Kodaikanal Observatory.

BULLETIN No. CIX.

PHOTOMETRIC STUDY OF THE LINES OF HYDROGEN AND OF CALCIUM IN THE FRAUNHOFER SPECTRUM AT DIFFERENT POINTS OF THE SUN'S DISC,

BY

T. ROYDS AND A. L. NARAYAN.

SUMMARY.

By means of photographic photometry, the contours of several strong lines in the sun's spectrum have been obtained for various points of the sun's disc between the centre and the limb, and the equivalent widths have been derived from the contour curves. The lines studied were Hα, Hβ, Hγ, Hδ, the H and K lines of ionised calcium and the 4226 line of neutral calcium

It is found that the residual intensities in every part of all the lines studied are greater as the limb is approached than at the centre of the disc. This is consistent with our previous knowledge of the tendency of the wings of lines to disappear towards the sun's limb, but the common appearance of lines becoming wider at the limb is partly due to the relative insensitiveness of the eye to the faint wings, for actually both in the core and in the wings the residual intensity is always (for the lines studied) greater towards the limb.

The residual intensities, equivalent widths and corresponding number of atoms lying above 1 cm^2 of the sun's surface are given for different points on the sun's disc in Tables I to VII.

It is of interest to compare the effects of the greater inclination to the vertical of the path through the atmosphere for the case of terrestrial lines produced by the earth's atmosphere, with the limb effect for solar lines Using 9 lines of the B band due to terrestrial oxygen it was confirmed that their equivalent width increases proportionately to the square root of the number of absorbing molecules, the residual intensity in the lines being decreased at all points of the contour with increasing zenith distance In the sun the effect is in the opposite direction as the inclination of the path through the reversing layer increases (as occurs towards the limb), and the difference is due to the fact that near the limb of the sun the effective level of the photosphere is higher than at the centre of the disc, whereas in the case of terrestrial lines the background of continuous spectrum is unchanged for both high and low sun.

The change in contour of solar lines as the limb is approached is the combination of two opposite effects, namely (1) an increase in the number of effective atoms due to the greater length of path when it is inclined to the vertical, tending to strengthen the line and increase its equivalent width, and (2) a decrease in the number of atoms due to the fact that the effective level of the photosphere is higher at the limb, tending to weaken the line and decrease its equivalent width The first effect can be allowed for from geometric considerations so that the second effect can be measured from the changes in the contours towards the limb. Hence we have derived the concentration of atoms at different levels in the sun's reversing layer as given in Table X.

The electron pressure derived from the ratio of neutral to ionised atoms, is about 2×10^{-5} atmospheres at all the levels considered.

Price Re. 1 as. 2 or 2s.

[illegible]

Many observers have made photometric studies of the lines of hydrogen and of calcium in the Fraunhofer spectrum, and a few¹ have made measures not only at the centre of the sun's disc but also at other points on the sun's disc. It is well known that the contours of the Fraunhofer lines are not identical all over the sun's disc, the [illegible] lines tending to become wider near the limb of the sun, although the wings of the strong lines tend to disappear near the limb. As will appear later in this bulletin the differences in the contours of the Fraunhofer lines as the limb is approached are largely due to the changes in the effective level of the sun's photosphere. The photometry of absorption lines enables the number of absorbing atoms to be deduced. Hence it is to be expected that a photometric study of the contours of the Fraunhofer lines at different points of the sun's disc will in consequence of the above mentioned change in the effective level give us a measure of the number of atoms lying above these different levels and consequently also give the relation between the different levels which are available for study. From this point of view photometric measures have been made at the Kodaikanal Observatory of the lines of hydrogen and of calcium in the sun's spectrum from different points on the sun's disc, the results of which are reported in this bulletin.

The spectrograph employed was the large grating spectrograph of the Observatory which has been described elsewhere.³ Briefly this spectrograph uses a large plane grating and its camera which has a focal length of 13½ feet lies at an angle of about 60° to the collimator. The dispersion of the spectrograph in the regions used in this research were as follows:—

Hα	([illegible])	[illegible]
Hβ	([illegible])	[illegible]
Hγ	([illegible])	[illegible]
λ 4226	([illegible])	[illegible]
Hδ	([illegible])	[illegible]
H & K	([illegible])	[illegible]

Special care was taken to reduce the internal scattering within the spectrograph by [illegible] possible of internal reflection. Spectrograms have been obtained using a Michelson plane grating and also using a Rowland plane grating. With the Michelson grating it was necessary to cut down both the width and [illegible] the length of the ruling in order to obtain the best definition. The results from the two gratings [illegible] systematically and the averages for the two have been taken.

The sun's image was formed by a [illegible] object glass (kindly loaned to the Observatory [illegible] Observatory, Hyderabad) fed from an 18 [illegible] siderostat. The diameter of the sun's image was [illegible]

---

¹ Plaskett M.N.R.A.S. 91 870 1931

Unsöld Z. f. Astrophysik [illegible] 1931

Minnaert and Houtgast Z. f. Astrophysik 1 81 1930 [illegible] interpreted from an entirely different point of view

³ Hale & Adams A. J. 25 300 1907

Kodaikanal Observatory Bulletin 36 45 1913

The sun's image was formed on a plate which could be displaced horizontally immediately in front of the vertical slit of the spectrograph. On this plate concentric circles were inscribed to facilitate accurate guiding of the sun's image which was kept concentric with the circles. In order to obtain the spectra from different points of the sun's disc, a series of small holes had been drilled along a horizontal diameter of the circles, and their positions relative to the circles accurately measured. By displacing the slit plate horizontally so as to bring any of these holes exactly central on the slit of the spectrograph, the sun's image being also displaced to be concentric with the inscribed circles, different points on the sun's disc from the centre of the disc to the limb could be photographed. Generally, eight different points between the centre of the disc and the limb were obtained on the same photographic plate, the point nearest the limb being as close to the limb as could be accurately measured and maintained.

The standardising spectrum for photometry was obtained on the same plate as the spectra to be studied and with identical exposures. In order to ensure uniform illumination along the whole length of the slit for the standardising spectrum, the object glass was temporarily removed so that parallel light from the coelostat fell on the slit, in front of which was placed a calibrated step wedge. As a check, a standardising spectrum was also obtained by means of a step wedge immediately in front of the photographic plate. So that the standardising spectrum could have suitable densities with the same exposure as the spectra to be measured, it was necessary to obtain the former with the first or second order spectrum when the latter were obtained with the second or third order respectively.

The photometric measures were made with the Cambridge pattern microphotometer which, after the necessary experience had been gained, was found to give reliable measures when proper precautions are taken. The effective width of the photometer slit was about 0.005 A so that the loss of resolving power in the photometer was insignificant.

No reliance can be placed on photographic photometry unless certain essential precautions are taken. In making the photometric studies reported on in this bulletin, the two following precautions were rigorously adhered to. First, equal exposures were given to the standardising spectrum and those to be measured photometrically in comparison with it; the standardising spectrum was exposed on the same plate which was developed with a brush in order to minimise the Eberhard effect. Secondly, the standardising step wedges were calibrated under exactly the same conditions as those in which they were used. This is most important at any rate for the type of wedge which has been used in this investigation. The wedges used were made by suitably exposing steps of a photographic plate. Photographically prepared wedges have the advantage that they can easily be made of sizes and densities to suit the object in view, but they have one great disadvantage in their graininess. This graininess introduces a very serious difficulty in their use. It is well known that the density of a medium depends on the optical arrangements when it is used. A wedge whose density values have been measured in one instrument cannot be used with these values in another instrument, nor used in another position in the same instrument. It was found, for instance, that when a wedge was used immediately in front of the photographic plate it gave entirely different densities from those when the same wedge was used in front of the spectrograph slit. This effect is considerable for photographically prepared wedges. The photographically prepared wedges used in this investigation were standardised in two ways for each optical arrangement in which they were used. One was by means of perforated screens with known ratios of the apertures of the perforations, and the other was by comparison with standard Ilford wedges used under conditions similar to those for which the maker's certificate was obtained. The values obtained in these two ways were consistent with each other. Two step wedges were used, each with 10 steps ranging from clear glass to the greatest density which was found necessary. One step wedge was used immediately in front of the photographic plate and the other was used immediately in front of the slit of the spectrograph. In order to illustrate the effect of using the wedges in these two different positions the values of their transparencies for a wave-length of 4100 Å are given in the following table:—

TRANSPARENCIES OF SIMILAR STEP WEDGES FOR λ 4100

	Step Wedge No. [illegible] used in front of plate	Step Wedge No. [illegible] [illegible]
Step 1	100	100
[illegible]	[illegible]	[illegible]
3	87.7	89.3
4	81.7	[illegible]
[illegible]	63.1	[illegible]
6	44.1	[illegible]
[illegible]	31	[illegible]
8	[illegible]	[illegible]
9	[illegible]	[illegible]
10	[illegible]	[illegible]

If the two wedges referred to had been used in similar positions, their transparencies would have been similar (although not identical for they were constructed independently of each other), but the above shows how different are their effective transparencies due to their different positions in the optical arrangement. Yet in the results obtained there was satisfactory agreement in the contour values obtained with the wedges in these two different positions.

