RESULTS OF OBSERVATIONS OF THE TOTAL SOLAR ECLIPSE OF JUNE 29, 1927

II. PHOTOMETRY OF THE CHROMOSPHERE AND THE CORONA

BY

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(WITH 1 PLATE AND 6 TEXTFIGURES)

VERHANDELINGEN DER KONINKLIJKE AKADEMIE
VAN WETENSCHAPPEN TE AMSTERDAM
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I. THE OBSERVATIONS.

1. *The instrument.*

The object of the corona-prismcamera was the investigation of the monochromatic emissions of the corona, by photographing the faintest rings possible and studying the distribution of light in each. The principles which have governed the design of this instrument are laid down in B. A. N. 86. The first condition to obtain images of faint rings is a great surface brightness, for which a large angular aperture of the camera is necessary. Since the continuous coronal spectrum by its great intensity may obliterate the faint monochromatic rings, it should be weakened by a large dispersion. When the dispersion and the angular aperture are chosen, the absolute dimensions of the rings and the amount of detail visible vary with the absolute dimensions of the instrument; in order to avoid the difficulties and the cost of a large instrument, it was deemed sufficient for a first trial to make use of a Zeiss astrocamera with astrotriplet of 6 cm aperture and 27 cm focal distance (1 : 4.5), for which the sun's diameter is 2.4 mm. In a first construction this camera was provided with a train of 4 flintprisms of 66°, giving a dispersion of 5.5° from $H\beta$ to $H\gamma$; this instrument has been made by the Carl Zeiss Works, and it was used in our first expedition to Palembang 1926 [1]). Its chief drawback was the large astigmatism caused by the train of prisms, the images of the greater wavelengths being compressed, those of the smaller wavelengths being extended in the direction of the dispersion. As a result of the discussions in the Solar Eclipse Committee the plan arose to make a trial with a liquid prism placed before the astrocamera. This instrument has been constructed by the Dr. STEEG und REUTER Works at Homburg v. d. Höhe; it consists of two cylindrical glassprisms fitting in a brass tube of 6 cm diameter, in such a way that they include a prismatic space filled with aethyl cinnamate, a strongly refracting liquid. The deviation is zero for the green rays, it has a dispersion of 2.9° between $H\beta$ and $H\gamma$, and the total length of the spectrum from $H\alpha$ to $H\zeta$ is 67 mm. By differences of temperature in the liquid irregular refractions may occur, which spoil the definition of the images. In order to avoid them the whole instrument was packed in a thick cover of cottonwool; the opening of the prism was covered by some sheets of black cloth, which were not removed until the sunlight had disappeared. The glassprisms should be mounted with their refracting edge horizontally, so that the spectrum is vertical; there was, however, some difficulty because the screwrings pressing the glassprisms, dragged them somewhat along in turning, and it could not be avoided

[1]) Report on the expedition to Sumatra for observing the total solar eclipse of 1926, Jan. 14th. Proc. Amsterdam Ac. Vol. XXIX n⁰. 9.

that the direction of the dispersion was inclined 5° to the vertical. The plateholder was inclined to the optical axis of the camera so as to get the largest possible part of the spectrum in focus ; owing to the curvature of the focal plane the extreme wavelengths at both sides are somewhat out of focus.

2. *The observations.*

The coronacamera with liquid prism was taken to Lapland chiefly to make a trial and to get an idea of its efficiency. We could not expect important scientific results with it, because the conditions of this eclipse were rather unfavourable for this instrument. Owing to the short duration

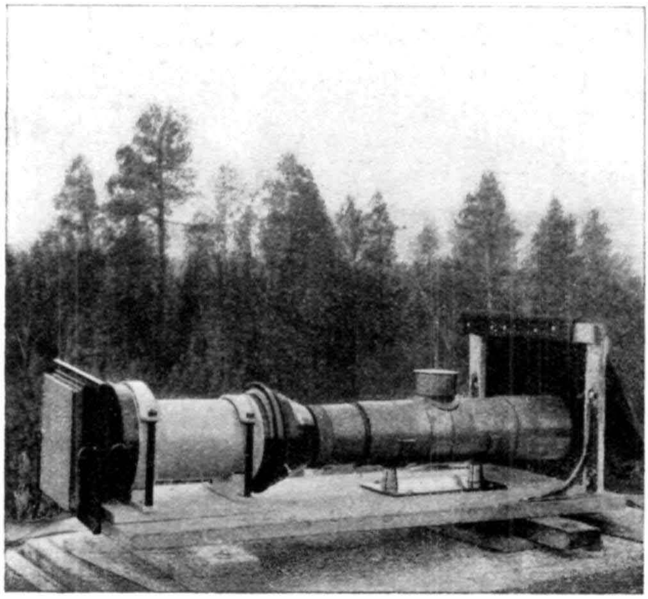

Fig. 1. Corona-camera with liquid prism, without its cottonwool cover.

of the eclipse a long exposure to bring out faint emissions was not possible. By the same circumstance the diameter of the moon exceeded the solar diameter by a small amount only, the most intense parts of the inner corona were not covered by the moon and their strong continuous spectrum formed a bright background for the coronal rings.

The sunlight was thrown into the instrument by means of a coelostat of the Hamburg Observatory, kindly lent to the expedition by Prof. R. SCHORR. Because the sun's declination was 23° 17′ and the latitude of the observingstation was 67° 3′, the beam of light reflected to the south was exactly horizontal ; the E-W direction on the sun corresponded to the horizontal direction on the plate. The mirror had an aperture of 18 cm, and it was placed at a distance of 6 m from the prism. This large distance was chosen to exclude as much as possible the light of the surrounding sky, which at Palembang, covered by a veil of light clouds, had blackened the whole plate. In the case of a clear sky, as we had in Lapland, the outer parts of the corona are cut off as a consequence of this large distance; but in drawing up the program of this expedition it was not our intention to include the study of the continuous spectrum.

The zenith distance of the sun at the moment of the eclipse was 62° 13′, and the angle of incidence at the coelostatmirror was 37.5°. In the plateholder two plates were placed side by side: an ordinary plate, Lumière Opta, 68 $\times$ 59 mm for the blue part, and an Ilford Panchromatic Plate 68 $\times$ 40 mm, for the red, yellow and green part; their common edge corresponded to 4900 AU. During totality two exposures were made on these plates, the plateholder being displaced 33 mm between them: the first from $+5^s$ to $+8^s$ after the beginning of totality, the other from $+11^s$ to $+37^s$. On the days after the eclipse comparisonspectra for standardization were taken on sisterplates cut from the same piece as the eclipseplates, and they were developed together with the eclipseplates.

The results are conformable to what might be expected. Only three monochromatic coronal rings are faintly visible on the plates, corresponding to λ 6375, 5303 and 3987 AU [1]). Further a large number of intense chromospheric rings appear, chiefly composed of images of prominences. We find 6563 ($H\alpha$), 5876 (He), 4861 ($H\beta$), 4472 (He), 4341 ($H\gamma$), 4216 ($Sr+$), 4102 ($H\delta$), 4078 ($Sr+$), 4026 (He), 3969 ($Ca+$) 3934 ($Ca+$), 3889 ($H\zeta$). Moreover a very strong continuous coronal spectrum is seen, consisting of two tangential bands decreasing towards the centrum as well as to the outer side.

In view of this result, in the discussion of the plates the chief weight had to be thrown on the prominences and the continuous spectrum, which it had not been our intention to study by means of this instrument. Nor are the conditions here very favourable; the coronal rings are difficult to measure by their extreme faintness, whereas the prominences are so by their extreme blackness. Still the circumstance that we had absolute intensity standards impressed upon our plates made it probable that some approximate result for the absolute intensity of some of these solar phenomena could be obtained. In any case we deemed it necessary to make a full investigation of these plates to obtain directives for the use of the instrument in future eclipses; in this way our results were used already in the preparation of the Indian Eclipse Expedition of 1929.

Part of the measurements and discussions contained in this paper have been made by the second of us — with the kind permission of Prof. L. S. ORNSTEIN — at the Physical Laboratory at Utrecht under the valuable direction of Dr. MINNAERT; they have been pursued at the Astronomical Institute of the University of Amsterdam.

[1]) Cf. Preliminary Report on the Expedition to Lapland, Proc. Amst. Ac. XXX p. 928, Fig. 2, 3, 4.

II. DERIVATION OF INTENSITIES BY MEANS OF THE CALIBRATION PLATES.

1. *The standardizing spectra.*

On the calibration plates impressions are made, for each wavelength, of radiations of different, accurately known intensities. By measuring the transmission in each of these impressions, the relation between the active intensity of radiation and the transmission of the silverdeposit due to it, may be found.

Before the liquid prism a collimator was placed, consisting of an astro-camera of the same dimensions, provided with a horizontal slit of exactly 2mm width. At a distance of 15 cm before the slit a piece of chalk was placed inclined 45°, which was illuminated from above, at a distance of 25 cm, by the standardlamp, a Nitralamp, for which the temperature and the radiation for different currents had been determined at the Utrecht Physical Laboratory. The slit was covered with the stepweakener, described pp 10—13 Results I. On one pair of plates exposures of 9^s and 90^s, on another pair exposures of 90^s and 900^s were made. On each pair of plates a neon-mercury spectrum was taken through the same slit in order to have a scale of wavelengths. On a separate plate this spectrum was impressed with this slit and with a narrow slit, to derive an exact dispersion curve. In order to control the homogeneous illumination of the slit spectra with and without the weakener were made on a special pair of plates (slitcontrol plates).

It appeared after the development that the standardizing exposures of 9^s and 90^s were less blackened than the prominences and the continuous spectrum on the 3^s exposure, and that only the 900^s had a sufficient blackness for the medium wavelengths. Hence for a large part of the spectrum the transmission curves had to be extrapolated.

2. *Derivation of the transmission curves.*

The fraction of light transmitted by each of the steps of the stepweakener has been determined for different wavelengths by MINNAERT at the Utrecht Physical Laboratory; the results are contained in Table 1 of Results I (p 13). By graphically smoothing these figures, we find the following values, which will be adopted here.

TABLE I

Adopted transmission of the reducer.

