A PHOTOELECTRIC STUDY OF EARLY-TYPE SUPERGIANTS AROUND h AND χ PERSEI

M. K. Vainu Bappu

(Communicated by the Director, Nizamiah Observatory)

(Received 1954 November 29)

Summary

Photoelectric colours and magnitudes for thirty early-type stars, classified as supergiants belonging to the double cluster in Perseus, have been determined with the aid of the Lick 12-inch refractor. Measures of four stars in Harvard Standard Region C12 were used for the tie-in to the (P, V) system.

A general increase of absorption is found as one passes from h to χ Persei, in accordance with the earlier conclusions of Miss Pismis. A considerable non-uniformity of interstellar absorption exists around the cluster.

The supergiants of type B2 and the B0, B0·5, B1 and B2 stars of luminosity class III yield a distance modulus of $11^{m}\cdot7$ for the cluster of supergiants, corresponding to a distance of 2·2 kps. Using the new value of the distance modulus, absolute magnitudes have been calculated for supergiants of other spectral classes. The number of stars used in this investigation is too few to give an estimate of the dispersion in M_v for these early-type supergiants.

Highly luminous early-type stars are generally too far away from the Sun to give a reliable determination of their absolute magnitudes from parallax data. We therefore resort to the study of magnitudes and colours of objects of this kind that form part of large stellar aggregates with known distance moduli. The double cluster in Perseus, the Orion aggregate and NGC 6231 have, more or less, a fair sample of such supergiants. The double cluster in Perseus, however, contains a larger number of B and A type supergiants than the other two. It also contains a few very luminous stars of type M. It is natural, therefore, that our knowledge of the absolute magnitudes of these objects, and their dispersion in luminosity, should rest heavily on the results that can be derived from this cluster.

Much of our knowledge concerning the remarkable cluster of supergiants around h and χ Persei depends on a thorough investigation by Bidelman (1). He employed the MKK system of classification and separated the likely cluster members from the field supergiants. More recently Morgan, Whitford and Code (2) have provided more accurate classes on the MK system for some of the cluster members sorted out by Bidelman.

It is the purpose of this investigation to determine accurate magnitudes and colours for those supergiants belonging to h and χ Persei which can be "resolved" by a photoelectric photometer on a visual refractor of medium focal length.

The photoelectric observations of colours and magnitudes for 30 supergiants in and around the double cluster were carried out on four nights in 1952 September using the 12-inch refractor of Lick Observatory. The photometer employed a

1P21 photomultiplier tube, the output of which was amplified by a d.c. amplifier, designed by Kron, and fed into a Brown recorder. The filters used were Corning 5562 and 3385 giving effective wave-lengths of approximately 4200 A and 5200 A respectively. The deflections were obtained in the order blue, yellow, blue, followed by readings on the sky in the two colours. Also, deflections caused by a standard source provided a check on the stability of the overall response of the system. Mean extinction coefficients determined from Mount Hamilton extinction data gathered over several years were utilized in the reductions. Nightly extinction coefficients were also derived by Eggen's method (3) for three of the four nights, and these proved to be very close to the mean coefficients used. The reductions were carried out using the mean extinction coefficients as well as the values determined observationally for the night under consideration. No sensibly different values were obtained for magnitudes or colours, and hence the mean extinction values were used throughout finally.

The instrumental magnitudes m_L and colours C_L were transformed to the (P, V) system by means of nightly comparisons with stars A, C, D, F of Eggen's photoelectric sequence (4) in the Harvard Standard Region C12. While the V magnitudes used were those of Eggen, the $P-V$ values used were revised values, kindly supplied by Dr Kron in advance of publication. The transfers were made every night when C12 and the double cluster had nearly the same zenith distance. The transformation equations used are the following:—

