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

Part II.

By

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§ 1.

Adopting the method first employed by Lo Surdo[1], one of the present writers, in conjunction with Mr. Yoshida[2], examined the effect of an electric field on the spectrum lines of helium.

The present paper describes the results obtained by further investigations relating mainly to the more refrangible lines of helium.

The arrangement was essentially the same as in the former experiment except that a valve tube and a spark gap were inserted in series with the discharge tube in the secondary circuit of an induction coil. For the capillary portion of the discharge tube, a transparent fused silica tube was employed. Helium gas prepared by Hilger was used in the present experiment. Beside the 4 prism spectrograph mentioned in the former paper[3], a 2 prism spectrograph was constructed; for the ultra-violet part, a quartz spectrograph (size C) of Hilger was employed. An Wollaston prism of quartz, and two quartz-fluorite achromatic lenses made by Hilger, were used for projecting the image of the source on the slit of the quartz spectrograph.

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1 Lo Surdo, Rendiconti d. Lincei, **22**, 664 (1913).

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

3 T. Takamine and U. Yoshida, Mem. Coll. of Sci., Kyoto, **2**, 137 (1917).

The dispersion of these spectrographs were as follows :—

4 prism spectrograph ...... 19 Å.U. per mm. at H_γ,
2 „ „ ...... 27 Å.U. per mm. at H_δ,
Quartz spectrograph ......{16 Å.U. per mm. at $\lambda = 3000$ Å.U., 9 Å.U. per mm. at $\lambda = 2500$ Å.U.

§ 2.

Some of the photographs obtained in the present experiment are reproduced in Pl. III and IV. As in the former paper, notations p- and s-component are uesd to represent the parallel and perpendicular component respectively.

In the region examined, between λ 5200 – 2200 Å.U., 11 affected helium lines, in addition to the 9 lines reported in the former paper, were observed.

The following table contains the wave-length, series relation and the dispersion on our photographs for each line.

TABLE I.

λ in Å.U.	Series	Dispersion in Å.U. per mm.
4388	Parhelium I. N. 5	21·0 (4 Prism Spectrograph)
4169	„ II. N. 6	29·5 (2 Prism Spectrograph)
4144	„ I. N. 6	29·0 („)
4026	Helium I. N. 5	8·5 (4 Prism Spectrograph) 24·5 (2 „ „)
4009	Parhelium I. N. 7	24·0 (2 Prism Spectrograph)
3965	„ H. 4	21·5 („)
3868	Helium II. N. 6	18·0 („)
3830	Combination series, m=6.	16·5 („)
3820	Helium I. N. 6	16·0 („)
3614	Parhelium H. 5	27·6 (Quartz Spectrograph)
3448	„ H. 6	25·0 („)
2945	Helium H. 5	15·2 („)

Of the 11 lines above mentioned, Stark and Kirschbaum[1] examined 4169, 4144, 4026, 3965, 3820 and 3614. Later, the fine separation of the line 4026 was observed by Koch[2].

1 Stark and Kirschbaum, Ann. d. Phys., **43**, 1017 (1914).
2 The results obtained by Koch are noted in the monograph of Stark: „ Electrische Spectralanalyse chemischer Atome" S. Hirzel, (1914), pp. 73, 74.

Employing Lo Surdo's method, Brunetti[1] examined the lines 4144 and 4026, but no quantitative measurement seems to have been carried out.

In 1915, Koch[2] found that in strong fields a series of new lines appeared in the helium spectrum, whose frequencies could be expressed by a formula of the Ritz type :—

$$\nu = (2, p, \pi) - (m, p, \pi),$$

where

$$m = 3, 4, 5 \cdots\cdots,$$

and p, π are the series constants for the principal series. According to Koch, the calculated and the observed wave-lengths are as follows:

$\lambda_{calc.}$	in Å.U.	6068.85	4518.65	4046.30	3830.05
$\lambda_{obs.}$	,,	6060	4518.77	4046.02	—.

Now, in some of our photographs, the line λ 3830, whose existence was predicted but not observed by Koch, made its appearance; showing the same peculiarities as noted by Koch for other lines.

Here it must be mentioned that, as the spectrum we obtained is by no means pure, we cannot be sure of the origin of any new lines unless they present some peculiar features in the electric field.

In the case of the above cited line λ 3830, the displacements of the p- and s-components toward the red side, as well as the sudden increase of their intensities in strong electric field, showed at once that they are of the same type of lines as described by Koch.

