On the Stark Effect of the Line H_β

著者	SAKURAI Takemaro
journal or publication title	Science reports of the Research Institutes, Tohoku University. Ser. A, Physics, chemistry and metallurgy
volume	2
page range	167-179
year	1950
URL	http://hdl.handle.net/10097/26313

On the Stark Effect of the Line H_β

Takemaro SAKURAI

The Research Institute for Scientific Measurements

(Received October 15, 1949)

Synopsis

In this paper, the writer wishes to describe the observational results of the Stark effect of the line H_β. The rest line of the canal-ray was separated spectroscopically from the Doppler lines and its Stark effect was observed. The rest line was much sharper compared with the line given by the transverse observation of the canal-ray and the Stark components were well resolved in the field of 11,570 V./cm. The intestities of the Stark pattern obtained were found to be in fair agreement with "dynamische Intensitäten", except those of the components ± 4 and ± 6. These discrepancies were explained by that the mean free time of the residual gas atoms was not extremely great compared with the mean lives of their excited states. The observed asymmetries of the displacements are in excellent accordance with the theoretical values computed by Ryde. It was found, however, that the displacement was about 0.4% greater in every individual component than that which is theoretically expected. The most probable value of the coefficient of the first-order Stark effect was given as $(6.433 \pm 0.012) \times 10^{-5}$.

I. Introduction

The asymmetrical displacement of the Stark components of the line H_β, arising from the fine-structure, is one of the very interesting subjects in the investigation of the Stark effect. But, owing to the difficulties of experimental technics, its observation has scarcely been carried out. It is theoretically predicted that the asymmetry is as small as the separation of the fine-structure and is invariant by the field strengths applied. Therefore, to observe this amount precisely, it is wanted to use the spectrograph of high dispersion and is desirable to work in such an electric field as weak as possible. Any ordinary discharge tube of the Lo Surdo or of the canal-ray type is not adaptable, as the spectral lines afforded are very faint and diffuse.

Some years ago, Steubing and Keil$^{1)}$ observed the asymmetry of the line H_β for the first time, using the glass spectrograph and the discharge tube of the ordinary canal-ray type, in the fields of 60,000, 40,000 and 25,000 V./cm. They compared the observed values of this asymmetry with the theoretical values compound by following Schlapp's$^{2)}$ method, and it was found that the former was in fair agreement with the latter, except the asymmetry between the components 8 and 10 which was 30% greater than the computed value. In their observation, the lowest electric field they applied is thought to be the lower limit in which each Stark component can be resolved. This value of the

---

(1) W. Steubing and A. Keil: ZS. f. Phys., **115** (1940), **150.**

(2) R. Schlapp: Proc. Roy. Soc., **119A** (1928), **313.**

field strength however, is not sufficiently small for observing the asymmetry of the Stark components.

Recently the writer[3] deviced a discharge tube of the canal-ray type which afforded sharp Doppler lines and an intense rest line. By viewing the tube in the longitudinal direction, the rest line of H_α was clearly resolved from the Doppler lines. Furthermore, applying an electric field transversely to the travelling direction of the canal-ray, the Stark effect of the rest line was observed in a moderate field of 14,790 V./cm. By using the same discharge tube, the investigation of the Stark effect of the line H_β was carried out. The main results obtained together with their theoretical interpretations will be described in the following paragraphs.

II. Apparatus

The apparatus used was the same as that which has been used in the investigation of the Stark effect of H_α. As it has been already described in detail in the previous paper, no further description will be here wanted. The low voltage arc which makes the ion-source of the canal-ray was maintained by the 300 V. battery with the current of 300mA. The high negative potential of about 3,000 V. for accelerating ions and the higher negative potential of from 2,500 to 1,700 V. for observing the Stark effect were supplied from double D.C. generators of 5,000 V., filtrating their ripples by condensers and chokes. The absolute value of the potential was measured by the resistance voltmeter within the error of 0.1% of the applied value. Furthermore, the small variation of the potential was detected by a sensible electrostatic voltmeter. By adjusting the field curernt of a generator and observing the electrostatic voltmeter, the electric field for observing the Stark effect was maintained at a very constant value during a long photographic exposure, within the fluctuation of merely 0.1%. The hydrogen gas pressure in the discharge tube was varied from 2×10^{-2} to 3×10^{-2}mm. Hg.

The spectrograph used was a concave grating, 21.5 feet in focal length, mounted after Eagle's manner. A cylindrical lens was inserted between the grating and the slit, and a stigmatic image was obtained. The dispersion at 4861 Å. in the second order spectrum was 1.259 Å./mm. In the case of H_α, it has been reported that the condensing lens of the spectrograph was set so carefully that the light from the canal-ray was not mixed with that of the low voltage arc, as one of the Stark components appears in the place where the field free line is seen. In the present case, the same precaution was also taken in the observation of the light from the canal-ray when an electric field was absent. In the observation of the Stark effect, however, a small amount of the light from the low voltage arc was mixed for comparison, since an undisplaced Stark component never appears.

