PHOTOMETRY OF THE GALACTIC CLUSTER NGC 6649.

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ICHTISAR.

Dengan menggunakan teknik fotoelektrik dan fotografik diberikanlah magnitudo dan warna daripada 80 bintang dalam gugus galaktik NGC 6649, dalam sistim UBV Johnson.

Dengan menggunakan reflektor 60 intji di Observatorium Boyden telah didapatkan observasi fotoelektrik dalam 3 warna. Untuk fotometri fotografik telah diambil katja² potret dalam 2 warna dengan menggunakan teleskop Schmidt 20 - 28 intji di Lembang.

Modulus djarak visuil semu daripada NGC 6649 ialah 14,2 mag., ekses warnanja ialah 1,2 mag. dan modulus sesungguhnja ialah 10,6 mag., sesuai dengan djarak 1300 parsek.

Observasi fotoelektrik membuktikan bahwa salah sebuah bintang dalam NGC 6649 mungkin adalah sebuah bintang berubah Cepheid.

ABSTRACT.

By using photoelectric and photographic techniques magnitudes and colours in the Johnson UBV system are given for eighty stars in the galactic cluster NGC 6649.

Photoelectric three-colour observations were made with the 60 inch reflector at the Boyden Observatory. Photographic plates taken in two colours with the 20 - 28 inch Schmidt type telescope at Lembang were used for the photographic photometry.

The apparent visual distance modulus of NGC 6649 is 14,2 mag., the colour excess is 1.2 mag. and the true modulus 10.6 mag., corresponding to a distance of 1300 parsecs.

The photoelectric observations show that one of the stars in the cluster NGC 6649 is a possible Cepheid variable.

1. INTRODUCTION.

NGC 6649 is a galactic cluster situated at R.A. $18^h27.^m9$, Dec. $-10°28'$ (1900); $l^I = 349.°4$, $b^I = -2.°3$ and $l^{II} = 21.°6$, $b^{II} = -0.°8$. According to Trumpler (1930) it is of class I 2m and has an angular diameter of 7'.5.

NGC 6649 has been investigated by several astronomers. The distances which they have obtained for this cluster range from 550 to 3850 pc. The distance determined by Trumpler (1930) is 1830 pc., while Shapley (1930) has estimated it between 2090 and 3310 pc. The greatest distance 3850 pc. was derived by Collinder (1931). Charlier (1918) was the first who made an estimate of the distance of NGC 6649; he found a value of 550 pc. This is in good agreement with the determination of Cuffey (1940). He gave a value of 570 pc. The most recent determination was made by Barkhatova (1950); she obtained a distance of 800 pc.

Photoelectric observations of one of the stars in the cluster region (the star denoted No. 64 by Cuffey, 1940) have shown that this star is a possible Cepheid variable (Roslund and Pretorius, 1962). An accurate determination of the distance of NGC 6649 is thus very important. In this paper the result of a new distance determination is given.

Star No. 42 is the visual double star ADS 11441. Although it fits the colour-magnitude diagram, it is probably a foreground star.

An identification chart for the stars in NGC 6649 is given in Fig. 1. The numbers of the stars on this chart are those used by Cuffey (1940).