$$P-V=A+BC_L, \tag{1}$$

$$V=m_L+D+F(P-V), \tag{2}$$

where

$$A=0{\cdot}417\pm0{\cdot}012,$$

$$B=1{\cdot}055\pm0{\cdot}005,$$

$$D=6{\cdot}494\pm0{\cdot}003,$$

$$F=-0{\cdot}116\pm0{\cdot}006.$$

From the individual values of V and $P-V$ obtained each night for the stars under observation the probable errors for one observation were found to be

$$P-V:\ \text{p.e.}=\pm0^{\text{m}}{\cdot}009,$$

$$V:\ \text{p.e.}=\pm0^{\text{m}}{\cdot}012.$$

In Table I are listed the relevant data for the stars included in this investigation. The first column contains the HD number, the BD number being given for one star not listed in the *Henry Draper Catalogue*. The second and third columns list the observed magnitudes V and colours $P-V$, these being means of three or four observations (rarely only two) on separate nights. Column 4 contains information on the spectral types; those with asterisks are due to Bidelman, the rest have been recently classified by Morgan (2) on the MK system. Finally in column 5 we have the colour excesses derived from the intrinsic colours of unreddened stars, on the (P, V) scale, as transformed from the (B, V) values given by Morgan, Harris and Johnson (5).

The available sources of reliable magnitudes or colours in the h and χ Persei region are the investigations of Wallenquist (6), Oosterhoff (7), and Stebbins, Huffer and Whitford (8). Fourteen stars in Table I have also been included in Wallenquist's photoelectric studies. Assuming that Wallenquist's system of

TABLE I

Colours and magnitudes of early-type supergiants around the double cluster

HD Number or BD Number	V	$P-V$	Spectral type	Colour excess	Remarks
12856	8·61	+0·08	*B0·5 ne	0·56	MWC 25
12953	6·73	+0·45	A1 Ia	0·59	
13051	8·75	−0·01	*B0·5	0·47	MWC 27
13267	6·42	+0·17	B5 Ia	0·52	
13476	6·49	+0·46	A3 Iab	0·54	
13744	7·65	+0·60	A0 Iab	0·77	
13621	8·17	−0·09	*B0·5	0·57	ADS 1714
13745	7·94	+0·01	B0 III	0·51	
13841	7·46	+0·08	B2 Ib	0·52	
13854	6·54	+0·13	B1 Iab	0·59	MWC 31
56° 473	9·13	+0·09	*B1n	0·55	MWC 441
13866	7·57	+0·05	B2 Ib	0·49	
13900	9·26	+0·02	*B1n	0·48	
13969	8·86	+0·15	*B1	0·61	
14250	9·01	+0·20	*B2n	0·64	
14322	6·82	+0·18	B8 Ib	0·45	
14321	9·31	+0·15	*B2	0·59	
14422	8·96	+0·36	*B1ne	0·82	MWC 37
14433	6·45	+0·42	A1 Ia	0·56	
14434	8·57	+0·04	*O7n	0·56	
14476	8·79	+0·25	*B0·5	0·73	
14520	9·23	+0·10	*B1	0·56	ADS 1810
14535	7·56	+0·57	A1 Ia	0·71	
14542	7·03	+0·47	B8 Ia	0·74	
14818	6·28	+0·15	B2 Ia	0·59	
14899	7·47	+0·29	*A0	0·46	
14956	7·26	+0·58	B2 Ia	1·02	
15316	7·29	+0·64	A3 Iab	0·72	
15497	7·08	+0·63	B6 Ia	0·96	
14143	6·70	+0·34	B2 Ia	0·78	

* Spectral classification by Bidelman. Those not starred are due to Morgan (2).