"Oriental Hyper-Sensitive Panchromatic Plates" were used and for the observation of the lines in absence of an electric field the exposure was about 3 hours and for that of the Stark effect, about 7 hours.

---

(3) T. Sakurai: Sci. Rep. RITU, A1 (1949), 283.

III. Results obtained

To account for the observational results of the Stark effect of the line H_β, it is most desirable to have some knowledge of the spectrum of the canal-ray when the electric field is absent. For this purpose, the observation of the canal-ray was made in various accelerating potentials, the results of which will be described in the first place.

The reproduction of one of the spectrograms obtained under the application of the accelerating potential of 2,880 V. is shown in Fig. 1. In this figure, D_1 and D_2 are the well-known Doppler lines H_2^+ and H_3^+, viz. the H_β emitted by the travelling atoms resulting from the accelerated ions H_2^+ and H_3^+ respectively. The Doppler line of H^3O^+ which was observed in the case of H_α, also appears and is designated as D_3. $ML\,1$, $ML\,2$ and $ML\,3$ are the molecular lines, emitted by residual hydrogen gas excited by the travelling ions or atoms. These lines were identified respectively with the line λ4849.303Å., λ4856.553Å. and λ4861.738Å.

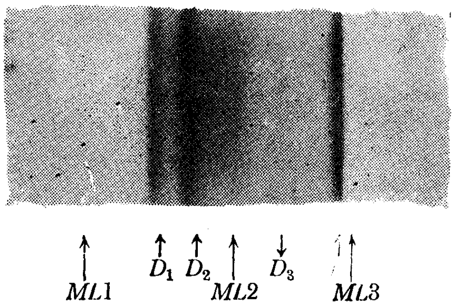

Fig. 1. Rest and Doppler lines of H_β

The rest line of H_β which was dealt with in the observation of the Stark effect is designated as R in the same figure. The intensity curve of the rest line was obtained from the microphotometric record, by eliminating the effect of the Doppler lines and by normalising the intensity refering to the blackening curve of the plate used. From this curve, the intensity curve of the individual component was analysed, assuming the theoretical separation and intensity of the fine-structure. The analysed curve, given in the accelerating potential of 2,010 V., is shown in Fig. 2. It is clearly seen in this figure that the intensity curve is not symmetrical, a short tail appearing in the shorter wave-length side. This asymmetry is attributed to the scattering of the residual gas atoms due to the collision when they are excited. From the various spectrograms obtained, it was found that the lower the accelerating potential of the canal-ray became, the sharper the individual component appeared. It was also found, however, that the decrease of an accelerating

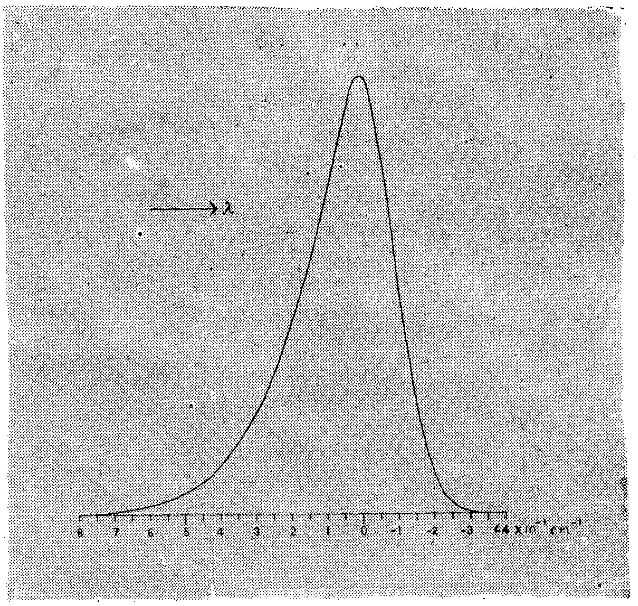

Fig. 2. Intensity curves of the rest line.

potential was inevitably associated with that of the intensity of a rest line. Considering these two restrictions, the accelerating potential used in the observation of the Stark effect was selected as 2,880 V.

In the present investigation, the electric field for observing the Stark effect was desired to be as weak as possible, provided each Stark component is resolved. For this purpose, preliminary spectrograms were photographed in the three fields of 8,000, 9,000 and 12,000 V./cm. From these, it was found that in the lowest field, the Stark components were hardly resolved, in the middle field, the intense components were resolved except the component −4 which was maskd by the molecular line $\lambda 4861.738$ Å. and that in the highest field, all of the intense components were well resolved. Therefore, in the following course of the investigation, the spectrograms were obtained in the highest field which was measured as 11.570 V./cm. within an error of ±0.1%.