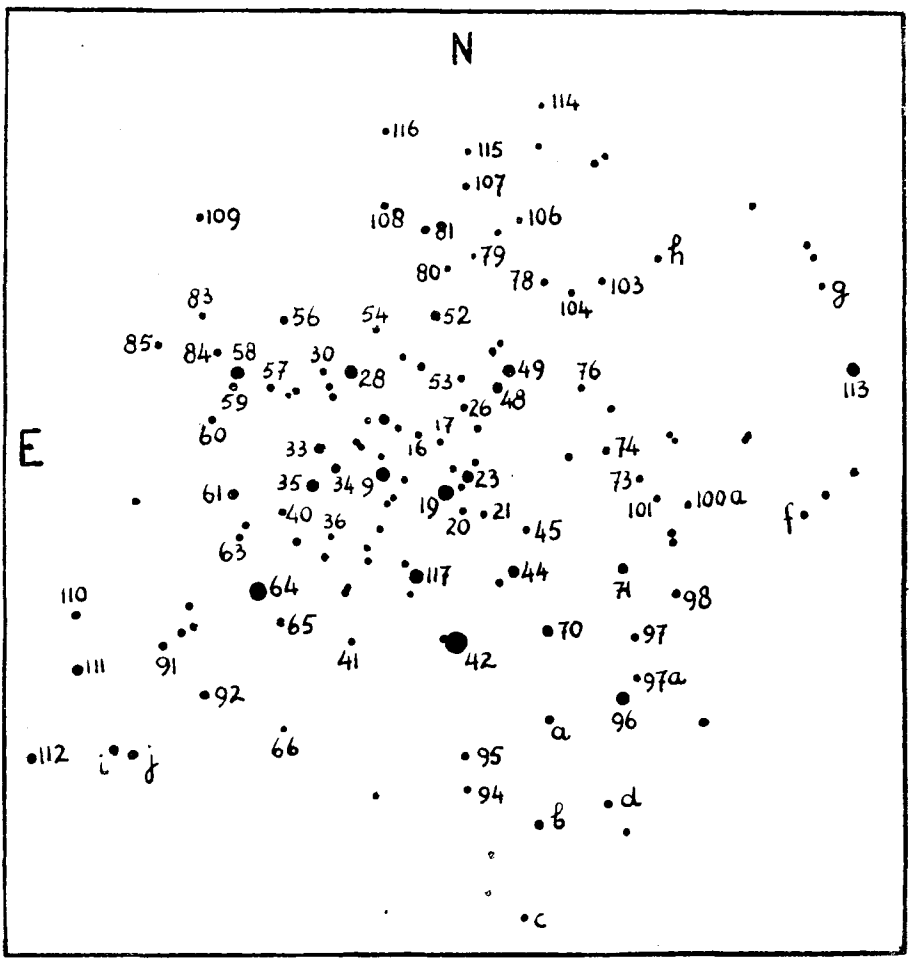

Fig. 1. Identification chart for stars in NGC 6649.

TABLE 1.

List of stars measured photoelectrically

No.	V	B-V	U-B	n	No.	V	B-V	U-B	n
9	11.76	1.21	0.20	Std	78	15.11	1.10	—	1
17	13.88	1.23	—	2	79	15.35	1.27	—	1
19	12.09	1.66	1.28	Std	80	15.54	1.15	—	1
21	14.28	1.15	—	2	81	14.08	1.50	—	2
28	12.39	1.27	0.66	2	94	14.54	1.10	—	2
33	12.72	1.13	0.57	2	95	15.05	1.05	—	2
34	13.76	1.15	0.49	2	96	13.32	1.04	0.43	2
35	13.04	1.11	0.54	2	97	14.81	1.10	—	1
40	14.38	1.11	—	2	97a	15.56	1.64	—	2
42	9.52	1.91	1.32	1	103	14.40	1.21	—	1
52	13.07	1.29	0.58	2	104	14.20	1.21	—	1
54	14.24	1.30	—	2	107	14.31	1.34	—	1
56	13.89	1.25	—	2	108	14.78	1.27	—	1
59	14.07	2.10	—	1	109	14.63	2.58	—	2
60	15.21	1.21	—	2	110	14.04	2.17	—	2
61	13.48	1.14	0.51	2	111	13.30	2.25	—	2
64	Var.	Var.	—	12	113	12.41	1.02	0.14	2
70	13.84	1.14	0.44	2	114	14.88	1.62	—	2
71	14.63	1.19	—	1	115	14.41	1.28	—	2
74	14.23	1.20	—	1	116	14.40	1.16	—	1
					117	12.03	2.50	—	2

2. PHOTOELECTRIC PHOTOMETRY.

Forty-one stars in NGC 6649 were observed photoelectrically by Mr. Willem Pretorius with the 60 inch Rockefeller reflector at the Boyden Observatory, South Africa. This photoelectric sequence reduced to the UBV system defines the photometric scale and zero point for the photographic photometry.

