Source: Prichini rasshireniya vodorodnikh linii v spektre solntsa, Akademiya Nauk SSSR. Krimskoy Astrofizicheskoy Observatorii, Izvestiya. Vol.16,54-66(1956).

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CAUSES FOR THE BROADENING OF HYDROGEN LINES IN THE SOLAR SPECTRUM

by A B SEVERNY

1. Introductory Remarks

Unsöld's papers (1, 2) and de Jager's recent paper on the solar hydrogen spectrum (3) are dedicated to the causes of broadening of hydrogen lines of the Balmer series in the solar spectrum. At first (1) Unsöld believed that the basic line of this series Hα is broadened as a result of natural damping. It is known that the Stark effect has least influence on the broadening of this line. For this reason Unsöld tried to determine the lower boundary of the broadening of this line neglecting the influence of the Stark effect and considering only the natural damping of the radiation. Unsöld assumes for the wings of Hα the absorption coefficient

$$s_\nu = \frac{s_0}{\Delta\lambda^2}, \quad s_0 = 5.40 \cdot 10^{-17}, \tag{1,1}$$

where $\Delta\lambda$ is expressed in angstroms. Assuming that the profile of Hα can be presented by the interpolation formula

$$1 - r_\lambda = \left(\frac{1}{R_c} + \frac{1}{x_\lambda}\right)^{-1}, \tag{1,2}$$

where x_λ, the optical thickness, is equal to $N_2 H s_\nu$ (considered small), the following expression is adopted for the equivalent width of Hα

$$E_\lambda = \int_{-\infty}^{+\infty} \frac{d\Delta\lambda}{1 + \frac{\Delta\lambda^2}{s_0 N_2 H}} \doteq \pi\sqrt{s_0 N_2 H} = 2.31 \cdot 10^{-8}\sqrt{N_2 H}. \qquad (1, 3)$$

Here, apparently, the factor R_c, the central contrast, is omitted. Taking, according to Allen, $E_\lambda = 2.53$ Å, we get $N_2 H < 1.2 \cdot 10^{16}$. Since Unsöld concludes that this upper value (expression (1, 3) gives the minimum E_λ) differs little from the lower one obtained from measurements of higher members of the series $(N_2 H > 5 \cdot 10^{15})$ and the "effective optical thickness" τ_0 in the solar spectrum is almost the same for λ 6563 and λ 3750, we conclude that the broadening of Hα in the solar spectrum is, at any rate partially caused by damping of the radiation. In the other paper Unsöld pointed out that the profile of Hα is in agreement with this assumption.

The point is that the concept of one "effective thickness" ceases to be correct for such broad lines as Hα : to different sections of this line correspond different values of the "effective thickness" (differing several times, see below). Besides, if one would even characterize such lines by one "effective thickness", it will be different for Hα and the higher members of the series. Finally, the formula (1,2) is too rough for the representation of profiles of such broad and deep lines as Hα and it is absolutely unable to explain the center--limb effect.

Later (2, p. 42) Unsöld found out that for the line $H\alpha$ the natural damping is immaterial as compared to the statistic Stark effect. De Jager studied the Stark broadening of hydrogen lines in the solar spectrum in great detail, especially in connection with the center--limb effect and found that the theoretical profiles, particularly of $H\alpha$, are perceptibly less deep than the observed ones, especially at the limb. Systematic discrepancies sometimes reach even 8% of the intensity of the continuous spectrum; this cannot be attributed to observation errors. The author tries to explain these discrepancies by possible inaccuracy of the adopted solar-atmosphere model without reaching a definite conclusion in this direction.

Naturally, the question presents itself whether the solar system has a more powerful absorption and broadening mechanism of hydrogen lines, expecially of $H\alpha$, causing the observed profiles and the center--limb effect. It has been repeatedly mentioned (see, for example, (2), p. 45) that in the spectra of "relatively cold" dwarf stars the broadening of the first members of the Balmer series may be caused by the intrinsic pressure of neutral hydrogen, i.e. by the effect of collisions of atoms among themselves. Indeed, as proved by observations (see below), the wings of hydrogen lines, especially of $H\alpha$, reach very far, up to 30 Å, i.e. they originate in very deep strata of the solar atmosphere where the partial pressure of hydrogen is high.

The opinion, that the pressure effects do not play any part in the solar atmosphere, comes from Unsöld ((1), pp. 308-309). Based on his old solar-atmosphere model ((1) table 36) which is incorrect because of neglect of the absorption of hydrogen by negative ions, Unsöld assesses the full number of atoms to $N = 5.44.10^{15}$ ($T = 5600°$ and $p = 4170$ bars) at the optical depth $\tau = 0.5$ (where the lines mainly originate). Actually, at the depth $\tau = 0.5$ the pressure is approximately 10^5 bars and the number of atoms (basically hydrogen) is $1.2 \cdot 10^{17}$ (see, for example, (3,4)). For metals, which account for not more than 10^{-4} parts of hydrogen content, the partial pressure, $\sim 10^{13}$, is insufficient for broadening under the action of intrinsic pressure, which, as experimentally observed, starts to make itself noticeable at a density of $\sim 10^{14}$ cm $^{-3}$ (corresponding experimental data are not available for hydrogen).

