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

By

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(Received June 15, 1917.)

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§ 1.

In a recently published paper[1], the writers reported an investigation of the Stark effect of hydrogen lines by means of Lo Surdo's[2] method. With the same experimental arrangements, the research has been extended to the case of helium.

In a series of researches Stark examined the electric effect on a large number of helium lines. Former investigations, of Stark and others, relating to this phenomenon are collected in Stark's monograph[3]; and it is stated therein that the finer separations of helium lines were observed by Koch. So far as we are aware, however, the detailed account of the investigation by Koch is not yet published, so that we have at present only the data relating to the number of parallel (p) and perpendicular (s) components of the three helium lines λ 4922, 4388, 4026 Å.U. at the field of 10^5volt/cm.

Lo Surdo's method was first applied to the case of helium by Brunetti. In his first paper[4], the modes of decomposition of six helium lines 5048, 4922, 4472, 4388, 4144 and 4026 were examined by means

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1 Mem. Coll. Sci., **2**, 137 (1917).

2 Rendiconti d. Lincei, **22**, 664 (1913).

3 Electrische Spectralanalyse chemischer Atome, Leipzig: S. Hirzel, (1914).

4 Rendiconti d. Lincei, **23**, 719 (1914).

of a prism spectrograph. In the second experiment[1], Brunetti employed an echelon grating of 12 plates to reveal the behaviour of lines which were very slightly affected by an electric field. In both cases, sketches are given to show the mode of decomposition of different lines; but it is to be regretted that in these figures, p- and s-components are not separately given and further, that no quantitative measurement is attempted.

Lo Surdo's method was also employed by Evans and Croxson[2] to examine the helium line λ 4686 Å.U.; but, so far as their preliminary report is concerned, they observed merely the broadening of this line.

Using a field of 10^5volt/cm., Koch[3] found that a series of new lines λ 6060, 4519, 4046 Å.U. appeared in the helium spectrum which could be expressed by a formula of Ritz type. According to Koch, the positions as well as the intensities of these lines depend on the strength of the electric field employed.

§ 2.

The method of the present experiment was the same as described in our former paper, with the exception of a few minor points.

The helium gas was obtained by heating powdered thorianite mineral mixed with double the quantity of $KHSO_4$.

The discharge tube was first filled with hydrogen; and, after it was highly evacuated by a Gaede pump, a combustion tube containing the mixture of thorianite and $KHSO_4$ was slowly heated by a Bunsen burner. The evolved helium gas was passed through two glass tubes containing KOH and P_2O_5 respectively. When the pressure in the discharge tube was reduced until the length of the Crookes dark space became about 2 mm., the side tubes were sealed. The inner diameter of the hard glass capillary tube was in most cases about 1.7 mm., and a current of about 1 milliampere was passed through the secondary circuit.

The cathode disintegration was much heavier than in the case of hydrogen, so that in most cases the exposure was about one hour.

The spectrum obtained was by no means pure; and, beside the hydrogen lines, the band spectrum of CO and certain lines of Al, Hg

1 Rendiconti. d. Lincei, **24**, 55 (1915).
2 Phil. Mag., **32**, 327 (1916).
3 Ann. d. Phys., **48**, 98 (1915).

also made their appearance. The presence of hydrogen lines was, however, convenient for determining the field intensity.

§ 3.

One of the photographs obtained is reproduced in Fig. 1, Pl. I. In the region examined, between λ 5200–4100 Å.U., seven affected lines belonging to the ordinary helium and parhelium spectra 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.
5048	Parhelium II. N. 4	41·0
5016	„ H. 3	41·0
4922	„ I. N. 4	40·0
4472	Helium I. N. 4	18·6
4438	Parhelium II. N. 5	16·8
4388	„ I. N. 5	15·0
4121	Helium II. N. 5	8·0

Beside the above lines, the definite separation in the p-component of the line λ 4686 Å.U., and also the appearance of one of the lines found by Koch, at λ 4519 Å.U. were observed.

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

In the following we give detailed accounts for each of the lines above mentioned. It is to be remarked that in all the sketches illustrating the mode of separation (Figs. 2, 3, 4, and 5), we cannot be sure of those parts designated by broken lines. The results obtained by Stark are marked on these figures by asterisks.