The photoelectric observations were made on four nights between September 6 and 14, 1961. Two stars, Nos. 9 and 19 of Cuffey's list were selected as photometric standard stars and were observed several times

during each observing night. The zero point of the magnitude scale was transferred from observations of standard stars in the Harvard Region E7 (Cousins and Stoy, 1961). The relation between the instrumental system of the Rockefeller reflector and the Johnson UBV system was determined from observations of stars in the same region.

The internal mean error in one photoelectric determination of the apparent visual magnitude V and the colours B — V and U — B is about $\pm$ 0.015 mag. for a star of magnitude V = 12.0, B = 13.0 and U = 12.0, respectively. For fainter stars the accuracy is considerably less. The corresponding mean errors exceed $\pm$ 0.10 mag. for stars fainter than V = 14.7, B = 16.0 and U = 15.2.

The result of the photoelectric measurements is given in Table 1. Col. 1 gives the number of the star according to the chart in Fig. 1 and Col. 5 the number of nights on which the star was observed.

3. PHOTOGRAPHIC PHOTOMETRY.

Seventy-three stars in NGC 6649 were measured on photographic plates taken with the 20 — 28 inch Unesco Schmidt type telescope at Lembang. The plates used were Eastman Kodak IIa-0 behind a 2 mm Schott GG13 filter for the determination of the blue magnitudes and for the visual magnitudes Eastman Kodak 103a-D combined with a 2 mm Schott GG11 filter. Six plates in the blue and four plates in the visual region were measured with the Eichner variable iris diaphragm photometer of the Bosscha Observatory. A specification of these plates is given in Table 2. In order to minimize the influence of an eventual tilt of the plates relative to the focal plane, pairs of plates were taken with the telescope reversed and not reversed. In Table 2 this is indicated in Col. 5 by respectively an N (north) or an S (south).

The stars measured photoelectrically were used in constructing calibration curves for the photographic photometry. In order to investigate the existence of any magnitude or colour equations between our photographic system and the standard system, the photographic and the photoelectric measurements of the standard stars were intercompared. The result of this intercomparison is illustrated in Figs. 2 and 3. These figures show that no magnitude or colour equations are present. Consequently, the photographic data reported in this paper are in the Johnson UBV system. From the intercomparison it is also found that the dispersion between the photographic and the photoelectric observations is about $\pm$ 0.04 mag. for B magnitudes and $\pm$ 0.10 mag. for V magnitudes and B — V colours for stars brighter than apparent visual magnitude 14.0.

