

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

I. PHOTOMETRY OF THE FLASH SPECTRUM

BY

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(WITH 20 TEXTFIGURES)

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INTRODUCTION.

While the general aspect of eclipse phenomena has already often been described and while also wave-lengths of their radiations concerned have been carefully determined, with the photometric investigation of these phenomena hardly a beginning has been made. Yet the measurement of the true intensities of the radiations must be considered as the determination of a new independent coordinate, the great importance of which is made clear by modern atomic theory.

For the chromosphere in particular, the intensity measurements must give us quantitative information concerning the composition and the state of ionisation of the solar envelope. Two lines of research present themselves; we may investigate: a) the total chromospheric radiation for the different lines; b) the variation of the intensity of every line with the height in the chromosphere.

For a long time, the intensities of the flash lines were only estimated on an arbitrary scale. SCHWARZSCHILD¹⁾ was the first to use more exact methods; his paper of 1906 gives a number of new possibilities and suggestions and a profusion of new photometric data, which however can only be considered as rough approximations. With respect to the photometry of the flash spectrum, we find there the first comparison being made between the intensities of some of the strong lines.

The beautiful flash spectrum obtained by DAVIDSON and STRATTON²⁾ during the English expedition of 1926 to Sumatra, was photometered in collaboration with the Physical Laboratory at Utrecht, and many interesting photometric data were obtained on the ultraviolet spectrum of the high chromosphere and the prominences.

CAMPBELL endeavoured many years ago to separate the emission of the different chromospheric layers by photographing the spectrum on a moving plate³⁾, but his records were not discussed in terms of intensities before 1927⁴⁾. This same method was used by MERFIELD in 1926 and by KIENLE in 1927. It gives good resolution of the different layers, but as it reduces the intensities of the flash lines by drawing them out, it can be applied only to the most intense lines.

1) Mitt. Sternw. Göttingen, **13**, 1906.

2) Mem. R. A. S. **64**, IV, 105, 1927.

3) CAMPBELL, Trans. Int. Union f. Sol. Res. **3**, **74**, 1911.

4) E. F. CARPENTER, Lick Obs. Bull. **12**, Nr. 384, 1927.

Verhand. Kon. Akad. v. Wetensch. (1e Sectie) Dl. XIII.

Instead of the continuous records, however, it is also possible to make discontinuous exposures as for a cinematographic film. Such spectrograms have at the same time the advantage of showing even faint lines, and by comparison between the successive spectrograms, of indicating the relative contribution of the different layers to the radiation.

In the present paper we have chiefly endeavoured to determine systematically the total intensities of a great number of flash lines; for two of them we have also made an attempt to find the intensity as a function of the height. In view of the relative novelty of the subject and with a view to possible future applications, we have described with some details our experimental methods.

The instruments used for these investigations had previously been designed and the scheme of the observations drawn up in collaboration with Messrs. W. J. H. MOLL and J. VAN DER BILT for the Sumatra eclipse of 1926. When this expedition failed through the clouded weather, it was decided to utilise the total eclipse of June the 29th, 1927, to renew the attempt. The new expedition consisted of Messrs. A. PANNEKOEK and M. MINNAERT, assisted by Messrs. N. W. DOORN and W. BLEEKER. The observations were made about 10 Km. to the south of Gällivare (Lapland), latitude of 67° 3'5" N. and longitude of 1 h. 52 m. 58 sec. E. The duration of totality amounted to 41,6 sec.; the altitude of the sun was 28°. During the eclipse, the sky was perfectly clear. The preliminary report of the expedition has been communicated to the *Koninklijke Akademie van Wetenschappen te Amsterdam* ¹⁾.

¹⁾ Proceedings, 30, 921, 1927. — See also: A. PANNEKOEK, *Hemel en Dampkring*, Nov.Dec., 1927.

I. THE OBSERVATIONS.

1. *The instrument.*

We hope to publish later a more extensive description of the instrument used; in the meantime a brief description will serve for general orientation (cf. fig. 1).

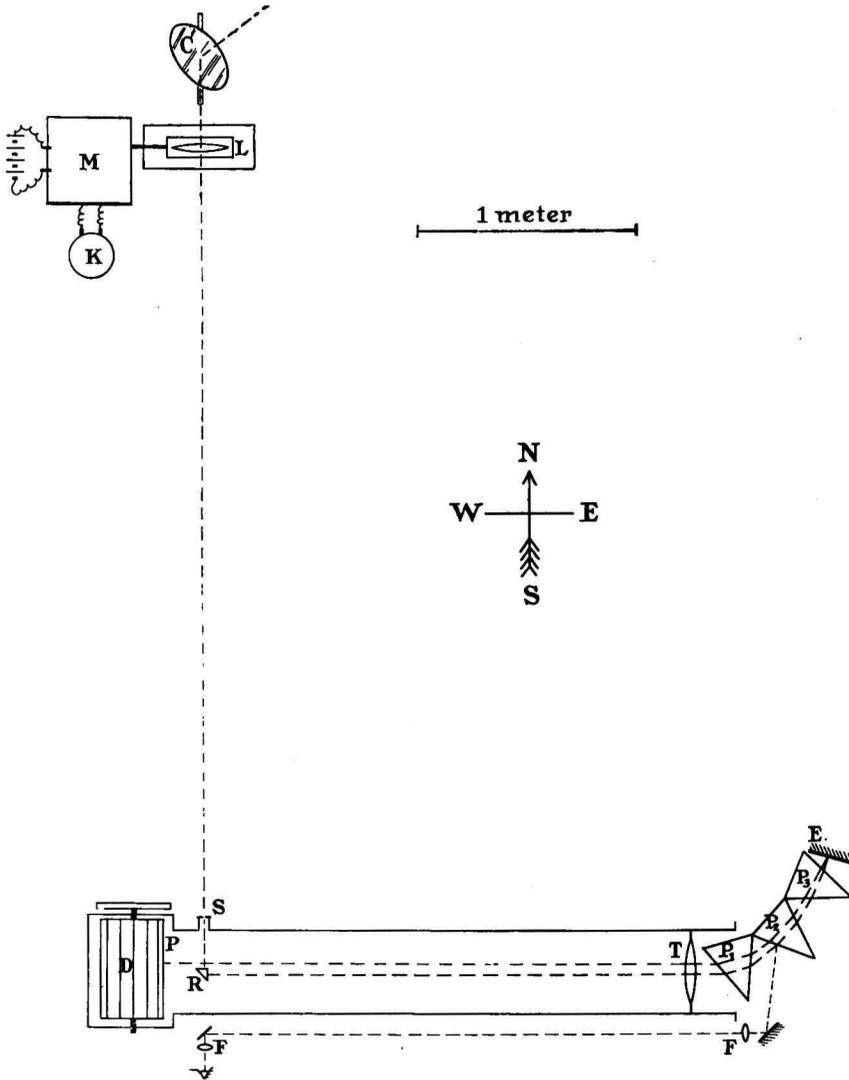


Fig. 1. Coelostat, moving lens and spectrograph.

A coelostat mirror *C* reflected the light of the sun in the meridian plane. It was a happy circumstance, that the latitude of the eclipse camp was nearly the exact complement of the declination of the sun ($67^{\circ} 3' 5''$ against $23^{\circ} 17'$), so that the reflected beam was inclined only at $0^{\circ} 20'$

to the horizon; a second mirror therefore could be dispensed of. The rays were collected by a photographic objective L , by Steinheil, of 26 cm. diameter and 345 cm. focal length; the solar image had a diameter of 3.15 cm., and was projected upon the slit plate S of a large 3 prism spectrograph with autocollimation. During the observation, the coelostat mirror was not moving, but the lens was shifted with the velocity sufficing to keep the sun's image exactly at the same place; this was done by an electromotor M , synchronised by a clock K . — This principle of the moving lens, devised by W. J. H. MOLL, is perfectly suited to eclipse work of short duration; the effect of the inevitable periodic errors of the worm screw, which would be strongly magnified by the rotation of the coelostat mirror, are now entirely negligible and the solar image is quite motionless.

In the spectrograph the rays are totally reflected by a small rectangular prism R , situated a little below the axis of the instrument. They pass through the objective T (Taylor triplet, diam. 15 cm., $f = 2.60$ m.), three large prisms of crown glass $P_1 P_2 P_3$ (refracting angle 45° , basis 15 cm., refracting surfaces 20 cm. \times 16 cm.), and are reflected back by a plane mirror E ; then they pass again through the prisms, and give a spectrum on the plate P . The images of the slit, seen by reflection in the objective, are a source of some false light; though they could not all be eliminated, by far the strongest of them was intercepted by a strip of black paper at the lower side of the objective.

For catching the flash spectrum at the right time, 12 long plates of 29×4.3 cm. were fixed on the sides of a twelve sided drum D , made from aluminium. This drum could be turned discontinuously automatically; each plate was exposed for 1—2 seconds, and about 0.5 second was needed for each displacement. The first six plates were devoted to the first flash.

By means of a finder FF , the observer could follow visually the whole aspect of the flash phenomena; this was attained, by making use of the rays reflected by the front side of the second prism. The observer was thus enabled to control the exact position of the slit till half a minute before the flash; from the height of the continuous spectrum observed in the finder, he could estimate the segment of the sun intercepted by the slit, and if necessary slightly correct the position of the slit by a micrometer screw, till it was approximately tangential. The slit was set perpendicular to the relative motion of the moon, hence it was inclined 7° to the vertical, and in the same way the prism train and the drum were inclined 7° to the horizon. The slit was adjusted to a fixed width of 0.130 mm. A perfectly sharp image of a chromospheric layer, 1000 Km. thick, would have a width merely of 0.022 mm.; so it was assumed that the images of the chromosphere would fall within the slit for all radiations, with the exception perhaps of $H\gamma$.

Much trouble was experienced with the exact focussing of the astronomical objective, because this had to be done with sunlight; under the

influence of the radiation the coelostat mirror became curved, with a corresponding alteration of the focal distance of the system mirror + lens. During the preliminary experiments, the mirror was therefore only exposed during a very short time at every turn. For determining the exact focussing, the observer used a colour screen of cuprammoniumsulphate.

2. *The plates.*

From the several sorts of plates of different makers, tried in the laboratory, the LUMIÈRE'S "Opta" was selected as being the most sensitive in the spectral region wanted, and nevertheless not coarse grained; the plates were backed and thus were protected against halation.

During the totality, the sky was perfectly clear and cloudless. We estimated that the six plates were taken at the following times about 2nd contact:

1.	— 4.5 sec.	to	— 2.5 sec.
2.	+ 1	to	+ 2.5
3.	3	to	4
4.	4.5	to	5.5
5.	6	to	7
6.	7	to	9

While the moments given for plate 1 are probably exact to 0.5 sec., there is more uncertainty for the other plates; their aspect suggests that the true times must have been somewhat later.

The interruption between 1 and 2 is due to the slipping of the cord of the motor.

After the eclipse, we kept the plates in the dark room till the calibration plates for the photometric comparison were ready. As explained below, for every flash plate a complete set of three calibration plates was made and then each flash plate developed at the same time as these calibration ones.

The formula of the developer used was:

water	1000
metol	2
hydrochinon	5
sodium sulfite (anhydrous)	10
borax	20

(When necessary, the borax may be first dissolved in hot water).

Even by working early in the morning and cooling the developing tank by water from a stream near the camp, it could not be avoided that the temperature reached 18° C. at the beginning of the development and soon exceeded 21°. The plates were developed for 10 minutes, then fixed in ordinary hypo solution, to avoid EBERHARD effects ¹⁾, and hardened with formaline (concentration $\frac{1}{30}$).

¹⁾ See G. EBERHARD, Publ. Astroph. Obs. Potsdam, 26, Heft 1, 1926, p. 50.

The developer used proved in all respects excellent. Notwithstanding the high temperature, clear plates were obtained with a moderate gradation, which allowed measurements over a large range of intensities, and were very suitable for microphotometer examination.

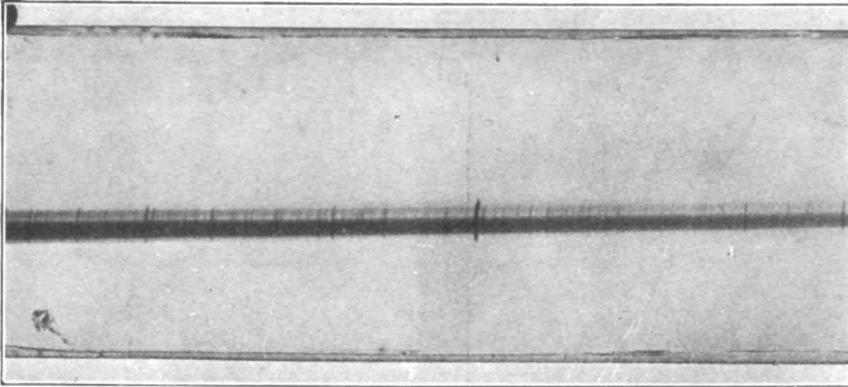


Fig. 2. Part of the flash spectrum on the first plate.

The first plate is by far the most important; we give here the reproduction already published in our preliminary report (fig. 2). It shows the spectrum of the chromosphere, superposed on a background of continuous light, and extending over a length of 20 cm., corresponding to an interval of wave lengths from 4153 to 4751 Å . Several hundreds of emission lines are shown, of which the most conspicuous is the hydrogen line H_{γ} , not far from the centre of the plate.

The continuous background, due to the last thin crescent of the photosphere, is the most intense near midheight, and vanishes at the borders of the spectrum. The distribution of its intensity across the spectrum may be seen from figure 3 made by methods described below (see p. 10 etc.). Near *a* a protruding mountain of the moon has reduced the continuous spectrum, so that the flash lines there appear nearly pure and can be investigated in the best way. Near *b* there is a slight local increase of the intensity; at this height we have made a second series of measures. Only a few of our measurements were made in the region *c* of maximal intensity.

The density of the background decreases almost regularly from the red towards the violet side. The central parts show the strongest contrasts, and are best suited for intensity measurements.

The flash lines are sharp on one side of the spectrum near the minimum of the continuous background *a*. On the other side, near the border of the spectrum, they grow somewhat broader, hazier, and at last nearly double. A good explanation for this is difficult to give, for the iron lines, photographed some days afterwards with exactly the same arrangement

of the spectrograph, are equally sharp over their whole length of more than 20 mm.

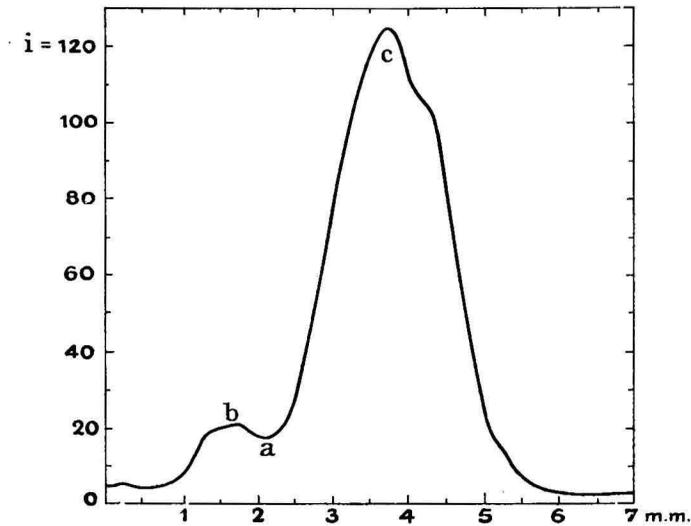


Fig. 3. The distribution of the intensity of the continuous background across the spectrum.

The flash lines have a curvature which corresponds to the radius of the sun, and which is much stronger than that of a monochromatic image of the slit. This suggests strongly that an arc of the chromosphere was included into the slit, and that the flash lines are really flash arcs, comparable with those obtained by a prismatic camera. By using a slit, however, we have had the advantage that much false light of all kinds has been avoided. We will discuss in chapter IV the question of whether all the lines correspond really with the integrated radiation of the whole chromosphere. — Near *a* the regularly curved shape of the lines is slightly disturbed, apparently by the protruding mountain of the moon.

The second flash plate shows only H_{γ} and $He\ 4472$, the two lines in this spectral region which reach the highest altitudes in the chromosphere. In the interval during the 1st and the 2nd plate, the moon appears to have covered already all the deepest layers.

The 3^d, 4th, 5th, 6th flash plate show these same two lines with decreasing intensities.

Owing to the importance of plate 1, our intensity measurements were made chiefly for that plate. Chapter II and also chapter III are concerned entirely with this one plate.

II. THE TRANSMISSION CURVES.

1. *General method used for the measurement of intensities.*

The intensities in the flash spectrum are studied by means of the registering microphotometer devised by MOLL¹⁾. The beam of an incandescent lamp is thrown upon the plate, and the fraction transmitted is measured by a thermopile and a galvanometer. This fraction, called the *transmission*, is the greater the smaller the density, that is: it decreases with increasing intensity of the light that has produced the image. Of course the quantitative relation between this intensity and the transmission of the developed plate must be expressed by a "*transmission curve*", and can be established only by careful calibration.

For the determination of the transmission curves, we use the methods developed at the Physical Laboratory of Utrecht by L. S. ORNSTEIN, H. C. BURGER, P. H. VAN CITTERT and others²⁾. The considerable advantage of these methods consists in the fact, that the curves are determined solely by experiment and without any theoretical assumptions, and that the series is determined anew for every plate investigated. Moreover, another important condition is fulfilled viz. that the transmission curve must automatically take account of all characteristic peculiarities of the plate, the exposure time, the development, the spectral apparatus etc., so that the intensities read on that curve are entirely independent of all such variable factors, and express the real distribution of the intensity in the spectrum which has been photographed.

We will first give a brief description in its main lines of that method, applied to our flash spectrogram; details will be given later in the paper.

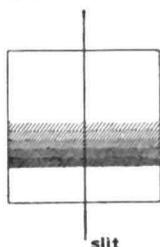


Fig. 4. The step-weaker.

Our eclipse spectrogram is compared with three calibration plates *A*, *B*, *C*, cut from the same part of a larger photographic plate, exposed in the same spectrograph, and developed at the same time as the eclipse plate and in the same bath. The following calibration plates were obtained: *A*. the line-spectrum of an electric arc between iron rods; *B*. the continuous spectrum of an incandescent lamp ("*Standard lamp*"); *C*. the Fraunhofer spectrum of the sun.

In photographing these spectra, one of our "*step-weakeners*" was placed before the slit of the spectrograph; this weakener consists of 6 different strips of increasing opacity, the transmission of which being constant may be determined once for all. If care has been taken that

¹⁾ W. J. H. MOLL, Proc. Phys. Soc. Lond. **33**, 207, 1921.

²⁾ L. S. ORNSTEIN, Proc. Phys. Soc. Lond. **37**, 334, 1925. — Physik. Zs. **28**, 688, 1927.

the illumination of the slit is quite homogeneous, every spectrum is obtained at the same time in 6 different degrees of intensity.

The plate with the flash spectrum and those with the calibration spectra are passed in the same manner through the registering microphotometer.

The transmission curve is deduced now, first for a small region of wave-lengths. The calibration spectrum *A* is especially suitable, because the flash lines may be compared more safely with other line-spectra than with continuous spectra. Every line of the iron spectrum gives six points for the transmission curve, and by graphical interpolation it is possible to combine all these curves into a single one. Generally the transmission curve itself will vary with wave length¹⁾. In many cases however, if the intensities of the different colours are properly adjusted, the transmission curves are practically identical within a limited region of wave-lengths; this appears to be the case for our plates. The light producing a silver deposit of given transmission may then be said to have a definite *apparent intensity*, independently of the wave-length.

These apparent intensities *i* are not the *real energetic intensities*, because the same number of ergs, entering through the slit of the spectrograph, have an effect on the photographic plate differing according to their wave-length, in consequence of the differences in dispersion, the colour sensitivity of the plate, the selective absorption in the apparatus etc. To find the real intensities we must multiply the apparent intensities by a *colour coefficient*, which will be a function of wave-length.

For this the spectrum *B* can give the data necessary. The temperature of the incandescent lamp is determined by a pyrometer and since it is known that such a lamp radiates as a gray body, Planck's formula gives the distribution of the energy over the various wave-lengths. By comparing this with the observed transmission of the continuous spectrogram, the reduction factors are found for transforming apparent intensities *i* into "*real intensities*" *I*.

The spectrum *C* of the sun may be used for the same purpose as spectrum *B*, because the distribution of the energy in the solar spectrum may be considered as known. In this way an independent control is obtained.

Finally, the intensities *I* may be reduced to *absolute intensities*, by standardizing the incandescent lamp, and by using the absolute values of the solar constant (in erg/cm² sec.). In this respect, the plates *B* and *C* once more provide an independent control.

It is easy to foresee, as will be confirmed later on, that the determination of the apparent intensities is the most accurate, that the determination of the real intensities is more difficult, and that the determination of the absolute intensities may be liable to many sources of errors.

¹⁾ Cf. FR. ROSS, The Physics of the Developed Photographic Image. p. 72 sqq.

2. *The calibration of the weakener.*

The weakener, made by C. ZEISS, Jena, consists of a thin glass plate of 0.5 mm., across the middle region of which platinum has been deposited in five transparent strips, each 1.8 mm. wide, but the ends of the glass being left free (fig. 4). The weakener is protected by a coverglass. At the ends, the light passes unobstructed through the thin glass plate, and the intensity is only reduced a little through the reflections; this intensity of the light passing here will be the maximum possible, we may make it the standard with which the transmissions of the five strips are compared and denote it by 100.

Such weakeners, made by metallisation, have the advantage that they do not scatter the light as fogged photographic plates do; moreover, their transmission is nearly independent of wave-length, even in the near ultraviolet region. Sometimes however they give most troublesome interference fringes in continuous spectra, probably due to double reflection against the metallic layer and the surface of the glass. This may be avoided: 1. by using a wide slit; 2. by mounting the weakener between two glass plates, two or three mm. thick, and bringing them into optical contact with a drop of cedar oil.

The determination of the transmission of the several strips is of fundamental importance for our inquiry. This determination was made for 8 different regions of the visual spectrum, because it was possible that the transmission depended on the colour.

Monochromatic rays of light were obtained by means of the monochromator previously designed for the Gorngrat measurements of solar radiation¹⁾. The weakener was placed directly behind the slit of that instrument. The pencil of rays, diverging somewhat, passed through the weakener strip under examination; the angular aperture of the beam was about $\frac{1}{15}$; as this was approximately equal to the eclipse-spectrograph with which the weakener had to be used the values obtained for the transmission could therefore be adopted without further correction for our spectrophotometric work. The pencil of light was now focussed by means of a lens on a thermo-element, and the thermoelectric current measured by a recording galvanometer.

We wished to keep the region of wave-lengths, of which the beam was composed, within as narrow limits as possible; moreover, colour-screens for avoiding false light of other colours reduced still more the intensity. It was therefore necessary to amplify the deflections of our galvanometer by a thermorelay²⁾, and to record the deflections on photographic paper. We measured in quick succession the transmission of the strip under examination and the transmission of the glass next to the strips. The light was transmitted or intercepted for a period of 20 sec. each time, in order to make sure that the galvanometer had attained its

¹⁾ W. J. H. MOLL, H. C. BURGER, J. VAN DER BILT, B. A. N. 3, 83, 1925.

²⁾ W. J. H. MOLL and H. C. BURGER, Phil. Mag. 50, 624, 1925; Zs. f. Phys. 34, 109, 1925.

position of equilibrium, and to make it possible to take the mean over small fluctuations. The weakener could be displaced by means of a micrometer screw, so that the different strips could successively be brought before the slit of the monochromator.

Finally the percentage transmission was found as indicated in the following Table I; the wave-lengths written above every column represent the "centre of gravity" of the region used, which however extended over about $20 \mu\mu$ in each case.

TABLE I.
Transmission of the reducer used for spectrophotometric work.

Wave-length :	660 $\mu\mu$	637	585	525	485	460	450	425
Glass next to strips	100	100	100	100	100	100	100	100
1 st strip	47.3	47.5	47.5	49.4	49.5	49.8	50.2	50.5
2 ^d ..	20.3	20.9	21.2	22.8	23.5	23.3	23.7	24.2
3 ^d ..	9.7	10.4	10.6	11.4	11.1	11.7	11.5	11.5
4 th ..	4.6	4.7	5.0	4.8	4.9	5.0	5.2	5.1
5 th ..	2.4	2.4	2.5	2.4	2.4	2.2	2.4	(2.5?)

The comparison between the individual results, made before the mean was taken, and the internal harmony in the table, give us the confidence that the remaining errors in the *percentage* transmission are less than 0.5 for the first lines, and diminish till 0.2 for the last lines. A systematic decrease of the transmission with the wave-length is undeniable, but it is small, especially in the region 415—476 $\mu\mu$ where we had to work. Some smoothing has been applied to the decimals before using Table I for further work.

3. The calibration plates.

At our request, the makers had cut the plates in groups of four at the same time from one single larger plate, and had packed them together in separate packets. Every flash plate could therefore be compared with a set of calibration plates of as near as possible similar properties in all respects. They were developed, fixed, washed in the same baths as the flash plate and at the same time. These calibration plates were exposed as follows.

A. Iron arc, continuous current, 199 V, distance of the electrodes: 5 mm.; exposure: 20 sec.; slit 0.130 mm., that is almost as for the flash spectrum. If we wish to illuminate all the points of the slit with the same intensity, it is not permissible to throw an image of the arc on the slit. The following device however proved very satisfactory.

The weakener was fixed on the slit plate, and close before it was put a spectacle lens serving as a collector lens and so chosen (here of 7 cm. focal length) that a strongly enlarged image of the arc could be formed on the dispersive system of our spectrograph; by putting the eye on the place of the plate, it was easy to observe whether the image of the arc was free from parallax compared with the prisms. A double condition was thus fulfilled: 1. every point of the slit received light from the whole arc, that is, the slit was uniformly illuminated; 1. every point of the spectral line received light from the same aperture, the diaphragms in the spectrograph acting always in the same manner. The reason for giving the image of the arc a strong magnification, was to endeavour to fill the whole objective with light so that all of it should contribute to the formation of the spectrum, as it was the case for the flash photograph.

B. A Philips nitralamp of 6 volt, run at 6,19 Amp. ("Standardlamp"); exposure 40 sec.; slit 0,440 mm. wide. This lamp was placed so that its perfectly straight filament was in a plane parallel to the slit plate and at right angles to the slit. An image of it was then thrown on the prisms, just as for the iron arc; but in this case a spectacle lens was used of 20 cm. focal distance, so that the length of the image of the spiral was nearly equal to the diameter of the spectrograph objective. The weakener was placed before the slit.

C. The Fraunhofer spectrum. Exposure: 0,02 sec. For this purpose an image of the sun was thrown on the slit, by means of the coelostat, the sun being about at the same altitude as during to eclipse. The central part of the sun's disc was used. To avoid getting negatives of too great density it was necessary to make the exposure as short as possible. Since instruments for exact timing of such short exposures were lacking, we resorted to the following rather rough method: a diaphragm, with an opening of 1 cm. wide, was moved rapidly before the slit according to the beating of a metronome.

First two plates were made to ascertain in how far the slit as employed in the eclipse had been parallel, one of the plates without a weakener, the other with it. These two plates were developed with a developer giving stronger contrasts than was the case for the other plates. They will be called: "*slitcontrol plates*". After that, the slit was adjusted to the width of 0,112 m.m., and a new exposure was made, called C, developed in the ordinary way together with the other corresponding calibration plates A, B and the flash plate.

Already a superficial examination of the calibration plates shows, that two of them are fogged by false-light; the solar spectrum C to a strong degree, the continuous spectrum B to a much less extent, and the slit plates only slightly. The iron spectrum A, which in several respects was the most important, seems to be free from any fog.

The fog on B and C is irregularly distributed over the plate. This

appears to be a result of the sliding shutter not passing perfectly closely through the slit in the drum; it would depend on fortuitous circumstances, (the hour of the day, shadows, etc.), whether sunlight could penetrate through the rims. The flash-plate of course is clear of fog.

4. *The main transmission curve.*

From the description of the calibration plates, it is clear that the ironspectrum *A* must be the basis for determining our transmission curves.

