NOTE ON THE WAVE-LENGTH OF $H\delta$ AND $H\epsilon$ IN THE SOLAR SPECTRUM

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The wave-length of the hydrogen line δ given in Rowland's Preliminary Table of wave-lengths in the normal solar spectrum, viz., 4102.000, has been previously called in question, since it does not agree with measures of the line obtained from vacuum tube discharges in hydrogen nor with measures of the bright line in *o Ceti.* According to Jewell, however, the position given in the table is most probably correct, taking into consideration the complicated structure of the line, due to the presence of other absorption lines.[1]

That the line should deviate in the sun from its theoretical position in the series, and from its position in terrestrial sources, by an amount so large as 0.10 Å., seems very improbable, the more so since it is now known how very closely the ultra-violet members of the series, as far as they can be photographed at eclipses, accord with the values derived from Balmer's formula. It seemed to the writer, therefore, desirable to get some measures of the emission line in the chromosphere, where the presence of interfering lines would have practically no effect. Accordingly in May 1907 a spectrograph was arranged for photographing $H\delta$ at the sun's limb.

A preliminary difficulty presented itself in the diminishing intensity of the hydrogen lines toward the ultra-violet, and the consequent rapidly diminishing height above the photosphere at which the lines can be photographed, as bright lines, under ordinary circumstances. In the case of $H\delta$, with a tangential slit at the sun's limb one obtains a broad bright line, corresponding with the lower region of the chromosphere, and even this is easily obliterated by a slightly diffusive sky, or by unsteadiness in the image. Probably it would be possible to photograph $H\delta$ as a narrow line in the brightest prominences, but possible motion in the line of sight in these would vitiate any measures of wave-length. It was found, nevertheless, that by placing the slit slightly within the limb, the bright line is still visible, but with the

[1] *Astrophysical Journal*, 9, 211, 1899.

narrow absorption lines superposed. This absorption line is fairly easy to measure, being free from interfering lines; and since the lines used as standards in the determinations of wave-length are due to the photospheric spectrum in the same locality as the hydrogen, motion in the line of sight due to rotation is eliminated. Recognizing, however, the possibility that the higher chromosphere might rotate at a speed differing from that of the underlying reversing layer, it was thought best to make a series of exposures on both east and west limbs, taking finally the mean values obtained from both. These mean values would still be subject to a small positive correction due to the shift of the low-level lines at the limb toward the red, discovered by Halm, which in all probability will not affect the hydrogen lines, at any rate to the same extent.

The spectrograph I employed consists of a plane grating, with 14,428 lines to the inch, and a ruled surface 3.2 inches in length. The collimator has a $3\frac{1}{4}$-inch visually corrected lens of 36 in. (914 mm) focal length; and a single plano-convex lens of 101 mm (4 in.) aperture and 213 cm (7 ft.) focus for $H\delta$ is used for the camera. The instrument is used in connection with the 12-inch Cooke photo-visual lens of this Observatory, which gives an image of the sun about 60 mm in diameter. The best results were obtained in the fourth order, notwithstanding the long exposures needed, and most of the plates obtained include, besides $H\delta$, the lines $H\epsilon$, H, and K. They are on a scale of 1 mm = 1.9 Å., approximately. Recently it has been found better to use the grating in the position to give greater magnification, as in this way the full photographic resolution can be realized with the greatest economy of light, and without increasing the length of the camera.

The results obtained from the few plates selected for measurement last year are not sufficiently numerous or accordant to give a really good value for the wave-length of $H\delta$; but they show nevertheless, I think conclusively, that the line does not differ appreciably from its theoretical position. A few measures have also been obtained from spot spectra, where the line seems always to be narrowed, and in many cases is very much weakened: these measures confirm the others in showing that Rowland's value, 4102.000, must certainly be erroneous.

