On the Stark Effect of the Line H_α

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On the Stark Effect of the Line $H\alpha$

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I. Introduction

Since Stark has discovered the brilliant effect of the electric field on the spectral lines, many reports on this effect of hydrogen lines have been published. But most of them are those observed in strong electric fields above 50,000 V./cm. and those in moderate or weak fields are very scarce. One of the reasons why the observation in the moderate field has rarely been carried out is due to the fact that the attension of many investigators was mainly directed to the study of the higher-order Stark effect, and another of them is the technical difficulty of getting the spectral lines sharp and intense enough to use the spectrograph of high dispersion.

On the other hand, the theory, in its early beginning stage, was beautifully developed for the first and higher-order Stark effect by Schwarzschild(1) and Epstein(2), and was later revised by Schroedinger(3) on the basis of wave-mechanics. By the experimental results, it was confirmed that schroedinger's theory was valid in strong electric fields, but it ignored the fine-structure and gave symmetrical displacements in moderate fields.

In 1928, Schlapp(4) showed that the Stark effect of hydrogen lines is affected by the fine-structure in a moderate field. He considered the behavior of the hydrogen atom in an electric field on the basis of the equation of Darwin and Dirac 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 10,0000 V./cm. From the result of his calculation in the second case, he proved that the Stark component of $H\alpha$ consists not always of a singlet but of a singlet or a doublet and that the individual component shows a minute displacement towards the red or violet side in its own way. Hence the displacement of the maximum of the resultant intensities of fine-structure components is not symmetrical in a moderate field, as was already concluded from the theories in the beginning stage. But, owing to the experimental difficulties mentioned above, only a small number of observations has hitherto been carried out in this direction and, as much as the present writer is aware, the reports by McRae(5), Foster and Snell(6), and Steubing and Keil(7) are the only that have been published.

Using the concave grating, 3.83 A./mm. in its dispersion together with the discharge tube of the Lo Surdo type, McRae observed an asymmetry in the Stark components of the line $H\alpha$ in the fields above 19,000 V./cm., and showed that the obtained results are in fair agreement with the theory. He also observed an asymmetry in the relative intensities of the components, but this remained theoretically uninterpreted. The observation by Foster and Snell for the lines α and β of hydrogen and of deuterium showed that the asymmetry of $H\alpha$ and $D\alpha$ is in qualitative agreement with the theory and also that the similar asymmetry is found in the lines $H\beta$ and $D\beta$. More recently Steubing and Keil have measured the asymmetry in the line $H\beta$ with the discharge tube of the canal-ray type and a glass spectrograph, 3.436 A./mm. in dispersion in the fields 25,000, 40,000 and 60,000 V./cm.

In these three experiments, the discharge tubes used were of the Lo Surdo or the canal-ray type without any remarkable modification, and the lowest electric fields that they applied may be the lower limit in which each component can be resolved. If more precise observational results are wanted, it is necessary to device a light-source affording more intense and sharper lines and, if possible, of the homogeneous field type in order to get the direct measurment of the field applied.

The diffuseness of the spectral lines obtained by the canal-ray tube may be explained as follows. The light emitted from the canal-ray may be classified into two classes by the moving state of the atoms concerned in emission; (1) the light emitted by the atoms travelling with high speed originating from the ions accelerated in the cathode-fall and, in the longitudinal observation, observed as Doppler lines (2) that emitted by the atoms of residual gas, coming into collision with the travelling ions or atoms and, in the longitudinal observation, seen as rest lines. The former is usually much more intense than the latter. In the transverse observation, used for the study of the Stark effect, the displacement of the Doppler lines will almost be nil but its trace will still remain in virtue of the condensing lens possessing an aperture and of the canal-ray expanding in the course of its travelling. Accordingly, in the case of using the spectrograph of high dispersion, the spectra emitted from the canal-ray are to have line-breadth of considerable amount even in the transverse observation.

Therefore the construction of a new tube consists in finding out a device how to restrict the observation to the light emitted by rest atoms. Recently Ives aed Stilwell[8] designed a canal-ray tube which afforded sharp Doppler lines in the longitudinal observation. This sharpness declines if the gas pressure is increased in order to obtain rest line intense enough for the spectrograph of high dispersion, but it does not decline so much as to disturb the observation of the rest line. Therefore, if the electric field is applied to the canal-ray transversely to the direction of its travelling, the Stark effect of a rest line may be observed. In this principle, the writer deviced a new type of canal-ray tube and found it operating satisfactorily. The results of the observation of the Stark effect of the line H_α together with theoretical interpretations will be described in the following paragraphs.

II. Apparatus

Discharge tube.