λ	Glass	1th	2th	3th	4th	5th step
4250	1.0	.504	.243	.117	.051	.024
6600	1.0	.470	.203	.100	.046	.024

For other wavelengths the values were linearly interpolated. In this way the intensity of the light falling through each step of the weakener is

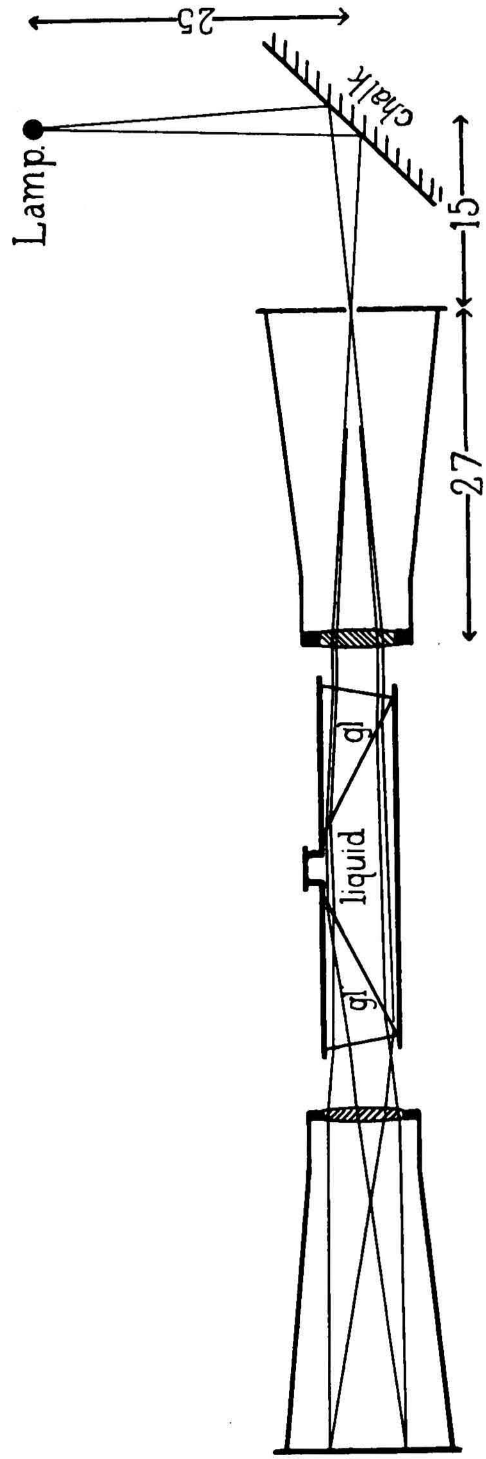

Fig. 2

known; if we measure the silverdeposit (i.e. its transmission) formed by each, we may construct a curve, giving the relation between transmission of some part of the image and the intensity of its object. The measures were made by means of a MOLL registering microphotometer.

First the Lumière Opta plates were treated. For five different wavelengths (λ 4750, 4470, 4220, 4080, 3970 AU) transverse tracings of the spectra were made, the transmission of each strip was read on them, plotted against log I as absciss, and a curve was drawn through the points. Such curves were obtained for the 900^s and 90^s exposures on one plate, and for the 90^s and 9^s exposures (for the strongest wavelengths) on the other. The curves for different exposure time should be parallel, and by a horizontal displacement (indicating what difference in log I corresponds to a ratio 10 of exposure time) they can be made to coincide. In this way combined curves (valid for 90^s) for each wavelength 4750, 4470, 4220, 4080 AU were obtained; for λ 3970 AU the faint deposit gave only a part of the 900^s curve. The displacement — representing the SCHWARZSCHILD exponent p — for these four wavelengths was found 1.02, 1.00, 1.06, 1.24. The four curves are represented in Fig. 3. Though for λ 4220 and λ 4470 the slope is found to be somewhat steeper than for λ 4080, the differences can not be warranted, and a combined "main transmission curve" is adopted. This curve is represented by the values in Table 2, where the intensities are expressed in an arbitrary unit.

For the sake of comparison the curve found in Results I, p. 19 is also inserted in Fig. 2 as a dotted line. This curve was derived by MINNAERT

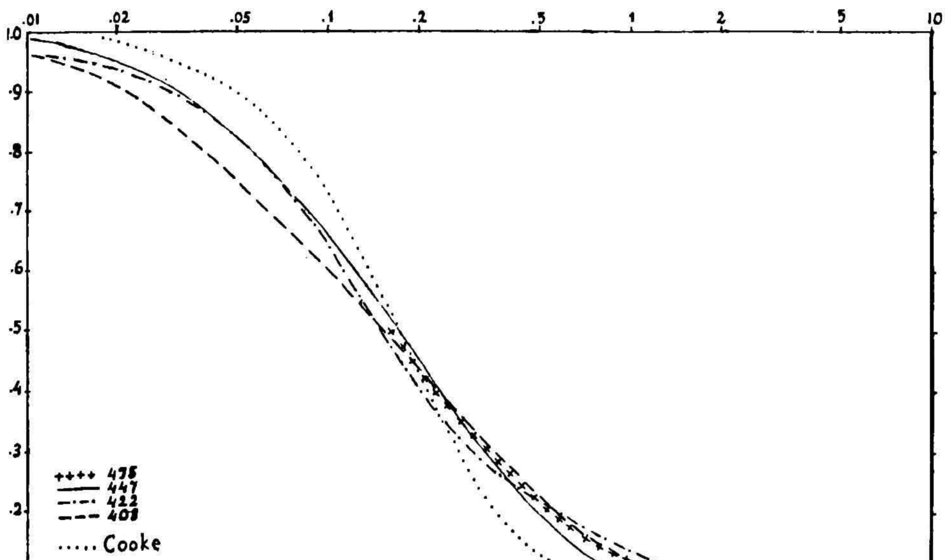

Fig. 3.

TABLE 2

Adopted transmission curve.

Transmission	Intensity	Transmission	Intensity
%		%	
100	.000	10	1.23
90	.026	5	2.90
80	.050	4	3.82
70	.076	3	5.78
60	.116	2	10.40
50	.163	1.2	24.60
40	.231	1.1	30.00
30	.340	1.0	33.80
20	.564	.9	62.00
		.88	76.00

from the calibration spectra made with the Cooke spectrograph. Though the Cooke camera plates are of the same brand (both Lumière Opta) and were developed and treated in the same way, the curves show a very different gamma. It seems difficult to ascribe the disparity to chance differences of say, duration of the development and temperature of the bath. We may look for its explanation to the effect of false light; if a certain amount of stray light falls upon the plate, it makes the curves appear less steep (Results I, p. 17). Now false light was certainly present on the calibration plates taken with the corona prism camera; on the 900^s and 90^s exposures at one side of the blackest strip another narrow band is visible, indicating a false series of spectrum strips somewhat displaced and out of focus, partly covering the strips measured; in the discussion these parts had been avoided as much as possible. Moreover a fainter spurious light covers the whole breadth of the exposed part of the plate, decreasing with the ordinary spectrum to the violet side. The parts of the curve corresponding to faint intensities may, by this cause, give too small values for the intensity; but it does not seem altogether probable that the parts belonging to the strong intensities were vitiated to an appreciable degree.

There is another difference between our results here and the results from the Cooke camera plates. The latter gave a value for the SCHWARZSCHILD exponent p of 0.82 (Results I, p. 30), while here values > 1 were found. Now the complete curves for some wavelengths are composed of parts coming from different exposures and only partly covering each other; if they are combined by means of displacements which by some cause are too large, the resulting curves will come out less steep. There is, however, no clear evidence, that this is the case, and though we cannot account for the cause of the discrepancy satisfactorily, there is no reason to substitute another curve for that resulting from our measurements.

The intensities in Table 2 are expressed in an arbitrary scale. In order to substitute the real scale for each separate wavelength we have taken the 90^s curve for each wavelength, read what intensities correspond to a transmission of 30 %, 40 %, 50 %, 60 %, 70 % and divided them by .340 .231 .163 .116 .076, the values corresponding to these transmissions in Table 2. Then we obtain the factor by which all the intensities of Table 2 are to be multiplied in order to stand for this special wave length. In this way we found for

λ	4750	4470	4220	4080	3970
factor	.22	.45	2.47	11.8	(71).

The value for λ 3970 is uncertain, because only a part of the 900^s curve could be used, which by the SCHWARZSCHILD exponent (assumed to be 1.05) had to be reduced to 90^s. By interpolating and extrapolating from these values (by means of a curve through their logarithms) we find the following table of reduction factors.

TABLE 3.
Reduction factors for intensities.

λ	Factor	λ	Factor
4900	.31	4300	1.29
4800	.23	4200	3.10
4700	.21	4100	9.0
4600	.25	4000	31
4500	.38	3900	128
4400	.65		

For the smallest wavelengths the extrapolated factors are rather uncertain.

In this first construction of a transmission curve no account was taken of a possibly unequal illumination of the slit, which judging from some indications, could not be very important. After the completion of a first discussion a special investigation of this point has been made. The result was that the lesser intensities would alter about 4% of their values and it was not thought worth while to make the reductions again.

When transmission curves for the panchromatic plate were derived in the same way, the correction for unequal illumination of the slit was investigated first. The panchromatic slitcontrol plate was measured with a HARTMANN microphotometer; from the measures of the strips photographed through the steps of the weakener a preliminary density-intensity curve was deduced. This was used to convert the density measures, made every .5 mm of the photograph taken without weakener, into intensities of the light transmitted through the slit. By means of this the first curve was corrected; after two approximations the accuracy reached was sufficient. The real quantity of light transmitted through each step of the weakener before the slit, instead of

	5th step	4th step	3th step	2th step	1th step	
1.00	.024	.049	.109	.225	.480	1.00 was found to be
1.00	.023	.048	.105	.211	.440	.832

These are the results for λ 5300 given as an example. The transmission curve for each wavelength has been deduced entirely from its own data. The wavelengths chosen were those for which monochromatic images are present and some others wanted in the discussion of the continuous spectrum. These transmission curves were not combined; they are given separately in Table 4.

3. *The derivation of intensities. General method.*

The unit of the intensities derived from the transmission curves (we will call them apparent intensities) is the intensity of the spectrum produced on the standard plates by the light entering the collimatorslit through the clear glass of the weakener. This light came from the Nitralamp and was reflected on the chalk; before entering the liquid prism it was weakened by the absorption in the collimator. The total radiation of the lamp is known as well as its distribution over different wavelengths; taking the reflection by the chalk into account we may compute the quantity of radiation entering 1 mm length of the slit, and by means of the dispersion curve, the quantity of radiation of each wavelength that has fallen on 1 sq. mm of the plate. This is the unit in which the apparent intensities are expressed. When deriving the intensity of a celestial object we have to consider that it too has suffered absorptions on its way to the liquid prism, viz. by the atmosphere, and by the reflection on the coelostatmirror. Moreover its exposure time was different from the exposure time of the standardizing spectra. These corrections and reduction elements will be deduced in the following paragraphs.

4. *The relative value of the intensity unit.*

We will first see what is the intensity unit for each wavelength in case that a quantity of radiation 1 falls on 1 mm length of the slit, on the supposition that the chalk reflects all the incident light diffusely. Then afterwards the absolute value in ergs per sec. of this unit will be computed.