Six groups of iron lines in the neighbourhood of the wave lengths 4730, 4603, 4529, 4430, 4308, 4240 ÅU were chosen for that purpose. Every group was composed of four or five lines of very different intensities. These lines were recorded by the microphotometer, under exactly the same conditions as the flash spectrogram (p. 35); records were obtained for each of the five strips of which the spectrum is composed, and for the two marginal strips corresponding with the maximum transmission. On every registrogram (compare fig. 5) the zero position *AA* of the galvanometer is added, by intercepting the light by a shutter before the thermopile; as well as the maximum deflection *B*, which corresponds to the dead plate alongside the spectrum. The transmission for the centre of the line *C* is given at

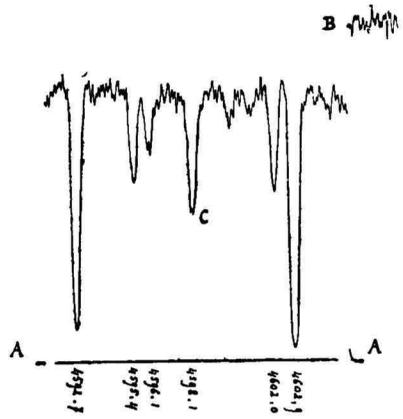


Fig. 5. Microphotometer record of iron lines.

once by the proportion $\frac{AC}{BA}$.

Our problem is to find the relation between the intensities of the different spectral lines, and the transmission of the photographic plate in

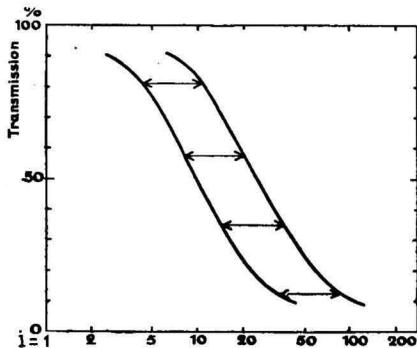


Fig. 6. Parallelism of transmission curves.

the centre of the images on the spectrogram. — Let us consider one of the lines, this of course appearing in the successive strips in six different, known intensities. From our registrogams we derive the 6 values of the transmission in the centre of the line, and plot them against the logarithm of the intensity; this is easily done on logarithmic paper (fig. 6). Similar graphs are made for the other spectrallines in the same spectral region. We thus obtain a set of curves, which must be a priori identical in shape, but displaced over different amounts (the log. of their relative intensity) in the direction of *log i*; we may call them "parallel".

Near the violet end of our iron spectrum, the two marginal strips of our spectrum have not *quite* the same transmission. This slight difference is probably due to false-light from reflections in the spectrograph, and was eliminated by drawing an approximate transmission curve, reading from it the intensities of the two marginal strips, and assuming that the false-light decreased uniformly from one side to the other. It is as if the relative intensities of the different strips had become in this case somewhat different from what they are in the other parts of the spectrum.

In comparing not only the lines of one group with each other, but the whole set of 26 curves for all the different regions of the plate, it appears that their parallelism (in the sense defined) is satisfactory. In this whole region the wave-length seems to have no influence on the shape of the lines. That the transmission curve is independent of the wave-length is a happy circumstance, which is not always fulfilled and seems to depend on the plates, the development, etc.; the further treatment of the curves is made thereby much more easy.

On the other hand, an influence of the intensity of the line is undeniable: for the faint lines the transmission curves are less steep than for the most intense ones.

To collect all the curves into one single transmission curve, one of them is provisionally chosen as a reference curve, and all the others displaced in a horizontal direction, till they agree as well as possible with the reference curve over their whole length. Then, for every value of the transmission we determine the mean of the abscissae of all the curves. As the number of curves is considerable, these different operations are executed not by graphical but by numerical calculation.

Instead of measuring the intensity as a function of the transmission $\frac{u}{u_0}$ of the lines, we could have chosen for example the *density* of the plate $\left(\log \frac{u_0}{u} \right)$, or indeed, every arbitrary function of the transmission; the results found for the intensities must remain the same, for properly speaking the method followed serves only for interpolation between the six strips.

Since from the calibration plates obtained in Lapland only plate A was satisfactory, it seemed desirable to verify our transmission curve by other methods. After our return from Sweden, therefore, the spectrograph was again put in working order in the Heliophysical Institute of the Physical Laboratory at Utrecht, and new calibration plates were made, under circumstances which were an exact reproduction of those in the eclipse camp: the same batch of plates was used, the same exposure time, developer, time of development, temperature of the bath etc. Plates were made with an iron spectrum and with a continuous spectrum with the same current as in Lapland. As it will appear from the following discussion, these new calibration plates are well comparable with the Laponian plates, and they can be treated collectively as quite homogeneous material.

The iron spectrum obtained at Utrecht is recorded by the micro-photometer just as the Laponian spectrum, and the transmission curve is determined from 5 lines of different intensities. The continuous spectrum is measured at about the wave-lengths 4718, 4609, 4522, 4405 AU, and the transmission curves are collected into a single mean curve as explained for the iron spectrum A.

We have now three independent transmission curves which must be compared and discussed:

1. the curve of the iron lines, photographed in Lapland;
2. " " " " " " " " at Utrecht;
3. " " " " continuous spectrum, photographed at Utrecht.

Fig. 7 shows that the curves 1 and 3 are nearly identical, whilst the curve 2 is somewhat steeper.

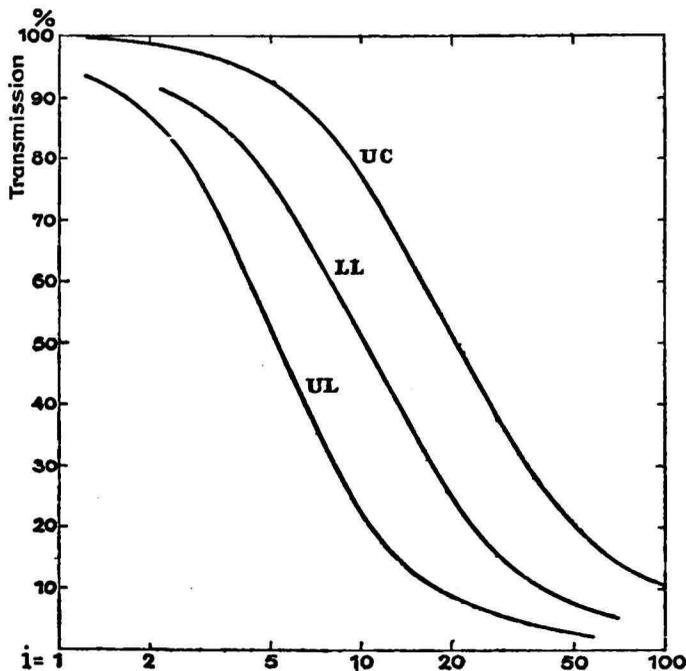


Fig. 7. Transmission curves obtained: UL. from iron lines at Utrecht; LL. from iron lines in Lapland; U.C. from continuous spectrum at Utrecht.

For a critical appreciation of the method, it is useful to realise the causes which may modify the shape of the transmission curves.

a. A slight general fog, produced by false-light falling on the plate, makes the curves appear less steep: though we assume that the different strips of the spectrum have been illuminated by intensities 100, 50, 25, ..., the *real* intensities have been $100 + k$, $50 + k$, $25 + k$, ...

All the spectrograms made with our eclipse spectrograph have been exposed to a slight amount of false light, arising from reflection of the slit in the objective (p. 6) and from the light diffused by the total reflection

prism near the plate; this amount will be relatively smaller for a line spectrum than for a continuous spectrum. Moreover it is possible that the iron spectrum obtained in Lapland has received extra false-light through the shutter, just as the other calibration plates. It is so little however that it can only be detected by a very slight change in the inclination of the transmission curves; for the eclipse spectrum this must have been still less, and for the plate made at Utrecht the presence of extra false-light is entirely precluded.

b. Photographic contrast effects, arising during the development, have been described by EBERHARD ¹⁾. By their influence the transmission curves of line spectra become steeper than those of continuous spectra; for they make the strong images of spectral lines on a clear background still stronger than they ought to be. EBERHARD says that these effects can be avoided by using EDER's iron oxalate developer. An iron spectrum and a continuous spectrum were photographed just as the preceding ones, but developed with normal iron oxalate, and recorded with the microphotometer. The transmission curves show indeed a better agreement than the plates (2) and (3) which had been developed with metol-hydrochinonborax. But the improvement is small and would not justify the use of iron-oxalate in future eclipse expeditions.

c. The microphotometric records are liable to a source of error, described for the first time by SCHWARZSCHILD and VILLIGER ²⁾. A continuous spectrum and a line, which are recorded as equally black by the microphotometer, may appear different for another distance of the microphotometer lamp or when the geometrical conditions are different. From control measures made with our microphotometer with different slit widths and distances of the lamp, it appears that the transmission in the centre of the line is hardly affected at all by this cause. ³⁾

Concluding, we find that the difference between the two iron spectra is probably explained by a slight amount of false-light on the spectrum made in Lapland, and that the difference between the iron spectrum and the continuous spectrum made at Utrecht are explained by effects of developing.

We are now in a position to make a choice between the three transmission curves. To avoid all possible influences of development and microphotometer, we use only the line-spectra; and as the flash-plate may be intermediate with respect to the false light between the spectrum of Lapland and that of Utrecht, we will take the mean of these two as the definitive curve.

A special investigation is made of that part of the curve corresponding to the large intensities. In this case the graphical treatment

¹⁾ Publ. Astroph. Obs. Potsdam, 26, Heft 1, 45, 1926.

²⁾ Ap. J. 23, 284, 1906.

³⁾ The effect on the slope of the spectral lines seems to be larger. Cf. L. S. ORNSTEIN and M. MINNAERT. Zs. f. Phys. 43, 404, 1927.

may be made much more accurate, by plotting *log transmission* instead of the transmission itself; this is done by using double logarithmic paper. It appears, that even transmissions as small as 0.5% may be incorporated

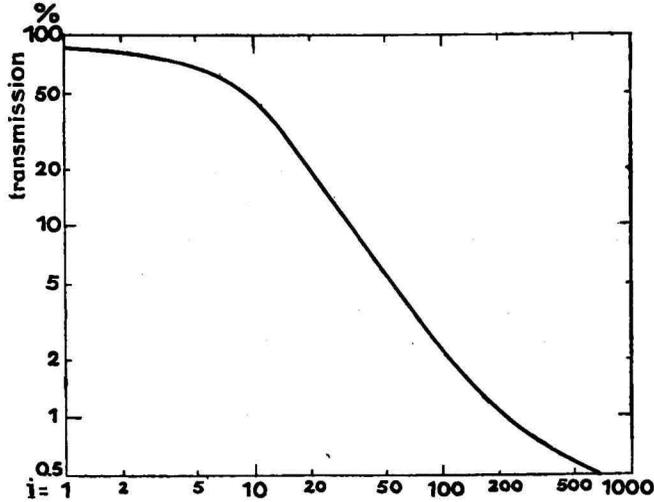


Fig. 8. Log. transmission for large intensities.

in the general transmission curve and may be considered as quite reliable. The iron spectra of Lapland and of Utrecht are both used, and again

TABLE II.
Main Transmission Curve.

Transmission	Intensity	Transmission	Intensity	Transmission	Intensity
1.00	0.	0.70	6.05	0.20	20.1
99	0.47	65	6.89	15	24.7
98	0.81	60	7.78	10	32.8
97	1.10	55	8.72	08	38.5
96	1.37	50	9.71	06	47.2
95	1.62	45	10.8	04	63.7
90	2.74	40	12.0	03	79.8
85	3.69	35	13.5	02	109
80	4.49	30	15.2	015	139
75	5.26	25	17.2	01	211

the mean of their curves is taken; the connection with the main curve for medium intensities is quite smooth.

Another special investigation is made of that part of the curve involving very small intensities (large transmission). Here it is found useful to plot the transmission against the intensity itself. The curve is found to run smoothly, and its prolongation passes through the origin as it is generally found when no potassium bromide is used in the developer.

The final transmission curve so obtained is drawn in fig. 8 and tabulated in table II (the last decimal given has only an interpolatory value). It will be referred to as: "*the main transmission curve*". We see that from our plate intensities may be read with sufficient exactitude within a range of values from 100 to 1. This is due to our using a developer not giving strong contrasts; it would seem that for eclipse photometry the use of such developers is especially advisable, because in the present stage of heliophysics it is more important to compare intensities in a wide range, than to increase the precision of the individual measures.

5. *The derivation of real intensities.*

The transmission curve, derived in the preceding chapter, may only be used to compare the intensities of lines in the same small region of the spectrum, not exceeding say 10 Å U. In general the apparent intensities i must first be reduced to *real intensities* I by multiplying them by a *colour coefficient* $c(\lambda)$, depending only on wave-length (p. 11). We will write

$$I = c(\lambda) \cdot i,$$

where i is given by the main transmission curve, and where I is the energy of the radiation falling on one millimeter of the plate (not one Ångström).

There are several causes acting together by which rays from the source of different wave-lengths may have an unequal effect upon the spectrogram. In our case these causes are:

1. the extinction of the light by the atmosphere of the earth;
2. the loss of light by the reflection on the coelostat mirror;
3. the absorption and reflection by the astronomical objective;
4. the loss of light in the spectrograph: diffraction by the slit, absorption and reflection by the weakener, the lens, the prisms, the mirror;
5. the dispersion of the prisms, which is a function of the wave-length;
6. the sensitivity of the photographic plate for the different colours.

The three first causes determine together the "*transmission before the spectrograph*". Some of these factors are easily calculated *a priori* with more or less accuracy, viz. the transmission before the spectrograph and the dispersion. The others must be determined by photographing the spectrum of a source of light in which the distribution of the energy is known. Such sources are: *a.* an incandescent lamp of known temperature, or *standardlamp*; *b.* the sun. Neither the iron spectrum nor other

line spectra are suited to our purpose, because the relative intensity of the lines varies with the strength of the current and other circumstances. But we may safely admit that the causes enumerated have the same influence on the intensities of spectral lines as on continuous spectra.

Two methods may therefore be utilised for determining the colour coefficients.

a. The transmission *before* the spectrograph is *calculated* and the other factors are *determined* by investigating the spectrum of the standard-lamp; from the combination of both, we derive the total transmission and the colour coefficients. This method has the disadvantage, that all uncertainty about the transmission of the atmosphere, which itself is variable, is transferred directly to the result.

b. The colour coefficient is determined directly from a photograph of the solar spectrum. This method has the disadvantage, that the distribution of the energy in the solar spectrum outside the atmosphere is not accurately known, not only because of the uncertain extinction by the atmosphere, but also owing to the lack of resolving power of the spectrophotometer; hardly anywhere in the blue and violet part of the spectrum is the continuous background, as measured, free from Fraunhofer lines. In our case, moreover, the solar spectrum plates are less suitable for exact measurement, because they are too black, and either fogged or made with a slit of unequal width. (p. 14, 16).

We will chiefly follow method a. Method b will be used only for obtaining a general control of the results.

a. *The determination of the colour coefficients from the standard lamp. —*

1^o. The transmission by the atmosphere of the earth.

During the eclipse, the sun had a zenith distance of $62^{\circ} 13'$. The calibration plate C and the slitcontrol plates were made at a moment when the sun had nearly the same zenith distance i.e. $z = 63^{\circ} 9'$. The fraction of the light transmitted by the atmosphere is given by $a^{\sec z}$. The transmission coefficients a have been measured by ABBOT for different wave-lengths and on a number of days; using the mean of the numbers given by him for Washington¹⁾, we obtain the transmission as given in table III column 2.

2^o. The reflection on the coelostat mirror.

Our mirror was silvered afresh some days before the eclipse; the reflecting power can therefore be considered as maximal. We adopt data from the measures of HAGEN and RUBENS for silver deposited by chemical methods²⁾, and those of ABBOT relating to the successive reflection on two mirrors³⁾, so that we must take the square root of his numbers. The data of these two observers are plotted, and appear to differ by

1) Ann. astroph. obs. Smiths. Inst. III, 135, 1913.

2) Ann. d. Phys. 8, 13, 1902.

3) Ann. astroph. obs. Smiths. Inst. II, 52, 1908.

no more than $2^0/0$; their mean value is given in table III, column 3.

3^o. The transmission of the astronomical objective.

The objective was composed of a crown and a flint lens, separated by a very small space. When x_0 is the thickness of a lens in its centre. k its absorption coefficient for a certain wave-length, the light transmitted is e^{-kx_0} . A more accurate value is obtained by representing the thickness of the lens as a function of the radius r by $x = x_0 + ar^2$; the light transmitted is then found as

$$\frac{1}{\pi R^2} \int_0^R e^{-k(x_0 + ar^2)} 2\pi r dr = \left(1 - \frac{akR^2}{2}\right) e^{-kx_0}.$$

In our case, $R = 8.5$ cm. for the part of the lens effectively contributing to the spectrum. As the exact sort of glass is not known, we assume values for "ordinary crown" and "ordinary flint" from tables ¹⁾.

For the crown lens we find $x_0 = 2.3$, $a = -0.007$, $\frac{aR^2}{2} = -0.252$, and the transmitted fractions:

$\lambda = 4190$	4350	4550	4770
0.905	0.936	0.964	0.967

For the flint lens: $x_0 = 1.7$, $a = +0.0045$, $\frac{aR^2}{2} = +0.16$, and the transmitted fraction:

$\lambda = 4150$	4250	5000
0.903	0.908	1.000

From FRESNEL'S formula $\left(\frac{n-1}{n+1}\right)^2$, the reflection on the four surfaces is estimated to be 0.15 of the incident light, this depending only slightly on the colour. The total transmission of the astronomical objective can now be plotted as a function of the wave-length; the results are given in table III column 4.

TABLE III.
Transmission of the light before the spectroscope.

λ	Atmosphere	Coelostat mirror.	Astron. objective	Total transmission
4700	0.407	0.906	0.81	0.297
4645	0.398	0.904	0.80	0.287
4477	0.366	0.893	0.77	0.252
4403	0.350	0.885	0.76	0.234
4319	0.330	0.874	0.73	0.211
4215	0.305	0.859	0.71	0.186
4163	0.292	0.851	0.69	0.172

¹⁾ Recueil de Constantes Physiques, Paris 1913, p. 526 after VOGEL, PFLÜGER, KRÜSS.

The combination of the factors 1, 2, 3 gives the total transmission before the spectrograph, tabulated in column 5. This is the proportion in which the light of a celestial body is reduced before it reaches the spectrograph; we can also say that the light of a source of illumination, placed before the slit, must be increased in the reciprocal proportion if we will compare it with the radiation of a celestial body. The extent of this loss of light before the spectrograph and its strong dependence on wave-length are certainly striking.

5°. The variable dispersion.

The area over which the energy contained within the same interval of wave-lengths is distributed by a prism spectrograph increases continuously as we move towards the shorter wave-lengths of the spectrum. A diminution of the apparent intensity is the consequence of this increasing dispersion. From the dispersion curve of our flash plate, we calculate the number of mm. corresponding to 1 A. U. in the different regions of the spectrum. The results are given in table IV, column 4.

4° & 6°. The transmission in the spectrograph and the sensitivity of the photographic plate.

The distinction between these two effects would be difficult and of no direct use. They are determined together by photographing the spectrum of a source of light in which the energy is distributed according to a known law. Our standard lamp was a nitralamp of Philips, run at a current of 6.19 A. From the researches of VAN ALPHEN¹⁾ we know that the wolframium-spiral of an incandescent lamp radiates approximately in the visible spectrum as a gray body; the distribution of the energy in its spectrum is given by PLANCK's law, but the absolute amount of the radiation must be determined by a special measure. With respect to colour temperature our lamp was standardized before our departure by DR. VAN ALPHEN by means of the optical pyrometer, and again after our return by MR. VERMEULEN; both deserve our cordial thanks. In both cases the spiral of the lamp was studied normally; the absolute colour-temperature was determined as a function of the current, and the resultant graph was found to be nearly a straight line. The current of 6.20—6.18 A used for the calibration plates corresponds to an absolute temperature of 2628° according to the first, of 2612° according to the second determination. The difference seems to arise from an uncertainty concerning the exact azimuth in which the pyrometer was directed on the lamp. We shall take the mean value: 2620° (abs.).

For the determination of the apparent intensities i in the continuous spectrum, we have at our disposal three spectrograms, made with the standard lamp: the calibration plate B, obtained in Lapland; and two similar plates obtained after our return at Utrecht, under circumstances reproducing these in Lapland. Plate B was corrected for fog as follows:

¹⁾ H. C. VAN ALPHEN, *Stralingsmeting aan wolframlampen*. Diss. Utrecht 1927.

for a given w .—l., the intensities of the different strips are read from the main transmission curve; from these 6 intensities found, the same number k is subtracted, so chosen that the remaining intensities are in the proportion 100 : 50 : 24 : ... (see p. 17).

The three plates are treated in the same way: the transmission curves are drawn for 6 points in the spectrum, the intensity in the marginal strips always being denoted arbitrarily as 100. The distances over which the curves are displaced with respect to one another, give then the proportion of the apparent intensities i .

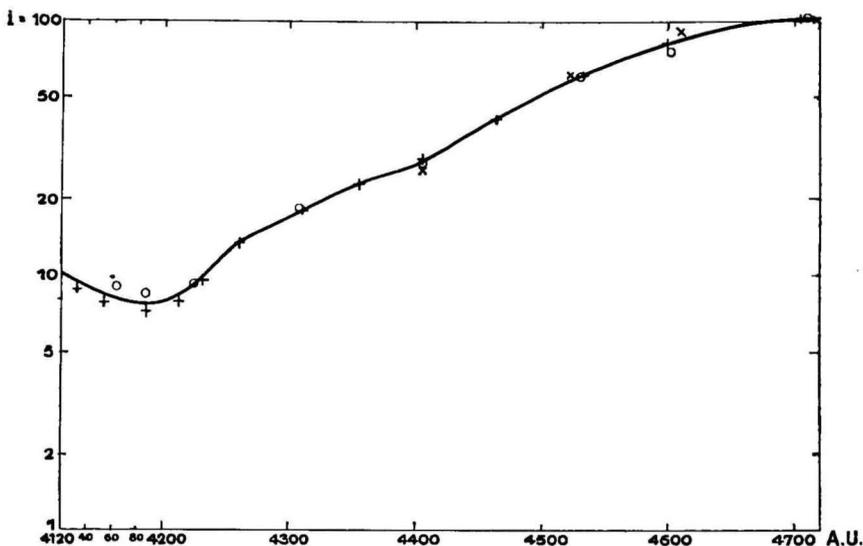


Fig. 9. Apparent intensities in the continuous spectra of the standard lamp.

In fig. 9, $\log i$ is plotted as a function of wave-length for the three plates considered. It is clear that the plates obtained at Utrecht and in Lapland may be perfectly comparable with respect to the relative intensities for different wave-lengths, while the absolute values may be slightly different; the curves were therefore shifted a little in the vertical sense, till they coincided as well as was possible. It will be seen that the plates obtained at Utrecht (the results of which are indicated by crosses) are concordant, and that the Laponian plate *B* (circles), notwithstanding some inevitable inaccuracy in the correction for fog, shows only a small deviation at the extremity of the plate in the region λ 4150—4250. Farther on we will see that the results of the Laponian slitcontrol plates point also more in the direction of the plate *B*. The remaining difference between the curves of Lapland and of Utrecht may be attributed with equal probability either to the imperfect reproduction of the Laponian conditions during the subsequent experiments in Utrecht, or to the remaining uncertainties in the photometric reduction of the Laponian plates. We therefore take the mean between the two curves.

We see that the curve begins with a maximum in the region λ 4700—4600, and falls off rapidly towards the shorter wave-lengths; a small depression in the curves near λ 4400 occurs in the three plates and is certainly real. After a minimum at λ 4200 a curious secondary maximum is shown near λ 4120 AU. In that curve, the effects are combined of the real distribution of the energy in the spectrum of the lamp, of the variable dispersion, of the transmission of the spectrograph and of the sensitivity of the plate.

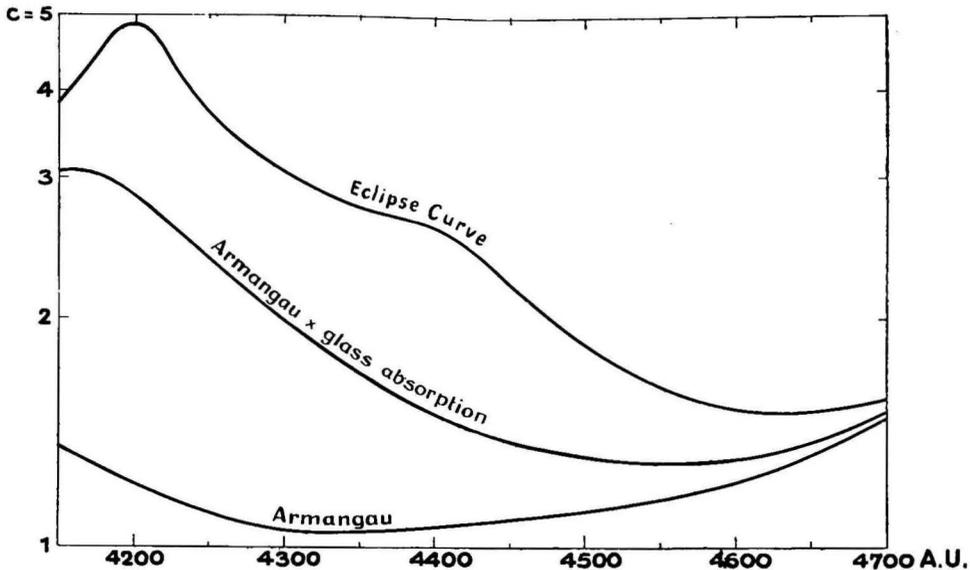


Fig. 10. Real intensity in ergs corresponding to a given density of the plate.

For investigating the relative importance of these factors, we eliminate the first two effects by calculating PLANCK'S function: ($i \times$ dispersion); that is to say: the real intensity in ergs corresponding for different wave-lengths to a given apparent intensity. The very considerable divergency of our curve (fig. 10) from others, e.g. that of ARMANGAU¹⁾, is chiefly due to the absorption by the glass of our prisms. This is demonstrated by the following facts. The rapid falling off and the secondary maximum are found also on spectra photographed on another brand of plates (cet. par.) and also after silvering afresh the mirror in the spectrograph; they remain after shifting the spectrum till λ 4200 occupies the middle of the plate. They disappear if the spectrum of the nitralamp is photographed on the same plate with a grating spectrograph. Moreover, two exposures are made with the prism spectrograph using only part of the aperture; when only one third of the beam is used, that near the refracting edge of the prisms, the curve becomes less abnormal; when the narrow beam passes near the basis of the prisms, the abnor-

¹⁾ H. ARMANGAU, *Journal de Physique*, 5, 213, 1926. (LUMIÈRE Σ).

mality is increased. Finally it may be shown that the influence of the absorption by the glass must really be strong; consider for example the transmission of "ordinary crown glass" Schott 0.203, in a layer of 1 cm. thickness¹⁾:

λ 4770	4350	4190	4000
0.985	0.969	0.952	0.964

A slight indication of a secondary maximum is seen near 4000. Considering now that our three prisms have each a basis length of about 15 cm. and that the rays go two times through them, the transmitted light is found by an easy integration:

0.656	0.449	0.321	0.404
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These numbers are only given for the sake of illustration, but they prove that the abnormal form of our curves may be explained for the main part by the regular absorption in the thick layer of glass. There is no doubt that the small incurvation near λ 4400 is likewise to be attributed to a slight irregularity in the absorption coefficients, so small that it could not have been detected in layers less thick.

The *i*-curve having thus been obtained, we proceed to calculate the colour coefficients. The radiation of the lamp per millimeter of the plate is found by taking the quotient PLANCK'S function/dispersion. Suppose now that the lamp be located outside the atmosphere; in order that we should find the same density as before in our spectrogram, the lamp must then radiate *more* energy in the different regions, in a proportion found by dividing by the transmission before the spectrograph (table III). The numbers thus obtained are the "real intensities" *I* which correspond to our spectrogram. The relation between *I* and *i*, according to the definition on p. 20, is therefore:

$$c = \frac{I}{i} = \frac{\text{PLANCK'S function}}{i \times \text{dispersion} \times \text{transmission before the spectrograph}}$$

In table IV are given the different factors involved, and the final values of *c*. This is the result given by method *a*.

b. The determination of the colour coefficients from the Fraunhofer spectrum.

In this method, the sun is used as a source of light of known energy distribution. Since it is situated outside the atmosphere, its light is reduced by the same causes which affect the flash spectrum, and its spectrum gives direct values for the colour coefficients.

The slitcontrol plates obtained in Lapland are the best suited for this purpose. One of these plates was made with a weakener before the

¹⁾ Recueil de constantes physiques, 1913, p. 526. After VOGEL, Berl. Ber. 33, 1219, 1896.

slit, the other without. It is necessary to take into account, that owing to the unequal width of the slit there is a considerable gradient in the density over the height of the spectrum; for the other plate this gradient adds itself to the reduction by the steps of the weakener, so that unless

TABLE IV.