In the course of measuring the photograms, we noticed that the two lines lying at λ 2804 and λ 2482 were displaced slightly toward the red side in the field $E = 60000$ volt/cm. Although there remains some doubt as to the origin of these two lines, they seem to be the mercury lines 2804.4 (I. N. I. 6) and 2482.1 (I. N. II. 6).

§ 3.

To determine the intensity of the electric field, Stark's data for H_γ line were relied on, as in the case of former experiments.

In the following we give detailed accounts for each of the lines mentioned above.

Figs. 1, 2, 3, 4 and 5 (Pl. I) illustrate the mode of separation of

1 Brunetti, Rendiconti. d. Lincei, **24.** (1), 719 (1915); **24,** (2), 55 (1915).

2 Koch, Ann. d. Phys., **48,** 98 (1915).

the lines λ 4144, 4026, 4009, 3820 and 4388 respectively, The results obtained by Stark are marked by asterisks on Figs. 2, 4 and 5.

(1) λ : 4144. (Pl. I, Fig. 1)

The amounts of displacement from the initial line and the roughly estimated intensities of different components at the maximum electric field applied ($E_{max.}$), are tabulated below.

TABLE II.

λ : 4144

$E_{max.} = 60000$ volt/cm.

p-component.

	v_3	v_2	v_1	r_1	r_2
$\delta\lambda$ in Å.U.	−17·5	−7·0	−0·8	5·0	15·4
Intensity	2	4	10	7	4

s-component.

	v_3	v_2	v_1	r_1	r_2
$\delta\lambda$ in Å.U.	−14·0	−5·4	−1·2	5·1	13·4
Intensity	2	8	6	10	4

Thus we have 5 p- and 5 s-components, while Brunetti gives 6 components of which 3 are non-polarised. Stark states that there are at least 4 p- and 4 s-components for this line.

As shown in Pl. I, Fig. 1, the outermost component on the violet side is, so to speak, *isolated* from the initial line. The occurrence of these isolated components has already been noticed in the former paper for the two preceding members of this series (Parhelium I. N. S.), namely λ 4922 and λ 4388. As will be shown later, this remarkable phenomenon may be regarded as a characteristic feature of the diffuse series lines of both helium and parhelium. The appearance of the isolated component is best shown in Pl. III, Fig. 7 for the line λ 4388.

(2) λ : 4026. (Pl. I, Fig. 2).

This line is a member of a doublet series; and according to

Runge and Paschen, we have 4026.512 (intensity 1) and 4026.342 (intensity 5).

TABLE III.

λ : 4026

$E_{max.} = 57000$ volt/cm.

p-component.

	v_3	v_2	v_1	r_1	r_2
$\delta\lambda$ in Å.U.	−10·6	−7·6	−1·7	5·6	7·4
Intensity	3	6	10	8	2

s-component.

	v_3	v_2	v_1	r_1	r_2
$\delta\lambda$ in Å.U.	−8·3	−6·4	−1·2	5·6	8·4
Intensity	3	6	10	8	2

For this line Brunetti gives 3 components, all being non-polarised. Stark, however, gives 3 p- and 3 s-component, of which only the central component shows the same amount of displacement. In Stark's monograph[1], it is stated that Koch observed 4 p- and 6 s-components.

In our study, there are 5 p- and 5 s-components, in each of which the two violet components are isolated, and start from a point lying at about E = 5000 volt/cm., and $\Delta\lambda = -1.1$ Å.U. Here it must be remarked, however, that, for the diffuse series lines of helium, the appearance of the isolated component is not so markedly shown as in the case of parhelium.

In the former experiment, it was noted that the central s-component of the line λ 4388 was apparently displaced about 0.3 Å.U. toward the violet at E = 20000 volt/cm. A quite similar behaviour of the central component was observed for the line under consideration. The reproduction (Pl. IV, Fig. 8) will show the discontinuity in the central line. A more complete study will be necessary to determine the transition state of this central component. As a possible cause of this feature, we may remark that the presence of the neighbouring line λ 4024.1 (Parhelium II. N. S. 7) may affect the appearance of the line under consideration.

[1] Stark, „Electrische Spectralanalyse chemischer Atome“ Leipzig. S. Hirzel, (1914).

Here it is to be remarked that in the measurement of the lines, as shown in Figs. 8 and 9, the correction due to the curvature of the lines was always taken into account.

(3) λ : 4009 (Pl. I, Fig. 3).

So far as we are aware, the electric effect on this line has not hitherto been observed. Owing to its feeble intensity, there was much difficulty in measuring the amounts of separation.

TABLE IV.

