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ON THE COLOUR OF MARS

BY

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Preface.

Among the colours of the planets the colour of Mars offers a special interest, as Mars, in many respects, displays a similarity to the Earth. Thus we may notice on Mars lasting forms of surface, which change their colour and partly their shape in connection with the Martian seasons; the rotation of Mars, its position with regard to the Earth, its distance from the Sun, its phase angle, all these may produce a change in colour.

Long series of photometric measurements of Mars were made by G. Müller, with a visual photometer from 1877 to 1889¹⁾, and by E. S. King photographically and photovisually from 1901 to 1923²⁾. King had direct measurements of the colour of Mars (i. e. ordinary and photovisual photographs on the same night) on 15 satisfactory nights. In order to increase the number of direct measurements of colour and in order to investigate the brightness of Mars in red radiation too, a series of photographs of Mars was taken by the writer at Tartu from 1926 to 1931. The present paper contains the conclusions drawn from the observations of E. S. King, P. Guthnick, and E. Öpik, and from those made at Tartu.

I should like to express my thanks to Mr. P. Simberg for his assistance in the determination of the plate-constants at Tartu and for drawing the figures for this paper.

1) Publikationen des Astrophysikalischen Observatoriums zu Potsdam vol. 8, p. 324.

2) Annals of Harvard College Observatory vol. 59, p. 255; vol. 81, p. 208; and vol. 85, p. 63.

Arrangement of Observations and Reductions.

At Tartu the observations were begun in autumn, 1926. As the weather during the opposition was unsatisfactory for photometric observations, the first photographs could not be taken earlier than December 2, 1926. Also, during the opposition of 1930/31, throughout January there was not a single satisfactory night. In order to obtain satisfactory results only quite clear nights were selected. Practice showed that nights which seemed uncertain gave unsatisfactory results.

The Instruments. In 1926/27 and 1928 the photographs were taken with the 160 mm Astro-Petzval camera, focal length 79 cm. In 1930/31 the photographs were obtained with the Steinheil triple-Apochromat camera of 60 mm aperture and 60 cm focal length, which was mounted on the Zeiss refractor. In 1926/27 the photographs were taken in photographic and in red radiation. In photographic radiation, in the ordinary manner without a filter on Agfa Extra-Rapid plates; in red radiation, through a red filter on Agfa Panchromatic plates. As comparison star α *Aurigae* was used. In 1928 the photographs were taken in blue, yellow, and red radiations; for the first two kinds of radiation orthochromatic Hauff Flavin plates, and for the blue and red radiations Agfa Panchromatic plates were used. α *Tauri* was used as comparison star. In 1930/31 the photographs were taken in blue, yellow, and red radiations on Hauff Analo-Flavin and Lumière panchromatic Chroma VR plates. The comparison star was α *Tauri*.

In 1928 and 1930/31 a blue, a yellow, and a red filter (in 1926 only the red one) were used. The filters were examined with an ordinary and an ultraviolet spectroscope. They proved to be good.

The regions of transmission of the filters were

blue: from 0.370μ to 0.490μ , with the maximum between 0.430 — 0.450μ ;

yellow: from 0.505μ up to the red end of the visible spectrum; not transparent for ultraviolet radiation;

red: between 0.639 and 0.765μ , with the maximum at about 0.67μ ; not transparent for ultraviolet radiation.

In 1930 the spectrum of the Sun was photographed by Mr. A. Kipper at Tartu on Hauff-Flavin plates. Combining the data of these photographs with the known qualities of ordinary and panchromatic plates for different kinds of radiation we find the effective wave-lengths of the system filter + plate

blue: = $0.43 - 0.44 \mu$

yellow: = 0.57μ

red: = 0.67μ .

The atmospheric absorption. In 1926/27, besides *α Aurigae*, *α Canis minoris* was often photographed to determine the atmospheric absorption. From determinations during 6 nights we have

coefficient of absorption for the blue radiation

(λ eff. = $0.43 - 0.44 \mu$)

$c = 0.34 \text{ mg} \pm 0.02 \text{ mg}$ (probable error).

This value is in good agreement with the results given in Tartu Publications vol. XXVI, No. 3, p. 16. The coefficient of absorption is relatively small, but taking into account that the nights for the photographs of Mars were selected, this seems quite natural.

From „Handbuch der Astrophysik“ vol. II, p. 199 we get for the coefficients of atmospheric absorption at Potsdam

blue radiation $c = 0.387 \text{ mg}$

(λ eff. = $0.43 - 0.44 \mu$)

yellow radiation $c = 0.21 \text{ mg}$

(λ eff. = 0.57μ)

red radiation $c = 0.15 \text{ mg}$

(λ eff. = 0.67μ).

Although the Tartu Observatory — 80 m above sea-level — is not so high as the Potsdam Observatory — 100 m above sea-level — the atmospheric absorption in blue radiation is somewhat less at Tartu than at Potsdam. The absorption in yellow and in red radiation at Tartu is unknown. Since the last coefficients are not large and we are only interested in the differential absorption between Mars and the comparison star, we adopt for Tartu, for the yellow and red radiations, the Potsdam values. For

the blue radiation at Tartu the directly determined coefficient

$$c = 0.34 \text{ mg}$$

was used. It may be remarked that the adopted value for the yellow radiation agrees with the results given in Tartu Publications vol. XXVI, No. 3, p. 12.

Since the observations of Mars were arranged so as to reduce, as far as possible, the influence of the differential atmospheric absorption, the mean coefficients were used throughout the whole period of observation.

Methods of observation and reduction. All the photographs taken are out of focus. In 1926/27 the photographs were taken before the focus, at a fixed distance, which was for photographic radiation 13 mm and for red radiation 5 mm. In order to have a more or less equal intensity of Mars and the comparison star, a variation of exposures of Mars in connection with its decreasing brightness was necessary. In 1926/27 generally two images of Mars and of the comparison star were obtained. Since a diaphragm, used for other purposes, covered the central part of the objective, the out-of-focus images had the form of rings. The homogeneity of the red images, which with the Petzval camera have no uniform distribution of intensity, was guaranteed in this manner by a fixed focus. On the other hand, this way of changing exposures requires a knowledge of photographic laws. In the present paper the Schwarzschild law

$$it^p = \text{const.}$$

(where i denotes the light intensity, t —the duration of exposure) was adopted and p was specially determined for photographic and for red radiation.

In order to be able to neglect p in 1928 and in 1930/31, the photographs in all kinds of radiation were taken behind the focus at different focal distances, with equal exposures for Mars and the comparison star. The focal distance for Mars was calculated in advance for each night in accordance with the brightness given in the American Ephemeris, to obtain, as far as possible, equal intensities for Mars and the comparison star. The objectives of the cameras used were not diaphragmed and the diameters of the images on the plates were measured with a Repsold apparatus. The precision of a measure of this kind is of about 0.001 mm. The intensities of the images were quite uniform for the Petzval camera for the blue and yellow radiations,

for the Steinheil camera for the yellow and red radiations. The red images of the Petzval camera and the blue ones of the Steinheil camera were divided into three concentric zones and the intensity of each zone was measured separately. Then the integrated intensity was calculated. The differences of intensities between the zones of the Steinheil camera were small — of about 0.1 mg or smaller; the differences for the zones of the red images of the Petzval camera (3 nights only) were larger, being at most 0.5 mg. We may, therefore, say that such a process of integration of intensities cannot produce any appreciable error. The yellow images of the Steinheil camera were of uniform intensity, but each image-disc was closely surrounded by a ring. We have, therefore, two kinds of diameters for the yellow Steinheil images — without the rings and with the rings. The first (without the rings) was finally adopted.

In 1926/27 the photographic and red images were taken separately, on ordinary and panchromatic plates respectively. In 1928 and 1930/31, on each plate there were taken images of two kinds of radiation: blue and yellow on orthochromatic, blue and red on panchromatic plates. The background effect of the plates was carefully kept apart for each kind of radiation. For this purpose one half of each filter was covered with dark paper. By photographing on one half of the plate through a given filter, the other half of the plate was preserved for the other kind of radiation.

The intensity of each image on the plate was measured at 3 points with a Hartmann microphotometer, keeping the negative and the wedge of the microphotometer slightly out of focus. The intensity of the background of the plate near the image was also measured. The mean background, separately for each plate and each kind of radiation, was calculated and the difference: intensity of the image of Mars (or comparison star) minus intensity of the mean background was found. Denoting this difference by δ , we have for each plate

$$\delta = \delta (\text{Mars}) - \delta (\text{comparison star}).$$

Transforming the δ or δ with specially determined plate-constants into stellar magnitudes and adding the corrections for ab-

sorption and for the differences in the diameters of the images (in 1926/27, in addition to these, the corrections for the differences in exposure), we have in stellar magnitudes the differences

Mars — comparison star.

The best results would be obtained if $\delta = 0$. In this case the Purkinje effect is eliminated, and no knowledge of plate-constants is required. In practice, influenced by the errors of focussing, of the ephemerides of Mars etc., we can but try to make δ as small as possible.

Determination of plate-constants. In order to convert the δ into stellar magnitudes, the density-function — the relation between Δ or δ and the corresponding stellar magnitude — had to be determined. For this purpose a photographic wedge was placed immediately in front of the plate. Photographs of the wedge were obtained with light from a white ceiling diffusely and equally illuminated by 2 electric lamps, the light passing through holes of different diameters. The diameters of the holes were carefully measured and so the difference of illumination furnished by the holes

$$m_{i+1} - m_i$$

was determined in stellar magnitudes. The corresponding points of the photographs of the wedge were measured with the microphotometer. Then the density function was calculated in two ways:

(1) Let us suppose that this function is a hyperbola¹⁾

$$m_{i+1} - m_i = b (\Delta_{i+1} - \Delta_i) + c \left(\frac{1}{\Delta_{i+1}} - \frac{1}{\Delta_i} \right),$$

where b and c are constants for a given kind of plates and radiation. Then the measurements of the wedge give us a number of linear equations with two unknowns b and c . The equations can be solved by using the method of least squares.

(2) Denoting the density function, given in Tartu Publications vol. XXV, No. 7, p. 11, by $f(\Delta)$, we may try to represent the density functions used in the present paper by

$$k \cdot f(\Delta).$$

For the same kind of plates and radiation k is a constant.