(1) λ : 4922 (Fig. 2).

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.

$E_{max.} = 4{\cdot}88 \times 10^4$ volt/cm.

p-component.

	v_2	v_1	o (Initial line)	r_1	r_2	r_3
$\delta\lambda$ in Å.U.	−15·70	−4·10	o	+2·26	+5·13	(+7·41 at $E = 3{\cdot}89 \times 10^4$ volt/cm.)
Intensity	6	7	2	2	10	(3)

s-component.

	v_2	v_1	o	r_1	r_2
$\delta\lambda$ in Å.U.	−15·50	−4·48	o	+4·60	+8·00
Intensity	5	8	3	10	3

Thus we have 6 p- and 5 s-components, including the faint initial line, while Brunetti gives four components of which three are non-polarised. Of the three points given by Stark for both of the p- and s-components, that lying at −0.8 Å.U. is marked as questionable. In our study, the presence of the faint line at the initial position may have been due to incomplete rectification of the secondary current in the induction coil.

In Stark's monograph it is stated that Koch obtained 7 p- and 7 s-components for the line under consideration, in which two of the latter are doubtful.

As shown in the figure, all the red side components start from the initial line and are displaced proportionally to the intensity of the electric field. On the violet side, one component is, so to speak, enentirely isolated, and the other is displaced toward the violet more slowly than is proportional to the field strength.

The isolated component first appears at the field strength of about 15000 volt/cm, as is shown by a small circle in the figure, and gradually gains in its intensity as the field strength is increased.

As will be shown later, the line 4388 is also accompanied by such a component. This phenomenon has already been recorded, in both cases, in one of the papers of Brunetti[1] above cited.

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1 Rendiconti d. Lincei, **23**, 719 (1914).

(2) λ : 4472 (Fig. 4).

This line is a member of doublet series; and, according to Runge and Paschen, we have λ 4471.858 (intensity 1) and λ 4471.646 (intensity 6).

TABLE III.

$E_{max.} = 6{\cdot}65 \times 10^4\ ^{volt}/_{cm.}$

p-component.

	v_3	v_2	v_1	o	r_1	r_2	r_3
$\delta\lambda$ in Å.U.	−7·89	−5·70	−3·48	0	+1·42	+4·09	+5·08
Intensity	3	7	1	4	2	10	3

s-component.

	v_3	v_2	v_1	o	r_1
$\delta\lambda$ in Å.U.	−7·50	−5·30	−2·84	0	+3·72
Intensity	3	7	2	5	10

For this line Brunetti records only two components; and Stark gives 3 p- and 3 s-components. In our photograph we could observe 7 p- and 5 s-components, including the initial line; but, owing to over-exposure, the detail is not clearly shown in the reproduction.

In both the p- and the s-components, there is a remarkable feature: the three violet components all start from a point corresponding to about $E=0.5 \times 10^4$volt/cm, and $\delta\lambda=-1.3$ Å.U., which is marked by a small circle in Fig. 4.

The disproportionality between the amount of separation and the field strength noted by Stark for this line (Compare Fig. 11 in the monograph of Stark), may be accounted for if we take the above phenomenon in consideration.

According to Paschen and Back[1], the line under consideration is in ordinary state accompanied by a satellite on the violet side. We think, the existence of a satellite must not be overlooked in the present case.

[1] Ann. d. Phys., **39**, 897 (1912).

(3) λ: 4388 (Fig. 5).

For this line Stark found 4 p- and 4 s-components; and Koch, in the case of "Feinzerlegung," observed 7 p- and 6 s-components; while Brunetti noted 5 components of which three were unpolarised. We obtained 6 p- and 5 s-components, including the initial line, as shown in the following table.

TABLE IV.

