ASTRONOMY

THE VALUE OF OBSERVATIONS OF CONTINUOUS SPECTRA IN THE CHROMOSPHERE AND PROMINENCES

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(Communicated at the meeting of Sept. 30, 1950)

Summary

The intensity of the continuous spectrum for various wavelengths to be expected in the chromosphere and in prominences is computed for electron temperatures of 5000°, 10,000°, 20,000° and 30,000° and electron or proton concentrations of the order 10^{11} (chromosphere) and 10^{10} (prominences). The result contained in Figures 2 to 5 and Table 2 may serve as a guide for future eclipse observations. It is pointed out that present evidence points to a chromospheric electron temperature a good deal lower than REDMAN's kinetic temperature of about 30,000° for atoms and ions. The spectra considered are the Ba_c spectrum, the other recombination and electron switch spectra indicated by C and that by scattering of photospheric light by free electróns marked c. For the chromosphere the determination of electron or proton concentration as well as of electron temperature appears possible. For prominences one can determine concentration and thickness, provided the electron temperature be known. A remark concerning the possible influence of the continuous spectrum due to the formation of negative hydrogen ions is made.

1. *Introduction* *)

Continuous spectra in the chromosphere and in prominences have been treated by various investigators. DAVIDSON, MINNAERT, ORNSTEIN and STRATTON, [1]) carried out approximate measurements of relative intensity for slit spectra taken by DAVIDSON and STRATTON at the 1926 eclipse. The continuous spectrum at the head of the BALMER series indicated electron temperature of 3600° for the lower chromosphere, 4000° for a prominence in the flash spectrum and 3200° for a prominence in the coronal spectrum. For the high prominence, the relative distribution in the region λ 4100 to 3800 was equivalent to a black body temperature

*) The considerations set forth in the present paper were presented in an abreviated form at the Astronomical Colloquium "Problems on Solar Physics" arranged in Dublin by Dunsink Observatory, September 21, 1950.

[1]) C. R. DAVIDSON, M. MINNAERT, L. S. ORNSTEIN and J. F. M. STRATTON, M.N. 87, 536 (1928).

of about 2000°. CILLIÉ and MENZEL [2]), discussing slitless spectrograms taken by CHAPPEL and MENZEL at the 1932 eclipse, found a chromospheric electron temperature of about 10,000° from the relative distribution of the Ba_c spectrum. The absolute intensity of the Ba_c spectrum yielded an electron or proton concentration of 3.8×10^{11} per cm^3 at the base of the chromosphere, likewise from KRAMERS' theory. This agrees, as regards order of magnitude, with PANNEKOEK's [3]) value of 6×10^{11} from the overlapping of the higher lines of the BALMER series due to STARK effect [3]). For prominences observed with the coronagraph LYOT [4]) found for the continuous spectrum in the region λ 5950 to 6400 a degree of polarisation of about 15 per cent, after correction for atmospheric scattering, and concludes that it is mainly produced by scattering of photospheric light by the free electrons in the prominence. On the basis of this assumption, WURM [5]) has recently shown that the ratio of the intensity of the Ba_c spectrum to the continuous spectrum at longer wavelength gives a method for determining the proton or electron concentration per cm^3 for a prominence, if the electron temperature be known, and carried out an approximate estimate on this basis.

The foregoing clearly shows the importance of observations of intensities of the continuous spectrum at various wavelengths in the chromosphere and prominences, preferably from spectra taken during an eclipse. Thus far the Ba_c spectrum and the scattering from free electrons, which will be indicated by the suffix c, has received most of the attention. For a complete discussion however, also the other recombination spectra due to captures on levels higher than the second plus the electron switch spectra must be considered and will in total be indicated by a capital C. The intensity of this C spectrum, like that of the Ba_c spectrum, follows from the KRAMERS theory. In the following the intensities of these three kinds of spectra to be expected theoretically will be worked out for a few electron temperatures and concentrations, to serve as a future guide for eclipse observations. Also a few provisional conclusions of a very approximate nature will be drawn. The results of the KRAMERS theory, which are given, might be slightly modified by the quantum mechanics, which can be done eventually by the use of GAUNT factors. Another source of continuous spectra might be furnished by captures of free electrons by neutral hydrogen atoms and corresponding electron switches. This will briefly be considered at the end of the paper, but is not thought to be of much importance for the matter on hand.