1) Compare Tartu Publications vol. XXV, No. 3, p. 26.

We have for the plates used in the present paper:

Agfa Extra-Rapid, photographic radiation

$$k = 0.66 \pm 0.00_9 \text{ (probable error)}$$

$$b = -0.873 \pm 0.07_3$$

$$c = +0.047 \pm 0.06_0.$$

Agfa Panchromatic, red radiation

$$k = 0.47 \pm 0.02_0 \text{ (probable error)}$$

$$b = -0.390 \pm 0.04_1$$

$$c = +0.155 \pm 0.01_7.$$

Agfa Panchromatic, blue radiation

$$k = 0.68 \pm 0.07 \text{ (probable error).}$$

Hauff Analo-Flavin, blue radiation

$$k = 0.82 \pm 0.01_5 \text{ (probable error)}$$

$$b = -0.935 \pm 0.02_0$$

$$c = +0.204 \pm 0.02_0.$$

Hauff Analo-Flavin, yellow radiation

$$k = 0.60 \pm 0.01_3 \text{ (probable error)}$$

$$b = -0.693 \pm 0.02_1$$

$$c = +0.131 \pm 0.01_9.$$

Lumière Panchromatic, blue radiation

$$k = 0.50 \text{ (found from two photographs:}$$

(1) of the Polar Sequence and (2) of some bright stars).

Lumière Panchromatic, red radiation

$$k = 1.10 \pm 0.06_5 \text{ (probable error)}$$

$$b = -1.066 \pm 0.18_5$$

$$c = +0.152 \pm 0.02_9.$$

Practice showed that for the blue and yellow radiations it was quite sufficient to use the k in plate reductions, since the δ are generally not large. For the red radiation, however, and relatively low densities there was a systematic difference between the hyperbola formula and the formula $k \cdot f(\Delta)$. The deduction of the Schwarzschild exponent p showed that the best value for the red radiation is given by the mean between the two formulae mentioned.

The value of the Schwarzschild exponent p was deduced for 1926/27 in 3 different ways:

(1) With the aid of special photographs. *a Bootis* was photographed at different focal distances, the duration of exposure being changed so as to obtain more or less equal

densities of all the images on the plate. The diameters of the images were measured with a Repsold apparatus. Taking into account the small differences between the densities of the images, p can be calculated from the known diameters and the exposure-times.

(2) When two or more photographs of a star are obtained on a plate at a constant focal distance with different exposures. Knowing the value of the density function of the plate, p can be calculated from the formula

$$p = 0.4 \frac{f(\Delta_2) - f(\Delta_1)}{\lg t_1 - \lg t_2}.$$

(3) By using the photographs of Mars taken at different epochs. Taking into account the changes of the brightness of Mars caused by the changes of distances between Mars, the Sun, and the Earth, as well as the changes depending on the phase-angle, we can calculate p from the corresponding changes in the time of exposure.

For the photographic radiation and Agfa Extra Rapid plates it was found

$$(1) p = 0.92 \pm 0.02 \text{ (probable error)}$$

$$(2) p = 0.96 \pm 0.02$$

$$(3) p = 0.95 \pm 0.04.$$

The mean for the photographic radiation is

$$p = 0.95 \pm 0.009.$$

For the red radiation and Agfa Panchromatic plates we have

$$(1) p = 1.10 \pm 0.03 \text{ (probable error).}$$

(2) The values obtained with this method were too uncertain. They clearly showed, however, that the best density function for the red photographs is the mean between the hyperbola and the empiric function $k \cdot f(\Delta)$.

$$(3) p = 0.98 \pm 0.01.$$

The weighted mean

$$p = 1.00 \pm 0.03$$

was adopted for the red radiation.

Tables of Results at Tartu.

The following tables give the results for Tartu; z denotes the zenith distance and Δ the density of the image in microphotometer readings.

Photographic Radiation 1926/27.

Table 1.

Neg. No.	Date	Local sidereal time	Object	Exposure in sec.	sec z	Diameter in mm.		Δ	
						I	II	I	II
308	Dec. 2-nd 1926	3h 7m	Mars	4, 12	1.44	2.447	2.453	0.82	2.42
"	" " "	3 21	α Aurigae	25, 60	1.07	2.461	2.496	2.25	3.30
"	" " "	3 32	β Gemin.	150	1.62	2.458		2.75	
309	Dec. 20-th 1926	3 43	α Can. min.	30	2.82	2.326		1.84	
"	" " "	3 58	α Aurigae	23, 30	1.05	2.256	2.250	2.12	2.36
"	" " "	4 9	Mars	5, 10	1.53	2.282	2.273	0.73	1.32
310	" " "	4 20	Mars	5, 10	1.55	2.278	2.264	0.81	1.39
"	" " "	4 35	α Aurigae	20, 30	1.03	2.252	2.262	1.93	2.40
314	Dec. 29-th 1926	5 43	Mars	7, 12	1.84	2.402	2.402	0.61	1.12
"	" " "	5 54	α Can. min.	30	1.81	2.418		2.73	
"	" " "	6 7	α Aurigae	20, 30	1.04	2.396	2.413	2.04	2.61
321	Jan. 8-th 1927	4 11	α Can. min.	20, 30	2.46	2.428	2.446	1.49	2.03
"	" " "	4 22	α Aurigae	20, 30	1.04	2.442	2.444	1.83	2.37
"	" " "	4 30	Mars	20, 30	1.48	2.438	2.448	1.39	1.90
328	Feb. 24-th 1927	6 58	Mars	50, 70	1.52	2.386	2.397	1.67	2.07
"	" " "	7 6	α Aurigae	20, 30	1.08	2.386	2.401	2.07	2.59
"	" " "	7 15	α Can. min.	20, 30	1.67	2.402	2.412	1.12	2.62
335	Feb. 25-th 1927	5 15	Mars	50, 70	1.28	2.374	2.382	1.65	2.07
"	" " "	5 24	α Aurigae	20, 30	1.03	2.396	2.402	2.19	2.72
"	" " "	5 34	α Can. min.	20, 30	1.89	2.386	2.387	2.00	2.49

Denoting by m_M the stellar magnitude of Mars and by m_c the magnitude of α Aurigae, we have

$$m_M - m_c = f(\Delta_M) - f(\Delta_c) + 2.5 p (\lg t_M - \lg t_c),$$

where the corrections for diameter, absorption etc. are taken into account.

Table 2.

Neg. No.	$f(\Delta_M) - f(\Delta_c)$	2.5 p. $(\lg t_M - \lg t_c)$	Corr. for diam.	Corr. for absorpt.	$m_M - m_c$		$m_M^1)$	$5 \lg \frac{r_0}{r_0(r_0-1)}$	m_M^0
	mg	mg	mg	mg	mg	mg	mg	mg	mg
308 I	+1.24	-1.88	+0.02	-0.12	-0.75	-0.84	+0.19	-0.15	+0.04
308 II	+0.80	-1.66	+0.04	-0.12	-0.93				
309 I	+1.23	-1.57	-0.03	-0.16	-0.53	-0.48	+0.55	-0.62	-0.07
309 II	+0.90	-1.13	-0.03	-0.16	-0.42				
310 I	+0.97	-1.42	-0.03	-0.18	-0.66	-0.54	+0.49	-0.62	-0.13
310 II	+0.88	-1.13	0.00	-0.18	-0.43				
314 I	+1.29	-1.08	-0.01	-0.27	-0.07	0.00	+1.03	-0.85	+0.18
314 II	+1.28	-0.94	+0.01	-0.27	+0.07				
321 I	+0.37	0.00	0.00	-0.15	+0.22	+0.24	+1.27	-1.10	+0.17
321 II	+0.41	0.00	0.00	-0.15	+0.26				
328 I	+0.37	+0.94	0.00	-0.15	+1.16	+1.17	+2.20	-2.10	+0.10
328 II	+0.46	+0.87	0.00	-0.15	+1.18				
335 I	+0.49	+0.95	+0.02	-0.09	+1.37	+1.37	+2.40	-2.12	+0.28
335 II	+0.57	+0.87	+0.02	-0.09	+1.37				

$5 \lg \frac{r_0}{r_0(r_0-1)}$ denotes the reduction to the mean distance $r_0 = 1.5237$ of Mars from the Sun and to the mean distance $\varrho = r_0 - 1$ of Mars from the Earth at opposition; m_M^0 denotes the stellar magnitude of Mars reduced to these mean distances.

Red Radiation 1926/27.

Table 1.

Neg. No.	Date	Local sidereal time	Object	Exposure.	sec z	Diameter in mm.		Δ	
						I	II	I	II
307	Dec. 2-nd 1926	2h 11m	α Aurigae	300s	1.15	0.959		0.16	
		2 30	Mars	50s	1.41	0.959		0.22	
311	Dec. 20-th 1926	5 18	α Aurigae	400s, 600s	1.02	0.992	0.996	0.25	0.50
"	" " "	5 46	α Can. min.	20m	1.85	0.994		0.47	
"	" " "	6 11	Mars	70s, 100s	2.13	0.990	0.989	0.16	0.34
312	" " "	6 21	Mars	100s	2.22	1.013		0.16	
"	" " "	6 40	α Aurigae	400s, 600s	1.06	1.010	1.015	0.15	0.38
313	Dec. 29-th 1926	4 37	α Can. min.	20m	2.23	1.013		0.14	
"	" " "	5 4	α Aurigae	600s	1.02	1.000		0.17	
"	" " "	5 24	Mars	140s, 200s	1.75	1.012	1.002	0.13	0.26
320	Jan. 8-th 1927	2 44	Mars	5m, 7m	1.35	1.014	1.008	0.28	0.57
"	" " "	3 11	α Aurigae	10m, 14m	1.08	1.010	1.016	0.21	0.35
"	" " "	3 44	α Can. min.	25m	2.81	1.028		0.31	
327	Feb. 24-th 1927	5 20	α Can. min.	25m	1.95	0.987		1.06	
"	" " "	5 54	α Aurigae	10m, 14m	1.03	0.982	0.986	0.88	1.25
"	" " "	6 28	Mars	12m, 16m	1.43	0.994	0.998	1.02	1.30
336	Feb. 25-th 1927	6 13	α Can. min.	25m	1.76	0.997		1.07	
"	" " "	6 48	Mars	13m, 16m	1.48	1.001	1.002	0.96	1.36
"	" " "	7 20	α Aurigae	10m, 14m	1.09	1.006	1.009	0.80	1.26

1) Taking according to E. S. King the photographic magnitude of α Aurigae = 1.03.