During the exposures the standardlamp was run at 6.30 Ampères. For this current the colour temperature, according to determinations at Utrecht, was 2662°. By means of the formula

$\varepsilon = \lambda^{-5}\, e^{-c_2/\lambda T}$ and PLANCK's formula for $\lambda > 8000$ AU, for $\int \varepsilon d\lambda = 1$

TABLE 4

Transmission curves for the panchromatic plate.

Intensity	Transmission in % for						
	λ 6560	λ 6410	λ 6030	λ 5880	λ 5500	5300	λ 5210
.023	83.1	95.0	95.5	93.4	—	96.1	—
.024	—	—	—	—	76.8	—	—
.050	55.6	58.1	70.0	76.2	70.7	90.0	91.0
.100	28.8	28.2	38.0	49.0	56.4	76.4	80.5
.200	12.3	12.2	16.8	22.9	32.2	50.0	56.5
.400	5.62	5.25	7.26	9.20	15.5	24.8	29.2
.800	2.69	2.34	3.22	4.13	7.08	11.2	13.2
1.00	—	1.78	—	—	5.50	8.66	—
1.60	1.41	—	1.41	2.08	3.22	—	5.75
2.50	—	—	.83	—	—	—	—
3.20	.79	—	—	1.15	1.48	—	2.58
4.00	—	—	—	1.05	—	—	2.00
5.00	.64 .52	—	—	.93	—	—	—
6.00	— —	—	—	.86	—	—	—
6.40	— —	—	—	—	—	—	1.15
6.70	— —	—	—	.83	—	—	—
10.0	.50 .29	—	—	.72	—	—	—

The curves which only gave a value of *p*, but which were not used in the followin discussions, are not given.

The coordinates given are sufficient to draw a curve with *log I* as absciss and *minu log Tr* as ordinate.

The numbers below the heavy line were found by extrapolation; for λ 6560 the curv was extrapolated in two ways in order to get an idea of the influence of inaccuracies i the extrapolation.

the fraction of the total emission per AU was computed; with the aid o the dispersion curve giving the number of AU per mm, we find the fractio of the total emission falling on each mm of the spectrum (cf. Table 5) These values must be corrected for absorption in the collimator, for selectiv reflection of the chalk, and for unequal illumination of the chalk.

a. The absorption in the collimator was computed by means of th

TABLE 5

Reduction to true intensities.

1	2	3	4	5	6	7
3900 AU	1.45 10^{-6}	10.2	.365	.688	.90	3.35 10^{-6}
4000	1.80	12.2	.425	.693	.92	5.97
4250	2.95	18.8	.506	.706	.94	18.7
4500	4.47	27.9	.550	.718	.97	47.6
4750	6.40	39.8	.580	.732	.99	107
5000	8.74	54.6	.600	.745	1.00	213
5250	11.44	70.3	.608	.760	1.00	372
5500	14.44	87.3	.610	.774	1.01	600
5750	17.72	105	.611	.785	1.03	921
6000	21.11	125	.610	.796	1.05	1333
6250	24.64	146	.608	.806	1.05	1850
6500	28.22	169	.605	.817	1.06	2510
6750	31.73 10^{-6}	195	.600	.825	1.06	3250 10^{-6}

1 — Wavelength in AU.
2 — Fraction of total energy within 1 AU.
3 — AU per mm.
4 — Transmission by the collimator.
5 — Relative reflection coefficient of the chalk.
6 — Factor for unequal illumination of the chalk.
7 — Intensity per sq. mm in fraction of the light entering the slit per mm height.

formula given Results I p. 22 ; the constants to be used for the astrocamera were kindly supplied by the Carl Zeiss Works.

	first lens	second lens	third lens
free aperture	60 mm	48 mm	60 mm
thickness centre	10 mm	2.5 mm	11.5 mm
thickness limb	5 mm	10 mm	2 mm
glass	A	B	A

Transmission per cm glass for

λ	6440	5460	4800	4360	4050	3660
A	.997	.997	.996	.992	.979	.945
B	.89	.91	.86	.74	.60	.17

Moreover we have two reflections at the surfaces of the weakener, which give a factor $(.96)^2$, and 6 reflections in the collimatorlens for which we take a factor $(.944)^6 = .708$. With these data the transmission of the collimator in column 4 Table 5 has been computed.

b. The selective reflection coefficients of white chalk have been taken from the determinations by WILSING [1]. The average of his values is .758 ; probably the mean reflection coefficient should be somewhat larger, but absolute values are not given there by him. The absolute reflection-coefficient is given by WILSING and SCHEINER [2] as being 1.04, which indicates a fairly high reflection.

c. In consequence of the position of the lamp above the chalk (cf. fig. 2, p. 7) the illumination of the chalk diminishes from above downward. The central parts of the spectrum receive light from the whole aperture of the prism, the violet end however, is formed by rays passing through the upper part of this opening, which when taking the standard-plates is illuminated only by the lower part of the chalk ; in the same way the red end gets light from the upper part of the chalk only. Hence the effect is the same as if the chalk had an additional selective reflection, which was smaller for the violet, larger for the red.

In order to find its amount the part of the aperture used in forming each wavelength in the spectrum must be determined. For this purpose the instrument was put in working order in the Utrecht Laboratory : at the place of the spectrum a slit was set to cut out a small part of it, and immediately behind the slit a spectaclelens was set to form an image of the prisms aperture at some distance. At this place the image — partly limited by the rim of the aperture, partly by some other diaphragm — was copied on transparent paper for 9 different wavelengths ; the place of its baricentrum relative to the centre of the full aperture indicates how much the place on the chalk to be used here, is situated above or below the central point lying in the axis of the collimator. An easy computation shows how much the illumination of the chalk here deviates from that in the central point. The corrections arising from this cause, which are not very large, are inserted in column 6 of Table 5. Multiplying the fraction of the total emission for 1 AU by the number of AU per mm and by the three correctionfactors contained in column 4, 5 and 6, we find what fraction of the light falling upon 1 mm length of the slit has worked within 1 sq. mm of the plate at different wavelengths.

5. *The absolute intensity unit.*

In Results I p. 30—31 we find for the radiation of the standardlamp, run at 6.19 Ampères (2620°), that it gives .00443 watt per sq. cm at a distance of 20.5 cm from the lamp. This value is too small, because in the experiment the radiation is measured through a piece of glass covering the thermopile, which by absorption and reflection reduces the radiation to $.90 \times .92$ of the original amount ; after correction we find .00443 :

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1) Publ. Potsdam **66** p. 34.

2) Publ. Potsdam **61** p. 19.

$(.90 \times .92) = .00535$ watt $= 5.35 \times 10^4$ erg per sec. In making our standardspectra the temperature was 2662° and the distance 25 cm ; thus the radiation at this distance falling perpendicularly upon 1 sq. cm was

$$\left(\frac{2662}{2620}\right)^4 \left(\frac{20.5}{25}\right)^2 \times 5.35 \times 10^4 = 3.84 \times 10^4 \text{ erg/sec.}$$

The quantity of radiation falling from the chalk through a hole of 1 sq. cm on the objective of the collimator is found by multiplying this value by $\sin^2\theta \times \cos 45°$, where θ is half the angular aperture of the collimator (for aperture 59 mm, $f = 270$ mm, $\sin\theta = .109$) and the factor $\cos 45°$ arises from the angle of illumination of the chalk. Through 1 mm length of the slit, which was 2 mm wide itself, passed an amount of energy $.02 \times .109^2 \times \cos 45° \times 3.84 \times 10^4 = 6.44$ erg/sec. This is the value of the unit by which all the values in column 7 Table 5 should be multiplied to express them in absolute measure.

6. *The corrections to the intensity of the solar phenomena.*

The fraction of light of a celestial object at a zenithdistance z trans-

TABLE 6

Correction for atmosphere and mirror.

1	2	3	4	5
3900 AU	.203	.813	.165	6.05
4000	.262	.828	.217	4.61
4250	.332	.863	.286	3.49
4500	.385	.890	.343	2.92
4750	.430	.906	.390	2.56
5000	.468	.913	.427	2.34
5250	.498	.917	.456	2.19
5500	.521	.919	.478	2.09
5750	.540	.920	.497	2.01
6000	.560	.921	.515	1.94
6250	.589	.923	.543	1.84
6500	.625	.927	.579	1.73
6750	.665	.933	.621	1.61

1 — λ in AU.
2 — Transmission of the atmosphere at 62°13′ zenithdistance.
3 — Reflective power of the coelostatmirror.
4 — Product of 2 and 3.
5 — Reciprocal of 4.

mitted by the atmosphere is given by $a^{\sec z}$. The values of a for different wavelengths have been determined by ABBOTT. Taking the mean of his results for Washington [1]) we find for $z = 62° 13'$ the values of column 2 Table 6.

For the reflective power of freshly silvered mirrors we take the values of HAGEN and RUBENS [2]) combined with ABBOTT's results [3]) (the square root of the combined reflective powers of two mirrors). The result is found in column 3 Table 6.

These two factors multiplied (column 4) give the total diminution of the light of a part of the sun on its way to the liquid prism. Hence the intensity found from the plate should be multiplied by the reciprocal of this product (column 5) to have the true intensity of the object.

7. *The reduction for exposure time.*

According to SCHWARZSCHILD's formula the actinic action is determined by the product It^p, where p, the SCHWARZSCHILD exponent, is variable with the kind of plates and usually has a value between .7 and 1. If two sources of light give the same density of silverdeposit with different times of exposure, their relative intensities are $(t/t')^p$. Since the transmissioncurves stand for $t = 90^s$ the intensities deduced from the 3 sec. exposure have to be multiplied by the factor 30^p. The value of p, which is wanted for this reduction, can be found by comparing the impressions of the same object with different exposuretime. We have already given the values of p for the Opta plate, deduced from the displacement necessary to bring the 900^s curve or the 9^s curve to coincide with the 90^s curve. In the same way the transmission curves for the panchromatic plate afforded values of p for the greater wavelengths.

For the panchromatic plate we find values varying from .50 to .86 (cf. Table 7, col. 2). In order to test whether there is a real dependence on wavelength, these plates have been measured once more with the HARTMANN microphotometer of the Amsterdam Astronomical Institute: the results are given in Table 7 column 3. Another source of information may be found in the eclipseplate itself, since it contains two exposures of 3^s and 26^s. On both transverse sections of the continuous coronal spectrum have been registered with the MOLL apparatus. Constructing curves of the apparent intensity as a function of the distance to the sun's limb we may read the distance of the curves $log\ (I/I')$ corresponding to $log\ (t/t') = log\ (26/3)$ and from it we may find the exponent p. These results are given in col. 4 of Table 7.