λ : 4009

$E_{max.} = 31500\ ^{volt}/_{cm.}$

p-component.

	v_2	v_1	r_1'	r_2
$\delta\lambda$ in Å.U.	−11·2	−2·5	6·0	10·3
Intensity	5	2	10	3

s-component.

	v_3	v_2	v_1	r_1	r_2
$\delta\lambda$ in Å.U.	−10·3	−4·0	−0·6	5·2	9·0
Intensity	5	3	2	10	3

Although in the reproduction (Pl. III, Fig. 6) the line appears only very faintly, yet under the microscope we could observe an isolated component on the violet side for both of the p- and s-component.

(4) λ : 3820 (Pl. I, Fig. 4).

For this line we have only the data given by Stark and Kirschbaum[1] who observed 4 p- and 4 s-components. As shown in Fig. 4, our results agree quite well with those of Stark.

1 Stark and Kirschbaum, loc. cit.

TABLE V.

λ : 3820

$E_{max.} = 60000$ volt/cm.

p-component.

	v_2	v_1	r_1	r_2
$\delta\lambda$ in Å.U.	−11·8	−4·3	4·2	10·2
Intensity	2	8	10	4

s-component.

	v_2	v_1	r_1	r_2
$\delta\lambda$ in Å.U.	−10·8	−3·0	2·6	10·5
Intensity	2	8	10	4

In Fig. 4 it will be seen that the outermost violet component is displaced to an extent greater than the corresponding red component. It is, we think, very probable that we have here also an isolated component, but its starting point is too close to the initial line to be seen separately. The next member λ 3705, observed by Stark and Kirschbaum, was too faint on our photographs.

(5) λ : 4169, 3965 (Pl IV, Fig. 9), 3868, 3614. 3448, 2945 (Pl. IV, Fig. 10).

All these lines are only displaced either toward the red or toward the violet in the electric field.

The results of our measurement are tabulated below.

TABLE VI.

λ in Å.U.	E in 10^4 volt/cm.	δλ in Å.U. p-comp	δλ in Å.U. s-comp.	Remark
4169	1·60	+0·9	+1·0	Stark gives
	2·30	+1·6	+1·5	$\delta\lambda_p$... +1·78 at E=2.85
	3·20	+1·8	+1·7	$\delta\lambda_s$ ... +1·60 at E=2.85
	5·70	+3·6	+3·6	
3965	1·60	−0·6	−0·4	Stark gives
	2·25	−0·8	−0·5	$\delta\lambda_p$ ... −0·40 at E=2.85
	3·15	−1·3	−0·8	$\delta\lambda_s$ ... −0·31 at E=2.85
	5·75	−2·0	−2·0	
3868	3·90	+0·3	+0·4	
	5·00	+0·5	+0·5	
	6·00	+0·6	+0·6	
3614	3·55	−2·6	−3·2	Stark gives
	5·00	−4·4	−4·2	$\delta\lambda_p$... {+0·67, −2·31} at E=2·85
	6·00	−6·6	−4·4	$\delta\lambda_s$... {+0·66, −1·82} at E=2·85
3448	2·00	−3·6	−3·0	
	3·85	−5·6	−4·4	
	5·70	−6·4	−7·6	
2945	2·00	+0·5	+0·5	
	3·30	+1·0	+0·9	
	5·70	+1·3	+1·5	

(6) λ : 4388 (Pl. I, Fig. 5).

This line has already been studied in the experiment by one of the present writers with Mr. Yoshida[1]. Here we give only the results of measurement on the photograph obtained in the present experiment which showed a greater number of components for this line.

[1] T. Takamine and U. Yoshida, Mem. Coll. of Sci. Kyoto, **2**, 325 (1917).

TABLE VII.

λ : 4388

$E_{max.} = 32000$ volt/cm.

p-component.

	v_3	v_2	v_1	r_1	r_2	r_3
δλ in Å.U.	−10·2	−8·4	−4·4	0·8	5·3	7·8
Intensity	3	8	4	10	8	2

s-component.

	v_4	v_3	v_2	v_1	r_1	r_2	r_3
δλ in Å.U.	−9·7	−8·2	−4·4	−0·4	4·0	5·7	8·6
Intensity	1	3	5	10	5	5	2

(7) λ : 3830

As stated above, the position of this line was calculated by Koch, using Ritz's formula. In our photograph we observed that both the p- and s-components of this line are displaced about 0.5 Å.U. toward the red at $E=3.15 \times 10^4$ volt/cm.

§ 4.

In order to get a glance at the modes of separation of all the helium and parhelium lines hitherto investigated, diagrams were drawn as shown in Pl. II.