magnitudes and colours can be converted to the (P, V) system by a linear transformation, we get the following relations, by least squares, using stars fainter than $9^{m}\cdot 0$ for the purpose:

$$P = m_{pe} + 0\cdot 037 - 0\cdot 140\ (P-V), \tag{3}$$

$$P - V = 0\cdot 119 + 0\cdot 966\ C_{pe}. \tag{4}$$

A similar procedure for Oosterhoff's photographic magnitudes gives the relation

$$P = m_{pg} + 0\cdot 051 + 0\cdot 163\ (P-V). \tag{5}$$

The values derived from equations (3), (4) and (5) are compared with those from Table I in Fig. 1. The central diagram of Fig. 1 shows that equation (4) is a good approximation, as the colour differences between the two photoelectric systems are negligibly small over the range of magnitudes observed. Below magnitude 9·0 a randomness sets in in the measures that might be considered to indicate the rapid approach of the limiting magnitude for accurate measurement with Wallenquist's experimental arrangement. The two magnitude systems, on the other hand, are not completely described by equations (3) and (5). The similarity between the trends in the upper and lower diagrams of Fig. 1 is probably due to the heavy weighting of Wallenquist's scale and zero point with the aid of Oosterhoff's magnitudes.

Twenty-two stars in Table I have colours on the C_1 scale measured by Stebbins, Huffer and Whitford. These colours can be transformed to the (P, V) system by the linear relation

$$P-V=0{\cdot}199+1{\cdot}722\ C_1. \qquad (6)$$

There is, however, a large scatter among the points. A better fit is obtained by the curve

$$P-V=0{\cdot}208+1{\cdot}833\ C_1-1{\cdot}042\ C_1^2. \qquad (7)$$

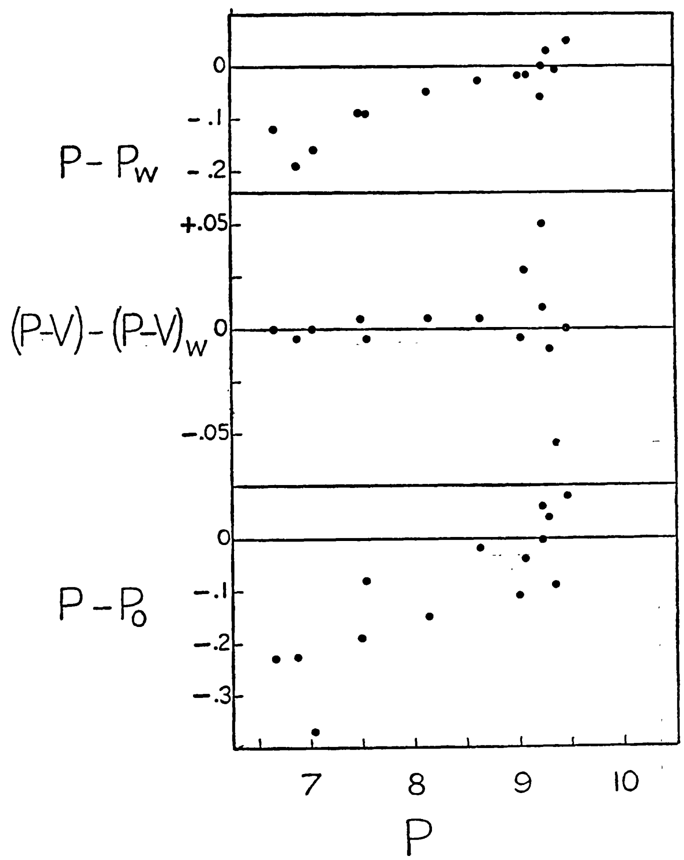

FIG. 1.—*Comparison of the photoelectric observations with the results of Wallenquist and Oosterhoff.* P_W, $(P-V)_W$ *and* P_O *are calculated values using equations* (3), (4) *and* (5) *respectively.*

A plot of observed colours against spectral type, as seen in Fig. 2, shows the non-uniformity of interstellar absorption around the double cluster. Fig. 3 shows the variation of colour excess (100× colour excess is plotted) over the region containing the two clusters. There is a general increase of absorption as one passes from h to χ Persei, in agreement with the results of Miss Pismis (9); and superimposed on this is the irregular variation caused by a patchy distribution of the absorbing clouds. Consequently, any observed colour-magnitude array would show a large dispersion in values along any of the sequences of interest.