Calculation of the colour coefficients by method a. (Standard-lamp).

Wave length λ	Apparent intensity i	Planck's function	Dispersion	Transmission before the spectrograph	Colour coefficient c
4700	100	386	0.247	0.297	52.6
4650	93	360	0.259	0.288	52.0
4600	82	335	0.272	0.278	54.0
4550	66	311	0.287	0.267	61.6
4500	52	288	0.303	0.257	71.2
4450	37.5	265	0.320	0.245	90.2
4400	27.5	244	0.340	0.233	112
4350	22.3	223	0.361	0.220	126
4300	17.0	204	0.383	0.207	151
4250	12.2	185	0.407	0.195	191
4200	7.9	169	0.431	0.181	274
4150	8.7	154	0.453	0.168	233

corrected the transmission curves cannot be relied upon. As it has been explained on p. 16, we first determine an approximate transmission curve, calculate by means of this the distribution of the intensity over the height of the spectrum made without a weakener, then again find better approximations for the transmission curve and for the distribution of the intensity. This last determination is used in drawing the transmission curves of different wave-lengths¹⁾.

The curves are not quite parallel, the deviations indicating a slight fog; small corrections of 0—4.5% are applied therefore. Then from the horizontal distances of the curves the values of i are deduced.

The distribution of the density in the solar spectrum outside the atmosphere is not yet really known in the region of the shorter wave-lengths. In bolometric measurement, it is impossible to avoid the influence of Fraunhofer lines, and this influence increases towards the violet. This

¹⁾ A small correction was added for the diminution of the intensity of the sun towards the limb.

is probably the reason why the curve of ABBOT falls off so irregularly and so quickly to the violet side of the maximum, while the decrease found photographically by PLASKETT¹⁾ is much more gradual, and corresponds to the radiation of a black body at about 6700°.

We give here for comparison the mean of the numbers of ABBOT for 1903-10 and for 1920-22, relating to the centre of the sun²⁾; and the numbers of PLASKETT, transformed from mean radiation over the disc into central radiation³⁾.

	<i>I</i> (ABBOT)	<i>I</i> (PLASKETT)
$\lambda = 3860$	29.2	—
4100	—	50.1
4330	43.8	50.6
4560	48.0	49.0
4810	47.7	47.6

As our measurements were made between the Fraunhofer lines, just as by PLASKETT, his results must be of much greater value for us than these of ABBOT. This is indeed confirmed by our curves; and we shall therefore only use PLASKETT's results.

The real intensities *I* for intervals corresponding to 1 mm. on the plate are now found by dividing PLASKETT's numbers by the dispersion (table V, column 3 & 4).

The colour coefficients are then calculated by taking the quotient $c = \frac{I}{i}$ (column 5).

TABLE V.
Calculation of the colour coefficients by method *b.* (Sun).

Wave length λ	Apparent intensity <i>i</i>	Intensity of solar spectrum pro ÅU	Dispersion	Colour coefficient
4645	95.5	494	0.260	19.9
4477	66.2	499	0.310	24.3
4403	49.5	501	0.339	29.9
4319	37.2	502	0.375	36.0
4215	19.7	503	0.424	60.2
4163	21.2	502	0.448	52.9

These coefficients, multiplied by a certain factor, ought to be the same as these determined by method *a.* For facilitating the comparison, the

¹⁾ H. H. PLASKETT, Publ. Dom. Obs. 2, 252, 1923.

²⁾ M. MINNAERT, B. A. N. 2, 75, 1924.

³⁾ M. MINNAERT, *ibid.* Table IV.

results of both are plotted on a logarithmic scale in fig. 11; the dotted curve is that given by the standard lamp, the crosses are those obtained from the sun, after being shifted over a proper distance in the vertical direction. The agreement is not satisfactory, the sun curve being flatter than the lamp curve. It is perhaps possible that PLASKETT's solar spectrum photographed with a smaller dispersion than ours shows in a stronger degree the influence of the faint Fraunhofer lines crowded together in the violet; or errors in our photometry may be introduced by the very short exposure and the unequal slit.

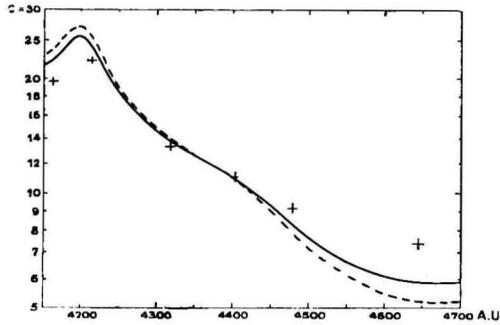


Fig. 11. Colour coefficients by methods *a* and *b*.

In view of the sources of error involved in method *b* (sun curve), in taking the weighted mean we will attribute a weight 2 to method *a*, and 1 to method *b*. The mean curve is given by the full line in fig. 11 and the values are tabulated in table VI, column 2.

6. *The determination of absolute intensities.*

Owing to various circumstances, an accurate determination of absolute intensities is always difficult. Nevertheless, it seemed to us very important to attempt an absolute determination, however rough, not only because it is of considerable theoretical importance, but also because its results may be useful for the preparation of future eclipse work.

For the determination of relative colour coefficients, we have used also the plates obtained at Utrecht, and the "slitcontrol plates" which were developed with a special developer. For determinations of the absolute coefficients however we shall only use the plates developed together with the flash spectrum itself. It will be necessary to apply some corrections owing to fog, but the determination of the colour coefficients has shown that this is well possible and that the results may be relied upon. We determine only the absolute value of the coefficients for λ 4500; the relative colour coefficients already determined give then at once the values for the other wave-lengths.

The calibration plates used (*B* and *C*) and the flash plate have very different exposure times. We reduce them all to one homogeneous exposure of 1 second, by means of SCHWARZSCHILD'S law: the transmission of a plate is a function of it^p . The exponent p has been determined at Utrecht, by photographing the continuous spectrum of an incandescent lamp with a reducer before the slit, during 3, 9, 27, 81 seconds. The plates were developed in the same circumstances as in Lapland, and the transmission curves were drawn for a wave-length near 4600 AU. From the horizontal distances between these curves, it was found that the different exposure

times had worked as if the intensity had been increased in the proportions 1; 2.87; 7.00; 20.0. By plotting $\log i$ against $\log t$, the exponent p is found to be 0.82, (fig. 12).

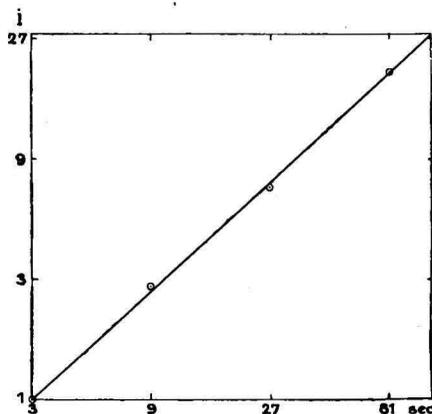


Fig. 12. Determination of the exponent p of Schwarzschild.

In the first place we will calculate the radiation which must fall on the slit of the spectrograph, in order that an apparent intensity 1 should appear on the plate; this determination will be made from the standard-lamp and from the sun (plates *B* & *C*) and the two results will be compared. After this, we will calculate the amount of chromospheric radiation which produces the same radiation through the slit.

a. *The absolute determination from the standard lamp.*

The calibration of the standard lamp is made, by measuring with a thermopile its radiation integrated over all wave-lengths; the surface of the thermopile is placed at 20.5 cm. from the lamp, that is at the same distance as the slit of the spectrograph has been from the lamp when the calibration spectrum was obtained. The thermopile is covered by a glass plate of 2 mm. thickness. Precautions are taken for avoiding false-light viz. a background of black velvet, a sheath with annular diaphragms. The thermo-electric potential is compared with a normal element by means of a compensation arrangement; a small rest-radiation is always subtracted.

For the normal current of the standard lamp with which we have worked, 6.19 A, a thermo-electric potential of $2.53 \cdot 10^{-3}$ V is measured. The thermopile used had been calibrated formerly by Dr. W. VAN DIJCK by a special method¹⁾. According to his determination, this potential corresponds to a radiation of 0.00443 watt/cm.² falling on the thermopile behind the glass.

A first correction is necessary, because the incandescent spiral of the lamp is somewhat beneath the centre of the glass bulb, so that its two reflected images seem to hang several millimeters above the filament; these images radiate on the thermopile but have not contributed to the spectrum. For determining their intensity, an image of the lamp is formed by a lens on a diaphragm, so that the radiation of the filament alone or that of the filament together with the reflection images can be transmitted. The proportion 1.066 is found. That gives for the absolute value of the radiation of the standard lamp the corrected value $0.00443/1.066 = 0.00415$ watt/cm.².

¹⁾ W. J. D. VAN DIJCK, Der Becquereleffekt an Kupferoxydelektroden. Diss. Utrecht, 1927. See p. 297. Also in Zs. phys. Chem. 127, 1927.

A second correction is needed, because the radiation has had to pass through two pieces of glass, the glass of the lamp and the glass plate before the thermopile, the later being by far the most important.

By a special experiment it is found that the (infrared) absorption in the glass plate has reduced the radiation to 0.90. Without this absorption the total radiation of the standard lamp at the distance considered would be: $0.00415/0.90 = 0.00461$ watt/cm².

From STEFAN's law, the total radiation of 1 cm² of a black body at 2620°, in the unit solid angle, amounts to $0.850 \cdot 10^9$ erg; from PLANCK's law, that part of the radiation which corresponds to an interval of

A.U. near λ 4500, is $3.373 \cdot 10^3$ erg. The same fraction of the light of our standard lamp must be radiated in 1 A.U. near λ 4500, that is $0.00461 \times 3.373 \cdot 10^3 : 0.850 \cdot 10^9$ watt/cm².

In this calculation, the reflection on the glass plate before the thermopile cancels out with the reflection on the spectacle lens which was used in making the calibration plate. The fact that the light is reduced by reflection on the glass of the reducer before the slit in the proportion 0.92 remains to be taken into account.

The radiation entering through the slit width of 0.044 cm. over a height of 1 cm. is now found by multiplying with 0.044. On 1 mm. of the plate near λ 4500, the radiation is 3.46 times stronger than on 1 A.U.

Thus the radiation producing 1 mm. of the spectrum near λ 4500, over a height of 1 cm., had on penetrating through the slit an energy of

$$\frac{0.00461 \times 3.373 \times 10^3 \times 0.92 \times 0.044 \times 3.46}{0.850 \cdot 10^9} = 0.256 \cdot 10^{-8} \text{ watt} = \\ = 0.0256 \text{ erg p. sec.}$$

The apparent intensity, deduced from the spectrum on plate C by means of the main transmission curve, on considering all the strips and all the wave-lengths, reduced to λ 4500, amounts to 48.4. If the plate had only been exposed during 1 sec. in stead of 40 sec., this apparent intensity would have been $48.8 : (40)^{0.82} = 2.37$. On a plate exposed during 1 sec., every unit of apparent intensity near λ 4500 corresponds therefore to a stream of $0.0256/2.37 = 0.0109$ erg. per sec., entering the spectrograph through 1 cm. height of the slit, and falling afterwards on 1 mm. of the spectrogram.

b. The absolute determination from the solar spectrum.

One cm² near the centre of the solar disk radiates in a wave-length interval of 1 A.U. near λ 4500 and in a solid angle $d\omega = 1$ 3.9 or $4.7 \cdot 10^6$ erg./sec. according to the data used¹⁾. We take the mean value: $4.3 \cdot 10^6$ erg./sec. This radiation is reduced by the atmosphere, the mirror, the objective, and the glass of the reducer, to $4.3 \cdot 10^6 \times 0.257 \times 0.92 = 1.01 \cdot 10^6$ erg./sec.

¹⁾ M. MINNAERT, B.A.N. 2, 79, 1924. (Table III).

Put R the distance earth-sun, $O = 235 \text{ cm}^2$ the transverse section actually used of the beam passing the objective; $f = 345 \text{ cm}$. the focal distance of the astronomical objective. On the slit plate, 1 cm^2 corresponds to $\frac{R^2}{f^2} \text{ cm}^2$ on the sun. The radiation passing through 1 cm^2 of the slit is therefore:

$$1.01 \cdot 10^6 \cdot \frac{O}{R^2} \cdot \frac{R^2}{f^2} = 1.01 \cdot 10^6 \times 0.00198 = 2.00 \cdot 10^3 \text{ erg./sec.}$$

Through a slit of 0.0112 cm . wide, over a height of 1 cm ., and for an interval of wave-lengths corresponding to 1 mm . on the plate, the radiation passing has an energy:

$$2.00 \cdot 10^3 \times 0.0112 \times 3.46 = 77.5 \text{ erg./sec.}$$

We desire to know now the apparent intensity produced on the plate by this radiation. The calibration plate C with the FRAUNHOFER spectrum is measured with the microphotometer at three points near the wave-lengths 4478, 4315 and 4230, where the spectrum is almost free from FRAUNHOFER lines. To the apparent intensities derived by means of our main curve we apply a correction for the fog here considerable, by subtracting 15% , 16% and 21% ; they are found: 148, 65, 65.

From each, we derive the apparent intensity for the wave-length $\lambda 4500$ and for an exposure of 1 sec . instead of 0.02 sec ., by multiplying by

$$\frac{\text{solar energy } (\lambda = 4500)}{\text{solar energy } (\lambda = x)} \cdot \frac{C_x}{C_{4500}} \cdot \frac{1}{(0.02)^{0.82}}$$

We get the values 3980, 3390, 6090. Since they correspond to a radiation 78.3 ergs/sec ., on a plate exposed during 1 sec . every unit of apparent intensity would correspond to a stream of 0.0194 — 0.0229 — 0.0127 erg/sec . entering the slit over 1 cm . height, and falling afterwards on 1 mm . of the spectrogram near $\lambda 4500$.

The mean of these numbers is 0.018 , while the standardlamp had given the value 0.011 . The order of magnitude is thus confirmed, and even better than could be expected, for the number of factors involved is so considerable, and both methods are so entirely independent, that a real concordancy is hardly possible. In particular, we must realise how many uncertainties and sources of error have been encountered in the course of the determination from the FRAUNHOFER spectrum; the more important are: 1. the uncertainty in the exposure time; 2. the irregularities in the solar spectrum arising from the FRAUNHOFER lines; 3. the extrapolation of SCHWARZSCHILD's law to exposures in the enormous proportion of $2000:1$; 4. the considerable fog on the plate. The effect of the factors 2 and 4 may be seen from the divergency between the three numbers found above. On the contrary, in the determination from the standardlamp there is only one uncertain factor: the extinction of the

solar radiation by the atmosphere. For these reasons we will as before take the weighted mean, assuming a weight of 3 for the standard lamp against 1 for the sun.

Our further calculations thus will be made with the value: *0.013 erg per sec.*; if this radiation enters the slit over a height of 1 cm., and falls afterwards on 1 mm. of the spectrogram about λ 4500 Å.U., 1 unit of apparent intensity is produced.

7. *The absolute colour coefficients for continuous spectra.*

We consider again the radiation at λ 4500.

Make *I* the radiation of the chromosphere over a length of 1 geocentric minute of arc, a solid angle 1, and an interval of wave-lengths corresponding to 1 mm. on the plate. A fraction 0.257 of this radiation reaches the slit, and we will suppose that the image of the chromospheric arc

TABLE VI.

Absolute colour coefficients. C.

Multiplied by the apparent intensity *i*, they give the radiation of 1' of the chromosphere (geocentric), in ergs per sec., for a solid angle 1.

Wave-length in Å.U.	Mean colour coefficient C_λ	<i>C</i>		<i>C''</i> for a flash line of central intensity = <i>i</i> .
		for 1 mm. of the plate for continuous spectra of apparent intensity <i>i</i>	for 1 A.U.	
4700	57.5	2,15 . 10 ²¹	0,527 . 10 ²¹	0,204 . 10 ²¹
4650	57	2,13	0,547	0,218
4600	57.5	2,15	0,583	0,242
4550	64	2,39	0,684	0,285
4500	75	2,80	0,843	0,359
4450	92.5	3,46	1,10	0,468
4400	112	4,18	1,41	0,594
4350	126	4,70	1,69	0,707
4300	148	5,52	2,11	0,863
4250	186	6,95	2,83	1,17
4200	263	9,80	4,25	1,71
4150	218	8,15	3,83	1,49

passes wholly through this, as it is broad. On the slit 1 cm. corresponds to $\frac{1}{f}$ rad. on the sky, or for $f = 345$ cm. with rather exactly 10'. Over that height of 1 cm., the radiation amounts to: $10 \times 0.257 IO/R^2$ erg/sec. But we have found that for a plate exposed for 1 sec. every unit of

apparent intensity corresponds to 0.013 erg/sec. over a height of 1 cm. For our flash plate, exposed for 2 seconds, we have the relation:

$$\frac{0.0143 i}{2^{0.82}} = 2.57 \frac{IO}{R}.$$

Or
$$C = \frac{I}{i} = \frac{0.013 \times 2.25 \cdot 10^{26}}{0.257 \times 2^{0.82} \times 235} = 2.8 \cdot 10^{21}.$$

The corresponding values for the other wave-lengths are easily obtained from the relative colour coefficients (table VI column 2), and are given in table VI column 3. These are the absolute coefficients by which the apparent intensities must be multiplied, in order to give the radiation of 1' of the chromosphere in ergs pro second, pro unit of solid angle, and in an interval of wave-lengths corresponding to 1 mm. on the plate.

In several instances it may be useful to know the intensities corresponding to intervals on the plate of 1 A.U. The column 3 gives the absolute coefficients C' for this case.

The significance of column C'' will be explained later (p. 39).

III. THE FLASH LINES.

1. *The microphotometric records of the flash-plates.*

The microphotometer used is of the well-known type devised by W. J. H. MOLL, based upon the thermo-electric measurement of the radiation.¹⁾ It records automatically the transmission of the plate under investigation on a drum covered by a sheet of photographic paper. The motion of the plate and of the drum are synchronous, so that variations in the speed of the motor have no influence on the record.

As we use the instrument, the scale of the curve obtained is about 20 times that of the plate; thus nearly 2 cm. of the plate can be registered on every strip of paper, 40 cm. long. The whole record for the entire length of the flash spectrum measures 4 meters.

The following disposition of the instrument is chosen:

- distance nitralamp to condensor: 20 cm.;
- width of the image of the incandescent spiral on the plate (estimated): 0,02 mm.;
- ratio in which the plate is magnified on the thermopile: 6;
- length of the slit before thermopile: 1,2 mm. (projected on plate: 0,2 mm.);
- width of the slit before thermopile: 0,15 mm. (projected on plate: 0,025 mm.);
- galvanometer: dead beat;
- velocity: 2 cm. of the plate in 40 min.

A preliminary experiment has proved that this speed is amply slow enough, and that the galvanometer gives the same deflection when the top of a line is passing as when the same line is kept motionless in the beam of the microphotometer.

The whole spectrum is recorded three times. First on the height *a*, where the density is the smallest (see fig. 3). By a small lever, the plate can be moved up or down till the deflection of the galvanometer is a maximum; this affords an exact method of adjusting the plate, so that we are sure that the microphotometric record is taken at the same height for the whole flash spectrum. A second set of records is now obtained on the height of the secondary maximum of the density *b*. Lastly, the violet end of the spectrum is also recorded on the height of the chief maximum *c*.

For the other flash plates, the lines H_{γ} and λ 4471 (He) are recorded at the same three heights, which can be recognised clearly on all the plates even after the continuous spectrum has disappeared.

On all the records, marks are added corresponding to the position of the galvanometer when a dark screen is put before the plate (transmission

¹⁾ Versl. Akad. Amsterdam, 28, 566, 1919. — Proc. Phys. Soc. London, 33, 207, 1921.

0) and others when the beam passes through dead plate (transmission 100 %). See p. 15). The character of the registrograms may be seen from the reproduction of a small part in our preliminary report.

The sheets are measured with the Hilger micrometer apparatus of the Astronomical Institute of the University of Amsterdam; the horizontal coordinates for wave length can be read to 0.01 mm., the vertical coordinates giving the intensity are read to 0.1 mm. The record for transmission 0 is taken as the zero for the readings of the vertical coordinate. The readings for clear film usually amount to 48—55 mm.; they are different on different days by differences in the radiation of the photometer lamp; thus each sheet has to be reduced with its own value for transmission 100%.

The chief difficulty in treating a spectrum by means of a registrogram lies in the irregular oscillations of the registered curve due to the silver grains of the negative. A smooth curve has to be drawn through these oscillations; sometimes accidental regularities in these wavelets may appear as a spurious small wave, sometimes these vibrations may hide a real wave in the intensity curve of the spectrum. The reality of such waves may be tested by visual inspection of the spectrum, whether a line is seen at this spot. In the faint parts of the spectrum, however, the registrogram is more sensitive than the human eye, because the deflection of the galvanometer is proportional to the quantity of light transmitted, thus a thin imperceptible silver deposit diminishing the transmission say from 100 to 95 is registered in the same way as a reduction of the light from 10 to 5. Therefore in the densest parts the eye distinguishes faint lines more easily; in the less dense parts the visual inspection may still afford a reliable control of the reality of lines; but in the faintest parts of the spectrum such a control can be only found in the comparison of the two strips *a* and *b*.

On the curve drawn in this way all the maximum and minimum-points are measured, moreover a number of intermediate points fixing the exact course of the curve, where the breadth of the lines, retardations or other irregularities in their figure make it necessary.

2. *The determination of the profile of the flash lines.*

In chapter II we have calculated the intensity for an area of the plate uniformly dense. It will be necessary now to determine the total intensity of a narrow flash line from its "*central intensity*", that is, the intensity corresponding to the centre of the line, as given by our main transmission curve. We will therefore find the *normal profile* of the flash lines, and then the relation between the central intensity and the total intensity.

For simplicity we assume that all the flash lines of a given spectral region have the same distribution of intensity (with the exception perhaps of the very strongest ones which extend to high levels).

This is plausible, as the equivalent width of the lines will be found about 0.4 Å., which must be due chiefly to instrumental causes. Sixteen lines as free as possible from blends, and most of medium or great inten-

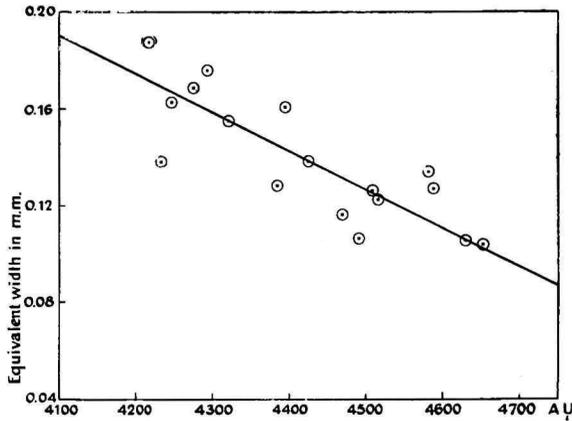


Fig. 13. The areas of the flash lines as a function of wave-length.

sity, are carefully selected from all parts of the spectrum. The micro-photometer curves of these lines are magnified some 6 or 7 times with an epidiascope, smoothed, then converted into profiles of apparent

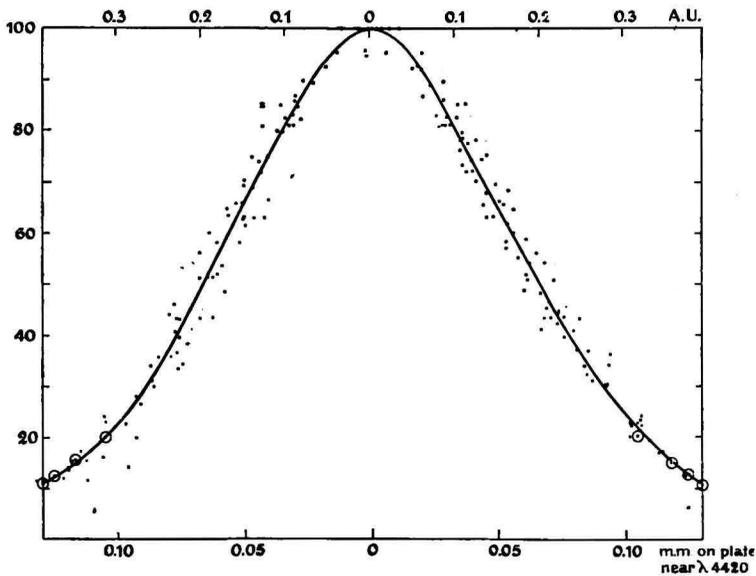


Fig. 14. The normal profile of the flash lines. After reduction for the wave-length effect, the 16 lines are nearly concordant.

Dots within circles are considered as the most reliable for the wings of the lines.

intensity and reduced to a central intensity 100, the abscissae being distances in mm. along the plate. The areas, measured with a plani-

meter, are plotted against the wave-lengths (fig. 13). These areas may be called the "equivalent widths" of the flash lines.

It will be seen at once, that the area of the lines increases towards the region of the small wave-lengths, that means that the lines become broader; the area is nearly a linear function of $w.-l.$

$$i = 0.126 + 0.0159 (4500-\lambda).$$

We assume now that the variation of the normal profile through the spectrum is simply a variation in the scale of abscissae. For the sixteen profiles, the abscissae are reduced in the proportion of the areas (fig. 14); they are nearly the same now, and examination shows that the individual deviations are entirely random. The mean curve will be considered as the normal profile of the flash lines, the scale of abscissae varying according to the linear formula given above.

It may be asked which are the factors determining that normal profile. The width of the slit cannot play a role, for the chromospheric arcs were much narrower (about 0.05 mm.) The diffraction is insignificant. We may consider the following causes of broadening; 1. the irregular shape of the flash arcs and their broadening by the scintillation; 2. imperfect focussing of the spectrograph, every degree of temperature variation producing 0.5 mm. displacement of the focal plane; 3. lack of achromatism of the astronomical objective and of the spectrograph objective; 4. imperfections in the surfaces of the prisms and in their glass: the rays pass through 14 glass surfaces and 7 prisms and are reflected two times; 5. some flash lines used may have been blends. The resulting curve approximates to a probability curve, as is to be expected from the cooperation of numerous sources of error; she differs from the Gaussian curve by a positive excess. The 3rd cause explains the variation with $w.-l.$, which, if \AA.U. are used, is just compensated by the variation of the dispersion with $w.-l.$ If in drawing the curves a scale of $w.-l.$ is taken for the abscissae, the width of the profiles is nearly a constant.

On the scale of A.U. the curve is given bij Table VII.

TABLE VII. Normal profile; argument in A.U.

0.0	1.000	0.25	.323	0.45	.038
0.05	0.938	0.30	.212	0.50	.014
0.10	794	0.35	.133	0.55	.003
0.15	621	0.40	.078	0.60	.000
0.20	461				

By means of our normal profile and the absolute colour-coefficients already determined, we can calculate now for all $w.-l.$ the total energy of a flash line having a central intensity 1, as read on our main transmission curve. This total energy C'' , equal to $C[0.126 + 0.0159 (4500-\lambda)]$,

which differs hardly from $0.4 C'$, is given in table VI, last column; the numbers refer to the emission of $1'$ (geocentric) of the chromosphere in the unit solid angle.

After the determination of the normal profiles for the flash lines in the curves a , we investigate if the same profiles will also hold for the curves b . This is not probable, because even the simple visual examination shows that the sharpness of the flash lines is not the same over their whole length (p. 8). For five of the lines already measured the profiles of the curves a and b are compared. The profiles b prove in all cases to be relatively broader; after reduction to the same central intensity, the areas on a and b and their proportions are found to be:

λ	a	b	b/a
4216	188	221	1.18
4233	138	165	1.20
4508	126	171	1.35
4515	122	170	1.39
4629	105	143	1.36

We therefore, in deriving the total energy of the b -lines from their central intensity, multiply the coefficients C'' by a factor which increases slowly with the wave-length, varying from 1.20 to 1.40.