The discharge tube here used was constructed after the manner diagrammatically shown in Fig. 1. E_1 and E_2 are the electrodes for applying an electric field; they are made of brass plates, about 5 cm broad and respectively 12 cm and 11.7 cm long for E_1 and for E_2, equipped with a semi-cylindrical water-jacket of copper. On the one end of the longer electrode E_1 is attached a circular disc A_2 of aluminum in which a slit, 0.7 mm in width and 2 cm in length, is cut so that one of its edges contacts with the plane of the flat surface of the electrode E_1, and this serves as one of the accelerating electrodes for hydrogen ions. These electrodes are roundly scraped at their edges and highly polished to minimize the sparking tendency between them. Moreover, the flat surfaces of the electrodes were well ground and polished in order to obtain a very homogeneous field. D is a semicircular glass plate, the same in diameter as A_2, and 3 mm thick, and in its chord it is ground off in the central portion as much as the width of the slit in A_2. It is placed between A_2 and E_2, and serves as an insulator between them. The electrodes E_1 and E_2 are maintained in parallel by the plane-parallel quartz plates Q_1 and Q_2. On the outside of the quartz plates, fused silica pipes P_1 and P_2 are inserted and two electrodes are fixed with apiezon wax as seen in Fig. 1 (b). The glass window W is also fixed with apiezon wax for the longitudinal observation. The separation between E_1 and E_2, measured from the thickness of Q_1 and Q_2, was 2.125 mm. It may be worth while to remark in Fig. 1 (a) that the slit in A_2 is not in the centre between the two electrodes, but is displaced towards the electrode E_1, to prevent the light of the low voltage arc to enter into the spectrograph as will be described later.

The combined electrodes E_1 and E_2 are inserted with another accelerating electrode A_1 into a glass tube C and are separated 3.5 mm by fused silica rods R and are fixed with apiezon wax. The side-tube in C is

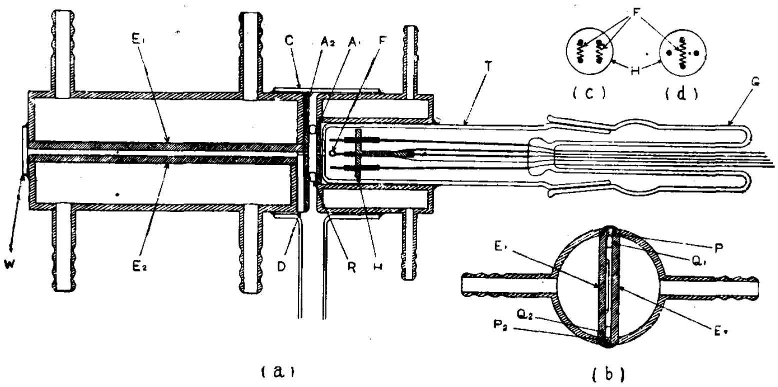

Fig. 1. Diagrammatic representation of the canal-ray tube. (a) Horizontal section view. (b) Virtical section view. (c) and (d) Equipment of the filament.

connected to the pumping system for evacuation or to let in the hydrogen gas to the system. The accelerating electrode A_1 is made of an aluminum disc, 2.6 cm in diameter, in which a slit, the same as in the other accelerating electrode A_2, is cut, and is held in a water-jacket of copper, 5 cm both in length and in outer diameter. In the water-jacket, a silica tube T is inserted tightly and fixed with apiezon wax. The tube has a bottom at which a slit, 1.5 mm in width and 5 mm in length, is opened in order to constrict the arc to the central portion of the slit in A_1. The other end of the tube is connected to the glass tube G. In the glass tube, five stems are mounted; four of them are to hold the oxide coated filament F and the last one is to joint the shielding electrode H to constrict the arc to the desired region, which is insulated from the other stems with silica pipes. At the preliminary trial in which two filaments were suspended with four stems outside of the slit as is shown in Fig. 1 (c), the low voltage arc was maintained between the cathode and the shielding electrode. But it was found that more ions were accumulated to the slit if the low voltage arc was maintained between the cathode and the accelerating electrode, hence, in the following course of the experiment, only two diagonal stems were used by which an oxide coated filament was suspended in front of the slit, as is shown in Fig. 1 (a) and (d).

In the preparation, the residual gas adsorbed on and in the electrodes and the filament was well removed by repeating the procedure of replacing the gas with pure hydrogen gas. The discharge tube thus prepared was operated very steadily for several hours or more and gave an intense canal-ray. The hydrogen pressure was from 2×10^{-2} to 3×10^{-2} mm Hg.

Electrical arrangement.

The arrangement to supply the electrical power to the discharge tube is diagrammatically shown in Fig. 2. The low voltage arc was maintained between the cathode F and the accelerating electrode A_1. The cathode filament F was heated by the 12 V. battery B_1 and the arcing voltage was supplied from the 300 V. battery B_2 through a resistance R_1 with the current of 300 mA.

The high negative potential to be afforded to the accelerating electrode E_1 and the higher negative potential for the electrode E_2 to observe the Stark effect were produced by double D.C. generators G of 5,000 V., driven by an A.C. motor M in a constant velocity. The exciting current of generators was supplied from the 120 V. battery B_3 through the resistances R_2, R_3, R_4 and R_5. The resistances R_2 and R_3 were used to control the high tension voltages while the resistances R_4 and R_5 were used for the fine adjustment of the voltages in use and were placed near the measuring apparatus. The high tensions thus produced were removed from their ripples by condensers C_1 and C_2 and a choke coil L_1, and by C_3, C_4 and L_2, and were supplied to the electrode E_2 and E_1 through the resistances R_6 and R_7, respectively. When the discharge tube had started to operate in a desirable

