The Effect of an Electric Field on the Spectrum Lines of Hydrogen.

By

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Quite recently, adopting Lo Surdo's method, T. Takamine and U. Yoshida investigated the effect of an electric field on the spectrum lines of hydrogen[1] and helium[2].

With the same experimental arrangement, the writer examined the mode of decomposition of the Balmer lines $H\beta$, H_δ, and H_ε, as well as that of a certain number of lines belonging to the secondary spectrum of hydrogen. A seven-prism spectrograph and a two-prism spectrograph were used in the experiment.

The seven-prism spectrograph was constructed of four large 60° prisms and three large 45° prisms. The spectrum was photographed with a portrait lens having a relative aperture of 3.5 and a focal length of 18 cm. The dispersion on the photographic plate was 9.5 Å.U. per mm. at $H\beta$. This instrument was adopted for this line and also for the lines belonging to the secondary spectrum of hydrogen lying in the neighbourhood of $H\beta$.

The two-prism spectrograph was constructed with two large 60° prisms. The spectrum was photographed with a Zeiss Tessar having a relative aperture of 4.5 and a focal length of 18 cm. The dispersion on the photographic plate was 22.6 Å.U. per mm. at $H\delta$.

About 30 photographs were taken with Ilford special rapid plates, the exposure being from 50 minutes to 2 hours. The primary current of the induction coil was about 3 amperes, while the secondary ranged from 0.3 to 0.8 milliamperes.

1 T. Takamine and U. Yoshida, Mem. Col. of Sci., Kyoto, **2**, 137, 321 (1917).

2 T. Takamine and U. Yoshida, Mem. Col. of Sci., Kyoto, **2**, 325 (1917).

To determine the field intensity, the following data for the outer components of H_γ given by Stark were relied on:—

4.6 Å.U. per 10^4volt/cm. for the parallel (p) components.
3.2 Å.U. per 10^4volt/cm. for the perpendicular (s) components.

At several different points, corresponding to various distances from the cathode, the amount of separation of the outer p- and s-components of H_γ was measured on the photographic plate obtained by the two-prism spectrograph.

In the present experiments, after the side tube leading to Kipp's apparatus was sealed, the evacuation was carried on until the end of Crookes dark space became very indistinct. Then the side tube leading to Gaede pump was sealed. In this manner a field intensity far greater than those employed by the former investigators was attained. Assuming the proportionality between the separation of the outer components of H_γ and the field intensity, the greatest field strength thus attained in the present experiment was 14.6×10^4volt/cm. at the immediate neighbourhood of the cathode. The decomposition of $H\beta$, in this case photographed by the seven-prism spectrograph, is reproduced in Fig. 2, Pl. 1.

(A) $H\beta$.

For the line $H\beta$, Stark found 11 p- and 11 s-components in the case of "Feinzerlegung." With Lo Surdo's method, however, only 2 p- and 2 s-components have been hitherto obtained by various investigators.

In the present experiment, 6 s-components were clearly observed; and, though far more indistinct than these s-components, 6 p- components were observed beside the undisturbed line. The photograph showing the finer decomposition of the $H\beta$ line is reproduced in Fig. 1, Pl. 1.

For the s-components of $H\beta$, the amount of separation of the components was found to be approximately symmetrical with respect to the central line. Further, as shown in Table 1, the separations were proportional to the field intensity E.

TABLE I.

Components / E in 10^4volt/cm.	+3 (Intensity 5)		+2 (Intensity 10)		+1 (Intensity 3)		−1 (Intensity 3)		−2 (Intensity 10)		−3 (Intensity 5)	
	δλ in Å.U.	δλ/E	δλ in Å.U.	δλ/E	δλ in Å.U.	δλ/E	δλ in Å.U.	δλ/E	δλ in Å.U.	δλ/E	δλ in Å.U.	δλ/E
8·45	+8·61	1·02	+6·32	0·75	+2·79	0·33	−2·91	0·34	−6·01	0·71	−8·45	1·00
6·40	+6·20	0·97	+4·70	0·73	+2·21	0·34	−2·22	0·35	−4·61	0·72	−6·35	0·99
4·73	+4·70	0·99	+3·60	0·76	+1·70	0·36	−1·51	0·32	−3·52	0·74	−4·73	1·00
3·20	+3·41	1·06	+2·40	0·75	+1·14	0·36	−1·04	0 32	−2·20	0·69	−3·21	1·00
2·20	+2·20	1·00	+1·65	0·75	+0 86	0·39	−0·75	0·34	−1·54	0·70	−2·21	1·00
1·38	+1·42	1·03	+0·94	0·68	+0·42	0·30	−0·44	0·32	−0·95	0·69	−1·41	1·02
Mean of δλ/E		1·01		0·74		0·35		0·33		0·71		1·00