A regular variation of p with the wavelength cannot be derived with certainty from these figures. Hence for the panchromatic plate a mean value

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[1]) Ann. Astroph. Obs. Smiths. Inst. III, 135, 1913.

[2]) Ann. der Phys. 8, 13, 1902.

[3]) Ann. Astroph. Obs. Smiths. Inst. II. 52, 1908.

TABLE 7

Results for the SCHWARZSCHILD exponent.

1	2	3	4	1	2	4
6870	.69	.72	—	4750	1.02	—
6560	.66	.68	—	4470	1.00	—
6410	.62	.68	—	4220	1.06	—
6110	.50	.73	.78	4140	—	1.08
5880	.82	.81	—	4080	1.24	—
5830	.62	—	—	4000	—	1.18
5460	.86	.85	.78	3930	—	1.08
5300	—	.85	—			
5210	—	.72	.70			
5050	.78	.81	—			

1 — λ in AU.
2 — p from calibration spectra, registered.
3 — p from calibration spectra, measured with the HARTMANN.
4 — p from the corona.

0.75, for the Opta plate a mean value of 1.05 may be adopted. HNATEK [1]) determined the dependence of p on λ for orthochromatic and panchromatic plates. In the region from 5100 to 5700 AU his values for the orthochromatic plate are in agreement with the values found here for the panchromatic plate.

The result for the Opta plate, where we find $p > 1$, is very curious. After the researches of KRON [2]) the SCHWARZSCHILD formula is only part of a more complicated function, in such a way that for small and moderate densities p will be nearly .80, but for more intense action of the light (the optimum action) and a corresponding denser silver deposit p rapidly changes through 1 to a value 1.2—1.3 for strong intensities. We might suppose that our large value of p for the Optaplate is due to the great blackness of the images here. Since, however, for λ 4000 and 3900, where the blackness is small, the same large values have been found, this explanation does not seem sufficient. Though we cannot but use the value of p, given concordantly by the standardization plates and the eclipse plate, the circumstance that in *Results I, p.* 30 for the Opta plate there used, $p = .82$ was found, may induce us to use it with some caution.

[1]) Zeitschr. f. wiss. Photogr. **22**, 177, 1923.
[2]) Publ. Potsdam **67**.

III. THE PROMINENCES.

1. *The measurements.*

The monochromatic images of the chromosphere are almost entirely formed by the prominences. A continuous arc of the chromosphere itself extending more than 90° can be seen in one exposure at the eastern, in the other exposure at the western side ; but these arcs nearly coincide with the tangential bands of continuous spectrum. The density of this spectrum is so great that on the tracings made with the MOLL instrument the small deviation of the curve due to the chromosphere arc disappears between its accidental oscillations caused by the silver grains. On this account only some prominences were measured in different wavelengths. Since our expedition had not taken a large scale photograph of the eclipse, Prof. Dr. R. SCHORR, Director of the Bergedorf Observatory had the kindness to furnish a copy of his photo, after which the print fig. 4 was made. On this print the dotted line is perpendicular to the dispersion, and the prominences measured are indicated by *a, b, c*. Prominence *c* was so bright that only the two strontium images could be measured ; the images in the other wavelengths were too black to be compared with the calibration spectra.

It was not possible to mount the prisma camera in such a way that every wavelength was in focus at the same time ; hence the images in several wavelengths were distorted and enlarged. Therefore it was not possible to determine the distribution of the light in the prominence. Only the total amount of light in every wavelength was available for investigation. It was determined by measuring the intensity along a number of adjacent sections of the prominence image. After having registered a first horizontal strip (the projection of the photometer slit on the plate had a width of .016 mm and a length of .1 mm), the plate was moved over a known distance (about .1 mm) in a vertical direction and the next strip was registered. In such a way the whole surface of the prominence was covered with the strips. The varying deviation of the galvanometer along each strip indicating the fraction of energy transmitted, was converted into intensity by means of the transmission curves given in Tables 2 and 4. For some points, where the density of the silver deposit was very strong, extrapolation beyond the limits of these curves was necessary. The intensity found in this way consists of the combined intensity of the prominence and the continuous background spectrum. The latter can be found from the tracing outside the border of the prominence ; after subtracting it we have the intensity of the prominence only. This intensity was integrated over each strip with the

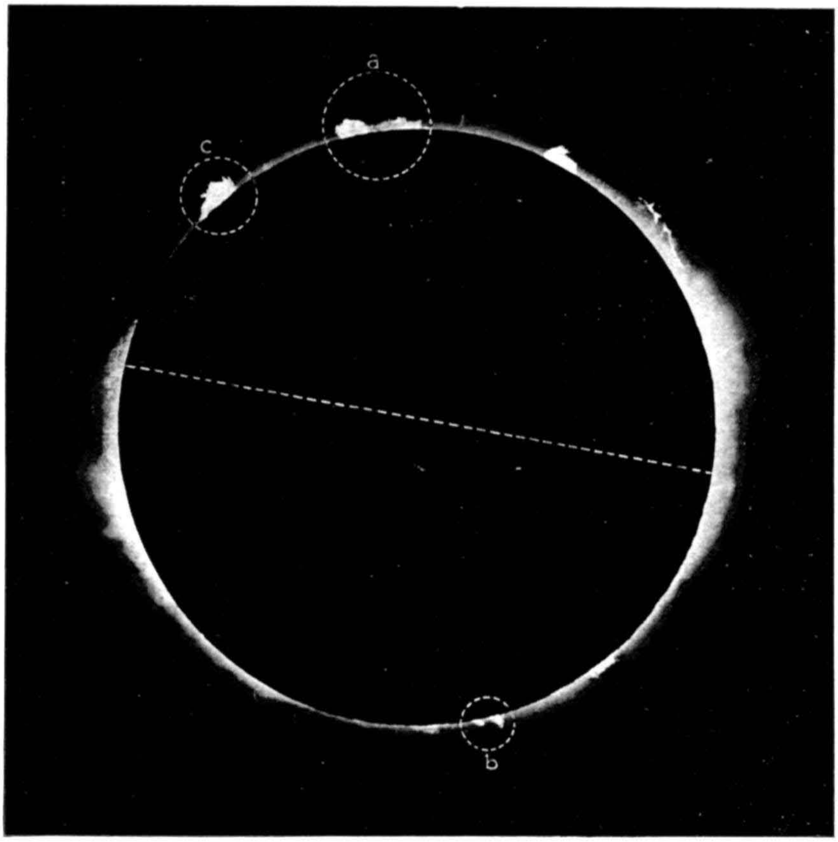

Fig. 4. Photograph of the corona, taken at Jokkmokk by Prof. Dr. R. SCHORR, Bergedorff, with the 20-meter camera.

help of a planimeter ; the result is $J = \int I\,d\,x$. These values J were plotted against the second coordinate y, and the value of $\int J\,dy = \iint I\,d\,x\,dy$ was determined in the same way (unit $d\,x\,dy$ is 1 mm^2). This value has to be multiplied, in the case of the Opta plate, by the reduction factor from Table 3 to get the apparent intensity.

The procedure to obtain the real intensity will be made clear by an example. In prominence *a* measured on the exposure of 3 seconds, the integrated intensity of $H\gamma$ derived from the general curve of Table 2 was found to be .695. To stand for the wavelength 4340 the reduction factor .93 from Table 3 must be applied ; the result .647 is the apparent intensity of this $H\gamma$ image. The unit, in which this intensity is expressed now, according to Table 5, is $26.7 \times 10^{-6} \times 6.44$ erg./sec., The factor 3.24, taken from Table 6, is necessary to correct for the absorption of the atmosphere and the reflection of the coelostate mirror. The result, after taking all these factors into account, $.647 \times 26.7 \times 10^{-6} \times 6.44 \times 3.24 = 361 \times 10^{-6}$ erg./sec., is found in Table 8, column 7. This would be the intensity, if the exposure time of the eclipse plate had been 90^s ; since it was 3^s the values of column 7 must be multiplied by 30^p where p is taken 1.05 for the Opta plate, 0.75 for the panchromatic plate (p. 16). The result gives the energy of $H\gamma$ radiation, which, coming from prominence *a*, entered the instrument per second through a circle of 3.0 cm radius. In order to find the total emission of the prominence in this wavelength, the energy falling upon a circle of 3.0 cm radius must be multiplied by $4\pi R^2 : (9.0\pi)$, in which R denotes the distance Earth-Sun. With $R = 1.49 \times 10^{13}$ this factor is $.99 \times 10^{26}$. Hence the values in column 6 are multiplied by $35.6 \times .99 \times 10^{26}$ for the Opta plate, by $12.8 \times .99 \times 10^{26}$ for the panchromatic plate, in order to find the total emission per second of the prominence in each of the monochromatic radiations ; the result, which is 126×10^{22} for $H\gamma$ is found in column 5. In Table 8 the results for the prominences *a*, *b*, *c* are given.

The accuracy of the results is not great, chiefly by the great density of the silverdeposit. For the $H\beta$ image of prominence *a* the transmission of the background was only 3 %, corresponding to a deviation of 8.5 mm in the tracing, and in the prominence it decreased for some points to .4 %. To measure these small amounts the tracings were magnified in Utrecht by means of an epidiascope ; at Amsterdam they were measured with a Hilger micrometer.

2. *The hydrogen lines ; temperature and density of the prominences.*

It may be of interest to compare our results on the relative intensities of the hydrogen lines with the theoretical intensities derived from the SCHRÖDINGER—PAULI formula. According to this formula the intensity I_l

TABLE 8.
Intensity of prominence emissions.

1		2	3	4	5	6	7	8
				Prominence *a*				
*$H\alpha$	6563	.511		.511	2685 10^{-6}	1.69	1500 10^{-5}	1890 10^{22}
$H\beta$	4861	2.32	.27	.625	147	2.46	146	512
$H\gamma$	4341	.695	.93	.647	26.7	3.24	36.1	126
$H\delta$	4102	.145	8.9	1.29	9.84	4.03	32.9	115
$H\xi$	3890	.0028	152	.426	3.13	6.25	5.36	18.8
*He	5876	.0767		.0767	1120	1.98	109	138
He	4472	.316	.44	.139	43.3	2.97	11.5	40.4
He	4026	.00457	22.8	.104	6.84	4.40	2.02	7.08
$Sr+$	4216	.00885	2.50	.0221	16.1	3.58	.822	2.88
$Sr+$	4078	.00702	11.5	.0807	8.79	4.15	1.90	6.65
$Ca+$	3969	1.25	47	58.8	5.04	4.95	944.	3310.
$Ca+$	3934	.670	78	52.2	4.14	5.56	774.	2720
				Prominence *b*.				
*$H\alpha$	6563	.171		.171	2685	1.69	501	634
$H\beta$	4861	.411	.27	.111	147	2.46	25.9	90.8
$H\gamma$	4341	.346	.93	.322	26.7	3.24	17.9	63.0
$H\delta$	4102	.0446	8.9	.396	9.84	4.03	10.1	35.5
*He	5876	.148		.148	1120	1.98	211	267
$Ca+$	3969	.328	47	15.4	5.04	4.95	248	869
$Ca+$	3934	.221	78	17.2	4.14	5.56	255	895
				Prominence *c*.				
$Sr+$	4216	.0326	2.50	.081	16.1	3.58	3.03	10.6
$Sr+$	4078	.0559	11.5	.643	8.79	4.15	15.1	53.0

* On panchromatic plate.