In Fig. 3 and Fig. 4, one of the spectrograms thus obtained and its microphotometric record are reproduced respectively. In these figures, the Stark components ±4, ±6, 8± and 10± will be seen very clearly. *ML* 3 is the molecular line which was already shown in Fig. 1. The most intense component in the center is the line H_β in absence of an electric field, which was inserted for comparison, using the light from the low voltage arc. It was very lucky that neither the spectrum of the canal-ray nor that of the low voltage arc showed a molecular line in the region where the Stark components appeared.

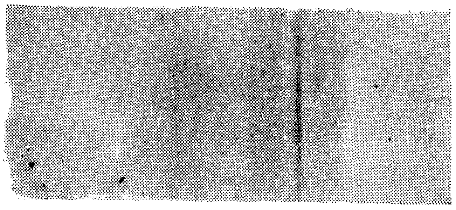

Fig. 3. Stark effect of the line H_β.

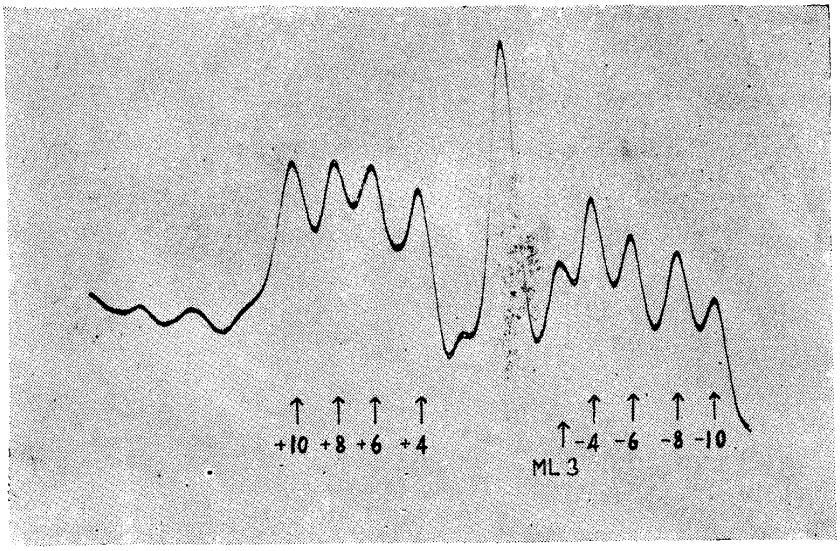

Fig. 4. Microphotometric record of the spectrogram in Fig. 3.

Comparing Fig. 3 with Fig. 1, it is seen that the intensity distribution of the Doppler lines is considerably deformed. This feature is mainly ascribed to the Stark broadening and partly to the fact that the travelling ions are disturbed by the electric field which is for observing the Stark effect. Of these, the latter effect is very important, as the intensity curve of the individual component is affected by the velocity distribution of travelling ions or atoms. It is impossible to observe this effect alone, separated from the Stark broadening. However, as the deformation of the intensity distribution in the Doppler lines is not great, it may be allowed to assume that the separation, at a given intensity in the intensity curve of the individual component, is proportional to the mean displacement of the Doppler lines which include their tails weighted by their intensity. The mean displacement of the Doppler lines when the electric field was applied, was found to be nearly the same with that in the spectrogram obtaind in absence of an electric field with the accelerating potential of 2,010 V. Accordingly, the intensity curve in Fig. 2 is considered to be corresponding also to the individual Stark component.

From the various microphotometric records, the mean intensity curve of the Stark patterns was obtained by normalising the intensity and eliminating the effect of the tails in the Doppler lines and of the molecular line *ML* 3. The obtained curve is shown in Fig. 5, in which the scale indicates the wave numbers measured from the maximum of the field free line. In this figure, the asymmetry of the dispalcement will be very clearly seen. It is also seen that the relative intensities of the components are not symmetrical, but this is not wholly ascribed to the asymmetry of the intensities of the corresponding components, because the displacements as well as the intensity curve of the individual component are not symmetrical.

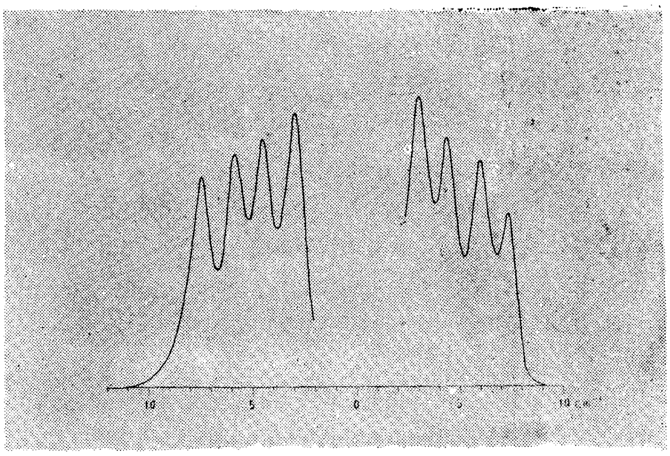

Fig. 5. Observed Stark pattern of the line H_β.