3. *The derivation of the wave-lengths.*

It has not been our intention to derive exact wave lengths for the flash lines, but only to determine their intensities. Their wave lengths are only needed for their identification. Therefore the plate itself has not been measured, and the computations are founded entirely on the measurement of the registrogram sheets. By means of their overlapping parts they are reduced to a common scale; from a number of well marked lines free from blends a HARTMANN formula is deduced

$$(\lambda - 2684)(n + 9710) = [7.307855],$$

where the extreme values $n = 100$ and $n = 4100$ mm. correspond to $\lambda 4776$ and $\lambda 4155$. There remain, however, on each sheet gradually varying differences $O-C$, which were attributed at first to unequal dilatations of the paper sheets in the processes of developping, washing and drying, but actually proved to be due to periodic errors in the transmission gear of the microphotometer drum. Thus it is necessary to derive a smooth correction curve for each sheet, in order to get a sufficient concordance of the computed and the true wave-lengths. For the identification of the lines the tables of KAYSER'S Hauptlinien der Linienspektra ¹⁾ are used, completed by some later researches; also the stronger lines in ROWLAND'S Preliminary Table of Solar Wave-Lengths, down to intensity 1 or 0 are compared.

¹⁾ Berlin, Springer, 1926.

4. *The derivation of the intensities.*

Each sheet has to be reduced with its own value of the vertical reading for clear film.

Now the transmission of the nonexposed parts of the plate is not wholly constant; therefore we connect the values for some of the sheets with the adjacent sheets by means of their common parts, in order to get more accurate values. By means of these corrected values for 100 % transmission, each reading of a vertical coordinate can be expressed as a transmission fraction, and with the aid of Table II can be transformed into apparent intensity i .

We can now trace an intensity curve of the spectrum, where the tops of maximum intensity correspond to the emission lines; the points of minimum intensity between them correspond to the background between these lines. This background is neither dark nor even constant; seldom or nowhere does the curve show a horizontal course over an appreciable distance; it always presents a sinuous figure, continually running up and down between more or less strong maxima and minima. Thus we cannot simply take the minimum values as constant background to be subtracted from the tops in order to get the intensities of the corresponding lines.

The light which is present in the background of the spectrum may be attributed to three causes.

1. The borders of the visible lines; usually the distance of adjacent lines is so small that their borders overlap and between them remains some light, whose intensity increases with decreasing distance of the lines. After the normal profile deduced p. 37 the central intensity between two equal lines is:

0.03	0.16	0.42	0.85	1.02	
times the intensity at the centre of the lines for distance					
1.0	0.8	0.6	0.4	0.3	A.U.

The last named figure means that there is no depression between the lines, because they have melted into one broad line.

2. The lines not separately visible. When a line of less intensity is situated between two stronger lines, its existence may cause only the interval between them to be less dark, but it may be not visible as a line itself. Generally spoken lines are not visible as lines if the positive curvature they produce in the total intensity curve of the spectrum is less than the negative curvature produced by the borders of other lines. We may be sure that the spectrum of the flash contains a large number of such faint lines besides the visible ones. By their combined light, dispersed to overlapping bands of the breadth of the normal profile, there must be a continuous background of spectral light, irregularly fluctuating up and down; from this sinuous background the stronger lines emerge as the visible tops.

3. A continuous spectrum of the suns border, or perhaps of the

chromosphere itself. Our registrograms *a* are made from a strip of the flash spectrum, where the continuous spectrum is weakest, between two darker parts, probably a part of the chromosphere where the lowest parts and the sun's border were occulted by a lunar mountain. But still some continuous background is visible especially in the greater wavelengths. It may be caused by a very narrow strip of solar border light not occulted by the moon. If the atoms of the chromospheric layer scatter the photosphere light from below in an appreciable amount, this may also cause a faint continuous background between the chromospheric lines. The strip *b* contains a larger amount of this photospheric light.

It is clear that it is not possible to deduce true intensities for the separate emissions of each element free from perturbations by other lines; always the light of the faint lines constituting the background will be included. The primitive procedure of subtracting from the maximum the average of two minimum values including the line can only give a rough approximation. In discussing the intensity curve of *a* we have used the method of first freeing the minima from the influence of the borders of the bright lines. By means of the normal profile curve we may compute what fraction of the maximum light in the centre of a line is present at a certain distance from this centre. Thus for a minimum between two maxima we find what intensity is produced there by each of the adjacent lines; by subtracting it we get the background due to causes 2 and 3. Because we do not know a priori the intensities of these lines, which themselves depend on the value of the background, successive approximations are necessary. If the interval between the lines is small, and large corrections would be necessary, this procedure may lead to large errors, especially because in the case of small fluctuations of the curve there is a predisposition of drawing them too steep, so that a too low background value is found. Therefore only such minimum points of the curve are used where the distance to the adjacent lines is sufficiently large and the corrections for border effect are small.

The results are represented by the points in fig. 15. The largest values denote parts of the spectrum where lines are present, which are just at the limit of being separated from the indiscernable bulk and included in a catalogue of lines. The lowest values indicate the places most or perhaps quite free from emission lines. *Through these lowest points* a curve has been drawn, which may be assumed to represent the background of continuous spectrum combined with that minimum amount of faint lines that is present everywhere and cannot be separated from the first. This curve appears to show the same fluctuations as the curve of the standard lamp ¹⁾ fig. 9. The background values of this curve, given by Table VIII,

¹⁾ At the minimum near λ 4200 it falls below $i=0$; here also by visual inspection the film appears more transparent than the clear film far from the spectrum, probably an EBERHARD effect due to the adjacent darker parts.

have been subtracted from all the topvalues to get the apparent intensity i of every line. In this intensity an unknown amount is included due to other faint nearly coinciding lines; its average value may be estimated by drawing a curve *through the mean of all the points* of fig. 15.

The flash spectrum as photographed with our instrument does not consist of a number of well separated lines; all kinds of blends occur, from lines so close together as to cause only a slight broadening of the profile, to broad wings and bands of varying intensity. The eye, by the effect of contrast, perceives often a separate companion line where

TABLE VIII. Apparent intensity of the continuous background.

λ	i		λ	i		λ	i	
	strip a	strip b		strip a	strip b		strip a	strip b
4150	1.0	1.8	4400	2.4	5.2	4650	13.0	16.6
4200	-0.2	0.4	4450	3.9	7.4	4700	14.2	17.4
4250	1.0	1.5	4500	6.5	10.1	4750	14.6	16.1
4300	1.3	2.7	4550	9.0	12.8			
4350	1.7	3.9	4600	11.2	14.0			

the intensity curve shows only a regular or irregular slow decrease of intensity; by analyzing this intensity curve, however, we may separate the companion theoretically and deduce its intensity; the same holds when visual inspection shows only a diffuse border at the line. We may say in a general way that the analysis of the intensity curve resolves it into the sum total of a number of normal profiles of different height, each representing an emission line. Strictly speaking the number of these lines decreasing to 0 is unlimited; thus practically the solution is not unambiguous, and among the fainter lines, deduced in this way, both wave-length and intensity remain uncertain in different degrees.

For the determination of the background of the curves b , a less accurate, but shorter method is used. On each sheet, a straight line is traced through the lower points of the registered curve. Care is taken to chose only such points where FRAUNHOFER lines and chromospheric lines are not present; and the inevitable oscillations of the registered line caused by the grain of the plate are accounted for.

The intensities deduced in this way are not yet the true intensities of the chromospheric spectrum, because the continuous spectrum superposed upon it is crossed by absorption lines. *These absorption lines of the Fraunhofer spectrum coinciding with the flash lines diminish their intensity*; where the continuous spectrum is strongest (strip c), strong arc lines appear as absorption lines while strong spark lines appear as

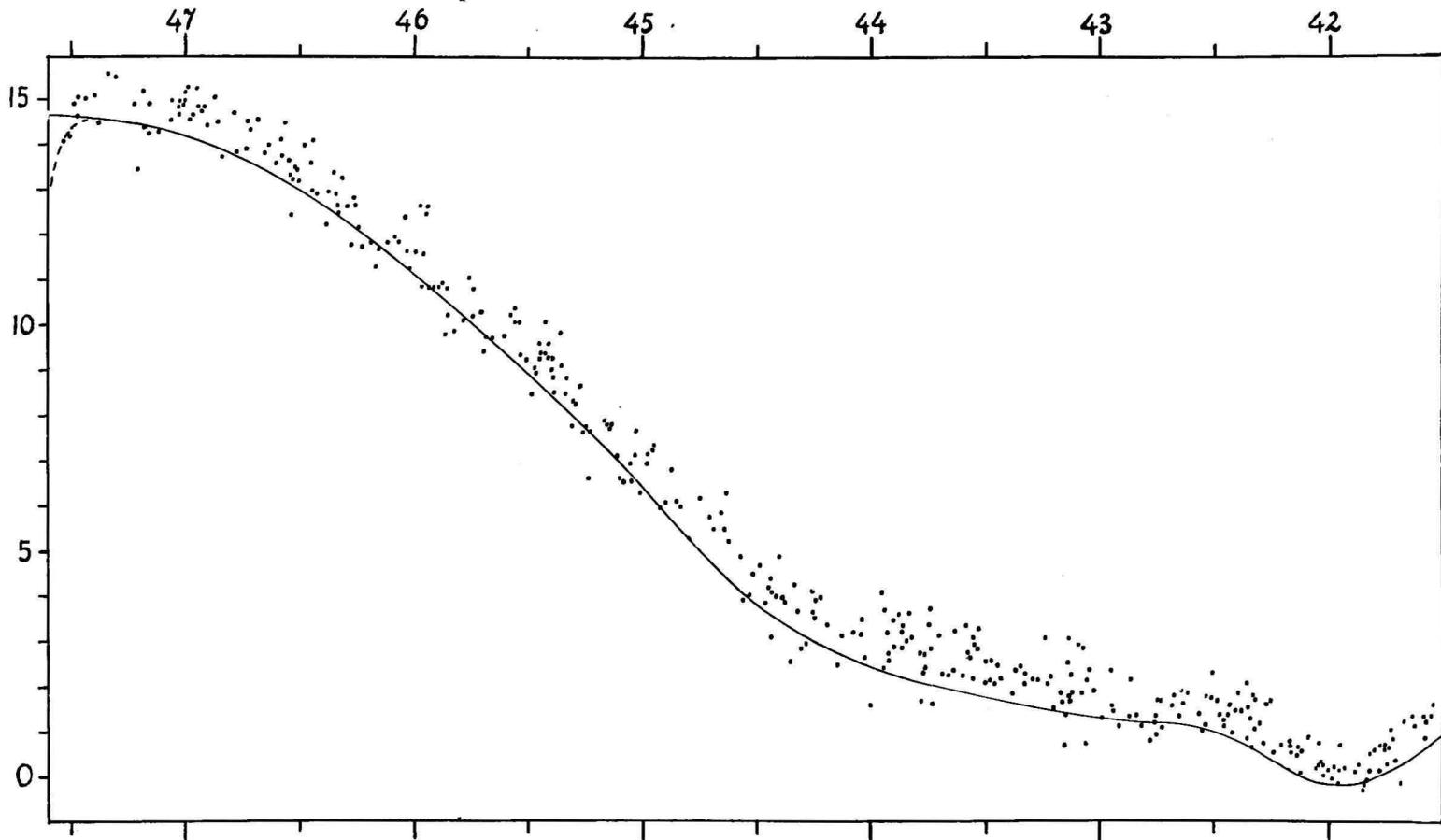


Fig. 15. The determination of the continuous background.

emission lines. The correction that should be applied to our intensities for this reason depends on the intensity of the FRAUNHOFER line; for this the value given in ROWLAND's Preliminary Catalogue is used, because the data on the intensity in the spectrum of the sun's limb are too incomplete.

The correction has been computed in the following way. For the normal profile due to the spectrograph we may assume a Gaussian function

$\frac{1}{\beta\sqrt{\pi}} e^{-x^2/\beta^2}$, where the constant $\beta = 0.22$ A.U. The true intensity in

the central part of a FRAUNHOFER line may also be represented by such a function¹⁾; then the broad wings are not taken into account, but they have little influence at the centre of the image and they change the intensity of the background in the same way as that of the line centre. Thus representing the true intensity in the Fraunhofer line by $1 - A e^{-x^2/a^2}$, we get for the central intensity of the line as given by the spectrograph:

$$\frac{1}{\pi\sqrt{\beta}} \int_{-\infty}^{+\infty} (1 - A e^{-x^2/a^2}) e^{-x^2/\beta^2} dx = 1 - A \frac{a}{\sqrt{a^2 + \beta^2}}$$

If the solar line is very narrow (a small) the depression in the centre of the image becomes Aa/β which can be computed easily from the aequivalent width $Aa\sqrt{\pi}$ (indicating the strength of the line) and β . For the narrowest lines, however, the width at half-height ($1.66 a$), according to v. KLÜBER, is nearly 0.20 A.U., too large to be neglected in the above formula. For the intensities in the ROWLAND scale of

0 1 2 3 4 5 6

we have assumed the width at half-height after VON KLÜBER

0.20 0.20 0.20 0.21 0.21 0.22 0.24 AU.

and the aequivalent width, after new determinations at the Utrecht Laboratory on a number of lines near λ 4500:

0.024 0.041 0.066 0.085 0.107 0.145 0.182 AU.

From these data we find the depression in the centre of the line

0.05 0.09 0.15 0.19 0.24 0.32 0.40.

For the small number of stronger lines that occur in the part of the spectrum concerned special measures of the profile have been made in Utrecht; the following table gives the values used and the results

Line	4227Ca	4261	4272	4326	$H\gamma$	4384	4405	4415
Rowland	20	10	15	8	20	15	10	8
A	0.84	0.81	0.82	0.82	0.75	0.83	0.83	0.81
$0.83 a$	0.50	0.27	0.30	0.32	0.50	0.50	0.29	0.22 AU.
$Aa/\sqrt{a^2 + \beta^2}$	0.79	0.67	0.68	0.71	0.71	0.78	0.69	0.63
Corr.	+5	+8	+8	+8	+8	+10	+9	+9.10 ²⁰

¹⁾ H. VON KLÜBER, Photometrie von Absorptionslinien im Sonnenspektrum, A. N. 5544.

The corrections to the flash line intensity are found by firstly multiplying the fraction $A\alpha/\sqrt{\alpha^2+\beta^2}$ with the intensity of the continuous background at that wave-length (Table VIII, p. 42); by this amount the intensity i of the flash line has been found too low on account of its coinciding with a FRAUNHOFER line in the continuous spectrum. This value must then be multiplied with C'' in order to find the correction to the absolute intensity I . For the strong lines the resulting corrections of I (for strip a) have been given in the last line of the above table.

The corrections have not been applied in the catalogue of flash lines, which contains only the immediate results of our plate. They can be computed for each separate line easily from the values of the depression, given above, and the following values of the background $i \times C''$, with which they have to be multiplied:

	λ	4150	4200	4250	4300	4350	4400	4450
$i C''$ {	for strips a	15	0'	12	11	12	14	18
	for strips b	27	7	18	23	28	31	35
	λ	4500	4550	4600	4650	4700	4750	
$i C''$ {	for strips a	23	26	27	28	29	28.10 ²⁰	
	for strips b	36	37	34	36	36	31.10 ²⁰	

Where flash intensities have been used for further discussions, these corrections have been applied.

5. The catalogue of flash lines.

At its short wave end the flash spectrum is very faint and the strips a and b show only few lines. Also in the irregularly vibrating curve of the registrogram it is difficult to trace with certainty the small waves produced by faint lines. The discussion of strips a and b is made independently for this part, and the lines, contained in the first part of our catalogue, do not always coincide; generally strip b contains some more lines here than a . The wave-length has been given here only to 0.1 A.U. Beyond λ 4240 the curve becomes more accentuated, and the λ are given to 0.01 A.U.

In column 2 and 3 the intensities I of the lines in strip a and b are given. For a they have been deduced by analyzing the curves as described above; therefore they have different degrees of certainty. If a line is not present in the curve as a separate top, but shows itself clearly in the figure of the curve, and it is visible too by visual inspection, it is denoted by *. If the line is not separately visible and its existence is only deduced from the figure of the curve, (small slope of another line or shallow interspace) so that its exact λ and intensity remain uncertain, it is denoted by †. Still more uncertain are lines (denoted by §) that appear as small waves in the curve but by visual inspection remain invisible or

doubtful. When the profile of a line is broader than the normal profile this is an indication that the line in reality is a close double line; this is denoted by *br*. When a number is added it denotes the width at half its height. This width depends on the distance of the components. From the normal profile we deduce that a width

	0.37	0.40	0.48	0.62	0.80	A.U. corresponds to
a distance	0	0.10	0.20	0.30	0.40	A.U. of two equal components.

For these latter distances the figure of the top becomes flattened and even shows a small depression between two tops. In these cases it is possible to get information about the relative intensity of the components from the asymmetrical shape of the profile; then the components are given separately in the catalogue, connected with a square bracket. Of course the separate intensities are much more uncertain than in the case of single lines. Ordinary brackets denote lines sufficiently distant to be separated but connected to one band.

In the column for the intensities in strip *b* compound lines that have not been analyzed are denoted by *co*, doubles by *d*, very faint lines by *f*; *fc* indicates that the line has a faint companion.

From λ 4280 till 4315 the column for I (b) gives two figures. Here the registrograms show clearly an irregularity in the background, so that it is brighter here than outside this limit. Probably we have to do here with an emission band of carbon, with its sharp edge at λ 4315, which as an absorption band is visible in the background of the solar spectrum. In strip *a* it is less clearly shown, and in the reduced background values of fig. 15 there are some very low values that occult the gap of the other points. Therefore in the discussion of *a* no account has been taken of this band, while in the discussion of *b* it seemed better to give two values, the second obtained by drawing the background curve close along the lowest points of the registrogram.

All the intensities are given in absolute units, every unit being equal to 10^{20} ergs per second, emitted in a solid angle 1 by 1' (geocentric) of the chromosphere (not 10^{21} as in table VI!).

In column 5 a comparison is made with lines of the elements. For each line the decimals of the wave-lengths, the element, and the intensity (usually after KAYSER) is given. Lines within a distance of 0.2 AU. are always included, sometimes even at greater distance, when we may assume that such lines have contributed to the intensity of the flash line. Except for iron, where all lines down to intensity 1 are included, the lowest intensities 1 or 2 are omitted; for the rare elements only the highest intensities are given. When ROWLAND lines of unknown origin (down to intensity 1) are coinciding this is indicated by wave length, fig. *u*, and ROWLAND intensity in parenthesis.

The sixth column gives the intensity in MITCHELL's Table of Flash lines.¹⁾

The faint lines do not always correspond because the analysis of the fluctuating intensity between the strong lines into separate faint lines may be somewhat arbitrary; we have found lines not contained in his list and some of his lines do not occur in ours.

The last column contains the ROWLAND lines corresponding to our flash lines; in the first half of the table it was sufficient to go down to intensity 1, but for the longer wave-lengths many lines 0 had to be included.

¹⁾ *Astroph. J.* 38, 407, 1913; *Publ. Naval Obs.* X B p. 43—107.

λ	$I(a)$	$I(b)$	Elements	MITCHELL	ROWLAND
4154.8	24		82 Fe 4; 03 Ti 1	3	82-4
55.4		12			
56.1	51	40	16 Nd 10; 23 Zr + 10	8	91-1; 23-1; 30-3
56.9	31	34	80 Fe 4; 67 Fe 1; 04 Mn 2	3	81-3
57.8	26		79 Fe 3	3	79-5
58.2	30	19	34 Ti 1	1	
58.8	22	16	81 Fe 2	2 d	80-5
60.3		10	56 Fe 1; 39 Ti 1	0	37-2
60.8		10	70 Co + 7	}	78-0
61.3	41	27	42 Cr 3; 21 Zr + 10		1
61.7	20	32	54 Ti + 3; 81 Sr + 1	}	52-4; 80-1
62.6	27	18	(46 u 1; 66 u 1)		2 d
63.7	51	51	65 Ti + 10; 63 Cr 4; 64 Nb 10; 68 Fe 1	10	66-4
64.2	29	20	19 Pr 10; 14 Ti 2	1	26-0; 33-0
65.6		21	42 Fe 1; 53 Cr 3; 61 Ce 10	2	39-3; 60-2
66.0		14	04 Ba + 10	0	00-0
66.9	38	22	00 Ni 3	1	97-0
67.5	33		24 Ti 1; 52 Y 7; 39 Mg	3	28-8; 56-1
67.9		29	86 Fe 2; 96 Fe 1; 99 Dy 10	2 d	72-1; 86-2; 97-2
68.8		17	62 Fe 1; 94 Fe 1; 70 Zr + 8	1 d	62-2; 95-2
69.3	18		35 Ti 2	0; 2	
69.6	26		78 Fe 1; 84 Cr 3	2	61-1; 77-2
70.2	26		05 Fe 1	0	
71.0	38	23	91 Fe 2; 04 Ti 2	3	91-4; 05-4
71.9	56	53 co?	91 Ti + 5; 70 Fe 2; 90 Fe 2	10 d	69-2; 91-2; 05-1
72.3	20		13 Fe 3	}	14-2
72.9		31	75 Fe 2		1 d
73.5	65	83	55 Ti + 3; 48 Fe + 6; 32 Fe 2	10	32-2; 46-3; 55-3
74.2	27	30	14 Y 7; 12 Ti 1; 93 Fe 2	1	93-3
74.8	24	15	80 Cr 3; 92 Fe 2	2	81-0; 92-4
75.2		15	30 Pr 5; (13 u 1)		13-1

λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
75.6	25	20	64 Fe 4	3	65-5
4176.4		12	57 Fe 2; 60 Mn 4	1	56-5
77.6	70	67	52 Y + 10; 60 Fe 2	12	54-3; 61-3; 70-1
78.2	31	20	05 Fe 1		06-2
78.9	68	78	87 Fe + 6	8	86-3
79.4	40	41	41 Cr + 2; 43 Pr 10	3	38-3
80.1		19		1	40-1
80.8	26	20	84 Ny 10; 81 C	2	81-2
81.7	31	23	76 Fe 6; 72 Cr 2	3 d	71-1; 76-5
82.4	26	16	38 Fe 2	2	39-3
83.3		11	31 Ti 2; 44 V + 10	2 d	30-1; 46-2
84.3	31	24	33 Ti + 2; 24 Lu 10; 47 Ni 4	3 d	00-4; 31-2
84.9	24	25	90 Fe 4	3	90-4
86.2		20	12 Ti 6		12-1
86.7		32	60 Ce 10	3	62-2
87.0	28		05 Fe 6	4	04-6
87.8	31	18	81 Fe 6	4	59-2; 78-5; 86-3
88.7	24	13	69 Ti 2; (73 u 4)	2	73-4
89.3		11	52 Pr 10	1	10-1; 56-2
90.2	32	8	29 Ti + 1; 13 Cr 3	2	24-0
90.4		8			39-0
90.7	24		71 Co 7; 91 Nb 10	0	71-1
91.4	35	31	44 Fe 6; 27 Cr 4; 68 Fe 2	5 d	43-6; 68-3
92.6		18	(57 u 2)	0	57-2
93.2		17		1, 2 d	68-0; 80-0
93.8		28	66 Cr 3	1	
94.4	22	13		1 N	49-0
95.1		20	95 Cr 3; 90 Fe 1; 10 Nb 8; 34 Fe 3	2	85-1; 33-5
95.9		36	22 Fe 2		21-4
96.7	33	(31) co	67 Fe 1; 53 Fe 1; 55 La 10	2	54-2; 68-1
97.0	24		10 C; 23 Cr 3	3	10-2
97.9	19	30	(06 u 2)		06-2

λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
4198.3	24	30	31 Fe 6; 27 Fe 1	5 d	26-4; 33-4
98.7	22		65 Fe 2	3	64-3
99.1	43	45	10 Fe 6; 29 Y + 3; 09 Zr 6	5	11-5
4200.1	17	17	98 Fe 1; 10 Cr 2	1	89-1; 99-2
00.8	27	13	74 Ti 2; 92 Fe 2	3 N	60-1; 79-1; 93-3
01.3	22	12			
01.8	24	21 co ?	73 Ni 5; 03 Fe 7	0; 6	71-1; 04-8
03.0	24	21	03 Sm 10; 75 Fe 1	3	76-2; 13-1
04.2	27	19	99 Fe 3; 95 Fe 1	2	94-3; 00-4; 20-0
04.8	20		70 Y 5; (76 u 2)	0	72-1; 76-2
05.1	43	54	03 Eu 10; 07 V + 10	8	03-1; 08-1
05.7	27	18	54 Fe 2	1	54-2
06.0	20			0	
06.6	28	(40) co	70 Fe 2; 72 Pr 10	2 d	57-1; 70-3
07.2	21	17	13 Fe 2	1 d	13-3
07.8	30				82-0
08.4		16	61 Fe 2; 35 Cr 2	0; 0	35-0; 61-3
08.9	39	40	98 Zr + 10	4	98-1
09.5		20	35 Cr 4		
09.8		19	80 V 8	0	82-1
10.4	31	26	36 Fe 6	3 d	33-4; 40-3
10.9		12	(97 u 3)	0	97-3
11.2	34			0	
11.8	32	19	79 V 10; 74 Dy 10; 88 Zr 5	3	89-2
12.7	25	23	(64 u 3)	1	64-3
13.9	24	19	86 Zr 5; 65 Fe 2	3 N; 0	65-3; 91-0
15.5 ¹	204	197	52 Sr + 10; 42 Fe 2	40	42-2; 54-5
16.2	36	29	19 Fe 4	1	98-1; 19-3
16.8		18	70 V 1; 48 V 5	2	
17.5	28	22	56 Fe 2; 55 La + 10; 61 Cr 3	2	26-1; 56-5
18.3	24		(22 u 1; 40 u 1)	1	22-1; 40-1
19.4	29	(15) co ?	37 Fe 5	3	38-4; 42-3

λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
4220.3	30		35 Fe 2	2	05-1 ; 35-3
20.7		19	62 Y 6	2	
21.0		16			
22.2	30	14	22 Fe 5	2	22-5
22.9	40	(27)	74 Cr 2 ; 62 Ce 10	1	73-0 ; 10-1
23.6		13	56 V ; (48 u 1)	1	48-1 ; 58-1
24.2	32	23	18 Fe 3 ; 24 Y 3	2	18-4
24.5		24	51 Fe 2 ; 85 Cr + 2 ; 81 Ti 2	1 d	51-3 ; 86-2
25.3	48	41	34 Pr 10 ; 46 Fe 4	2	46-3
26.1		25	96 Fe 2		96-2
26.5	21		43 Fe 2		42-2
26.8	93	98	73 Ca 10	25	74-20
27.3	37	41 co ?	44 Fe 7 ; 64 Ti 1	2	31-1 ; 45-4
28.3		co		0	93-1
28.9		12	(72 u 1)	1	72-1
29.7	24	20 co ?	75 Fe 1 ; 52 Fe 1	3	52-2 ; 77-3 ; 91-1
30.7		14		}	48-0 ; 57-0
31.1		23	05 Ni 5		2
31.62	21	21	52 Fe 1 ; 61 Zr 3 ; 70 Fe 1		61-1 ; 69-1
32.40	26br	25	40 Nd 8 ; 46 V 6	1	
33.14	120	128	16 Fe + 8	20	17-4
33.66	31	32	61 Fe 6	1	61-6
34.38	26	24	53 V 6	1	
35.24	44	40	14 Mn 8 ; 29 Mn 8	3	14-2 ; 29-3
35.81	33	co	71 Y + 8	1	73-0
36.05	33		95 Fe 8	6	95-8 ; 12-1
37.21	39	23	16 Fe 2. (08 u 1 ; 25 u 1)	2 d	08-1 ; 18-3 ; 25-1
38.03	31	21	04 Fe 1	2	03-3
38.50	28	36	39 La 10	2	40-1
38.86	29	31	82 Fe 4 ; 96 Cr 3	2	81-5
39.4		16	31 Zr 8		36-2
39.86	44	38	73 Mn 5 ; 85 Fe 2 ; 91 Ce 8	3	73-3 ; 85-3 ; 95-1

