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

PART III.

BY

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§ 1. As reported in our preceding paper[1] relating to the Stark effect on hydrogen lines, some improvements were made in the experimental method for increasing both the field intensity and the brightness of the source of light.

In addition to the prism spectrographs mentioned in our former paper, a 6 inch plane grating mounted in Littrow type, and provided with a photographic objective of 48 cm. focus, was employed for examining the red and yellow lines. The dispersion in the second order was about 18 Å per mm. at λ 6500 Å.

Further, in order to detect a very small displacement of the lines, an echelon grating of 10 plates made by Hilger was placed behind the collimator of a single prism spectrograph. The use of an echelon grating for examining the Stark effect was first described by Brunetti[2], with sketches illustrating the mode of electrical resolution of the helium lines 6678 and 5016.

Although our experiments using an echelon was only of a preliminary nature, one of the photographs thus obtained is reproduced in Fig. 1, Pl. IV. In this photograph, the lines 5016 and 4713 are seen slightly displaced, the sign of the displacement in the echelon photograms being opposite to that in the prismatic dispersion. The lines largely affected by an electric field appear very confused, but

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1 Takamine and Kokubu, Mem. Coll. of Sci., Kyoto., **3**, 271 (1919)

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

the method is useful to see whether, for a certain line, there is any influeuce of the electric field at all. For instance, we have examined the mercury lines 5461, 4359 and 4047, and also a group of strong lines in the red and yellow part of the neon spectrum. In both cases, we found that all these lines remain fairly sharp even in the strong field of over 50000 volt/cm. for mercury, and over 100000 volt/cm. for neon.

It may be worthy of note that the strong yellow line λ 5852 of neon remained perfectly sharp in such a high field. We think, the fact may be of significance in discussing the adequacy of choosing the this neon line as the standard in the accurate measurement of wave-lengths.

It may be suggested that if we employ optical instruments possessing a high resolving power, we may perhaps find out the existence of a very weak field by means of the Stark effect. The exposure for obtaining a good echelon photogram needs not be long, in fact, the photograph reproduced in Fig. 1, Pl. IV was obtained with an exposure of only 10 minutes.

§ 2. In the summary of our previous investigation relating to the Stark effect on helium lines, we stated that :—

(I) There are three different ways in which helium lines are affected by an electric field, namely:

a) Symmetrical decomposition (λ 4686 line).

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

c) One-sided displacement (Principal series of lines and sharp series lines of helium and parhelium). Of c), 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.

In the present experiment, the maximum field strength was greatly increased. Assuming the proportionality between the field intensity and the amount of separation, the value of the maximum field, exterpolated from Stark's data, was about 150000 volt/cm.

Now, owing to the increased field strength, the lines 4121, 4438 and 3965, which have hitherto been said to be merely shifted by an electric field, were found to be resolved into a number of components, all being shifted in the same direction. For 4121 and 4438, we observed 2 *p*- and 2 *s*-components, and for 3965, 3 *p*- and 3 *s*-components. The photograph showing the fine resolution of the line 3965 is reproduced in Fig. 2, Pl. IV. It seems very likely that the other lines belonging to the principal and sharp series of helium and parhelium may, if examined under a greater dispersion, be resolved into a greater number of components.

The helium lines newly examined in the present experiment were 6678, 5876, 4713, 3889 and 3188. Including the lines examined by one of us with Mr. Yoshida[1] which are marked by asterisks, and also those reported in our second communication[2], the Stark effect on the following 26 lines have been investigated in all.

6678, 5876, 5048*, 5016*, 4922*, 4713, 4686*, (4518*), 4472*, 4438*, 4388*, 4169, 4144, 4121*, (4046), 4026, **4009**, 3965, **3889**, **3868**, **(3830)**, 3820, 3614, **3448**, **3188**, **2945**.

For the seven lines printed in gothic types in the above table, the Stark effect has not been observed by any of the former investigators such as Stark and Kirschbaum[3], Koch[4], Brunetti[5] and Nyquist[6]. The lines in brackets belong to the combination series first observed by Koch.

§ 3. As the result of closer examinations into the mode of separation, some alterations in the diagrams given in our previous communications became necessary.

In Pl. I, the lines are arranged according to the series relations. As will be seen, the peculiar mode o each series described in our previous paper has been confirmed in all the newly-examined lines.

In Pl. II, the mode of decomposition of various helium lines are illustrated. Here, the intensity of each component is roughly represented by its breadth in the diagram.

By aid of the grating spectrograph, the red line 6678 was found to be displaced toward the red side; and by aid of the echelon photograms the yellow line 5876 (D_3) was found to be displaced toward the violet side.