Therefore, the action of the mechanism of intrinsic pressure (collisions) in the broadening of hydrogen lines should not be neglected, especially in connection with the higher partial pressure of hydrogen than the one taken for granted earlier. This paper is dedicated to the study of the broadening of hydrogen lines in the solar spectrum caused by the effect of intrinsic pressure, to the calculation of theoretical profiles connected with this effect, and to their comparison with the profiles observed by us using the photoelectric method.

2. Comparison of Broadening Caused by Intrinsic Pressure with the Stark Broadening of Hydrogen Lines.

In accordance with up-to-date models of the solar atmosphere, the number of meutral hydrogen atoms N_H changes rather slowly with increasing depth. The calculations reveal (3), that the wings, for example of the $H\alpha$ line, $(\Delta\lambda \geqslant 1\,\text{Å})$ originate at depths $\tau \geqslant 0.6$. For these optical depths (for an average absorption coefficient) the magnitude $N_H \geqslant 1.1 \cdot 10^{17}$ $(\tau = 0.5)$ and it increases up to $1.55 \cdot 10^{17}$ (at $\tau = 2.5$ or a little greater). Therefore we only minimize the effect of broadening by intrinsic pressure if we take

$$N_{\text{H}} = 1.1 \cdot 10^{17} \qquad (2, 1)$$

and shall assume this magnitude a constant for the calculation of the theoretical profile.

The constant of the damping, because of collisions in the case of broadening by inherent pressure, equals according to Lindholm (see (2), p. 16)

$$\gamma_{\text{cr}} = 4\pi^3 CN, \qquad (2, 2)$$

and the magnitude

$$C = \frac{e^2}{8\pi m\omega_0} f_{ik}, \qquad (2, 3)$$

where f_{ik} is the force of the oscillator for the transition $i \rightarrow k$. For the line $H\alpha$ the magnitude $f_{32} = 0.637$ and

$$C = 2.22 \cdot 10^{-9}, \qquad (2, 4)$$

so that according to (2,1):

$$\gamma_{\text{ст}} = 3.04 \cdot 10^{10}. \qquad (2,5)$$

Comparing this with the constant of damping caused by radiation for the line $H\alpha$

$$\gamma_{\text{зат}} = \gamma_2 + \gamma_3 = A_{21} + A_{32} + A_{31} = 5.66 \cdot 10^{8}, \qquad (2,6)$$

we see that the damping caused by collisions of hydrogen atoms among themselves is almost a 50-times more effective process than the natural damping of the radiation.

Let us compare approximately with each other the magnitudes of the coefficients of absorption caused by intrinsic pressure and the one caused by the Stark effect for the line $H\alpha$. The absorption in the wing $H\alpha$ may be taken in the form

$$s_\nu = \frac{c^2}{m_e c} \frac{f_{23}\delta_{23}}{(\nu - \nu_0)^2} = 10^{10} \frac{c^2}{m_e c^3} \frac{f_{23}\delta_{23}\lambda_0^4}{\Delta\lambda^2}, \qquad (2,7)$$

if $\Delta\lambda$ is expressed in angstroms; here $\delta_{23} = \frac{1}{4\pi}\gamma$, and $\gamma = \gamma_{\text{зат}} + \gamma_{\text{ст}} = 3.1 \cdot 10^{10}$ according to (2,5), (2,6). After substitution of the magnitude γ into (2,7) we get

$$s_\lambda = \frac{2.49 \cdot 10^{-15}}{\Delta\lambda^2} \qquad (2,8)$$

On the other hand, we have for the Stark effect

$$s_\nu = m_{11} f_{23} 10^8 \left(\frac{s'_\nu}{n}\right), \qquad (2,9)$$

where the magnitudes of s_ν/n were tabulated by Verweji (5) for the temperature of 11 000° and various p_e. At the distance $\Delta\lambda = 2\text{Å}$ from the center of H_α we have according to (2,8), $(s_\lambda)_{cr} = 6.23 \cdot 10^{-10}$. On the other hand, for this $\Delta\lambda$, the "effective" optical depth τ_0 for an average absorption coefficient can be found by interpolation using the data (3) and from the model of the atmosphere we find according to τ_0 $\lg p_e \approx 2.$ From table VI (6) we find (at T = 11 000°): $10^8 \frac{s_\nu}{n} = 4.5.$ For T = 5500° this magnitude equals approximately 2 the Stark coefficient (2,9) will be: $(s_\nu)_{\text{пт}} \approx 2 \cdot 10^{-10}$, i.e. approximately three times smaller than s_ν because of intrinsic pressure.