In the column giving wave-lengths in Å.U., the lines marked by asterisks were measured in the former experiment by one of the present writers with Mr. Yoshida[1], and those in rectangles are perhaps observed for the first time.

On examining the diagrams given in Pl. II., we notice the following facts :—

1). There are three different types of electric effect on helium lines, namely

a. Symmetrical decomposition, as shown by the line λ 4686 Å.U.

b. Non-symmetrical decomposition, as shown by the lines belonging to the diffuse series of helium and parhelium.

[1] T. Takamine and U. Yoshida, Mem. Coll. of Sci., Kyoto, **2**, 325 (1917).

c. One-sided displacement, as shown by the lines belonging to the principal and sharp series of helium and parhelium.

2). Of the lines showing the one-sided displacement, only those belonging to the principal series of parhelium are displaced toward the violet side.

3). The lines belonging to the diffuse series are usually accompanied by an isolated component on the violet side.

4). The starting point of the isolated component, which is marked by a small circle in the figure, approaches more and more to the initial line as the term number of the line in the series increases.

If we denote the distance of the starting point of the isolated component from the initial line by $\Delta\lambda$, we have the data as shown in Table VIII.

TABLE VIII.

Diffuse Series of Helium				
Term number	λ in Å.U.	Δλ in Å.U.		
		p-comp.	s-comp.	Mean
4	4472	−1·6	−1·6	−1·6
5	4026	−1·2	−1·0	−1·1

Diffuse Series of Parhelium				
Term number	λ in Å.U.	Δλ in Å.U.		
		p-comp.	s-comp.	Mean
4	4922	−13·0	−13·2	−13·1
5	4388	− 4·6	− 5·2	− 4·9
6	4144	− 3·2	− 2·8	− 3·0
7	4009	− 2·0	− 2·0	− 2·0

So far as our experiment is concerned, the field strength at which the isolated component first appears is of the order of several thousands volt per cm.

5). Stark remarks that for the lines belonging to the sharp series, helium lines are less affected than those of parhelium. In the present experiment, the same feature was observed also for the lines of principal series and diffuse series.

6). Former investigation of Stark and Kirschbaum[1], and also that of Lüssem[2], have shown that, in the electric effect on helium and lithium lines, the amount of displacement of the diffuse series lines increases as the term number increases. In the present experiment,

1 Stark and Kirschbaum, loc. cit.

2 Lüssem, Ann. d. Phys., **49**, 865 (1916).

this relation was found to hold good even for the higher members of these series in the helium spectrum.

7). For the lines of helium and lithium, Stark remarked that the decomposition of the p-component is generally a little greater than that of the s-component. This was found to be true for most lines examined in the present experiment.

It may be remarked here that, as the amount of displacement differ only slightly for p- and s-component, it is very likely that they might be mistaken for "non-polarised," when examined with a spectroscope having a small dispersion.

Summary.

1. Adopting Lo Surdo's method, the effect of an electric field on the ultra-violet spectrum lines of helium has been investigated.

In addition to the 9 lines λ 5048, 5016, 4922, 4686, 4519, 4472, 4438, 4388 and 4121 examined in the previous experiment, the electric effect on the following 11 lines has been observed in the fields lying between 3000 to 70000 volt/cm.

λ: 4169, 4144, 4026, 4009, 3965, 3868, 3830, 3820, 3614, 3448, 2945.

The results have been compared with those of Stark, Brunetti and Koch.

3. It has been found that there are three different ways in which helium lines are affected by an electric field, namely:—

(i). Symmetrical decomposition (λ 4686 line).

(ii). Non-symmetrical decomposition (Diffuse series lines of helium and parhelium.)

(iii). One-sided displacement (Principal series lines and sharp series lines of helium and parhelium). Of (iii), only the lines belonging to the principal series of parhelium are displaced toward the violet side, while the other three series lines are all displaced toward the red side.

4. Diffuse series lines are usually accompanied by an isolated component on the violet side, whose starting point approaches nearer and nearer to the initial line as the term number increases.

5. The line λ 3830, whose position was calculated by Koch, but not observed by him, appeared in some of the photographs taken in the present experiment.

Beside the helium lines mentioned above, two lines at λ 2804 and λ 2482 Å.U., probably due to mercury, were found to be displaced slightly toward the red in the electric field.

In conclusion the writers wish to express their hearty thanks to Professor T. Mizuno for his interest in the work.

