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OBSERVATIONS ON THE STARK EFFECT IN HYDROGEN AND HELIUM

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ABSTRACT

Stark effect measurements for hydrogen and helium lines in fields 1 to 38 kv/cm.—The *Lo Surdo method was improved* by using a rotating cathode to minimize pitting. A three prism glass spectrograph, and a Hilger quartz spectrograph E_1 were used. Enlargements of the spectrograms for $H\gamma$ and for six He lines are given. (1) *Hydrogen Balmer lines.* At fields below 3 kv/cm, the red side of each line is more diffuse than the violet side, in agreement with Kramers' theory of the connection between the Stark effect components and the fine structure components. For fields above 5 kv/cm ten p components of $H\gamma$ are symmetrically arranged, the ratios of $\Delta\lambda$ to field coming out $\pm$(.230, .191, .153, .065, .026) A/kv/cm. Changes in the relative intensities of components of $H\gamma$ and of $H\delta$ with increasing field are noted and the observed relative intensities of $H\epsilon$ are found to agree fairly well with Kramers' theoretical predictions. (2) *Parhelium lines.* Measurements at five field strengths are given for the groups near the D lines 4388, 4144, 4009, and near λ3614, including some new components. The number of lines in each group increases with the order. Combination series of the type $2P-mQ$, $2S-mQ$ ($Q=S$, P, B, E, F, . . .; $M=4$, 5, 6 . . .) are suggested which include these lines and also the components of Stark's "diffuse principal" series and which fit into the scheme proposed by Tschulanowsky. The variable behavior of lines near λ4388 in low fields is noted and observations are given for the λ3927 group. As a rule the *Stark effect pattern* is constant for the members of each series but varies with the series. Many components vanish with increasing field. (3) *Orthohelium lines.* Measurements are given for groups λ3820 and λ3705 and observations for λ4026.

INTRODUCTION

THE effect of high electric fields on the lines of the Balmer series has been observed by Stark[1] and is well known. The explanation is based on the quantum theory and was given independently by Epstein[2] and Schwarzschild.[3] Kramers[4] has used the principle of correspondence

[1] J. Stark, Ann. der Phys. **48**, 193 (1915)

[2] P. Epstein, Ann. der Phys. **50**, 489 (1916)

[3] K. Schwarzschild, Ber. Akad. Berlin, p. 548, 1916

[4] H. A. Kramers, Det. Kgl. Danske Vidensk. Skrifter, Naturo. og Math. Afd., 8 Raekke, III. 3 (1919)

to explain the polarizations and relative intensities of the components observed in hydrogen and ionized[5] helium. We are indebted to the same author for an account of the behavior of new fine structure components of the Balmer series in very weak fields. In a later paper Kramers[6] has discussed the gradual change from the fine structure to the commonly observed Stark effect, and has represented the detailed connections for Hα and He λ4686. From this important paper one may conclude that the Stark effect pattern contributed by a fine structure line varies with the type of the line.

The Stark effects to be expected in the case of the fine structure lines in the Balmer series are as follows.

Transition associated with emission of fine structure component	Stark effect components contributed by fine structure component	
	Parallel	Perpendicular
n_1-2_1	1	0
n_k-2_1 ($k=2, 3, 4$, etc.)	1	1
n_1-2_2	1	1
n_2-2_2	2	2
n_k-2_2 ($k=3, 4, 5$, etc.)	2	3

In any Balmer line the group of fine structure components corresponding to transitions to the 2_1 orbit contribute a Stark effect group pattern of imperfect symmetry in which the components do not intersect one another. A somewhat similar though greater contribution to the group pattern in the electric field is made by the fine structure components emitted when the electron passes to the 2_2 orbit. These two groups of fine structure components of a single Balmer line are so close together that many Stark effect components from one group cross components from the other group. The structure at very low fields is thus considered to be very complicated and quite beyond complete experimental inquiry.

This view of the connections between the fine structure and the Stark effect components in hydrogen at once suggests an interpretation of the effect of an electric field on the spectra of heavier atoms. Bohr[7] has called attention to some "isolated components" observed by Nyquist near the diffuse lines of both systems in neutral helium. These he believes to be new combination lines corresponding to transitions which cannot occur in the absence of the field. He observes that in addition to lines in the Koch[8] series $2p-mp$ and the corresponding parhelium series

[5] H. Nyquist, Phys. Rev., **10,** 226 (1917); also J. Stark, O. Hardtke and G. Liebert, Ann. der Phys. **56,** 569 (1918)

[6] Kramers, Zeit. f. Phys. **3,** 199 (1920)

[7] N. Bohr, The Quantum Theory of Line Spectra, Part III.

[8] J. Koch, Ann. der Phys. **48,** 98 (1915)

$2P-mP$, Nyquist's data include new lines which fit the formulas $2p-mb$ and $2P-mB$, $(m=4,5)$.

Quite recently Tschulanowsky[9] has measured certain lines on plates taken by Paschen during the examination of the fine structure of Fowler's series in ionized helium. These are believed to be members of the neutral helium series $2p_{1,2}-mb$ (measured for $m=4,5$) and $2P-mB$ (measured for $m=4,5,6,7$). The measurements indicate that the electric field in the source was very weak.

Tschulanowsky gives a sketch of line series which, by analogy with hydrogen, might appear in the systems of neutral helium. These are limited to those emitted when the electron passes to orbits with principal quantum number 2. They are

Parhelium	Orthohelium
$2S-mQ$	$2s-mq$
$2P-mQ$	$2p-mq$

where $Q=S,P,D,B,E,F,G$, etc., and $q=s,p,d,b,e,f,g$, etc. B refers to Bergmann terms; E,F,G to terms associated with orbits which have azimuthal quantum numbers 5,6,7 respectively. It is suggested that the lines of Stark's" diffuse principal" series in both systems are represented in the electric field by a single parallel component and a single perpendicular component, and that the other "components" reported are in reality new combination lines not attached to the diffuse lines at "zero" field.

The classification of the neutral helium spectra just presented was also suggested by the author.[10] The suggestion was based on the experimental evidence given in the present paper. It is found that the study of the Stark effect often assists in the identification of a combination line.