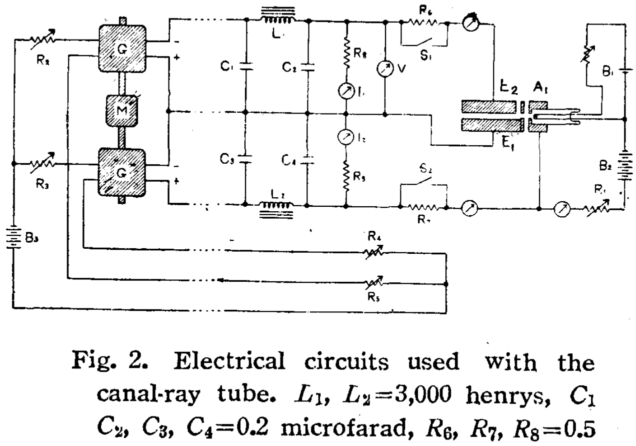

Fig. 2. Electrical circuits used with the canal-ray tube. L_1, L_2=3,000 henrys, C_1 C_2, C_3, C_4=0.2 microfarad, R_6, R_7, R_8=0.5 megohm, R_9=1 megohm.

condition, the resistances R_6 and R_7 were removed by the switches S_1 and S_2 and full tensions were afforded.

The absolute value of the potential difference between the two electrodes E_1 and E_2 was measured by the resistance R_8 and the milliammeter I_1 which were carefully calibrated. The probable error is estimated to be within $\pm 0.1\%$ of the obtained value. On the other hand, the small variation of the voltage was detected by the electrostatic voltmeter V which was equipped with a small concave mirror by which the image of a slit was projected on the scale. By this equipment, the variation of 10 V. was indicated as the displacement of 10 mm of the image on the scale in the voltage of 3,000 V. The potential difference between the accelerating electrodes was also measured by the resistance R_9 and the milliammeter I_2.

The applied potential difference between the two electrodes E_1 and E_2, and that between the electrodes A_1 and E_1 were about 3,000 and 4,000 V. respectively.

Spectrograph.

The spectrograph here 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 6563 Å. in its first order spectrum was 2.580 Å./mm.

When the light from the canal-ray was admitted into the spectrograph through the slit, it was most necessary to take away the light from the low voltage arc. For this purpose, the condensing lens was set so that the edge of the electrode E_2 which contacts with the glass plate D in Fig. 1, be focused sharply on the slit of the spectrograph. In such a condition, the light from the low voltage arc which entered the condensing lens through the slit in the electrode A_2 directly or after one or more reflections by the surfaces of E_1 and E_2 was focused to make sharp images of the slit of the spectrograph, and was refrained from entering into the grating.

The photographic plates used were Agfa Isopan and were hypersensitized by dipping into alcohol solution of ammonia and drying them immediately before the exposure. The exposure was 2 hours for the observation of the canal-ray and 4 hours for that of the Stark effect.

III. Results obtained

Before reporting the observational results of the splitting and the intensity of the line H_α in an electric field, those in absence of an electric field will be described as they are not only necessary for the theoretical interpretation of the results but are interesting in some other points of view. In Fig. 3 and Fig. 4 one of the spectrograms, obtained with the accelerating potential of 3,940 V., and its microphotometric record are reproduced respectively. In these, the most intense line R is the rest line, viz. the H_α emitted by residual gas atoms while the fairly intense lines D_2 and D_3 are well known Doppler lines of H_2^+ and H_3^+, viz. the H_α emitted by travelling atoms resulting from the accelerated ions H_2^+ and H_3^+ respectively. These Doppler lines are accompanied with long tails on the longer wave-length side. This feature is ascribed to the elastic and inelastic collisions while ions and atoms are travelling. Besides the lines D_2 and D_3, other two Doppler lines will be seen, the one of them D_4 appears on the longer wave-length side of the line D_3

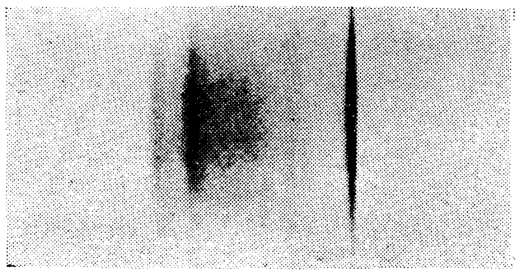

Fig. 3. Rest and Doppler lines of H_α.

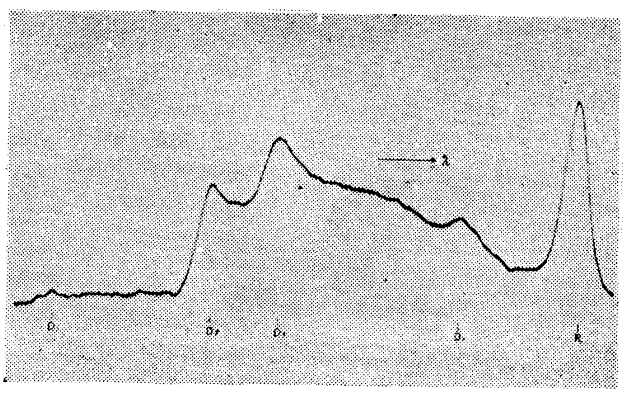

Fig. 4. Microphotometric record of the spectrogram in Fig. 3.

and another D_1 appears very faint on the shorter wave-length side of the line D_2. The displacements of the Doppler lines from the rest line, $\Delta\lambda$, are given in Table I. From this table it will be seen that the ratio of the displacement of the line D_1 to that of the line D_3, $\Delta\lambda(D_1)/\Delta\lambda(D_3)$ amounts to about $\sqrt{3}/\sqrt{1}$. Consequently the line D_1 is certainly the Hα emitted by hydrogen atoms generated from the accelerated protons. The ratio of the displacement of the line D_4 to that of the line D_3, $\Delta\lambda(D_4)/\Delta\lambda(D_3)$ is about $\sqrt{3}/\sqrt{19}$, hence the line D_4 is to be considered as attributed to the hydrooxide ions H_3O^+.