Similar measurements were performed on the plate reproduced in Fig. 2; and it was found that, for the intense components (+3), (+2), (−3), and (−2), the proportionality held good up to the field of 14.6×10^4volt/cm. The results of these measurements are tabulated in Table 2.

TABLE 2.

E in 10^4volt/cm.		14·6	13·2	11·9	10·8	9·8	8·8	7·6	6·0	5·4	Mean of δλ/E
+3	δλ in Å.U.	+15·5	+13·5	+12·2	+11·3	+10·3	+9·4	+7·4	+6·1	+5·3	
	δλ/E	1·06	1·02	1·02	1·04	1·05	1·06	·97	1·02	·98	1.03
+2	δλ in Å.U.	+11·0	+9·8	+8·6	+8·0	+7·3	+6·5	+5·9	+4·2	+3·7	
	δλ/E	·76	·74	·72	·74	·74	·74	·78	·70	·69	0·74
−2	δλ in Å.U.	−10·7	−10·0	−8·4	−7·7	−7·1	−6·5	−5·8	−4·0	−3·6	
	δλ/E	·73	·76	·71	·72	·72	·74	·76	·67	·67	0·72
−3	δλ in Å.U.	−16·0	−13·0	−12·3	−11·4	−10·4	−9·5	−7·5	−6·2	−5·4	
	δλ/E	1·10	.99	1·04	1·06	1·06	1·08	·99	1·04	1·00	1·03

As shown in Table 3, the 6 components correspond to the components (+3), (+2), (+1), (−1), (−2), and (−3) given by Stark in the case of "Feinzerlegung" of Hβ.

TABLE 3.

The s-components of H_β at $E = 7.4 \times 10^4$volt/cm.

		+3	+2	+1	−1	−2	−3
Stark	δλ in Å.U.	+7·3	+5·8	+2·5	−2·5	−5·0	−7·4
Nitta	δλ in Å.U. (calc.)	+7·5	+5·4	+2·6	−2·4	−5·3	−7·5

In this case, values of E were determined by the p- and s-components of H_γ photographed simultaneously by the two-prism spectrograph.

For the p-components, it was found that the six components corresponded to the components (+5), (+4), (+3), (−3), (−4), and (−5) given by Stark in the case of "Feinzerlegung" of H_β.

(B) H_δ.

For H_δ four s-components and two p-components were observed, as shown in Fig. 3, Pl. 1.

The following tables (Table 4 and Table 5) give the relation between the field intensity and the amount of displacement $\delta\lambda$ from the position of the undisturbed line.

TABLE 4.

The p-components of H_δ.

Components \ E in 10^4volt/cm.		8·4	4·4	2·4	1·2	Mean of δλ/E
+1	δλ in Å.U.	+25·5	+14 5	+8·0	+4·0	
(Intensity 2)	δλ/E	3·03	3·29	3·33	3·33	3·25
−1	δλ in Å.U.	−25·0	−15·4	−8·3	−4·0	
(Intensity 2)	δλ/E	2·98	3·50	3·46	3·33	3·31

TABLE 5.

The s-components of H_δ.