Method

The method is a modification of that first used by Lo Surdo. A vertical cross-section of the central portion of the discharge tube is shown in Fig. 1. The light to be examined passes out through the slit S. In order to prevent pitting of the cathode by the action of the positive ions and the consequent change in the electric field near it, the cathode is arranged so that it can be frequently turned about the axis of the tube, exposing new surface.

In the experiments here reported, a 4 kw motor-generator supplied a 500 cycle current to the primary of a standard 110-13200 volt trans-

[9] W. Tschulanowsky, Zeit. f. Phys. **16,** 300 (1923)

[10] J. S. Foster, Proc. Am. Phys. Soc. Phys. Rev. **23,** 293 (1924). When this note was written the author was unaware of the earlier interpretation by Professor Bohr.

former designed for 60 cycles. The secondary current was rectified in the usual manner, and the ripples were reduced to a very low value by sufficient capacity and inductance. The voltage on the tube (5 to 8 kv) was kept constant by the adjustment of a resistance in the primary of the transformer.

The vacuum system contained a ballast capacity of 16 liters. Hydrogen and helium were mixed in various proportions. The hydrogen increased the light intensity; moreover it was convenient to have the Balmer lines on the plates. The current was 5 m-amp. to 20 m-amp.

Immediately in front of the discharge tube was a double-image prism. The images were focused on the slit by a rapid rectilinear lens of 50 cm focal length. The tube support, double-image prism, lens, and spectro-

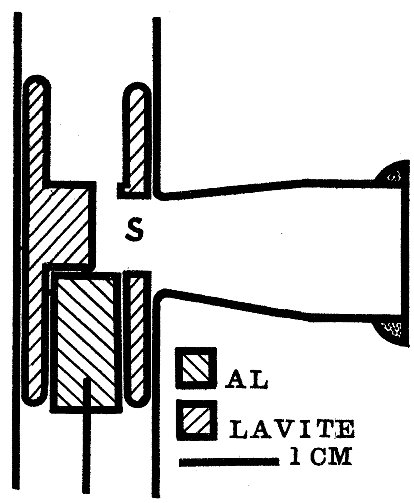

Fig. 1. Modified Lo Surdo tube with rotating cathode.

graph were so connected as to form a very rigid system. Two spectrographs were employed. Fig. 2 is taken from a plate exposed for 50 minutes in a newly mounted glass prism spectrograph, with six prisms of which only three have been used. The dispersion is 6 A/mm at $H\gamma$. The mountings are of metal throughout. This instrument, which contains a few new features, is described in the J. Op. Soc. Am., **8,** 373, 1924. Fig. 3 is from a plate exposed 1.5 hr in a Hilger quartz spectrograph, type E_1. The arrows indicate new lines.

Results for Hydrogen Balmer Lines

By means of a canal-ray tube, Stark and Kirschbaum[11] found that in strong electric fields each line of the Balmer series was replaced by a

[11] J. Stark and H. Kirschbaum, Ann. der Phys. **43,** 991 (1914)

symmetrical group of lines each one of which was displaced from the position of the original line by an amount proportional to the field. This fundamental research has enabled later investigators to determine field strengths from separations of conveniently chosen components in

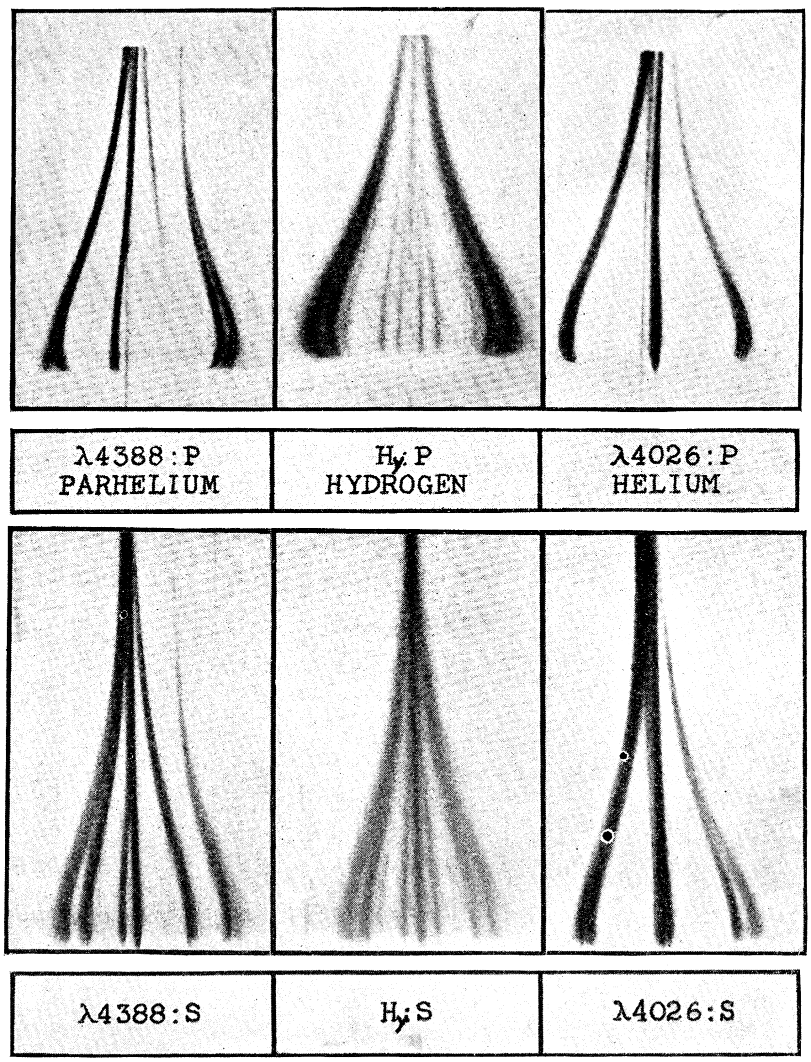

Fig. 2. From a plate taken with glass prism spectrograph. Magnification × 8.

some Balmer pattern. Moreover, since the Stark effect for each Balmer line is well known, any such line may be used as a guide by which to judge the quality of the analysis obtained by Lo Surdo's method for other lines on the same plate. Because of its photographically convenient wave-length and moderate intensity, Hγ has been employed for this double purpose. Although the Stark effect for this line is well known at high fields, a few details have been observed at lower fields which seem to be of sufficient interest to record. To these are added a few notes on Hϵ and on the general behavior of the Balmer lines in very low fields.