Fig. 1. λ: 4144

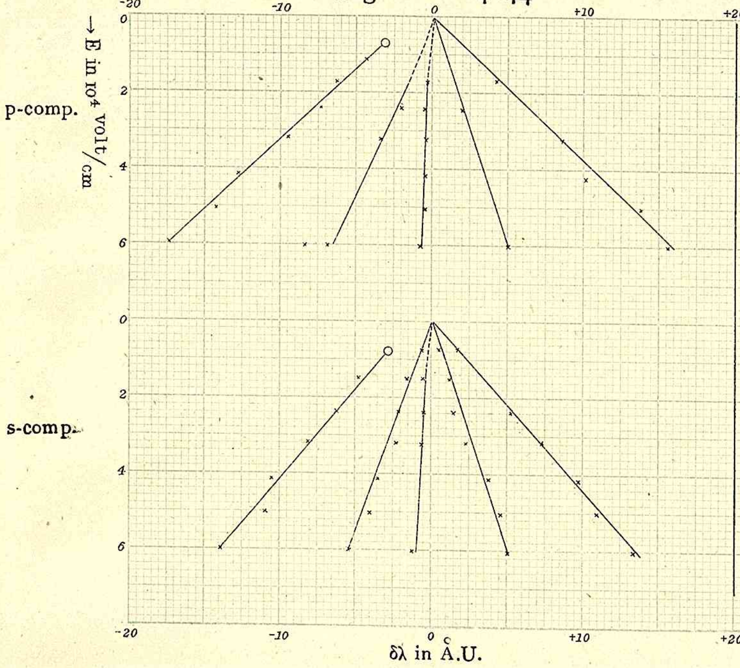


Fig. 2. λ: 4026

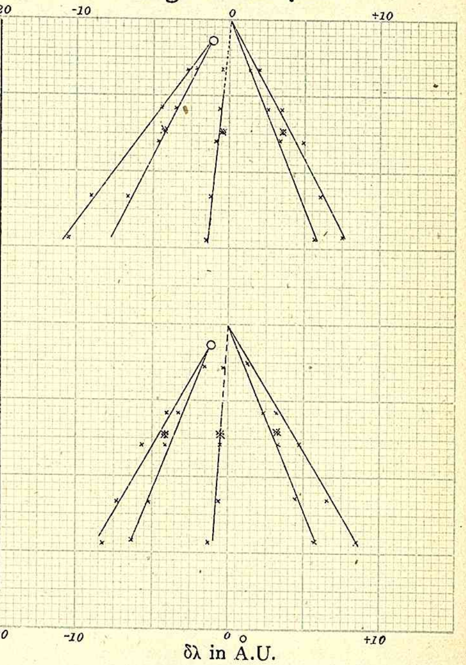


Fig. 3. λ: 4009

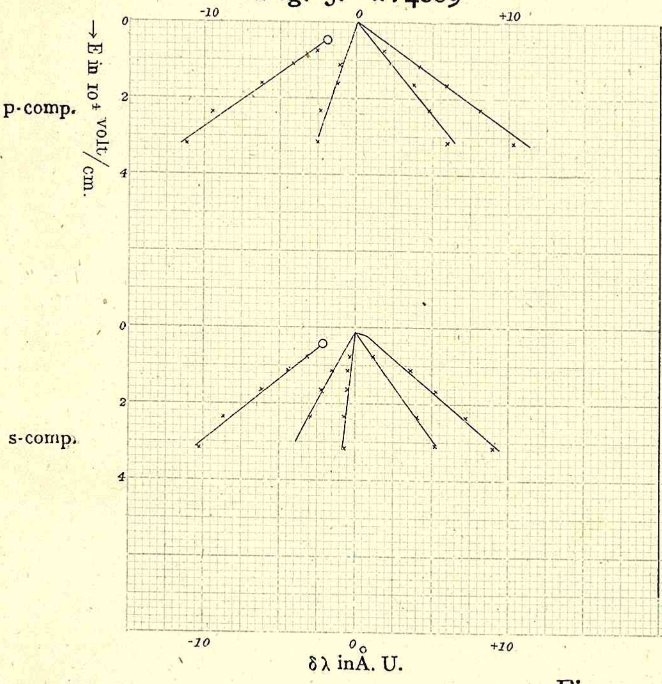


Fig. 4. λ: 3820

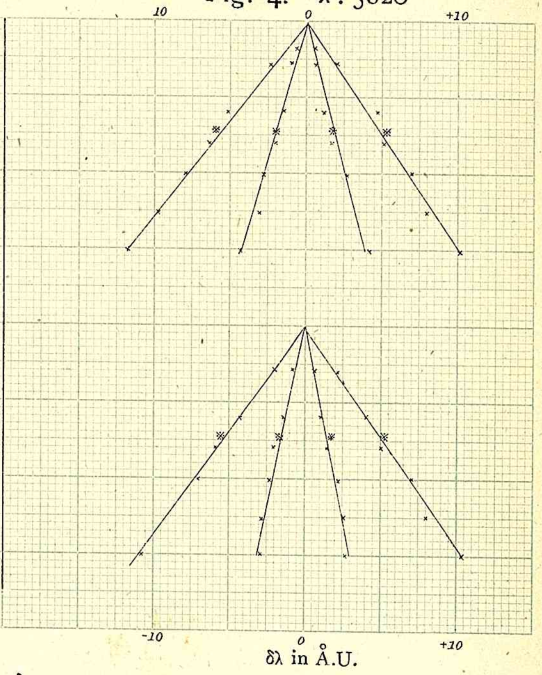
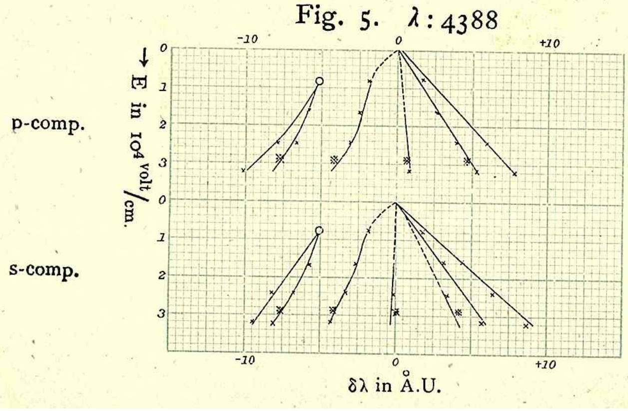