2. *Intensities of the various continuous spectra to be expected*

In the following it will generally be assumed that most of the electrons

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[2]) G. G. CILLIÉ and D. H. MENZEL, Harvard Circular, no. 410 (1935).
[3]) A. PANNEKOEK, M.N. **98**, 694 (1938).
[4]) B. LYOT, Comptes Rendus **202**, 392 (1936).
[5]) K. WURM, Mitt. Hamb. Sternw. Bergedorf **21**, 103 (1948), no. 206.

originate from hydrogen atoms and only very few form negative hydrogen, so that the concentration per cm³ of electrons n_ε becomes equal to that of protons n_1. Moreover the electron temperature T_ε is considered not to vary throughout the chromosphere or the prominence.

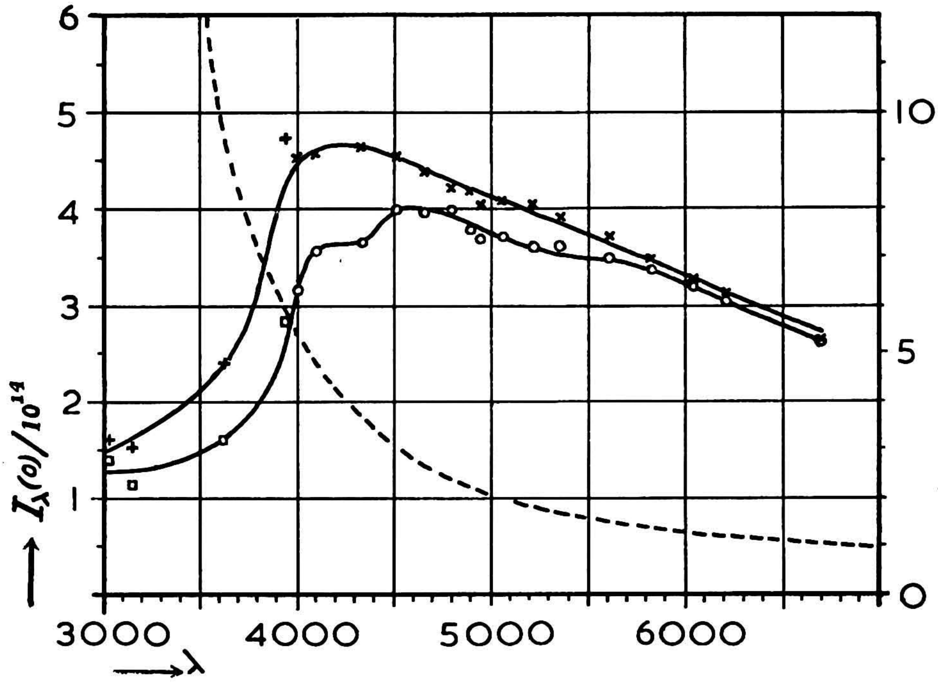

Fig. 1. Values of the intensity at the centre of the sun's disc according to MULDERS. Upper drawn curve: ${}_0I_\lambda(0)$ for the continuous background. Lower drawn curve: ${}_0I_\lambda(0)$ for the spectrum with the FRAUNHOFER lines fuzzed out. Crosses and circles refer to H. H. PLASKETT's observations, vertical crosses and squares to those of FABRY. The dotted curve and righthand scale give the darkening coefficient.

Let $\varepsilon_\lambda\, d\lambda$ be the energy of one of the continuous spectra emitted in a certain direction per unit solid angle per second per cm³, and $E_\lambda\, d\lambda$ the same quantity per cm², or intensity per cm² which is observed or predicted. Then

$$E_\lambda = \int \varepsilon_\lambda\, dl \tag{1}$$

where dl is the element of length along the line of sight.

According to KRAMERS' theory as worked out by CILLIÉ [6]), the emission per cm³ per second per unit frequency for hydrogen is given by

$$J_n(\nu)\, d\nu = n_1 n_\varepsilon \frac{Q}{n^3\, T_\varepsilon^{3/2}}\, e^{-\frac{h\nu-\chi_n}{kT_\varepsilon}}\, d\nu, \tag{2}$$

$$J'_n(\nu)\, d\nu = n_1 n_\varepsilon \frac{Q'}{T_\varepsilon^{1/2}}\, e^{-\frac{h\nu}{kT_\varepsilon}}\, d\nu, \tag{2a}$$

where J_n refers to captures on the level n and J' to electron switches.

[6]) G. G. CILLIÉ, M.N. **92**, 820 (1932) and **96**, 771 (1936).