In the following table I give the values of $H\delta$ separately for the east and west limbs. The measures were made with a Hilger micrometer microscope, having a screw of 1 mm pitch, and reading to 0.01 mm, and by estimation to 0.001 mm. Each determination is a mean of two separate measures, in which the end of the spectrum toward the red was placed to the right and left respectively. The lines used as standards are the iron lines given in Rowland's table at 4100.315, 4100.901, 4101.421, 4104.288, and the line at 4103.097 attributed to silicon and manganese.

TABLE I

$H\delta$ Absorption Line

Date 1907	East Limb		West Limb	
	Latitude	Wave-Length	Latitude	Wave-Length
May 18...........	−13°	4101.88	+12°	4101.89
May 18...........	−10	.89	+ 7	.91
May 18...........	− 8	.92	− 8	.90
May 19...........	+ 8	.91	−10	.91
May 19...........	+10	.90		
May 20...........	+ 9	.88	− 8	.91
May 30...........			+14	.90

Mean, east, 4101.897; mean, west, 4101.903; mean of east and west, **4101.900**; mean width of emission line, 0.62; of absorption line, 0.29.

In spot spectra the line shows a tendency to be displaced to the violet, which in some instances is very marked. In the spot of July 16, 1907, $H\delta$ is displaced about 0.05 to the violet, while $H\gamma$ is apparently in the normal position. It is to be remembered that the absorption lines in the two cases may represent different levels in the chromosphere. In the following measures the iron lines in the spot spectra were used as standards. Any displacements therefore are relative to the spot lines, and not those of the sun. No measurable displacements were detected, however, in the reference lines of the spot spectra, compared with those of the neighboring photosphere.

Three spot spectra photographed with the 18-ft. grating spectrograph at Mount Wilson in November 1906 give respectively . 4101.897
.883
.839

Spot spectra photographed at the Kodaikanal Observatory:
Large spot, 1907, June 20 . . . . 4101.821
Same spot, 1907, June 22 868
Spot of 1907, July 16 866

The rather large deviations in the separate measures in Table I are not due to errors of measurement, but are probably partly accounted for by the disturbing effect of a bright sky on the position of the reference lines. This is almost certainly the case with the plate of May 18, latitude $-13°$ east. In this image the chromospheric lines δ, ϵ, H, and K are very strong as bright lines, but the Fraunhofer lines are weak, and are probably partly due to skylight. Rotation displacement will therefore affect the measures to some extent. In the mean values the west limb seems to give a slightly larger wave-length than the east, which would indicate a greater rotational speed for hydrogen compared with the reversing layer. But as the influence of the sky spectrum would tend in this direction it would be unsafe to draw this conclusion without further evidence. In the plate of May 20, however, in which the east and west spectra are photographed side by side, the evidence of a forward drift of the hydrogen and calcium over the gases of the reversing layer seemed so clear when direct measurements of the displacements were obtained, and the measures were extended to H and K, that it was decided to make a separate investigation to determine whether this was a normal condition or merely a local drift of the higher chromosphere. I give in a subsequent paper some of the results of measures made on plates in which the two limbs are photographed simultaneously.

The line $H\epsilon$ is easily photographed as a bright line, as it comes under the protection, so to speak, of the broad shading of H, but in only one instance have I found any trace of an absorption line, and this was too faint for measurement. In the measures the broad line was bisected, and the edges, which are well defined, were also measured, the mean of the two edges being used to correct the central bisections. The measures with the less refrangible end of the spectrum placed to the right and left respectively show a greater degree of accordance than those of $H\delta$, and in Table II, I retain the third decimal figure, since the mean error for each determination is well below 0.005 Å. The lines used as standards are the iron lines in Rowland's table at 3960.422, 3965.655, 3969.413, 3971.475, and 3977.891; and in one plate the aluminium line at 3961.674 was used.