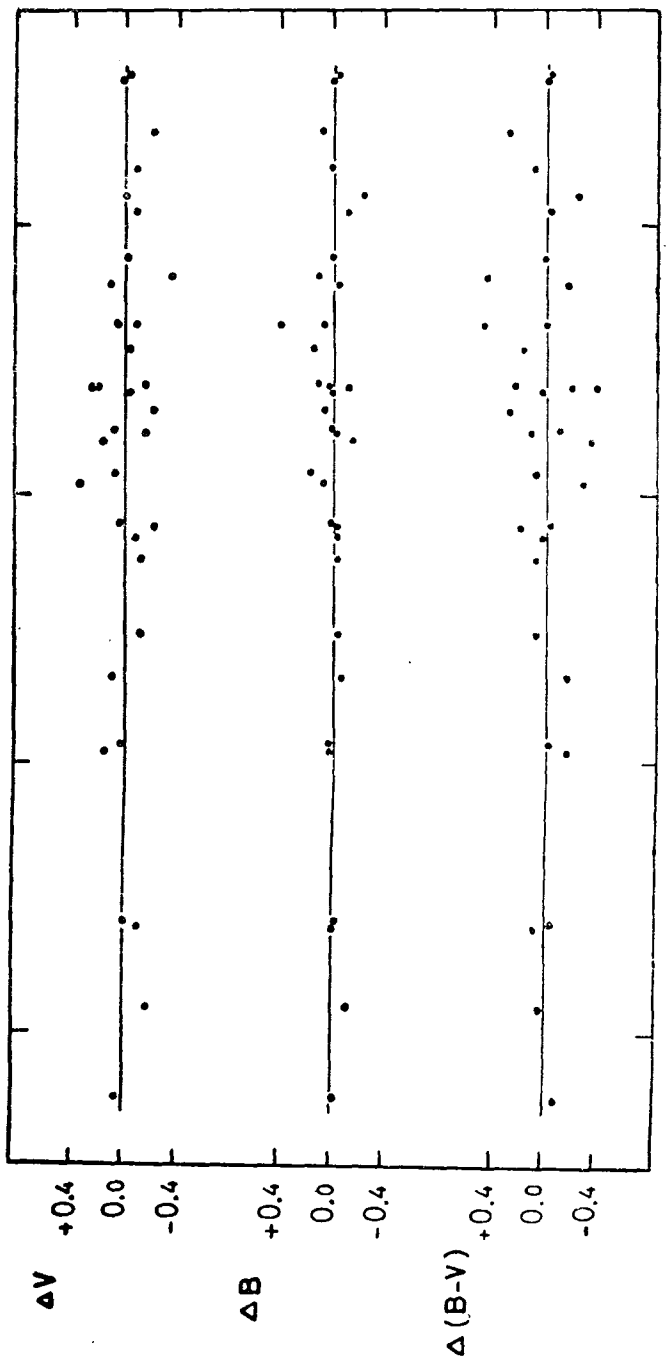

Fig. 2. The intercomparison between the photoelectric and the photographic measurements.