The constants in the present paper are based on BIRGE's 1941 values [7]), which give

(2b) $$Q = (2.170 \pm 0.005) \times 10^{-32}, \quad Q' = (6.88 \pm 0.01) \times 10^{-38}.$$

It may be remarked that for objects outside the sun's limb only spontaneous captures should be considered. Forced captures, being negative absorptions, only come into play when the object is observed projected on the disc, strengthening the incident beam without altering its direction.

To obtain ε_λ from J_n or J' one has to multiply by $c/(4\pi\lambda^2)$. Equations (2) and (2a) readily yield the intensity E_{Ba_c} of the Ba_c spectrum at the series limit and of the other spectra added together $E_{\lambda C}$ and their ratio

(3) $$\frac{E_{\lambda C}}{E_{Ba_c}} = \frac{\varepsilon_{\lambda C}}{\varepsilon_{Ba_c}}$$

since T_ε was considered constant. These values for four electron temperatures are plotted in Figures 2, 3, 4 and 5 using the result of BARBIER's [8]) computations, slightly extended, in the full-drawn curves marked with a capital C. Likewise the ratio $E_{\lambda Ba_c}/E_{Ba_c}$ of the intensity of the Ba_c spectrum at the wavelength λ to its value at the series head is represented by the full-drawn curve marked Ba_c.

For $n = 2$, equation (2) yields at the series limit λ 3646.9

(4) $$\varepsilon_{Ba_c} \equiv \varepsilon_{3646\,Ba_c} = (4.86 \pm 0.01) \times 10^{-21}\, n_1 n_\varepsilon \left(\frac{10^4}{T_\varepsilon}\right)^{3/2}.$$

For scattering of photospheric light by free electrons just above the photosphere, the c spectrum, one has

(5) $$\varepsilon_{\lambda c} = I_\lambda(0)\, \frac{\frac{1}{2} + \frac{15}{64}\beta}{1+\beta}\, \sigma\, n_\varepsilon$$

where σ the scattering coefficient per electron

(5a) $$\sigma = (6.67 \pm 0.01) \times 10^{-25}.$$

In this formula $I_\lambda(0)$ represents the intensity at the centre of the solar disc and β the coefficient of darkening for the wave length λ. It may be obtained from equations (3), (4) and (5) of a former paper by the writer [9]) for scattering by an oscillator, which applies equally well to the present case.

The values of $I_\lambda(0)$ were taken from MULDERS, [10]) essentially using a re-plot of his Fig. 2, from his Tables VI and VII. It is represented in our

[7]) R. T. BIRGE, Reports on Progress in Physics of the Physical Society 8, 90 (1941).

[8]) D. BARBIER, Ann. d'Astrophys. 7, 80 (1944). His J' for 30,000° (p. 104) should be 0.0255.

[9]) H. ZANSTRA, M.N. 101, 250 (1941).

[10]) G. F. H. MULDERS, Aequivalente breedten van FRAUNHOFER-lijnen in het zonnespectrum. Proefschrift Utrecht (1934).

Fig. 1. The upper curve represents ${}_0I_\lambda(0)$, the intensity of the continuous background, which he has obtained by correcting for absorption lines, the lower curve his I_{red} representing the spectrum in which all lines are fuzzed out except the very strongest of ROWLAND intensity larger than 20. We may take I_{red} equal to our $I_\lambda(0)$, since scattering by free electrons will result in a fuzzing out on account of the small mass and consequent high termal velocity. The values of β were obtained from a re-plot of MINNAERT's [11]) values of $I_\lambda(0)/F_\lambda$ based on ABBOT's observations using the expression

$$\frac{F_\lambda}{I_\lambda(0)} = \frac{1+\frac{2}{3}\beta}{1+\beta}$$

as a definition of β, so that this β gives the correct flux. The values of β are given by the dotted curve in Fig. 1, using the right hand scale, or, more accurately by Table 1.