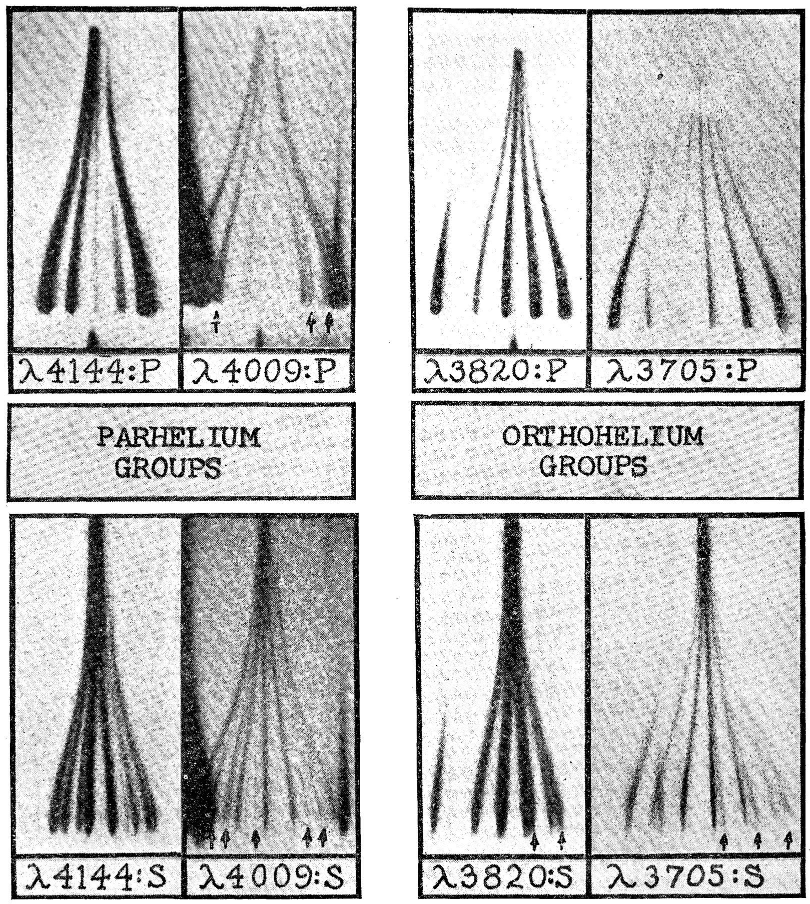

Fig. 3. From a plate taken with quartz spectrograph. Magnification $\times$ 8.

Fine analysis of Hγ. The fine analysis for the parallel components of Hγ is given in Table I for ten field strengths ranging from 4.6 kv/cm to 38.0 kv/cm. The perpendicular components have not been measured in a similar way because of their slightly inferior quality. This defect was brought about by the fact that the two images formed by the

Rochon prism did not focus in the plane of the slit. It is assumed that the separation of the strong outer parallel components may be used to determine the field strengths. On this basis, and through the use of Stark's[12] most recent data, the measurements are plotted in Fig. 4. All components are found to have displacements very nearly proportional to the field, for the range of fields here considered, the ratios being $\pm$(.230, .191, .153, .065, .026)A/kv/cm. As Stark[13] has reported a considerable asymmetry in his rough analysis at 28.5 kv/cm, it should be noted that the symmetry is disturbed very little.

TABLE I

Parallel components of Hγ

Field	Δλ from strongest fine structure comp. in zero field									
38.0 kv/cm	8.78	7.26	5.80	2.52	1.02	8.75	7.30	5.80	2.47	1.02
34.7	7.99	6.59	5.34	2.27	0.90	7.94	6.60	5.35	2.22	0.91
28.9	6.68	5.55	4.51	1.90	0.81	6.60	5.55		1.86	0.75
23.3	5.39	4.49		1.53	0.66	5.30	4.38		1.43	0.54
18.4	4.24	3.58		1.20		4.21	3.57		1.20	
14.2	3.30	2.78				3.24	2.81			
10.6	2.44					2.43				
7.9	1.77					1.88				
5.8	1.26					1.39				
4.6						1.08	0.90			

The displacements just recorded are measured from an undisplaced line. This line was produced by a comparatively faint glow in the side tube leading from the main discharge. It is very sharp and probably represents no more than the strongest component in the fine structure of Hγ.

Changes in relative intensities of components of Balmer lines with increasing field. (a) In moderate fields the components on the red side of each original line are usually stronger than the corresponding ones on the violet side. This is true of all lines observed, Hβ to Hε inclusive, and is an effect observed by Stark in a canal-ray tube when the canal-rays were accelerated by the electric field. In a field of 104 kv/cm, however, Stark found perfect symmetry. (b) The parallel components $5_0-2_{\pm 1}$ (Kramers' notation) for Hγ are weaker than $5_{\pm 1}-2_0$ when they first appear on the plate; but in the highest fields they are the stronger, just as observed by Stark. (c) In low fields the first of the weak outside perpendicular components of Hγ to appear is 5_4-2_0 and this is the one which, on the theory, has its origin in a fine structure line present at zero field. Its intensity increases very little with increasing field. On my plates there is no evidence of the components $5_{\pm 3}-2_{\mp 1}$ although

[12] J. Stark, Ann. der Phys. **48**, 193 (1915)