The theory of the formation of absorption lines has been formulated many times. We shall [illegible] the method of Unsöld[4] who was the first to deduce the number of absorbing atoms in stellar atmospheres. [illegible] showed that absorption lines could be accounted for by the scattering effect of the [illegible]. He made use of the value of the selective scattering coefficient given by Voigt from the classical theory of scattering by bound electrons, namely

$$\sigma = \frac{2\pi e^4}{3m^2c^4}\,\frac{\bar{\lambda}^2}{(\bar{\lambda}-\lambda)^2}\,N f \qquad (1)$$

where σ is the scattering coefficient per cm. length,

$\bar{\lambda}$ is the wavelength at the centre of the absorption line,

N is the number of absorbing atoms per c.c.,

f is the oscillatory strength for the particular line,

and the remaining terms have their usual significance.

The above expression only applies in the absence of Doppler broadening due to the motion of the absorbing atoms in the line of sight, in the absence of collisions between the atoms such as [illegible], and absence of the Stark effect due to interatomic electric fields. In the presence of Doppler broadening the expression may only be strictly applied to the wings of the absorption line sufficiently far from the centre to be unaffected by the Doppler displacements which come into consideration.

---

[4] Unsöld, Z. f. Phys., 44, [illegible]; Z. f. Phys., 46, [illegible]

No exact expression has yet been given for the contour of an absorption line produced by an atmosphere of finite thickness. The best that can be done is to use approximations made under simplifying assumptions. Schuster showed that if we assume a definite photospheric surface at the base of a homogeneous scattering atmosphere, the contour of the resulting absorption line will be given by

$$r = \frac{1}{1+\sigma H} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where r is the ratio of the intensity in the line to the intensity of the photospheric radiation,

σ is the scattering coefficient of the atmosphere,

and H is the height of the atmosphere.

Substituting Unsöld's expression for the scattering coefficient, it will be seen that the contour of an absorption line broadened by scattering will be of the form

$$r = \frac{1}{1+\alpha/(\lambda-\lambda_0)^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

where $\alpha = 2\pi e^2\lambda_0{}^2 NfH/3m^2c^4$.

The actual contours found for Fraunhofer lines do not follow the above form for r. Neither the contours which are published in this bulletin nor those which have been published by others resemble that given by the above equation (3) Unsöld and others have sometimes interpreted their results by taking the widths of lines at a certain value of r. This corresponds to selecting a point on the actual contour where it is cut by the theoretical contour given by (3). Naturally, the results obtained will depend on the value of r selected.

Also, the intensity at the centre of an absorption line predicted by equation (3) is not verified in the actual measures of absorption lines in the sun and stars. According to equation (1) the scattering coefficient at the centre of the line, where $(\lambda-\lambda_0)$ is zero, is infinitely large and therefore the absorption of photospheric radiation should be complete, making the central intensity zero. Actually it is found that the central intensities in Fraunhofer lines are considerable, being of the order of at least 10 per cent even for strong lines. It should be mentioned, however, that since the work published in this bulletin was completed, Thackeray,[5] using a monochromator in front of the slit to reduce scattering in the spectrograph, has found much smaller central intensities particularly for the resonance line of neutral calcium, λ 4226 If the results of Thackeray are correct, they remain difficult to explain. Some attempts have been made by Woolley[6] and by Strömgren[7] to interpret the appreciable intensities found at the centre of Fraunhofer lines as fluorescence effects in the manner suggested by Rosseland. Whether these interpretations are well based or not, it is difficult to see why the calcium line 4226 should have the lowest central intensity as found by Thackeray. Whatever may be the processes in stellar and solar atmospheres which cause appreciable intensities in other lines, it is not easy to see why λ 4226 line should be an exception.

The evidence of the central intensity in the terrestrial lines in the Fraunhofer spectrum should not be neglected. It is shown later in this bulletin that the lines in the Fraunhofer spectrum which are most certainly conditioned solely by pure scattering are lines in the terrestrial bands due to absorption by gases in the earth's atmosphere. Take for instance the B band due to molecular oxygen. If any lines in the Fraunhofer spectrum should have the zero central intensity predicted by the scattering theory, they are lines such as those of the B band, the photometric results for which are given in a later section of this bulletin. Anticipating the results there given, we may state that the central intensities of the lines examined are of the order of 40 per cent of the sun's continuous spectrum. This deviation from the predicted zero value is so considerable that there is no possibility of explaining it as due to defective experimental conditions such as internal scattering within the spectrograph

Notwithstanding the abovementioned discrepancies between the contours actually found in the Fraunhofer spectrum and those to be expected from the theory of scattering considerably more confidence has been placed in deductions from the equivalent widths of absorption lines than in the deductions from actual contours. The equivalent width of an absorption line is defined as the width of continuous spectrum which would contain the same energy as the total energy absorbed in the line. It is expressed by $\int^{\infty}(1-r)\,d\lambda$. In the case where the Doppler widening is small the equivalent width of a line is readily obtained from equation (3) and is given by

$$W = \frac{\pi e^2}{m\ ^2}\ \lambda\ \sqrt{\frac{2\pi}{3}}\ \sqrt{NfH} \qquad (4)$$

If the Doppler widening is large enough to be the principal agent in broadening an absorption line the equivalent width is given by [8]

$$W = \frac{\pi}{mc^2}\ \lambda^2\ NfH \qquad (5)$$

Actually neither (4) nor (5) corresponds to solar conditions for the wide lines which we are considering in this bulletin. Under actual conditions where the Doppler widening is not negligible but not large enough to be the controlling agent we can only regard (4) as an expression for the upper limit of NfH and (5) as the lower limit. It must also be noted that Unsold has shown [9] that for the oscillatory strengths f terms which he has designated by f should be used. He has calculated the f values for H α, H β and H γ. For resonance lines such as the H & K lines of Ca+ and the 4226 line of Ca the f value are the same as the oscillatory strengths.

The lines of the B band in the Fraunhofer spectrum have been variously used [10] for the verification of the expression (4) for the equivalent widths of absorption lines as a function of the number of absorbing atoms when the lines are produced by pure scattering. In the case of Fraunhofer lines due to absorption in the earth's atmosphere the Doppler widening, the effect of atomic collisions and the Stark effect can all be assumed to be negligible and we have in these lines an ideal case of absorption lines produced by pure scattering. The number of effective atoms varies with the altitude of the sun. All that is necessary for the tests is therefore to make photometric measures of spectrum photographs taken at high and low altitudes of the sun preferably on the same day. As the previous results of different observers were not in exact agreement measures of some of the lines in the B band have been made at the Kodaikanal Observatory in view of the importance of the matter. Photographs were taken of the B band with the sun at a zenith distance of 72 and at a zenith distance of 23 each with its own standardising spectrum for photometry. The lines chosen for measurement were the nine lines from λλ 6877 650 to 6870 959. Two photographs were taken at low altitude. For zenith distances up to 72 the lengths of the paths through the air and consequently the number of absorbing atoms may be assumed to be proportional to the secant of the zenith distance. It is sufficient to quote the mean for the above 9 lines.