TABLE I

λ	3500	3646	4000	4500	5000	5500	6000	6500	7000
β	14.1	9.6	5.36	3.05	2.05	1.56	1.26	1.06	0.93

From equations (1), (4), (5) and (5*a*) follows the expression for the ratio of intensity per cm² of the scattering spectrum *c* at wave length λ to the Ba_c spectrum at λ 3646

$$(6) \qquad \frac{E_{\lambda c}}{E_{Ba_c}} = (0.684 \pm 0.001)\, \frac{1+\frac{15}{32}\beta}{1+\beta} \cdot \frac{I_\lambda(0)}{10^{14}} \cdot \left(\frac{T_\varepsilon}{10^4}\right)^{3/2} \cdot \frac{10^{10}}{\bar{n}_1},$$

where

$$(6a) \qquad \bar{n}_1 = \frac{\int n_1 n_\varepsilon dl}{\int n_\varepsilon dl}.$$

The quantity $\bar{n}_1$ may be termed the effective concentration of protons for the ratio of *c* to Ba_c intensity. Equation (6) enables to determine $\bar{n}_1/T_\varepsilon^{3/2}$ from the observed intensity ratio $E_{\lambda c}/E_{Ba_c}$, which is WURM's method. It is however somewhat more refined than the equation given by WURM, since the dependence of scattering upon direction is taken into account and central intensity with darkening coefficient has been used in preference to the black body approximation.

If, as an approximation, the object is assumed to have a thickness L within which the concentration n_1 or n_ε is constant, (1) and (6*a*) reduce to

$$E_\lambda = \varepsilon_\lambda L, \quad (1a) \qquad \bar{n}_1 = n_1 = n_\varepsilon. \quad (6b)$$

One might assume this for prominences.

For the chromosphere however one may, following CILLIÉ and MENZEL, assume a concentration n_1 or n_ε falling off with height x as $e^{-\frac{1}{2}a'x}$, where x is very much smaller than the solar radius. Then (6*a*) leads to

$$(7) \qquad \bar{n}_1 = \frac{n_1(x)}{\sqrt{2}} = \frac{n_\varepsilon(x)}{\sqrt{2}},$$

[11]) M. MINNAERT, B.A.N. 2, 75 (1942), no. 51, Table IV and Fig. 3.

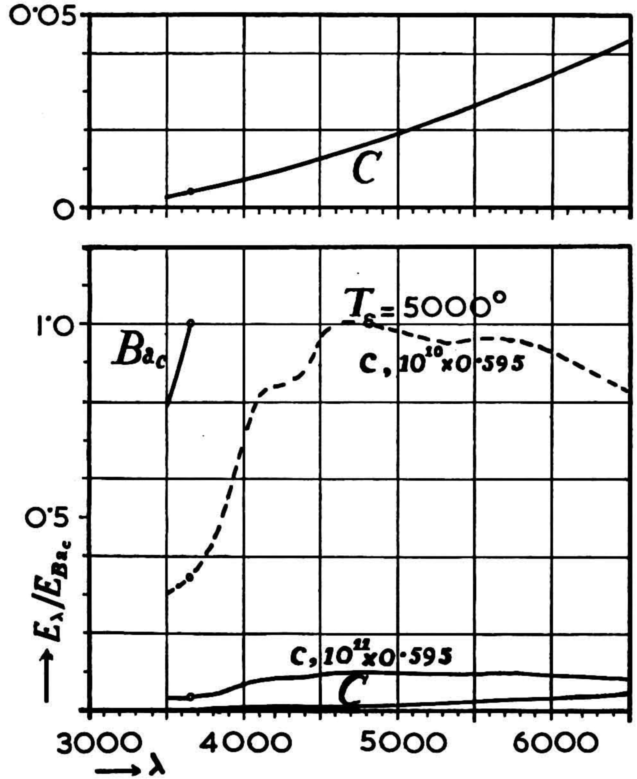

Fig. 2. Theoretical intensities of continuous spectra, expressed in the Ba_c intensity a the head as a unit: C for all recombination and electron switch spectra except Ba_c; c for scattering of photospheric light by free electrons; followed by the effective concentration of protons or electrons. The full drawn c curve is typical for the chromosphere at 1300 km, and the dotted curve for a prominence. Electron temperature 5000°.