The displacements of the Stark components, measured from the maximum of the line H_β when the electric field was absent, $\Delta\nu''_{Obs.}$ and their relative intensities $I''_{Obs.}$ are given respectively in the last column in Table V and Table II. The average error of the measurement for the displacement was $5\times10^{-3}\text{cm}^{-1}$.

IV. The interpretation of the results obtained

The theoretical treatment of the Stark effect of hydrogen line by taking into considerations of its fine-structure was first carried out by Schlapp(4). He considered the behavior of the hydrogen atom in an electric field on the basis of the equation of Darwin and Dirac, and calculated the displacement and the intensity of the Stark components of

---

(4) Reference 2.

H_α for two limiting cases, (1) where the Stark splitting is small compared with the fine-structure, corresponding to the field less than 300 V./cm.; and (2) where the fine-structure is small compared with the Stark splitting, corresponding to the field above 10,000 V./cm.

More recently Steubing and Keil⁵⁾ computed the displacement of the Stark components of H_β for the second limiting case after Schlapp's method. From their results, it was predicted that the displacement $\Delta\nu$ of the individual Stark component in H_β is given by the formula

$$\nu\Delta = \frac{3}{8}\frac{h}{\pi^2\mu e c}F\sigma + \frac{1}{1680}\frac{\pi^4\mu e^8}{c^3h^5}\tau,$$

where μ is the reduced mass of the electron and is given by the equation

$$\mu = \frac{m}{1+\frac{m}{M}},$$

and σ and τ are the constants which have the values shown in the third and the fifth column in Table I. It will be noticed here that the values of τ in this table are different from those afforded by Steubing and Keil. This difference is attributed to the fact that $\Delta\nu$ in their report represented the displacement from the Stark component $\sigma=0$ given by the transition from $j=5/2$ to $j=3/2$, while in this paper it indicates that from the field free line $\nu^\circ = nR$ given theoretically ignoring the fine-structure. In the above formula, the first term affords the first-order Stark component, while the second, its fine-structure. Substituting the values $h=6.624\times10^{-27}$ erg.sec., $c=2.9978\times10^{10}$cm.sec.$^{-1}$., $e=4.8026\times10^{-10}$e.s.u., $m=9.109\times10^{-28}$g. and $m/M=1/1837$, and representing the value of F in unit of V./cm., the first term becomes $6.405\times10^{-5}\ F\sigma\text{cm}^{-1}$, and inserting the measured value 1,570 V./cm. of F, its value, for various values of σ, amounts to what is shown in the fourth column. By the similar substitution, the second term becomes $0.435\times10^{-3}\tau\ \text{cm.}^{-1}$, the values of which for various values of τ are shown in the sixth column. It is seen in this column that the number and displacements of the fine-structure components are different for the various values of σ, but are the same for the

Table I

2m' 2j' k'	2m 2j k	σ	The First Term in cm^{-1}.	τ	The Second Term in cm^{-1}.	$\Delta\nu$ in cm^{-1}.	Polarization.	I_s	I_d
1 1 0	1 3 1	−14	−10.374	670	0.291	−10.083	p	1	2
1 1 0	3 3 1	−12	− 8.892	110	0.048	− 8.844	s	4	9
1 1 0	−1 1 1			670	0.291	− 8.601	s	4	9
3 3 1	1 3 1	−10	− 7.410	728	0.316	− 7.094	s	3	7
1 1 1	−1 3 1			699	0.304	− 7.106	s	3	7
1 1 0	1 1 0			670	0.291	− 7.119	p	361	799

---

(5) Reference 1.