1. Intensity measured.
2. Reduction factor from Table 3.
3. Apparent intensity.
4. Coefficient from Table 5.
6. Coefficient from Table 6.
7. Intensity entering the instrument if the exposure time had been 90^s.
8. Total intensity emitted by the prominence for each wavelength.

of a line with series number l (3, 4, ... for $H\alpha$, $H\beta$ ...) is given in the form

$$I_l = \frac{4^3\,(l-2)^{2l-3}\,(3\,l^2-4)\,(5\,l^2-4)}{l\,(l+2)^{2l+3}}\,e^{\frac{hR}{l^2 kT}}$$

where $h = 6.55 \times 10^{-27}$ is PLANCK's constant, $R = 3.29 \times 10^{15}$ is RYDBERG's constant, $k = 1.37 \times 10^{-16}$ is BOLTZMANN's constant, and T is the absolute temperature. This formula is valid on the supposition that the hydrogen is in thermodynamic equilibrium. Though certainly a prominence does not consist of gases in thermodynamic equilibrium, we will compare this formula with our results to see in how far the intensity of the different lines corresponds to gas of a definite temperature. For this purpose we write the formula

$$I_l = \varphi\,(l)\; e^{\frac{hR}{l^2 kT}} = \varphi\,(l)^{15.73 \times 10^4 \times \frac{1}{l^2 T}},$$

or

$$\log \frac{I_l}{\varphi\,(l)} = .4343 \times 15.73 \times 10^4\,\frac{1}{l^2\,T} = 6.83 \times 10^4\,\frac{1}{l^2\,T}.$$

If $\log I_l - \log \varphi\,(l)$ is plotted against $1/l^2$ the result should be a straight line; the slope of this line gives the temperature T. Constant factors in $\varphi\,(l)$ may of course be omitted.

The result of the computations for the prominences *a* and *b* is given in Table 9, while it is plotted against $1/l^2$ in fig. 5, where points represent

TABLE 9.

Comparison of hydrogen lines.

1	2	3	4	5	6	7
$H\alpha$	1.206	.1111	3.277	2.802	2.071	1.596
$H\beta$	0.867	.0625	2.709	1.958	1.842	1.091
$H\gamma$	0.588	.0400	2.102	1.799	1.514	1.211
$H\delta$	0.357	.0278	2.062	1.550	1.705	1.193
$H\zeta$	9.987	.0156	1.274		1.287	

1. Hydrogen line. 2. log $\varphi\,(l)$. 3. Factor $1/l^2$. 4. and 5. log I_l for prominence *a* and *b*. 6. and 7. log $I_l\;/\;\varphi\,(l)$ for prominence *a* and *b*.

prominence *a*, crosses prominence *b*. The slope of the straight line drawn through the points (.75 difference in *log*. for .10 difference in $1/l^2$), being $7.5 = 6.83 \times 10^4/T$ corresponds to a temperature $T = 9100^\circ$; for prominence *b* in the same way a slope of 6.2 and a temperature $T = 11000^\circ$ was deduced.

The slope of the line and the temperature depend chiefly on the difference between $H\alpha$ and the other lines. Since $H\alpha$ has been reduced with another SCHWARZSCHILD exponent p than the other lines, an error in one of the

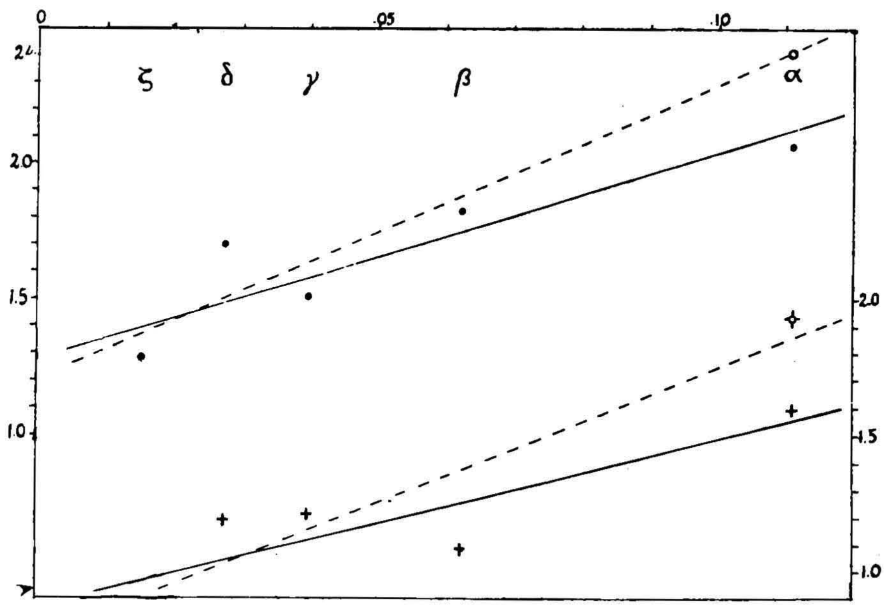

Fig. 5.

assumed values influences the result to its full amount. If instead of our value 1.05 we should assume for the Opta plate the value .82 found from the Cooke camera plates, the relative intensities of $H\beta$, $H\gamma$, $H\delta$ would remain the same, but the relative intensity of $H\alpha$ would be increased in the ratio $30^{1.05-0.82} = 2.19$. The open circles for $H\alpha$ and the dotted straight lines in figure 4 correspond to this case; the temperatures then would be lowered to 6400° and 6800°. Owing to the uncertainties of the measures and the reduction elements, caused by the great density of the prominence images, the extrapolation from the density curves and the large influence of the SCHWARZSCHILD exponent, these results are hardly more than a very rough estimate. We cannot consider them as an indication that the temperatures of the prominences are really above 6000°.

Our measures of the absolute intensity radiated by these prominences make it possible to derive some conclusions on the density of the hydrogen gas. FRANCIS G. SLACK has computed the absolute emission value, i.e. the energy emitted in the different line radiations per second by one hydrogen atom. He finds that an atom in the 5th quantum state when going from an orbit with quantum number 5 to one with quantum number 2 emits 1.15×10^{-5} erg. per second as $H\gamma$ radiation. Since the same emission of prominence *a* amounted to 126×10^{22} erg., the number of hydrogen atoms in the fifth quantum state in that prominence was 1.10×10^{27}, on the supposition that self absorption had no influence. We can make an estimate of the volume of space, occupied by this prominence by assuming that its extension in the line of sight was equal to its tangential extension. Measuring its dimensions on the Jokkmokk print of Dr. SCHORR (fig. 4) we find for its volume $.41 \times 10^{-3}$ times the solar volume or 5.8×10^{29} cm^3. Hence the prominence contained per cm^3 .19 atoms of hydrogen in the fifth quantum state. The number of hydrogen atoms at large can be deduced from this result only if we assume the fraction of atoms in this state to be the same as in the case of a gas in thermodynamic equilibrium at a definite temperature, for which we assume 5500°. In this case the fraction is given by $e^{-\frac{24}{25}\frac{hR}{kT}} = e^{-27.45} = 1.20 \times 10^{-12}$; then the density of hydrogen atoms in prominence *a* was 1.6×10^{11}, which for the same temperature corresponds to a pressure of 1.2×10^{-7} atmospheres. For prominence *b*, assuming a volume of $.14 \times 10^{29}$, in the same way a density of 33×10^{11} was found.

The density of hydrogen in the lower layers of the chromosphere could not be determined from our negatives, because, as explained already above, the chromosphere arcs could not be separated satisfactorily from the continuous corona spectrum. We can, however, determine it from the measures on the Cooke spectrograph negatives. Their discussion shows (Results I, p. 104) that the total $H\gamma$ emission of a layer of the chromosphere of 1 km thickness, extending (viewed from the earth) 1′ of arc along the solar border, of a height of h km amounts to $4\pi \times 2.7 \times 10^{20} \times e^{-h/617}$ ergs per second. After the computations in *B.A.N.* 158 (Vol. IV, p. 264) the equivalent volume of this layer is 2.16×10^{24} cm^3. From the emission 1.58×10^{-3} erg./sec. of one cm^3 at the bottom of the chromosphere we find that in this unit volume a number of 136 atoms in the fifth quantum state is contained. With the same temperature of 5500° the density of hydrogen is $.83 \times 10^{12}$ times more, i.e. 1.13×10^{14} atoms per cm^3, which exert a pressure of 8.3×10^{-5} atmospheres.

The pressure of hydrogen atoms in the prominences is nearly 800 times smaller than at the bottom of the chromosphere. It exceeds of course far the density of a regularly decreasing chromosphere at that height. The mean height of prominence *a* was estimated from the Jokkmokk print to be .033 solar radii or 23000 km ; after the above formula the hydrogen pressure at that level would only be 10^{-20} atmospheres. Our numerical results are in harmony with the view that a prominence consists of gas, driven out from lower chromospheric levels by a strong radiation pressure and expanding in a strong degree during the upward movement.

3. *The helium lines.*

In prominence *a* three helium lines, all belonging to the $2\,p$—nd series have been measured. The results for the intensity from Table 8 are

$$138 \qquad 40.4 \qquad 7.08 \times 10^{22}.$$

There is a regular decrease from the first to the third line. We may compare it with the decrease found for the same lines in laboratory experiments, made by Dr. D. BURGER at the Utrecht Physical Laboratory [1]). The relative values, expressed in the 2d line as unit, are :

	$2p-3d$	$2p-4d$	$2p-5d$
Prominence	3.4	1	0.18
Laboratory	21.	1	0.1

The rate of decrease with quantum number in the prominence is less than in the laboratory experiments. It cannot be considered improbable that this is due chiefly to the high temperature of a solar prominence compared with the Geissler tube. It may be remarked, moreover, that in prominence *b*, which was smaller and lower than *a*, the intensity of *He* 5876, relative to $H\alpha$, was greater than in *a*.