Table I.

	D_1	D_2	D_3	D_4
Δλ in Å	18.96	13.24	10.83	4.29

The rest line *R* is much sharper than the line observed transversely in the canal-ray, but not so sharp as that which is obtainable by the ordinary Pluecker tube, and the doublet of Hα is not resolved. Moreover, the intensity is not symmetrical, a little tail appearing in addition on the shorter wave-length side. This feature is more clearly seen in the intensity curve in Fig. 5 which was analysed from the microphotometric records as to be available for the individual component in Hα. Since the broadness and the asymmetry of the intensity of the component are ascribed to the scattering of the residual gas atoms due to the collisions, this intensity curve is interesting as it shows the ratio of the probabilities of the excitation and the scattering. It is also very important in the present problem for obtaining the curve of the resultant intensities from the theoretical calculation. It is most suitable to remark here that in virtue of the intensity curve of the rest line being affected by the velocity distribution of moving ions or atoms, the curve in Fig. 5 is adequate only when Doppler lines have the intensity distribution as is shown in Fig. 4.

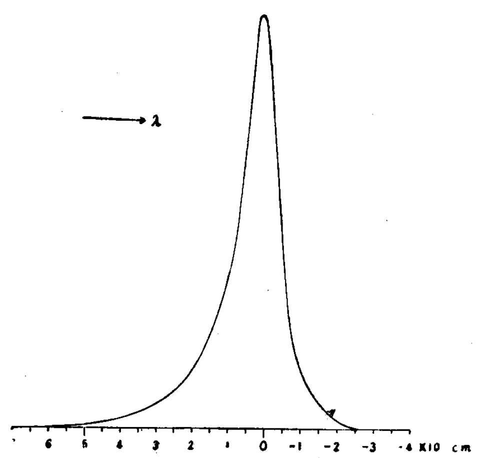

Fig. 5. Intensity curve of the individual component in the rest line.

Since the characteristics of the canal-ray in absence of the electric field have been made clear, the observational results when the field was applied may be described as follows.

In Fig. 6 and Fig. 7, one of the spectrograms obtained and the microphotometric record of it are reproduced respectively. The field strength applied was measured as 14,790 V./cm. within an error of ±0.1%. In these figures, the Stark components of the rest line will be clearly seen. Stark components of the Doppler lines are not resolved at all, but comparing the reproduction in Fig. 7 with that in Fig. 4, it is seen that the intensity distribution of Doppler lines is deformed by the Stark broadening. This may be partly ascribed to the bending, by the electric field, of the path of travelling ions,

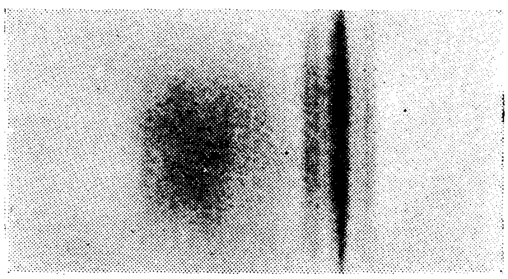

Fig. 6. Stark effect of the line Hα.

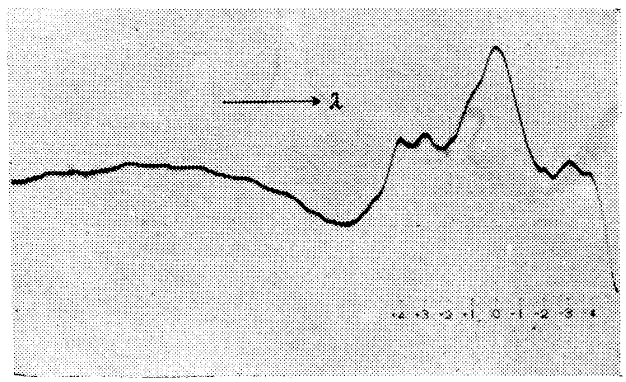

Fig. 7. Microphotometric record of the spectrogram in Fig. 6.

but this effect may be much smaller. Owing to this deformation of the intensity distribution in Doppler lines, the intensity curve of the individual component in the rest line will be slightly deviated from that shown in Fig. 5. It is very difficult to evaluate this deviation strictly from the intensity distribution of Doppler lines. But as the deformation of the intensity in Doppler lines is not great, it may be allowed to assume that the separation, at a given intensity in the intensity curve of the rest line, is proportional to the mean displacement of Doppler lines including their tails weighted by their intensity. The mean displacement of Doppler lines, when the electric field was applied, was measured as to be 0.881 of that when the field was absent. Consequently, using the above assumption, the intensity curve of the individual component was obtained from Fig. 5 by multiplying the values of the separation by the factor 0.881.