In Fig. 4, I have plotted apparent visual magnitudes corrected for interstellar absorption (2·8× colour excess) against spectral type for the stars listed in Table I.

46*

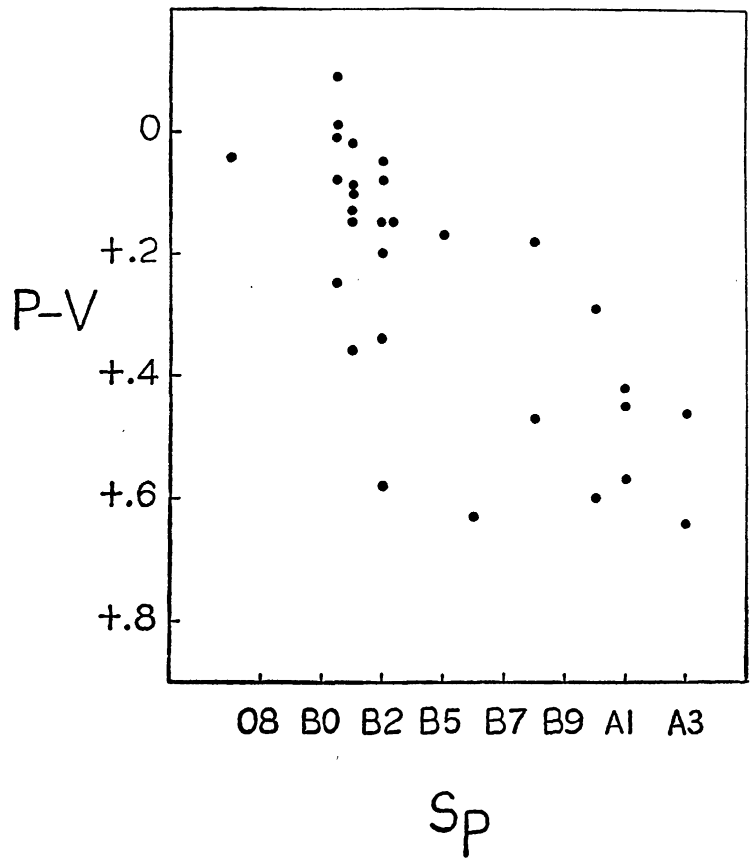

Fig. 2.—*Colour-spectrum diagram for supergiants around the double cluster.*

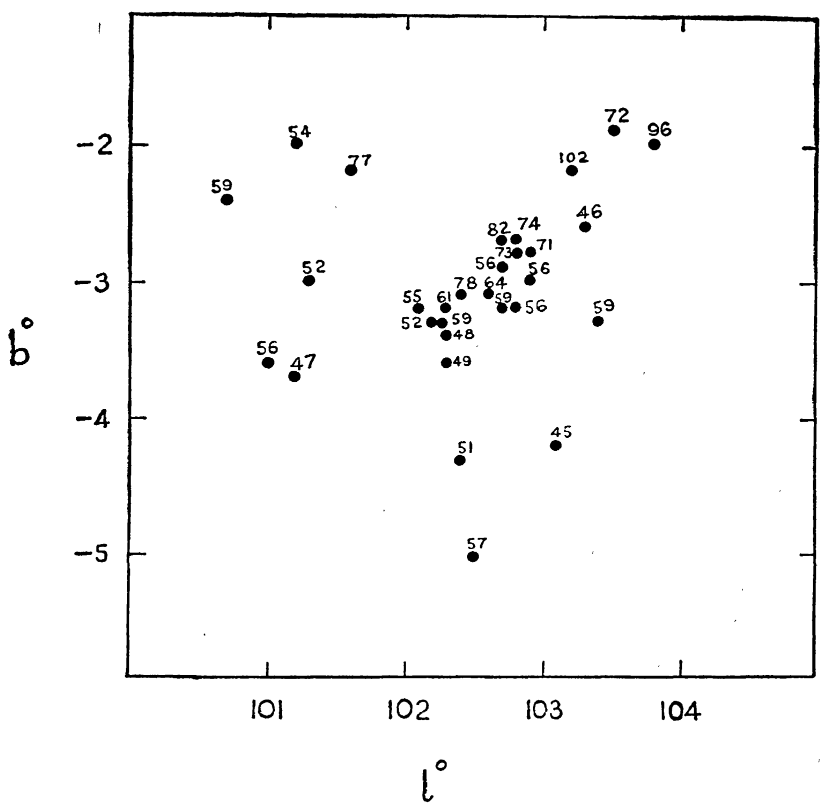

Fig. 3.—*Variation of colour excesses in the region around h and χ Persei. The figures shown are 100× colour excess.*