A more exact and complete calculation of the absorption coefficients may be carried out as follows. In the case of instrinsic pressure we have

$$s_\nu = s_0\left[e^{-v^2} - \frac{a}{\sqrt{\pi}}\left(1 - 2vF(v)\right)\right], \qquad (2,10)$$

whereby

$$v = \frac{\Delta\lambda}{\Delta\lambda_D}, \qquad a = \frac{\gamma}{\Delta\omega_D}, \qquad s_0 = \frac{\sqrt{\pi}e^2}{mc^2} f_{32} \frac{\lambda_0^2}{\Delta\lambda_D}, \qquad (2,11)$$

where $\gamma = \gamma_{cr} + \gamma_{\text{зат}} = 3.1 \cdot 10^{10}$; the function $(1 - 2vF(v))$ is tabulated in (1, p. 179) for $v \leqslant 10$; for $v > 10$ we used the representation of the function s_ν/s_0 in the form

$$\frac{s_\nu}{s_0} \equiv H(a, v) = \frac{a}{2} H_1(v) + \left(\frac{a}{2}\right)^3 H_3(v),$$
$$H_1(v) = 0.5642v^{-2} + 0.846v^{-4}; \quad H_3(v) = -0.56v^{-4}, \qquad (2,12)$$

where the functions $H_0(v)$, $H_1(v)$ etc. are calculated by Harris (6). Calculating $\Delta\lambda_D$ and a, we assumed the temperature of the sun to be 5740°. This gives

$$s_0 = 6.15 \cdot 10^{-13}, \quad \Delta\lambda_D = 0.212\,\text{Å}, \quad a_{\text{зат}} = 0.006097, \quad a = 0.3341.$$

The magnitudes of s_v for the case of damping caused by radiation and damping caused by intrinsic pressure (table 1) were calculated with these values of a and s_0.
We see that the absorption caused by intrinsic pressure is almost a hundred times more effective process than the damping caused by radiation.

For the calculation of the coefficient of absorption caused by the Stark effect we used his expression for the wings of the line (see (3), p. 39).

$$s_{\text{шт}}(\Delta\lambda) = C_n F_0^{3/2} \Delta\lambda^{-5/2}. \qquad (2,13)$$

For the line Hα the magnitude $C_n = 3.43 \cdot 10^{-16}$ and the normal field intensity $F_0 = 2.61\ en^{2/3}$ where n is the number of perturbing particles (ions and electrons) in 1 cm^3. Unsöld demonstrated (2) that the action of electrons may be neglected since they affect only very distant wings. Therefore $n = n_i \approx n_e$ is equal to the number of electrons in 1 cm^3 and (2,13) is

$$s(\Delta\lambda) = 1.51 \cdot 10^{-20} n_e \Delta\lambda^{-5/2}, \qquad (2,14)$$

where $\Delta\lambda$ is expressed in angstroms. Each distance from the center of the line H_α has its own "effective" optical thickness τ_0 (in frequencies of the continuous spectrum) and thereby its own electronic pressure p_e. We found these values of n_e and τ_0 for various $\Delta\lambda$

Table 1

v	$\Delta\lambda$ (Å)	s_ν зат	s_ν давл	s_ν шт
0	0	$6.129 \cdot 10^{-13}$	$4.991 \cdot 10^{-13}$	—
2.0	0.124	$1.170 \cdot 10^{-14}$	$3.505 \cdot 10^{-14}$	—
3.0	0.636	$2.223 \cdot 10^{-16}$	$8.093 \cdot 10^{-15}$	$1.58 \cdot 10^{-15}$
4.0	0.848	$7.368 \cdot 10^{-17}$	$4.034 \cdot 10^{-15}$	$9.33 \cdot 10^{-16}$
5.0	1.06	$4.515 \cdot 10^{-17}$	$2.474 \cdot 10^{-15}$	$6.31 \cdot 10^{-16}$
7.0	1.48	$2.228 \cdot 10^{-17}$	$1.221 \cdot 10^{-15}$	$3.72 \cdot 10^{-16}$
10.0	2.12	$1.074 \cdot 10^{-17}$	$5.884 \cdot 10^{-16}$	$2.09 \cdot 10^{-16}$
20.0	4.24	—	$1.445 \cdot 10^{-16}$	$5.25 \cdot 10^{-17}$
40.0	8.48	—	$3.397 \cdot 10^{-17}$	—
60.0	12.7	—	$1.611 \cdot 10^{-17}$	—
100	21.2	—	$5.799 \cdot 10^{-18}$	—

by interpolation from the model of solar atmosphere used by de Jager (3); the τ_0 for various $\Delta\lambda$ are listed at the same place presuming that the broadening of H_α is a Stark broadening the last assumption is unessential for the given calculation). The calculation

Fig.1.