λ	$I(a)$	$I(b)$	Elements	MITCHELL	ROWLAND
4240.64	[18	13	37 Fe 2; 71 Cr 3	0 d	38-2; 46-1; 71-1
41.10	[16	11	03 Pr 10; 11 Fe 1	1	12-2
41.81	15		68 Zr 7		
42.36	30	35	35 Mn; 35 Cr + 5	3 N	37-2; 45-2
42.66	14§		59 Fe 1; 73 Fe 2	1	61-2; -74-2
43.49	24 br 80	21	37 Fe 2; (55 u 1)	2; 1	36-1; 45-3; 55-1
44.0	} 22	} 5	42 Fe 1	} 1 N	82-2; 25-0
44.6					
44.78	13§	7	71 Sm 5; 80 Mo + 8		
45.24	27	28	26 Fe 2; (35 u 2)	2	26-4; 36-2
45.97	28	21 d.	87 Fe 1; 09 Fe 2	1	02-0; 09-2
46.84	166	192	85 Sc + 10	30	84-5
47.38	43	38	37 Nd 10; 44 Fe 5; (30u 1)	1	30-1; 43-4
48.26	19†		22 Fe 2	2	22-2
48.68	[26	24	67 Ce 8	3 N	72-2
48.92	[13†	14	(94 u 2); 97 Cu 6		94-2
49.60	20	19	(49 u 1; 64 u 2)	1	49-1; 64-2
50.10	36	42	13 Fe 7	4	13-8
50.81	41	41	79 Fe 8	5	78-8; 91-1
51.3		5			33-0
51.70	23	22	60 Ti 0; 76 Ti 1; 75 Gd 8	2	74-00
52.24	20	20	30 Co 5	3	31-0
53.26	17	17	36 Gd 4; (20 u 1)	1	20-1; 36-00
53.78	23	16	62 Gd + 5; (90 u 1)		90-1
54.36	74	76	34 Cr 10	15	34-8
55.27	15†		(25 u 1)	0	25-1
55.77	25	26	85 Fe 1; 79 Ce 8; (63 u 1)	1	63-1; 83-2
56.35	27	24	21 Fe 2; 33 Dy 8; 40 Sm 9; 42 Zr 3	1	21-1; 31-00; 41-00
57.63	20 (§)	9	66 Mn 5	1	66-2
58.17	35	34	16 Fe +; 38 Fe 1	4 N	06-1; 32-2
58.58	22*	22	61 Fe 1; 57 Ti 2	1	61-2; 72-1
59.03	18	16	95 Fe 1	1 N	95-1

λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
4259.54	16		64 Bi + 10; (30 u 1)		30-1
60.1	18†		99 Fe 2; 13 Fe 2	2 d	99-2; 12-3
60.48	47	49	48 Fe 10	8	48-10
61.6	23†	} 24co	63 Ti 3; 37 Cr 3; (73 u 2)	1	52-2; 73-2
62.00	32		09 Gd 9; 10 Nb 8	2	93-1; 98-1
62.63	15	16	68 Sm 6		70-0
63.22	19	17	14 Ti 8; 14 Cr 5	1	13-2
64.14	19	16	21 Fe 2; (97 u 1)	1 d	97-1; 21-3
65.13	15‡	11	26 Fe 2; 28 Ti 2	0	26-2
65.70	17br	9	73 Ti 2; 92 Mn 5	1	67-0; 92-2
66.86	18	19	91 Y 3; 97 Fe 2	1 N	96-3
67.30	14	13	(38 u 2)	0	38-2
67.84	28	28	84 Fe 2; 00 Zr 4	3	74-1; 82-3; 98-0
68.65	21	16	64 V 8; 75 Fe 2	2	64-0; 75-2
69.32	15)	18	49 La 7	1	46-0
69.66	16)	7	74 V 3	1	74-2; 86-2
70.12	21	25	16 Ti 3	1	17-1
70.54	17	13			
71.20	33	38	16 Fe 7	4	16-6
71.74	48	47	76 Fe 8	10	77-15
72.35	16		27 Pr 9; 44 Ti 3		30-0
72.76	16br	20	(89 u 1)	1	54-1; 89-1
73.35	39	41	32 Ti 1; 48 Zr 4; 33 Fe + 0	3	32-3; 48-2
73.82	25		(88 u 1; 94 u 1)	0	88-1; 94-1
74.82	69	65	59 Ti 10; 80 Cr 10	20	59-2; 80-7
75.51	30br	30	64 La 4	2	65-0
76.47	14)		44 Ti 3; 67 Fe 1; 68 Zr 3	1	43-0; 68-2
76.89	12)		96 V 6	1	99-1
77.45	17	18	38 Zr 2; (53 u 2)	1	38-0; 53-2
78.17	19br 53		13 Fe 1; 23 Fe 1; 24 Ti 3	2	23-3
78.83	13		82 Ti 1; 98 V + 5	0N	85-1

λ	$I(a)$	$I(b)$	Elements	MITCHELL	ROWLAND
4279.73	29br	30	87 Fe 2 ; 70 Sm 7 ; 48 Fe 1	2	48-2 ; 71-2 ; 87-1
80.17	24br	co	09 Ti 1 ; 20 Zr 6 ; 33 Ti 1 ; 41 Cr 4	1 ; 1	03-1 ; 21-1 ; 40-1
81.10	33br	26	10 Mn 5	2	95-1 ; 10-2
81.91	22	19	(97 u 2)	2	97-2
82.46	42br 48	35	41 Fe 6	5	40-5
83.10	16		10 Ca 8	3	01-4
84.22	21	24	(22 u 2) ; 09 Mn 3 ; 06 V 7	2 N	22-2
84.54	19		50 Nd 6 ; 67 Ni 6		68-1
84.96	22	19	98 Ti 3 ; (83 u 1)	1	83-1 ; 00-2
85.51	29br	25	45 Fe 1 ; (53 u 1)	2	36-1 ; 45-3 ; 53-1
86.08	29	23	01 Ti 9 ; 83 Fe 1 ; (19 u 1)	2	01-2 ; 19-1
86.52	20	25	44 Fe 1 ; 68 Fe 1	1	47-3
86.97	26	19	89 Fe 1 ; 98 Fe 1 ; 94 La 8		87-1 ; 00-2
87.51	9*		42 Ti 9 ; 58 Fe 1		41-1
87.94	52	43 45	88 Ti + 2 ; 01 Ni 6	4	88-2 ; 99-1
88.91	24	18 23	96 Fe 1 ; 08 Ti 10	1 ; 2	96-1 ; 08-2
89.39	19 †		36 Ca 8	} 15	37-4
89.75	66	51 55	72 Cr 10 ; 92 Ti 1		71-5 ; 92-1
90.23	92	62 65	23 Ti + 10 ; 38 Fe 2	15	22-2 ; 38-1
91.08	30	22 29	94 Ti 4 ; 14 Ti 9 ; 87 Fe 1	} 3 d	88-1 ; 95-3 ; 12-2
91.47	17 †	17 26	47 Fe 1 ; (30 V 2)		47-2
92.08	27	14 co 22	(05 u 1 ; 13 u 2) ; 98 Cr 2 ; 29 Fe 1	3 d	05-1 ; 13-2 ; 29-2
92.48	12 (§)				
93.04	30	16 23	(03 u 2 ; 11 u 3)	3 d	03-2 ; 11-3
93.62	16 §	7 11	57 Cr 2		
94.12	91	59 68	10 Ti + 10 ; 13 Fe 6	15	04-2 ; 14-5
94.77	20 †		78 Sc + 5 ; 79 Zr 6	2	78-2
95.09	26	12 co 23	94 Fe 1 ; 02 Dy 6 ; (22 u 3)	2	03-3 ; 22-3
95.80	} 17		76 Ti 9 ; 90 Ni 5 ; 76 Cr 3	} 3 d	75-2 ; 88-1
96.04		25	20 co 33		05 La 9 ; 12 V 6
96.59	58	38 50	56 Fe + 6	5	57-3 ; 68-1
96.94	22 †		(95 u 2)	1	95-2 ; 04-1

λ	<i>I</i> (a)	<i>I</i> (b)		Elements	MITCHELL	ROWLAND
4297.30	22			(21 u 2; 29 u 2)		21-2; 29-2
97.68	10†	}	co	69 V 6; 75 Pr 8; 75 Cr 3	1	52-1
97.96	27			04 Fe 2	1	98-1; 04-2
98.61	{ 23	}	co	67 Ti 10	2	67-2
98.91	{ 20†			99 Ca 6; 78 Ni 2	3	81-2; 99-3
99.25	36		co	22 Ti 6; 24 Fe 7; (14 u 1)	3	14-1; 25-4
4300.08	103	64	77	05 Ti + 8	15	05-3
00.54	27*			55 Ti 10; 51 Cr 3		57-2
01.09	29	12	26	08 Ti 10; 10 Nb 10; 19 Cr 3	2	00-2; 10-4; 17-1
01.95	61	35	48	93 Ti + 5; 81 Zr 2	5	92-2
02.25	9†			19 Fe 2; 30 Y 10		19-2; 30-2
02.59	41	14	28	53 Ca 10; (75 u 2)	2	53-4; 75-2
03.18	60	30	44	18 Fe + 4; 97 Ti 1	3d	91-1; 18-2
03.55	33	25	38	59 Ti + 1; 61 Nd 10		42-1; 59-1
03.87	24*	4	18	(83 u 2; 94 u 4)	1	83-2; 94-4
04.50	25 br 70	10	21	55 Fe 1; 40 Ti 1	1	39-1; 57-2
05.38	26			46 Fe 2; 46 Sr + 5; (32 u 1)	3	32-1; 45-3
05.68	[26	}	20 30	71 Sc + 6	}	71-2
05.94	[29			91 Ti 10		4 d
06.78	36	15	26	73 Ce 8; 95 Ti 1; (86 u 2)	2	70-2; 86-2
07.28	25*			18 V 5; (30 u 2); 25 Ni 3	1	30-2
07.70	[31†			74 Ca 8; (56 u 2)	}	56-2; 75-3
07.94	[67	36	50	89 Ti + 4; 91 Fe 8		15
08.57	23	4	18	50 Ti 2; (60 u 2)		60-2
09.00	25	4	18	04 Fe 2; 07 Ti 1	0	90-1; 04-2
09.33	12†			38 Fe 2 (46 u 1)		38-3; 46-1
09.65	57	28 d	43	62 Y + 10; 80 V 6	4	63-1; 72-1
10.08	24			(11 u 2; 23 u 1)		11-2; 23-1
10.50	26 br	7	20	(47 u 1); 38 Ti 1	0; 0	38-2; 47-1
10.8	} 25	7	20	78 Fe 1; (99 u 1)		70-2; 90-1; 99-1
11.2		7	20	06 Mo + 5; (17 u 2)		17-2
11.57	30 br	7	18	53 Fe 1; 66 Mo + 5; 65 Ti 2	1	45-2; 51-2; 72-2

λ	<i>I</i> (a)	<i>I</i> (b)		Elements	MITCHELL	ROWLAND
4312.22	25 br	8	19	(09 u 2; 15 u 1; 30 u 2)	0	09-2; 15-1; 30-2
12.88	72	39	46	88 Ti + 8	10	87-3; 03-1
13.60	19	10	14	(64 u 2)		64-2
14.13	69 br 51	56	59	12 Sc + 10	10	09-3; 22-1
14.97	80	54	57	98 Ti + 5; 81 Ti 7; 09 Fe 5	12	80-1; 98-3; 10-4
15.47	14†	12		50 Y 3		
16.10	14	6		05 Gd 5	0	
16.77	25	14		80 Ti + 2	2	80-1
17.38	16	8		31 Zr 5	1	30-0
17.62	10‡	3				72-0
18.08	10	4				07-0
18.60	[22 16]	} 26		64 Ca 8; 65 Ti 9	4	66-4
18.92				95 Sm 10		
19.56	13	5		65 Cr 2		64-0
20.19	10†					
20.75	99	86		80 Sc + 10; 95 Ti + 3	15	75-3; 96-2
21.74	18	17		80 Fe 2; 67 Ti 7	1	80-2
22.49	21	10		52 La 6	1	51-0
23.18	24 br 66	co		(01 u 1; 23 u 2); 46 Ti 1	2 d	01-1; 23-2
23.95	25 br	co		(85 u 3; 98 u 1); 01 Zr 3	0 d	85-3; 98-1
25.01	61	55		00 Sc + 10; 96 Fe 1; 08 Cr 3	6	99-4; 15-1
25.47	19†			37 Ni 2; 61 Ni 6	} 12	36-1; 62-1
25.80	65	63		77 Fe 9; 66 Gd 9; 77 Nd 10; 82 Tb 5		62-1; 78-8; 96-1
26.45	19	13		36 Ti 6; 37 Nb 10		36-0
26.97	23 br 60	17		76 Fe 2; 98 Ti 1; 10 Fe 2	1	76-2; 11-3
27.89	20	11		93 Nd 7	1	92-2
28.95	20	13		03 Sm 8	1 N	
29.40	12‡	9				29-0; 40-0
30.19	[24 32]			25 Ti + 3; 03 V 6	2	24-1; 03-0
30.66		23		71 Ti + 3; 96 Fe 1; 78 Y 3; 70 Ni 5	3	71-2
31.66	20	14		64 Ni 5	1	65-2
32.72	22	17		83 V 8; 58 Cr 2	1	58-0; 83-0

λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
4333.77	56	46	80 La 10; 98 Pr 10	5	76-1
34.25	13*		17 Sm 8		
34.77	15	6	86 Ti 2; 97 La 6		67-0; 80-0; 94-0
35.3		6	(27 u 1)	0	27-1
35.74	12§	5	74 Pr 4	0	
36.21	17	12		1	
37.06	24	21	05 Fe 5	2	06-5
37.47	21†		32 Ti + 1; 41 Mn 3; 57 Cr 6		56-3
37.93	102	88	92 Ti + 10; 27 Fe 2	15	92-4; 27-1
38.72	20	18	69 Pr 5; 71 Nd 6; 80 Cr 2	1	
39.41	18*	f	45 Cr 6; 72 Cr 5		45-4; 72-3
40.53	1003		47 H	80	47-20
41.4	26*		39 Ti + 3		37-2
41.9	{ 13*	} 13			83-0; 93-0
42.38	{ 13		18 Gd 10	1 N	
43.28	{ 18	13	28 Fe 2	2 N	21-2; 27-2
43.75	{ 17	17	70 Fe 2; 81 Ti 1	1	70-2
44.29	[41	} 31	31 Ti + 3; 40 Pr + 10; 27 Ti	} 5	29-2
44.53	[19		51 Cr 7		51-4
45.89	{ 19 br	} co	87 Sm 4; 10 Ti 2		91-0
46.58	{ 19 br		56 Fe 2; 59 Ti 1; 83 Cr 3	0	56-2; 83-1
47.30	14		24 Fe 1	0 d	24-1
47.80	23	co	85 Fe 1; 80 Sm 9; 89 Zr 7	2	56-1; 84-2
48.55	} speck	7			34-1
49.12		9	95 Fe 1; 79 Y 9	1	95-2
49.77	15	12	79 Ce 8	1	
50.40	12§	10	34 Mo 6; 48 Sm 7		59-0
51.04	24 br	21	05 Cr 5; 83 Ti + 2	2	84-1; 06-3
51.80	87	57	77 Fe + 6; 77 Cr 7; 55 Fe 3; 91 Mg 6	12	55-2; 77-5; 92-5
52.76	30	19 fc	74 Fe 4; 88 V 8	5 d	75-4
53.96	15(§)	7	07 Ti 2; 98 Cr 2	0; oN	95-0
54.58	24	co	62 Sc + 5	3	62-1

λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
4355.10	14*		10 Ca 6 ; 32 Ti 1	0	10-2 ; 35-0
55.87	17 br	9	95 V 3 ; 91 Ni 4	2	71-0 ; 90-0 ; 00-0
56.52	14 br	7		1	61-0
57.45	12§	5	52 Cr 2		52-0
58.17	26	16	20 Nd 9	2 N	17-0
58.67	39	25	72 Y + 10 ; 51 Fe 2	4	51-2 ; 72-0
59.35	14†				
59.70	39	31	63 Cr 6 ; 58 Ni 5 ; 74 Zr + 10	5	62-3
60.48	25	11	50 Ti 2	0	48-1
60.80	14†		81 Fe 1	0	80-1
61.74	14§	6		0 N	
62.30	18 br 68	8	(53 u 1)	1	10-0 ; 53-1
63.24	19 br 78	12	13 Cr 4	2	11-1
64.16	19	8	(04 u 1 ; 19 u 1)	2	04-1 ; 19-1
64.64	19	12	65 Ce 6 ; 66 La 5	2	
65.45	8	3		0	53-0
65.95	14		90 Fe 1	0	90-2
66.55	19	co	45 Zr 5 ; (68 u 1)	2 d	50-1 ; 68-1
67.66	28	17	67 Ti + 6 ; 58 Fe 2	4	59-5 ; 68-2
68.00	11†		91 Fe 1 ; 05 V 5	0	91-2
68.42	15* br 90	co ?	33 Pr 9 ; 44 Nb 8 ; 30 Ni 4	0	
69.41	16*	13	41 Fe + 1	1	41-1
69.78	26	18	78 Fe 3	4	78-4
71.00	26		95 Zr + 10 ; (06 u 1)	3	98-1 ; 06-1
71.3	13* br	co	28 Cr 6 ; 56 Fe 1	1	28-2
72.33	14	6	40 Ti 2	0	34-0
72.80	15	5	99 Fe 1		74-0 ; 85-0 ; 99-0
73.26	8†		26 Cr 3		26-1
73.60	21	co	57 Fe 2 ; 61 Co 4	1 N	57-1
74.39	45	32	51 Sc + 10 ; 49 Fe 1 ; (22 u 1)	10	17-1 ; 22-1 ; 47-3
74.92	107	69	95 Y + 10 ; 94 Mn 4 ; 82 Ti + 3 ; 00 Nd 10	15	82-0 ; 94-2
75.92	47	28	93 Fe 5	6	95-6

λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
4377.18	17	8	(23 u 2)	1	23-2
78.30	15	5	(26 u 2) ; 17 Cu 8 ; 23 Sm 4	2	26-2
78.82	8 (§)		(90 u 1)		91-1
79.22	20	11	24 V 10 ; 34 Y 4	3	24-4
79.78	18	12	77 Zr 8	2	77-0
80.07	11 †	11	08 Co		06-2
80.49	10	} 8	43 Sm 4	} 1	49-0
80.87	10		(71 u 2) ; 12 Cr 3		72-2
82.16	22br 68	15	17 Ce 8	2	
82.81	20		78 Fe 2 ; 65 Mn 2	0	77-2
83.60	76	48	55 Fe 10 ; 45 La + 8	15	56-15
84.37	26	20	(31 u 1) ; 53 Ni 3	1	32-1 ; 53-0
84.77	24	19	68 Fe 1 ; 73 V 10 ; 81 Sc + 5	2	71-3 ; 83-0
85.07	12 †		98 Cr 6 ; (13 u 1)	0	98-2 ; 13-1
85.38	51	35	39 Fe + 1 ; 26 Fe 1	5	25-1 ; 39-2
85.75	14*		68 Nd 10		
86.88	29	16	84 Ti + 5 ; 80 Ce 8	3	85-1 ; 06-1
87.56	12	} co	47 Cr 3	0	40-0 ; 50-0 ; 60-0
87.95	20		90 Fe 2 ; 93 He ; 06 Ti 2	2	90-2
88.40	21		42 Fe 2 ; 51 Ti 1	2	41-3
89.33	16	8	25 Fe 2	0	25-2
90.00	20br 76	co	99 V 10 ; 85 Ni 4	2	99-2
91.00	33	21	96 Fe 3 ; 87 Sm 10 ; 02 Ti + 2	3	95-2 ; 02-1
91.67	33	17	76 Cr 5 ; 66 Ce 8	3	75-1
92.15	8 (§)		(06 u 1)	} 0	06-1
92.65	10 (§)	3	(58 u 1)		58-1
93.40	13br 78		(52 u 1)		52-1
94.06	37	23	06 Ti + 2 ; 93 Ti 5	3	06-2
95.04	151	101	04 Ti + 10 ; 24 V 10 ; 29 Fe 2	25	03-3 ; 24-2
95.88	26	12	86 Ti + 2	2	84-1
96.55	11			0	

λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
4396.98	{ 10		(95 u 1)	} ON	95-1
97.43	{ 11				
98.00	48	29	03 Y + 10	} 8	99-1
98.40	9†		31 Ti + 1		29-0; 48-0
98.77	12	5			
99.22	12*	8			28-0
99.76	56	36	77 Ti + 6; 60 Ni 4	12	77-3
4400.36	57	36	42 Sc + 10; 35 Fe 1	12	39-3; 57-1
00.87	{ 21*	16	84 Nd 10; (01 u 1); 87 Ni 3	0	85-0; 01-1
01.47	{ 26br 52	f	45 Fe 2; 30 Fe 3; 55 Ni 10	6	29-2; 44-1; 54-2
02.45	8	fd	55 Ba 8		
03.28	23	12	38 Cr 2; 48 Cr 3; (18 u 1)	3	18-1; 36-0
04.29	19	8	28 Ti 6	2	26-1
04.79	53	32	75 Fe 8; 90 Ti 3	15	76-10; 02-1
05.78	12		67 Ti 1; 84 Pr 8	0	73-0
06.59	17		65 V 8; 68 Gd + 10	2	64-2
07.09	13			0	
07.71	26	12	72 Fe 2; 68 Ti + 1; 65 V 8	2	64-2; 71-4
08.15	12†		21 V 6; 07 Mn 2	} 4d	19-2
08.44	26	21	42 Fe 4; 48 Ti 1; 52 V 6		41-3; 51-2
08.78	18		83 Pr 10	1	
09.12	10†		12 Fe 2; 23 Ti + 1		12-1
09.41	21	16	40 Dy 8; 53 Ti + 1	2	51-1
10.55	13br	fd	49 Ni 5; 72 Fe 2; 49 Mn 2	2	51-2
11.08	30	13	10 Ti 5; 03 Nd 8; 09 Cr 3	4	07-1
11.94	22br 45	9	94 Ti + 1; 87 Mn 3; 28 Cr 3	0; 2	92-1
13.10	9(§)		03 Zr 4		
13.72	18	8	86 Cr 3; 77Pr 5; (59 u 1)	1	59-1; 85-0
14.40	[11	} 5			
14.76	[17		74 Fe 2; 87 Mn 8	2	88-2
15.11	36	19	13 Fe 8	10	12-8
15.57	47	29	58 Sc + 10; 59 Ti 1	10	55-3

λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
4416.26	11		48 V 7; 53 Ti 2		47-0
16.83	49	32	81 Fe + 4; 61 V + 10	8	81-2
17.25	11†		29 Ti 6	1	28-0
17.72	66	39	71 Ti + 6	15	72-3
18.30	27	f	33 Ti + 2; 43 Fe 1	2	33-1
18.81	16br	15	78 Ce 7	1	
19.85	10br	4	77 Mn 3; 94 V 3	0;1	
20.52	20br 50	11	54 Sm 7; 62 Nb 8; 66 Sc + 1	2	28-0
21.11	21	} co	14 Sm 9	0	
21.86	22br 63		80 Ti 3; 95 Ti + 2	2	93-1
22.60	36	20	57 Fe 4; 60 Y + 10; 83 Ti 5	3	57-3; 82-0
23.17	16	f	14 Fe 1; 08 Ni 3	1	13-1
23.74	13	f	86 Fe 2; 63 Mo 8	1	84-2
24.32	32	16	30 Cr 4; 19 Fe 1; 35 Sm 10; 39 Ti 1	3	29-0
25.44	24	9	44 Ca 10; 66 Fe 1	5	44-4
26.07	14	9	06 Ti 5; 02 V 6	1; 1	03-0
26.53	6	f	70 Mo 5	0N	
27.34	49	36	31 Fe 5; 11 Ti 8	10	10-2; 31-5
27.97	17		(00 Mg + 2)	1	
28.50	12	7	52 V 5; 50 Cr 3	1	54-1
29.23	20	11	23 Pr 10	2	
29.91	38	28	80 V 5; 90 La 10; 04 Ti 1; 94 Cr 2	4	
30.29	8†		20 Fe 2; 28 Ti 3		19-1
30.62	20	14	62 Fe 4; 55 Cr 3	2	61-3
31.34	16	7	35 Sc + 1; 28 Ti 2	1	35-0
31.8	10br			0	84-0
32.15	17	6	10 Ti + 1; 18 Cr 3	0	16-0
32.6	8	4	57 Fe 2	0	57-1
33.24	23	10	22 Fe 2	2	22-3
34.00	21	15	00 Ti 6; 81 Fe 2	2d	78-1; 00-0
34.41	19	14	34 Sm 10	1	44-0
35.02	34	18	96 Ca 10; 96 Mo 10; 15 Fe 2	7	96-5; 15-2

λ	$I(a)$	$I(b)$	Elements	MITCHELL	ROWLAND
4435.66	37br 50	18	68 Ca 8 ; 54 Eu 10	6	68-4
36.15	9†		14 V 7 ; 06 Mn 2	} 2	14-0
36.39	16	10	36 Mn 7		35-2
36.99	15	6	93 Fe 2 ; 98 Ni 5	2	94-2
37.70	13	7	84 V 7 ; 58 Ni 2	1d	84-0
38.30	14	6	35 Fe 2 ; 20 Ti 2 ; 23 Gd + 8	1	34-1
39.17	10		22 Ny 8	0	16-0
39.67	10		64 Fe 1	} 0	64-0
40.07	6†	} co	89 Fe 2		88-1
40.46	20		35 Ti 5 ; 45 Zr 4 ; 48 Fe 1	3	46-1
40.95	13		84 Fe 1 ; 97 Fe 2	1d	82-1 ; 98-0
41.66	26	11	69 V 7	3	71-3
42.38	28	11	35 Fe 5 ; 48 Ni 4	3	34-6
42.99	[23	18	99 Zr + 10 ; 84 Fe 2	3	83-1 ; 99-0
43.23		20 Fe 3 ; 18 Ti 1		20-3	
43.83	125	90	80 Ti + 10	20	81-5
44.55	32	35	56 Ti + 1	4	56-2
45.39	11		43 Fe 1	0	47-1
45.79	7*	1		0	
46.43	22	10	37 Nd 10	3	
46.91	[12	} 6	85 Fe 2	} 2d	84-2
47.19			14 Fe 2 ; 22 Nb 10 ; 13 Mn 2		13-2
47.75	24	7	72 Fe 5	4	72-6
49.32	28	17	15 Ti 8 ; 33 Ce 9	4	14-2
49.78	19	f	72 Dy 8 ; 74 Mo 7 ; 84 Pr 8	2	
50.50	55	36	49 Ti + 10 ; 32 Fe 2	8	31-1 ; 48-2
50.96	14*	f	91 Ti 7	2	92-1
51.61	28	15	59 Mn 9 ; 55 Nd 10 ; 61 Fe + 0	3	58-3
52.08	14	f	04 V 10	1	00-0
52.77	[15	11	75 Sm 9	1d	61-0
53.09		9†	7	01 Mn 5	} 1
53.40	9†	7	32 Ti 7	32-2	
53.75	11		71 Ti 7	1	

λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
4454.40	14*	f	39 Fe 3	2	38-3
54.78	38	26	78 Ca 10; 67 Fe 1; 79 Zr 5	6	78-5; 02-1
55.27	18br	f	32 Mn 6; 33 Ti 10; 02 Mn 6; 04 Fe 2	2	31-2
55.86	23	8	82 Mn 5; 88 Ca 8	3d	81-2; 89-3
56.40	19	11	33 Fe 1; 62 Ti + 1	1 N	33-1; 62-2
56.98	9 (§)	3	90 Fe 1; 04 Mn 5	0	04-0
57.43	26	15	44 Ti 9; 55 Mn 6	} 3d	43-2; 54-2
57.69	5 †		67 V 4		77-0
58.16	18	co	10 Fe 2; 26 Mn 6	0	07-2; 24-2
58.49	13		53 Cr 4	0	52-0
59.10	23	15	12 Fe 5; 05 Ni 9	3	03-2; 13-3
59.75	18	f	78 V 8; 74 Cr 3	1	75-1
60.24	37	21	20 Ce 10; 31 V 10	4	29-1
61.17	26	14	09 Mn 6; 20 Fe 2	2	07-1; 20-1
61.65	37	26	66 Fe 4	4	65-4
62.02	10 †		03 Mn 9; 08 Ti 1	2	00-3
62.37	22	17	46 Ni 8; 37 V 9	1	45-1
62.98	22	11	96 Nd 10	2	
63.43	16	8	39 Ti 2; 55 Ti 5; 42 Ni 3	2	40-0
64.43	36		47 Ti + 2	} 6d	45-2
64.78	18*	} co	77 Fe 2; 68 Mn 7		67-2; 77-1
65.23	12		35 Cr 4	0	35-0
65.72	12		82 Ti 6	1	80-1
66.55	30	19	56 Fe 5; 38 Ni 4	4	56-5
66.93	7 †		94 Fe 2; 90 Co 6	0	93-1
67.33	21	10	33 Sm 9	1	
67.73	6 †		56 Cr 2	0	
68.56	130	84	49 Ti + 10; 67 Pr 9	20	49-5
69.20	22	} co	15 Ti + 1	} 2	15-1
69.43	18		39 Fe 4; 57 Co 10		37-4; 56-0
70.06	9*	f	14 Mn 7	0	13-1
70.38	13*	f	48 Ni 9	2	48-2