Excepting the west limb spectrum of May 20, which gives abnormally large values for all the four chromospheric lines (δ, ϵ, H, and K),

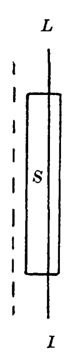
TABLE II

Hε Emission Line

Date 1907	East Limb		West Limb	
	Latitude	Wave-Length	Latitude	Wave-Length
May 18..........	−13°	3970.222	+12°	3970.200
May 18..........	−10	.219	+ 7	.195
May 18..........	− 8	.220	− 8	.203
May 19..........	+ 8	.215	−10	.204
May 19..........	+10	.220		
May 20..........	+ 9	.213	− 8	.229
May 30..........			+14	.201

Mean, east, 3970.218; mean, west, 3970.205; mean of east and west, **3970.212**; mean width of emission line, 0.52.

the values for the west limb are all smaller than those for the east, the mean diffeernce, excluding May 20, being 0.018 Å. The displacement is in the opposite direction to that shown by $H\delta$ in Table I, but this apparently anomalous behavior of the two hydrogen lines receives a probable explanation when we consider the conditions in photographing a bright chromospheric line like ϵ, and a dark reversal of a bright line as in δ. In the former case, we have an angular separation amounting to several seconds of arc between the source of the bright line and that of the dark lines to which the measures are referred; and a slit of finite width. A consideration of the subjoined diagram will show that the displacement due to this cause may amount to half the slit-width × the ratio of the focal lengths of collimator and camera, when the bright radiation extends outward from the photosphere with uniform intensity for a distance equal to, or greater than, the slit-width.



In the diagram, *LL* represents the position of the sun's limb during an exposure, *S* is the opening of the slit greatly magnified, while the dotted line represents the upper limit of the chromospheric radiation, the photosphere being on the opposite side of *LL*. It is evident that whatever position the limb may occupy within the opening of the slit, provided it remains stationary during the exposure, the spectral images of the photosphere and chromosphere will be displaced relatively by half the slit-width, and this of course will be increased in proportion as the length of the camera exceeds that of the collimator. Obviously a dark reversal on a broad bright line will not be subject to this displacement, as the source of the reversal is the same as the source of the reference lines. It will, however, be unsymmetrically placed on the bright line.

In the spectrograph I employed the optical parts were so arranged that the east limb was on the more refrangible side of the spectral images of the slit. The width of slit used was 0.05 mm, and the camera magnified 2.3 times: therefore, under the ideal conditions of perfect steadiness of the sun's limb represented in the diagram, and uniform intensity in the chromospheric radiation, there would be a linear displacement of $0.025 \text{ mm} \times 2.3 = 0.057$ mm, equal to 0.108 Å., with the dispersion employed. This would be in the direction which would increase the east limb values, and decrease those of the west limb. In the actual case of an unsteady image, the whole slit may be illuminated many times in succession by both photosphere and chromosphere during an exposure, and this tends to bring the chromospheric lines to their normal positions with respect to the photospheric lines. Also the ϵ radiation does not extend uniformly to any considerable height, the effective portion of the light coming from a very low level. That the actual displacement found is only one-sixth of the value deduced above is not therefore at all surprising.

Although no significance, therefore, can be attached to the apparent displacement of $H\epsilon$ at the two limbs, the mean value of east and west will be entirely free from this source of error.

I give finally in Tale IV a comparison of the principal hydrogen lines in the sun, and the computed values from the formula $\lambda = \frac{an^2}{n^2-4}$ where n is the series number and a is the value of the limit of the series *in vacuo*, derived from Rowland's values of the first three lines, viz., 3647.1369. The computed values have been corrected to air, in accordance with a table by Runge.[1]

The observed values of the lines α, β, and γ are from Rowland's table; δ and ϵ are the values found above, and are subject to the small positive correction before mentioned due to pressure-shift of the reference lines. They are not, of course, definitive values, but they

[1] *Astronomy and Astrophysics*, **12**, 426, 1893.

TABLE IV

WAVE-LENGTHS OF HYDROGEN LINES

Designation	Observed	Computed	O.–C.
α	6563.045	6563.063	–0.018
β	4861.527	4861.516	+ .011
γ	4340.634	4340.631	+ .003
δ	4101.900	4101.893	+ .007
ε	3970.212	3970.225	– .013

show much a closer accordance with the values derived from Balmer's formula than is the case with Rowland's measures of these two lines.

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