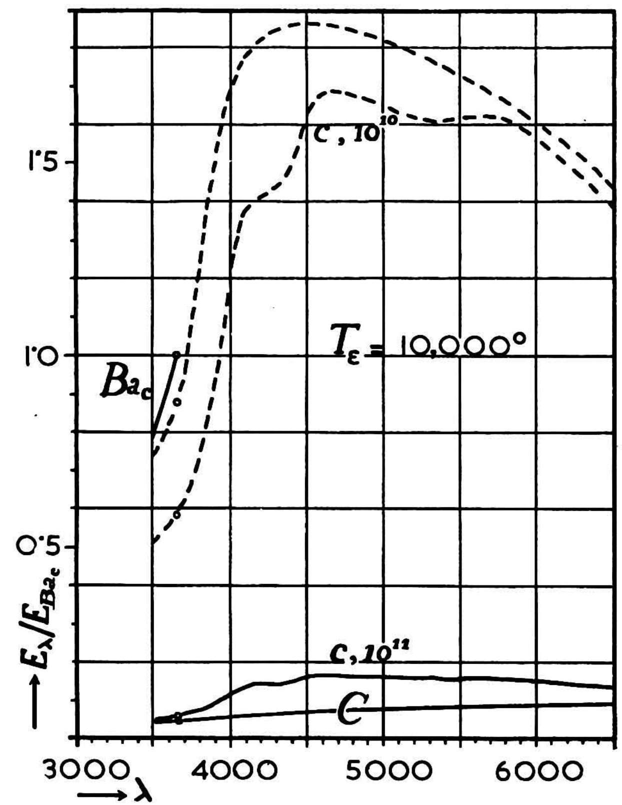

Fig. 3. The same as Fig. 2, but for electron temperature 10.000°. The upper dotted curve refers to scattering without FRAUNHOFER lines. N.B. *The value of* $E_{\lambda c}/E_{Ba_c}$ *for any* $\bar{n}_1$, *and any* T_ε, *is obtained by multiplying the reading of the lower dotted curve by* $\dfrac{T_\varepsilon}{10^4} \cdot \dfrac{10^{10}}{\bar{n}_1}$,

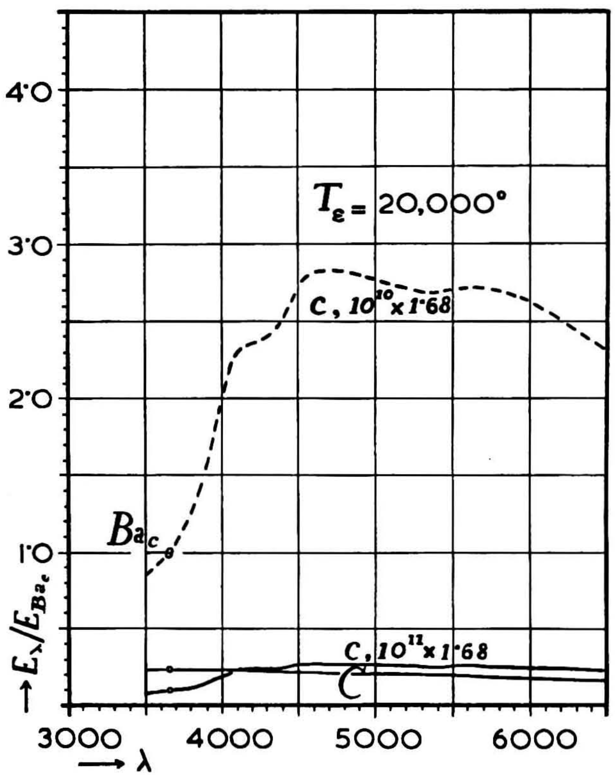

Fig. 4. The same as Fig. 2, but for electron temperature 20,000°.

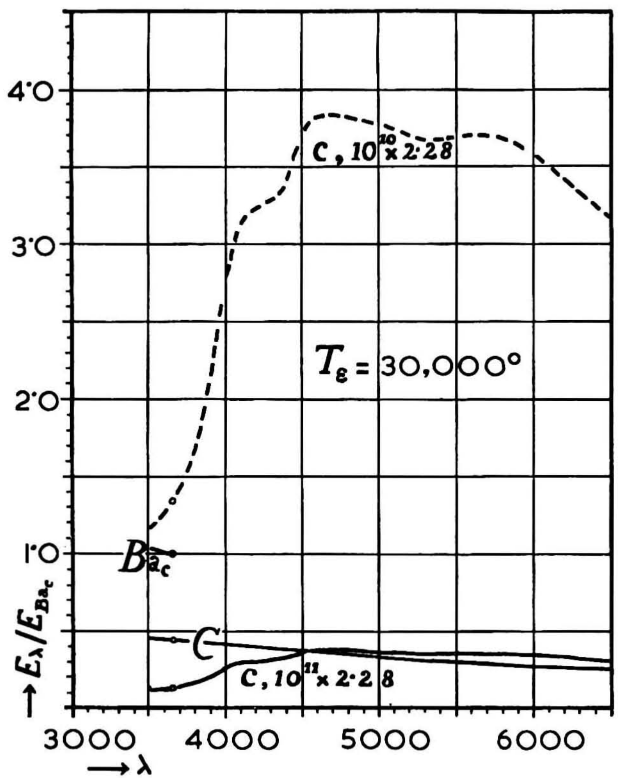

Fig. 5. The same as Fig. 2, but for electron temperature 30,000°.

if x represents the height at which the line of sight approaches closest to the limb.