$E_{max.} = 6{\cdot}65 \times 10^4$ volt/cm.

p-components.

	v_2	v_1	o	r_1	r_2	r_3
$\delta\lambda$ in Å.U.	$-16{\cdot}70$	($-4{\cdot}3$ at E= $2{\cdot}85 \times 10^4$ volt/cm.)	0	$+2{\cdot}74$	($+3{\cdot}65$ at E= $5{\cdot}53 \times 10^4$ volt/cm.)	$+11{\cdot}3$
Intensity	8	(4)	6	8	2	10

s-component.

	v_2	v_1	o	r_1	r_2
$\delta\lambda$ in Å.U.	$-14{\cdot}40$	$-8{\cdot}20$	$-0{\cdot}3$	$+2{\cdot}70$	$+9{\cdot}20$
Intensity	5	4	10	2	6

As may be seen in Fig. 5, the mode of decomposition of this line is similar to that of λ 4922. The isolated components on the violet side first appear near the point corresponding to E = 9000 volt/cm and $\delta\lambda = -4.3$ Å.U.

In the s-components the initial line shows a curious behaviour, being displaced about 0.3 Å.U. toward the violet side at the field of 2×10^4 volt/cm., and thence remaining unaffected in stronger fields.

In connection with this, it is desirable to note that in the experiment of Paschen and Back[1] relating to the Zeeman effect of helium lines, they state as follows:—

"The line λ 4388·100 Å.U. has no satellite in the natural state, but in the magnetic field, a satellite appears at λ 4387·6 Å.U."

Further, it may worthy of note that the violet component lying

1 Ann. d. Phys., **39**, 897 (1912).

nearer to the initial line becomes more and more faint as the field strength is increased, quite contrary to the cases generally observed.

The new appearance of a component at a certain field strength may mean the rise of new electronic vibration. The phenomena were observed for all the three lines λ 4922, 4472, and 4388. The case of 4472 is peculiar in that the new component is split up into three as the field intensity is increased. We believe that these phenomena may have an important bearing on the theory of the atom.

(4) λ 5048, 5016, 4438, 4121.

All these four lines are only slightly displaced either toward the red or toward the violet by the electric field.

The results of our measurements are tabulated below.

TABLE V.

λ	p-component		s-component	
	$\delta\lambda$ in Å.U.	E in 10^4 volt/cm.	$\delta\lambda$ in Å.U.	E in 10^4 volt/cm.
5048			+1·5	6·65
5016	−1·0	6·65	−0·8	6·65
4438	+2·10	4.88	+2·00	4·88
	+1·30	3·82	+1·04	3·82
	+0·69	2·92	+0·61	2·96
	(+0·80)*	(2·85)	(+0·71)	(2·85)
4121	+0.71	5·70	+0·74	5·70
	+0·51	4·80	+0·52	4·80
	+0·34	4·00	+0·39	4·00

Of the four lines, Stark examined only the line 4438; while Brunetti obtained two components for 5048 and for 5016.

It may be remarked that the effect on the line 4121, which belongs to the second subordinate series of helium, was perhaps observed for the first time. As in the case of 4472, the line 4121 is a close doublet; and according to Runge and Paschen we have 4121.143 (intensity 1) and 4120.973 (intensity 3).

The manner in which those helium lines, 4438 and 4121, are

* Numbers in brackets are those given by Stark.

affected by the electric field is somewhat analogous to that of certain secondary spectrum lines of hydrogen.

(5) λ: 4686 (Fig. 3), (Dispersion 25·7 A.U. per mm.)

The behavior of this line in an electric field is of special interest. Although the presence of this line in certain celestial spectra has been noted since 1896, it was Fowler[1] who first observed this line in the laboratory. The line has since become of increased importance in connection with Bohr's[2] theory on the constitution of the atom, according to which this line is attributed to helium. In his later work on enhanced lines, Fowler[3] pointed out that this line belongs to the series of enhanced lines whose series constant is four times that of Rydberg (4N type series). This line was observed by Stark[4] and later by Evans[5], in the helium tube free from any trace of hydrogen. As was stated before, employing Lo Surdo's method Evans and Croxson[6] observed the broadening of this line at the field of 37000 volt/cm.

In the present experiment we could clearly observe the separation of the p-component (about 5 Å.U.) and a definite broadening of the s-component at the field of 6.65×10^4 volt/cm.

The portion of Fig. 1 near this line is enlarged in Fig. 6 and the result of measurement is sketched in Fig. 3.

It must be mentioned that the presence of the secondary hydrogen lines λ 4686.94 and 4690.30 on the red side and λ 4683.96 on the violet side somewhat blurred the image of the separated components, especially as the intensities of these secondary lines were much increased in the region of the strong field.