[13] Stark, Monograph, p. 51

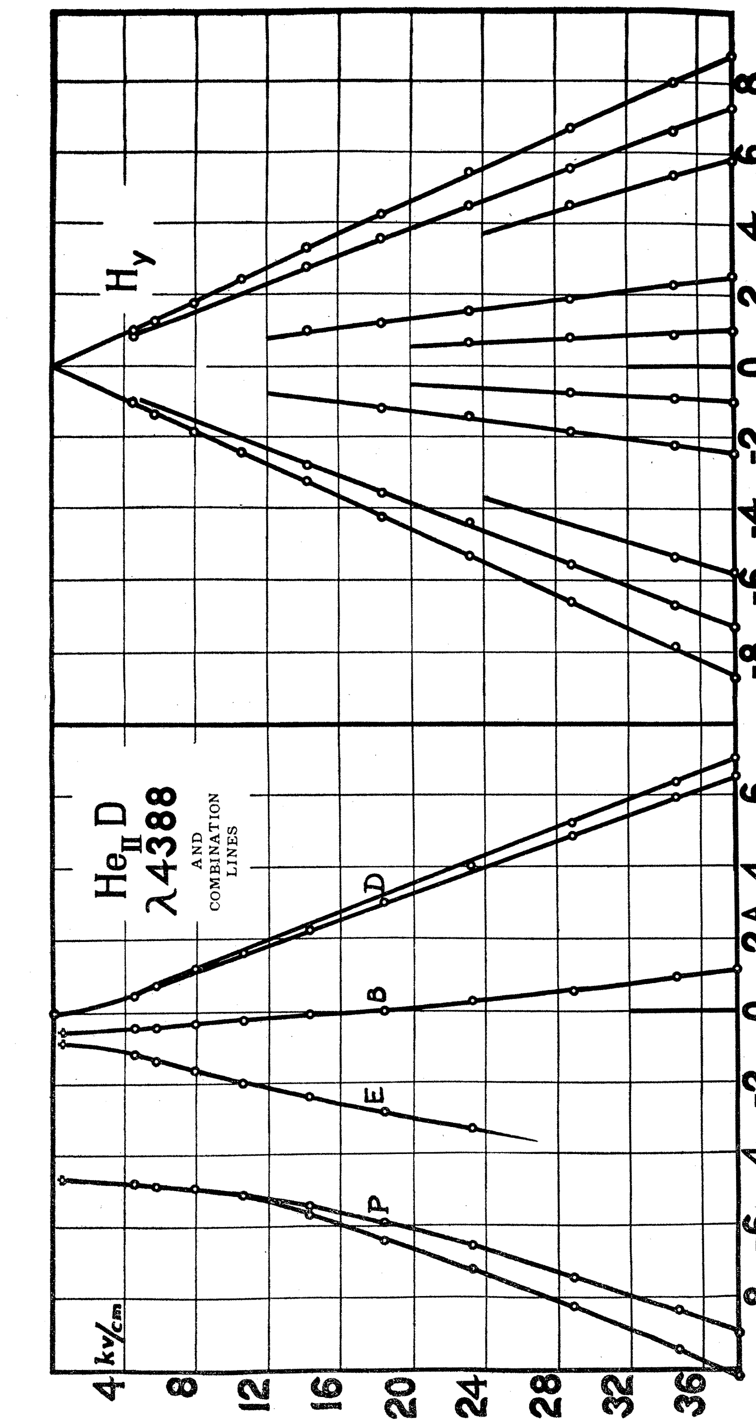

Fig. 4. He λ4388 group and Hγ in electric field.

these appear on Stark's plates at 104 kv/cm with a greater density than $5_{\pm 4}-2_0$. A similar statement may be made in regard to the corresponding perpendicular components of Hδ.

The Balmer series in very low fields. The rough analysis of Hβ, Hγ, and Hδ at very low fields (less than 3 kv/cm) shows that the red side of the affected line is more displaced from the strongest fine structure component and more diffuse than the violet side. Such relative displacements are observed with certainty only in the parallel components. The red side of each line is relatively diffuse, however, in both parallel and perpendicular images. The effect is apparent on all plates. It is not brought about by the slightly greater intensity of the apparently diffuse components.

It should be mentioned that according to Kramers' theory the fine structure line n_1-2_1 contributes but one Stark effect component. Presumably in the region in which the diffuse effect is actually observed, the theory claims that this strongest p-component crosses the other strong components on the red side of each Balmer line. The strong violet p-components are not so seriously disturbed. Theoretically the s-components present a more complicated structure in low fields. The displacements have not been calculated for every field strength throughout this region and for that reason one cannot predict the character of a rough analysis. One might guess, however, that for fields above 1.5 kv/cm the effect should agree with that observed.

Relative intensities of components of Hϵ. At the time Kramers' dissertation was published there were no observations with which to compare his theoretical estimates of the relative intensities of the Stark effect components of Hϵ. Two of the plates exposed in the glass spectrograph during this investigation show many components of this line. It is believed that a more complete analysis can be obtained through the use of the quartz spectrograph, and for that reason the present report is very brief. The relative intensities of the stronger inner components are very close to the predicted values. The strong outer p (and s) components at 60 kv/cm are relatively less intense than they were predicted to be at 100 kv/cm.

Parhelium

Near each diffuse line in parhelium there appears, in weak electric fields, a group of new lines. The extreme violet line in each group is a member of the series $2P-mP$. Direct measurements of the wavelengths at very low fields (0.2 kv/cm to 0.8 kv/cm) have been made on a plate exposed for ten hours in the glass spectrograph. In Table II these are recorded in the following manner. The first row gives the wave-lengths for the series $2P-mP$. The next row marked "Series I" contains the wave-lengths of the lines which lie next those of the $2P-mP$ series. Continuing in this manner, "Series II" includes lines adjoining those in "Series I" and still nearer the D lines. Finally the D lines are measured as a means by which the fields may be determined more accurately at a later date.

TABLE II

Wave-lengths of combination lines in parhelium; $E<1$ kv/cm.

	$m=5$	$m=6$	$m=7$
$2P-mP$:	4383.29 (2)	4141.34 (1)	4007.47 (1)
"Series I" :	4387.07 (3)	4143.16 (1)	4008.55 (1)
"Series II" :	4387.42 (5)	4143.41 (3)	4008.90 (2)
"Series III":	———	4143.79 (5)	4009.19 (2)
D lines :	4388.01	4144.05	4009.41

The observations are tabulated as above merely as a matter of convenience. It is not believed that the lines in "Series I," for example, are members of an actual spectral series. One reason for such a conclusion is that they have an almost constant separation from the D lines. The additional experimental data contained in the following tables offer some aid to the problem of assigning the new lines to series.