Ratio of equivalent widths for low and high sun 1 4
Ratio of secants of zenith distance 1 0

This result shows that the proportionality of the equivalent width to the square root of the number of absorbing atoms is actually realised when the lines are conditioned by pure scattering. Although the results confirm the scattering theory in showing that the equivalent widths of the lines of the B band are proportional to the square root of the number of scattering atoms yet the central intensities in these lines are very different from the zero value predicted by the theory of scattering. With high sun the central intensities of the 9 lines in a uted average 42 per cent of the continuous background and with low sun 26 per cent. Since absorption in the earth's atmosphere fulfils almost ideally the conditions required for the application of the theory of absorption by scattering and yet shows appreciable central intensities in the absorption lines it would seem that the central intensities in the Fraunhofer line may be due to the defects of the scattering theory rather than to obscure physical processes in the reversing layer.

Unsold, St and Elvey, Z f Astrophysik 1 314 1930

Z f Astrophysik, 2 199 1931

Mon 14 1047.193

The photometric results for the various lines studied at the Kodaikanal Observatory are given below i Tables I to VIII and in figs. 1 to 8, which are the averages from 5 or more plates. Since it was desirable t

TABLE I.—CALCIUM LINE λ 4226.

Residual intensity, Equivalent width, and Number of atoms above 1 cm² of photosphere.

Sin θ*	0	0·44	0·65	0·77	0·86	0·95	0·98
Cos θ	1·0	0·898	0·760	0·638	0·510	0·312	0·199
(λ – λ₀)§							
0 . .	16·9%	18·8%	18·3%	18·8%	19·6%	20·9%	22·1%
± 5†	20·8	22·0	22·7	23·4	24·2	26·2	26·9
± 10† . . .	26·2	27·8	28·3	29·9	31·6	35·1	36·7
± 15	31·6	33·8	33·7	36·6	37·2	42·2	44·8
± 20	37·7	39·7	38·7	41·0	42·5	47·9	50·9
± 25	44·1	45·9	45·6	46·4	47·3	51·9	55·3
± 30	50·5	51·1	49·1	51·4	51·6	55·8	59·2
± 35 . .	54·5	55·7	53·6	55·3	55·1	58·8	62·3
± 40	58·0	59·4	57·1	58·3	58·4	61·4	64·7
± 45	60·9	61·9	59·9	61·0	60·6	63·4	66·7
± 50	63·2	64·2	62·2	63·3	63·4	65·5	68·6
± 60	67·7	68·5	66·6	68·2	67·6	69·8	72·0
± 70	72·3	72·6	71·1	73·3	72·0	74·0	75·8
± 80	78·4	78·7	76·2	78·0	77·9	79·1	79·3
± 90	85·2	82·8	81·5	82·9	83·3	83·8	83·0
±100	87·5	85·1	84·6	86·0	86·3	87·7	86·1
Equivalent width . .	1·35 A	1·33	1·40	1·35	1·34	1·24	1·21
** NH per cm² . . .	$3\cdot10\times10^{16}$	3·02	3·35	3·09	3·05	2·64	2·49

* Sin θ = distance from centre of disc expressed in radii.

§ 100 units = 1·57 A, or 1 A = 63·6 units.

† Contours for intermediate points near centre of line were determined but are not here reproduced.

** By formula (4) ; f = 2, ∴ $NH = W^2 \times 10^{16}/0\cdot587$.

TABLE II —H LINE OF IONISED CALCIUM

Residual intensities, Equivalent width, and Number of atoms above 1 cm² of photosphere

Sin θ *	0	0·44	0·65	0·77	0·86	0·95	0·98
cos θ	1·0	0·898	0·760	0·638	0·510	0·312	0·199
[illegible]							
0	14·4%	15·4%	16·4%	17·4%	16·6%	21·1%	22·0%
5	19·5	21·1	22·0	23·9	23·0	28·6	30·0
10 †	24·4	26·7	27·2	29·9	29·6	37·2	38·2
15	28·3	31·4	31·3	34·2	33·4	42·1	44·3
20	32·6	35·2	35·6	38·6	37·0	45·9	49·0
30	41·8	44·2	43·8	47·5	44·3	54·2	[illegible]
40	51·0	54·0	53·6	56·2	53·7	61·7	63·9
50	59·2	63·2	62·5	63·5	59·6	69·0	[illegible]
60	66·2	70·3	68·2	69·3	65·6	74·0	74·8
70	76·0	75·7	74·6	75·0	69·5	78·0	78·7
80	81·3	81·5	81·1	83·0	74·3	82·6	82·4
Equivalent width	8·91 A	9·20 A	8·88 A	9·28 A	9·38 A	7·82 A	6·81 A
** NH per cm²	9·30 × 10¹⁸	9·93	9·25	10·10	10·34	7·17	5·44

---

* Sin θ = distance from centre of disc expressed in radii.

§ 100 units = 8·25 A, or 1 A = 12·1 units.

† Contours for intermediate points near centre of line were determined but are not here reproduced.

** By formula (4); $f = 1/3$, $\therefore NH = W^2 \times 10^{18}/8{\cdot}53$.

TABLE III.—K LINE OF IONISED CALCIUM.

Residual intensity, Equivalent width, and Number of atoms above 1 cm² of photosphere.

Sin θ*	0	0·44	0·65	0·77	0·86	0·95	0·98
Cos θ	1·0	0·898	0·760	0·638	0·510	0·312	0·199
$(\lambda-\lambda_0)$ §							
0	14·0%	15·2%	16·7%	16·9%	18·2%	20·3%	21·2%
± 5 †	18·2	19·0	20·6	21·4	23·2	25·6	28·0
±10 †	22·0	23·0	24·9	26·2	28·3	31·3	33·6
±15	25·2	26·2	28·4	30·1	32·6	35·5	38·8
±20	28·4	29·4	31·8	33·3	36·1	40·8	43·0
±30	35·2	35·4	37·9	39·2	42·[illegible]	47·8	50·8
±40	42·5	42·6	45·1	46·0	48·3	53·1	57·5
±50	50·1	49·6	51·8	52·5	54·6	58·9	64·0
±60	58·2	57·5	59·2	59·6	61·5	64·4	69·5
±70	66·4	66·2	67·3	67·1	68·1	70·0	74·6
±80	71·8	72·4	73·8	73·3	71·1	73·1	79·2
Equivalent width	10·77 A	10·74	10·60	10·44	10·09	9·68	8·54
** NH per cm²	10·85×10^{13}	10·80	10·51	10·20	9·53	8·78	6·83

* Sin θ = distance from centre of disc expressed in radii.

§ 100 units = 8·32 A, or 1 A = 12·0 units.

† Contours for intermediate points near centre of line were determined but are not here reproduced.

** By formula (4) ; $f = 2/3, \therefore NH = W^2 \times 10^{13}/10 \cdot 69$.

TABLE IV.—Hα LINE.

Residual intensity, Equivalent width, and Number of atoms above 1 cm² of photosphere.

Sin θ * . . .	0	0·44	0·65	0·77	0·86	0·95	0·98
Cos θ	1·0	0·898	0·760	0·638	0·510	0·312	0·199
$(\lambda - \lambda_0)$ §							
0	25·1%	25·4%	26·4%	26·9%	27·9%	29·0%	29·1%
± 5†	25·8	26·2	27·3	27·8	28·8	30·0	30·0
± 10†	28·2	28·4	29·8	30·2	30·9	32·2	32·0
± 15	33·0	33·0	34·4	34·5	35·2	36·1	36·0
± 20	41·4	40·4	42·7	42·2	43·4	43·8	43·8
± 25	51·8	51·0	53·7	53·3	53·9	55·5	55·2
± 30	61·0	60·5	64·4	63·6	65·6	68·6	68·4
± 35	67·0	67·6	70·0	71·1	73·4	79·1	79·6
± 40	70·9	71·2	73·4	75·2	77·9	83·8	86·2
± 45	73·3	73·3	75·4	77·8	80·6	86·6	89·1
± 50	75·2	75·2	76·8	79·4	82·4	88·4	90·9
± 60	78·0	78·1	79·8	82·2	85·1	90·7	93·2
± 70	80·6	80·7	82·6	84·2	86·8	92·2	94·6
± 80	82·4	82·2	83·8	85·8	88·1	93·1	95·0
± 90	83·8	83·8	85·7	87·1	89·6	94·0	95·7
±100	84·8	84·8	86·8	88·4	90·4	94·8	96·2
Equivalent width 0—105.	1·56 A	1·56	1·47	1·41	1·31	1·13	1·07
Do. 105—388	0·97 A	0·97	0·85	0·75	0·65	0·31	0·24
Total E. W. . . .	2·53 A	2·53	2·32	2·16	1·96	1·44	1·31
Total number of atoms above cm² of photosphere.	$12\cdot0\times10^{15}$	12·0	10·1	8·71	7·20	3·88	3·20

* Sin θ = distance from centre of disc expressed in radii.