(6) λ: 4519.

Of the new lines found by Koch[7], we could observe a line λ 4518.8. Some of the peculiarities noticed by Koch were observed by us also: firstly, both the p- and s-components of this line was displaced about 1 Å.U. toward the red at $E = 6.65 \times 10^4$ volt/cm, and secondly, the p-component was much stronger than the s-component.

1 Monthly Notices, **73**, 62 (1913).
2 Phil. Mag., **26**, 476 (1913).
3 Trans. Roy. Soc., A **214**, 225 (1916).
4 Verh. d. Deutsch. phys. Ges., **16**, 468 (1914).
5 Phil. Mag., **29**, 284 (1915).
6 loc. cit.
7 loc. cit.

It may be remarked that for all the lines, 4922, 4472, and 4388, the red side components behave normally, the violet ones anomalously. Further we remark that the separation of the s-components occurs upon a somewhat smaller scale than that of the p-components. As the number of lines investigated in the present experiment is not very large, it would be premature to discuss the behavior of lines with respect to the series relations.

In the former paper the advantage of using a heterogeneous electric field was mentioned. Here it may be emphasized that, in the present experiment, there were many cases where observation in a uniform field only might have proven inadequate.

§ 4. Summary.

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

2. Relying on Stark's data given in the case of "Grobzerlegung," the intensity of the electric field has been calculated from the amount of separation of the outer components of H_γ, which appeared in our photograph together with helium lines.

3. In the fields varying from 3000 to 70000 volt/cm. in strength, the manner of decomposition of the following 7 lines has been examined:—

λ in Å.U. 5048, 5016, 4922, 4472, 4438, 4388, 4121.

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

4. In each of the p- and s-components of the three lines λ 4922, 4472, and 4388 Å.U., an isolated component appeared on the violet side at a certain electric field; and in the case of the 4472 line, the component was further decomposed into three as the field strength was increased.

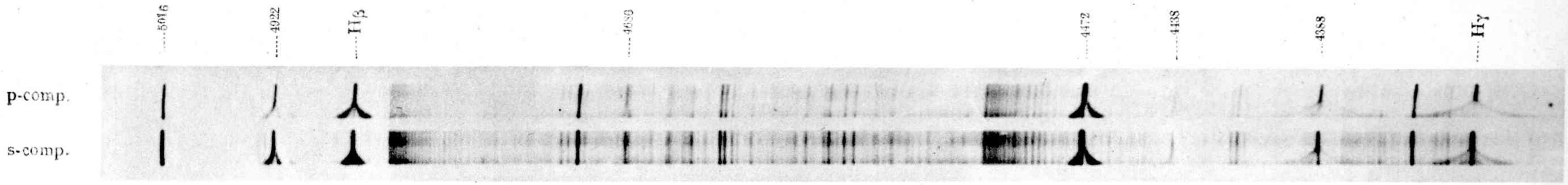
5. Beside the lines mentioned above, the separation of the p-component of the line 4686 has been observed.

One of the new lines found by Koch has been observed in the present experiment also.

6. Excepting the line 4686, the mode of decomposition of all the helium lines examined has been found to be dissymmetrical with respect to the initial line.

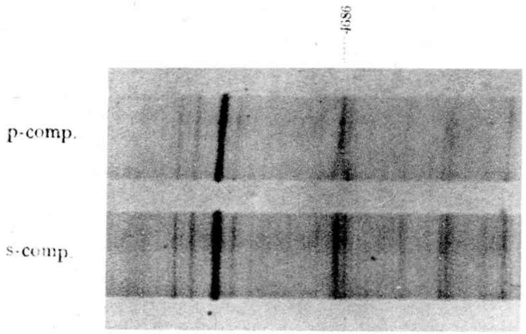
In conclusion, the authors wish to express their hearty thanks to Prof. T. Mizuno for his kind advice; and their great indebtedness to Prof. M. Chikashige of the Chemical Institute for the grant of the thorianite mineral, without which the present experiment could not have been carried out.

Fig. 1



Magnification : 8

Fig. 6



Magnification : 14

Exposure : $1^{h}\ 15^{m}$

$E_{max.}$: $6{\cdot}65 \times 10^{4}\ ^{volt}/_{cm.}$

Plate II.