4. *The Calcium lines.*

For the atoms of ionized calcium we can derive the density in the same way as for hydrogen, because the transition probability for the *Ca* + atom has been computed by A. ZWAAN [2]). The probability coefficient $A_{42\rightarrow 41}$ for the transitions $2\,S—2\,P_1$ and $2\,S—2\,P_2$ combined, which give rise to the lines *H* and *K*, was found by him 1.55×10^8. Each atom of *Ca* + then emits $1.55 \times 10^8\, h\nu$ erg./sec. $= 7.69 \times 10^{-4}$ erg./sec. (computed with λ 3950 AU). The total emission of *H* and *K* radiation by prominence *a* was 6.03×10^{25}, by prominence *b* 1.76×10^{25} erg./sec. Hence the number of *Ca* + atoms is found in prominence *a* 7.8×10^{28}, in prominence *b* 2.3×10^{28}.

In this computation the effect of selfabsorption is neglected. If our results for the intensities of the *H* and the *K* images had a higher degree of accuracy, their relative value could tell us something on the amount of self-absorption. Now we can not even make an estimate and the results obtained for the number of radiating atoms are minimum values. By means of the volumes already mentioned we find the number of *Ca* + atoms per cm^3 to be .13 in one, 1.6 in the other prominence, corresponding at temperature 5500° to partial pressures of 9.6×10^{-20} and 12×10^{-19} atmospheres.

That this extremely small admixture of *Ca* + atoms to the hydrogen prominences produces monochromatic images even stronger than those of hydrogen finds of course its reason in this that all the *Ca* + atoms take part in the emission of the *H* and *K* lines, while only a very small fraction of hydrogen atoms exists in a state capable of producing the Balmer series.

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1) Thesis Utrecht 1928.

2) Archives Néerlandaises, **12**, p. 1 (1929).

IV. THE CORONA.

A. THE MONOCHROMATIC RADIATION.

The three monochromatic images of the corona, which can be seen on the plate, with wavelengths 6375, 5303, 3987 AU, are hardly distinguishable from the continuous background. The red and the green ring are more clearly seen on the 3 seconds exposure, whereas the violet ring stands out best on the exposure of 26 seconds. Therefore the intensity of the rings has been measured in these different exposures. They are not equally strong along the circumference ; the most intense parts are situated near the tangential bands, in the equatorial regions of the sun. Here, however, they are difficult to measure, because in running the plate perpendicular to this part of the ring, the intensity of the background would vary extremely rapidly. Thus it was deemed better to measure them in the middle between the tangential bands of the continuous spectrum ; there the background is less black than elsewhere, and moreover the plate could then be moved in the direction of the dispersion, along which the blackness of the background varied little over a distance corresponding with the dimensions of the ring.

In making the registrograms the ring is cut twice by the trail of the photometer, and the tracing shows two minima at a distance equal to the diameter of the ring. The knowledge of this distance was of great help to distinguish the ring from the accidental fluctuations due to dust and the grain of the plate. For the deflection of the galvanometer was only from 1 to 3 cm against 22 cm for the dead plate. To determine the intensity of the ring, the curve representing the continuous spectrum had to be interpolated over the width of the ring ; the greatest difference in the registrogram between the ring and the interpolated background was 3.5 mm. From the transmissions read for points of the ring and of the interpolated background the intensities were computed by means of Table 1 (or Table 4) ; their difference represents the intensity in some point of the monochromatic ring image. By plotting this intensity against the linear coordinate and by integrating over this contour of the ring intensity the total intensity of the ring was obtained, as follows :

	λ 6375	λ 5303	λ 3987
one side of the ring	.0030	.010	.018
other side of the ring	.0064	.014	.019
mean	.0047	.012	.0185

The better agreement for the two sides of the violet ring is due to the small intensity of the continuous background in that region. The result for

λ 3987 must be multiplied by the intensity factor 36, according to Table 3. The measures for the red ring have been reduced with the transmission curve for λ 6410 instead of λ 6375 ; a factor of 1.035 amends this. Thus the apparent intensities in column 2 Table 10 have been found.

To convert these apparent intensities into absolute intensities first the factors from Tables 5 and 6 must be used in the same way as followed in Chapter III for the prominences with $H\gamma$ as an example ; they are found in columns 3 and 4. The difference in exposure time is taken into account by the factor $(90/3)^{0.75} = 12.8$ for the red and the green ring, $(90/26)^{1.05} = 3.68$ for the violet ring. Multiplying by 6.44 erg./sec., the value of the intensity unit, we find the values of column 5 Table 10, also expressed in ergs per second.

TABLE 10.
Intensities of monochromatic corona emissions.

1	2	3	4	5	6
6375	.0049	2170 10^{-6}	1.78	15.6 10^{-4}	12.0 10^{23}
5303	.012	415	2.17	8.91	6.82
3987	.666	5.57	4.74	4.17	3.19

1. Wavelength. 2. Apparent intensity. 3. Factor from Table 5. 4. Factor from Table 6. 5. Absolute intensity emitted by 1′ of arc of the corona and entering the instrument in erg/sec. 6. Absolute intensity emitted by the whole corona in erg/sec.

This result gives the light that entered the instrument through a circle of 3 cm radius and fell upon a part of the corona ring measuring 1 mm along the circumference of the sun. The total emission of this part of the corona in each wavelength is found by multiplying by $4\pi R^2/9\pi = .99 \times 10^{26}$; the emission of the whole corona is found by multiplying by the circumference of the solar image $2\pi \times 1.24$ mm ; the product of these factors is 7.66×10^{26}. The result, the total emission of the corona in each monochromatic wavelength is contained in column 6 of Table 10. The combined radiation of the three coronal rings is found by adding the results of this column ; it amounts to 2.20×10^{24} ergs per second. As over this part of the spectrum the corona emits 1.90×10^{27} erg./sec. in the continuous spectrum (cf. p. 37), the monochromatic emission is only $^{1}/_{860}$ of the total radiation.

B. THE CONTINUOUS CORONA SPECTRUM.

1. *The connection between surface brightness and space intensity.*

In investigations on the decrease of the brightness of the corona with increasing distance from the sun's limb, usually only the projection of the corona on the sky is considered, i.e. the corona is treated as a flat phenomenon. In reality the corona occupies the three dimensional space around the sun and the problem is to find the space distribution of its intensity, i.e. how much light is emitted by a cubic centimeter at a given distance of the sun. Of course in such calculations it is necessary to assume that the space intensity only depends on the distance from the sun, and to neglect variations depending on the direction.

The same problem is met when the space distribution of stars in globular clusters is derived from the decrease of surface density with increasing distance from the centre. The beautiful solution given by PLUMMER [1]) can also be used for the corona. He derives the number of stars contained in narrow strips perpendicular to a diameter of the cluster and from these numbers he derives the space distribution.

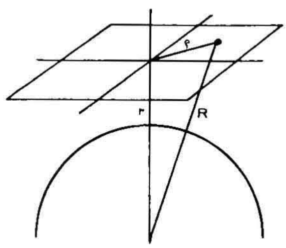

Fig. 6.

We consider a thin slab of thickness dr at a distance r from the centre of the sun, perpendicular to the sky surface. The light emitted by this slab appears to come from a narrow strip of the corona image with a width dr. The quantity of this light can be computed from the space distribution of the emission in the following way. If a unit volume at distance R from the centre of the sun (cf. fig. 6) emits $D(R)$ towards our instrument, then the emission of the slab is $\int D(R)\, ds$, the integration being extended over the whole slab. Introducing polar coordinates this integral can be written

$$I(r)\, dr = \int_0^\infty D(R)\, 2\pi\varrho\, d\varrho\, dr,$$

or, by substituting $\varrho^2 = R^2 - r^2$,

$$I(r)\, dr = 2\pi\, dr \int_r^\infty D(R)\, R\, dR.$$

If we now wish to find the function $D(R)$ from the strip intensity I, we have only to differentiate this integral, and we find

$$D(r) = -\frac{1}{2\pi r}\frac{dI(r)}{dr}.$$

For the corona this method of course can only be used when r is greater than the solar radius. If r is smaller than the radius a central band must be excluded from the integration over the slab.

[1]) Monthly Notices R.A.S. **71**, p. 460 (1911).

To apply this method to an ordinary picture of the corona it is necessary to integrate the measured intensity along a line perpendicular to the radius. In our case, however, this integration is automatically made by the spectrograph. Every point in the spectrum, produced by a prism camera, receives light from every point of the object situated on a line parallel to the dispersion, every point of course working with another wavelength. If the photographic effect of each wavelength upon the plate was the same, the density of the silver deposit in some point of the continuous corona spectrum would strictly correspond to the integrated intensity wanted in the formula. The same holds true if the photographic effect varies linearly with the place in the spectrum ; in the general case for a second approximation a correction for deviations from the linear relation would be necessary. If we consider, that in our case the spectrum has a length of 67 mm, while the solar diameter is only 2.4 mm, and this diameter corresponds to 400 AU at λ 6500, to 100 AU at λ 5000, to 30 AU at λ 4000, this second approximation hardly seems necessary. Of course we have to assume that also the outward decrease of intensity is independent of λ, or at least shows only a linear variation. Thus we find that the intensity in some point of the continuous spectrum is equal to the light emitted by the slab mentioned above for the corresponding wavelength. In the same way the total light of all wavelengths emitted by this slab is found by integrating the measured intensity along a line in the direction of the dispersion, i.e. of the tangential bands of continuous spectrum.

The intensity per unit volume is found by differentiating this intensity with regard to r. Thus we have to determine the intensity curve of the spectrum in a direction perpendicular to the dispersion. This simple method was, however, much complicated in our case owing to the screening off of the field of the instrument by the contour of the coelostat mirror.

2. *The screening off by the coelostat mirror.*

The corona prism camera with liquid prism has been specially designed to study the monochromatic emissions of the corona. During the eclipse of Jan. 14th 1926 at Palembang the sun was covered by clouds ; the light scattered by them formed a strong background, on which only the brightest chromosphere rings could faintly be seen. In order to get rid of this spurious light in Lapland we placed the coelostat mirror at 6 metres from the instrument. In this way only the light from the immediate surroundings of the sun could enter the camera. As the study of the continuous corona spectrum was not our object, little heed was given to the fact that the outer parts of the corona too would not fill the instrument. The consequence is that points at a greater distance from the sun do not contribute to their full extent to the integral, which renders the solution complicated.