Table 2.

Neg. No.	Image of Mars minus image of Capella			$2.5 p$ $\lg(t_M - t_C)$	Corr. for diam.	Corr. for absorpt.	$m_M - m_C$		r_0 $5 \lg \frac{r_0}{r_0 - 1}$	$m_M - m_C$
	k.f.(Δ)	hyperbola	mean.				mg	mg		
307	mg	mg	mg	mg	mg	mg	mg	mg	mg	mg
	-0.08	-0.30	-0.19	-1.94	0.00	-0.04	-2.17		-0.15	-2.32
311 I	+0.13	+0.38	+0.26	-1.89	0.00	-0.16	-1.79	-1.85	-0.62	-2.47
311 II	+0.16	+0.20	+0.18	-1.94	+0.01	-0.16	-1.91			
312 I	-0.01	-0.06	-0.04	-1.51	0.00	-0.17	-1.72	-1.68	-0.62	-2.30
312 II	+0.27	+0.64	+0.46	-1.94	0.00	-0.17	-1.65			
313 I	+0.06	+0.29	+0.18	-1.58	-0.02	-0.11	-1.53	-1.54	-0.85	-2.39
313 II	-0.13	-0.36	-0.24	-1.19	0.00	-0.11	-1.54			
320 I	-0.08	-0.21	-0.15	-0.75	-0.01	-0.04	-0.95	-0.98	-1.10	-2.08
320 II	-0.22	-0.25	-0.24	-0.75	+0.02	-0.04	-1.01			
327 I	-0.10	-0.08	-0.09	+0.20	-0.02	-0.06	+0.03	+0.03	-2.10	-2.07
327 II	-0.03	-0.03	-0.03	+0.14	-0.02	-0.06	+0.03			
336 I	-0.11	-0.09	-0.10	+0.28	+0.01	-0.06	+0.13	+0.09	-2.12	-2.03
336 II	-0.05	-0.05	-0.05	+0.14	+0.01	-0.05	+0.05			

Observations in 1928.

Table 1.

Date	Plate and filter	Local sidereal time	Object	Exposure	sec z	Diameter in mm.		Δ	
						I	II	I	II
Sep. 11-th 1928	Pan. red	0h 22m	Mars	6m, 3m	2.15	0.442	0.442	1.25	1.87
" " "	" "	0 39	α Tauri	6, 3	1.99		0.299	1.07	1.39
" " "	Pan. blue	1 9	α Tauri	2, 4	1.80	0.726	0.734	0.11	0.73
" " "	" "	1 25	Mars	2, 4	1.71	1.096	1.101	0.29	0.65
" " "	Flav. blue	1 46	Mars	2, 4	1.61	1.248	1.245	1.30	2.19
" " "	" "	1 54	α Tauri	2m, 250s	1.60	0.758	0.768	1.24	2.18
" " "	Flav. yell.	2 12	α Tauri	2m, 4m	1.54		1.028	1.86	3.03
" " "	" "	2 27	Mars	2, 4	1.46		1.535	2.18	3.21
Oct. 30-th 1928	Flav. yell.	2 8	Mars	2, 4	1.87	1.974	1.986	1.68	2.74
" " "	" "	2 29	α Tauri	2, 4	1.49	0.916	0.941	1.93	2.80
" " "	Flav. blue	2 46	α Tauri	2, 4	1.45	0.765	0.766	1.14	1.92
" " "	" "	3 5	Mars	122s, 4m	1.57	1.703	1.701	1.20	1.96
" " "	Pan. blue	3 31	Mars	2m, 4m	1.48	1.349	1.347	0.86	1.46
" " "	" "	3 48	α Tauri	2, 4	1.36	0.466	0.476	1.35	1.93
" " "	Pan. red	4 10	α Tauri	3, 6	1.35		0.280	1.14	1.92
" " "	" "	4 28	Mars	3, 6	1.33		0.955	0.28	0.68
Nov. 11-th 1928	Pan. red	2 23	α Tauri	4	1.51	0.526		0.38	
" " "	" "	2 35	Mars	4	1.72	0.893		0.69	
" " "	Pan. blue	2 51	Mars	4	1.64	1.504		1.34	
" " "	" "	3 13	α Tauri	245s	1.40	0.484		1.79	
" " "	Flav. blue	3 33	α Tauri	4m	1.38	0.774		2.34	
" " "	" "	3 45	Mars	4	1.44	1.881		2.92	
" " "	Flav. yell.	3 58	Mars	4	1.40	2.332		2.78	
" " "	" "	4 9	α Tauri	4	1.35	1.075		2.41	

Denoting by m_A the stellar magnitude of α *Tauri* we have for 1928:

Table 2. Blue radiation, Flavin plates.

Date	Exp.	$f(\Delta_M) - f(\Delta_A)$	Corr. for diam.	Corr. for absorpt.	$m_M - m_A$		m_M 1)	$5 \lg \frac{r\varrho}{r_0(r_0-1)}$	m^0_M
		mg	mg	mg	mg	mg	mg	mg	mg
Sep. 11-th 1928	2 ^m	-0.06	-1.08	0.00	-1.14	-1.12	+1.54	-1.42	+0.12
	4	-0.05	-1.05	0.00	-1.10				
Oct. 30-th 1928	2	-0.04	-1.74	-0.04	-1.82	-1.82	+0.84	-0.75	+0.09
	4	-0.04	-1.73	-0.04	-1.81				
Nov. 11-th 1928	4	-0.61	-1.93	-0.02	-2.56		+0.10	-0.57	-0.47

Table 3. Blue radiation, panchromatic plates.

Date	Exp.	$f(\Delta_M) - f(\Delta_A)$	Corr. for diam.	Corr. for absorpt.	$m_M - m_A$		m_M 1)	$5 \lg \frac{r\varrho}{r_0(r_0-1)}$	m^0_M
		mg	mg	mg	mg	mg	mg	mg	mg
Sep. 11-th 1928	2 ^m	-0.37	-0.89	+0.03	-1.23	-1.00	+1.66	-1.42	+0.24
	4	+0.09	-0.88	+0.03	-0.76				
Oct. 30-th 1928	2	+0.43	-2.31	-0.04	-1.92	-1.90	+0.76	-0.75	+0.01
	4	+0.42	-2.26	-0.04	-1.88				
Nov. 11-th 1928	4	+0.37	-2.46	-0.08	-2.17		+0.49	-0.57	-0.08

Table 4. Yellow radiation, Flavin plates.

Date	Exp.	$f(\Delta_M) - f(\Delta_A)$	Corr. for diam.	Corr. for absorpt.	$m_M - m_A$		m_M 1)	$5 \lg \frac{r\varrho}{r_0(r_0-1)}$	m^0_M
		mg	mg	mg	mg	mg	mg	mg	mg
Sep. 11-th 1928	2 ^m	-0.26	-0.87	+0.01	-1.12	-1.05	-0.11	-1.42	-1.53
	4	-0.14	-0.87	+0.02	-0.99				
Oct. 30-th 1928	2	+0.21	-1.66	-0.08	-1.53	-1.59	-0.65	-0.75	-1.40
	4	+0.05	-1.62	-0.08	-1.65				
Nov. 11-th 1928	4	-0.31	-1.68	-0.01	-2.00		-1.06	-0.57	-1.63

1) Adopting according to E. S. King the photographic magnitude of α *Tauri* = 2.66 and the photovisual magnitude of α *Tauri* = 0.94 (Harvard Annals vol. 85, No. 3, p. 58).

Table 5. Red radiation, panchromatic plates.

Date	Exp.	Image of Mars minus image of α Tauri			Corr. for diam.	Corr. for absorpt.	$m_M - m_A$		$5 \lg \frac{r_0}{r_0 - 1}$	$m_M^0 - m_A$
		k. f(Δ)	hyperbola	mean			mg	mg		
Sep. 11-th 1928	3 ^m	mg	mg	mg	mg	mg	mg	mg	mg	mg
	6	-0.10	-0.09	-0.10	-0.84	-0.03	-0.97	-1.05	-1.42	-2.47
Oct. 30-th 1928	3	-0.29	-0.22	-0.26	-0.84	-0.03	-1.13	-1.95	-0.75	-2.70
	6	+0.70	+0.74	+0.72	-2.66	0.00	-1.94	-1.95	-0.75	-2.70
Nov. 11-th 1928	4	+0.78	+0.63	+0.70	-2.66	0.00	-1.96	-1.43	-0.57	-2.00 ¹⁾
	4	-0.28	-0.30	-0.29	-1.15	+0.01	-1.43	-1.43	-0.57	-2.00 ¹⁾

Observations in 1930/31.

Table 1.