§ 100 units = 2·22 A, or 1 A = 45·0 units.

† Contours for intermediate points near centre of line were determined but are not reproduced.

** By formula (4); $f' = 7\cdot59$, ∴ $NH = W^2 \times 10^{15}/0\cdot536$.

TABLE V.—Hβ LINE.

Residual intensity, Equivalent width, and Number of atoms above 1 cm² of photosphere.

Sin θ *	0	0·44	0·65	0·77	0·86	0·95	0·98
Cos θ	1·0	0·898	0·760	0·638	0·510	0·312	0·199
$(\lambda - \lambda_0)$ §							
0	24·1%	25·7%	26·6%	27·2%	27·0%	28·5%	29·2%
± 5 † . . .	25·6	26·9	27·6	28·2	28·2	29·8	30·3
± 10 † . . .	28·8	29·9	30·9	31·4	31·0	32·6	33·2
± 15	33·4	34·3	35·3	36·0	35·9	37·0	38·4
± 20	39·2	40·0	41·8	42·8	42·7	44·8	46·6
± 25	45·3	46·0	48·0	49·3	49·6	53·4	56·5
± 30	50·9	52·2	54·1	56·0	56·8	62·7	66·0
± 35	56·5	57·6	60·2	61·4	63·8	69·1	72·9
± 40	60·1	61·3	64·0	64·8	67·9	73·3	77·2
± 50	65·4	66·2	69·2	69·9	73·4	78·9	82·4
± 60	68·6	69·2	72·0	74·0	76·8	83·0	85·7
± 70	71·0	71·2	74·5	76·1	79·0	84·9	87·7
± 80	73·0	73·1	76·4	77·2	80·6	86·5	88·5
± 90	75·0	74·9	77·8	78·9	82·1	87·7	89·2
±100	76·8	76·8	79·4	80·0	83·4	89·2	90·2
±120	78·6	79·5	81·4	84·0	84·4	88·8	91·5
±140	81·6	83·0	82·8	82·5	85·6	90·9	92·1
Equivalent width 0—150.	1·45 A	1·41	1·33	1·25	1·18	0·995	0·90
Do. 150—800	1·81 A	1·70	1·59	1·45	1·34	0·835	0·70
Total W.	3·26 A	3·11	2·92	2·70	2·52	1·83	1·60
Total number of atoms above 1 cm² of photosphere.	$4{\cdot}04 \times 10^{17}$	3·66	3·24	2·76	2·40	1·27	0·97

* Sin θ = distance from centre of disc expressed in radii.

§ 100 units = 1·39 A, or 1 A = 71·8 units.

† Contours for intermediate points near centre of line were determined but are not here reproduced.

** By formula (2); $f' = 0{\cdot}681$, ∴ $NH = W^2 \times 10^{17}/2{\cdot}64$.

TABLE VI.—Hγ LINE

Residual intensity, Equivalent width, and Number of atoms above 1 cm² of photosphere

Sin θ *	0	0 44	0 65	0 77	0 86	0 95	0 98
Cos θ	1 0	0 898	0 760	0 638	0 510	0 312	0 199
$(\lambda - \lambda_0)$ §							
0	28 8%	27 5%	28 3%	28 9%	29 4%	31 6%	34 7%
± 5 †	30 6	29 2	29 8	30·9	31 5	33·5	36 7
± 10 †	35 0	33·4	34 8	35·4	36·8	38 9	44·0
15	41 2	40·4	41·9	43·5	45 0	48·4	53 4
20	48·0	47 6	48·8	51·4	53 1	58 4	63 6
25	53 9	53 6	55·6	58·4	60·8	66 0	72·6
30	58·4	58·2	60·6	62·8	65 7	71 7	79·8
± 35	61 3	62 0	63·4	66·0	68·8	74 8	83 2
± 40	63·6	64 2	64·8	68 2	71 0	76 3	84 7
± 45	64 8	65 8	66·0	69 3	72 0	77·2	85·3
± 50	66·2	66 6	67·2	70·2	72·5	78 0	85 7
± 60	68·4	68 8	69·3	72·4	74 2	79·0	86 7
± 70	70·9	71 1	71·4	75·0	76 6	80 6	87 8
± 80	73·6	73·7	73·9	77 2	78·4	82 2	88 8
± 90	77·0	76 2	76·4	80 0	80·6	83 4	[illegible]
±100	79·2	79·4	78·8	82 9	83·0	84 5	[illegible]
Equivalent width 0 -105	1 20 A	1·20	1·18	1·09	1 04	0 90	0 70
Do 105 400	0 96 A	0·94	0 98	0 78	0·79	0 69	[illegible]
Total W.	2 16 A	2·14	2 16	1·87	1 83	1 59	[illegible]
Total number of atoms above 1 cm² of photosphere	$7{\cdot}92\times10^{17}$	7 79	7 92	5·94	5·70	[illegible]	[illegible]

---

* Sin θ -- distance from centre of disc expressed in radii.

§ 100 units = 1 52 A, or 1 A = 65 9 units.

† Contours for intermediate points near centre of line were determined but are not here reproduced

** By formula (4), $f' = 0{\cdot}191$, . . $NH = W^2\times10^{17}/{\cdot}589$.

TABLE VII.—Hδ LINE.

Residual intensities, Equivalent width, and Number of atoms above 1 cm² of photosphere.

Sin θ*	0	0·44	0·65	0·77	0·86	[illegible]	[illegible]
Cos θ	1·0	0·898	0·760	0·638	0·510	0·31[illegible]	[illegible]
$(\lambda - \lambda_0)$ §							
0	31·5%	31·8%	33·0%	34·1%	35·7%	44·0%	44·[illegible]
±5†	33·1	34·0	35·2	36·9	38·6	44·2	44·2
±10†	37·7	38·8	40·2	42·0	44·6	51·8	51·1
±15	43·2	43·6	45·4	48·2	51·5	61·0	60·6
±20	48·7	48·2	50·4	53·8	57·3	68·6	68·6
±25	52·0	52·0	54·2	57·8	61·5	73·4	73·3
±30	55·2	55·7	57·5	61·2	65·1	76·6	76·6
±35	58·0	58·4	60·4	64·2	67·4	79·2	78·7
±40	60·4	61·1	62·2	66·4	70·1	81·0	80·0
±45	62·4	62·6	64·1	68·2	71·8	82·5	81·6
±50	64·4	63·7	65·6	69·4	73·8	83·6	82·5
±60	67·2	66·7	68·2	72·0	76·0	84·8	84·4
±70	70·1	69·2	70·6	75·0	78·1	86·3	85·4
±80	71·4	71·1	72·5	76·3	79·5	86·9	85·8
±90	72·6	71·7	73·4	76·9	79·8	86·1	86·3
±100	72·8	72·1	73·8	77·9	80·3	86·8	86·1
Equivalent width 0–105	1·34 A	1·33	1·28	1·16	1·05	0·76	0·81
Do. 105–235	0·58 A	0·59	0·56	0·47	0·45	0·28	0·29
Total W	1·92 A	1·92	1·84	1·63	1·50	1·04	1·10
Total number of atoms above 1 cm² of photosphere**	$13{\cdot}4\times10^{17}$	13·4	12·3	9·6	8·2	3·9	1·4

* Sin θ = distance from centre of disc expressed in radii.