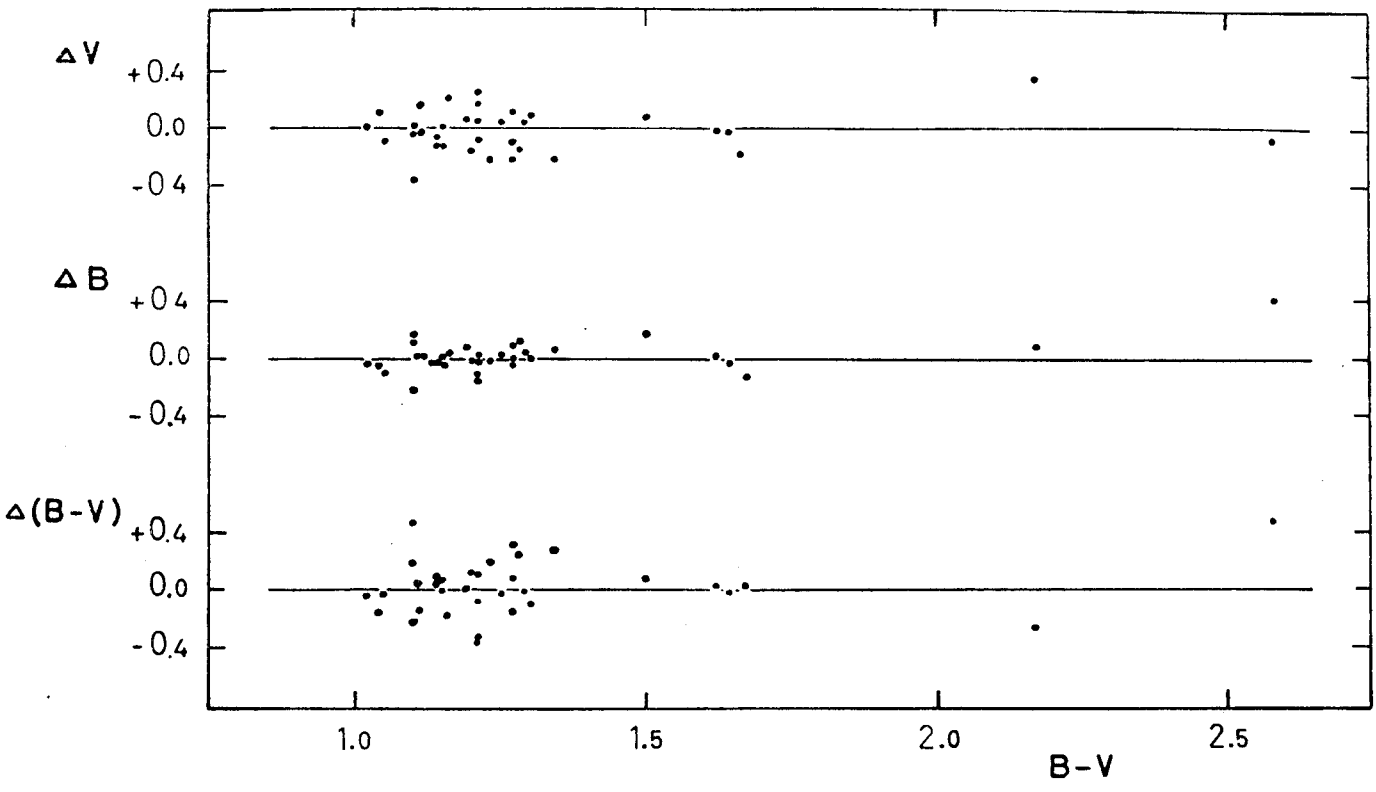

Fig. 3. The intercomparsion between photoelectric and photographic measurements.

The result of the photographic photometry is given in Table 3, in which the stars are identified according to their numbers in Fig. 1.

TABLE 2.

List of photometric plates.

Colour	Plate No.	Date 1961	Emulsion	Filter	Exp. time	Telescope
V	129	Spt. 6-7	103a-D	GG11	3 min.	S
	130	6-7			1	S
	145	10-11			1	N
	146	10-11			3	N
B	131	Sept. 7-6	IIa-0	GG13	10	S
	132	6-7			3	S
	133	6-7			1	S
	148	10-11			10	N
	149	10-11			3	N
	150	10-11			1	N

4. DISCUSSION OF THE PHOTOMETRY.

The colour-magnitude diagram for eighty stars in the cluster region of NGC 6649 is shown in Fig. 4. The filled circles represent the individual photoelectric observations from Table 1, while the open circles represent the data obtained photographically in Table 3.

Fig. 4 shows that the observed cluster sequence of stars runs almost vertically from the 12th to the 16th apparent visual magnitude. This feature was also obtained by Cuffey (1940). The upper end of the sequence is bent towards the red side of the diagram. In the lower part of the magnitude-colour diagram the scatter in colour is considerable, indicating that a number of field stars have been included in the observations or that the number of photoelectrically measured stars is too small to control adequately the photographic calibration curves for the faintest stars. Even for the brighter stars the stellar sequence is rather wide. This may be due to differential interstellar absorption across the cluster. No attempt has been made to correct for such an effect.

It is of interest to note the general similarity of the colour-magnitude diagram of NGC 6649 with those of other clusters containing a cepheid variable.