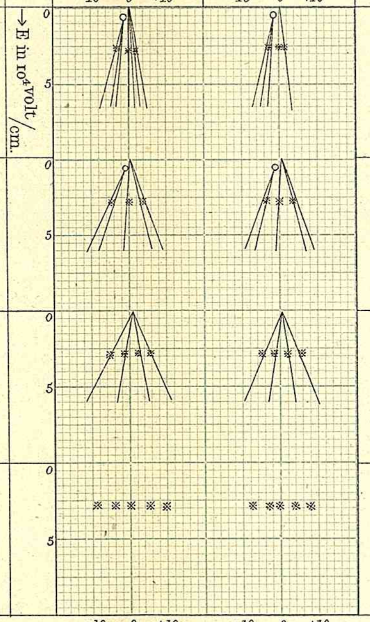
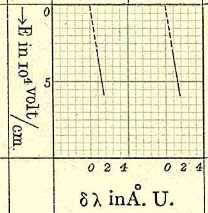
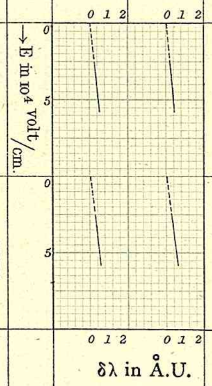


Fig. 5. λ: 4388

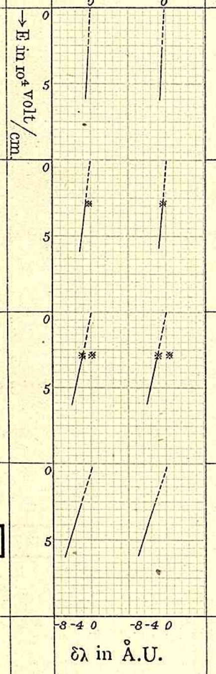
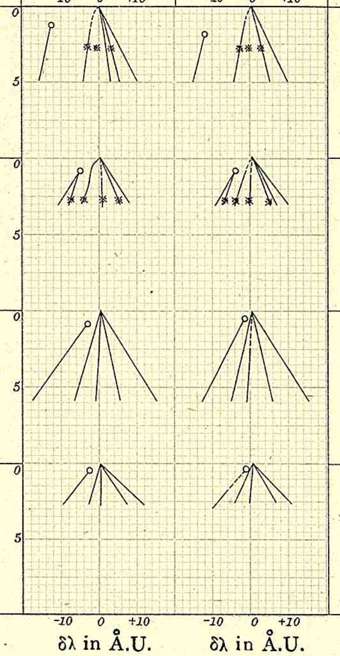
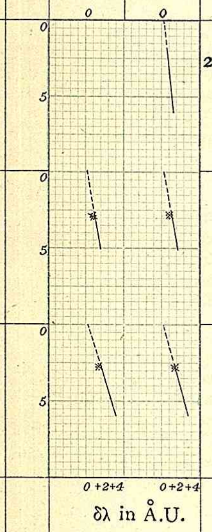


*......Observed by Stark and Kirschbaum.