Components \ E in 10^4volt/cm.		8·4	5·2	3·9	1·5	Mean of $\delta\lambda/E$
+3 (Int. 2)	$\delta\lambda$ in Å.U.	20·0	12·4	8·6	4·1	
	$\delta\lambda/E$	2·38	2·38	2·20	2·73	2·42
+1 (Int. 5)	$\delta\lambda$ in Å.U.	8·1	4·2	2·9	1·4	
	$\delta\lambda/E$	0·96	0·81	0·74	0·93	0·86
−1 (Int. 5)	$\delta\lambda$ in Å.U.	7·7	4·1	3·0	1·1	
	$\delta\lambda/E$	0·92	0·79	0·77	0·73	0·80
−2 (Int. 2)	$\delta\lambda$ in Å.U.	21·0	13·0	9·0	4·1	
	$\delta\lambda/E$	2·50	2·50	2·31	2·73	2·51

Thus the separation is approximately symmetrical and is proportional to the field intensity.

As shown in the following table (Table 6), the p- and s-components were all well identified with those of Stark given in the case of "Grobzerlegung" of H_δ.

TABLE 6.

Components of H_δ at $E = 2.85 \times 10^4$volt/cm.

		p-components		s-components			
		+1	−1	+2	+1	−1	−2
Stark	$\delta\lambda$ in Å.U.	8·54	9·16	6·27	1·96	2·36	6·72
Nitta	$\delta\lambda$ in Å.U. (calc.)	9·1	9·4	6·9	2·4	2·3	7·1

(C) H_ε.

For this line, Stark gives only two p-components. Adopting Lo Surdo's method, Sonaglia[1] found two p- and five s-components, but he did not measure the amount of separation.

The result obtained in the present experiment was by no means satisfactory. Fairly good images of the two p-components were obtained in a few cases; while, for the s-components, two outer and two inner components appeared very indistinctly.

[1] Sonaglia, Rendiconti d. Lincei, **24**, 621, (1916).

The numerical values obtained are tabulated below (Table 7, 8, and 9).

TABLE 7.

The p-components of H_ε.

E in 10^4volt/cm.		6·9	4·8	3·25	Mean of $\delta\lambda/E$.
+1	$\delta\lambda$ in Å.U.	+30·0	+19·8	+14·2	
	$\delta\lambda/E$	4·35	4·13	4·37	4·28
−1	$\delta\lambda$ in Å.U.	−27·5	−18·8	−12·4	
	$\delta\lambda/E$	4·00	3·92	3·81	3·91

TABLE 8.

The s-components of H_ε

E in 10^4volt/cm.	6·9	3·5	0·9	Mean of $\delta\lambda/E$
Distance between the outer components in Å.U.	35·0	17·5	5·7	
$\delta\lambda/E$	5·1	5·0	6.3	5·5
Distance between the inner components in Å.U.	6·3			
$\delta\lambda/E$	0·91			

TABLE 9.

$\delta\lambda$ in Å.U. at $E = 2.85 \times 10^4$volt/cm.

	+1	−1
Stark	+12·2	−11·3
Nitta (calc.)	+12·1	−11·1

(D) Secondary spectrum lines of hydrogen.

In the present experiment, the regions in which a number of affected lines were measured, were from λ 4340 to λ 3900 and in the neighbourhood of H_β.

The wave-lengths of the lines in these regions, which were determined by the comparison spectrum of the iron arc, were found to agree well with those obtained by Watson and given in Kayser's Handbuch der Spectroscopie. In the following, the writer has adopted Watson's values to the first decimal of an Å.U.

In Fig. 4, the curves showing various modes of decomposition presented by the affected lines have been roughly drawn. With the dispersion used in the present experiment, it was difficult to measure the amounts of displacement in the region adove the dotted line.

Summary.

1. Employing Lo Surdo's method, the effect of an electric field on the spectrum lines of hydrogen has been investigated.

2. To determine the field intensity, the data given by Stark for H_γ in thc case of "Grobzerlegung" were relied on.

3. By lowering the pressure in the discharge tube until the end of Crookes dark space became very indistinct, a field intensity far greater than those employed by the former investigators has been attained, its maximum value being about 14.6×10^4volt/cm.

4. For H_β 6 s-components have been observed and identified with those obtained by Stark. The proportionality between the amount of separation and the field intensity was found to hold good for these components.

5. For H_δ, 2 p- and 4 s-components, and for H_ε 2 p- and 4 s-components have been obtained; and excepting the 4 s-components of H_ε, identified with the components obtained by Stark.