From their observed absolute values of the intensity of the Ba_c spectrum and KRAMERS' theory then follows

$$E_{Ba_c} = 3.62 \times 10^{12}\, e^{-a'x}, \quad n_\varepsilon(x) = n_1(x) = 3.8 \times 10^{11}\, e^{-\frac{1}{2}a'x} \left(\frac{T_\varepsilon}{10^4}\right)^{3/4}; \tag{8}$$

C.&M.

where $a' = 1.54 \times 10^{-3}$ km^{-1}. For $x = 1300$ km one gets

$$\bar{n}_1 = n_1(x)/\sqrt{2} = 10^{11} \left(\frac{T_\varepsilon}{10^4}\right)^3.$$

In Figures 2, 3, 4 and 5 the values of $E_{\lambda c}/E_{Ba_c}$ from (6), using $I_\lambda(0)$ and β from Fig. 1, are plotted against λ for four different electron temperatures and these values of $\bar{n}_1$ corresponding to a chromospheric height of 1300 km. The curves are full-drawn and marked with a C, followed by this value of $\bar{n}_1$. They are meant as a guide for future eclipse observations to estimate the intensity of the scattering spectrum c to be expected. Its estimated absolute value follows by multiplication by CILLIÉ and MENZEL's value of E_{Ba_c} given in (8) and can be compared with the continuous background ${}_0I_\lambda(0)$ for the centre of the sun by means of Fig. 1. Once the new eclipse observations are carried out, the values (8) for E_{Ba_c} and $n_1(x)$ viz $\bar{n}_1(x)$ should of course be replaced by new values following from these observations. The value $E_{\lambda C}/E_{Ba_c}$ for the KRAMERS spectrum C is given by the curves marked C and is determined by the electron temperature only, independent of the concentration.

3. *Provisional Conclusions for the Chromosphere*

For wavelengths longer than the series limit λ 3646.9 one should take the sum $E_{\lambda C} + E_{\lambda c}$, and for shorter wavelengths the sum $E_{\lambda Ba_c} + E_{\lambda C} + E_{\lambda c}$. This is done in Table II for the wavelengths λ 5000, λ 3700 and λ 3647 just adjoining Ba_c, as compared with λ 3646 Ba_c. The values in parentheses are the same with the c spectrum left out.

TABLE II

Chromosphere = 1300 *km. Values of* E_λ/E_{3646} *expected for three* λ*'s.*

The values in parentheses are those for $E_{\lambda c} \to 0$ or $\bar{n}_1 \to \infty$ and should provide lower limits for any concentration or any height

T_ε	5000°	10,000°	20,000°	30,000°
$\frac{E_{5000}}{E_{3646}}$	0.113	0.219	0.33	0.45
	(0.0191)	(0.073)	(0.170)	(0.236)
$\frac{E_{3700}}{E_{3646}}$	0.040	0.104	0.254	0.374
	(0.0046)	(0.0049)	(0.187)	(0.308)
$\frac{E_{3647}}{E_{3646}}$	0.038	0.098	0.248	0.369
	(0.0042)	(0.0047)	(0.187)	(0.312)

Examining the reproduction of the chromospheric slit spectrum taken at the 1926 eclipse by DAVIDSON and STRATTON [12]), one cannot escape the impression that at λ 3700 the continuous spectrum, which hardly registers there, is extremely weak as compared with λ 3646, and that the ratio falls considerably below the value 0.37 or 0.31 of the Table required for $T_\varepsilon = 30{,}000°$. This would mean that the electron temperature of the chromosphere falls a good deal below the kinetic temperature of about 30,000° for atoms and ions, which REDMAN [13]) derived from line widths at the 1940 eclipse. Theorists [14]) thus far have mostly been assuming that the two kinetic temperatures of electrons and atoms or ions have the same value of about 30,000°, and for this reason chromospheric observations actually determining the electron temperature would be of great theoretical importance. A much lower electron temperature than 30,000° might perhaps be explained by the electrons losing their thermal energies by exciting collisions, as is the case in nebulae.