Date	Plate and filter	Local sidereal time	Object	Exposure	sec z	Diameter in mm.	Δ
Nov. 11-th 1930	Pan. blue	4 ^h 1 ^m	α Tauri	315 ^s	1.35	0.105	1.35
	" "	5 38	Mars	5 ^m	1.62	0.172	2.47
Nov. 18-th 1930	Flav. blue	4 41	α Tauri	4	1.35	0.363	2.86
" " "	Flav. yell.	4 57	α Tauri	4	1.35	0.422	1.97
" " "	" "	5 14	Mars	4	1.80	0.595	2.22
" " "	Flav. blue	5 30	Mars	4	1.72	0.500	3.38
Nov. 21-st 1930	Pan. blue	4 30	α Tauri	5	1.35	0.248	1.44
" " "	Pan. red	4 46	α Tauri	10	1.35	0.174	0.47
" " "	" "	5 10	Mars	10	1.85	0.241	0.76
" " "	Pan. blue	5 28	Mars	5	1.75	0.357	2.14
Dec. 12-th 1930	Flav. yell.	5 38	α Tauri	4	1.39	0.454	2.55 ²⁾
" " "	Flav. blue	5 51	α Tauri	4	1.40	0.481	2.21 ²⁾
" " "	" "	6 16	Mars	4	1.62	0.835	2.66 ²⁾
" " "	Flav. yell.	6 29	Mars	4	1.57	0.793	(2.78) ²⁾
Dec. 14-th 1930	Pan. blue	5 27	α Tauri	5	1.38	0.282	1.18
" " "	Pan. red	5 44	α Tauri	10	1.39	0.183	0.30
" " "	" "	6 15	Mars	10	1.63	0.301	0.60
" " "	Pan. blue	6 37	Mars	5	1.54	0.524	1.72
Dec. 15-th 1930	Flav. blue	5 32	α Tauri	4	1.38	0.626	0.94
" " "	Flav. yell.	5 44	α Tauri	4	1.40	0.500	1.02
" " "	" "	6 6	Mars	4	1.66	0.961	0.54 ³⁾
" " "	Flav. blue	6 18	Mars	4	1.62	1.086	0.67 ³⁾
Feb. 3-rd 1931	Flav. blue	5 32	Mars	4	1.47	1.511	2.24
" " "	Flav. yell.	5 45	Mars	4	1.43	1.282	1.87
" " "	Pan. red	6 0	Mars	10	1.40	0.404	1.07
" " "	Pan. blue	6 16	Mars	4	1.35	0.694	2.45
" " "	" "	6 26	α Tauri	4	1.49	0.273	1.61
" " "	Pan. red	6 51	α Tauri	10	1.53	0.156	0.74
" " "	Flav. yell.	7 4	α Tauri	4	1.58	0.540	1.10
" " "	Flav. blue	7 14	α Tauri	4	1.61	0.638	1.35
Feb. 4-th 1931	Flav. blue	4 57	α Tauri	4	1.35	0.638	1.34
" " "	Flav yell.	5 6	α Tauri	4	1.36	0.568	1.20

1) The image of Mars seems anomalous.

2) The background of the negative is too dark.

3) The sky near Mars was perhaps slightly hazy.

Date	Plate and filter	Local sidereal time	Object	Exposure	sec z	Diameter in mm	Δ
Feb. 4-th 1931	Pan. red	5h19m	α <i>Tauri</i>	10m	1.37	0.175	0.72
" " "	Pan. blue	5 30	α <i>Tauri</i>	4	1.38	0.275	1.64
" " "	" "	5 49	Mars	4	1.41	0.781	2.38
" " "	Pan. red	6 9	Mars	10	1.36	0.478	0.86
" " "	Flav. yell.	6 22	Mars	4	1.34	1.481	1.26
" " "	Flav. blue	6 34	Mars	4	1.32	1.716	1.75
Feb. 10-th 1931	Flav. blue	4 59	α <i>Tauri</i>	4	1.35	0.613	0.79
" " "	Flav. yell.	5 9	α <i>Tauri</i>	4	1.36	0.520	0.70
" " "	" "	5 26	Mars	4	1.44	1.373	0.80
" " "	Flav. blue	5 37	Mars	4	1.41	1.588	1.11
Feb. 13-th 1931	Flav. blue	4 45	Mars	4	1.57	1.637	1.39
" " "	Flav. yell.	5 0	Mars	4	1.51	1.395	1.16
" " "	Pan. red	5 15	Mars	10	1.46	0.466	0.55
" " "	Pan. blue	5 29	Mars	4	1.42	0.784	1.38
" " "	" "	5 58	α <i>Tauri</i>	4	1.41	0.278	1.17
" " "	Pan. red	6 12	α <i>Tauri</i>	10	1.44	0.156	0.54
" " "	Flav. yell.	6 25	α <i>Tauri</i>	4	1.47	0.562	0.89
" " "	Flav. blue	6 35	α <i>Tauri</i>	4	1.49	0.664	0.80
Feb. 28-th 1931	Flav. yell.	5 42	α <i>Tauri</i>	4	1.39	0.560	1.08
" " "	Flav. blue	5 47	α <i>Tauri</i>	4	1.40	0.650	0.84
" " "	Pan. blue	5 55	α <i>Tauri</i>	4	1.41	0.262	1.28
" " "	Pan. red	6 12	α <i>Tauri</i>	10	1.44	0.172	0.62
" " "	Pan. "	6 35	Mars	10	1.26	0.342	0.81
" " "	Pan. blue	6 50	Mars	4	1.24	0.602	1.71
" " "	Flav. blue	7 0	Mars	4	1.23	1.330	1.04
" " "	Flav. yell.	7 11	Mars	4	1.22	1.078	1.13
" " "	" "	7 28	α <i>Aurigae</i>	4	1.10	0.782	1.17
Mar. 8-th 1931	Flav. yell.	6 19	Mars	4	1.28	1.069	0.96
" " "	Flav. blue	6 31	Mars	4	1.26	1.306	0.87
" " "	" "	6 45	α <i>Tauri</i>	4	1.52	0.632	0.80
" " "	Flav. yell.	6 55	α <i>Tauri</i>	4	1.55	0.526	1.00
" " "	" "	7 6	α <i>Aurigae</i>	4	1.07	0.724	1.26
Mar. 9-th 1931	Pan. red	6 15	Mars	10	1.29	0.330	0.68
" " "	Pan. blue	6 30	Mars	4	1.27	0.596	1.27
" " "	" "	6 42	α <i>Tauri</i>	4	1.51	0.258	1.33
" " "	Pan. red	6 55	α <i>Tauri</i>	10	1.54	0.177	0.68

We have for 1930/31:

Table 2. Blue radiation, Flavin plates.

Date	$f(\Delta_M) - f(\Delta_A)$	Corr. for diam.	Corr. for absorpt.	$m_M - m_A$	m_M	$5 \lg \frac{r_0}{r_0(r_0-1)}$	m_M^0
	mg	mg	mg	mg	mg	mg	mg
Nov. 18-th 1930	- 0.52	- 0.69	- 0.13	- 1.34	+ 1.32	- 1.54	- 0.22
Dec. 12-th 1930	- 0.46	- 1.34	- 0.08	- 1.88	+ 0.78	- 1.14	- 0.36 ¹⁾
Dec. 15-th 1930	+ 0.34	- 1.19	- 0.08	- 0.93	+ 1.73	- 1.09	+ 0.64 ²⁾
Feb. 3-rd 1931	- 0.92	- 1.87	+ 0.05	- 2.74	- 0.08	- 0.71	- 0.79
Feb. 4-th 1931	- 0.42	- 2.15	+ 0.01	- 2.56	+ 0.10	- 0.72	- 0.62
Feb. 10-th 1931	- 0.38	- 2.06	- 0.02	- 2.46	+ 0.20	- 0.78	- 0.58
Feb. 13-th 1931	- 0.64	- 1.96	- 0.03	- 2.63	+ 0.03	- 0.82	- 0.79
Feb. 28-th 1931	- 0.24	- 1.55	+ 0.06	- 1.73	+ 0.93	- 1.06	- 0.13
Mar. 8-th 1931	- 0.08	- 1.58	+ 0.08	- 1.58	+ 1.08	- 1.22	- 0.14

1) The background of the negative is too dark.

2) The sky near Mars was perhaps slightly hazy.

Table 3. Blue radiation, panchromatic plates.

Date	$f(\Delta_M) - f(\Delta_A)$	Corr. for diam.	Corr. for absorpt.	$m_M - m_A$	m_M	$5 \lg \frac{r\varrho}{r_0(r_0-1)}$	m_M^0
	mg	mg	mg	mg	mg	mg	mg
Nov. 11-th 1930	-0.74	-1.08	-0.09	-1.91	+0.75	-1.64	-0.89
Nov. 21-st 1930	-0.46	-0.80	-0.14	-1.40	+1.26	-1.48	-0.22
Dec. 14-th 1930	-0.33	-1.34	-0.06	-1.73	+0.93	-1.11	-0.18
Feb. 3-rd 1931	-0.57	-2.02	+0.05	-2.54	+0.12	-0.71	-0.59
Feb. 4-th 1931	-0.50	-2.26	-0.01	-2.77	-0.11	-0.72	-0.83
Feb. 13-th 1931	-0.12	-2.25	0.00	-2.37	+0.29	-0.82	-0.53
Feb. 28-th 1931	-0.26	-1.80	+0.06	-2.01	+0.65	-1.06	-0.41
Mar. 9-th 1931	+0.04	-1.82	+0.08	-1.70	+0.96	-1.24	-0.28

Table 4. Yellow radiation, Flavin plates.

Date	$f(\Delta_M) - f(\Delta_A)$	Corr. for diam.	Corr. for absorpt.	$m_M - m_A$	m_M	$5 \lg \frac{r\varrho}{r_0(r_0-1)}$	m_M^0
	mg	mg	mg	mg	mg	mg	mg
Nov. 18-th 1930	-0.20	-0.74	-0.10	-1.04	-0.10	-1.54	-1.64
Dec. 12-th 1930	-0.19	-1.21	-0.04	-1.44	-0.50	-1.14	-1.64 ¹⁾
Dec. 15-th 1930	+0.48	-1.42	-0.06	-1.00	-0.06	-1.09	-1.15 ²⁾
Feb. 3-rd 1931	-0.58	-1.88	+0.03	-2.43	-1.49	-0.71	-2.20
Feb. 4-th 1931	-0.04	-2.08	0.00	-2.12	-1.18	-0.72	-1.90
Feb. 10-th 1931	-0.10	-2.11	-0.02	-2.23	-1.29	-0.78	-2.07
Feb. 13-th 1931	-0.22	-1.98	-0.01	-2.21	-1.27	-0.82	-2.09
Feb. 28-th 1931	-0.04	-1.42	+0.04	-1.42	-0.48	-1.06	-1.54
" " "	+0.03	-0.70	-0.03	-0.70	-0.67	-1.06	-1.73 ³⁾
Mar. 8-th 1931	+0.04	-1.54	+0.05	-1.45	-0.51	-1.22	-1.73
" " "	+0.23	-0.85	-0.04	-0.66	-0.63	-1.22	-1.85 ³⁾

Table 5. Red radiation, panchromatic plates.