λ	$I(a)$	$I(b)$	Elements	MITCHELL	ROWLAND
4470.85	12*	f	88 Ti + 2		85-1
71.57	149	146	48 He	40	
72.86	28	15	93 Fe + 1; 80 Mn 7; 71 Fe 2	4	71-1; 80-0; 92-0
73.96	9br	1	89 Y 3; 06 V 6	0	
74.74	13	4	73 V 6; 60 Mo 7; 86 Ti 4	1	86-0
75.20	8*	1	36 Cr 3	0	30-00
76.00	34	17	02 Fe 7; 06 Ag 5	5	01-4; 08-3
76.88	7 (§)	co	96 Y 5	0	
77.40	10	f	44 Y 4	0d	
78.18	10	} 4		1	02-0
78.61	12		73 Mn 1	0	
79.43	16br 78	8d	37 Mn 2; 36 Ce 6; 61 Fe 2	2d	38-0; 60-1
80.08	15	f	14 Fe 2	1	14-1
80.62	13	4	61 Ti 3	0	58-0
81.19	23	14	27 Ti 8; 13, 33 Mg + 10	3	27-1
81.67	10	3	62 Fe 2		61-1
82.24	32	18	17 Fe 3; 26 Fe 4	5	17-5; 27-3
82.75	13	8	75 Fe 2; 70 Ti 4; 88 Cr 3	2	73-1
83.46	7	1		0	
83.93	14	} 8	94 Co 5	} 2N	77-0; 91-0
84.27	14		23 Fe 3		22-4
84.84	6	3	98 Mo 6		
85.67	13	co	67 Fe 2	3	68-3
86.95	21	14	89 Ce 6; 05 Mo 5	3	91-0
87.57	5 (§)		49 Y 5		
88.09	5 †		13 Fe 2; 05 Cr 3	} 3	05-0; 13-1
88.33	17	10	32 Ti + 6		32-1
88.94	9 †		92 Fe 2; 90 V + 10		90-1
89.23	32	25	21 Fe + 4; 10 Ti 6	6	09-0; 18-2
89.78	14	} d	74 Fe 3	1	74-4
90.12	13		10 Mn 3	2	08-3
90.71	13		77 Fe 2; 53 Ni 3	1	77-2

λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
4491.42	41	21	41 Fe + 4	6	40-2
92.42	11	d	55 Ti 2 ; 32 Cr 3	} 1d	31-01
92.86	6*		69 Fe 1		68-1
93.54	15	7	52 Ti + 1	2	52-1
94.08	9*		(05 u 1)	0	05-1
94.57	21	14	57 Fe 4 ; 60 Zr + 10	3	57-6
95.43	10	6	39 Fe 1 ; 59 Fe 1	1	42-0 ; 57-0
96.23	16	13	15 Ti 8 ; 24 Ti 1	2	15-1
96.96	26	20	97 Zr + 10 ; 86 Cr 6	3	85-3 ; 97-0
97.83	8	6	75 Ti 2	0	67-0
98.87	11	8	90 Mn 7 ; 71 Cr 3	0	73-0 ; 90-1
99.18	5†		(14 u 1)	} 0	14-1
99.61	6	f			
4500.34	10	6	28 Cr 3	1	28-0
01.31	116	85	27 Ti + 10 ; 10 Cr 3	20	09-0 ; 28-5
02.12	6	f	22 Mn 7		22-2
02.54	7	f	59 Fe 1	0	59-0
03.60	3	co	78 Ti 2		
04.85	6br	co	85 Fe 2	0	83-1
05.89	4		75 Ti 1 ; 96 Y 8		
06.44	5†		35 Ti 2	0	
06.77	8	7	84 Cr 3	1d	
08.28	42	33	29 Fe + 8 ; 27 Ti 1	8	28-4
09.25	} 4 6br 80		18 Ce 4	1	29-0
10.08		6	15 Pr 10	0	
11.10	3		13 Ti 2	0	
11.81	10br 57	7	92 Cr 4	1	89-1
12.83	7	7	74 Ti 10 ; 00 Ni 3	2	74-3 ; 99-0
13.36	6	4			43-0
14.15	[8 8	} 8	19 Fe 2		19-1
14.43			8	51 Cr 5 ; (42 u 1)	2d
15.32	46	40	33 Fe + 6 ; 58 Ti 2	6	34-3

λ	$I(a)$	$I(b)$	Elements	MITCHELL	ROWLAND
4516.35	7	4		0	27-0
17.00	3†	6	11 Co 6		15-0
17.50	8	4	53 Fe 2	1	53-3
18.08	12	} co	03 Ti 9	2	03-3
18.42	13		(34 u 1); 54 Lu 10; 66 Ti 2	3	34-1; 58-0; 70-0
19.63	8	4	58 Fe 1; 64 Sm 8	1	
20.24	49	38	24 Fe + 6; 99 Ni 4	8	23-3
21.17	4	3	14 Cr 3	1	13-0
21.81	2		81 Fe 1		
22.67	65br 49	50	64 Fe + 6; 81 Ti 9	12	52-0; 63-3; 80-2
23.16	8*		08 Ce 8; 40 Fe 2	1	08-0; 40-1
23.91	9	8	91 Sm 9; 10 Fe 2	1	
24.74	11	} co	72 Ti + 0; 95 Ba + 10	1	69-0; 94-0
25.14	17		15 Fe 3	3	14-5
26.07	6*	f	11 La + 8; 93 Ti 1; 87 Fe 1	1	86-0; 10-0
26.51	13	f	48 Cr 5; 36 Ti 1; 57 Fe 2		41-1; 47-2; 57-1
26.97	7*	f	98 Ca 6	1	93-3
27.39	20	17	32 Ti 10; 35 Ce 10; 46 Ti 1; 43 Cr 3	3	32-3; 47-0
27.90	4	f	80 Fe 1		78-0
28.61	27br 45	21	62 Fe 7; 28, 47 Ce 10	5	48-0; 63-8
29.58	21br 46	17	46 Ti + 2; 56 Fe 1; 68 Fe 2	4d	49-1; 56-1; 68-1
30.95	20	co?	97 Co 7	1	74-1; 95-2
31.23	8†		15 Fe 5	3	16-5
31.70	6	6	64 Fe 2; 44 Fe 1	1	63-2
33.21	17	15	14 Fe 1; 25 Ti 10	2d	25-4
34.00	147	97	97 Ti + 6; 17 Fe + 1; 00 Co 6	15	97-6; 17-1
34.79	18	13	78 Ti 9	2	78-4
35.67	} 22	} 25d	58 Ti 8; 72 Cr 7; 74 Zr 8	3	57-3; 71-1; 74-0
36.04			23	92 Ti 6; 05 Ti 8	3
36.58	4	} d?		0	
37.17	4		23 Ti 1	0	
37.94	9	4	97 Sm 7; 68 Fe 1	1N	

λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
4538.94	7br	6	76 Fe 1; 08 Ti 2	0N	76-0; 84-0
39.79	19	17	73 Ce 10; 78 Cr 3	3	78-0
40.68	13br 60	11	71 Cr 4; 49 Cr 3	2	50-2; 71-2
41.52	27	18	52 Fe + 1; 33 Fe 1	4d	52-2
42.08	7	} 6	03 Sm 6; 22 Zr 6	0	22-0
42.60	12		72 Fe 1; 61 Cr 3	1	43-1; 61-0; 71-0
43.94	18	8	01 Ti + 1; 94 Sm 7; 82 Co 6	2d	02-1
44.71	15		70 Ti 9	2	62-1; 69-3
45.12	16		14 Ti + 1	2	14-1
45.40	5†		40 V 8; 33 Cr 2		34-0
45.98	13	6	96 Cr 5	2	96-3
46.98	14br 52	7	94 Ni 4; 03 Fe 2	2	93-1; 02-2
47.93	13	6	85 Fe 3; 83 Ti 1; 12 Ti 1	2	85-3
48.70	12	7	77 Ti 9	0	77-2
49.65	140	113	64 Ti + 10; 48 Fe + 4; 65 V 7; 66 Co 7	20	47-2; 64-6
50.83	9	} d	82 Fe 2	1	77-2
51.32	8		29 Ni 4	1	23-0
51.83	3(§)				65-0
52.44	17br 58	11	46 Ti 9; 55 Fe 2	3N	47-2; 55-1
53.11	5		06 V 5; 21 Ni 3	0	18-0
54.10	134	108	04 Ba + 10	20	04-8
55.02	11	10	07 Cr + 9; 08 Ti 1; 12 Zr 5; (98 u 2)	1	99-2
55.50	10†		49 Ti 9	2	48-3
55.93	59	46	90 Fe + 6; 13 Fe 3; 18 Cr 3	10	88-3; 13-4
57.30	3br	f		0	28-0
58.64	32	29	67 Cr + 10	8d	65-3
59.37	2		29 La 4; 37 Y 4	0	
59.97	6†		92 Ti 3; 11 Fe 2; 94 Ni 3	1	92-0; 09-2
60.28	12	7	27 Ce 5	2	
60.91	9	f	72 V 7	0; 1	
61.40	5*	3	(41 u 1)	0	41-1

λ	$I(a)$	$I(b)$	Elements	MITCHELL	ROWLAND
4562.35	19	13	35 Ce 10	4	36-0
63.20	9		26 Cr 2	1	
63.80	88	75	77 Ti + 10	15	76-4
64.69	9	3	72 Fe 1 ; 83 Fe 1	1	69-0 ; 82-0
65.54	16br 50	12	53 Cr 5 ; 61 Co 7 ; 68 Fe 2	2	51-3 ; 66-2
66.18	8	4co?	21 Sm 7	0	
66.82	6br	co	52 Fe 2 ; 99 Fe 1	0	51-1 ; 87-1
67.54	3			0	
68.37	8	d	30 Ti + 1	1	32-0
68.77	4		79 Fe 1 ; 84 Fe 1	1	76-1
69.53	7	4	62 Cr 4	1	61-0
69.95	3*		02 La 6 ; 02 Co 4	0	
71.11	21	13	12 Mg 5	3	10-5
72.01	92	85	98 Ti + 10 ; 79 V + 10	20	98-6
72.83	3	1	09 Nb 10	0	86-0
73.95	3		24 Fe 1	0	22-1
74.76	11	6	73 Fe 2 ; 86 La 8	1	72-2
76.34	25	17	31 Fe + 4	4	33-2
77.12	9	4	17 V 8	1	18-0
77.73	9	3	70 Sm 7	1	
78.68	9	6	57 Ca 8 ; 73 V 6	0;1	55-3
79.25	4*	f	34 Fe 1	1	33-0
80.08	16	10	06 Cr 7 ; 83 Fe 1	3	82-0 ; 05-3
80.48	10		40 V 8 ; 46 Ti + 1 ; 60 Fe 1 ; 61 Ni 3	2	41-1 ; 58-1
81.51	16br 50	10	45 Ca 8 ; 53 Fe 2 ; 62 Co 8	3	40-4 ; 51-4
82.29	5*			0	30-0
82.83	21	17 fc	84 Fe + 1	2d	83-1
83.38	6;†		44 Ti + 1		41-0
83.84	81	80	84 Fe + 6	15	84-4
84.82	8	3	73 Fe 1 ; 83 Fe 2	1d	72-1 ; 82-2
85.88	8	8	84 Ti 1 ; 84 Ca 6 ; 91 Ca 2	2	87-4
86.29	11		37 V 8 ; 13 Cr 2 ; 13 Mn 2	2	23-1 ; 37-1

λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
4587.06	8	1	00 Cu 10; 14 Fe 2	1	13-2
88.19	26	21	22 Cr + 10	5	20-3
88.52	4†	f	73 W 7		
89.97	30	23	96 Ti + 3	6	95-3
90.93	6*	f			79-0
91.37	9	6	23 V + 8; 41 Cr 6	1;2	39-2; 51-1
92.13	10	7	07 Co + 5	2	05-1
92.61	18	10	53 Ni 9; 66 Fe 4	3	53-2; 66-4
93.92	19br 50	15	93 Ce 10; 07 Eu 10; 10 V 10	3d	13-2
95.33	{ 10	} 6d	37 Fe 2; 59 Cr 4; 34 Mn 2	2	36-2; 59-0
96.00	{ 8		06 Fe 2; 95 Ni 4	1N	95-0; 06-2
96.90	8		90 Co 6	1d	90-0
97.90	10br	4	90 Gd 4; 14 Fe 2; (75 u 1)	2;1	75-1; 87-1; 12-3
98.56	3 (§)		45 Cr 2	0	
99.16	2 (§)		24 Ti 3		23-00
99.88	5†		90 Fe 2	0	84-2
4600.22	{ 14	} 11	11 Cr 4; 20 V + 8; 36 Ni 8	1	10-1; 36-2
00.72	{ 13		75 Cr 6; 94 Fe 1	2	75-3; 93-0
01.10	{ 6†		16 Mn 3; 03 Cr 3	1	03-0
01.99	7	4	01 Fe 2	2	00-3
02.91	13br 78	8	95 Fe 3	3	95-6
04.22	5		96 Fe 1		
04.65	6†		60 Fe 2; 80 Y 4	0	56-2
05.01	13	8	99 Ni 9; 25 Fe 2	2	98-3
05.55	9	f	(59 u 2); 37 Mn 3	1	36-0; 59-2
06.27	12	8	15 V 5; 41 Ce 4; 21 Ni 5	2d	22-2
07.00	3†		76 Nb 10		
07.32	[10	} d	34 Sr 10	2	33-1
07.64	[7		66 Fe 4	1	65-4
08.68	2 (§)	f			
09.24	6	f	37 Ti 2	1	27-0
10.06	4br	3	88 Mo 10	1	91-0; 18-0

λ	$I(a)$	$I(b)$	Elements	MITCHELL	ROWLAND
4611.25	18	8	29 Fe 4	3	19-0; 29-5
11.88	3†			0	
12.42	5		27 Dy 8	0	
13.27	21	8	21 Fe 3; 34 Cr 7; 39 La + 5	4	21-3; 36-3
13.96	9br	6	(92 u 1); 21 Fe 1; 30 Ti 1	2	92-1; 21-1
14.76	2 (§)			1	
15.63	9	10	57 Fe 2; 71 Sm 6	2	56-1
16.13	17	10	13 Cr 6; 13 Nb 8; 22 Ti + 1	3	12-4
16.62	11	8	70 Cr + 3 (62 u 1)	1	62-1
17.29	11	6	28 Ti 9	2	27-3
18.11	3	f	06 Ni 3	0	
18.87	21	17	84 Cr + 10; 76 Fe 2	4	79-4
19.37	13	11 fc	30 Fe 4; 50 Ti 1; 54 Cr 4	2	29-3; 53-1
19.85	6		86 La 5; 68 V 8	0	
20.54	19	14	52 Fe + 1	4	51-1
21.37	2	f	35 Mo 7	1	
22.03	6	3	96 Cr 3	2d	89-0; 95-1
22.56	7	f	47 Cr 4	1	63-1
23.09	10br	8	11 Ti 7	3	93-0; 10-2
24.38	4*		57 Cr 2	0	
25.02	11	7	06 Fe 4	2	05-5
26.09	13	} d	19 Cr 6	3	18-5
26.41	14		41 Zr 6; 45 Mo 10; 54 Mn 5		54-0
27.41	5		26 Eu 10	1d	37-0
28.16	17	12	15 Ce 10	3	16-0
29.38	76	47	33 Fe + 4; 34 Ti 5; 38 Co 8	12	34-6
30.09	7	f	13 Fe 3; 12 Nb 10	1	13-4
30.95	2	1	91 Er 6		03-0
32.04	6	3	20 Cr 2	0	14-0
32.83	11	6	92 Fe 3; (81 u 1)	2	81-1; 92-4
34.10	22	11	11 Cr + 8; 98 Zr 9	3	07-2
34.70	5		82 Ti 1		72-1

λ	$I(a)$	$I(b)$	Elements	MITCHELL	ROWLAND
4635.78	4*		85 Fe 2; 52 Ti 1	0	85-2
36.30	6	} co	34 Ti + 1	0	32-0
37.18	4†		18 Ti + 1; 18 Cr 2	0	17-0
37.51	10		52 Fe 4	1	50-5
38.04	9	d	02 Fe 4	2	01-4
38.73	4*	3			
39.36	[11 10	} d	37 Ti 5	} 2	36-2; 50-0
39.70			67 Ti 5; 60 Cr 3		67-2
40.18	8†		95 Ti 5; 06 V; (29 u 1)	2d	94-1; 29-1
40.71	4†		74 V		
41.26	4	3		0N	21-0
42.21	10	7	23 Sm 6; 98 Tb 10	2	
42.71	4	f	81 Mn 3		
43.45	8 br 60	6	47 Fe 3; 69 Y 8	2	46-4
44.11	3†			} 1N	
44.43	6	4			
45.23	8	6	20 Ti 5; 29 Tb 9	1	19-0
46.18	24	15	17 Cr 7	5	17-5
46.64	8*	f	(64 u 1); 81 Cr 2	1	64-1; 78-0
47.38	17	10	44 Fe 4; 35 Ni 2	2	44-4
48.04	10	6	(96 u 1); 12 Cr 2	0	96-1; 12-0
48.70	14	10	66 Ni 10	2d	65-4
49.48	5		46 Cr 3	0	43-0
50.07	6	3	02 Ti 5	0	01-0
50.98	5†	f			
51.32	12	7	30 Cr 6; 17 Cu 8	2	28-4
52.18	19	11	16 Cr 6	3	16-5
53.46	4	1		0	
54.56	17 br 65	10	50 Fe 4; 63 Fe 3	3d	49-4; 62-5
55.75	9 br	co	69 Ti 1; 49 La + 10; 65 Ni 2	1N	65-0; 79-0
56.48	8		46 Ti 8	1	46-3
57.14	18 br 56	17	98 Fe + 1; 20 Ti + 2	3d	97-1; 20-2

λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
4658.35	3	1	31 Y 6		30-0
59.37	3	1			
60.23	3			0d	42-0
60.87	3	3			90-0
61.44	4	4	54 Fe 2		53-1
61.98	6		98 Fe 2; 90 Eu 10	0	97-1
62.53	9	8			41-0; 75-0
63.32	9	12	35 Cr 3; 19 Fe 1; 41 Co 7	1	17-0; 31-1; 41-0
63.72	13		76 La + 8; 86 Cr 3	2	82-1
64.73	6	3	81 Cr 4	0;0	79-3
65.86	5	f	92 Cr 2	1d	90-1
66.37	6†		54 Cr 4		21-0; 47-1
66.74	23	22	75 Fe + 1; 98 Ni 3	3N	74-1; 98-1
67.58	17	14	46 Fe 4; 59 Ti 10; 76 Ni 3	3	45-4; 59-3; 76-1
68.20	10br	6	15 Fe 4; 35 Ti 1; (06 u 2)	1d	06-2; 15-4
69.33	13br 70	14	18 Fe 3; 34 Cr 3	2d	17-3; 32-1
70.40	24br 52	23	42 Sc + 10; 50 V 7	4	41-2
71.61	4		69 Mn 3; (42 u 1)	0	42-1; 68-0
72.44	6	6	(33 u 3)	1	33-3
73.27	9	7	17 Fe 3; (28 u 1)	2	17-4; 28-1
74.03	3		(10 u 1)	0	10-1
74.68	10	10	61 Sm 7; 84 Y 8; 76 Cu 5	1	65-0; 75-0
75.75	5 v br	f	61 Er 5	0	60-0
77.03	7	6	98 Ti 1; 92 Sm 6	0	
77.71	6	f	49 Ti 1		60-0
78.28	9	f	30 Sr 4; 15 Cd 10		17-3
78.90	14	11 fc	85 Fe 5	2N	85-6
79.27	6*		23 Fe 1		23-2
80.30	12	d	30 Fe 2; 14 Zn 10; 48 Fe 1	1	14-1; 30-1; 48-1
80.91	7		92 Cr 2	1	91-3
82.08	12	d?	11 Fe 1; 91 Ti 9	2	12-1
82.42			13	31 Y + 10; 36 Co 6	2

λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
4683.55	6	4	57 Fe 2	1	56-3
84.65	7 v br	10	52 Ti 1 ; 61 Ce 4		59-0
85.28	6	f	27 Ca 4	1d	27-2
86.22	9	8	22 Ni 5	1	21-3
87.32	7br	7	92 Ti 2 ; 92 V 5 ; 39 Fe 1	0d	39-2
88.33	5*		21 Fe 1 ; 37 Ti 1 ; 45 Zr 8	} 1N	18-2 ; 37-0
88.66	6br	6	62 Tb 5 ; 63 Er 5		68-0
89.44	8	8	39 Cr 4 ; 50 Fe 1	1	36-2 ; 50-1
90.23	[6	d	15 Fe 2	0	14-4 ; 38-0
90.57			82 Ti 2	0	80-00
91.49	16br 56	14	34 Ti 8 ; 42 Fe 4 (60 u 1)	3	34-1 ; 42-5 ; 60-1
92.68	} 6	f	49 La 6	0	65-0
93.23			20 Co 7	0	19-0
93.80	5		68 Ti 2 ; 74 W 5 ; 96 Cr 3	0	67-0 ; 94-1
94.96	6br		17 Cr 2	0	86-1 ; 15-0
97.22	8br 73	10	94 Ti 2 ; 17 Er 4 ; 40 Gd 4	1	05-1 ; 40-0
98.46	[13	} 17	49 Cr 4 ; 38 Co 4	} 3d	46-1
98.76			[10		77 Ti 8
99.39	7	6	(33 u 4)	1	33-4
4700.20	6	f	20 Fe 2 ; 20 Ti + 1	0	16-4
01.07	3†		05 Fe 1 ; 15 Mn 4	0	05-1
01.48	7	} co	54 Ni 6 ; (36 u 1)	1	36-1 ; 53-1
01.83	6*			0	90-0
02.72	6*				60-0
03.07	14	10	07 Mg 10 ; 07 Ti 1	3	00-10
03.84	8	8	80 Ni 5	1	81-3
04.50	6	7	40 Sm 5 ; 60 Cu 4	0N	48-0
05.15	7	7	96 Fe 3	1	95-4
05.61	4	f	46 Fe 1		46-0
06.58	8	11	58 V 5 ; 54 Nd 7	1	55-0
07.39	13br 54	11	28 Fe 5 ; 49 Fe 2	2	28-5 ; 49-2
08.05	9	7	04 Cr 7	1	02-2

λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
4708.80	14	co	65 Ti + 2; 97 Fe 1; 98 Ti 1	2	67-2; 97-1
09.10	6*		09 Fe 2	1	09-3
09.75	9		70 Mn 7	2	72-2
10.26	13	co	29 Fe 3; 20 Ti 6; 07 Zr 10	3	29-3
11.10	1			} 1	
11.8	5	6			48-0
12.3	6	f	10 Fe 1	0	08-0
13.20	18br 60	22	15 He	4	
14.09	7*		07 Fe 1; 18 Fe 1	0	07-0
14.45	18	22 fc	42 Ni 10; 37 Fe 1	3	37-1; 42-6
14.93	8*			1	
15.76	12	12	76 Ni 8	2	77-4
17.22	4	7		0;0	
17.77	6	8	61 Zr 5; 69 V 5	0	58-0
18.46	9	11	45 Cr 7	2	42-3
19.68	8br	7	51 Ti + 1	1	51-0
20.19	3*		91 La 6		
21.12	6	6	00 Fe 1	1d	00-2
22.16	15	14	16 Zn 10	3	16-3
22.61	4†		63 Ti 3		62-0
23.18	5	7	18 Ti 3	0d	
24.55	7br	8	42 Cr 3; 42 La + 5; 66 Ti + 1	1N	41-0
25.59	4				
26.06	[3	} 6	94 Fe 1; 16 Fe 1	0	15-0
26.38					
27.18	4†		15 Cr 3		16-0
27.46	12	14	41 Fe 2; 46 Mn 7	2d	42-3; 50-2
28.08	6*			0	17-0
28.56	10	12	55 Fe 2; 53 Y 5	2	55-4
29.27	7	6	22 Sc 5; 02 Fe 1	} 0	03-1
29.68	[4	f	70 Fe 1; 74 Cr 3		68-1
30.00	[4	7	(03 u 2)	1	03-2

λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
4730.80	8	f	72 Cr 4; 90 Fe 1	1	72-1
31.49	21	26	49 Fe + 1	3	47-4
32.44	6br	6	33 Zr 6; 38 Y 3; 49 Ni 4	1	46-1
33.57	[8	} 10	60 Fe 3	2	60-4
33.91	[8		10 Fe 1; 87 Nb 5	1	10-1
34.64	4	6	68 Ti 1		
35.86	7	8	84 Fe 2	1	85-3
36.85	} 14	17	78 Fe 6	3	78-6
37.33		} 9	14	34 Cr 5	2N
37.77	} 4†		63 Fe 1; 64 Sc 5	1	64-1
39.09	6	1	00 Mn 5	2	11-3
39.43	3*		48 Zr 10	0	
40.30	13	14	34 Fe 1; 27 La 8	2 d	35-1
41.02	5	7	03 Sc 6; 09 Fe 1	0N	95-1; 08-1
41.59	7	10	53 Fe 3	1	54-3
42.26	3(§)	6	14 Ti 1	0	
42.86	8	10	80 Ti 7; 08 La 8	1	80-1
43.79	3	4	82 Sc 7		
44.37	6	7	31 Cr 2	1	39-3
45.04	4	f	12 Fe 1		
45.79	8	11	81 Fe 3	2	81-4
47.14	4	4	28 Ti 1		
48.14	9	12	(14 u 4)	1	14-4
48.71	4	6	72 La 6		
49.60	[8	} 10	69 Co 8	} 2 d	67-0
49.90			[6		93 Fe 1
51.07	} 3	3	10 Fe 1	1	10-0
51.6		} 6			
52.28	} 8br	d	11 Cr 4; 41 Ni 4; 50 Tb 10; 13 Ni 3	1; 2	11-2; 43-3
54.03	13	10	05 Mn 10; 37 Co 4	3	04-7; 37-00
54.70	5	7	75 Cr 2; 78 Ni 3	1	77-1
56.08	[9	} d	13 Cr 6; 86 Fe 1; 10 Fe 1	1	12-2
56.51			[10	52 Ni 7	2

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λ	<i>I</i> (a)	<i>I</i> (b)	Elements	MITCHELL	ROWLAND
4757.58	6	6	58 Fe 2 ; 50 V 5	1	59-2
58.17	9	8	13 Ti 8	2	13-1
59.28	9	8	28 Ti 8	2	28-2
59.81	2	3	98 Fe 1	0	
61.0	2	f	00 Y 5	1	
61.5	7	8	53 Mn 5	2	54-3
62.6	14 d	d	38 Mn 9 ; 78 Ti + 1 ; 63 Ni 3	3 d	39-5 ; 64-1
63.9	18	17	92 Ti 1 ; 31 Cr 4 ; 95 Ni 4	4	93-4
64.8		11		1	
65.8		7	86 Mn 5 ; 48 Fe 1	1 ; 1	87-3
66.2		7	42 Mn 6 ; 33 Ti 1	2	44-4
66.8		10	70 Cr 2		
67.9		6	86 Cr 2	0	
68.2		6	33 Fe 1 ; 40 Fe 1	2	34-3 ; 42-2

IV. DISCUSSION OF RESULTS.

1. *Comparison of strips a and b.*

The narrow strips *a* and *b* of the flash spectrum of which registrograms have been made, at visual inspection differ by the amount of continuous background being somewhat larger in *b*. Had the exposure been instantaneous, then we should say, that in both the whole chromosphere was depicted, combined with a different amount of solar border light in both cases. Since, however, during the exposure the moon's edge was moving, it is probable that in each case the lowest part of the chromosphere has been covered during part of the exposure, which part in case *a* was larger (see p. 101). Thus we should expect the total intensity of the chromospheric lines in *a* to be somewhat smaller than in *b*; and this difference should be largest for the lines which extend to the smallest height. This possible difference is, however, obliterated by other differences due to differences in the treatment of the registered curves. It was our chief aim by using both strips to get a controll, as to what amount uncertainties in the method of treatment would change the results; therefore *a* and *b* were discussed after different principles, as has been explained p. 41—42. As a result we see that generally the intensities found from *a* are larger than those found from *b*.

A first cause is to be found in the choice of the background in *a*, as it is given by fig. 15 p. 43. In order to get the total intensity produced at every wave length by the chromospheric emissions the background curve has been laid through the lowest points. If we wish to have the emission of a separate line, however, it is better to subtract the average value of the emission due to the lines not separately visible. This can be found by drawing in fig. 15 a line through the midst of all the points. It is seen to lie higher by an amount varying between 0.5 and 0.7 in *i*; the resulting negative corrections to the *I* of the catalogue between

λ	4205	4225	4245	4270	4335	4415	4470	4540	are
	9	8	7	6	5	4	3	2	1.

