indicated on plate IV.