§ 100 units = 1·604, or 1 A = 62·3 units

† Contours for intermediate points near centre of line were determined but are not here reproduced.

** By formula (4); $f' = 0{\cdot}1$, $\therefore NH = W^2\times10^{17}/{\cdot}2755$.

TABLE VIII.—MEAN CONTOUR OF 3 SIMILAR LINES IN B BAND.

Residual intensities expressed as percentages of continuous spectrum.

Distance from centre of line (10 units = 0·219 A).	Secant of Zenith Distance.	
	1·09	3·34
$(\lambda-\lambda_0)$ §		
0	42·1%	26·5%
1	43·5	27·2
2	49·2	28·6
3	57·4	34·0
4	65·0	41·8
5	71·8	49·8
6	78·2	57·2
7	83·0	65·8
8	87·5	73·4
9	91·2	80·1
10	93·4	84·4
11	95·8	88·4
12	97·0	90·4
13	97·8	92·4
14	98·4	94·1
15	98·8	95·5
16	99·2	96·6
17	99·4	97·6
18	99·6	98·0
19	99·8	98·8
20	100	99·7
21	100	99·8
22	100	100

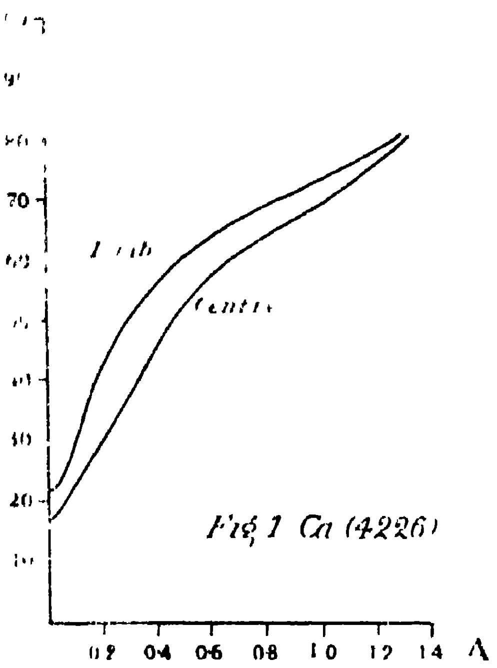

Fig 1 Ca (4226)

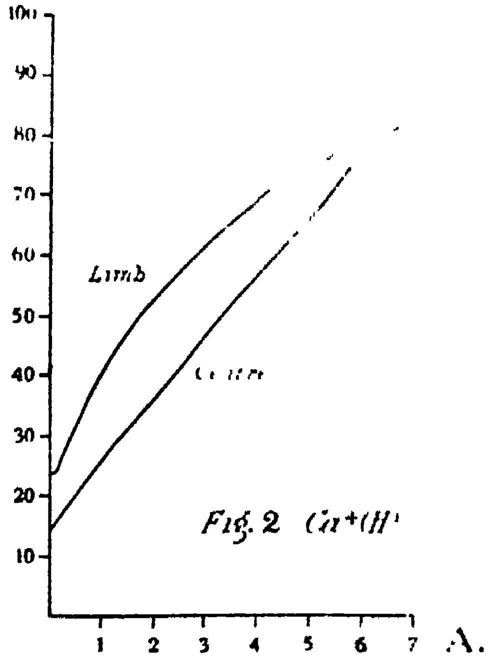

Fig. 2 Ca⁺(H)

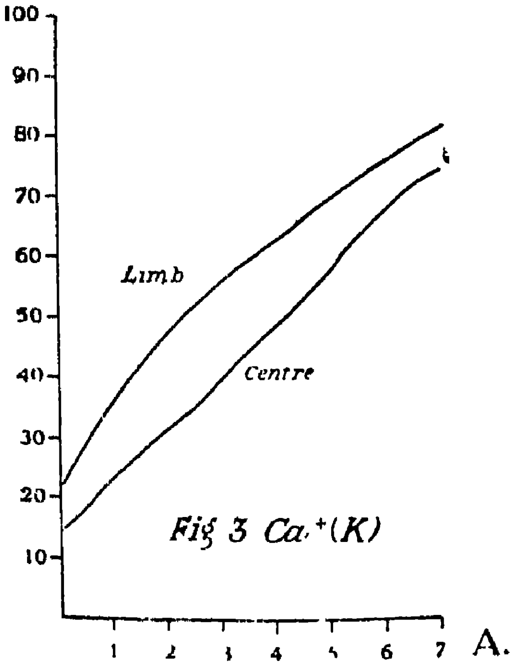

Fig 3 Ca⁺(K)