HELIUM

Term number	Principal Series λ in Å.U.		p-comp.	s-comp.	Diffuse Series (I. N. S.) λ in Å.U.		p-comp.	s-comp.	Brunetti's observation	Sharp Series (II. N. S.) λ in Å.U.		p-comp.	s-comp.	Brunetti's observation
3	3888.8				5876.2 (Intensity 1) **5875.9** (Intensity 10)		Stark gives: $\delta\lambda = +0.14$ Å.U. E = 2.85 × 10^4 volt/cm.	Stark gives: $\delta\lambda = +0.09$ Å.U. E = 2.85 × 10^4 volt/cm.	First line 1 comp λ_1: nonpolarised λ_2; polarised ⊥ Second line 2 comp. λ_1: nonpolarised λ_2; polarised ⊥	7066·0 (1) **7065.5** (5)				
4	3187.8				4471·9 (1) **4471.6*** (6)	→ E in 10^4 volt/cm.			2 comp. λ_1: nonpolarised λ_2: „	4713·5 (1) **4713.3** (3)				2 comp. λ_1: nonpolarised λ_2: polarised ⊥ ?
5	**[2945.2]**	→ E in 10^4 volt/cm			4026·5 (1) **4026.3** (5)				3 comp. λ_1 nonpolarised λ_2 „ λ_3 „	4121·1 (1) **4121.0*** (3)	→ E in 10^4 volt/cm.			
6			δλ in Å. U.		3819·9 (1) **3819.8** (4)					3867·8 (1) **[3867 6]** (2)				
7					3705·3 (1) **3705.2** (3)							δλ in Å.U.		
							δλ in Å.U.	δλ in Å.U.						

PARHELIUM

Term number	Principal Series λ in Å.U.		p-comp.	s-comp.	Brunetti's observation	Diffuse Series (I. N. S.) λ in Å.U.		p-comp	s-comp.	Brunetti's observation	Sharp Series (II. N. S.) λ in Å.U.		p-comp.	s-comp.	Brunetti's observation
3	5015.7*	→ E in 10^4 volt/cm			2 comp. λ_1: polarised // λ_2: polarised ⊥	6678.4		Stark gives: $\delta\lambda = +0.44$ Å.U. E = 2.85 × 10^4 volt/cm.	Stark gives: $\delta\lambda = +0.34$ Å.U. E = 2.85 × 10^4 volt/cm.	3 comp. λ_1: nonpolarised λ_2: „ λ_3: „	7281.8				
4	3964.9					4922,1*				4 comp. λ_1: nonpolarised λ_2: polarised ⊥ λ_3: nonpolarised λ_4: „	5047.8*				2 comp. λ_1: nonpolarised λ_2: „
5	3613.9					4388.1*				5 comp. λ_1: nonpolarised λ_2: polarised ⊥ λ_3: nonpolarised λ_4: polarised ⊥ λ_5: nonpolarised	4437·7*				
6	[3447·7]					4143·9				6 comp. λ_1: nonpolarised λ_2: polarised ⊥ λ_3: nonpolarised λ_4: polarised ⊥ λ_5: „ λ_6: nonpolarised	4169·1				
7			δλ in Å.U.			[4009.4]							δλ in Å.U.		
								δλ in Å.U.	δλ in Å.U.						

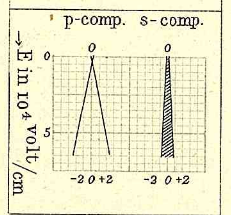
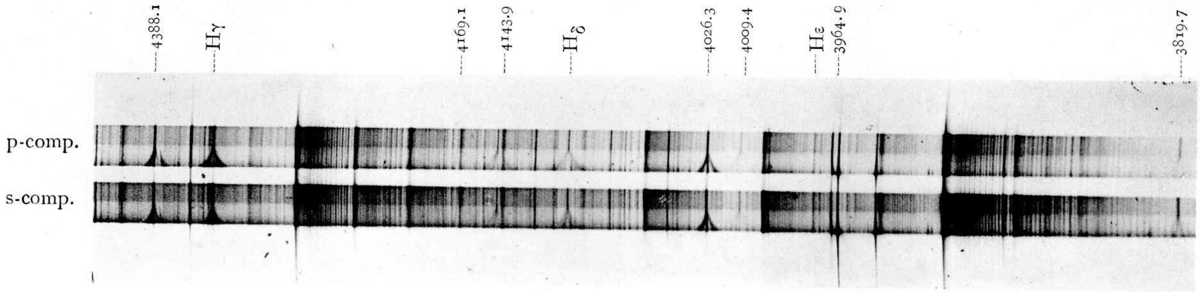
λ: 4686 Å.U.*	
p-comp.	s-comp.
	