6. The influence of the electric field on certain lines belonging to the secondary spectrum lines of hydrogen has been investigated.

In conclusion, the writer wishes to express his sincere thanks to Assist. Prof. T. Takamine and Lecturer U. Yoshida for their kind guidance in the course of the experiment. The writer's thanks are also due to Prof. M. Fukui of Kyoto Higher Technical School for the loan of a Krüss spectrometer.

Fig. 1.

Exposure : 2h
$E_{max.}$: $11{\cdot}6 \times 10^4$volt/cm.
Magnification : 8

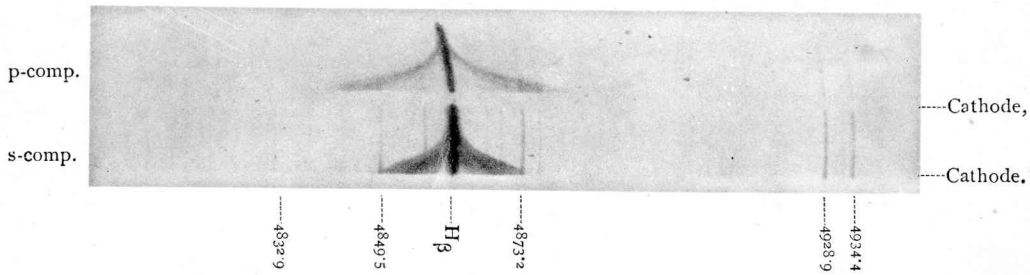


Fig. 2.

Exposure : 50m
$E_{max.}$: $14{\cdot}6 \times 10^4$volt/cm.
Magnification : 8

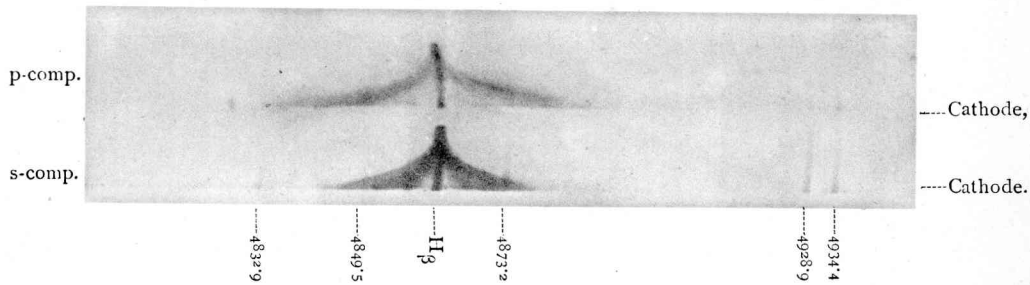


Fig. 3.