TABLE III

Parallel components of the λ4388 group in electric field

E	Δλ from D line in zero field
38.0 kv/cm	7.03, 6.52, 1.11, −9.03, −10.12
34.7	6.36, 5.92, 0.92, −8.39, − 9.42
28.9	5.21, 4.83, 0.55, −7.45, − 8.27
23.3	4.02, 0.26, −3.30, −6.58, − 7.22
18.4	3.02, 0.03, −2.80, −5.90, − 6.41
14.2	2.26, −0.07, −2.36, −5.43, − 5.69
10.6	1.82, ——, −1.75, −5.11
7.9	1.20, −0.31, −1.62, −4.90
5.8	0.74, −0.42, −1.36, −4.83
4.6	0.47, −0.42, −1.17, −4.75
0.2*	0.08, −0.51, −0.86, −4.64

* Taken from another plate.

TABLE IV

λ4144 group in electric field; p and s-components

Field		Δλ from D line in zero field
34.8 kv/cm	p:	9.72, 4.52, −0.50, −5.61, −10.01, −11.78
	s:	9.77, 7.31, 4.39, 2.47, − 2.41, − 5.38, −7.28, −10.04, −10.98
26.8	p:	7.25, 3.12, −1.02, −4.74, −8.14, −9.21
	s:	7.41, 5.54, 3.39, 1.18, −1.92, −4.52, −5.70, −7.95, −8.62
15.2	p:	4.26, 1.65, −0.74, −3.66, −5.41
	s:	4.04, 2.99, 1.57, 0.79, −1.32, −3.35, −5.02
7.0	p:	1.83, 0.48, −0.93, −3.54
	s:	1.61, 0.49, −0.78, −1.70, −3.19
3.2	p:	0.87, −0.41, −2.61

TABLE V

4009 group in electric field p and s components

Field		Δλ from D line in zero field
34.8 kv/cm	p:	( )*, 8.04, 2.53, −8.08, −9.27, −11.71, −13.17
		( )*, 7.93, 5.65, 1.73, 0.22, −4.93, −7.66, −10.00, −12.41
26.8	p:	10.24, 5.78, 1.62, −6.37, −10.29
	s:	10.48, 8.32, 6.01, 4.25, 1.61, 0.19, −3.92, −6.12, −8.15, −10.34
15.2	p:	6.01, 3.36, 0.92, −4.21, −6.48
	s:	5.75, 4.74, 3.21, 2.34, −0.09, −2.37, −6.18
7.0	p:	2.74, 1.44, 0.10, −3.64
	s:	2.62, 1.27, 0.05, −1.26, −3.17
3.2	p:	1.35, 0.86, 0.10, −2.17

* Hidden by the λ4026 group. See Fig. 3.

TABLE VI

λ3614 group in electric field; p-components only

Field	$2S-5P$	$2S-5E$	$2S-5B$	$2S-5D$
5.0 kv/cm	λ3613.62			
9.0	13.40			
12.6	13.09	λ3615.35	λ3616.85	λ3618.42
18.8	12.42	14.83	16.96	19.28
28.2	11.23	14.28	17.32	20.51
34.4	10.38	13.90	17.56	21.29

λ3927 group. These lines are here observed in an electric field for the first time. They are too weak to permit accurate measurements. Three parallel components are seen with certainty—the two outside ones, and a third with a large displacement toward the red. The arrangement is quite similar to that of the parallel components of the 4144 and 4009 groups. There are two strong central perpendicular components as in 4144. The one on the red side has a weak companion. Spaced off toward the red is a cluster of about four components of nearly equal intensity. The components on the violet side are hidden by a band.

ORTHOHELIUM

TABLE VII

λ3820 group in electric field

Field		Δλ from d line in zero field
34.8 kv/cm	p:	12.78, 6.27, 1.48, −3.28, −8.06
	s:	12.47, 5.90, 1.70, −2.21, −3.28, −6.37, −7.93
26.8	p:	11.59, 4.94, 1.19, −2.51, −6.26
	s:	11.44, 4.49, 1.28, −1.79, −2.50, −5.01, −6.10
15.2	p:	10.53, 2.98, 0.70, −1.48, −3.70
	s:	10.13, 2.24, 0.36, −1.54, −3.60
7.0	p:	1.33, 0.25, −0.88, −2.08
	s:	1.07, 0.15, −0.82, −1.75
3.2	p:	0.62, 0.09, −0.57, −1.10

TABLE VIII

λ3705 group in electric field

Field		Δλ from d line in zero field
34.8 kv/cm	p:	12.98, 3.60, −1.11, −6.29, −10.97
	s:	12.41, 9.19, 4.49, −0.05, −1.23, −4.56, −6.13, −9.13, −10.34
26.8	p:	10.63, 3.05, −0.81 −4.71 −8.66
	s:	10.16, 6.67, 3.50, 0.06, −0.78, −3.37, −4.42, −6.96, −8.45
15.2	p:	7.73, 2.09, −0.36, −2.74, −5.14
	s:	7.09, 3.62, 1.59, −0.29, −2.20, −2.78
7.0	p:	1.13, −0.10, −1.18, −2.31
	s:	1.67, 0.84, −0.13, −1.06

λ4026 group. It has been reported that the central *s*-component in this group crosses another component at a high field. The details are not easily reproduced in a half-tone, but are clear on the plate. The central undisplaced line is produced in a manner already described. Up to the maximum field here considered, it is not crossed by any visible line. The central Stark effect component is for $2p-5b$ and is displaced toward the red. Takamine has found that it crosses the undisplaced d line in very high fields. At about 20 kv/cm, however, the photograph shows a component breaking away from the $2p-5b$ component already mentioned. This phenomenon is unusual. The branch component is displaced toward the violet. A similar effect makes its appearance at a lower field in the λ4388 group, where the corresponding component is displaced toward the red.

DISCUSSION

$2P-mP$ series. It is an easy matter to pick out the lines in the series $2P-mP$. These lines were first measured by Nyquist (for $m=4,5$), and the classification was suggested by Liebert.[14] An error was made by the latter, who assumed that a strong line observed by Nyquist near λ4144 was $2P-6P$. It has been recorded as such in Fowler's tables. It is much stronger than the real $2P-6P$ which lies a little toward the violet. The observed wave-lengths of $2P-6P$ and $2P-7P$ are recorded in Table IX. These lines are affected very little by weak electric fields.