Seen from the opening of the liquid prism the mirror looked like an ellipse with axes of 18.0 and 13.3 cm, the minor axis making an angle of 52° with the horizon. The radius of the sun, projected upon the mirror, was 2.75 cm

The horizontal direction on the mirror corresponded to the direction east-west on the sun. To know what part of a beam of light coming from a point in the sky, is entering the instrument, we imagine a beam of light starting from the opening of the liquid prism — strictly speaking the entrance pupil of the prism, which is different for different colours, should be used, but from this complication we refrained — and reaching a point of the sky after reflection on the mirror. The intersection of this beam with the projection of the mirror is a circle of 6 cm diameter, the aperture of the prism. If this circle lies entirely within the mirror, then the point of the sky fills the aperture of the prism entirely with light. If this circle lies outside the mirror, no light from that point can enter the instrument. The projections on the mirror of the points which can fill the prism entirely, lie within an ellipse with axes of 12.0 and 7.3 cm, whereas the points from which no light can enter the instrument, are projected outside an ellipse with axes of 24.0 and 19.3 cm. At the sky these ellipses correspond to ellipses with the sun as centre and axes of 4.4 and 2.6 solar radii for the inner, and 8.7 and 7.0 solar radii for the outer ellipse.

The computation of the average loss of light in linear sections of this inclined elliptically screened image of the solar corona is a rather complicated matter. It depends on the decrease of light with increasing distance, which itself cannot be found without knowledge of this correction. Thus we have to proceed with different steps. As a first approximation we computed simply the effect of screening on a radius perpendicular to the dispersion. For this purpose the middle ellipse with axes 18.0 and 13.3 cm and the circle with diameter 6.0 cm were drawn to scale and the fraction of the circle situated inside the ellipse was measured with a planimeter. The reciprocal of this fraction gives the factor by which the intensity found for the corresponding point has to be multiplied to get the intensity of the full beam. This factor is found in Table 11 ; points at a larger distance than 4.2 solar radii cannot send light into the instrument.

TABLE 11.
Screening factors, first approximation.

r	Factor	r	Factor
1.6	1.000	2.8	1.93
1.8	1.013	3.0	2.38
2.0	1.059	3.2	3.33
2.2	1.164	3.4	4.55
2.4	1.342	3.6	8.20
2.6	1.549	4.2	∞

For a second approximation we have used the results for the intensity as a function of distance, corrected after Table 11. Since it represents integrated strip-intensities a table of surface intensities as a function of the distance was first derived; then on a drawing, which contained the different ellipses as locus of screening effect 0.0 0.1 0.9 1.0, for a number of equidistant points on lines perpendicular to the radius the intensity without and with screening was found, and by integrating the total intensity along a line without and with screening was deduced. So the factors for the screening effect of Table 12 were obtained.

TABLE 12.

Screening factors, second approximation.

r	Factor	r	Factor	r	Factor
0.0	1.018	1.2	1.023	2.4	1.72
0.2	1.017	1.4	1.058	2.6	2.00
0.4	1.016	1.6	1.12	2.8	2.4
0.6	1.015	1.8	1.21	3.0	3.0
0.8	1.012	2.0	1.33	3.2	4.0
1.0	1.006	2.2	1.49	3.4	5.9

For large distances these coefficients are very uncertain, and they have a practical use for small distances only.

3. *Determination of the apparent and the space distribution of intensity.* The intensity of the continuous spectrum was measured in a direction perpendicular to the dispersion at eight different wavelengths, viz 3920, 4000, 4150, 4400 and 4790 AU on the Opta plate, and at 5210, 5500 and 6030 AU on the Ilford panchromatic plate. This was done, if possible, for both exposures. The transmission was reduced to intensity by means of the curves of Tables 2 and 4. After taking the average of the values for the W. and the E. side of the corona, the logarithms of these average intensities were plotted against the distance to the centre expressed in solar radii (1 solar radius = 1.24 mm on the plate). For each wavelength two curves were obtained in this way, one for 26 sec., one for 3 sec. exposure (for λ 4790 the long exposure was too dense to be used). By a vertical displacement these curves could be made to coincide; this displacement is equal to $p \log (t_2/t_1)$, and in this way the values of p given in Table 7 for the corona, were obtained.

At great distance the intensity does not become zero, but tends to a small positive value; also directly a certain amount of fog, caused by stray light is visible, especially on the 26^s exposure. Since from a distance greater than $r = 4.2$ solar radii no light from the surroundings of the sun could reach the plate, the intensity at that place was subtracted from all the other intensites. The remaining values were considered as the observed intensities. For different wavelength of the same plate the curves of these intensities have the same shape ; for the two kinds of plates, however, they show a considerable difference. As may be seen in Fig. 7, the red, yellow and

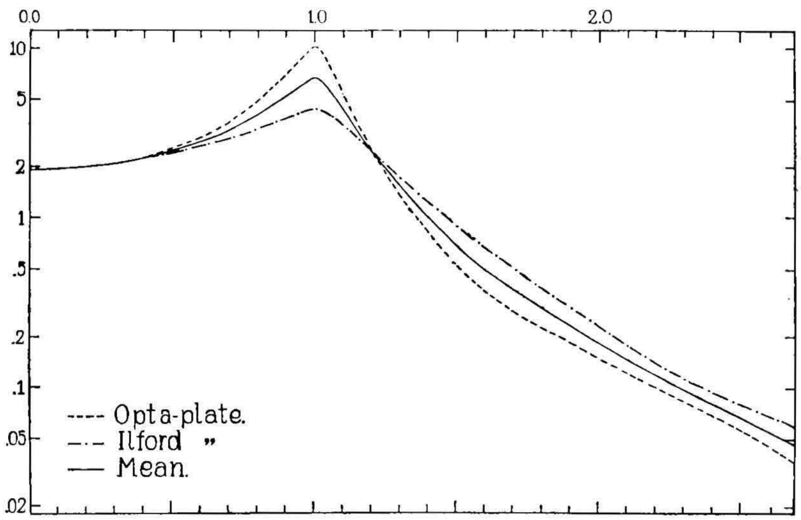

Fig. 7.

green wavelengths show a smaller decrease with increasing distance and a less steep top at $r = 1.0$ than the Opta plate. An exact identity of these curves would mean that the decrease of intensity with increasing distance is the same for each wavelength, i.e. that the spectral composition of the continuous corona light is the same at different distances from the sun. It is doubtful, however, whether we may conclude from our result that near to the sun's surface the coronal light is more bluish and far from the sun more reddish. The identity of shape and of the steepness of the top from λ 3920 to λ 4790 and the sudden change to λ 5210 suggest that the phenomenon has an instrumental origin. If e.g. instead of our mean transmission curve of Table 2 we should use the curve of *Results I*, which gives smaller values for the strong intensities, the slope of the corona intensity curve for the Opta wavelengths would be diminished.

Since it is not possible from our data to decide which curve should be preferred, we have simply taken the mean of the two curves of Fig. 7 ; this curve may represent the variation of observed intensity with distance for the total light. By applying the correction factors of Table 11 a first approximation of the corrected intensity was obtained, which was used for the computation of the second approximation of the screening factors of Table 12. By applying the factors of Table 12 we find the values for the corrected intensity, free from screening effect, of Table 13. The first column gives the distance from the sun's centre r in solar radii, the second gives the intensity in arbitrary units. The curve shows a somewhat rounded top at $r = 1.0$; for an instantaneous photograph the intensity should have a sharp top ; by the duration of the exposure and by the registering of a strip of finite width this top must be flattened. Hence the value for 1.0 has been extrapolated from the rest of the curve. The other columns will be explained below.

TABLE 13.
Intensity of continuous corona radiation.

1	2	3	4	1	2	3	4
0.0	1.93			1.4	1.06	1.08	.430
.1	1.98			1.5	.738	.771	.245
.2	2.03			1.6	.539	.575	.149
.3	2.13			1.7	.429	.442	.100
.4	2.28			1.8	.351	.348	.071
.5	2.52			1.9	.292	.281	.051
.6	2.84			2.0	.239	.229	.037
.7	3.27			2.1	.202	.191	.027
.8	4.05			2.2	.174	.160	.021
.9	5.15			2.3	.154	.136	.017
1.0	(8.35) *)	8.96	11.1	2.4	.134	.117	.013
1.1	4.40	4.37	3.98	2.5	.119	.102	.011
1.2	2.48	2.49	1.64	2.6	.108		
1.3	1.59	1.58	.811	2.7	.096		

*) Extrapolated ; the curve reading is 6.6.
1. Distance from the sun's centre in solar radii.
2. Integrated intensity in the continuous spectrum (arbitrary unit).
3. The same computed by formula.
4. Space intensity of the corona radiation.

The values of the second column are the $I\ (r)$ from p. 12. In order to make the differentiation less arbitrary we have tried to represent them by a simple formula. Since the faint intensities at large distance are rather uncertain by the effects of fog and screening, we contented ourselves by representing only the brighter intensities at smaller distance in this way. After some trials a formula

$$I\,(r) = .44\,(r - 0.7)^{-2.5}$$

was found to fit for these parts, as may be seen from the computed values in column 3 Table 13 ; for $r = 1.5$ to 1.7 it gives somewhat too large, beyond 1.8 it gives somewhat too small values. Then according to the formulae of p. 27 we have for the space density

$$D(r) = \frac{2.5 \times .44}{2\pi r}(r - 0.7)^{-3.5} = \frac{2.5}{2\pi}\frac{I(r)}{r(r - 0.7)}.$$

The values of the space density, computed from the observed I by means of the latter formula, are found in the 4th column of Table 13. They are so far expressed in an arbitrary unit, which will be determined in the next paragraph.

The relative values of Table 13 may be said to represent $I(r)$ as well for one wavelength as for the totality of all wavelengths. We may compute the total visible light of the corona by simply taking the integral $2\int I(r)\,dr$ between the limits 0 and ∞. Remembering that $I(r)$ gives the intensity per square millimeter, while the argument of the function r is the solar radius, we find 12.0 for the total light, expressed in the unit 1.0 for the light falling on 1 mm^2 at $r = 1.42$.

4. *The absolute intensity for different wavelengths.*

The intensities in Table 13 are expressed in an arbitrary unit, which is the value for $r = 1.42$. To find the absolute values the intensity curves for each separate wavelength and exposure time were laid upon the adopted general curve and brought into coincidence with it as well as possible (giving the greatest weight to the parts between $r = 1.1$ and 1.7). Then the intensity was read which corresponded to the unit 1.0 of the general curve. These intensities are found in column 2 of Table 14. They are reduced first to the true exposure time, by multiplying them by $(90/26)^p$ and $(90/3)^p$; these factors are 3.68 and 35.6 for the Opta plate, 2.54 and 12.8 for the panchromatic plate. Then for the Opta plate the reduction factors for wavelength from Table 3 are applied (column 3); the result of these reductions is the apparent intensity from each exposure in column 4 of Table 14. After multiplication by the coefficients from Tables 5 and 6 (found in columns 5 and 6 Table 14) and the constant 6.44 erg/sec, we obtain the real intensities per mm^2 on the plate, given in column 7. If now we wish to have the energy not per mm along the length of the spectrum, but per AU, we have to divide by the number of AU per mm; then we find the values of column 8. They represent the energy falling upon a circle of 6 cm diameter on earth, emitted in 1 AU by a strip of the corona, which, at a distance 1.42 times the solar radius, extends radially over a length corresponding to 1 mm on the plate and perpendicularly through the whole corona.