The solid dots represent stars classified by Morgan, while the circles indicate the remaining stars having Bidelman spectral types. The trend followed by the stars of luminosity class I clearly shows that it may be reasonable to assume some of the stars classified by Bidelman to fall in the category of luminosity class III.

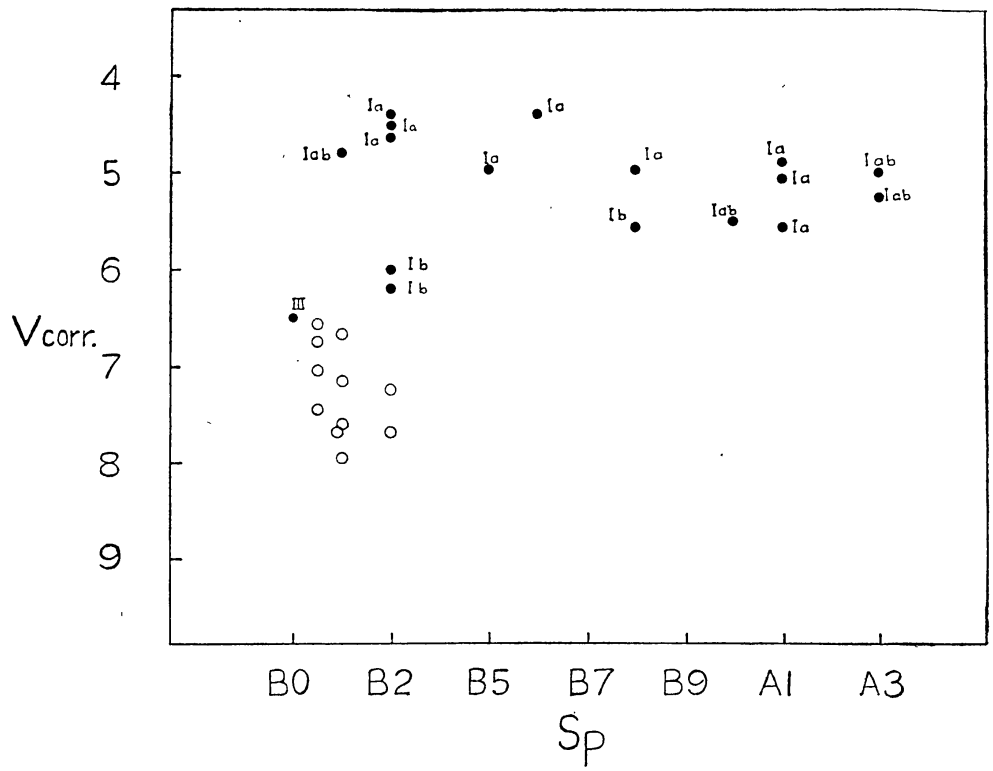

FIG. 4—*V magnitudes, corrected for interstellar absorption, for supergiants around h and χ Persei. Filled circles are for stars classified by Morgan, while the open circles represent stars having Bidelman spectral classes.*