$2P-mB$ series. As Bohr has already pointed out, the calculated wave-lengths of the first two members of this series agree satisfactorily with those observed by Nyquist for the lines nearest 4922 and 4388. In the present experiments a fourth combination line is observed in the 4144 group which previously was known to contain three. This is

[14] G. Liebert, Ann. der Phys. **56,** 610 (1918)

believed to be the third member of the series $2P-mB$, and is so recorded in Table IX. With the discovery of this line, it becomes rather well established that each group of combination lines contains one more line than the preceding group. Thus while there is but one line near λ6678, the succeeding members of the diffuse series viz., 4922, 4388, and 4144 are accompanied in very low fields by 2, 3, and 4 lines respectively. Observations on the weak group 4009 are probably incomplete. In this group only four combination lines are observed with certainty.

The lines of the series $2P-mB$ are much more affected by weak fields than the members of $2P-mP$, and it is therefore difficult to get very

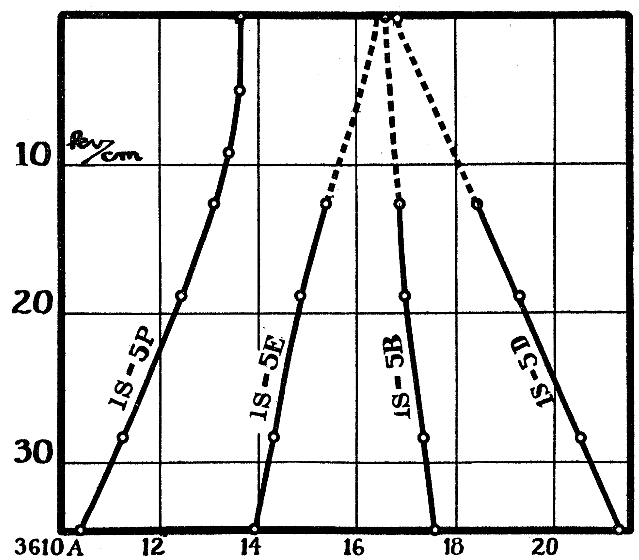

Fig. 5. λ3614 group in electric field.*

accurate measurements of the positions at zero field. Examination of the series in higher fields shows that there is a change in the direction of displacement with increasing order. The first member of the series is displaced toward the violet, whereas the second and all remaining members are displaced toward the red. Such an effect has been observed by Takamine and Kokubu[15] in the diffuse series of magnesium and by Takamine[16] in the diffuse and sharp series of copper. It is noted, also, that Kramers' theory of the connection between the fine structure and the Stark effect components in the Balmer series demands just this effect.

* In this figure "*1S*" should read "*2S*".

[15] T. Takamine and N. Kokubu, Mem. Coll. Sci. Kyoto, **3**, 173 (1918)

[16] T. Takamine, Astrophys. Journ. **50**, 23 (1919)

Since $2P-6B$ is displaced toward the red and has been measured in a field wherein the D line 4144 was displaced 0.28A, its wave-length at zero field may be estimated by deducting half this amount from the observed value. This gives 4143.65A. Tschulanowsky has measured a single line in this group, believed by him to be $2P-6B$. Its wave-length at a very weak field was found to be 4143.53. There is a strong sharp line immediately on the violet side of $2P-6B$. It is displaced toward the violet, and in high fields is nearly symmetrically opposite $2P-6B$ (see Fig. 6). It is a little less affected by electric fields than is $2P-6B$; but assuming the same correction to hold, the estimated wave-length at zero field is 4143.55. This is in good agreement with Tschulanowsky's observation at 4143.53.

In taking the lines next the D lines as members of the series $2P-mB$, one is guided not only by the calculated wave-lengths, but by the fact that with increasing order there is an increasing similarity between the Stark effects in helium and in hydrogen. On the grounds of this very great similarity, it seems allowable to select the lines for each new series in the manner suggested by Kramers' theory. In making the selections in this way, no conflict in found with experimental evidence.

$2P-mE$ and succeeding series. There is now left in the 4388 group but one unassigned line and that, on the Bohr theory, must be $2P-5E$. According to the assumed arrangement, the line next $2P-6E$ is the first member of a new series $2P-mF$. Thus the line on the extreme violet side of each group, exclusive of lines in $2P-mP$, is the initial line of a new series. When a line is missing from a group, the Stark effects should act as a guide to identify those present in the analysis.

The following wave-lengths are observed in a low field.

TABLE IX

Observed and calculated wave-lengths of combination lines $2P-mQ$

	λ(obs.)	λ(calc.)	λ(calc.) $-\lambda$(obs.)
$2P-5P$	4383.29	4383.25	-0.04
$2P-6P$	4141.34	4141.32	-0.02
$2P-7P$	4007.47	4007.74	-0.27
$2P-5B$	4387.42	4387.59	-0.17
$2P-6B$	4143.79		
$2P-5E$	4387.07		
$2P-6E$	4143.41		
$2P-6F$	4143.16		

The connections between the additional lines observed in the 4009 group and the Stark effect components are not sufficiently clear to permit one to assign them to series.

The $2S-mQ$ series. The series $2S-mS$ has been observed by Stark.[17] As only one displacement is recorded for each line, and that without specification of the polarization, it seems possible that this series may be plane polarized in agreement with the predicted nature of the corresponding series in hydrogen.

It has been noted that the parhelium groups already considered, $2P-mQ$, resemble the Balmer series in the electric field; but that certain components are missing from the helium patterns (see Figs. 4, 6, 7).