For future eclipse observations the best procedure would probably be to determine n_1 by PANNEKOEK's method from the STARK broadening of the higher BALMER lines, preferably by measuring line profiles corrected for instrumental profile, thermal velocities and fine structure. This gives a kind of average n_1, which could serve for $\bar{n}_1$. Assuming STARK effect due to protons only with $\bar{n}_1 = 10^{11}$, one expects for quantum number $n = 25$ a STARK width of about one quarter of the kinetic theory width at 30,000°, while the separation between subsequent lines is four times this kinetic theory width. For $n = 30$, the figures are 1/3 and 2.4. So it appears possible to measure the STARK effect in the wings, since its intensity falls off less rapidly with the distance from the line centre than for the kinetic theory profile.

The ratio E_λ/E_{3646} should further be measured, which for a given λ is a known function of $\bar{n}_1$ and T_ε, and $\bar{n}_1$ being known, T_ε would be determined. [15]) Independent determinations for various λ might provide a check. Provided the observed continuum between lines is strong enough in the ultraviolet, one might find it possible to extrapolate from longer wave lengths to λ 3647 (see the last row in Table II) which would eliminate the effect of differential absorption in the ultraviolet.

If the STARK effect method does not give satisfactory results, it might be replaced or checked by the absolute determination of E_{Ba_c} which yields $n_1/T_\varepsilon^{3/4}$ according to KRAMERS' theory (Cf. equation (8)). However

[12]) C. R. DAVIDSON and F. J. M. STRATTON, Memoirs of the R.A.S. **64**, 105 (1927), Plate 1, DAVIDSON, MINNAERT, ORNSTEIN and STRATTON, loc. cit., Plate 7.

[13]) R. O. REDMAN, M.N. **102**, 140 (1942).

[14]) Cf. R. N. THOMAS, Ap. J. **108**, 142 (1948); R. G. GIOVANELLI, M.N. **109**, 298 (1949).

[15]) $E_{\lambda C}/E_{Ba_c}$ (3), (2), (2a) is known as $f(T_\varepsilon)$.

$E_{\lambda c}/E_{Ba_c}$ (6) is a known constant times $T_\varepsilon^{3/2}/\bar{n}_1$. The extreme case $\bar{n}_1 = \infty$, $E_{\lambda c} = 0$ gives therefore T_ε directly. The other extreme $E_{\lambda C} = 0$ gives $T_\varepsilon^{3/2}/\bar{n}_1$ or T_ε for known $\bar{n}_1$. There should be no difficulty for the general case.

if the chromosphere has a filamentary structure, this method of CILLIÉ and MENZEL should give low values, since it would give a kind of average concentration, while PANNEKOEK's and WURM's methods would refer to the concentration in the filaments.

One might also think of determining T_ε from the relative distribution in wave length in the Ba_c spectrum from KRAMERS' Theory with GAUNT factors, but the results thus far obtained for the chromosphere and the experience of the same method with nebulae seems to show that this method is not very reliable.

It would be very desirable to have the investigation of the continuous spectra leading to an electron temperature carried out at the same eclipse where the kinetic temperature from line widths is determined, if possible at the same spot in the chromosphere, so as to make sure that the two temperatures are determined under the same circumstances.

4. *Prominences*

Individual concentrations in prominences may vary a great deal from case to case. The average derived by UNSÖLD [16]) is $n_\varepsilon = n_1 = 8 \times 10^9$. Let us assume, merely for the purpose of illustration, a concentration n_1 in prominences of one tenth of the n_1 values we took as typical for chromosphere. Then, by the procedure outlined in section 2, the dotted curves of Figures 2, 3, 4 and 5 are obtained for the ratio $E_{\lambda c}/E_{Ba_c}$ in prominences, which are marked by c, followed by the value of n_1. For the other ratios $E_{\lambda C}/E_{Ba_c}$ and $E_{\lambda Ba_c}/E_{Ba_c}$ the full-drawn curves remain valid. Figure 3 applies to $T_\varepsilon = 10{,}000°$, $n_1 = 10^{10}$ protons or electrons per cm³ and contains also the curve for scattering by free electrons if the solar spectrum would be free from FRAUNHOFER lines, that is if $I_\lambda(0)$ of Fig. 1 would be replaced by ${}_0I_\lambda(0)$.

Figures 2 to 5 show that probably always $E_{\lambda c}$ is much larger than $E_{\lambda C}$, so that scattering by free electrons predominates for wavelengths longer than the series limit, in agreement with LYOT's observations of polarisation. One may observe therefore $E_{\lambda c}/E_{Ba_c}$ and then equation (6) yields $\bar{n}_1/T_\varepsilon^{3/2}$. [17]) which is WURM's method. However, unless the electron temperature is high, or the concentration a good deal higher than assumed, the C spectrum is relatively weak and a reliable determination of T_ε is not possible on this basis.