The mean intensity curve of the observed patterns which were obtained from the microphotometric records by normalising the intensity and eliminating the effects of the stray light of the low voltage arc and of the tails in Doppler lines, is shown in Fig. 8(c). In this figure, it will be very clearly seen that the displacements of the Stark components are not symmetrical to the central component 0. For instance, the displacement of the component +1 from the component 0 is greater than that of the component −1, therefore, the former is observed as a conspicuous lump while the latter, as a very obscure one. For another instance, the distance between the components +3 and +4 is larger than that between the components −3 and −4. It is also seen that the relative intensities of the components are not symmetrical, but this is not wholly ascribed to the intensity asymmetry of the corresponding components, because the displacements as well as the intensity curve of the individual component are not symmetrical.

The displacements of the resolved components, measured from the central component 0, $\Delta\nu''_{obs.}$ and their relative intensities $I''_{obs.}$ are given in the last column in Table VI and in Table III respectively. The average error of measurement for the displacement was $\pm 6\times 10^{-3}$ cm^{-1}.

IV. The interpretation of the results obtained

It has been derived by Schlapp that the displacement of the individual Stark component in Hα, $\Delta\nu$, in a moderate field, is given by the formula

$$\Delta\nu = \frac{3}{8}\frac{h}{\pi^2\mu e c}F\sigma + \frac{1}{405}\frac{\pi^4\mu e^8}{c^3 h^5}\tau$$

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

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

and σ and τ are the constants which have the values shown in the first and the third column in Table II. In this formula, the first term affords the first-order Stark component while the second, its fine-structure. Substituting the values $h=6.624\times 10^{-27}$ erg. sec., $c=2.9978\times 10^{10}$ cm. sec.$^{-1}$, $e=4.8026\times 10^{-10}$ e. s. u., $m=9.109\times 10^{-28}$ g. and $m/M=1/1837$, and representing the value of F in the unit of V./cm., the first term becomes $6.405\times 10^{-5}F\sigma$ cm.$^{-1}$, and inserting the measured value 14,790 V./cm. of F, its values, for various values of σ, amount to what is shown in the second column. By similar substitution, the second term becomes $1.804\times 10^{-3}\tau$ cm.$^{-1}$, the values of which for various values of τ, are shown in the fourth column. The displacement of the individual component, $\Delta\nu$, thus obtained, is given in the fifth column, and its polarization, in the sixth column. The intensity of the individual component has been also derived by Schlapp, which will be denoted as I_s and given in the seventh column. The summation of these values to each Stark component becomes quite the same with the value, derived by Schroedinger in which the fine-structure was put cut of consideration.

As already mentioned, Schroedinger's theory, for the displacement of the Stark components, is well founded, but for their intensities, there still remain some points unexplained according to his theory. In general, the observed intensities are in fair agreement with the theory, when the

Table II.

σ	The first term. (cm⁻¹)	τ	The second term. (cm⁻¹)	Δν (cm⁻¹)	Polarization.	I_s	I_d
−8	−7.578	87	0.157	−7.421	p	0.1	0.1
−6	−5.684	−48 87	−0.087 0.157	−5.771 −5.527	s	0.9 0.9	0.8 0.8
−5	−4.737	99 123	0.179 0.222	−4.558 −4.515	s	0.8 0.8	0.6 0.6
−4	−3.789	87	0.157	−3.632	p	168.1	156.2
−3	−2.842	−12 99	−0.022 0.179	−2.864 −2.663	p	115.2 115.2	90.7 90.7
−2	−1.895	103	0.186	−1.709	p	72.9	161.6
−1	−0.947	99 123	0.179 0.222	−0.768 −0.725	s	96.8 96.8	76.2 76.2
0	0	−32 0 103 119	−0.058 0 0.186 0.215	−0.058 0 0.186 0.215	s	44.1 230.4 44.1 230.4	97.8 357.1 97.8 357.1
+1	0.947	99 123	0.179 0.222	1.126 1.169	s	96.8 96.8	76.2 76.2
+2	1.895	103	0.186	2.081	p	72.9	161.6
+3	2.842	−12 99	−0.022 0.179	2.820 3.021	p	115.2 115.2	90.7 90.7
+4	3.789	87	0.157	3.946	p	168.1	156.2
+5	4.737	99 123	0.179 0.222	4.916 4.959	s	0.8 0.8	0.6 0.6
+6	5.684	−48 87	−0.087 0.157	5.597 5.841	s	0.9 0.9	0.8 0.8
+8	7.578	87	0.157	7.735	p	0.1	0.1

discharge tube of the Lo Surdo type is used, but in the case of canal-ray, they are affected by the exciting condition and by the directions of the motion of the canal-ray relative to the electric field, and are not always in accordance with the theory.