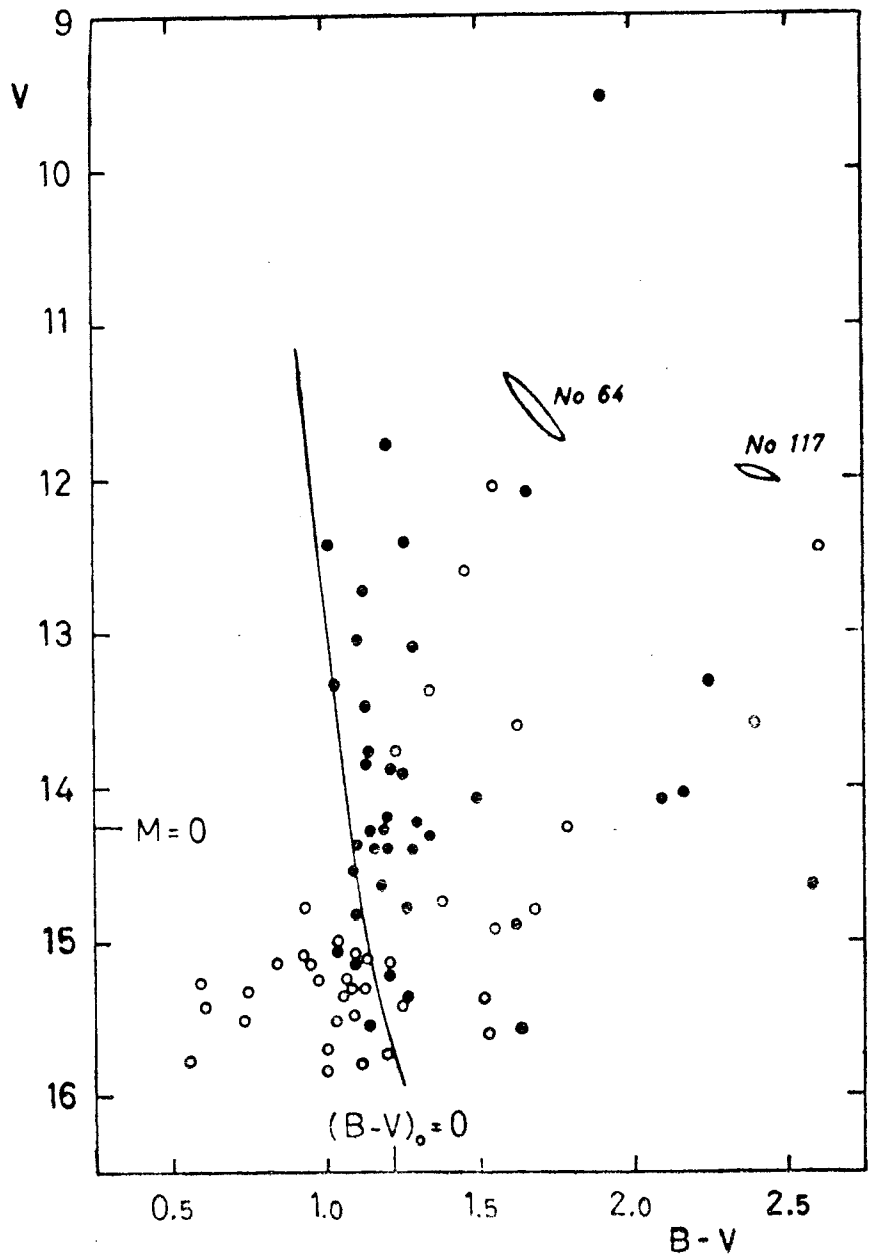

Fig. 4. The colour-magnitude diagram of NGC 6649. Filled circles represent photoelectric measurements and open circles photographic measurements.

The amount of interstellar absorption in front of the cluster is determined from the two-colour diagram shown in Fig. 5 for stars with measured U — B colours. The large dots represent stars in the center of the cluster (inside ring No. 3 in Cuffey's paper) and the small dots stars in the outer regions of the cluster. According to Johnson (1958) the slope of the reddening line can be written as $E_{(U-B)}/E_{(B-V)} = X + 0.05.E_{(B-V)}$, where the quantity X is a function of spectral type and luminosity class. In the same paper Johnson gives X as a function of the intrinsic colours for stars on the main sequence. The stars in NGC 6649 with known U — B colours are probably slightly evolved from the main sequence. However, for B stars in the luminosity interval III — V it can be assumed that X does not change significantly with luminosity class owing to the constancy of the colours B — V and U — B over this luminosity range. For such stars Johnson's nomogram can be used for derivation of their intrinsic colours. Excluding the brightest stars in NGC 6649 which may be supergiants, the mean intrinsic colour of the stars