Adopting this assumption, and using the absolute magnitudes given by Keenan and Morgan (**10**) corrected by $-0^{m}{\cdot}1$ to bring them in accordance with the visual magnitudes used here, I get the values for the distance moduli given in Table II. The distance moduli derived from the B2 Ia and B2 Ib stars agree remarkably well with those of B0, B0·5, B1 and B2 stars of luminosity class III. Assuming then that the distance modulus of the B-star aggregate is $11^{m}{\cdot}7$, we get the values of absolute magnitudes given in Table III for the other spectral types. The quantity in parentheses after each value of M_v indicates the number of stars used for its determination. It becomes apparent from Table III as well as from Fig. 4 that the absolute magnitudes of the super-giants of class Ia do not possess the

TABLE II

Determination of distance modulus of the cluster of supergiants around h and χ Persei

Spectral type	$\overline{m}_v$	M_v	$\overline{m}_v - M$
B0·5 III	6·95	−4·5	11·45
B1 III	7·40	−4·4	11·80
B2 III	7·44	−4·2	11·64
B2 Ia	4·51	−7·1	11·61
B2 Ib	6·10	−5·8	11·90
	Mean $\overline{m}_v - M = 11{\cdot}7$		

same values for all spectral types. A decrease in M_v from B2 to A2 is quite noticeable. This cluster contains very few stars to permit a reliable study of the dispersion in M_v among the early-type supergiants. Nevertheless it does appear that the intrinsic dispersion may be much smaller than is generally assumed. If the cluster of supergiants is spherical and has an angular diameter of four degrees, the depth of the cluster in the line of sight will cause a scatter of $0^m{\cdot}15$ in the values of M_v. This value is on the assumption that the intrinsic dispersion experienced by the supergiants is zero.

TABLE III

Derived absolute magnitudes for early-type supergiants

Spectral type	Ib	Ia
B5		−6·7 (1)
B6		−7·3 (1)
B8	−6·1 (1)	−6·7 (1)
A1		−6·5 (3)

A very accurate luminosity classification of many more supergiants around h and χ Persei, along with photoelectric magnitudes and colours, will be required to determine the dispersion in M_v. The ideal regions for getting more information about absolute magnitudes of all representative supergiants are the Magellanic Clouds. It is natural to hope, therefore, that those having access to these external galaxies would be able to solve the problem before long.

I am grateful to Dr C. D. Shane and Dr Akbar Ali for having generously provided all facilities for work at the Lick and Nizamiah Observatories respectively. It is a pleasure to acknowledge indebtedness to Drs Kron, Bok and Miczaika for critical discussions, and to Mr M. Ramanathan of the Nizamiah Observatory for having carried out a major portion of the reductions.

Nizamiah Observatory,
Begampet, Hyderabad,
Deccan, India:
1954 *October* 1.

References

(1) W. Bidelman, *Ap. J.*, **98,** 61, 1943.
(2) W. Morgan, A. Whitford and A. Code, *Ap. J.*, **118,** 318, 1953.
(3) Olin J. Eggen, *Ap. J.*, **111,** 65, 1950.
(4) O. J. Eggen, *Ap. J.*, **114,** 141, 1951.
(5) W. Morgan, D. Harris and H. L. Johnson, *Ap. J.*, **118,** 92, 1953.
(6) Ake Wallenquist, *Uppsala Astronomiska Observatoriums Annaler*, **3,** No. 2, 1949.
(7) P. Th. Oosterhoff, *Leiden Annals*, **17,** 5, 1937.
(8) J. Stebbins, C. M. Huffer, and A. Whitford, *Ap. J.*, **91,** 20, 1939.
(9) Paris Pismis, *Harv. Bull.*, No. 915, 1941.
(10) P. C. Keenan and W. Morgan, *Astrophysics* (ed. J. A. Hynek), p. 23, McGraw-Hill, 1951.