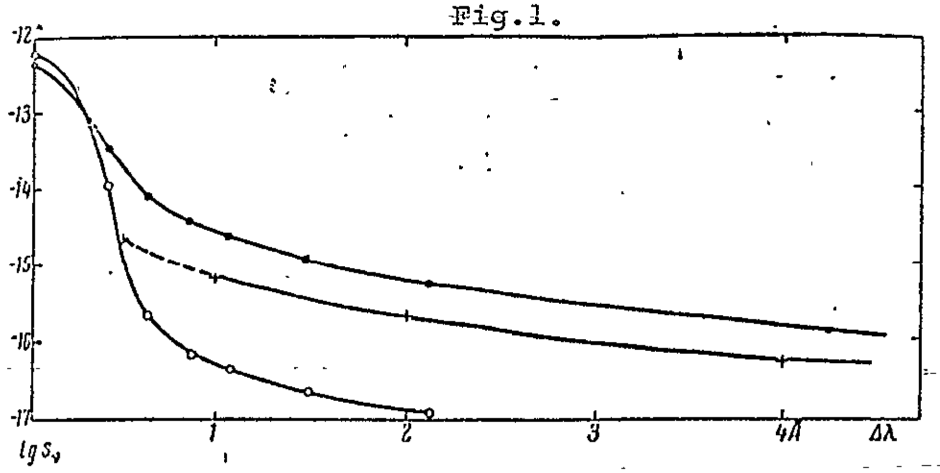

Fig. 1. Comparison of absorption coefficients for various broadening mechanisms of the line $H\alpha$: natural damping of the radiation (circlets), Stark effect (crosslets), damping caused by pressure effect (points).

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results according to (2,14) are given in the fifth column of table 1 ($\Delta\lambda < \sim$ 0.5Å the formula (2,13) is unusable). A juxtaposition of these three absorption coefficients is displayed in fig. 1. Table 1 and fig. 1 illustrate that the coefficient of absorption caused by intrinsic pressure is three to five times greater than the one caused by the Stark effect in the wings of the line $H\alpha$

Thus, the broadening of the line $H\alpha$ in the solar spectrum is caused basically by the effect of intrinsic pressure (collisions of hydrogen atoms among themselves) and not by the Stark effect.

Let us investigate ~~now the line $H\beta$~~ For the line $H\beta$ the magnitude C (see (2,3)) is $\frac{f_{42}}{f_{32}} = 0.187$ times smaller than for $H\alpha$ (f_{42} = 0.119) and for $H\beta$ the magnitude $\gamma_{c\tau} = 4.23 \cdot 10^9$. The magnitude $\gamma_{nat.}$ for $H\beta$ equals $4.99.10^8$, therefore $\gamma = 4.73.10^9$ and

$$a(H_\beta) = \frac{\gamma_\beta}{\gamma_\alpha}\frac{\lambda_\beta}{\lambda_\alpha} a(H_\alpha) = 0.113 a(H_\alpha),$$

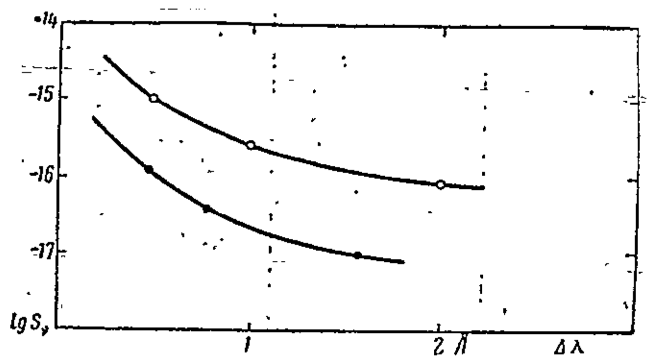

Fig. 2. Comparison of absorption coefficients for various broadening mechanisms of the line H_β : Stark effect (circlets), pressure effect (points).

$s_0(H_\beta) = \frac{\lambda_\beta}{\lambda_\alpha}\frac{f_{42}}{f_{32}} s_0(H_\alpha) = 0.855 \cdot 10^{-13}$. With these values of a and s_o the s_ν were calculated using the formula (2,10). A calculation analogous to the H_α case was carried out for the Stark coefficient with the formula (2,13) where $C(H_1) = 0.858.10^{-16}$ (4, p. 162). The results are shown in fig. 2, from which it may be concluded that for H_β the Stark absorption coefficient exceeds considerably the absorption caused by the intrinsic pressure, and the line H_β in the solar spectrum is broadened basically under the action of the Stark effect. The same is valid also for the remaining hydrogen lines of the Balmer series where the influence of the Stark effect is even stronger.