2m'	2j'	k'	2m	2j	k	σ	The First Term in cm^{-1}.	τ	The Second Term in cm^{-1}.	$\Delta\nu$ in cm^{-1},	Polarization.	I_s	I_d
3	3	1	3	3	1	− 8	− 5.928	168	0.073	− 5.855	p	192	469
1	1	1	1	1	1			699	0.304	− 5.624	p	192	469
1	3	1	1	3	1	− 6	− 4.446	702	0.305	− 4.141	p	81	443
3	3	1	1	1	0			728	0.316	− 4.130	s	147	359
1	1	1	−1	1	0			699	0.304	− 4.142	s	147	359
5	5	2	3	3	1	− 4	− 2.964	187	0.081	− 2.883	s	192	928
3	3	2	1	1	1			728	0.316	− 2.648	s	192	928
1	3	1	3	3	1			142	0.062	− 2.902	s	36	197
1	3	1	−1	1	1			702	0.305	− 2.659	s	36	197
3	5	2	1	3	1	− 2	− 1.482	733	0.318	− 1.164	s	36	88
1	3	2	−1	3	1			702	0.305	− 1.177	s	36	88
1	3	1	1	1	0			702	0.305	− 1.177	p	9	49
3	5	2	1	3	1	+ 2	1.482	733	0.318	1.800	s	36	88
1	3	2	−1	3	1			702	0.305	1.787	s	36	88
1	3	1	1	1	0			702	0.305	1.787	p	9	49
5	5	2	3	3	1	+ 4	2.964	187	0.081	3.045	s	192	928
3	3	2	1	1	1			728	0.316	3.280	s	192	928
1	3	1	3	3	1			142	0.062	3.026	s	36	197
1	3	1	−1	1	1			702	0.305	3.269	s	36	197
1	3	1	1	3	1	+ 6	4.446	702	0.305	4.751	p	81	443
3	3	1	1	1	0			728	0.316	4.762	s	147	359
1	1	1	−1	1	0			699	0.304	4.750	s	147	359
3	3	1	3	3	1	+ 8	5.928	168	0.073	6.001	p	192	469
1	1	1	1	1	1			699	0.304	6.232	p	192	469
3	3	1	1	3	1	+10	7.410	728	0.316	7.726	s	3	7
1	1	1	−1	3	1			699	0.304	7.714	s	3	7
1	1	0	1	1	0			670	0.291	7.701	p	361	799
1	1	0	3	3	1	+12	8.892	110	0.048	8.940	s	4	9
1	1	0	−1	1	1			670	0.291	9.183	s	4	9
1	1	0	1	3	1	+14	10.374	670	0.291	10.665	p	1	2

equal absolute value of σ, independent of its sign. Therefore the fine-structure components deviate in their own way with various amounts. Hence the displacement of the maximum of the resultant intensities of the fine-structure components is not symmetrical as was concluded from the theories in the beginning stage of development. The displacement of the individual component, $\Delta\nu$, thus obtained, is given in the seventh column, and its polarization, in the eighth column.

In Steubing and Keil's work, the intensity of the individual Stark component was not computed. The summation of the intensities of the fine-structure components, however, is to have the value given by ignoring the fine-structure. Moreover, it has been predicted by Schlapp that the doublet components which are given by the transition from m' to m and by that from $m'-1$ to $m-1$ will have equal intensities. As is seen in Table I, the doublet of every Stark component in H_β is produced by such a transition except that of the components ±12 and one of the doublets of the components ±4. Both exceptional doublets are given by the transition from $m'=1/2$ to $m=3/2$ and by that from $m'=1/2$ to $m=-1/2$. Of these, the former is very faint while the latter has a considerable intensity but its amount is merely one fifth of that of another doublet of the same component. Therefore it may be assumed that the fine-structure components of these doublets have equal intensities. Under these considerations, the intensity of the individual component can be computed from the value which was obtained by ignoring the fine-structure. We know two sorts of theoretical intensities, viz. "statische Intensitäten" and "dynamische Intensitäten." Accordingly the results obtained will be interpreted by using these two kinds of intensities. The values of "statische Intensitäten," here quoted, are those deduced by Schrödinger[6], while the values of "dynamische Intensitäten" are those computed by Ryde[7]. "Statische Intensitäten" I_s and "dynamische Intensitäten" I_d, assigned to the individual components, are given in the ninth and the last column in Table I.

In order to compare the observed values of the displacements and the intensities of the Stark components with those resulting from the theoretical calculation, the patterns of the resultant intensities have been secured by using the intensity curve of the individual component, given in the preceding paragraph. In Fig. 6 (a) and (b), the I_s- and the I_d-pattern thus obtained are shown respectively. In these patterns, it will be remarked that, owing to a short tail attending to the shorter wave-length side of the individual component, most of the shorter wave-length components have stronger intensi-

Table II.

Component.	Resultant Intensity.		Relative Intensity.		
	I_s'	I_d'	I_s''	I_d''	$I_{Obs.}''$
−10	369	816	100	100	100
− 8	441	1059	120	130	130
− 6	432	1299	117	159	144
− 4	515	2386	140	292	168
+ 4	452	2194	122	269	158
+ 6	439	1486	119	182	143
+ 8	452	1164	122	143	134
+10	425	958	115	117	122

---

(6) E. Schödinger: Ann. d. Phys., **80** (1926), 437.

(7) M. Ryde: ZS. f. Phys., **111** (1938-39), 683.

ties than the corresponding longer wave-length components. The resultant intensities I_s' and $I_d''$of the resolved components together with their values relative to the component -10, I_s'' and I_d'' are shown in Table II.

Comparing these patterns with the observed one in (c) of the same figure, it can be clearly seen that the observed intensities are in qualitative agreement with the values of I_d''.