For the registrogram of *b* on each sheet a straight line has been drawn through the lowest vales, which seemed sufficiently distant and free from the influence of adjacent lines, without applying corrections for this influence. The differences between the *I* from *a* and *b* sometimes seem to change somewhat abruptly from one sheet to another; this points to small errors arising from the drawing of the lines for dead film, for

zero point and for background. The intensities found for the strongest lines are very sensible to minute differences in the zero point (transmission 0) adopted. Time has failed to investigate all these lesser causes of error originating from peculiarities of the new method of registering the spectra and afterwards measuring the registrograms. The possibility is left open that the systematic difference between a and b is due to real inequalities of the chromosphere, varying a little from one point of the limb to the other.

Still a comparison between the two strips is very useful; on the whole, it gives a good confirmation for the stronger lines and for all the following considerations on multiplet ratio's, and this is of special value where discrepancies occur between observation and theory.

2. Intensities of multiplet lines.

For the lines classified in multiplets the relative intensities emitted by a volume element of gas are on the whole ¹⁾ governed by simple sum rules; moreover, formulae for the single lines have been deduced by several physicists²⁾.

These formulae give the transition probabilities as functions of the quantum numbers; these probabilities, multiplied by ν^4 , are proportional to the energy emitted in the separate lines.³⁾

From table IX on p. 81 below, it will be seen at once *that the energy emitted by the whole chromosphere in each of these wave-lengths, as measured by means of our negatives, is not proportional to this theoretical emission.* In general the observed intensities increase together with the theoretical intensities, but more slowly. *This proves that the chromosphere may not be considered as an optically thin layer of very small effective depth, but that there is an appreciable amount of self absorption in the layer of gas viewed tangentially.*

The observed intensity for the whole chromosphere will, however, be a uniform function of the theoretical intensity for a volume element. For if we have to do with atoms of one element, all being in thermodynamic equilibrium at the same temperature, two spectral lines having the same theoretical emission coefficient will also have the same absorption coefficient; the self reversal and thus the observed intensity will be equal for them. For the chromosphere this cannot exactly hold, because the atoms are not in thermodynamical equilibrium but are excited by a strong radiation

¹⁾ Exceptions, where these simple rules do not hold, have been found at Utrecht: 1. for the principal series of the alkali doublets; 2. for the multiplets of some complicated spectra, as Ni and Co.

²⁾ R. DE L. KRONIG, Zs. f. Phys. 31, 885, 1925; 33, 261, 1925; RUSSELL, Proc. Nat. Ac. 11, 314, 1925; ORNSTEIN and BURGER, Zs. f. Phys. 31, 355, 1925; SOMMERFELD and HÖNL, Sitzungsber. d. Preuss. Akad, 9, 141, 1925; H. HÖNL, Ann. Phys. 79, 273, 1926.

³⁾ See ORNSTEIN and BURGER, Zs. f. Phys. 40, 403, 1926.

from below. The deviation from an isothermal state will, however, be small and in a first approximation we may consider the observed energy of all the lines of a certain kind of atoms (thus of an element in a given state of ionization) to be a uniform function of their theoretical energy; this theoretical energy is known only for the lines within each multiplet, not for the different multiplets relative to one another.

The determination of this function, which characterizes the optical properties of the chromosphere of the sun, is one of the main results of our discussion. From the curve found, it must be possible to deduce by theoretical considerations the absolute number of absorbing and emitting centra in the chromosphere. Another result will be the determination of the relative intensities of different lines and entire multiplets relatively to one another, about which theory as yet gives no information, and which are measured here in quasi equilibrium conditions of temperature, pressure and radiation, as it would be hardly possible in the laboratory. As soon as these intensities — the transition probabilities from one level to another — can be computed by theory, the values deduced from the chromosphere may offer perhaps the best data for comparison.

To find the "observed intensity" some corrections have been applied to the values given in the catalogue of flash lines. Firstly from the $I(a)$ the corrections of p. 77 have been subtracted, to free them from the average estimated contribution of the faint lines. Secondly an attempt is made to free the intensity of a line from the influence of blends. When a line is combined with another of the same order of strength, it is not possible to find the share of each separately, and such lines must be omitted in the comparisons. If on the other hand we restrict ourselves to lines quite free from blends, only a small number is left in these crowded blue and violet parts of the spectrum. There are, however, a large number of lines where faint blends change the intensity in a moderate degree. Mostly they are faint iron lines; therefore a list is made of all iron lines that seem free from blends, and a simple relation is deduced for them between their intensity in KAYSER's lists and the chromospheric I . There is a strong variation with wave length; for

	$\lambda = 4200$	4300	4400	4500	4600	4700	KAYSER'S intensity
1 corresponds to $I =$	8	7	6	5	4	3	
2 ..	14	12	10	9	7	5	
3 ..	20	17	15	13	10	7	

On the average ROWLAND's solar intensities for these Fe lines are nearly equal to KAYSER's figures. For the other elements of this group (Cr , Mn , Ti , Ni , Co) the ROWLAND intensity is much lower than the figures given in the element tables; here a sufficient number of comparisons can be found only by taking the ROWLAND values of them all together and

comparing them with I ; these ROWLAND values are used, when the line is visible separately there; and for the cases where it is a blend also here a little table is used to convert for this element KAYSER's intensities into ROWLAND values. The correction which must be subtracted to eliminate a blend at a distance $\lambda - \lambda_0$, is computed by multiplying its intensity, found in the said way, by the relative intensity in the normal profile at a distance $\lambda - \lambda_0$ from the centre. Lines at a greater distance than 0.2 AU. are not taken into account because they change the background as well as the centre of the line.

This whole procedure can of course only be considered as a first and rough approximation, because the laboratory intensities and the solar ones will not show such a precise correlation for different series and levels; thus it is only used for faint blends. In the case of rare earths it cannot be used because in the flash spectrum the lines of these elements are strongly intensified.

Thirdly the correction for the FRAUNHOFER lines in the superposed continuous spectrum was computed in the way explained p. 44.

In the following comparison of multiplets¹⁾ for each multiplet after the wave-lengths the inner quantum numbers are given, then the intensities in the laboratory, then the transition probabilities f , and the logarithm of the theoretical intensities $E = f\lambda_0^4/\lambda^4$, where λ_0 is taken 4500. Then follow the corrected observed intensities of the lines in strip a. They have been put in parentheses, when they contain still some blends, which perhaps are hardly sensible, but also may be considerable.

As a rule only those members of the multiplets are given, for which the intensity could be freed from the influence of *faint* blends. When all the lines of a multiplet are faint or blended, so that no real information can be got from them (Sc, Y, Co, Zr...), these elements have been omitted.

The most important lines in this part of spectrum are the lines produced by ionized titanium and by ionized iron. They are the most intense lines (exception is made for $H\gamma$, He 4471, and Sr^+ 4215), therefore the weak points of our discussion, the uncertainty of different corrections, are here of little importance. Some strong lines are present also in the spectrum of Sc^+ , Y^+ and Cr ; in Fe , however, the strongest lines belong to intercombinations of different systems, for which nothing is known about the theoretical intensity.

¹⁾ In the compilation of multiplets chiefly RUSSELL's „List of ultimate and penultimate lines of astrophysical interest" (Ap. J. 61, 223, 1925) was used, completed by later researches in physical reviews. While the intensities in the general catalogue were taken from KAYSER, these of table IX have been usually borrowed from this same list of RUSSELL; where this was not the case, the numbers have been put in brackets and are not comparable with the others.

TABLE IX.

Ionized Iron.
 $2\ ^4P-1\ ^4F'$ (2.68)

4369.41	1-2	—	(3)	(0.53)	13
4296.56	2-3	6	(5)	(0.78)	56
58.16	2-2	—	(1)	(0.10)	28
4178.87	3-4	6	(8)	(1.03)	68

 $2\ ^4P-1\ ^4D'$ (2.68)

4416.81	1-2	4	25	1.43	48
4385.39	1-1	—	25	1.44	46
51.77	2-3	6	63	1.86	(72)Cr 7.
03.18	2-2	4	32	1.59	57
4273.33	2-1	—	5	0.79	32 ¹⁾
33.16	3-4	8	120	2.19	115
4173.48	3-3	6	27	1.56	56

 $2\ ^4F-1\ ^4F'$ (2.82)

4666.75	4-5	—	175	2.18	25
29.33	5-5	4	1925	3.23	92
4582.84	3-4	—	225	2.32	23
55.90	4-4	6	1280	3.09	60
34.17	2-3	—	168	2.21	on border of Ti + line
20.24	5-4	6	175	2.23	52
15.33	3-3	6	867	2.93	49
4491.41	2-2	4	672	2.83	42
89.23	4-3	4	225	2.35	31
72.93	3-2	—	168	2.23	22

 $2\ ^4F-1\ ^4D$ (2.82)

4648.82	3-4	—	5	0.65	not seen
4620.52	4-4	—	100	1.95	21

¹⁾ This line, not observed in the laboratory and omitted from RUSSELL's List, is clearly visible in the flash spectrum.

TABLE IX (continued).

 $2\ ^4F-1\ ^4D$ (2.82) (continued)

4595.6	2-3	—	7	0.80	not seen
83.84	5-4	8	875	2.91	86
76.31	3-3	4	128	2.08	28
49.48	4-3	4	600	2.76	on border of $Ti +$ line
41.52	2-2	—	98	1.97	28
22.64	3-2	6	392	2.58	66
08.29	2-1	8	245	2.39	46

Ionized Titanium. $a\ ^2D-a\ ^2F$ (1.08)

4450.49	3-3	4	1	0.02	50
43.80	2-3	25	14	1.17	128
4395.04	3-4	25	20	1.34	(147) (V10)

 $a\ ^2D-a\ ^2D'$ (1.08)

4344.31	3-2	3	1	0.06	(39) ($Pr\ 10$)
37.92	2-2	10	9	1.01	100
4294.10	3-3	8	14	1.23	(91) ($Fe\ 6$) ¹⁾
87.88	2-3	2	1	0.08	43

 $a\ ^2G-a\ ^2F$ (1.12)

4501.27	4-3	25	27	1.43	121
4468.49	5-4	25	35	1.56	133
44.56	4-4	1	1	0.02	32

 $a\ ^2P'-a\ ^2D'$ (1.22)

4589.96	2-2	3	1	-0.03	34
63.77	1-2	15	5	0.68	93
33.97	2-3	20	9	0.94	141 ²⁾

¹⁾ This line is fainter than 4337.92; the same discrepancy from theory is found in the laboratory.

²⁾ Blend $Fe +$; intensity of this line 25 gives a correction -11, which has been applied.

TABLE IX (continued).

 $a^2H' - a^2G'$ (1.57)

4571.98	5-4	15	44	1.61	101 (V10)
49.64	6-5	25	54	1.71	104 ¹⁾
29.46	5-5	1	1	-0.01	14

 $b^2F' - b^2G'$

4386.84	3-4	(10)	27	1.39	(26) (Ce 8)
67.67	4-5	(15)	35	1.49	17
75.35	4-4	—	1	-0.05	on border of Y+ line

 $c^2D - c^2F$

4488.32	3-4	(15)	20	1.30	18
4411.10	2-3	(15)	14	1.19	(23) Nd 8

 $b^2P' - a^2P$

4350.83	2-2	(1)	5	0.76	(22) (Cr 5)
37.32	2-1	(1)	1	0.07	(16) (Cr 6)
30.25	1-2	(0)	1	0.07	(21) (V6)
16.80	1-1	(1)	2	0.37	21

 $a^4P' - a^4D'$ (1.16)

4330.71	3-2	1	3	0.55	28
20.95	2-1	1	5	0.77	on border of Sc+ line
14.98	1-1	5	25	1.47	56
12.88	3-3	7	27	1.51	69
07.89	2-2	12	32	1.59	(66) (Fe 8)
01.93	1-2	5	25	1.48	58
00.05	3-4	12	120	2.16	100
4290.23	2-3	8	63	1.88	82

¹⁾ Blend Fe +; from the intensity of this line, deduced from p. 82 to be 74, a correction -43 has been applied.

TABLE IX (continued).

 $a \ ^2P' - a \ ^4D'$

4399.77	2—3	6	(12)	(1.12)	55
94.06	1—2	2	(5)	(0.74)	34
4407.68	1—1	—	(3)	(0.52)	(18) (V 8)
18.33	2—2	1	(3)	(0.51)	20
32.1	2—1	—	(1)	(0.03)	15

 $b \ ^4P' - a \ ^4D'$

4411.94	1—1	—	25	1.44	18
4409.53	2—2	—	32	1.55	(18) <i>Dy</i> 8
09.23	3—3	—	27	1.47	on border of <i>Fe</i> line
4398.31	1—2	—	25	1.44	6
95.86	3—4	25	120	2.12	23
91.02	2—3	—	63	1.84	17

. *Calcium.* $1 \ ^3P - 2 \ ^3D$

4456.61	2—3	10	1	0.02	(5?) ¹⁾
55.88	2—2	40	15	1.20	22
54.77	2—1	80	84	1.94	37
35.67	1—2	40	15	1.21	(38) <i>Eu</i> 10
34.95	1—1	60	45	1.68	33
25.43	0—1	50	20	1.33	23

 $1 \ ^3P - 1 \ ^3P'$

4318.65	1—2	45	10	1.07	(20) <i>Ti</i> 9
07.74	0—1	45	8	0.98	30: 2)
02.52	2—2	60	30	1.56	35
4298.99	1—1	30	6	0.84	19
89.38	1—0	40	8	0.98	17
83.01	2—1	40	10	1.09	14

¹⁾ Not in the catalogue; a line of intensity 4 or 5 may be present at this wavelength, coinciding with an equally faint *Ti* + line.

²⁾ Part of a combined line; probably too high.

TABLE IX (continued).

 1^3D-3^3F

4585.87	3-2, 3, 4,	50	7	0.81	13
81.41	2-2, 3	40	5	0.67	20
78.57	1-2	30	3	0.45	13

Ionized Scandium. $1^3F-1^3F'$

4431.35	2-3	4	80	1.93	14
20.66	3-4	1	81	1.94	(17) Nb. 8
15.55	2-2	40	640	2.84	47
00.38	3-3	50	847	2.97	50
4384.80	3-2	8	80	1.95	8
74.46	4-4	60	1215	3.13	37 ¹⁾
54.60	4-3	8	81	1.97	21

 $1^3F-1^3D'$

4325.00	2-1	50	189	2.35	52
20.73	3-2	75	280	2.52	83 ²⁾
14.09	4-3	100	405	2.68	67
05.71	2-2	10	35	1.62	23
4294.77	3-3	10	35	1.62	(17) Zr 6
79.95	2-3		1	0.09	—

 $1^1D-1^1D'$

4246.84	—	75	—	—	163
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Ionized Yttrium. 1^3D-1^3P

4422.60	1-0	10	20	1.33	18 ³⁾
4398.03	2-1	15	45	1.69	47

¹⁾ On the border of a stronger $Y+$ line, but clearly separated.

²⁾ Corrected for the influence of a $Ti+$ line at distance 0.22 AU, for which the intensity 35 has been deduced from the curve p. 95.

³⁾ A negative correction for a Fe line (4) has been applied; since in ROWLAND's list the combined intensity is given only 3 the correction probably has been too large.

TABLE IX (continued).

 1^3D-1^3P (continued)

4358.72	1-1	8	15	1.24	31
09.61	3-2	20	84	2.00	53
4235.71	2-2	6	15	1.29	26
4199.28	1-2	3	1	0.12	—

Titanium. $a^3F'-a^3G'$

4715.31	4-4	4	63	1.88	3
4693.68	3-3	5	63	1.87	3
4681.91	4-5	30	1232	3.16	17
4667.59	3-4	25	945	3.04	21
4656.47	2-3	25	720	2.92	12

 $a^5F'-b^5F$

4555.50	5-4	30	88	1.96	14
52.45	4-3	35	125	2.12	16
48.77	3-2	35	120	2.10	15
44.70	2-1	30	80	1.92	21
36.00	1-1	40	160	2.21	30
35.92	2-2	40	200	2.31	
34.78	4-4	50	507	2.72	24
33.25	5-5	60	792	2.91	20
18.03	3-4	50	125	2.11	15
12.74	4-5	40	88	1.94	10

 $a^5F'-c^5D'$

4305.91	5-4	60	110	1.96	24
00.55	3-2	50	48	1.60	18
4298.67	2-1	40	28	1.36	21
95.75	1-0	22	14	1.06	5
86.01	3-3	25	21	1.24	22

TABLE IX (continued).

$a^3P'-d^3D'$					
4723.18	2-2	10	15	1.26	5
22.63	1-1	10	15	1.26	4
4698.79	1-2	20	45	1.73	12
$b^3F'-e^3F'$					
4457.42	4-4	40	1215	3.06	25
55.32	3-3	30	847	2.91	14
53.32	2-2	30	640	2.79	9
82.69	4-3	10	81	1.90	3
$a^5P'-d^5D'$					
4650.02	2-1	10	9	1.02	6
39.66	3-3	15	28	1.50	11
39.36	2-2	18	35	1.60	14
23.10	2-3	25	56	1.80	13
17.27	3-4	30	108	2.07	15
$a^5P'-b^5P'$					
4496.15	3-2	20	28	1.45	16
81.27	3-3	30	56	1.74	23 ($Mg+$) ¹⁾
80.61	2-2	5	5	0.69	12
65.80	2-3	20	28	1.44	11
$a^3G'-e^3G'$					
4453.70	3-3	20	2625	3.40	10
50.90	4-4	25	3249	3.49	13
49.13	5-5	30	4224	3.60	28 (Ce 9)
$a^3H'-c^3H'$					
4759.28	6-6	25	11375	4.15	14
58.13	5-5	25	9251	4.06	11
34.68	4-5	3	324	2.60	3

¹⁾ The intensity 23 is in accordance with the curve; thus $Mg+$ cannot have an appreciable intensity.

TABLE IX (continued).

*Vanadium.*1 ⁴F-1 ⁴G'

4619.77	4-4	25	32	1.56	5
06.15	3-3	15	24	1.42	(15) (C)
4594.10	5-6	60	353	2.59	(22) Ce 10
86.36	4-5	50	279	2.48	12
77.17	2-3	40	151	2.21	9

1 ⁴F-1 ⁴F'

4368.05	4-3	10	51	1.66	3
55.95	3-2	10	38	1.52	13
32.83	3-3	30	198	2.23	17
07.18	2-3	12	38	1.50	20

1 ⁶D-1 ⁶P'

4460.30	5-4	50	420	2.60	(34) Ce 10
59.77	4-3	30	216	2.31	13
41.69	3-3	25	153	2.17	27 ¹⁾
37.84	4-4	20	120	2.06	11
36.14	1-2	15	84	1.90	7
28.52	2-3	15	50	1.67	7
19.94	3-4	12	20	1.27	6

1 ⁶D-2 ⁶F'

4408.51	{ 1-1 2-2	45	53 + 82	2.09	9
08.21	3-3	70	95	1.94	10
06.65	5-5	80	58	1.72	(14) Gd + 10
4389.99	3-4	100	149	2.14	18
79.24	5-6	150	360	2.51	19

1) High intensity in ROWLAND (3) points to a blend.

TABLE IX (continued)

Chromium. 1^1S-1^1P

4289.72	3-2	350	5	0.62	65
74.80	3-3	400	7	0.76	67
54.34	3-4	500	9	0.85	75

 $1^5S-1^5P'$

4580.05	2-1	20	3	0.51	18
45.96	2-2	20	5	0.72	17
4496.85	2-3	45	7	0.85	(28) Zr + 10

 $1^5D-1^5P'$

4652.20	3-2	30	56	1.81	27
51.31	2-1	20	21	1.38	18
46.17	4-3	40	108	2.09	32
26.18	1-1	20	27	1.48	21
16.11	2-2	25	35	1.58	(27) Nb 8
13.36	0-1	15	12	1.12	(20) La + 5
00.73	3-3	20	28	1.49	15
4591.44	1-2	20	9	0.98	(12) V + 8
65.53	2-3	12	4	0.62	13

 1^5D-1^5F

4384.99	4-4	20	15	1.13	12
73.26	2-1	8	2	0.25	7
71.32	3-3	20	21	1.27	11
59.66	2-2	20	20	1.24	(33) Zr + 10
44.52	3-4	40	75	1.82	20
39.46	2-3	40	48	1.62	18: 1)

1) On the border of *H γ* .

TABLE IX (continued).

Manganese. $1\ ^4D-1\ ^4F'$

4739.00	2-2	8	98	2.08	11
27.46	3-3	10	128	2.20	10
09.70	4-4	10	100	2.08	12
01.16	3-2	3	7	0.93	1
4671.69	4-3	3	5	0.77	4

 $1\ ^4D-1\ ^4D'$

4502.22	4-3	7	40	1.60	8
4498.90	3-2	7	49	1.69	10
90.08	2-1	5	35	1.54	15
70.14	2-2	6	56	1.74	9
64.68	3-3	8	121	2.07	12
53.01	1-2	6	35	1.52	8
51.58	4-4	15	240	2.36	(29) Nd 10
36.36	2-3	8	49	1.67	16
14.89	3-4	10	40	1.57	11

 $1\ ^4D-1\ ^4P'$

4284.08	1-2	5	5	0.79	(16) V 7
81.10	3-3	6	27	1.52	30
57.66	1-1	5	25	1.50	16
39.73	2-1	5	25	1.50	(30) Ce 8
35.30	4-3	8	120	2.19	47
35.14	3-2	6	63	1.91	

Iron. $1\ ^3F-1\ ^5G$

4415.13	2-3	20	Laboratory measures 12.8	43
04.75	3-4	30	48	59
4383.55	4-5	45	100	83 La + 8

TABLE IX (continued).

 1^3F-1^5G (continued)

4367.91	2-2	2	faint		9
37.05	3-3	10	1.4		24
4294.13	4-4	15	5		coinc. with $Ti +$
91.47	3-2	4	faint		14
29.75	4-3	1	faint		14

 $1^3F-1^3G'$

4325.77	2-3	35	720	2.79	(68) Nd, Gd
07.91	3-4	35	1008	2.92	(66) $Ti +$
4271.76	4-5	35	1232	3.00	51
50.79	3-3	25	63	1.70	41 ¹⁾
02.03	4-4	30	63	1.68	15

 $1^5P-3^5D'$

4528.62	3-4	18	108	2.04	37
4494.57	2-3	12	56	1.75	(28) $Zr + 10$
82.26	1-2	6	21	1.31	30
59.13	3-3	10	28	1.43	19
47.73	1-1	9	27	1.41	28
42.35	2-2	12	35	1.52	30
30.62	1-0	6	12	1.05	20
08.42	2-1	6	9	0.91	(27) $V6$

 $1^5P-1^5S'$

4352.74	1-2	9	3	0.42	29
15.09	2-2	10	5	0.63	coinc. with $Ti +$ line
4282.41	3-2	12	7	0.76	41

 $1^7D'-m^7D$

4299.25	4-5	18	264	2.34	28
71.17	3-4	20	375	2.68	33

1) This is much higher than it would be expected from theory; still there is no obvious blend.

TABLE IX (continued).

 $1^7D' - m^7D$ (continued)

4260.49	5-5	35	1056	2.93	47
50.13	2-3	25	360	2.46	35
35.95	4-4	25	441	2.53	31
33.61	1-2	18	240	2.27	28
22.23	3-3	12	105	1.91	23
10.36	1-1	15	120	1.96	23
4198.31	5-4	20	264	2.30	15
91.45	2-1	15	240	2.26	17
87.81	4-3	20	375	2.45	(22) Ni +
87.05	3-2	20	360	2.43	19

 $1^5D' - m^5F$

4736.79	4-5	12	110	2.17	25
07.29	3-4	8	75	1.96	21
4668.15	2-3	6	48	1.74	19
54.64	4-4	5	15	1.24	(25) stronger Fe
37.52	1-2	3	28	1.50	18
25.06	3-3	3	21	1.37	19
13.22	0-1	2	14	1.19	(21) La + 5
07.66	2-2	3	20	1.34	13
4568.79	2-1	1	2	0.33	2

Nickel. $^5G - ^5F$

4756.53	4-4	(10)	891	3.05	14
15.76	3-3	(8)	875	3.02	18
14.42	6-5	(25)	9200	4.04	25
4686.21	2-2	(5)	600	2.85	14
48.66	5-4	(15)	5544	3.80	20
04.99	4-3	(12)	4125	3.65	15
4592.53	3-2	(10)	3000	3.51	11

TABLE IX (continued).

⁵ D—⁵F

4470.48	2—3	(15)	48	1.67	13
62.46	1—2	(10)	28	1.44	(21) V9
36.98	0—1	(5)	14	1.13	5
01.55	4—5	(30)	110	2.00	14
4325.61	3—3	(6)	21	1.25	14
4284.67	4—4	(6)	15	1.09	(15) Nd 5

Ionized iron.

These lines belong to a quartet system.

The logarithms of the theoretical and the observed intensities for each multiplet have been plotted against one another. The curves obtained show but for two exceptions a parallel course; by displacing them horizontally i.e. by multiplying the values $f\nu^4$ with a determinate coefficient for each multiplet, we can bring them into coincidence and trace a general curve relating true and observed intensity (fig. 16). For this curve a straight line may be taken, representing the relation $\log I(\text{obs}) = 0.5 \log E(\text{theor})$. The exceptions consist firstly in the abnormal multiplet $2^4P-1^4F'$, where the azimuth quantum number changes 2; for this case we have no formulae, but values of f may be computed which comply with the sum rule. These

	$f'^{3/2}$	$f'^{5/2}$	$f'^{7/2}$	
	2098	3260		
$p^{1/2}$	228799			3
5976	4369.41			3
$p^{3/2}$	234777	232680		1 5
9815	4258.16	4296.56		6
$p^{5/2}$	244592	242495	239231	0 1 8
	4087.3	4122.6	4178.87	9
				4 6 8

values have been inserted in parentheses in our table. It appears, however, that they are not in accordance with the chromospheric intensities, which rather point to $1/3$ instead of 3 for the first line¹⁾. If we deduce for all these 4 lines relative true intensities from the curve and the observed values we find nearly 1; 14; 4; 21. The other exception is the line

¹⁾ The same discrepancy is found in the spectrum of η Carinae, in which P. MERRILL has made a special study of the Fe^+ lines. (Astroph. J. 67, 399, 1928).

Among the other "forbidden" lines of this element, found by MERRILL, only 4359.34, 4413.79, 4416.28 faintly but distinctly appear in our flashspectrum. The chromospheric densities, however small, are evidently of a much greater order of magnitude than these of the star considered.

4520.24 which in the chromosphere is much too strong; the high laboratory intensity too points to the supposition that it is a blend with another unclassified *Fe + line*. From the horizontal displacements given to each multiplet (+1.55, +0.0, +0.40) we can get the total transition probabilities of the multiplets relative to one another, by multiplying Σf (which is 300, 5880, 2450) with these factors. So we find for the multiplets

$$\begin{array}{ccc} 2^4P-1^4D' & 2^4F-1^4F' & 2^4F-1^4D \\ 84 & 59 & 61 \end{array}$$

as the relative values of their emission in the ideal case of thin layers without selfabsorption in the conditions of temperature, pressure and excitation occurring in the chromosphere.