3. Theoretical Profiles of the H_α Line and Comparison with the Observed Profiles

The intensity in the sphere of the absorption line at a sufficient distance from its center may be calculated with the formula

$$I(\Delta\lambda, 0)=\int_0^\infty B_\nu(\tau_0)e^{-\tau_\lambda \sec\theta}\frac{k_\nu+\sigma_\nu}{k_0}\sec\theta d\tau_0, \qquad (3,1)$$

where σ_ν is the coefficient of selective absorption (in the sphere of the line), k_ν is the absorption coefficient within the frequency of the continuous spectrum ν_0, and k_0 is the mean absorption coefficient; all coefficients are computed per unit mass. The intensity in the frequency ν_0 of the continuous spectrum (in the absence of the line) is

$$I_0(0)=\int_0^\infty B_\nu(\tau_0)e^{-\tau_\nu \sec\theta}\frac{k_\nu}{k_0}\sec\theta d\tau_0; \qquad (3,2)$$

The following designations are used in (3,1) and (3,2)

$$\tau_\nu=\int_0^{\tau_0}\frac{k_\nu}{k_0}d\tau_0, \quad \tau_\lambda=\int_0^{\tau_0}\frac{k_\nu+\sigma_\nu}{k_0}d\tau_0. \qquad (3,3)$$

For the determination of the values of $\frac{k_\nu}{k_0}$ the papers of Chandrasekhar and Breen (7) and Chandrasekhar and Munch (8) were used. For k_ν we have the expression (see (8))

$$k_\nu=(1-x)\frac{1}{1.8m_H}[k_\nu(H^-)p_e+k_\nu(H)], \qquad (3,4)$$

where the values of k_ν (H^-), the coefficient of absorption by negative hydrogen ions, (for p_e = 1) are tabulated for various values of $\theta=\frac{5040}{T}$ in the table VII (7); the magnitude 1--x practically equals 1. In (8) (table II) the values of k_0 are given for different p_e' and θ. As far as k_ν (H), the coefficient of absorption by neutral hydrogen atoms, is concerned, it has been calculated with the formula (see (4))

$$k_\nu(\mathrm{H}) = \frac{C_0 Z^2 x p_e}{\nu_0^3 T^{\frac{3}{2}}} \left\{ \frac{2hRZ^2}{kT} \sum_{n_0}^{\infty} \frac{g'}{n^3} e^{\frac{hRZ^2}{n^2kT}} + g'' \right\} \left(1 - e^{-\frac{h\nu_0}{kT}}\right),$$

$$g'' = 1 + 0.1728 \left(\frac{\nu}{RZ^2}\right)^{\frac{1}{3}} \left(1 + \frac{2kT}{h\nu}\right), \qquad (3, 5)$$

$$g' = 1 - 0.1728 \left(\frac{\nu}{RZ^2}\right)^{\frac{1}{3}} \left[\frac{2}{h^2}\left(\frac{RZ^2}{\nu}\right) - 1\right]$$

The share contributed by k_ν (H) in (3, 4) becomes perceptible for optical depths $\tau_0 > 1$. As the most up-to-date and accurate, the model of the sun's photosphere calculated by de Jager (3) was taken as the basis for the computations. The following data are given in table 2: data on this model (the first three columns), the magnitudes of k_ν (H) calculated according to (3, 5), the values of k_ν (H^-) obtained by interpolation using the table VII (7), the values of k_ν calculated with the formula (3, 4), and the values of k_0 determined by interpolation using the table II (8). These data may be useful in the study of origination conditions for hydrogen lines.

Further (see (4), p. 191), if s_ν is the absorption coefficient for one atom (#2), the absorption coefficient for 1 g. is (for depths of $\tau_0 \leq 5$ which are of interest to us)

$$\sigma_\nu = \frac{1}{1.8 m_H} \frac{g_{02}}{g_{01}} e^{-\frac{\varepsilon_{02}}{kT}} s_\nu = \frac{1}{1.8 m_H} s_\nu 4 e^{-23,302\theta}, \qquad (3, 6)$$

where s_ν for each distance from the center of the line $\Delta\lambda$ is given in table 1 (column 4). In table 2 (last column) the values of σ_ν (0) (3, 6) are given for the center of the line $\Delta\lambda = 0$. For all the remaining $\Delta\lambda$ the values of σ_ν are obtained by multiplying these values $\sigma_\nu(0)$ with the ratios $\frac{s_\nu(\Delta\lambda)}{s_\nu(0)}$, given in table 1. Specifically from table 2 it may be seen that $\frac{\sigma_\nu}{k_0}$ and $\frac{\sigma_\nu}{k_\nu}$ are changing