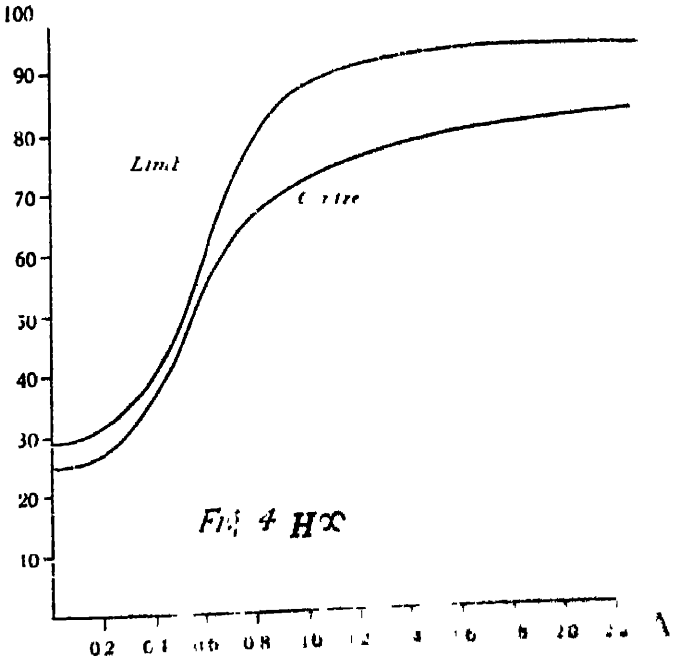

Fig 4 Hα

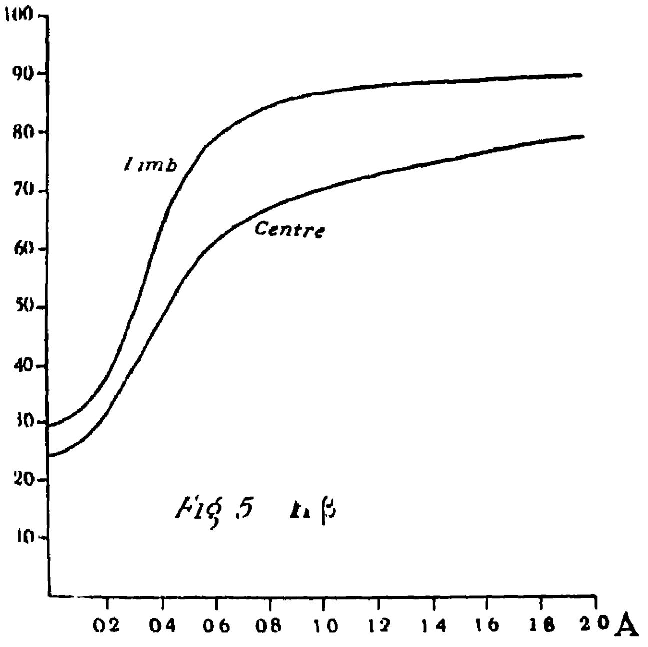

Fig 5 Hβ

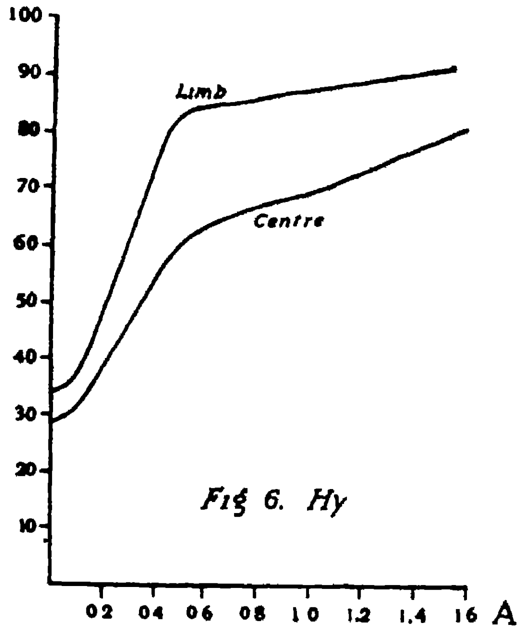

Fig 6. Hγ

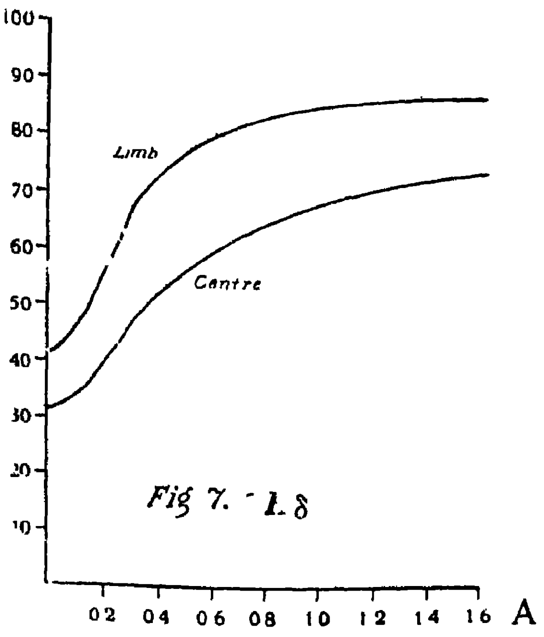

Fig 7. Hδ

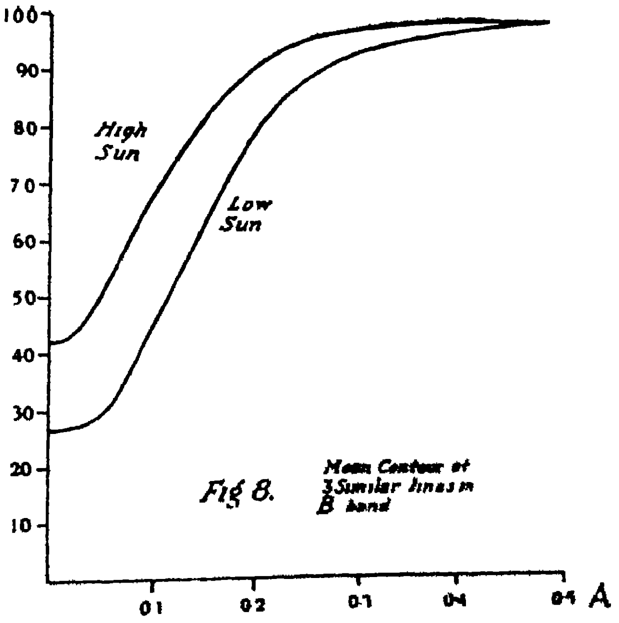

Fig 8.

Mean Contour of 3 Similar lines in B band obtain photographs when the sky conditions were as nearly ideal as possible, the plates were [illegible] at about the same time of the years 1934 and 1935, and the size of the sun's image was practically identical for all the plates taken. Consequently, the same holed plate in front of the slit as described on page [illegible] gave identical distances from the centre of the sun's disc for all the plates. The equivalent widths of the [illegible] were obtained from the contour curves by determining the area of the space between the continuous spectrum and the contour curve over the whole width of the line. It should be noted that the value obtained for the equivalent width of these wide lines depend to a considerable extent on the point to which the extreme extent of the lines is judged to stretch, and consequently that it is necessary to estimate the limits of the width of the lines as accurately as possible. This estimation is largely a matter of judgment, especially in those regions of the spectrum which are rich in lines, in which case it is often difficult to decide the limits of the absorption line. In some cases where the red or the violet wing is less confused by foreign lines than the other, it is useful to assume that the real extent cannot be very different on the two sides. The importance of the contribution of the wings to the total equivalent width may be judged from the results given in the tables IV to VII. Although the amount of absorption in the wings is small, the extent of the wings may be so great that the contribution to the equivalent width becomes considerable. Looking at table IV for the Hα line, the exact contours are given up to 100 units from the centre of the line, which is equivalent to 2·2 A. At this point the intensity of the line has risen to 85 per cent. of the intensity of the continuous spectrum. The exact contour of the line beyond this point is unimportant but it is important to fix the total width of the line. It was found to be sufficient to determine this total width of the line independently of the contour of the central portion of the line. The contour of the central portion of the line was determined from a large scale photometric record, *i.e.*, with the bromide paper on which the record is obtained moving at its maximum speed relative to the speed of the plate. As the exact contour in the wings is not important, the extreme width of the wings was estimated from records made with the minimum speed of recording so that a considerable length of the spectrum on each side of the line could be included in the record. Exact contours were thus obtained only for the central portions of the lines, and approximate contours used for the wings, the limits of which were determined once for all for each position on the sun's disc from one photograph. No appreciable error in the equivalent widths can be introduced in this procedure. Reverting again to table IV for the Hα line, the equivalent width within 2·30 A from the centre of the line is 1·56 A but the equivalent width beyond this point amounts to 0·98 A. In the wings of the line it is not the exact shape of the contour which is important, but rather the great extent of the wing before the feeble absorption shades off into the continuous spectrum.

To derive the number of effective atoms in the sun's reversing layer from the equivalent widths in the above tables we adopt the method of Unsöld. Let us look first at the results for hydrogen. The f' values for the first 3 Balmer lines were calculated by Unsöld namely, 7·59 for Hα, 0·681 for Hβ and 0·191 for Hγ. Since the results for the higher members of the Balmer series will be neglected in the end, it is not worth while calculating the f' values for Hδ, but it has been taken as being of the order of 0·1.

Taking first the values for the centre of the sun's disc we see that as we ascend the Balmer series the values deduced for the number of effective absorbing atoms increase. This is because the conditions of pure scattering are seriously departed from in the sun, the cause being principally the Stark effect which is greater the higher we ascend in the Balmer series. The conditions of pure scattering are most nearly approached in the case of the Hα line, and we shall take the values for this line as the nearest approach we can get to the number of hydrogen atoms in the 2-quantum state. Using formula (4), we obtain for the upper limit to the number of hydrogen atoms in the 2-quantum state in the sun's reversing layer the value $12 \cdot 0 \times 10^{15}$ atoms per square cm of the sun's surface. This value being an upper limit there seems to be no good reason for departing from [illegible] 2-quantum state above each square cm.

We now turn to the variation of equivalent width across the sun's disc. Although we are taking Unsöld's formula for deducing the number of atoms in the sun's reversing layer, the results for the variation across the disc do not really much depend on the particular formula used but are rather dependent on the sole assumption that the equivalent width of a line is a measure of the total number of absorbing atoms. There is much more ground for the correctness of this assumption than there is for the assumption that absorption lines are formed by pure scattering. Whatever may be the conditions in the sun's reversing layer causing the Fraunhofer lines to be broadened beyond their so-called natural width, the chief effect of their variation in width across the sun's disc must be the variation in the number of absorbing atoms. Whatever role we give to other causes of broadening in the sun's reversing layer besides that of pure scattering, this role will be played to a similar extent at all parts of the sun's disc. Secondary effects may doubtless arise from these other causes of broadening as a result of the fact that near the limb of the sun the lines are formed at a higher effective level than at the centre of the sun's disc, but in a first examination of the problem we will neglect these effects. For the present, therefore, we will make no other assumption regarding the formation of absorption lines than that the equivalent width measures the number of absorbing atoms, using Unsöld's law of scattering merely for convenience, not vitally affecting the nature of the results obtained.