In the previous investigation it was foun dthat the observed intensities of the Stark components of H_α were in close accordance with "dynamische Intensitäten," and this fact was explained to be very natural. A brief description of this explanation will be here given. In the derivation of "dynamische Intensitäten," it is assumed that the numbers of atoms, excited into different states per second, are equal. This assumption is adequate when the mean free time of atoms is large, compared with the mean lives of their excited states. It is the reason why "dynamische Intensitäten" are responsible for the intensities of "Abklingleuchten" observed by Mark and Wierl[8]. The light which was dealt with in the previous observation as well as in the present

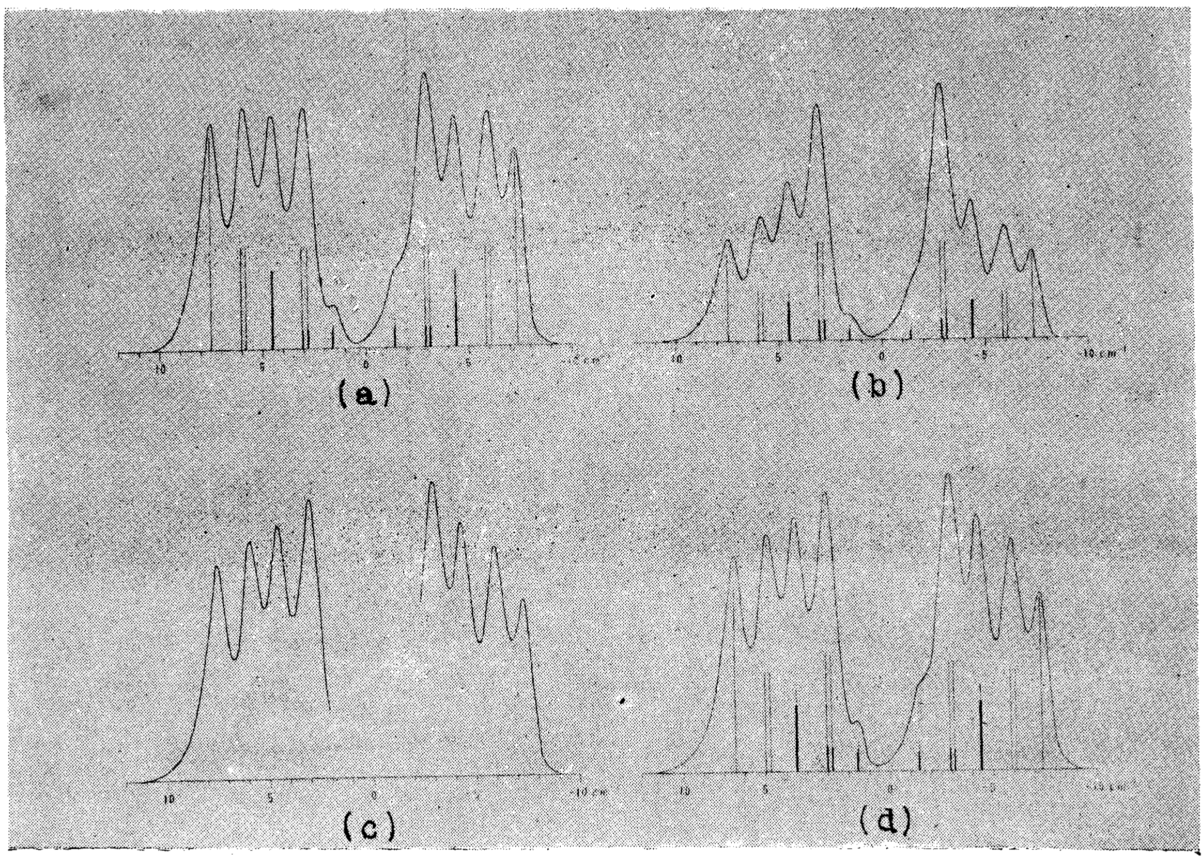

Fig. 6. Calculated and observed Stark pattern of the line H_β.
(a) Pattern given by "statische Intensitäten" I_s.
(b) Pattern given by "dynamische Intedsitäten" I_d.
(c) Observed pattern.
(d) Pattern given by analysed intensities I_a.

---

(8) H. Mark and R. Wierl: ZS. f. Phys., 53 (1929), 526.

one, is undoubtedly "ruhendes Stossleuchten" that is the light emitted by the residual gas atoms, come into collision with the travelling ions or atoms. As the pressure of the residual gas was less than 10^{-4}mm. Hg in the case of "Abklingleuchten" while it was 2.5×10^{-2}mm. Hg in the case of the observed "ruhendes Stossleuchten," it is true that the mean free path of atoms in the former case is several hundred times greater than that in the latter. The mean velocity of the residual gas atoms, however, being a fraction of one hundredth in its magnitude compared with that of the travelling atoms, the mean free time becomes nearly to the same amount in both cases. Consequently, if "dynamische Intensitäten" are responsible for the intensities given by "Abklingleuchten," they must be responsible also for those given by "ruhendes Stossleuchten." The above considerations were more confirmed by the present observation.