Date	Image of Mars minus image of α Tauri			Corr. for diam.	Corr. for absorpt.	$m_M - m_A$	$5 \lg \frac{r\varrho}{r_0(r_0-1)}$	$m_M^0 - m_A$
	k. f. (Δ)	hyper-bola	mean					
	mg	mg	mg	mg	mg	mg	mg	mg
Nov. 21-st 1930	-0.59	-0.45	-0.52	-0.71	-0.07	-1.30	-1.48	-2.78
Dec. 14-th 1930	-0.70	-0.58	-0.64	-1.08	-0.03	-1.75	-1.11	-2.86
Feb. 3-rd 1931	-0.54	-0.41	-0.48	-2.06	+0.02	-2.52	-0.71	-3.23
Feb. 4-th 1931	-0.24	-0.17	-0.20	-2.18	0.00	-2.38	-0.72	-3.10
Feb. 13-th 1931	-0.02	-0.02	-0.02	-2.38	0.00	-2.40	-0.82	-3.22
Feb. 28-th 1931	-0.35	-0.26	-0.30	-1.49	+0.03	-1.76	-1.06	-2.82
Mar. 9-th 1931	0.00	0.00	0.00	-1.35	+0.04	-1.31	-1.24	-2.55

- 1) Uncertain; the background of the negative is too dark.
- 2) The sky near Mars was perhaps slightly hazy.
- 3) Comparison star α Aurigae.

Discussion of the Measurements of Colour of Mars.

The measurements of the brightness of Mars for blue and yellow radiations by E. S. King¹⁾ and for blue, yellow, and red radiations at Tartu, are represented in Figures 1, 2, 3, 4, and 5. We may notice that the change of brightness of Mars in connection with the phase-angle is linear for all kinds of radiation. The formulae, graphically derived from the Tartu measurements, are

$$\begin{array}{l}
 \text{blue radiation} \\
 (\lambda_{\text{eff.}} = 0.43\text{--}0.44 \mu) \\
 \text{yellow radiation} \\
 (\lambda_{\text{eff.}} = 0.57 \mu) \\
 \text{red radiation} \\
 (\lambda_{\text{eff.}} = 0.67 \mu)
 \end{array}
 \left\{
 \begin{array}{l}
 m_{\text{M}}^0 = -0.92 + 0.025 \alpha \\
 m_{\text{M}}^0 - m_{\text{A}} = -3.58 + 0.025 \alpha \\
 m_{\text{M}}^0 = -2.22 + 0.019 \alpha \\
 m_{\text{M}}^0 - m_{\text{A}} = -3.16 + 0.019 \alpha \\
 m_{\text{M}}^0 - m_{\text{A}} = -3.39 + 0.021 \alpha
 \end{array}
 \right.$$

where m_{M}^0 and m_{A} are the stellar magnitudes of Mars and α *Tauri*, and α denotes the phase-angle.

The following remarks may be added to the given formulae:

(1) The blue photographs of 1926/27 show Mars less bright than the photographs of 1930/31. A possible explanation of this phenomenon will be given below. They were not taken into account, because they were observed only for larger values of α and would therefore systematically influence the deduction of the coefficient of α .

(2) We suppose that our yellow filter is equal in quality to the yellow filter of E. S. King. This is confirmed by the description of King's filter in Harvard Annals vol. 81, p. 201, although we do not know the precise effective wave-length of the Harvard filter. Our magnitudes of Mars, deduced from the comparisons with either α *Tauri* or α *Aurigae*, accord with each other and with King's photovisual magnitudes.

1) Annals of Harvard College Observatory vol. 59, p. 262; vol. 81, pp. 211, 212; vol. 85, pp. 65, 66.

(3) In Tartu there are unfortunately few determinations near the opposition, a fact which diminishes the precision of the formulae given.

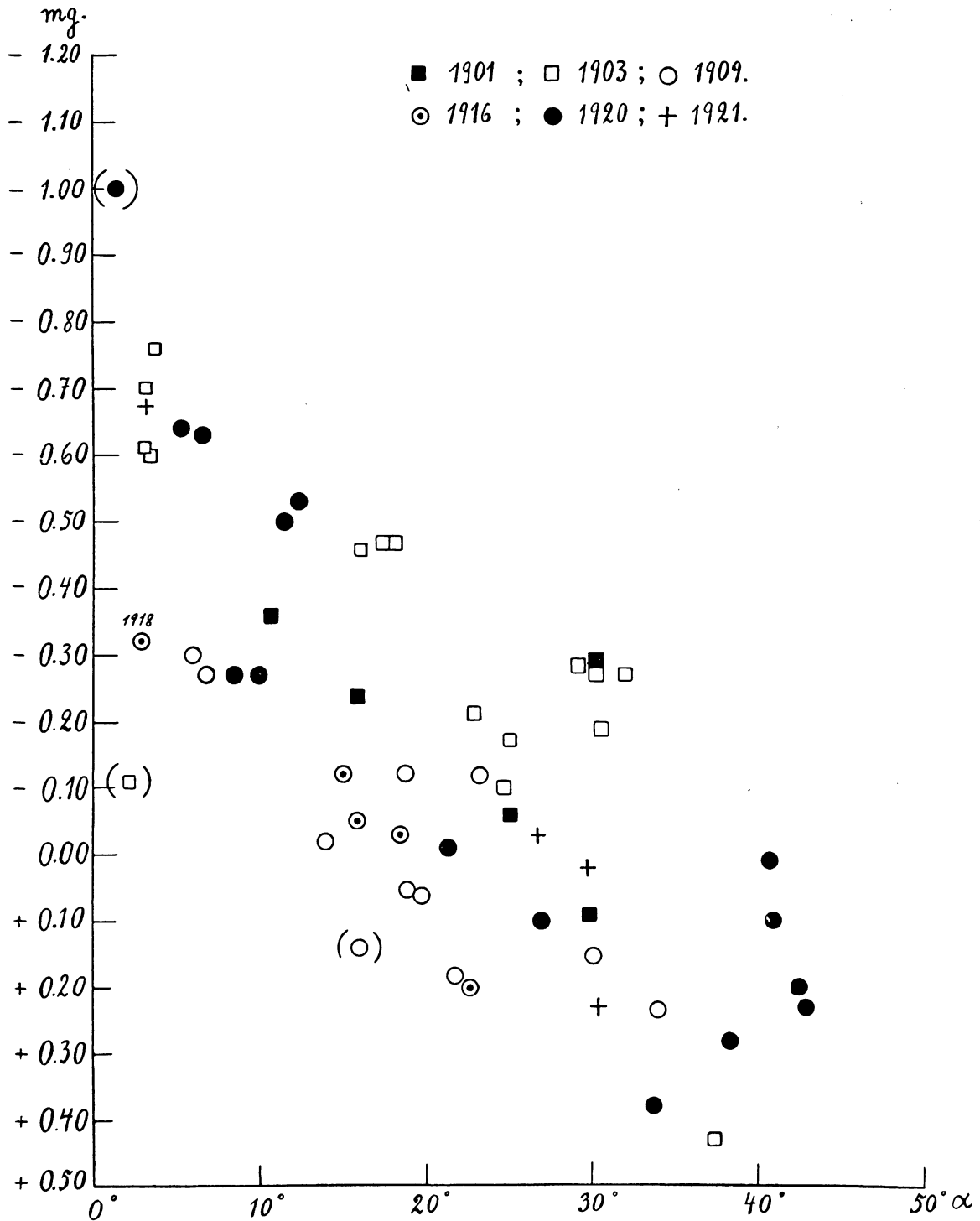


Fig. 1. The observations of E. S. King in photographic radiation.

When examining the photographic determinations of the brightness of Mars in Figure 1 and in Figure 3, we see that the stellar magnitude of Mars is different at different oppositions.

So, *e. g.*, the observations of 1903 and 1930/31 give for Mars in blue radiation a greater brightness than those of 1909. For the yellow radiation in Figures 2 and 4 the variation of the brightness with different oppositions is not obvious enough to be clearly detected.