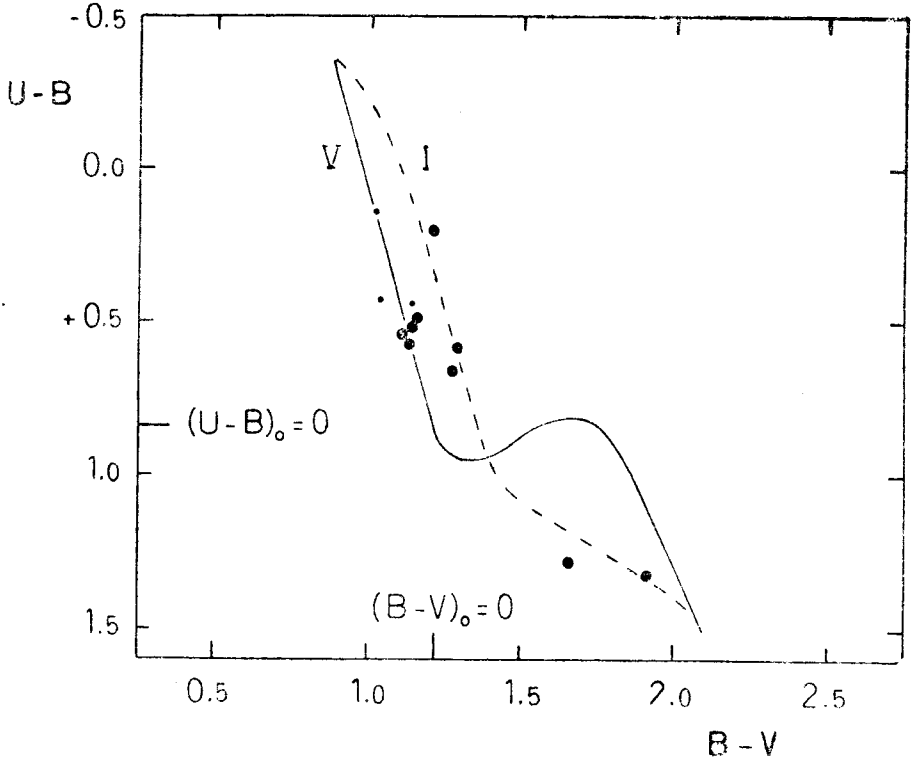

Fig. 5. The two-colour diagram of NGC 6649 for stars measured photoelectrically. The line denoted V represents main sequence stars and the dashed line denoted I stars of luminosity class I.

situated in the centre of the cluster, Nos. 33, 34, 35 and 61 is $(B - V)_o = -0.09$, giving mean colour excess for these four stars $E_{(B-V)} = 1.22$ and an absorption $A_V = 3.66$, if the ratio of total-to-selective absorption is $A_V/E_{(B-V)} = 3.0$. It is here assumed that all stars in the cluster region are effected by the same amount of interstellar absorption.

After correcting the observed B — V colours for the interstellar reddening the absolute visual magnitudes M, which the stars would have if they were on the zero-age main sequence, are obtained from the calibration by Johnson and Iriarte (1958). The individual distance moduli V — M for each cluster star which have been observed photoelectrically are calculated and plotted against the observed apparent visual magnitudes V. See Fig. 6. As in Fig. 5 the large dotsrepresent stars in the centre of the cluster. The standard evolutionary deviation curtve (Johnson, 1960) is adjusted for the best fit to the points in Fig. 6. It is seen immediately that the observed cluster sequence does not reach the unevolved main sequence. Therefore, the determination of the distance modulus can be subject to errors, because we have no observations of