Table III.

o ponent.	I_a	$(I_a - I_d)/I_d$ in %.
−10	7 7 799	0
− 8	469 469	0
− 6	394 320 320	−11
− 4	501 501 106 106	−46
+ 4	538 538 114 114	−42
+ 6	377 305 305	−15
+ 8	460 460	− 2
+10	7 7 839	+ 5

In order to consider the observed intensities more precisely, the intensity of the individual component has been analysed from the observed values, assuming that the intensity ratio of the fine-structure components retain the values I_d. The intsnsities thus analysed are denoted as I_a and are shown in the second column in Table III. In the same table, the values of $(I_a - I_d)/I_d$ are also given for the convenience of comparison. From these values, it will be clearly seen that the value of I_a of the components ±10 and ±8 are in good accordance with the values of I_d but those of the components ±4 and ±6 are considerably different. The values of $(I_a - I_d)/I_d$ of the components ±4 amount to about −44%, while those of the components ±6, to about −13%.

To explain these discrepancies, it was thought that the mean free time of the residual gas atoms was not extremely great, compared with the mean lives of their excited states. It leads first to the fact that the deviation occurs towards I_s in its direction, and secondly that the component which has longer mean lives of the initial states, gives larger amount of deviation. It has been deduced by Ryde that the mean lives of the initial states of the components ±4 are twice as long, compared with those of the components ±10 and ±8. Moreover, the values of $I_{Obs.}$" of these components deviate from I_d" toward I_s", as will be see in Table II. Hence the anomaly of intensities of the components ±4 is well explained by the considerations above described. The components ±6 consist of the *p*- and *s*-components; the former of these has the same initial states with the components ±4 and the latter, with the components ±8. Therefore it is deduced that the intensities of the *p*-components must be about 44% smaller than the values of I_d, while those of the *s*-components remain in the same values. It is very regretted that the *p*- and *s*-components were not separately observed in the present investigation. However, as the intensities of the *p*-components amount to 62% of those of the *s*-components, the decrease of 44% in the intensities of the *p*-components is to afford that of 15% of the total intensities. Consequently the anomaly of intensities of the components ±6 is also well explained by the above consideration.

It also appears in Table III that the intensity of the component +4 is 4% and that of the component +10 is 5% larger, while that of the component ±6 is 4% and that of the component +8 is 2% smaller than the corresponding component respectively, and thus the asymmetries appear in the intensities. Of these, the values of the components ±4, ±6 and ±10 exceed slightly the value of the experimental error. These discrepancies can be explained by that the numbers of atoms, excited into different initial states per second, were not strictly equal.

Table IV.

j'	j	Displacement in cm^{-1}.	Intensity.
5/2	3/2	0.078	922
3/2	3/2	0.011	102
3/2	1/2	0.423	725
1/2	3/2	0.017	20
1/2	1/2	0.382	117

The displacements of the Stark components of the I_s-pattern, $\Delta\nu_s'$ and those of the I_d-pattern, $\Delta\nu_d'$ are shown respectively in the second and the third column in Table V. It will be noticed here that these values of the displacements are those from the imaginary line $\nu^\circ = nR$. For the interpretation of the observed pattern, on the other hand, it is necessary to know the displacements from the line H_β in absence of an electric field. For this purpose, the wave number of the maximum of the resultant intensities of H_β was computed, assuming that the intensities and displacements of the fine-structure components follow the values that are shown in Table IV. From the results of the calculation, it was found that the wave number of H_β, ν'_0 is given by

$$\nu'_0 = nR + 0.225\ \mathrm{cm}^{-1}.$$

Therefore the displacements of the Stark components of the I_s-pattern from the field free line, $\Delta\nu_s''$ are afforded by $\Delta\nu'_s - 0.225$ while those of the I_d-pattern, $\Delta\nu_d''$, by $\Delta\nu'_d - 0.225$. The values of $\Delta\nu_s''$ and $\Delta\nu_d''$ thus obtained are given respectively in the fifth and the sixth column in Table V. From these values, it can be seen that the displacements are considerably affected by the intensities of the individual components. By this fact, it results that these displacements are not so responsible for the interpretation, in virtue of that the theoretical intensities being more or less different from the observed values. In this consideration, the pattern of the resultant intensities has been reconstructed by considering the individual components possessing the values of the theoretical displacements and the analysed intensities I_a. The schema of the individual components and the pattern of their resultant intensities are given in Fig. 6 (d). The displacements of the Stark components $\Delta\nu_a'$ and their values relative to the field free line $\Delta\nu_a''$, are shown in Table V.