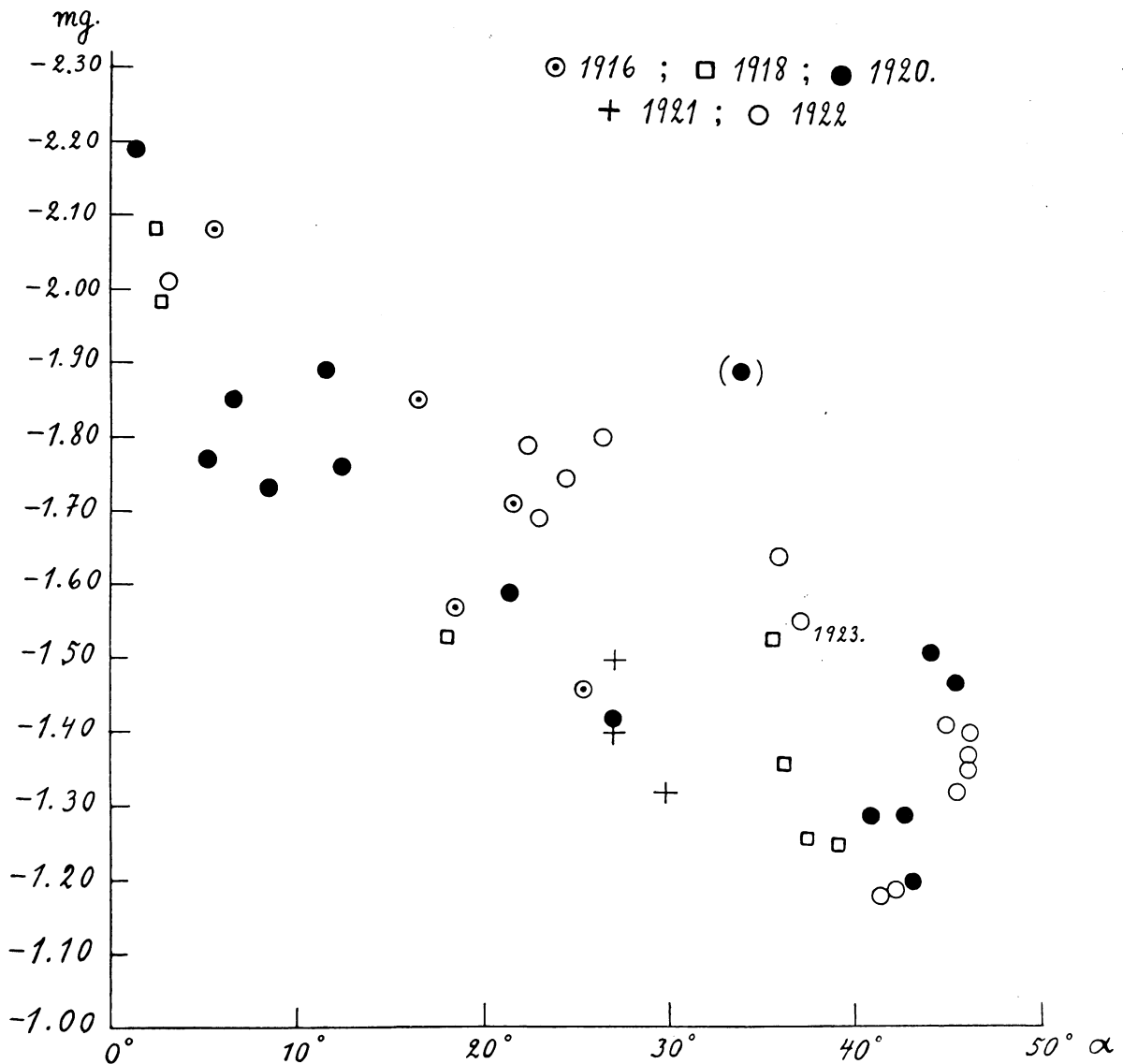


Fig. 2. The photovisual observations of E. S. King.

Defining, for the present case, as the „colour-index“ of Mars the difference in stellar magnitudes

$$m_M^0(\text{blue}) - m_M^0(\text{yellow}),$$

a diagram is drawn, Figure 6, with phase-angle as abscissae and colour-index as ordinates. All the satisfactory direct colour-determinations (when photographic and photovisual measurements were made on the same night) are used. The number of such determinations is 15 for King and 10 at Tartu.

For the magnitudes of Mars, at Tartu, in blue radiation the weighted mean between the Flavin and Panchromatic plates was taken, giving to the Flavin plates a relative weight of 1.0 and to the Panchromatic plates a weight of 0.5. These weighted colour-indices were in 1928: 1.69, 1.47, 1.29; in 1930/31: 1.42, 1.48,

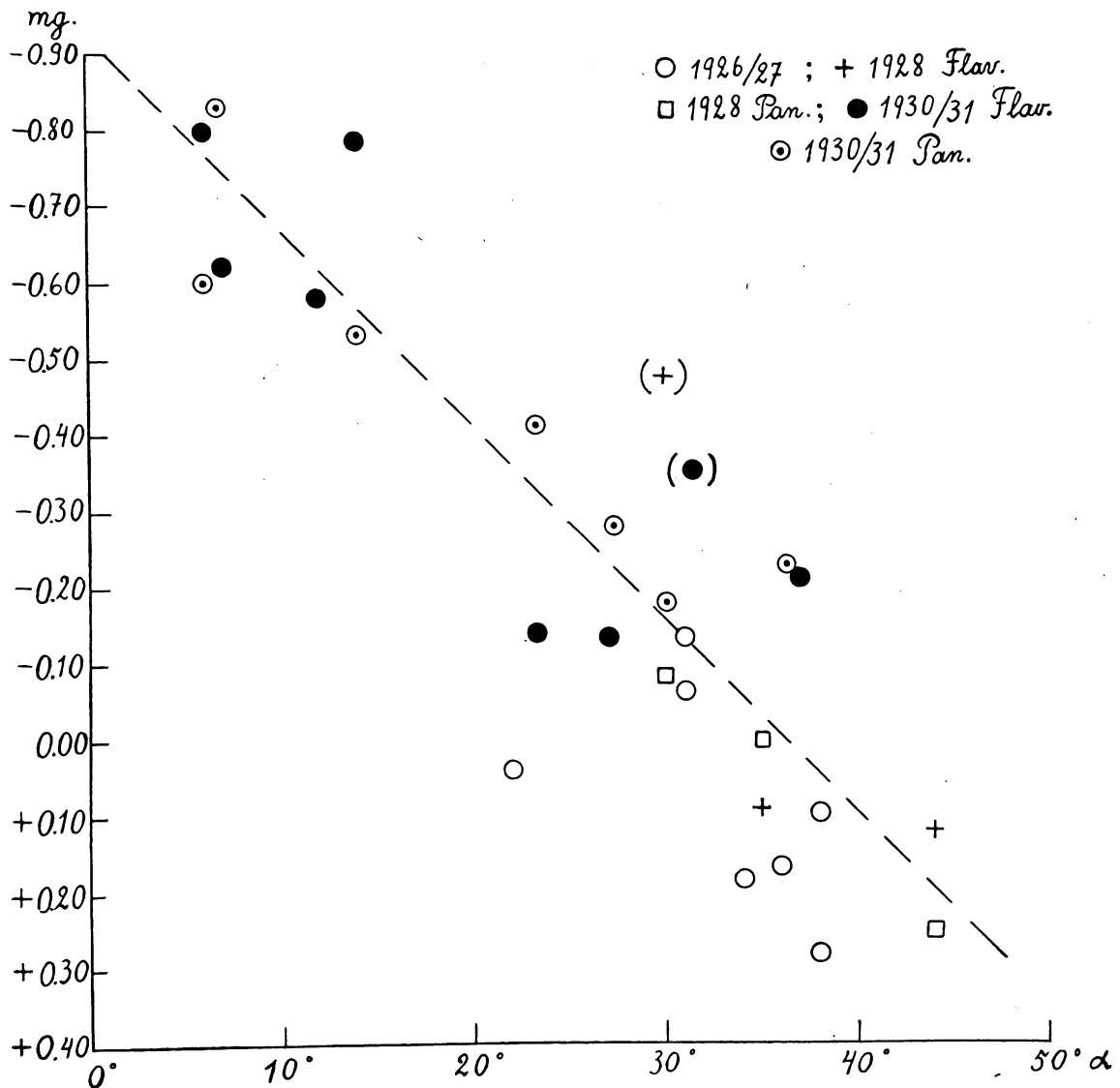


Fig. 3. Observations of Mars in blue radiation.

1.20, 1.48, 1.38, 1.31, 1.59. The values of December 12 and December 15, 1930 (1.28 and 1.78) were not taken into account, the nights being unsatisfactory.

E. S. King has found from numerous observations separately for photographic and yellow radiation¹⁾ (the photographic and photovisual observations were, to a great extent, made at different epochs)

1) Harvard Annals vol. 85, p. 69. Compare also our Figures 1 and 2.

photographic radiation: $m_M^0 = -0.55 + 0.0202 \alpha$

photovisual radiation: $m_M^0 = -2.00 + 0.0152 \alpha$.

According to these formulae the colour-index of Mars is linearly variable, being larger for larger phase-angles. The value of the colour-index is

$$\text{c. i.} = +1.45 + 0.0050 \alpha.$$

In Figure 6 this value is drawn as a dotted straight line.

We notice that, on the whole, King's as well as the Tartu values of the colour-index increase with an increasing phase-angle. Thus, the directly measured colour-indices of E. S. King and the observations at Tartu confirm the variability of the colour of Mars with the phase-angle, which follows from King's formulae. It is therefore probable that with an increasing phase-angle Mars becomes redder. This phenomenon offers also an explanation of the results obtained by G. Müller¹⁾ and by P. Guthnick²⁾, who find for visual and photoelectric observations different values of the coefficients of phase-angle — 0.01486 and 0.019 respectively.

From the abovesaid we draw the conclusion that it is not permissible without further discussion to derive a mean colour-index from observations at different phase-angles.

The question may arise, whether the change in the colour-index of Mars is not caused by seasonal changes on the surface of Mars, which might, on Figure 6, cause an illusion as if the colour-index were changing in connection with the phase-angle. In Figure 7, where the uncorrected colour-indices found by E. S. King and the author are plotted together with the declination of the Sun on Mars, we cannot detect any seasonal variation of the colour-index. Thus there remains only the probability of the variation of the colour-index, depending on the phase-angle.

It may be remarked further that by using the same observational material, with the colour-indices corrected for phase-angle, no seasonal variation can be detected. At first this seems contrary to expectation, since the visual observations show distinct changes in the contours and colours on the surface of Mars.

1) Publikationen des Astrophysikalischen Observatoriums zu Potsdam vol. 8, p. 327.

2) Astronomische Nachrichten No. 4976, p. 107.

But taking into account that seasonal influences are of opposite sign in the two hemispheres of Mars, a fact which diminishes the integrated changes in colour of the whole visible disc, we conclude that seasonal variations in colour can be detected only with a much greater number or a greater precision of observations.