Table 2

τ_0	θ	$\lg p_e$	k_ν (H)	k_ν (H^-)	k_ν	k_0	σ_ν
0.01	1.18	−0.12	$6.65 \cdot 10^{-28}$	$2.07 \cdot 10^{-25}$	0.0524	0.0463	0.688
.02	1.136	+0.06	8.33	1.76	0.0675	.0600	1.92
.03	1.098	0.20	$1.02 \cdot 10^{-27}$	1.52	0.0806	.0720	4.68
.04	1.075	.31	.19	1.39	0.0950	.0850	8.00
.06	1.043	.49	.87	1.23	0.127	.113	16.9
.08	1.020	.58	2.12	1.11	0.141	.128	29.0
.10	1.003	.68	2.71	1.03	0.165	.150	43.8
.15	0.972	.87	4.71	0.901	0.224	.206	89.1
.20	.941	1.03	5.31	0.791	0.284	.261	$1.81 \cdot 10^2$
.30	.883	.21	$1.22 \cdot 10^{-26}$	0.620	0.406	.368	$7.09 \cdot 10^2$
.40	.843	.48	2.14	0.519	0.530	.484	$1.82 \cdot 10^3$
.50	.829	.54	.42	0.489	0.573	.523	$2.52 \cdot 10^3$
.60	.819	.61	.98	0.465	0.640	.586	$3.19 \cdot 10^3$
.80	.803	.74	4.27	0.431	0.801	.740	$4.64 \cdot 10^3$
1.00	.785	.85	5.90	0.397	0.955	.890	$8.90 \cdot 10^3$
.20	.769	.96	8.46	0.368	1.14	1.08	$1.03 \cdot 10^4$
.40	.754	2.08	$1.23 \cdot 10^{-25}$	0.343	1.41	.30	$1.46 \cdot 10^4$
.60	.739	.19	1.91	0.319	1.71	.59	$2.07 \cdot 10^4$
.80	.728	.28	2.59	0.300	1.99	.90	$2.68 \cdot 10^4$
2.00	.718	.36	3.40	0.286	2.29	2.16	$3.39 \cdot 10^4$
.5	.700	.50	5.50	0.260	2.91	.74	$5.17 \cdot 10^4$
3.0	.690	.60	7.45	0.246	3.51	3.33	$6.54 \cdot 10^4$
4.0	.670	.74	11.6	0.222	4.44	4.35	$1.04 \cdot 10^5$
5.0	.658	.84	15.7	0.209	5.33		

more than 1000 times due to depths, within the limits where the line Hα originates, i.e. in this case the Miln - Eddington model with $\frac{\sigma_\nu}{\kappa_\nu}$ = const. is absolutely unusable. The magnitude $\frac{k_\nu}{k_0}$ changes only by 5% so that the equation $\tau_\nu = \frac{k_\nu}{k_0}\tau_0$. is fulfilled with a high grade of accuracy. Practically, the difference of integrals (3, 2) and (3, 1) and the integral (3, 2) were computed separately by mechanical squaring.

Table 3

$\Delta\lambda$ (Å)	$\cos\theta = 1.00$	$\cos\theta = 0.142$
0.64	0.540	0.738
1.06	0.641	0.821
2.12	0.758	0.914
4.24	0.845	0.968
8.48	0.934	0.991
12.72	0.968	0.996

Dividing this difference by I_0 (θ) (see (3,2)) we obtained the contrast Hα , i.e. the magnitude $\frac{I_0(\theta) - I(\Delta\lambda, \theta)}{I_0(\theta)}$. The computations were carried out for two values: $\cos\theta = 1$ and $\cos\theta = 0.142$. The results in residual intensities r_ν are given in table 3.

The actual profile of the line Hα was measured by means of the device for photoelectric recording of the solar spectrum on the new tower solar telescope (see in (9) for a description of the telescope). This installation and the working method with it are described in our paper in the same volume (10). The recording was carried out with the grating setting in the second order at the practical resolving power of 0.04Å and dispersion of 0.7 Å/mm, and recording amplitude of 60Å. The recording was carried out by the scheme limb-center-limb in order to eliminate the influence of rapid changes of transparency although at the recording time (July 20, 1955) the transparency remained constant. The best ones were selected of all recordings: five for the center, five for the east limb, and four for the west limb. The processing of the recordings, taken on film, was carried out with consideration of the distortion introduced by the screen of the oscillograph. For each recording a distortion diagram, i.e. the dependence of the wave lengths of distinctive lines (within the limits of the profile H_α) on the scale, was plotted. In all cases this dependence turned out linear with a high grade of accuracy. This permitted to determine the scale of the wave lengths quite reliably.