Table V.

Component.	Displacement im cm^{-1}.			Relative Displacement in cm^{-1}.			
	$\Delta\nu_s'$	$\Delta\nu_d'$	$\Delta\nu_a'$	$\Delta\nu_s''$	$\Delta\nu_d''$	$\Delta\nu_a''$	$\Delta\nu_{Obs.}''$
−10	−7.113	−7.113	−7.113	−7.338	−7.338	−7.338	−7.361
− 8	−5.792	−5.787	−5.788	−6.017	−6.012	−6.013	−6.033
− 6	−4.177	−4.163	−4.173	−4.402	−4.388	−4.398	−4.414
− 4	−2.815	−2.796	−2.815	−3.040	−3.021	−3.040	−3.052
+ 4	3.100	3.165	3.166	2.945	2.940	2.941	2.955
+ 6	4.706	4.675	4.696	4.481	4.450	4.471	4.496
+ 8	6.063	6.025	6.041	5.838	5.800	5.816	5.840
+10	7.652	8.650	7.650	7.427	7.425	7.425	7.454

Comparing this pattern with the observed one in (c) of the same figure, it is found that both the patterns are in a close resemblance. It implies that the observed displacements are in qualitative agreement with the theoretical values. However, the quantitative comparison of the values of $\Delta\nu_{Obs.}''$ with those of $\Delta\nu_a''$ in Table V shows that the minute discrepancies are found between these two values.

In order to interpret the observed displacements further, the deviation of the center of the displacements $\frac{1}{2}(|\Delta\nu''(+)|-|\Delta\nu''(-)|)$ has been considered for two corresponding components, which is shown in Table VI. In this table, the asymmetries of the displacements are well illustrated. Explaining these, the components ±4 and ±8 deviate towards red while the components ±6 and ±10, towards violet. The agreement of the observed values with the computed ones is very excellent; no discrepancy is found which exceeds the experimental error. Therefore it may be concluded that the observed asymmetries entirely follow the values theoretically expected.

Table VI.

Component	$\frac{1}{2}(\lvert\Delta\nu''(+)\rvert-\lvert\Delta\nu''(-)\rvert)$ in cm^{-1}.	
	by $\Delta\nu_a''$	by $\Delta\nu_{Obs.}''$
±10	0.044	0.047
± 8	−0.099	−0.097
± 6	0.037	0.041
± 4	−0.050	−0.049

From the above considerations, it is clear that the discrepancies of the displacements in Table V are attributed to the anomaly of the first-order Stark effect. To evaluate these values, the displacement by the first-order Stark effect, $\frac{1}{2}(|\Delta\nu''(+)|+|\Delta\nu''(-)|)$ has been considered for two corresponding components, which is shown in Table VII. In this table, it appears that the observed value of the components ±4 is 0.43%, that of the components ±6 is 0.45%, that of the components

±8 is 0.37% and that of the components ±10 is 0.35% greater than the theoretical value respectively. Consequently it seems to be certain that the displacement by the first-order Stark effect is about 0.40% greater in every individual component.

Table VII.

Component	$\frac{1}{2}(\lvert\Delta\nu''(+)\rvert+\lvert\Delta\nu''(-)\rvert)$ in cm_{-1}.	
	by $\Delta\nu_a''$	by $\Delta\nu_{Obs.}''$
±10	7.382	7.408
± 8	5.915	5.937
± 6	4.435	4.455
± 4	2.991	3.004

In the beginning of this paragraph, it has been shown that the theoretical value of the coefficient of the first-order Stark effect amounts to 6.405×10^{-5}. If this value is reconsidered by the observed increase of 0.40%, it becomes to 6.431×10^{-5}. Since the error in the measurement of the displacement has been estimated as ±0.1%, and that of the electric field, as ±0.1%, the experimental error of the above value becomes ±0.2%. Thus there still remains a little discrepancy which can not be covered. In the calculation by Steubing and Keil, it is assumed that the fine-structure is small, compared with the Stark splitting. This assumption does not hold strictly in the present observation because the applied electric field was not so great. This fact might give any explanation to the observed discrepancy. It is supposed, however, to be too small to account for the whole amount. In the previous paper, it has been reported that the value of the coefficient is measured as 6.44×10^{-5} ±0.3%, which is in excellent agreement with that given in the present observation. By taking the weighted mean of these values, the most probable value of the coefficient of the first-order Stark effect is thought to be $(6.433\pm0.012)\times10^{-5}$.

In conclusion, the writer wishes to take this opportunity to express his best thanks to Prof. J. Ôkubo, for his continual interest in this work, and to Mr. K. Miyagi, for his valuable assistance through the whole course of this investigation.

(July, 1944.)