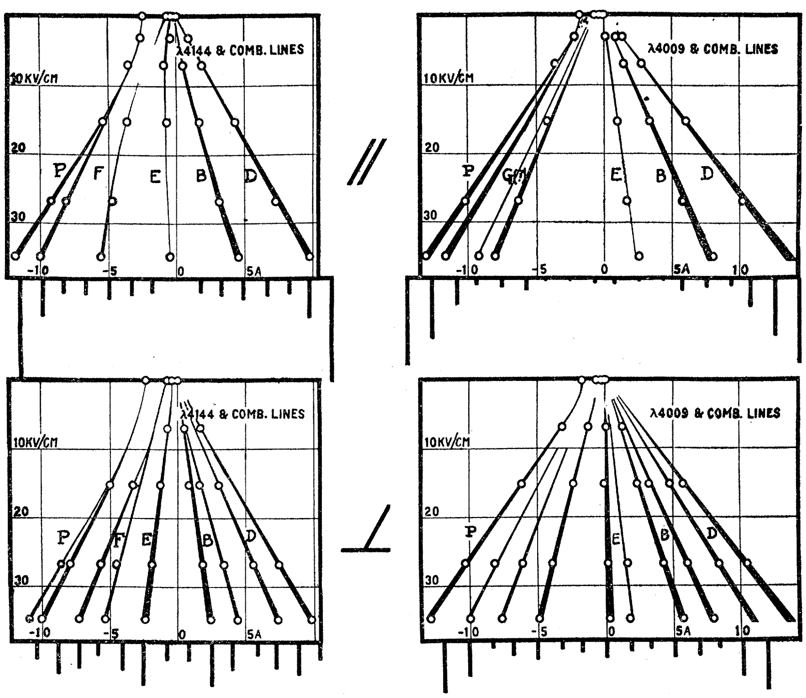

Fig. 6. Parhelium groups in electric field.

On the Bohr theory these should be associated with the lines emitted when the electron passes to the 2_1 orbit. For example, the components missing in the group 4388 (Fig. 4) should be found in the group 3614 (Fig. 5). It occurred to the writer that the very unusual curves which represent the relations between displacements and field strengths for the 4388 group made it seem probable that the new lines $2S-5Q$ might be identified by a similar set of curves. The 3614 group was therefore examined at four field strengths, and the line 3614 was measured at two lower fields where the other lines presumably were too weak to

[17] J. Stark, Ann. der Phys. **56**, 577 (1918)

affect the plate. The observations are plotted in Fig. 5. By comparison with Fig. 4, it is found that the Stark effect for each line in the 3614 group is much like that for the corresponding line in the 4388 group. While the effects are not expected to be identical, they are unusual yet similar in the two groups. It is therefore believed that the two groups have a common set of initial orbits at zero field, and the violet lines have been classified accordingly in Table VI. By extrapolation it appears that at zero field the lines $2S-5D$ and $2S-5B$ have very nearly the calculated wave-lengths.

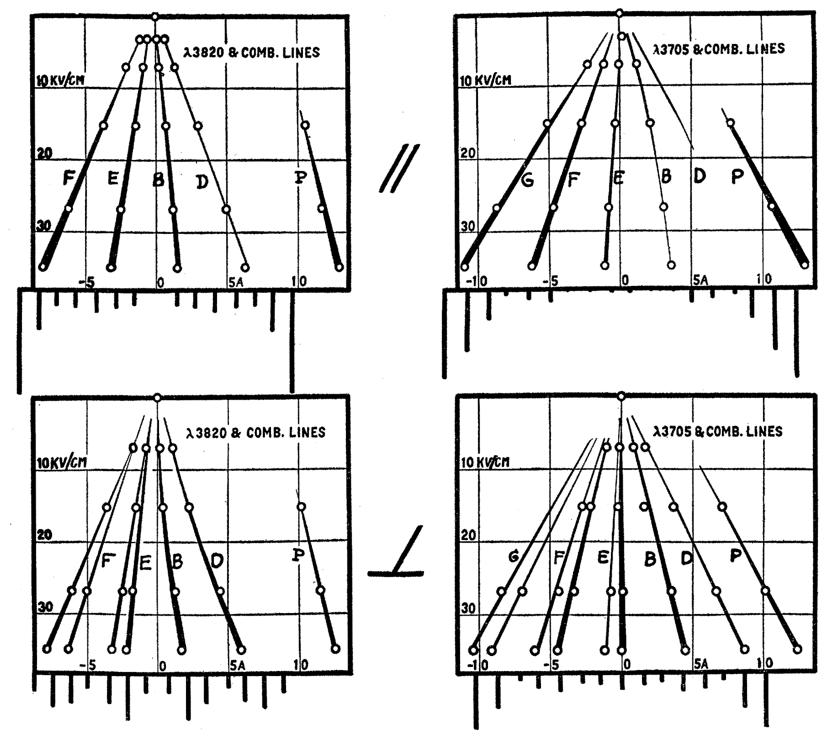

Fig. 7. Orthohelium groups in electric field.

Stark effect in parhelium. The Stark effects contributed by the two groups of lines $2S-mQ$, $2P-mQ$ ($Q=S,P,D,B,E$, etc.) combine to present in parhelium patterns analogous to those found in the Balmer series. This seems to be rather good experimental evidence that the conditions in the Balmer series are substantially those predicted by Kramers. The number of components observed to originate in a given helium line is never greater than the number predicted for the corresponding fine structure line in hydrogen. On the other hand, the number of components in helium is often less than might be expected. The separation of the components of a helium line is usually less than the separation of the corresponding components in hydrogen. It is therefore believed that in many cases more components would appear in higher fields (see $2p-5b$), or with greater dispersion. The s-component of $2p-6b$ seems double in some photographs; so does the p-component of $2P-6D$. Others may be relatively so weak that they fail to appear with those photographed.

Stark effect patterns. As a rule the observed Stark effect pattern is constant for the members of any one series of parhelium, but varies with the series. The sharp (n_1-2_2) and principal (n_2-2_1) series have but one p and one s-component. The series $2P-mQ$, $(n_{3,4,5\ldots}-2_1)$, have the same pattern. The $2P-mP$ series (n_2-2_2) is known to have two p and two s-components in the case of some lines. In others the pattern is apparently incomplete. The remaining series here considered might be expected to have two p and three s-components. The observed patterns are much simplified, however, and in many cases but one p and one s-component are found.

Vanishing components. Stark effect components which vanish or at least decrease in intensity with increasing field are rather numerous. If fact the representation of some of the new series seems to be limited, among the p-components, to a few orders. These lines do not vanish abruptly at a certain field strength. While remaining well defined, they decrease in intensity and appear to vanish at a field which varies with the exposure. As plotted in the diagrams, they are concave toward the position of the undisplaced line. Quite often the s-component is bent in the opposite direction, and the intensity increases with the field. In some photographs at least, the intensity of the p-component of $2P-6F$ passes through a minimum at a low field.