Substituting the measured $\bar{n}_1/T_\varepsilon^{3/2}$ or $n_\varepsilon/T_\varepsilon^{3/2}$ (6*b*) into (5), one obtains $\varepsilon_{\lambda c}/T_\varepsilon^{3/2}$, and then (1*a*) $E_\lambda = (\varepsilon_\lambda/T_\varepsilon^{3/2})\, L\, T_\varepsilon^{3/2}$ yields $L T_\varepsilon^{3/2}$. In other words, if the electron temperature be known, one can determine both the concentrations n_1 or n_ε and the thickness L of the prominence.

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[16]) A. UNSÖLD, Physik der Sternatmospharen, p. 415, 419 (SPRINGER 1938).

[17]) Dividing the observed $E_{\lambda c}/E_{Ba_c}$ by its value for 10,000° read from the lower dotted curve of Fig. 3, one obtains directly $\left(\frac{T_\varepsilon}{10^4}\right)^{3/2} \cdot \frac{10^{10}}{\bar{n}_1}$, instead of using (6*b*).

5. *Remark on the continuous spectrum due to the formation of H^-*

CHANDRASEKHAR and Mrs. BREEN [18]) have computed the absorption coefficient of negative hydrogen a_p expressed per neutral hydrogen atom and per unit of electron temperature for various temperatures and wave-lenghts. For temperatures up to about 10,000° and wave-lengths near λ 3646, forced transitions are negligible, as may be seen by comparing their Tables 5 and 6. For a given electron temperature T_ε, electron pressure p_ε and concentration of neutral hydrogen n_0 the number of recombinations and electron switches for a certain velocity interval, and therefore the emission in a certain wave-length interval, is then the same as for thermal equilibrium at a temperature equal to T_ε. Or also: the emission per unit wave-length and unit solid angle per cm³ per second $\varepsilon_{\lambda H^-}$ is the same as the absorption for $T = T_\varepsilon$, and therefore given by

$$\varepsilon_{\lambda H^-} = B(\lambda, T_\varepsilon) \cdot a_p(\lambda, T_\varepsilon) \cdot k T_\varepsilon n_\varepsilon n_0 \tag{9}$$

where $B(\lambda, T_\varepsilon)$ is the intensity of black body radiation, and $p_\varepsilon = n_\varepsilon kT_\varepsilon$ has been substituted.

From their Table 5 for a_p, equation (9) and KRAMERS' theory, viz. equation (4), we obtain, for λ 3647, by a slight linear extrapolation

$$\tag{10} \left\{ \begin{array}{ll} T_\varepsilon = 5040^0, & \dfrac{\varepsilon_{3647H^-}}{\varepsilon_{Ba_c}} = 2.2 \times 10^{-4} \dfrac{n_0}{n_1}, \\[2ex] T_\varepsilon = 10{,}080^0, & \dfrac{\varepsilon_{3647H^-}}{\varepsilon_{Ba_c}} = 5.3 \times 10^{-3} \dfrac{n_0}{n_1}, \end{array} \right.$$

as a general theoretical result, holding therefore for the chromosphere as well as for prominences.

An actual determination of n_0 has not been devised as yet. However, WURM, [19]) by comparing the ionisation of Sr^+ into Sr^{++} with the ionisation of H into H^+, and assuming a plausible abundance ratio of Sr to H estimates for prominences n_0/n_1 between 1 and 0.1, so that the ratio (10) of H^- to Ba_c spectrum would be less than $^1/_{200}$ for an electron temperature of 10,000° or lower. An estimate for the chromosphere has not been carried out, but assuming the same or a smaller $n_0/(n_1\, n_\varepsilon)$ and a ten times larger n_ε, the ratio of the two spectra would be smaller than $^1/_{20}$.

Pending further evidence, it might be well to keep the possibility of the H^- spectrum in the chromosphere in mind. If it be present, this would make the determined T_ε still lower.

The writer wishes to express his gratitude to Professor H. H. PLASKETT for clarifying discussions, in particular regarding the STARK effect as means of determining the chromospheric concentration.

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[18]) S. CHANDRASEKHAR and FRANCES HERMAN BREEN, Ap. J. **104**, 430 (1946).

[19]) K. WURM, loc. cit.