Mark and Wierl[9] studied the intensities of the Stark components very extensively and their result in the case of the canal-ray travelling in the perpendicular direction to the electric field will be described now. They classified the emission of the light in the canal-ray, according to the exciting condition, into three kinds; i.e. "Abklingleuchten", "bewegtes Stossleuchten" and "ruhendes Stossleuchten". By "Abklingleuchten" is meant the light-emission by the canal-ray when it is admitted into the high vacuum of about 10^{-4} mm. Hg., and by "bewegtes Stossleuchten", that by travelling atoms which they produced by introducing the hydrogen canal-ray into the nitrogen of from 2×10^{-2} to 3×10^{-2} mm. Hg. By "ruhendes Stossleuchten" they indicate the light-emission by rest atoms generated by introducing the nitrogen canal-ray into the hydrogen of about from 2×10^{-2} to 3×10^{-2} mm Hg. The reason why

"Stossleuchten" was produced by the collision between different kinds of atoms was that, otherwise, it was difficult to discriminate between "bewegtes" and "ruhendes Stossleuchten" from each other in the case of viewing transversely. From the results of the observation, Mark and Wierl found that the intensities of the Stark components given by "bewegtes Stossleuchten" were in agreement with those derived by Schroedinger's theory for the lines H_α, H_β and H_γ, except the s-components of H_γ, while those given by "Abklingleuchten" were markedly different. The intensities given by "ruhendes Stossleuchten" were observed only for the p-components of H_β and were found to be in qualitative agreement with those given by "Abklingleuchten" but not with those given by "bewegtes Stossleuchten".

The anomalous intensities of "Abklingleuchten" were later theoretically examined by Bethe[(10)]. The intensities derived by Schroedinger's theory have been given by the transition probabilities by assuming that the numbers of atoms in different states are equal. This assumption is adequate in the case of "bewegtes Stossleuchten" where the travelling atoms transfer the energy by successive collisions, but is not adequate in the case of "Abklingleuchten" where the excited atoms are able to travel for a long duration without perceptible collisions. For "Abklingleuchten", it is more suitable to assume that the numbers of atoms, excited into different states per second, are equal. In this case, the intensities are given by the transition probabilities, multiplied by the mean lives of the initial states. In this consideration, he computed the intensities for the line H_α which were found to be in fair agreement with those given by "Abklingleuchten". The intensities thus reconsidered were called "dynamische Intensitaeten" while the ordinary intensities, "statische Intensitaeten". More detailed and extensive calculation of "dynamische Intensitaeten" has been given by Ryde[(11)] for the various lines of hydrogen, using Bethe's method.

For the anomalous intensities of "ruhendes Stossleuchten", a reasonable explanation has not yet been put forward. The values given by Mark and Wierl are in qualitative agreement with "dynamische Intensitaeten", but, as the observation was restricted to the line H_β, there still remains the doubt that it might be an accidental coincidence. For the confirmation of this, further research for other lines is much desired.

Now to return to the present problem, since the Stark components here obtained are undoubtedly those, given by "ruhendes Stossleuchten", it is very interesting to see to what sort of intensities they belong. Thereafter, the theoretical interpretation will be afforded not only by "statische Intensitaeten", derived by Schlapp but also by "dynamische Intensitaeten", computed by Ryde. Although "dynamische Intensitaeten" have been derived ignoring the fine-structure, it is easy to assign the intensity to the individual component, as the fine-structure consists of doublets, equal in their intensities. "Dynamische Intensitaeten" thus assigned are denoted as I_d and are shown in the eighth column in Table II.

In order to compare the observed values of the displacements and the intensities of the Stark components with those resulting from theoretical calculation, the patterns of the resultant intensities have been secured using the intensity curve of the individual component, given in the preceding paragraph. In Fig. 8 (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 the shorter wave-length side of the individual component, all of the shorter wave-length components have stronger intensities 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 central component, I_s'' and I_d'', are shown in Table III, while the displacements $\Delta\nu'_s$ and $\Delta\nu'_d$ and their values relative to the central component, $\Delta\nu_s''$ and $\Delta\nu_d''$, appear in Table VI. Comparing these patterns with the observed one in (c) of the same figure, it can be clearly seen that the observed intensities are conspicuously different from the values of I_s'' but closely resemble those of I_d''.

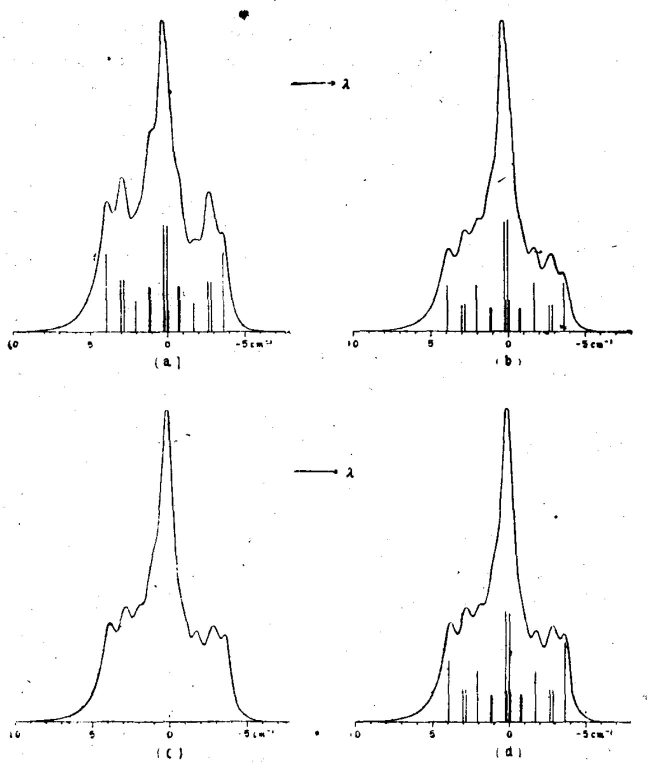

Fig. 8. Theoretical and observed patterns of the Stark effect in the line H_α. (a) Pattern given by "statische Intensitaeten". (b) Pattern given by "dynamische Intensitaeten". (c) Observed Pattern. (d) Pattern given by analysed intensities.