Fig. 3

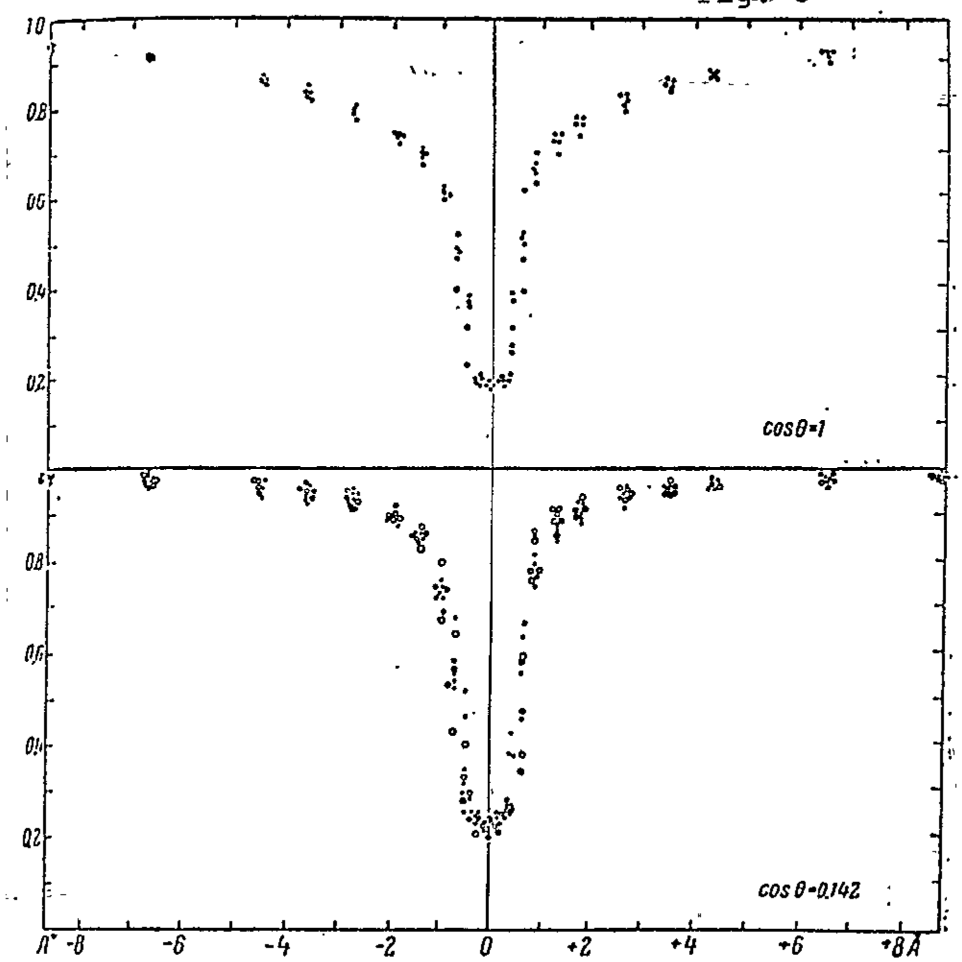

Fig. 3. Original photoelectric measurements of the profile H_α; at the center ($\cos\theta = 1$) at the limb ($\cos\theta = 0.142$).

In fig. 3 the results of individual measurements of the residual intensities of the profile H_α are given whereby for the center ($\cos\theta = 1$) and for the limb (the choice was made for $\cos\theta = 0.142$ in order to permit a comparison with the results obtained by de Jager (3)); in this last case the points belong to the east limb and the circlets to the west one.

We see that the convergence of individual measurements among themselves is good: the average deviation from the mean is for the center 0.6%, for the limb 0.8%; the root mean square error of an individual measurement is 1%.