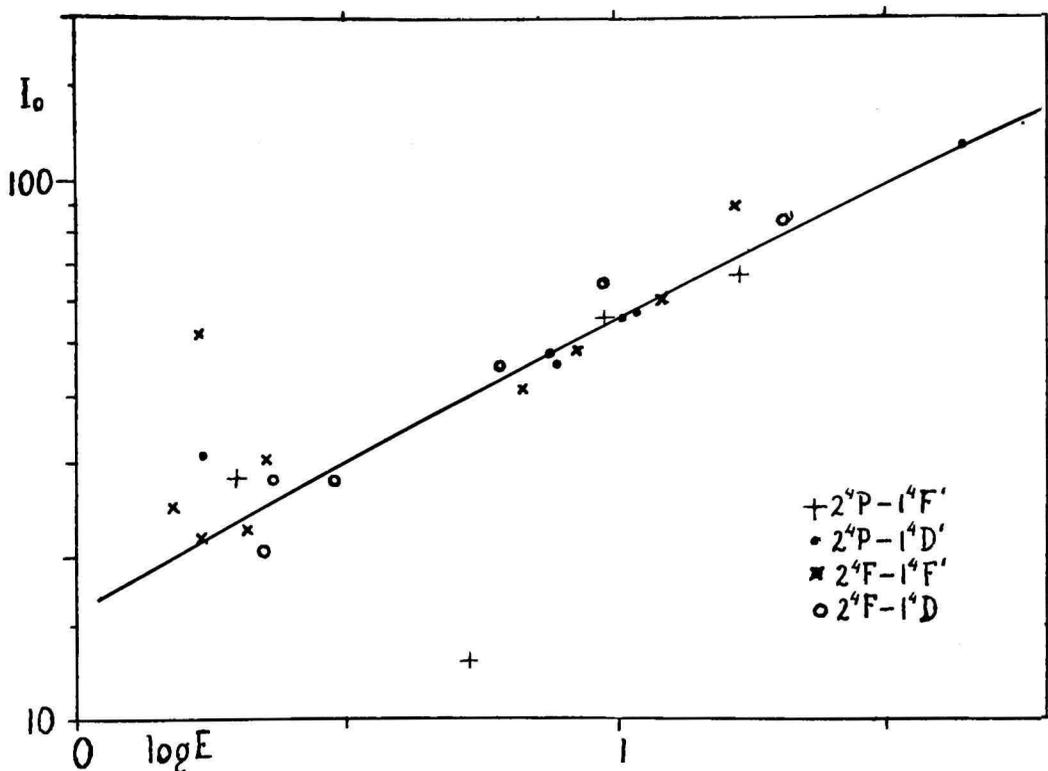


Fig. 16. Observed and theoretical intensities of the ionized iron multiplets.

Ionized titanium.

For ionized titanium the multiplet systems, by the work of H. N. RUSSELL, are among the best and most completely known of all the elements. In the chromosphere the multiplets of the doublet system and one of the quartet system contain the strongest lines in this part of the spectrum. In the diagram fig. 17 the logarithms of the observed intensities have been plotted against the logarithms of the theoretical intensities, which were found by multiplying the values $f\nu^4$ by such coefficients as to bring

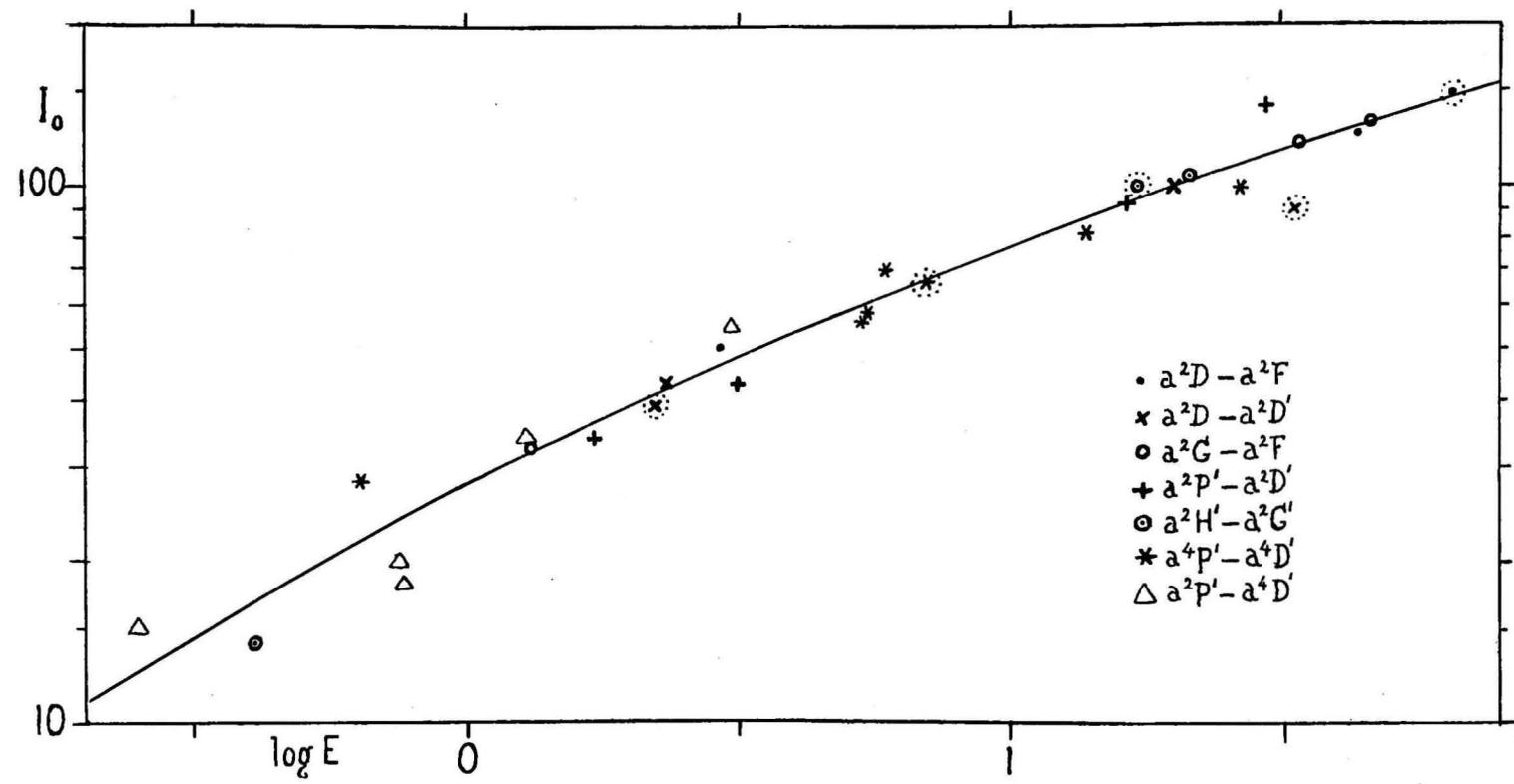


Fig. 17. Observed and theoretical intensities of the ionized titanium multiplets.

them all upon the same curve. It is seen that also here there can be drawn a simple curve, nearly straight, representing for all of them the relation between theoretical and observed intensity ¹⁾).

Only the multiplets containing strong lines have been used in tracing this curve, viz. the first five doublets of the list and one quartet.

For the fainter lines the uncertainty of their intensity becomes so much larger, that it is not well possible to continue the curve to the left side. Then there is an intercombination of the doublet and the quartet system (²P'—⁴D') for which it was possible to derive probability numbers from the sum rule; it is represented by rather strong chromosphere lines, the intensities of which are in sufficient accordance with the curve. (On the diagram they have been inserted afterwards and denoted by triangles). For the other regular multiplets of either system, for which the strongest lines are rather faint in the chromosphere, the observed intensities of these strongest lines may be used to derive from the curve the theoretical intensities and thus the total emission of the whole multiplet. The following table X gives for the different multiplets of *Ti* + the curve displacement,

TABLE X.
Multiplet intensities for *Ti* +.

Multiplet	EP	EP'	Log. Coeff.	Σf	Total intensity
a ² D — a ² F	1.08	3.90	+ .47	35	104
a ² D — a ² D'	1.08	3.93	+ .29	25	49
a ² G — a ² F	1.12	3.90	+ .10	63	79
a ⁴ P' — a ⁴ D'	1.16	4.04	— .74	300	55
b ⁴ P' — a ⁴ D'	1.21	4.04	— 2.25	300	1.7
a ² P' — a ² D'	1.22	3.92	+ .53	15	51
a ² P' — a ⁴ D'	1.22	4.04	— .63	24	5.6
a ² H' — a ² G'	1.57	4.27	— .38	99	41
b ² P' — a ² P	2.05	4.80	— .54	9	2.6
b ² P' — b ² D'	2.05	4.85	— .28	15	7.9
b ² F' — b ² G'	2.58	4.27	— 1.86	63	.86
c ² D — c ² F	3.10	5.87	— 1.73	35	.65

¹⁾ Attention may be drawn to some curious discrepancies. The values in parenthesis, surrounded by a dotted circle on the diagram, may be expected to lie above the curve because they possibly contain some blend. We find them, however, usually on or below the curve. Thus we should conclude that these blends are only faint. But in the case of 4307.89 the *Ti* + line coincides with a strong *Fe* line (8), which may account for a chromospheric emission 40 (cf. p. 91 the list for iron); still their combined light fits well into the curve for *Ti* + alone. The same in a lesser degree holds for 4294.10.

i.e. the logarithm of the coefficient, with which the probability numbers are to be multiplied, the sum total of these numbers, and the resulting total emission of the multiplet. Two multiplets are included for which only 1 or 2 lines were present, so that they have not been included in the preceding lists. For every multiplet the excitation potential is given: 1°. for the lower level (EP); 2°. for the higher level (EP').

Ionized scandium.

The triplets of ionized scandium show a divergence. In both of them the strongest line in the chromospheric spectrum is not the line with the highest inner quantum numbers, but the next line which after the formulae and the laboratory estimates should be fainter. This reversed sequence of intensities is confirmed by MITCHELL's estimates, which are 10—12—10 for the first and 10—15—6 for the second triplet. It seems to be connected with the F level; it is perhaps not chance that the faint $D-F$ triplet of Calcium shows the same reversal, while the $P-D$ and $P-P$ triplets of Calcium and ionized Yttrium show the regular sequence.

Other elements.

The results for Ca , $Sc+$, Ti , Cr , Fe have been plotted in the same way. Though the individual deviations are much larger here we find for all these elements a slow increase of $\log I$ with $\log E$, at a rate that in some cases even seems to be still slower than for $Ti+$. In the same way as has been explained for $Fe+$ and $Ti+$ mean curves have been constructed for some of these elements. They cannot, of course, give evidence for the special figure of these curves, but they may be used to deduce the theoretical intensities of the total multiplets. The unity, in which these relative values are expressed, is arbitrary for each element: it has been chosen in such a way, that for all these elements and for $Ti+$ the same theoretical intensity corresponds to the observed intensity $I=32$ ($\log I=1.5$). Thus in table XI the contents of the preceding table for $Ti+$ should be added, and the results for $Fe+$ are included after reduction to the same unit.

On the whole we see the intensity decreasing with increasing energy of the lower level, indicated by the excitation potential. For titanium the transitions of the quintet system are clearly more intense than the transitions of the triplet system. For chromium it must be remarked that the value for the first strong resonance triplet of the septet system depends on a strong extrapolation, so that its numerical value cannot be very precise.

3. *The Helium lines.*

On our flash plate the following lines of helium are present:

TABLE XI.

Multiplet intensities for some other elements.

		<i>E.P.</i>	<i>E.P.</i> '	Total intensity	
Calcium	1 $3P-2\ 3D$	1.88	4.68	5.5	
	1 $3P-1\ 3P'$	1.88	4.77	2.5	
	1 $3D-3\ 3F$	2.53	5.23	0.90	
	1 $1S-1\ 1P$	0.	2.79	15.	
Ionized Scandium	1 $3F-1\ 3F'$	0.60	3.44	8.8	
	1 $3F-1\ 3D'$	0.60	3.48	18.	
	<i>a</i> $1D-a\ 1D'$	0.30	3.21	81.	
Titanium	<i>a</i> $3F'-a\ 3G'$	0.	2.66	0.73	
	<i>a</i> $5F'-b\ 5F$	0.82	3.56	5.5	
	<i>a</i> $5F'-c\ 5D'$	0.82	3.70	3.3	
	<i>a</i> $3P'-d\ 3D'$	1.05	3.68	0.32	
	<i>b</i> $3F'-e\ 3F$	1.44	4.22	0.87	
	<i>a</i> $5P'-d\ 5D'$	1.73	4.41	1.4	
	<i>a</i> $5P'-b\ 5P$	1.73	4.50	2.7	
	<i>a</i> $5P'-b\ 5S'$	1.73	4.62	0.66	
	<i>a</i> $3G-e\ 3G'$	1.87	4.66	0.69	
	<i>a</i> $3G-f\ 3F$	1.87	4.68	0.54	
	<i>a</i> $3H'-c\ 3H$	2.24	4.85	0.59	
	Chromium	1 $7S-1\ 7P$	0.	2.91	39.
		1 $5S-1\ 5P'$	0.94	3.70	1.15
1 $5D-1\ 5P'$		0.98	3.69	4.4	
1 $5D-1\ 5F$		0.98	3.84	2.6	
Iron	1 $3F-1\ 3G'$	1.54	4.49	13.	
	1 $5P-3\ 5D'$	2.19	5.00	9.2	
	1 $5P-1\ 5S'$	2.19	5.08	6.6	
	1 $7D'-m\ 7D$	2.46	5.42	16.	
	1 $5D'-m\ 5F$	3.25	5.96	2.8	
Ionized Iron	2 $4P-1\ 4D'$	2.68	5.65	37.	
	2 $4F-1\ 4F'$	2.82	5.58	26.	
	2 $4F-1\ 4D$	2.82	5.56	27.	

4387.93	2^1P-5^1D	Int. 6 (Laboratory 19).
4471.48	2^3P-4^3D	203 (" 990).
4713.15	2^3P-4^3S	28 (" 167).

To the intensity of the first line corrections as described p. 79—80 have been applied; for the other lines the total intensity is given, for 4471 derived by numerical integration over the broad profile curve, for 4713 computed from the width at half height. The relative intensities nearly correspond to those measured in the Utrecht Laboratory¹⁾.

ORNSTEIN and BURGER have found in the laboratory the remarkable phenomenon, that at low pressures (10^{-1} cm) the singlet lines of the helium spectrum predominate upon the lines of the triplet system; at higher pressures the reverse is the case, and the ratio between the triplet as a whole and the corresponding singlet line approximates to 3 : 1. The writers explain this by assuming that the transition from the deepest term, which is a singlet term, towards the triplet terms is only possible by collisions with atoms and not by absorption of radiation or by collision with electrons²⁾.

In the chromosphere the pressure is so low that system transitions by collision cannot play a role. Since neither by the solar radiation a transition from the deepest singlet state to a triplet state is possible, the only possible cause for the strong intensity of the triplet lines is the process of recombination after collision. On the flash spectra photographed by MITCHELL and by DAVIDSON and STRATTON the He^+ line 4686 is clearly visible, extending to 2000 Km. An explanation for the occurrence of ionized helium in the solar chromosphere, which could not be understood on the basis of SAHA's equilibrium theory, has recently been given by the impacts of particles of high velocity³⁾.

4. *Emission and absorption lines in strip c.*

In strip *c* of our flash spectrum, the flash lines are seen on a background of continuous sunlight originating from the extreme limb of the photosphere. The result is a very curious intermixture of absorption and emission, so that in the microphotometric record the lines are hardly recognised. It is even difficult to trace the line corresponding to the continuous spectrum, for a vale of the curve may be as well an interval between two emission lines as an absorption line; the very identification of the lines is thus closely connected with the exact drawing of the background. From the small part of this record reproduced in fig. 18, it will be seen how emission and absorption lines often occur side to side,

1) D. BURGER, *Onderzoekingen in het spectrum van helium*; Diss. Utrecht 1928.

2) *Physica*, 8, 111, 1928. A more extensive paper in the *Zeitschrift für Physik* is under press. Cf. J. STARK, *Ann. Phys.* 86, 530, 1928.

3) R. W. GURNEY, *M. N.* 88, 377, 1928. — W. ANDERSON, *Zs. f. Phys.* 49, 749, 1928.

so that the wave-lengths seem considerably modified; in other cases, as for the Ca-line 4227, emission and absorption are almost equal and the line has disappeared.

For the discussion of these puzzling combinations, MITCHELL'S catalogue of flash lines proves very useful, because it gives at the same time the

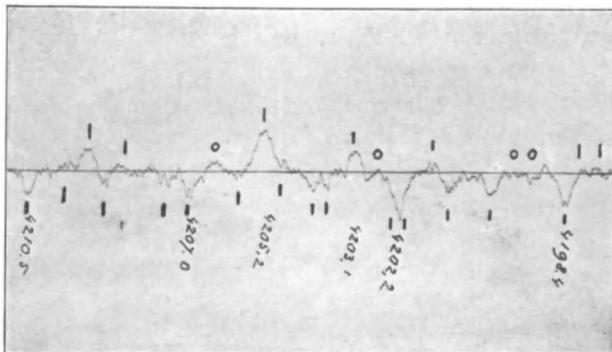


Fig. 18. A part of the flash spectrum in strip c. The lines are marked to the lower or the upper side, as the intensities of ROWLAND (absorption) or these of MITCHELL (emission) are stronger; where the two numbers are equal is put the sign 0.

estimated intensities in the photosphere (after ROWLAND) and in the chromosphere. We find, that in every case where MITCHELL'S chromospheric intensity exceeds ROWLAND'S the line appears in emission; and that in these cases where the intensity in the ordinary solar spectrum after ROWLAND prevails, the line appears in absorption. This is the key by which the interpretation of the spectrum c is made very easy. Even without measurements, this qualitative fact proves that the proportionality between the intensity scales of ROWLAND for absorption lines and of MITCHELL for emission lines is certainly not bad. On the whole, the MITCHELL scale is a little too low for the faint lines, or too high for the strongest ones.

5. Height of the chromospheric layers corresponding to our flash spectrogram.

The width of the slit was 0,13 mm.; from the width of the strip continuous light, say 3 mm., the thickness of the segment of the photosphere falling into the slit is found 0,07 mm. The exposure was estimated to durate from 4,5 to 2,5 sec. before totality; on the other hand, the comparison of the emission and absorption lines in our record c with the photograph of CAMPBELL on a moving plate ¹⁾ gives the time 3,5 to 1,5 sec. We take the mean: 4 to 2 sec. and find that the distance of the moon's edge from the point of contact was 0,032 mm. at the

¹⁾ See E. E. CARPENTER, Lick Obs. Bull. Nr. 384, pl. IX, 1927.

beginning, 0,016 mm. at the end, as far as strip *c* of the spectrum is concerned. For the strips *a* and *b* these distances are smaller, because of protruding mountains of the moon.

It will be seen that the reversing layer till a height of about 3000 Km. (0,07 mm.) was almost entirely included into the slit; near *a* and *b*, even greater heights were reached, and only layers higher than 5500 Km. must have been lost.

We will now ask whether the mountains of the moon near *a* and *b* have reached the chromosphere before the end of the exposure.

A. We will assume first that the brightness *i* of the photosphere near the extreme limb of the sun remains constant, and then falls off at once. Let *t* be the time which the moon's edge in *c* needs at a given moment for reaching the limb of the sun; the total intensity of light giving the continuous spectrum is then $I = it$. And as the photographic action depends on $I t^p$ (for a constant illumination, on $\int I dt$ or $\int t^p dI$ for a variable illumination), the photographic intensity of the spectrum *c* exposed from

— 4 to — 2 sec. will be: $i \int_2^4 t^p \cdot dt = \frac{i}{p+1} (4^{p+1} - 2^{p+1})$. If the mountains

near *a* or *b* would protrude so far that at the end of the exposure it reached the basis of the chromosphere, the photographic intensity of the

continuous spectrum there would be $i \int_0^2 t^p dt = \frac{i}{p+1} 2^{p+1}$. The proportion

between the two intensities is $\frac{2^{p+1}}{4^{p+1} - 2^{p+1}} = \frac{1}{2^{p+1} - 1}$. Putting $p = 0,82$

(see p. 30) we find the proportion $\frac{1}{2,54}$. That is to say: if the intensity

of the continuous spectrum near *a* or *b* is less than $\frac{1}{2,54}$ of that near

c, the mountains have reached the basis of the chromosphere before the

end of the exposure. Since the observed proportions are $\frac{1}{8}$ and $\frac{1}{6,2}$, we

must conclude that the chromosphere has been totally exposed only during 1,1 sec. in *a* and during 1.2 sec. in *b*, and that for the deepest layers the intensities on the plate have been reduced in the proportion

$$\left(\frac{1,1}{2}\right)^{0,82} = 0,61 \text{ and } \left(\frac{1,2}{2}\right)^{0,82} = 0,66.$$

B. We may also assume that the brightness of the photosphere is gradually falling off towards 0 at the extreme limb, so that $i = rt$, *r* being a constant¹⁾. By an argument as before, we find for the proportion

¹⁾ See MOLL, BURGER, VAN DER BILT, B. A. N. 3, 83, 1925.

KIENLE & JUŠKA, Zs. f. Phys. 47, 426, 1928.

of the intensities in *c* and *a* (or *b*): $\frac{2^{p+2}}{4^{p+2} - 2^{p+2}} = \frac{1}{5.54}$. The observed proportions being $\frac{1}{8}$ and $\frac{1}{6.2}$, we conclude that the whole chromosphere has only been exposed during 1.7 sec. and 1.8 sec., and that the intensities of the flash lines have been reduced for the deepest layers in the proportions 0.88 and 0.92.

So long as more precise knowledge is lacking concerning the brightness of the photosphere at the extreme limb, we can only say that in the strips of our flash spectrum near *a* and *b*, the flash lines of the deepest chromospheric layers have been probably somewhat reduced in intensity, the reduction being equivalent to a factor of about 0.75 in *a*, and 0.80 in *b*.

The arguments given in this section would be somewhat invalidated if the action of the atmospheric scintillation and possible imperfect focussing of the astronomical objective had to be taken into account. In this case, only a part of the chromospheric arcs would perhaps fall into the slit, the absolute intensities would be found somewhat too small, but the relative intensities would probably remain true. However, we feel inclined not to attribute a great importance to these disturbances, remarking that the flash arcs on our plate have distinctly a curvature corresponding with the circumference of the sun's image: the image of the chromosphere on the slit must have been sharp.

It will be seen from this discussion, that there is an advantage in taking a flash spectrogram somewhat before totality, so that the exposure ends just at 2^d contact. Since the time of exposure is necessarily finite, either the moon will have covered already the deepest layers before the end of the exposure, or a faint background of continuous light will be unavoidable. In both cases a correction is necessary.

6. *The lines H_γ and He 4471 at different heights in the chromosphere.*

The six plates taken near second contact, and showing *H_γ* and *He 4471* at successive stages, cannot be compared before prealable reduction, because the times of development and the temperature of the bath have been different. However, the exact photometry is made possible by using their sisterplates, on which the spectrum of the constant standard-lamp has been photographed, and each of which has been developed together with the corresponding eclipse plate.

The microphotometric measurement of these continuous spectra shows that their density curves are parallel within the errors of measurement; they are only shifted a little with respect to each other in the direction of the abscissae. It is therefore possible to determine the intensities of spectral lines on these plates by using the main transmission curve, if only the numbers found are afterwards multiplied by factors varying for the different plates from 0,74 to 1,00.

For both lines, the profiles are determined at the regions *a*, *b* and *c* on all the plates where they can be seen. The areas are taken, and the correction for FRAUNHOFER absorption is applied. We take account of the somewhat different exposure times by using SCHWARZSCHILD's law ($p=0,82$, see page 29), and reducing all the observations to 1 second. The intensities found are given in table XII.

TABLE XII.

Intensities of the lines $H\gamma$ and He 4471 at different moments near 2nd contact.

No. of plate	$H\gamma$			He 4471			Mean moment of exposure
	<i>a</i>	<i>b</i>	<i>c</i>	<i>a</i>	<i>b</i>	<i>c</i>	
1	1719	1600	1710	203	188	—	— 3 sec.
2	338	413	641	43	41 ₅	134	+ 1.75
3	172	250	393			41	+ 3.5
4	58	78	138			18	+ 5.0
5	32	46	96				+ 6.5
6	21	40	44				+ 8.5

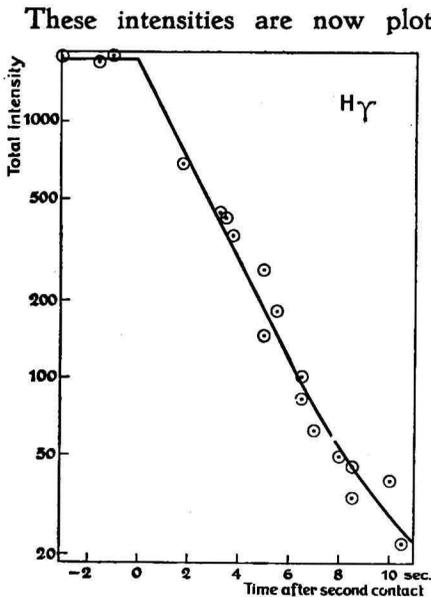


Fig. 19. The decrease of the total intensity of the line $H\gamma$ after 2^d contact.

These intensities are now plotted against the mean moment of the exposure, so that it is shown how the lines decrease in intensity after 2nd contact. The curves for *a*, *b*, *c* must only differ by phase differences in the time, arising from the fact that the mountain of the moon near *a* reaches the limb of the sun earlier than the valley at *c*. From the continuous spectrum, we have estimated this phase differences to 2.5 sec. for *a*—*c*, and to 2 sec. for *b*—*c*; from the $H\gamma$ curves, we get the values 1.5 sec. and 1 sec. Taking the mean, 2 sec. and 1.5 sec., we plot again the three curves, this time shifted over 2 sec. for *a* and 1.5 sec. for *b*.

The resulting curve (fig. 19) shows very clearly how the total intensity of the chromosphere first remains constant, then from the moment of totality decreases according to the exponential law $e^{-0.47t}$, *t* being the time in seconds after 2^d contact.

By differentiating, we obtain the rate at which the intensity in the chromosphere is falling off; in absolute units:

$$780 \cdot 10^{20} \cdot e^{-0.47 t} dt.$$

Reducing the seconds to kilometers height H above the limb, we find that the emission of an arc of the chromosphere long 1 minute of arc (geocentric), broad dH , at a height H above the limb, in the unit solid angle, is

$$2.7 \cdot 10^{20} e^{-\frac{H}{617}} dH \text{ ergs per second,}$$

H and dH being expressed in kilometers.

The exponential form points to an atmosphere only partially supported by radiation pressure. For a normal hydrogen atmosphere, where solar gravity is only counterebalanced by the pressure gradient, the equivalent height would be 160 Km. (for $T = 5100^\circ$). Thus we find that hydrogen in the chromosphere is supported for $\frac{3}{4}$ of its weight by radiation pressure.

It may be asked if the highest part of the chromosphere has not been hidden by one of the jaws of the slit of the spectrograph. This is improbable; for then there ought to be an intensification of the chromospheric lines on both sides of the spectral strip, where the whole chromosphere would be intercepted by the slit. Now such an intensification is not found; and this cannot be ascribed to the moon covering already these points, for it is easily calculated that the moon overlaps only 0.006 mm. farther there than in the middle strip of the spectrum. No more than 1% of the chromospheric light can have been lost by this cause.

The decrease found seems very rapid. SCHWARZSCHILD, MITCHELL, DAVIDSON and STRATTON have found heights varying from 5000 to 8500 Km. At the exponential rate, the intensity at the tips of the chromospheric arcs would only be from 10^{-4} to 10^{-6} of the intensity in the centre of the arcs. It is true that the photographic plate can record images within

a considerable range of intensities, but it seems more probable that in the higher parts of the chromosphere the rate of decrease is slower than the exponential one. We notice that the last part of our curve seems to give an indication in that sense.

For the heliumline 4471 the same constructions are made, but this time we plot the intensities on a linear (not logarithmic) scale (fig. 20). The curious fact is shown, that during the first seconds the curve gradually gets steeper, so that we would be compelled to assume that this helium line *increases* in intensity towards the higher chromospheric layers (cf. the dotted curve of fig. 20). This, if real,

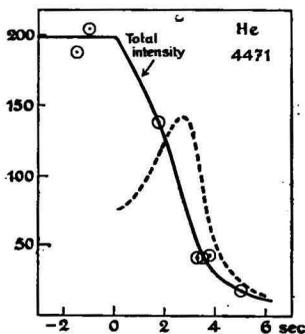


Fig. 20. The decrease of the total intensity of the line He 4471 after 2^d contact. Dotted curve: the derived curve.

would be an interesting confirmation of the observations of DYSON: "the

helium lines are stronger in the higher than in the lower chromosphere" ¹⁾, and of DAVIDSON and STRATTON: "the arcs of helium are long but intrinsically weak" ²⁾.

It will be understood that this discussion is chiefly given as an illustration. It shows that the method of discontinuous exposures near second and third contact can give valuable informations about the decrease of the intensity with the height in the chromosphere. In our case, the accuracy is impaired by the fact that no chronographic signals have been recorded, determining the exact moments at which every exposure has been started and finished; such signals are very easy to obtain, and for all future photometric observations they will be of the greatest use.

¹⁾ F. W. DYSON, *Phil. Trans. A* **206**, 449, 1906.

²⁾ C. R. DAVIDSON and F. J. M. STRATTON, *Mem. R. A. S.* **64**, 138, 1927.

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