Table III.

Component.	Resultant intensity.		Relative intensity.		
	I'_s	$I'_{\bar{a}}$	I''_s	$I''_{\bar{a}}$	$I''_{obs.}$
−4	207.9	188.4	323.8	192.7	281
−3	293.0	249.5	456.4	255.2	309
−2	193.8	266.9	301.9	273.0	293
−1					
0	642.0	977.6	1000	1000	1000
+1					
+2		359.4		367.6	
+3	323.2	322.6	503.4	330.0	367
+4	272.9	261.6	425.1	267.6	318

The unexpected result the "ruhendes Stossleuchten" follows "dynamische Intensitaeten" may be explained as follows. The fundamental difference between "bewegtes Stossleuchten" and "Abklingleuchten" consists in the fact whether the mean free time of the hydrogen atoms is small or large compared with the lifetime of their excited states. As "ruhendes Stossleuchten" is given by the residual gas atoms, while "bewegtes Stossleuchten" is given by the travelling atoms in the canal-ray, it is true that the former is comparable to the latter so far as the mean free path of the hydrogen atoms is concerned. However, the mean velocity of the residual gas atoms being a fraction of one hundredth in their size compared with that of the travelling atoms, the mean free time of the former is several hundred times greater than that of the latter. In order to afford the mean free time of the travelling atoms in such a quantity, it is necessary to reduce the pressure of residual gas to a fraction of one hundredth. In such a high vacuum, the emission of light by travelling hydrogen atoms is nothing else than "Abklingleuchten". Consequently, if "dynamische Intensitaeten" are responsible for the intensities given by "Abklingleuchten", they must be responsible also for those given by "ruhendes Stossleuchten".

In order to consider the observed intensities more precisely, the intensity of the individual component has been analysed from the observed values, assuming the doublet has equal intensities. The values of I_a and the values of $(I_a - I_{\bar{a}})/I_{\bar{a}}$ are shown in Table IV. From these values, it may be seen that the values of I_a are in agreement with those of $I_{\bar{a}}$ in the components ±2, but considerable discrepancies are found in the other components.

Table IV.

Component.	I_a	$(I_a - I_{\bar{a}})/I_{\bar{a}}$ (%)
−4	243	56
−3	103 103	13
−2	165	2
−1	86 86	13
+1	86 86	13
+2	162	0
+3	109 109	19
+4	198	26

To explain these discrepancies, it has been thought that the numbers of atoms excited into the different initial states per second were probably not strictly equal. In this consideration, the enhancement and asymmetry of the components ±4 are explained by the increase in the number of atoms excited into the initial states of the component +4 and the greater increase in that of the component −4. The equal enhancement of intensities between the components ±1 and ±3 is also explained similarly, since the initial levels of the components +3 and −3 are the same as those of the components +1 and −1 respectively. The inequality in numbers of atoms excited has been considered further to be caused by that the mean free time of residual gas atoms was not so large compared with the life time of their excited states, in the discharge tube here employed. The life time, computed by Ryde, τ is shown in Table V. In this table, the values of τ of the components 0 and ±2 are larger than those of the other components, hence it is probable that the numbers excited into the initial states of these components were affected more and relatively those of the other components increased. But the greater increase of the components ±4 can not be explained because the value of τ of these components are a little larger than that of the components ±3. It is also difficult to account for the asymmetry of the components ±4 by the above consideration.

Table V.

Conponent.	Life time ($\times 10^{-8}$sec).
0	1.550 * 2.217 †
1	0.787
2	2.217
3	0.787
4	0.929

* $I_{\bar{a}}$=357.1
† $I_{\bar{a}}$= 97.8

Turning now to the interpretation of the observed displacements, the theoretical values given by I_s and by $I_{\bar{a}}$ in Table VI will be considered at first. From these values, it can be seen that the displacements are considerably affected by the intensities of the individual components. Therefore, 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. The schema of the individual components and the pattern of their resultant intensities are given in Fig. 8(d). In this figure, the asymmetries of the displacements are so clearly seen in the resultant as well as in the individual components. The displacements of the resolved components $\Delta\nu'_a$ and their values relative to the central component $\Delta\nu''_a$ are shown in Table VI.

Comparing this pattern with the observed one in (c) of the same figure, it is found that both the patterns are in a close agreement. This implies that the observed

Table VI.