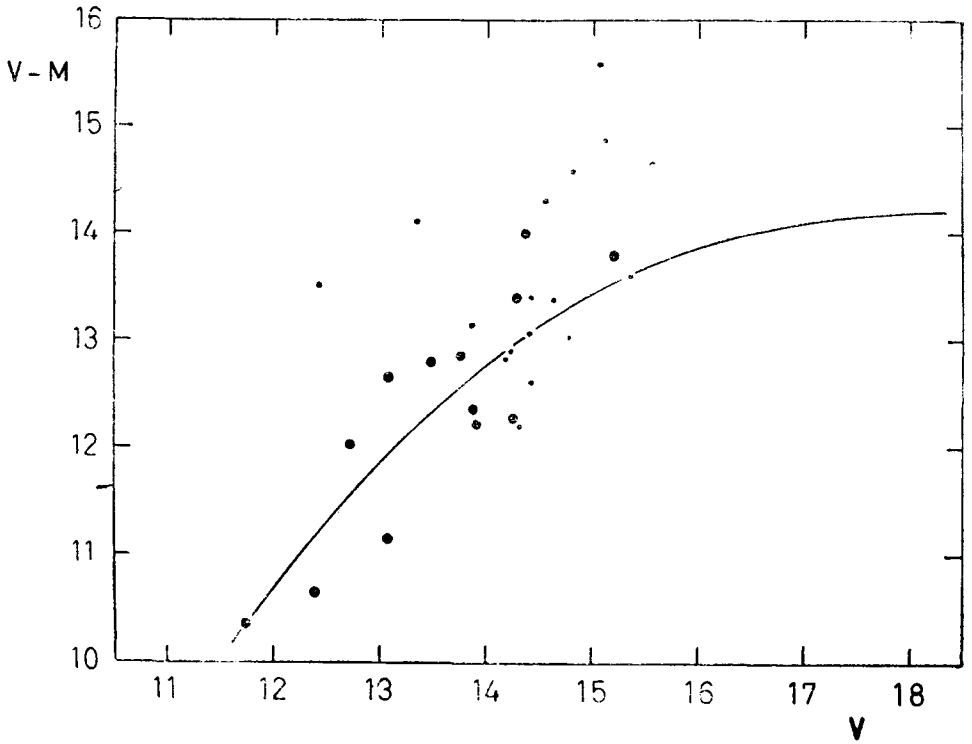

Fig. 6. The evolutionary deviation curve of NGC 6649 for stars measured photoelectrically.

unevolved main sequence stars in NGC 6649. The apparent visual distance modulus obtained from Fig. 6 is 14.25 mag. with an estimated mean error of $\pm$ 0.25 mag. The true distance modulus of NGC 6649 is 10.6 $\pm$ 0.3 mag., corresponding to a distance of 1300 $\pm$ 200 parsecs.

TABLE 3.

List of stars measured photographically.

No.	V	B — V	No.	V	B — V	No.	V	B — V
9	11.70	1.29	61	13.59	1.05	101	15.13	0.95
16	15.09	1.14	63	15.77	0.56	103	14.14	1.58
17	14.09	1.03	65	15.26	0.60	104	14.02	1.54
19	12.26	1.62	66	15.51	0.74	106	15.77	1.13
20	15.42	0.75	70	13.90	1.10	107	14.52	1.05
23	12.59	1.46	61	14.56	1.18	108	14.66	1.42
26	14.92	1.57	73	15.34	1.07	109	14.71	2.09
28	12.48	1.18	74	14.37	1.07	110	13.69	2.44
30	13.60	1.63	76	15.30	1.13	112	13.57	2.40
34	13.87	1.07	78	15.11	1.32	113	12.40	1.06
35	12.88	1.25	79	15.56	0.96	114	14.89	1.59
36	15.07	1.10	80	15.52	1.15	115	14.55	1.02
40	14.41	1.07	81	14.00	1.41	116	14.18	1.34
41	15.07	0.93	83	14.73	1.39	a	15.80	1.12
44	13.77	1.25	84	15.40	1.26	b	15.70	1.01
45	15.47	1.10	85	14.81	1.68	c	15.05	1.05
48	13.35	1.35	91	14.25	1.79	d	15.60	1.54
49	12.43	2.61	92	15.24	1.07	e	15.51	1.04
52	13.02	1.30	94	14.57	0.91	f	15.23	0.98
53	15.29	1.08	95	15.13	1.07	g	15.35	1.52
54	14.41	1.39	96	13.21	1.20	h	15.13	0.85
56	13.84	1.27	97	15.16	0.63	i	15.84	1.01
57	14.77	0.94	97a	15.58	1.65	j	15.42	0.61
58	12.03	1.55	98	15.74	1.21			
60	15.29	1.10	100a	15.14	1.21			

5. VARIABLE STARS IN NGC 6649.

Photoelectric observations have shown that the star No. 64 in NGC 6649 is an intrinsic variable (Roslund and Pretorius, 1962). From the observations alone it has not yet been possible to draw any definite conclusion about which type of variable it belongs to. But if the star No. 64 is a physical member of the cluster, its position in the colour-magnitude diagram strongly suggests it to be a Cepheid variable.

Photoelectric observations of the star No. 117 repeated in June and July, 1962 indicate that this star may also be a variable. In 1962 the following values were obtained for its magnitude and colour, $V = 11.93$ and $B - V = 2.31$, compared with $V = 12.03$ and $B - V = 2.50$ in 1961.

Further photoelectric observations of the stars Nos. 64 and 117 are planned for the next observing season.

6. ACKNOWLEDGEMENTS.

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