Going back to the case of the B band of oxygen lines formed by absorption in the earth's atmosphere, we saw that when the path through the atmosphere is inclined to the vertical the effective width of the lines increases and the intensity at the centre of the line decreases, [illegible] the lines become broader and stronger. In the case of the sun's reversing layer the inclination of the path of the rays to the vertical becomes greater as we approach the sun's limb, and we might have expected an effect similar to the case of the B band had it not been well known that the observed effect is in the opposite direction. It has long been known that near the sun's limb the Fraunhofer lines become wider, that their wings on the contrary become weaker and the central absorption becomes weaker. This at once shows that the method of formation of the Fraunhofer lines in the sun's reversing layer is dissimilar to that of the terrestrial oxygen lines. A little consideration will show that the essential difference in the two cases is in the difference in the behaviour of the continuous background. In the case of the setting sun the background of continuous spectrum is the same as when the sun is overhead. This does not apply in the case of inclined and vertical rays from the photosphere through the sun's reversing layer. In this case the intensity of the background of continuous spectrum is weaker at the limb of the sun's disc than at the centre, the phenomenon being known as the darkening of the sun's limb. The cause of this phenomenon has been explained with universal acceptance as due to general absorption in the sun's reversing layer and to the temperature gradient in the sun. As the inclination of the rays of continuous spectrum increases towards the limb of the sun the intensity of the continuous spectrum emerging in the direction of the observer becomes weaker by general absorption. Expressed in other words, the effective level of general absorption is higher at the limb than at the centre of the disc, and as a result of the falling temperature gradient in the sun the emission from the higher level is weaker than that from the lower. Indeed the darkening of the sun's limb is the best evidence we have of a falling temperature gradient with height in the sun.

We may elaborate this point further. Looking at the sun's disc in the light of the continuous spectrum we look through the sun's atmosphere down to a depth sufficient to be opaque to light from below, and the continuous spectrum is of an intensity corresponding to the temperature of the average depth which is reached. At the sun's limb complete opacity is reached at a higher level than at the centre of the sun's disc on account of the longer path due to the greater inclination of the path to the vertical. If then this atmosphere should also show selective absorption in addition to the general absorption, we cannot possibly get the absorption effect of atoms lying below the depth of complete opacity. In an absorption line therefore the atoms which are effective in producing the absorption line extend to less depths in the sun (measured vertically) at the limb [illegible] the disc. On the other hand the greater inclination of the rays to the vertical when we are [illegible] observing [illegible] limb of the sun increases the effective number of atoms. As we proceed toward the sun's limb we therefore have two opposing tendencies, (1) the smaller number of atoms above the higher level tending to diminish the width of the absorption line, and (2) the greater inclination of the path of light tending to increase the width of the line. We see from the tables I to VII that the former tendency slightly preponderates and to make the equivalent widths at the limb actually less than at the centre of the disc. In the case of the Balmer lines for example, we see that near the sun's limb the equivalent width is about one half of its value at the centre of the disc. For the H & K lines of Ca+, the effect is smaller and we find very little change in the equivalent width until very close to the limb, for the apparent changes up to 0·86 radii from the centre have probably no real significance.

Returning now to the actual equivalent widths of the lines in different parts of the solar disc, we see from the tables I to VII that these widths gradually diminish towards the limb of the sun, the diminution being more rapid as the limb is approached. As we have stated previously, the equivalent widths found for the different points of the solar disc are taken to be measures of the number of absorbing atoms above the photosphere in the direction of observation. It follows therefore from what we have said above that we are measuring the effect not only of the number of atoms lying above the level of the photosphere, a level which is higher the nearer we approach to the limb, but also the effect of the increased length of path through the reversing layer as the inclination to the vertical of the direction of observation increases when we approach the limb of the sun. As we approach the limb we have first the effect of raising the photospheric level which is measured by the limb darkening in the continuous spectrum, and secondly, we have the effect of the inclination of the path through the reversing layer above this level. The increase of path due to its inclination to the vertical through the reversing layer is determined by geometrical considerations in the case of a homogenous atmosphere, namely proportional to the cosine of the angular distance of the point of observation from the centre of the sun's disc. For the actual reversing layer this is not strictly accurate but in view of the present unsatisfactory state of the theory of formation of absorption lines, a more accurate computation is not justified.

The change in contour of Fraunhofer lines as the limb is approached is apparently in different senses in different parts of the line. Hale and Adams[11] have shown that the absorption in the wings is less at the limb than at the centre of the disc, but that the core of the line is wider (apparently implying greater absorption). The actual contours as illustrated in figures 1 to 7 do however show that at the limb the absorption is less in all parts of the line and not in the wings alone. The apparent contradiction is due, to some extent (but not entirely), to physiological causes. The apparent effect of the core being widened at the limb is partly due to the physiological insensitiveness of the eye to the feeble absorption in the wings, causing the eye to misjudge the width of the core compared to the continuous background. Nevertheless the change in contour in different parts of the line as the limb is approached is not simple The change in contour of a solar line as the limb is approached is markedly different from the change in the B band as the sun sinks lower in the sky. The exact interpretation of the more complicated behaviour of the solar lines is not clear, but it shows that the structure of the reversing layer is not so simple as that of the earth's atmosphere.

Our argument for the interpretation of our results may be stated, in effect, as follows. The equivalent width at the centre of the sun's disc measures the number of absorbing atoms above a certain level in the sun. The equivalent width at the limb measures the number of atoms above a higher level in the sun. Therefore, the difference between these two equivalent widths measures the number of atoms between the two levels, and if these levels are known we obtain immediately the density of the atoms between these levels. The varying inclination to the vertical of the path of light through the reversing layer is allowed for by geometrical considerations.

Before we can apply this argument we therefore have to translate the change of effective level of the photosphere as the limb is approached into actual depths in the sun This is determined from the coefficient of general

---

[11] Hale and Adams, A. J., 25.300.1907.

absorption in the sun The effective level of the photosphere clearly depends on the level at which complete opacity is reached and this in turn depends on the general absorption coefficient. Milne [12] from his expression for the general absorption coefficient namely $K = 0\ 85\ P\Big/\left(\frac{T}{10^4}\right)^{\frac{9}{2}}$ has calculated the levels in the sun as a function of opacity His results have been modified by Chandrasekhar [13] who, by using a more probable value for the mean atomic weight of the constitutents of the sun s atmosphere obtains temperature gradients in the sun about 40 times smaller than those of Milne We shall here use the values given in Chandrasekhar s Table II

Milne s and Chandrasekhar s values for depths in the sun are expressed as a function of the optical depth in light of the continuous spectrum Milne has shown that Unsöld s procedure of measuring the distance from the centre of a line at which the residual intensity has risen to half of the background intensity corresponds to measuring the number of absorbing atoms above an optical depth of $\tau = \frac{1}{3}$ Instead of these so-called half widths we have used the equivalent widths We here adopt the same effective optical depth although our procedure differs slightly in that we have used equivalent widths in place of Unsöld s so-called half widths but the difference is not important for the results do not much depend on the actual optical depth chosen changing the adopted value for τ from $\frac{1}{3}$ to $\frac{1}{2}$ produces only a slight change in the results. We have therefore taken the effective optical depth of the photosphere at all points of the sun s disc as $\tau = \frac{1}{3}$ the path to this optical depth being inclined more and more to the vertical as we approach the limb of the sun. These inclined depths have been converted into vertical depths from geometrical considerations by multiplying by the cosine of the angular distance from the centre of the sun s disc. That is, we have taken the level of the photosphere to be at a vertical optical depth of $\tau = \frac{1}{3} \cos \theta$ The actual depths in the sun corresponding to the above vertical optical paths have been calculated from Chandrasekhar's equations in a manner similar to the values given in his table II Tables I to VII show that the changes in the equivalent widths of the lines studied are small and somewhat irregular until near the limb of the sun. It was therefore found sufficient to derive the results from three points only on the sun s disc at the following distances from the centre of the sun s disc measured in radii namely 0 0 86 and 0 98 The point at 0 86 radii gives results for a depth in the sun almost midway between the depths corresponding to the other two points For these three points the results derived from Tables I to VII are as follows —

TABLE IX —NUMBER OF ATOMS PER CM³ ABOVE DIFFERENT HEIGHTS.