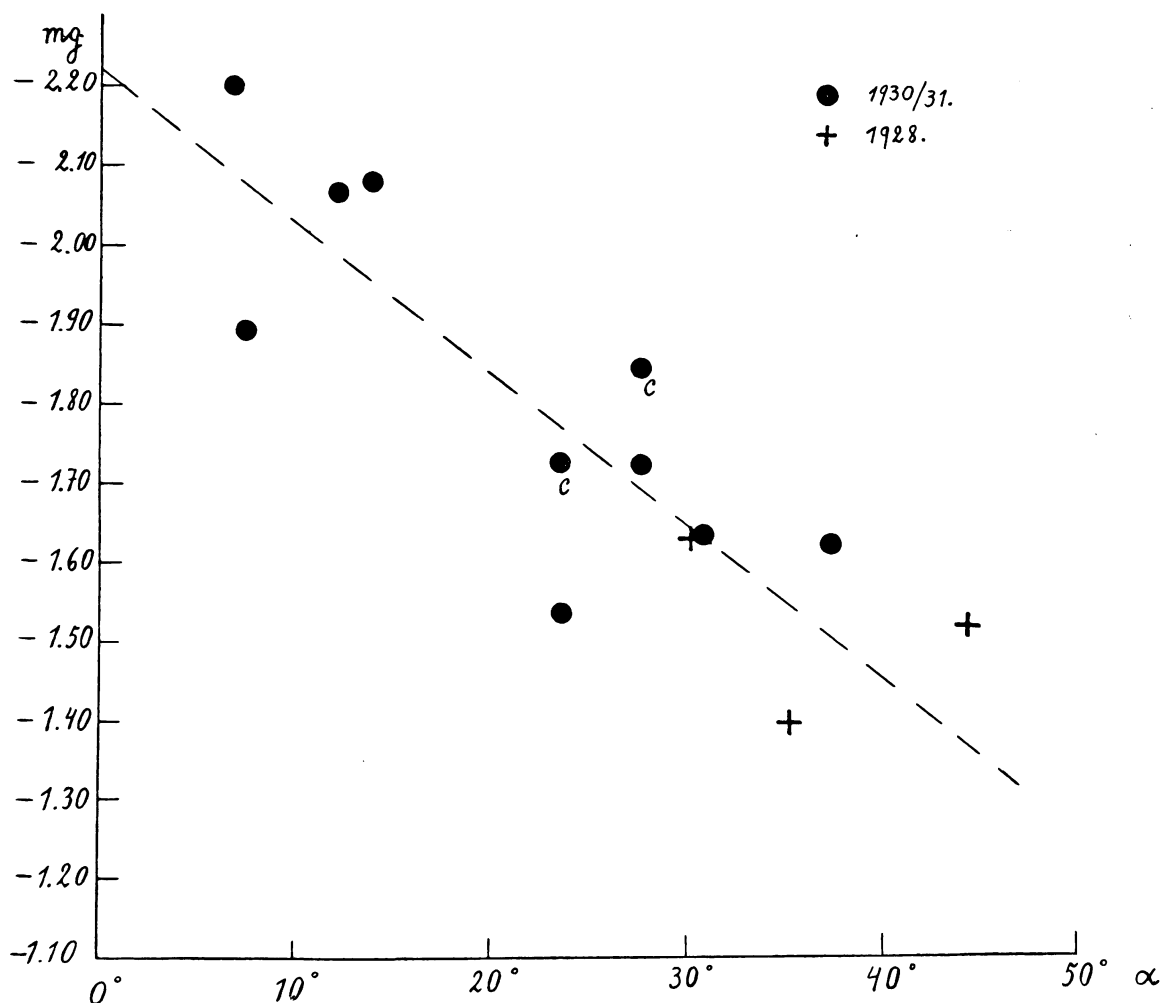


Fig. 4. Observations of Mars in yellow radiation.

Further we see on Figure 6 that all the directly measured colour-indices of E. S. King as well as all the colour-indices determined at Tartu are practically situated to one side of the dotted line. Thus the directly measured colour-indices do not agree with the colour-index deduced from a longer series of non-simultaneous photographic and visual observations. This phenomenon can be explained in two ways:

I. The colour-index of Mars, being variable with the

phase-angle is, besides that, still variable with different oppositions. Denoting

$$c. i. = a + ba,$$

a is different at different oppositions, being on the average $+1.45$. The range of this variation of the colour-index is about 0.10 — 0.15 magnitudes.

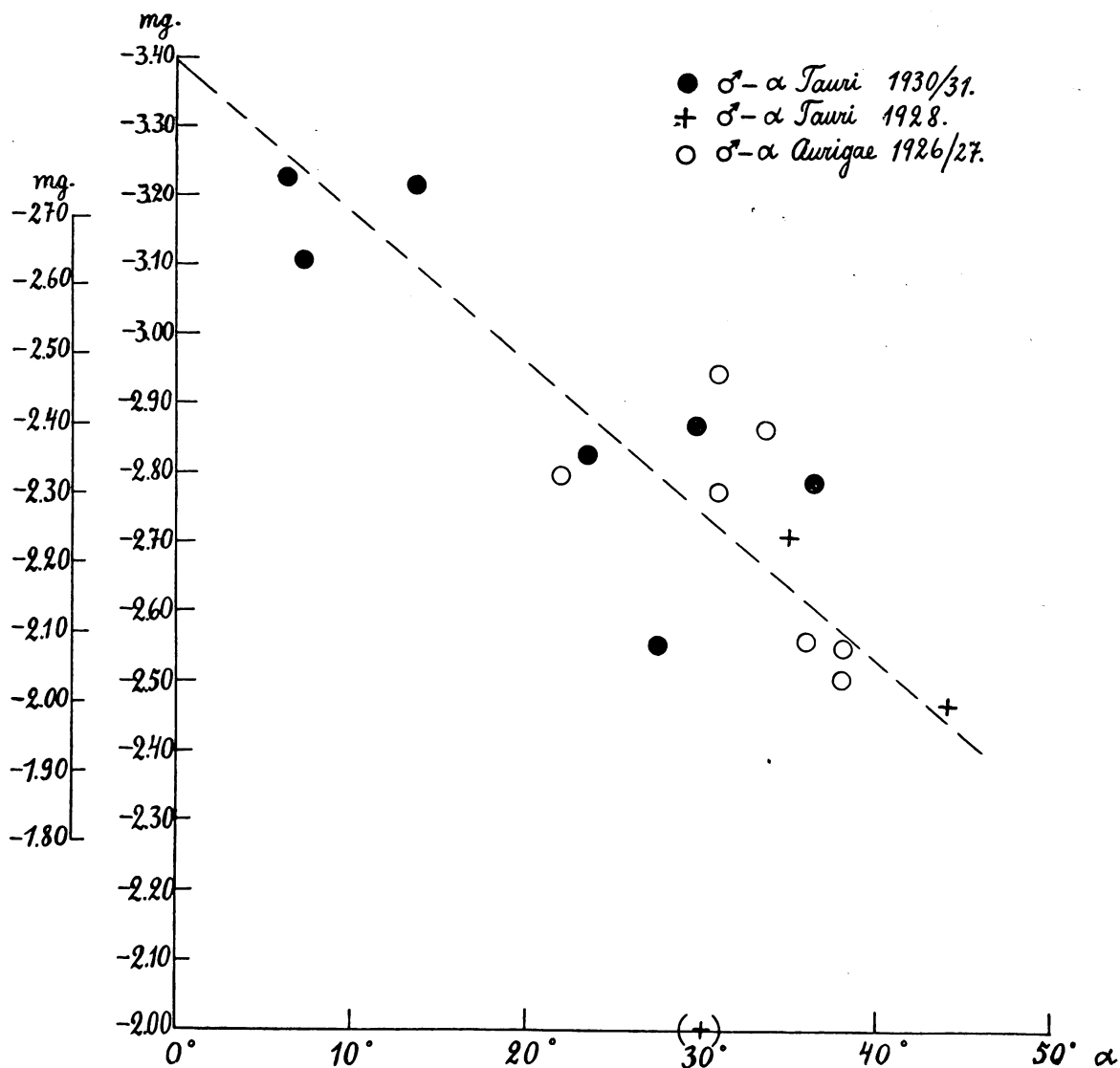


Fig. 5. Observations of Mars in red radiation.

The following table contains the existing photographic observations of Mars. Under " m_M^0 " the stellar magnitude of Mars in blue radiation is given at the phase angle 0° for $r_0 = 1.5237$ and $q = r_0 - 1 = 0.5237$. This magnitude of Mars is graphically deduced from Figure 1. For the observations of P. Guthnick and E. Öpik m_M^0 is deduced numerically, using for the coefficients of phase-angle 0.019 and 0.020 respectively.

Under "Mean Brightness" or "Low Brightness" an approximate estimate is given for the cases where the number of observations is very small and for larger phase-angles only. The "Mean Brightness" is between -0.50 and -0.59 magnitudes, and the "Low Brightness" -0.49 or smaller. D_{\oplus} denotes the mean declination of the Earth as seen from Mars during the period of observation. Under " $lg r$ " the logarithm of the distance of Mars from the Sun is given; the next column gives $lg r$ about $1\frac{1}{2}$ months earlier than the beginning of the given observation. "The Season" is given for that hemisphere of Mars which is turned toward the Earth. Under "Relative Number of Zurich" the mean relative number of the Sun's activity for the observational period is given, taken from "Astronomische Mitteilungen, Sternwarte Zürich".

Year	m^0_M	D_{\oplus}	$lg r$	$lg r$ $1\frac{1}{2}$ months earlier	Season on Mars	Relative number of Zurich	Observer
1901	mean brightness	$+ 21^0$	0.220	0.210	spring	2	King
1903	-0.75	$+ 22^0$	0.216—0.197	0.221	summer	18	King
1909	-0.42	$- 20^0$	0.141—0.158	0.141	spring	51	King
1914	-0.53 ^{1) 5)}	$+ 9^0$	0.221	0.215	spring	17	Guthnick
1914	-0.52 ^{2) 5)}	$+ 9^0$	0.221	0.215	spring	17	Öpik
1916	-0.53 ¹⁾	$+ 16^0$	0.220	0.221	spring (summer)	71	Guthnick
1916	low ³⁾ brightness	$+ 15^0$	0.221	0.219	spring	60	King
1918	-0.58 ¹⁾	$+ 22^0$	0.220—0.204	0.222	summer	76	Guthnick
1920	-0.70	$+ 19^0$	0.202—0.171	0.214	summer	28	King
1921	mean or low ⁴⁾ brightness	$- 24^0$	0.147	0.141	summer	31	King
1926/27	mean ⁵⁾ brightness	$- 20^0$	0.173—0.203	0.157	summer	83	Livländer
1928	mean ⁴⁾ brightness	from $- 2^0$ to $+ 4^0$	0.160—0.182	0.147	winter	67	Livländer
1930/31	-0.92	$+ 11^0$	0.199—0.221	0.183	spring	33	Livländer
1922	low ⁶⁾ brightness	from $+ 9^0$ to $- 22^0$	0.156— -0.140 — -0.149		autumn; spring and summer	11	King

1) Photoelectric measurements of P. Guthnick. Berlin-Babelsberg, Veröffentlichungen Bd. II, Heft 3, pp. 162, 163.

2) Photographic observations of E. Öpik. Astronomische Nachrichten No. 5162, p. 22.

3) Only 4 measurements at mean phase-angles.