The relative values can give some information on the quality, the spectral constitution of the coronal light. For the sake of comparison in column 9 for the same wavelengths the energy emitted per AU by 1 cm^2 of the

TABLE 14.

Absolute intensity of the continuous corona spectrum at $r = 1.42$.

1	2	3	4	5	6	7	8	9
6030 3^s	0.43:		5.51	1390 10^{-6}	1.93	914 10^{-4}	7.1 10^{-4}	9.3 10^6
26^s	1.37		3.48			574	4.5	
5500 3^s	0.46:		5.90	600	2.09	478	5.5	10.4
26^s	2.13		5.40			436	5.0	
5210 3^s	0.73:		9.35	343	2.21	457	6.7	10.7
26^s	2.70		6.84			334	4.9	
4790 3^s	1.97	.22	15.4	121	2.52	303	7.2	11.5
26^s	13.9		11.2			221	5.3	
4400 3^s	1.20	.65	27.7	33.3	3.11	185	7.7	10.6
26^s	16.4		39.3			262	10.9	
4150 3^s	0.24	5.1	43.5	12.2	3.82	131	8.2	9.2
26^s	2.12		39.8			120	7.5	
4000 3^s	.040	31	44.1	5.97	4.61	78	6.4	7.7
26^s	.50		57.0			101	8.3	
3920 3^s	.0049:	96	16.7	3.80	5.68	23	2.2	6.9
26^s	.056		19.5			27	2.5	

1. Wavelength in the continuous spectrum; exposure time.
2. Intensity measured, after Tables 2 and 4.
3. Reduction factors for wavelength from Table 3
4. Apparent intensity for the true exposure time.
5 and 6. Reduction factors from Tables 5 and 6.
7. Intensity in erg/sec falling through the aperture upon 1 mm^2 of the plate.
8. The same, falling on 1 mm radially, 1 AU transversally of the plate.
9. Energy in erg/sec emitted within 1 AU by 1 cm^2 of the sun's surface.

: indicates weight $^1/_2$.

solar surface after the discussion of MINNAERT [1]) is added. These values for the sun show a small increase from the red to a maximum at λ 4800 and then a slow decrease. In our corona values the differences are much greater. For the larger wavelengths the results of the most reliable exposure are smaller than for the blue part of the spectrum; the value for λ 3920 falls far below the others, but here irregularities of the fog may have had some influence. A difference of spectral distribution, compared with the

[1]) Recent Data on Solar Radiation, B.A.N. II, 75 (N^0. 51), 1924.

sun, cannot be derived with any certainty from these results. Especially, because the relative values for the larger and the smaller wavelengths depend in a high degree on the different SCHWARZSCHILD exponents p adopted for these plates. If e.g. for the Opta plate the value of p .82, derived from the Cooke camera plates, should be used, the results for the smaller wavelengths would be lowered 1.33 and 2.2 times. The great influence of the value of p on these results, and the possibility that it may vary itself in some continuous way with the wavelength, makes it impossible to make more definite conclusions on the spectral composition of the coronal light.

The values of column 8 for the corona are on an average 6.5×10^{-11} times the values of column 9 for the sun. The radiation integrated over the spectrum between wavelengths 4000 and 6500 AU amounts to 25×10^{-9} erg/sec for the sun, while for the corona this integrated radiation between the same limits of wavelength, is 1.6 erg./sec. This value is expressed in the same units as all the values of column 8 Table 14, and must be transferred now into absolute units.

The radius of the sun is 6.96×10^{10} cm, and a millimeter on the plate corresponds to 1/1.24 solar radius, i.e. to 5.6×10^{10} cm. If we divide the values of column 8 Table 14 by 5.6×10^{10}, they represent the radiation (falling upon a circle of 3 cm radius on earth) of a slab of the corona of thickness of 1 cm, at a distance 1.42 solar radius from the centre. The integrated radiation of such a slab between 4000 and 6500 AU is $1.6/5.6 \times 10^{10} = 2.8 \times 10^{-11}$ erg./sec. These values must be multiplied by $.99 \times 10^{26}$ in order to have the total radiation to all sides ; hence the total radiation of that slab is 2.8×10^{15} erg./sec. In deriving the space intensities in Table 13, the values of the slab intensities of column 2 are divided by $r\ (r - 0.70)$, expressed in solar radii. Hence to have the space density per cm^3 we have to divide by $5.61 \times 10^{10} \times (6.96 \times 10^{10})^2 = 2.71 \times 10^{32}$. If then we multiply by $.99 \times 10^{26}$, we find the total radiation to all sides, emitted within 1 AU by 1 cm^3 of the corona, at a point where Table 13 column 4 gives the value 1, (viz. $r = 1.42$) ; i.e. by multiplying the values of Table 14 column 8 by 3.66×10^{-7}.

It is not necessary now to treat the different wavelengths separately, since a difference of composition with the solar radiation could not be established. The integrated light for all wavelengths between 4000 and 6500 for 1 cm^3 of the corona at distance 1.42 is now $1.6 \times 3.66 \times 10^{-7} = 5.9 \times 10^{-7}$ erg./sec. The radiation at the surface of the sun between the same limits of wavelength is 25×10^9 erg./sec., while the total radiation for all wavelengths, 62×10^9, is 2.5 times more. If we may assume that the coronal radiation has exactly the same composition as the light of the sun, then the total radiation for all wavelengths of 1 cm^3 of the corona at distance 1.42 solar radius is $2.5 \times 5.9 \times 10^{-7} = 14.7 \times 10^{-7}$ erg./sec.

If we assume the coronal light to be produced by the scattering of the sunlight by free electrons, we can compute the electron density from the fraction of the light which is scattered. After the classical theory the energy scattered by N electrons is

$$8\,\pi\, e^4\, IN/3\, m^2\, c^4 = 6.65 \times 10^{-25}\, IN$$

where I is the energy of the incident radiation. The incident radiation at different distances from the sun may be assumed to be simply proportional to $1/r^2$. In Table 15 column 2 the intensity of the scattered light, found by multiplying the figures of Table 13 column 4 by 14.7×10^{-7}, is given for different distances r; column 3 gives the intensity of the incident light, computed by $62 \times 10^9/r^2$; the resulting electron density is found in column 4.

TABLE 15.

Electron density in the corona.

1	2	3	4
1.0	163 10^{-7}	62 10^9	40 10^7
1.1	58.5	51	17
1.2	24.1	43	8.4
1.3	11.9	37	4.8
1.4	6.3	32	3.0
1.6	2.2	24	1.4
1.8	1.04	19	.82
2.0	.54	16	.52
2.2	.31	13	.36

1. Distance from the sun's centre in radii.
2. Emission of 1 cm^3 of the corona in erg/sec.
3. Intensity of solar radiation.
4. Electron density in 1 cm^3.

5. *The total light of the corona.*

It was not our intention to determine the total light of the corona. For the sake of comparison with other results, however, it may be useful to deduce this quantity from our data. The value of the unit, in which the relative values of Table 13 column 2 are expressed, is given for each separate wavelength in column 8 of Table 14; they give for the integrated light of all wavelengths between 4000 and 6500 AU 1.6 erg./sec. The total light, integrated along a line perpendicular to the dispersion, was found p. 33 to be 12.0 of these units. Hence the integrated light of the visible corona, not covered by the moon, falling upon a circle of 3.0 cm radius is $12.0 \times 1.6 = 19.2$ erg./sec.; the energy, emitted by this visible corona to all sides, is $.99 \times 10^{26} \times 19.2 = 19.0 \times 10^{26}$ erg./sec. (always between 4000 and 6500 AU). The amount of light between these wavelengths from the visible corona falling upon 1 cm^2 is $19.2/9\pi = .68$ erg./sec., and the total energy of all wavelengths 2.5 times more, or 1.70 erg./sec. Comparing it with the energy of the solar radiation, expressed in the same way 1.35×10^6 erg./sec., we find the energy emitted by the corona 1.36×10^{-6} times the energy emitted by the solar disc. Since for the full moon this ratio is 2.2×10^{-6}, our result means that the corona emitted a little more than half the light of the full moon.

Conclusions.

The chief source of uncertainty in deriving results from our eclipse plate, besides the great density of the images, was situated in the exposure time of the standardization spectra, which was much different from the exposure time of the eclipse images. By this reason the reduction elements for the eclipse plate had to be extrapolated from the standardization data, and variations in the SCHWARZSCHILD exponent influenced the results to their full amount. Still valuable results on absolute intensities could be obtained, because with the primitive state of our knowledge on this point the amount of uncertainty in our reduction elements did not matter very much. Thus the absolute intensity of prominence radiations, of the monochromatic and of the continuous corona emission could be determined, and estimates of the density of atoms in the prominences and of electrons in the corona could be made. The relative values, however, for which a higher degree of accuracy is wanted, are much more vitiated by errors in the reduction elements, especially by the difference in behaviour of the two kinds of plates. By this reason all deductions we tried to make e.g. on the temperature of the prominences and on the colour of the corona must remain extremely uncertain. It appears that to derive reliable results on intensities from eclipse photographs it is necessary to make the standard impressions with as nearly as possible the same exposure time as the eclipse plates.

CONTENTS.

I. THE OBSERVATIONS 3
1. The instrument 3
2. The observations. 4

II. DERIVATION OF INTENSITIES BY MEANS OF THE CALIBRATION PLATES 6
1. The standardizing spectra. 6
2. Derivation of the transmission curves 6
3. Derivation of intensities. General method 11
4. The relative value of the intensity unit. 11
5. The absolute intensity unit 14
6. The corrections to the intensity of the solar phenomena. . 15
7. The reduction for exposure time 16

III. THE PROMINENCES 18
1. The measurements 18
2. The hydrogen lines; temperature and density of the prominences 19
3. The helium lines. 23
4. The calcium lines 24

IV. THE CORONA 25
A. The monochromatic radiation 25
B. The continuous corona spectrum 26
1. The connection between surface-brightness and space intensity 26
2. The screening off by the coelostat mirror. 28
3. Determination of the apparent and the space distribution of intensity 30
4. The absolute intensity for different wavelengths . . . 33
5. The total light of the corona 36

CONCLUSIONS 37