Sin θ	Cos θ	τ	T	h	Number of atoms per cm³ above h.		
					H (2-quantum)	Ca+	Ca
0	1 0	0 333	5348	0	12 0 × 10^{14}	16 1 × [illegible]	2 10 × 10^{1}
0 86	0 510	0 170	5113	136 km.	3 06	5 07	1 56
0 98	0 199	0 066	4948	287 km	0 63	1 22	0 50

From these results we calculate the density of atoms, i.e the number per cm³ in the reversing layer of the sun, as given in the following table In the last two rows of the table we have taken the whole reversing layer as extending to a height of 600 kms (as derived from eclipse results)[14] and that the number of atoms in

---

[12] Milne Phil Trans Roy Soc 228 421 1929

[13] Chandrasekhar M N R A S., 92.186.1932

[14] Handb d Astrophysik IV p 312

the chromosphere is negligible compared with the number in the reversing layer, the actual proportion for Ca+ being, according to Unsöld[15], less than 1 : 10^6.

TABLE X.—NUMBER OF ATOMS PER CM³ IN REVERSING LAYER.

Heights above photosphere.	Number of atoms per cm³		
	Ca	Ca+	H (2-quantum).
0—136 kms.	$11 \cdot 3 \times 10^8$	$3 \cdot 68 \times 10^{11}$	$6 \cdot 13 \times 10^8$
0—287 kms.	$9 \cdot 05 \times 10^8$	$3 \cdot 40 \times 10^{11}$	$3 \cdot 61 \times 10^8$
136—287 kms.	$6 \cdot 95 \times 10^8$	$2 \cdot 55 \times 10^{11}$	$2 \cdot 61 \times 10^8$
0—600 kms.	$5 \cdot 2 \times 10^8$	$1 \cdot 7 \times 10^{11}$	$2 \cdot 0 \times 10^8$
287—600 kms.	$1 \cdot 6 \times 10^8$	$0 \cdot 4 \times 10^{11}$	$0 \cdot 2 \times 10^8$

It should be noted that the equivalent widths which we have found for the H and K lines of Ca+ are not exactly proportional to the square roots of their oscillatory strengths, as found by Unsöld for their half widths. Indeed, Unsöld, Struve and Elvey[16] have shown that the ratio of the equivalent widths of the H and K lines would be $\sqrt{2}$ for pure scattering, 2 for the case of Doppler broadening alone, and ~ 1 in the transition region, so that the ratio of their equivalent widths may be anything between 1 and 2. We actually find that the equivalent widths of the H and K lines are in the ratio 1·2, the ratio remaining practically constant across the whole disc. Consequently the number of atoms deduced for the two lines from formula (4) do not agree but are in the ratio $1 \cdot 2/1 \cdot 414 = 0 \cdot 85$. It is therefore sufficiently accurate for our present purpose to take the mean value for the two lines as the number of Ca+ atoms in the ground state.

It is well known that Saha's theory of ionisation enables the electron pressure to be calculated from the ratio of ionised to neutral atoms. The equation is[17], in the usual notation, where x is the fraction of the ionised atoms of any element,

$$\log \frac{x}{1-x} = -\frac{5040\,\mathrm{I}}{\mathrm{T}} + \tfrac{5}{2}\log \mathrm{T} - 6 \cdot 49 - \log \mathrm{P}_e + \tfrac{3}{2}\log \frac{\mathrm{T}_1}{\mathrm{T}} + \log \tfrac{1}{2} + \log \frac{\sigma \mathrm{B}'}{\mathrm{B}}.$$

It seems clear that for T, the effective temperature, we should for our purpose take the effective temperature of the radiation from the centre of the sun's disc, and not from the disc as a whole. This temperature we have taken as 6070°, and for T_1 we have taken, from Chandrasekhar's tables, the mean temperature between the levels considered. For calcium, $\mathrm{I} = 6 \cdot 09$, $\frac{\sigma \mathrm{B}'}{\mathrm{B}} = 2$ and we have from the results in Table X, the following values for the ratio of ionised to neutral calcium atoms, giving the accompanying values of the electron pressure :—

TABLE XI.—IONISATION OF CALCIUM IN THE REVERSING LAYER.

Heights above photosphere.	0—136 kms.	136—287 kms.	0—287 kms.	Whole reversing layer.
$x/(1-x)$	$3 \cdot 29 \times 10^2$	$3 \cdot 63 \times 10^2$	$3 \cdot 40 \times 10^2$	$3 \cdot 25 \times 10^2$
Electron pressure in atmospheres	$2 \cdot 4 \times 10^{-5}$	$1 \cdot 7 \times 10^{-5}$	$1 \cdot 9 \times 10^{-5}$	$2 \cdot 1 \times 10^{-5}$

---

[15] Unsöld, A. J., 69, 207, 1929

At these electron pressures the number of doubly ionised calcium atoms should be taken into account in obtaining the total number of calcium atoms We have the following results for the average number of calcium atoms per c c at different levels

TABLE XII —NUMBER OF NEUTRAL AND IONISED ATOMS ~~AND~~ of CALCIUM PER C. C. AT DIFFERENT LEVELS.

Heights above photosphere		0—[illegible] kms.	[illegible]—[illegible] kms.	0—[illegible] kms.
Number of atoms per cm³	Ca	[illegible] × [illegible]	[illegible] × [illegible]	[illegible]
	Ca.+	[illegible]	[illegible]	[illegible]
	Ca.++	[illegible]	[illegible]	[illegible]
Total number of calcium atoms per cm³		[illegible] × [illegible]	[illegible] × 10^{11}	[illegible] × 10^{11}
Partial pressure due to calcium atoms		[illegible] × 10^{-1} dynes/cm²	[illegible] × 10^{-1} dynes/cm²	[illegible] × 10^{-1} dynes/cm²

Having determined the number of atoms per c. c. of any particular element which constitutes a known fraction of the total number of atoms present in the sun, we can next determine the density of all atoms and total gas pressure Our results for hydrogen cannot be used for this purpose on account of the great uncertainty of the ratio of the number of atoms in the ground state in the sun to the number in the 2 quantum state and it is the latter alone that we are in a position to determine. Indeed the proportion of the non-metallic elements in the sun relative to the metallic elements is a matter of great uncertainty due, principally, to the fact that the lines of the non-metals which determine the number of atoms in the ground state are not observable Nevertheless, Russell[1] has made estimates of the relative proportion of all the elements in the sun, and we take his value of the proportion of Ca to make use of our results to derive the total number of atoms of all kinds in the reversing layer. According to Russell, the number of calcium atoms in the whole reversing layer is about 0 064 per cent. of the total number of atoms present. Our results have given the number of atoms per c. c. at different levels in the reversing layer and assuming the same proportion of calcium atoms at all heights, we deduced the following values for the total gas pressure in the reversing layer.

TABLE XIII.—TOTAL GAS PRESSURE IN THE REVERSING LAYER IN DYNES PER CM²

Height above photosphere.	0—[illegible] kms.	[illegible]—[illegible] kms.	0—[illegible] kms.
Partial pressure of Ca (dynes cm²)	[illegible] × 10^{-1}	[illegible] × 10^{-1}	[illegible] × 10^{-1}
Total gas pressure (dynes cm²)	[illegible] × [illegible]	[illegible] × [illegible]	[illegible] × [illegible]

These values for the total gas pressure depend on the assumed proportion of calcium atoms in the reversing layer They are higher than Chandrasekhar's values [illegible] of the gas pressure deduced from Milne s theory

Taking Chandrasekhar's values for the gas pressure at the levels considered and our values of the partial pressure of the calcium atoms, we deduce that the proportion of calcium at all the levels considered of the reversing layer is 0 6 per cent of the total number of atoms present about 10 times the estimate of Russell.

We acknowledge our indebtedness to the Nizamiah Observatory for the loan of the 15 object glass used to form an image of the sun for this research and to Mr C P S. Menon, M.A. who assisted in the early stage of the work which he had to leave on taking up an appointment

---

[1] Russell A J 70 11 1929 and A J 75 337 1932

KODAIKANAL OBSERVATORY
25th November 1936

T ROYDS
A L NARAYAN

[illegible] 26 4 37—430