Exposure : 1h 40m
$E_{max.}$: $8{\cdot}45 \times 10^4$volt/cm.
Magnification : 5

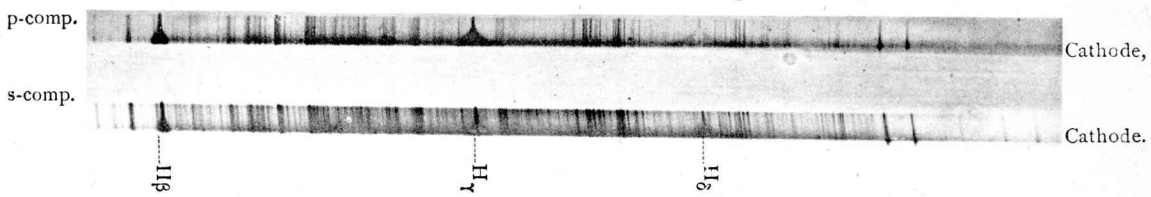
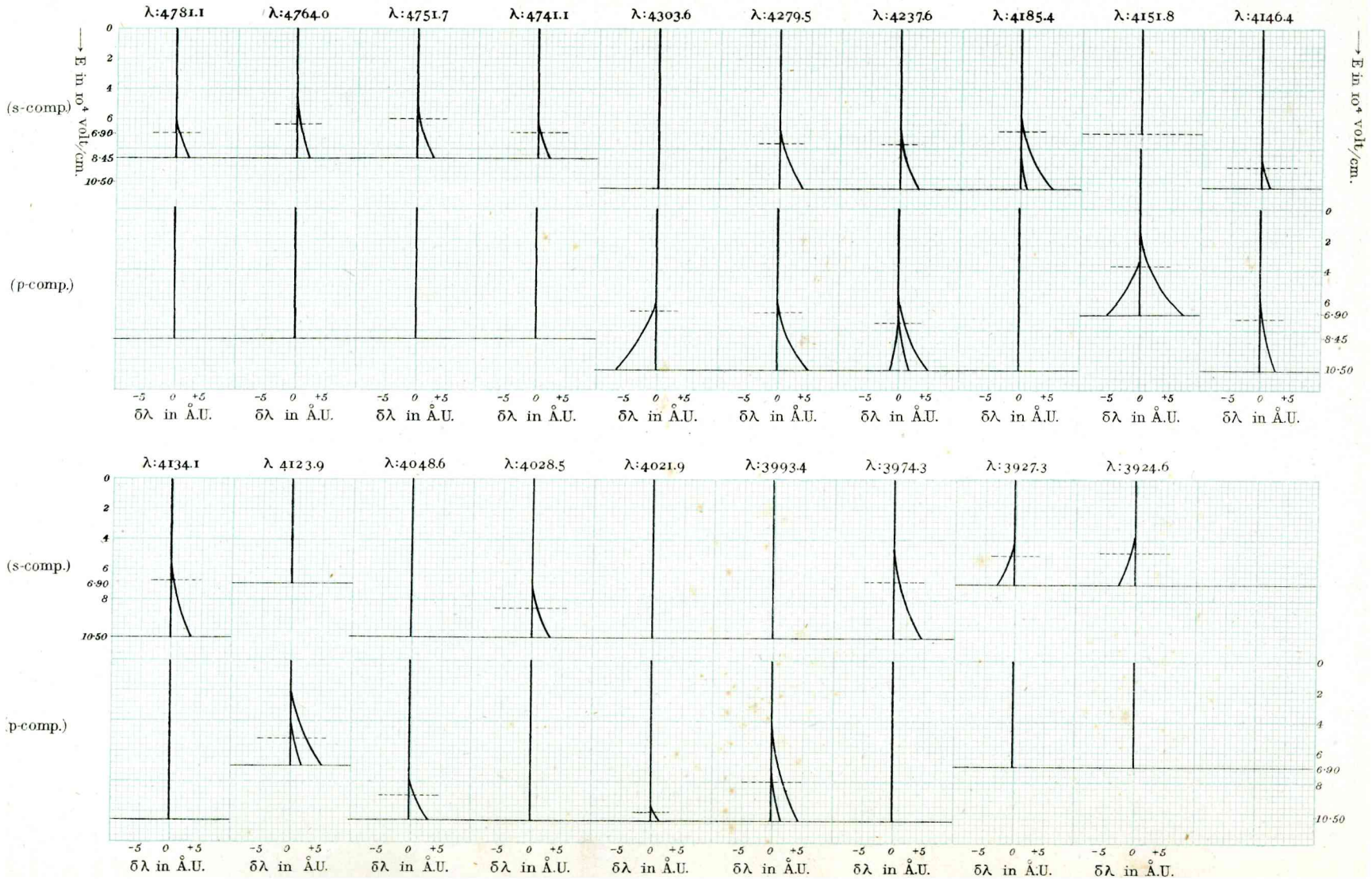


Fig. 4.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λ:4764.0
λ:4751.7
λ:4741.1
λ:4303.6
λ:4279.5
λ:4237.6
λ:4185.4
λ:4151.8
λ:4146.4
(s-comp.)
(p-comp.)
E in 10^4 volt/cm.
0
2
4
6
6·90
8·45
10·50
−5 0 +5
δλ in Å.U.
λ:4134.1
λ 4123.9
λ:4048.6
λ:4028.5
λ:4021.9
λ:3993.4
λ:3974.3
λ:3927.3
λ:3924.6
8