Component.	Displacement. (cm.$^{-1}$)			Relative displaceent. (cm.$^{-1}$)			
	$\Delta\nu'_s$	$\Delta\nu'_{\bar{a}}$	$\Delta\nu'_a$	$\Delta\nu''_s$	$\Delta\nu''_{\bar{a}}$	$\Delta\nu''_a$	$\Delta\nu''_{obs.}$
−4	−3.523	−3.539	−3.568	−3.609	−3.633	−3.662	−3.692
−3	−2.794	−2.787	−2.817	−2.880	−2.881	−2.911	−2.919
−2	−1.775	−1.687	−1.725	−1.861	−1.781	−1.819	−1.831
−1							
0	0.086	0.094	0.094	0	0	0	0
+1							
+2		1.847			1.753		
+3	2.878	2.776	2.822	2.792	2.682	2.728	2.738
+4	3.844	3.840	3.851	3.758	3.746	3.757	3.782

asymmetries are in qualitatively good accordance with those theoretically expected. In the measurement, these patterns have been compared very minutely by enlarging them enormously, nevertheless there have not been found any perceptible discrepancies in the central portion, consisting of the unresolve components +2 and ±1. Hence, if the displacements of these components were differed from the theoretical values, it seems that the difference in the component +2 would be less than ±1%, and those in the components ±1 less than ±2% of their values. As to the resolved components, however, it has been found that all of the displacements are slightly greater in the observed values as seen from the values in Table VI.

In order to consider further these discrepancies, the displacement by the first-order Stark effect $\frac{1}{2}(|\Delta\nu''(+)|+|\Delta\nu''(-)|)$ has been considered for two corresponding components ±3 and ±4, which are shown in Table VII. In this table, it will be seen that the observed displacement of the components ±3 is 0.3 % greater while that of the components ±4 is 0,7% greater than the theoretical value. Consequently, it seems to be certain that the displacement of the first-order Stark effect is about 0.5% greater in every individual component.

Table VII.

Component.	$1/2(\lvert\Delta\nu''(+)\rvert+\lvert\Delta\nu''(-)\rvert)$ (cm⁻¹.)	
	by $\Delta\nu''_a$.	by $\Delta\nu''_{obs}$.
±3	2.820	2.829
±4	3.710	3.737

The asymmetry due to the fine-structure is expressed by the displacement of the centre of the two corresponding components $\frac{1}{2}(|\Delta\nu''(+)|-|\Delta\nu''(-)|)$, the values of which are given in Table VIII. In this table, the observed asymmetries of the components ±3 and ±4 are in accordance with those computed within the experimental error. The value of the components ±2 could not be given because the component +2 was not resolved. But if the theoretical value of the displacement of the component −2 is revised by taking into account the observed increase in the first-order Stark effect, it becomes −1.828 cm.$^{-1}$ and agrees with the observed value. From these facts, it may be concluded that the observed asymmetries are in excellent agreement with the theoretical values given by Schlapp's formula.

Table VIII.

Component.	$1/2(\lvert\Delta\nu''(+)\rvert-\lvert\Delta\nu''(-)\rvert)$ (cm.$^{-1}$)	
	by $\Delta\nu''_a$.	by $\Delta\nu''_{obs}$.
±3	−0.092	−0.091
±4	0.048	0.045

At last, the coefficient of the first-order Stark effect will be evaluated. It has been stated in the above that the displacement of the first-order Stark effect was observed to be 0.5 % greater compared with the theoretical value. If the coefficient is computed from the observed displacement, its value amounts to 6.44×10^{-5}. Since the error in the measurement of the displacement has been given as ±0.2 %, while that of the electric field as ±0.1%, the experimental error of the above value becomes ±0.3 %, hence there still remains a little discrepancy which is not covered.

It will be noticed that the size of the experimental error here afforded is considerably smaller compared with the errors which have hitherto been obtained in the measurements of this coefficient. In the observations using the spectrograph of small dispersion, the electrodes were separated by the small distance of about a fraction of 1 mm in order to obtain sufficient displacements. Because of the smallness of the separation between the electrodes, it was difficult to hold them plane-parallel and to measure their distance accurately, hence the electric field was not measured without large experimental error. In the present observation, on the other hand, the canal-ray being so intense, as is observable by the grating of high dispersion, the electrodes were separated by further distance, hence the field strength was measured very accurately.* Even in the present observation, a small disturbance might have taken place by the polarization of the electrodes. If it is true, the discrepancy in the coefficient of the first-order Stark effect may be well explained, however, for the confirmation of this, further research will be desired.

Summary

(1) A new canal-ray tube was designed to obtain sharp Doppler lines and an intense rest line of H_α. By observing the tube in the longitudinal direction, the Stark pattern of the rest line was photographed in the field 14,790 V./cm.

(2) The observed intensities are in general accordance with "dynamische Intensitaeten", but considerable enhancements and asymmetries were found in some of the components.

(3) These discrepancies have been explained by the inequality in numbers of atoms excited into the initial states per second, caused by that the mean free time of residual gas atoms was not so large compared with the life time of their excited states.

(4) The observed asymmetries in the displacements are in good accordance with the theoretical values derived by Schlapp.

(5) Small enhancement was observed in the displacement of the first-order Stark effect.

(6) The coefficient of the first-order Stark effect amounts to $6.44\times10^{-5}\pm0.3$ %, which is 0.5 % greater than the theoretical value.

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