Fig. 4

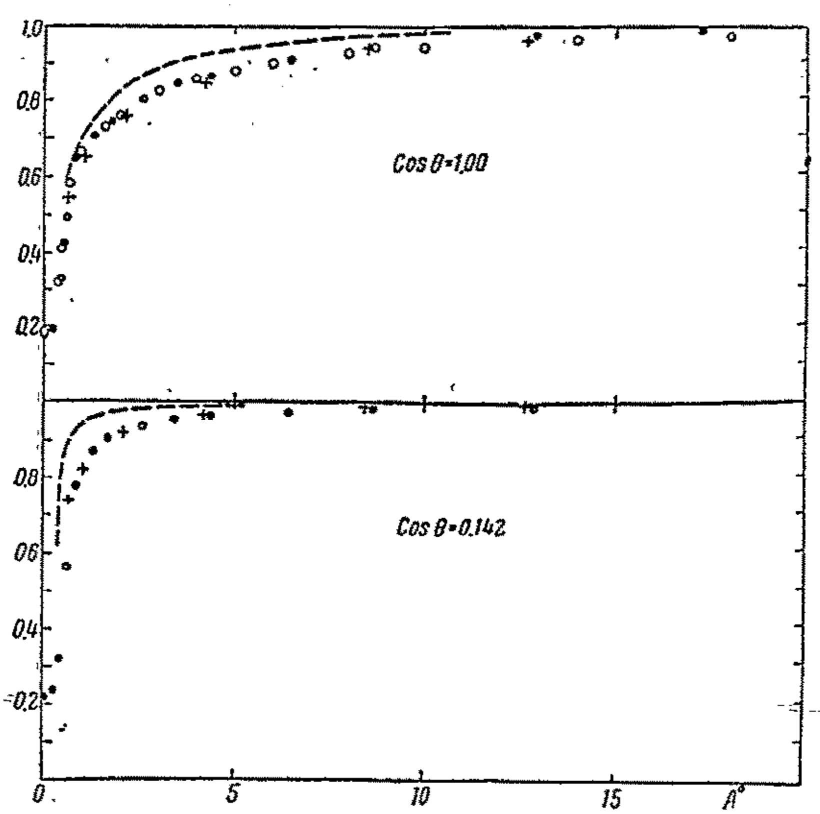

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Fig. 4. Observed medium profiles of the line H_α at the center and at the limb (points); medium observed profile of the line H_α from Pierce's data (11) (circlets); theoretical profile of the line H_α for the case of intrinsic pressure (crosslets) and profile of H_α in the case of the Stark effect (dotted line).

Scatter is observed only in the most steep part of the profile for $\Delta\lambda \approx 0.5$--$0.8\text{Å}$. This may be explained by the small scale of the recording. For the recording of the core of H_α it is necessary to use the small amplitude of 8 Å. However, such an amplitude does not permit to construct the wings of the line and find confidently the position of the continuous spectrum. There is no systematic difference between the east and west limbs; evidently, for such a broad line as H_α the rotation effect of the sun of 0.08Å cannot influence the form of the profile (on the possibility of systematic instrumental errors see (10)). The medium profiles of H_α by our measurements for the center and limb are given in table 4. They are also shown in fig. 4 (points). These profiles were obtained by averaging the values of r_ν for the red and blue wing, since the profile H_α is symmetrical with sufficient accuracy (the little assymetry in the domain $\Delta\lambda \approx 2\text{Å}$, not exceeding 2%, is unimportant for our purposes).

Table 4

$\Delta\lambda$ (Å)	r_ν Cos θ = 1	r_ν Cos θ = 0.142	$\Delta\lambda$ (Å)	r_ν Cos θ = 1	r_ν Cos θ = 0.142
—17.2	0.995	0.998	—1.72	0.748	0.904
—12.9	0.978	0.996	—1.29	0.708	0.871
— 8.60	0.942	0.986	—0.86	0.636	0.775
— 6.45	0.911	0.978	—0.65	0.492	0.564
— 4.30	0.865	0.966	—0.43	0.324	0.320
— 3.44	0.838	0.954	—0.22	0.194	0.236
— 2.58	0.802	0.938	0	0.186	0.223

In the same fig. 4 the profile of H_α is shown (for the center of the disk) according to Pierce's recent photoelectric measurements (11) (circlets). As it may be seen, our profile H_α practically coincides with the profile measured by this author. In the distant wings ($\Delta\lambda >$ 10 Å) some little divergence (not over 2%) is observed: the distant wings according to our measurements have a little less depth than according to Pierce's measurements. This divergence is quite real and associated with the fact that our section of recording (60Å) was smaller than in (11) where the distant wings were traced better than ours and thereby the position of the continuous spectrum is somewhat more accurate in this paper. Data are also given there for the theoretical profile (crosslets) according to table 3, and dotted lines show the theoretical profiles of H_α calculated by de Jager (3) for the case of broadening of this line under the action of the Stark effect. Our theoretical profile H_α (crosslets -- broadening caused by intrinsic pressure) is in good agreement with the observed profile in the center as well as in the limb, whereas de Jager's theoretical profile (dotted line -- broadening caused by the Stark effect) disagrees considerably with the observed profile, especially on the limb of the disk.

In such a way we arrive at the conclusion that the line H_α in the solar spectrum is broadened under the effect of intrinsic pressure (damping because of collisions of hydrogen atoms among themselves). From the agreement between the observed and theoretical profiles for the absorption coefficient (2,10), on the other hand, one may conclude that the magnitude $\gamma = 3.1.10^{10}$ has been determined correctly, i.e. the number of hydrogen atoms in the photosphere equals approximately 10^{17} and that the adopted model of the sun (model VII, 3) is sufficiently accurate.

As far as the remaining lines of the Balmer series are concerned, in their broadening the dominating part is played by the Stark effect for which the theoretical profiles obtained in (3) satisfactorily agree with the observed ones.

Finally, let us note that our photoelectric measurements of the core H_α (carried out with the amplitude of 8 Å) also confirm the assymmetry of the core of H_α detected by Pierce (11) (a shift of the central intensity to the blue side and a greater curvature of the red part of the core than that of the blue one).

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