Orthohelium. As the orthohelium system is a system of doublets, one might expect to find evidence of this in the new combination lines which appear in the presence of an electric field. Tschulanowsky reports doublets near the diffuse lines 4472 and 4026. These he has classified as $2p_2-mb$ and $2p_1-mb$, $m=4,5$. The second term, as calculated from each line of the doublet, was found to vary appreciably. The wavelengths of the lines constituting the doublet near 4026 differed by 0.09A. The present photographs show two lines very near 4026. From their Stark effects, one is believed to be $2p_1-5b$ and the other $2p_1-5e$. They differ greatly as regards their behavior at high fields (see Fig. 2). At low fields they remain sharp ($2p_1-5b$ is unusually sharp) and approach one another up to the point where they become too weak to be distinguished. In a field such that Hδ has assumed twice its width at zero field, these lines are separated by 0.15A. There is no evidence of a line between them or on either side. It seems possible that Tschulanowsky's doublet may have been formed from these lines

The manner in which the doublet nature of these lines manifests itself in high fields will be described in a later paper.

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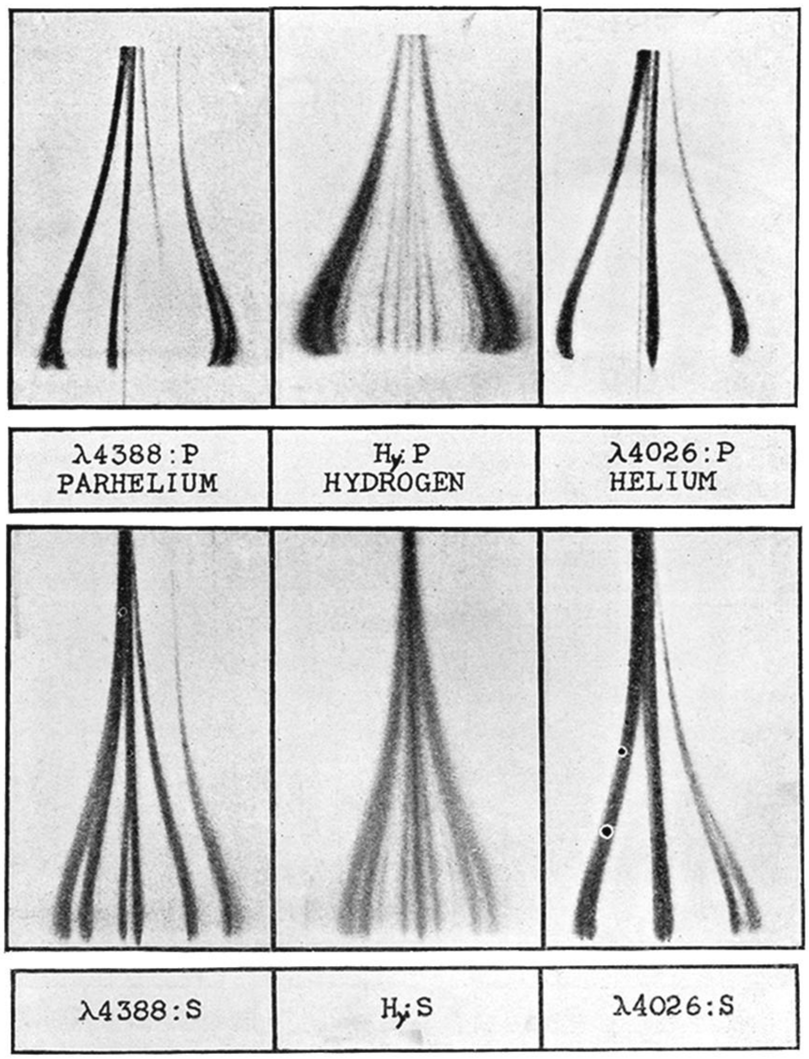

Fig. 2. From a plate taken with glass prism spectrograph. Magnification × 8.

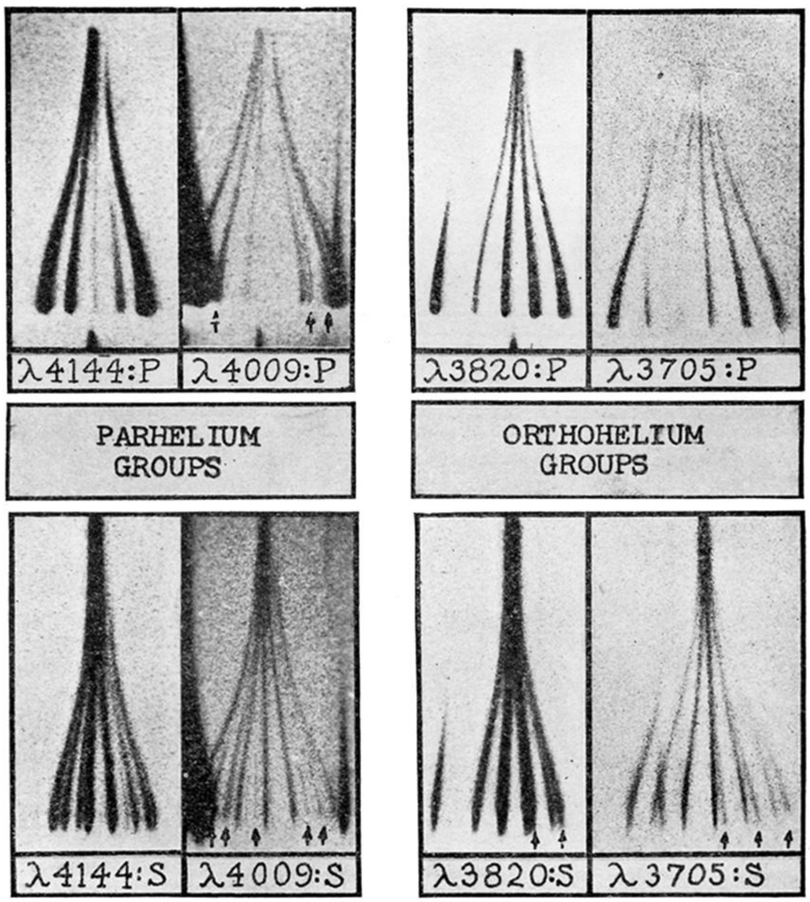

Fig. 3. From a plate taken with quartz spectrograph. Magnification × 8.