4) Only 3 measurements at large phase-angles.

5) Large phase-angles only.

6) See corresponding remarks in the text.

Assuming that the colour-index of Mars is variable with different oppositions we may extend the table for the year 1922 indirectly with the aid of E. S. King's 1922 photovisual observations. Since King's photovisual magnitude and his colour-index of Mars are chiefly defined by the observations in 1920 and 1922, and since the direct observations of colour in 1920 give a colour-index lower than the mean, the colour-index

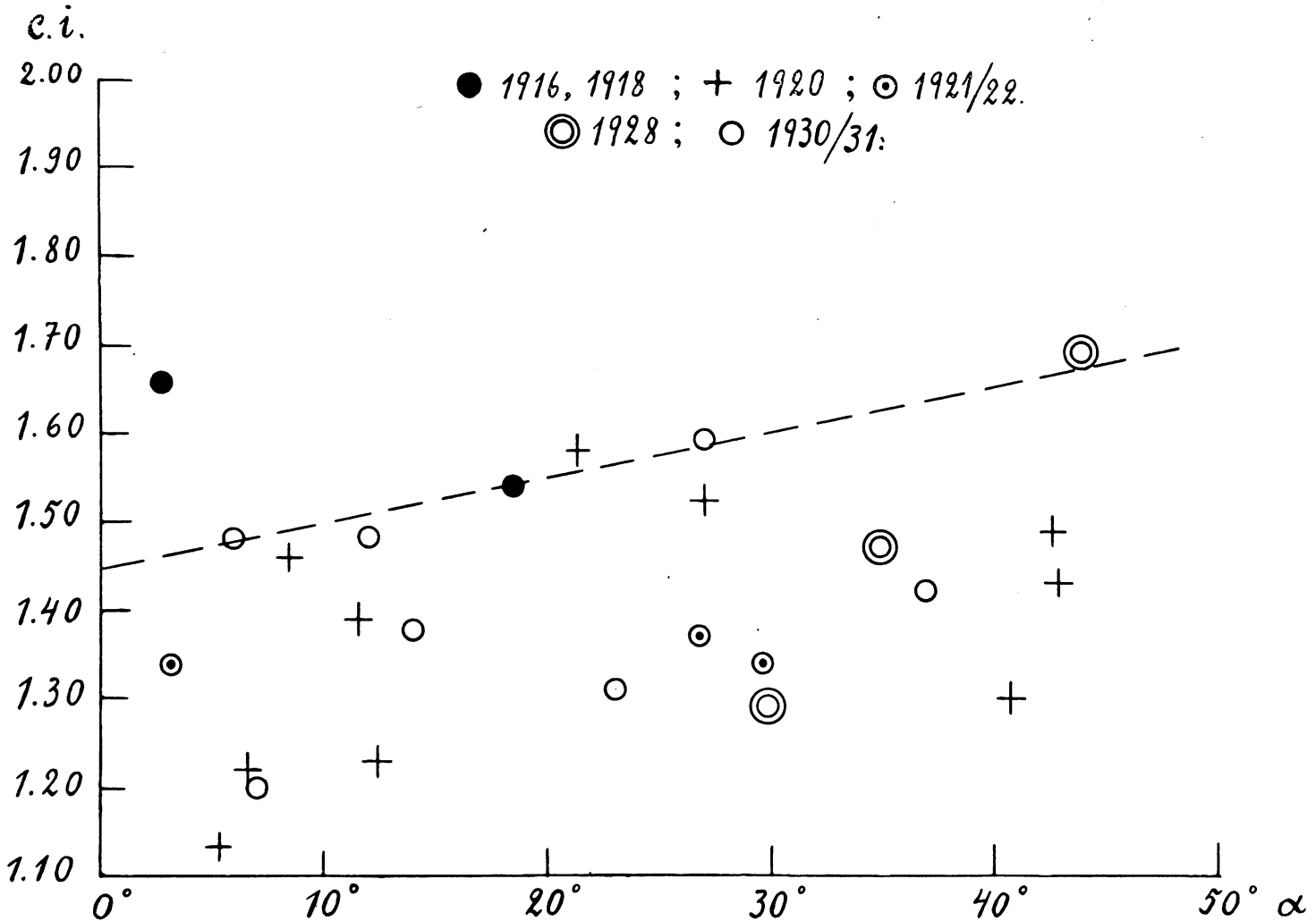


Fig. 6. The directly measured colour-indices of Mars at different phase-angles.

for 1922 must be larger than the mean value. Therefore the brightness of Mars in blue radiation must be „low“ or at most „mean“.

When inspecting the table, we cannot find any certain correlation between the photographic brightness of Mars and the seasons on Mars or between the photographic brightness and the relative numbers of Zurich. But a tendency can be seen, as if the photographic brightness of Mars depended on the distance of Mars from the Sun. Since the $lg r$ move more

or less parallel to D_{\oplus} , the brightness may depend on D_{\oplus} too. We conclude therefore:

(1) The colour-index of Mars depends probably on the distance of Mars from the Sun, being smaller for large distances and larger for small distances.

(2) The colour-index of Mars may as well depend on the hemisphere of Mars turned toward the Earth being smaller for the northern hemisphere and larger for the southern hemisphere.

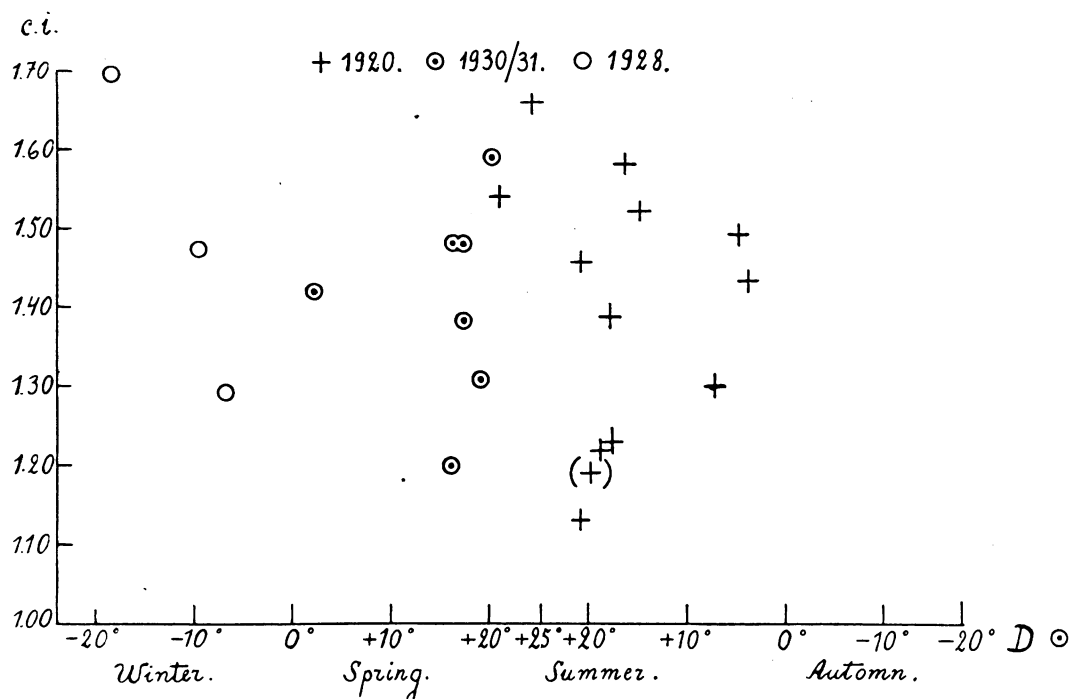


Fig. 7. The measured colour-indices of Mars in connection with the seasons.

P. Guthnick¹⁾ and E. Öpik²⁾ have shown for photoelectric and photographic radiations that the brightness of Mars is variable with its rotation, with an amplitude of about 0.09 mg. The observations of E. S. King and the writer do not show a variation of colour depending on the rotation of Mars.

II. There is, however, another explanation. Supposing that the colour of Mars, reduced to the phase 0° , is practically not variable, we must assume that the whole brightness of Mars is different at different oppositions, equally for each kind of radiation, with an amplitude of 0,10—0,15 magnitudes. In this case the brightness probably depends on the distance

1) *Astronomische Nachrichten* No. 4976.

2) *Astronomische Nachrichten* No. 5162.

of Mars from the Sun, being larger for larger distances. But the brightness might also depend on the hemisphere of Mars turned toward the Earth being larger for the northern hemisphere.

In this case we cannot derive the colour-index of Mars from separate photographic and photovisual observations made at different epochs. Then the value of E. S. King

$$+ 1.45 + 0.005 \alpha$$

is too large and must be substituted by

$$+ 1.30 + 0.005 \alpha.$$

Summary.

(1) The determinations of the brightness of Mars in blue, yellow, and red radiations were made at Tartu in 1926/27, 1928, and 1930/31. The corresponding formulae for the concluded variation with phase-angle are given on page 18.

(2) It is highly probable that the colour-index of Mars increases with the phase-angle. The observations at Tartu confirm the variability, which was originally found by E. S. King. The expression for the mean colour-index is

$$+ 1.45 + 0.005 \alpha.$$

This formula also explains the observations of G. Müller and P. Guthnick.

(3) The colour (or perhaps even the whole brightness) of Mars, reduced to the phase 0° , is certainly variable at different oppositions.

(4) Assuming that the colour-index of Mars is different at different oppositions, a dependence of colour on the distance of Mars from the Sun is probable. The changes of colour may as well arise from the hemisphere of Mars turned toward the Earth. The colour is redder for smaller distances or for the southern hemisphere. The amplitude of the change of the colour-index is about 0.10—0.15 mg.

(5) Supposing that the colour of Mars, reduced to the phase 0° , is not variable, we must assume that the whole brightness of Mars is variable with different oppositions, with

an amplitude of 0.10—0.15 mg. In this case the colour-index of Mars must be smaller than the value given by E. S. King. The formula for this case is

$$\pm 1.30 \pm 0.005 \alpha.$$

It is possible that the changes depend on the distance of Mars from the Sun or from the hemisphere seen.

(6) A variability of the colour of Mars with the seasons on Mars or with its rotation cannot be detected with the present observational material.