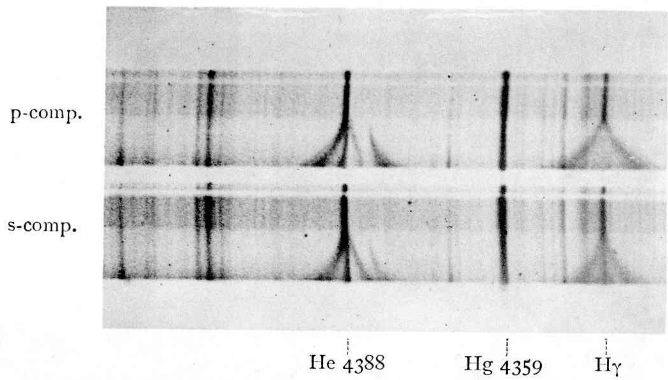
Fig. 6.



Magnification : 6

$E_{max.}$: 3.15×10^4 volt/cm
Exp. : 1^h 40^m
Spectrograph : 2 prism.

Fig. 7.



Magnification : 14

$E_{max.}$: 3.15×10^4 volt/cm.
Exp. : 1^h 40^m
Spectrograph : 4 prism.

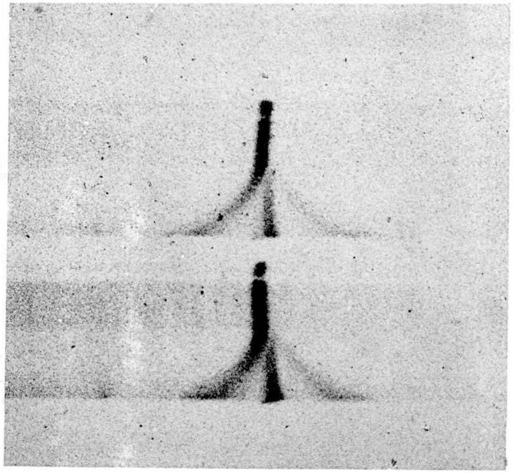
Fig. 8.

λ : 4026

$+\delta\lambda \leftarrow 0 \rightarrow -\delta\lambda$

p-comp.

s-comp.



Magnification : 18

$E_{max.}$: 3.15×10^4 volt/cm.
Exp. : 1^h 40^m
Spectrograph : 4 prism.

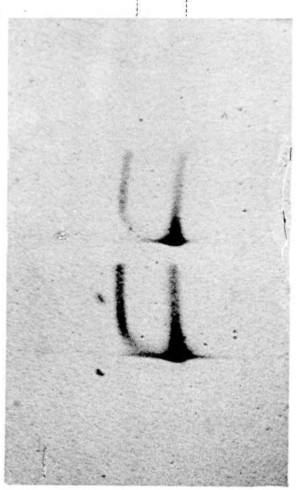
Fig. 9.

λ : 3965

He 3965
Al 3962

p-comp.

s-comp.



Magnification : 13

$E_{max.}$: 5.7×10^4 volt/cm.
Exp. : 1^h 40^m
Spectrograph : 4 prism.

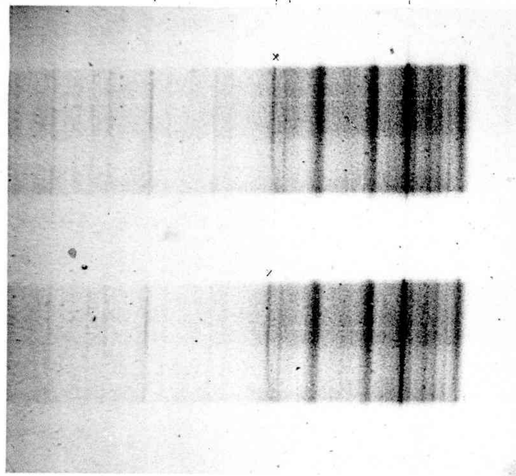
Fig. 10.

λ : 2945

Hg 2925
He 2945
Hg 2947
Hg 2967

s-comp.
...End of the dark space
...Cathode

p-comp.
...End of the dark space
...Cathode



Magnification : 12

$E_{max.}$: 6.0×10^4 volt/cm.
Exp. : 1^h 30^m
Quartz spectrograph.