Fig. 2. λ : 4922

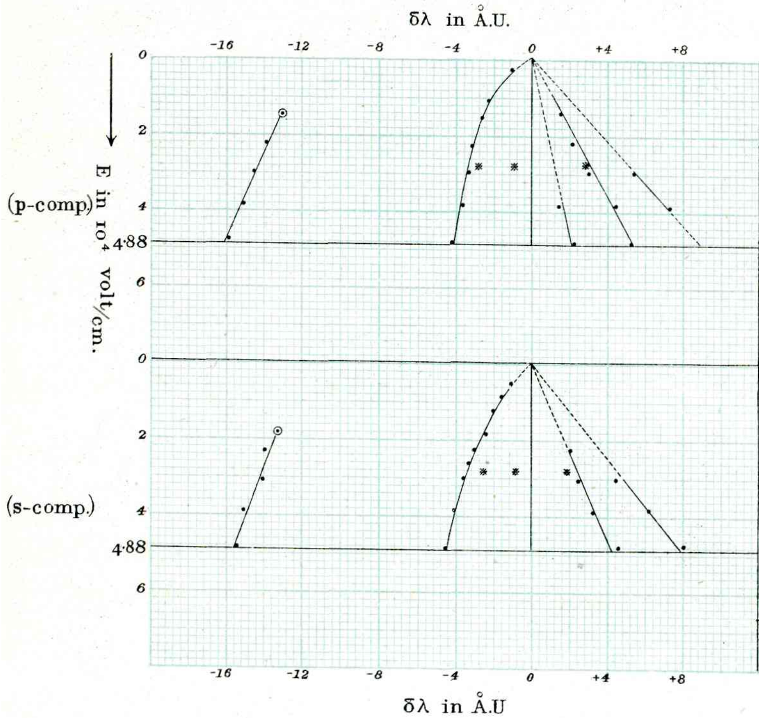


Fig. 3. λ : 4686

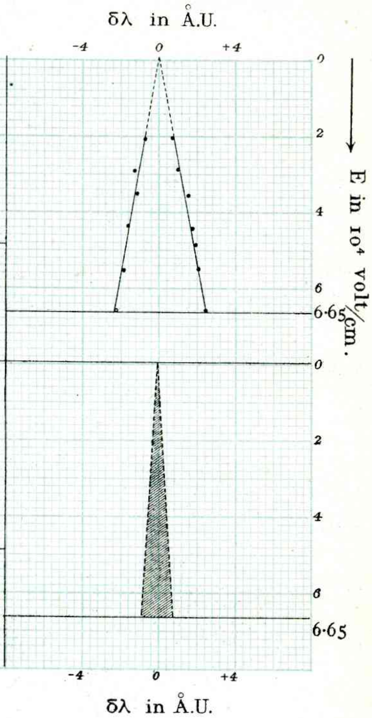


Fig. 4. λ : 4472

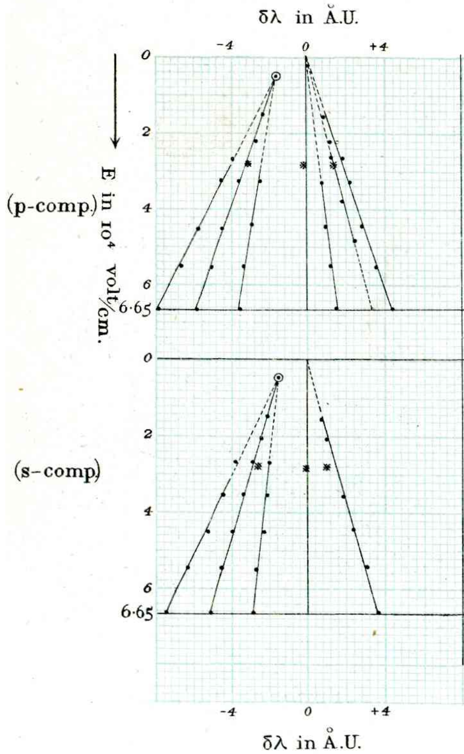


Fig. 5. λ : 4388