For both of the lines 5876 and 4472, a faint accompanying line

1 Takamine and Yoshida, Mem. Coll. of Sci., Kyoto. **2**, 325 (1917).
2 Takamine and Kokubu, Mem. Coll. of Sci., Kyoto, **3**, 81 (1918).
3 Stark and Kirschbaum, Ann. d. Phys., **43**, 1017 (1914).
4 Koch, Ann. d. Phys., **48**, 98 (1915).
5 Brunetti, Rendiconti d. Lincei, **23**, 719 (1914); **24**, 55 (1915).
6 Nyquist, Phys. Rev., **10**, 226 (1917).

constituting a doublet with the main line was observed in the echelon photograms. Although the behaviour of these faint lines was difficult to be observed in detail, they seemed to be affected in nearly the same way as the central component of the main line.

§ 4. In glancing at the results hitherto obtained, the following features come to our notice.

a) The Isolated Components.

In the first report communicated by one of us, together with Mr. Yoshida[1], the appearance of a component which is, so to speak, quite isolated from the main line, was noted for the lines 4922, 4472 and 4388. In the second experiment[2], the same feature was found to be common to all the lines belonging to the diffuse series lines of helium and parhelium. In Fig. 4, Pl. V, a photograph showing the isolated component of the line 4922 is reproduced.

In the present experiment, a closer examination revealed that, in such cases, there are generally more than one isolated component, just as stated by Nyquist[3]. Referring to the isolated component which is far removed from the main line, we notice that its starting point approaches nearer and nearer to the main line as the term number in a series is increased.

One remarkable feature observed in the present experiment is that, for the lines 4388 and 4026, an isolated component which appears first on the immediate violet side of the initial line is shifted toward the red side as the field strength is increased, and finally, at the strong field over 120000 volt/cm. it even comes out on the red side of the initial line. It is especially noteworthy that, in the case of 4026, the strong *s*-component which first appears on the immediate violet side of the main line is seen to cross through another component. A brief account of this interesting phenomenon has already been noted in our second report[4], stating that a curious discontinuity is seen in 4026. At that time, however, the real feature was not revealed owing to the weak field.

Quite a similar phenomenon of the birth of a new component was observed by Paschen and Back[5] for the line 4388 when studying

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1 Takamine and Yoshida, Mem. Coll. of Sci., Kyoto, **2**, 325 (1917).
2 Takamine and Kokubu, Mem. Coll. of Sci., Kyoto, **3**, 81 (1918).
3 Nyquist, loc. cit.
4 Takamine and Kokubu, Mem. Coll. of Sci., Kyoto, **3**, 81 (1918).
5 Paschen and Back, Ann. d. Phys., **39**, 897 (1912).

the Zeeman effect. According to them, the position of this new satellite is -0.5 Å, measured from the initial line. It is remarkable that this position almost coincides with the starting point of one of the isolated components observed in the present experiment.

b) Intensity Variation of the Components.

Generally speaking, the intensity of the components increases with the field strength. A notable exception is observed in one of the violet components of the line 4388, and also that of 4144, which fades away as the field increases.

c) Lines of Combination Series.

Three of the lines belonging to the combination series first noted by Koch, namely λ 4518, 4046 and 3830, were observed in our experiments. As shown in Figs. 4, 5, Pl. V, they do not appear when there is no electric field. In this respect, they may be said to stand with the isolated component above mentioned. In the case of the isolated components, however, some of them can be traced almost up to the zero field, but the combination lines seem to appear at much stronger fields; in other words, the rate of increase of intensity with the field is much greater for the latter.

It may be remarked that, according to Mr. Yoshida's[1] paper dealing with the Stark effect on lithium lines, a line at λ 4148, belonging to the combination series, was found to possess similar properties. The fact that the combination series lines of this sort are excited only in strong electric fields may be counted as one of the distinctive features peculiar to the series.

d) Similarity between 4388, 4026 *and* H_γ.

In *a*) we have mentioned that in the *s*-component of the line 4388, one line which appears precisely on the violet side of the initial lines, is shifted toward the red side and even reaches the opposite side of the initial line in every strong fields. A similar component is also seen for the line 4026.

When we compare these two lines with the hydrogen line H_γ, we are struck by the great similarity in the mode of electrical resolution of these three lines.

From the series relation we have:

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1 Yoshida, Mem. Coll. of Sci., Kyoto, **3**, 161 (1918).

	Hydrogen (Balmer Series)	Helium (Diffuse Series)	Parhelium (Diffuse Series)
Term No. $n=5$	H_γ	4026	4388

The essential likeness in the Stark effect on these three lines consists in that:—

1. The central line in the *s*-component is almost the strongest line of all the components.
2. The said line is shifted toward the red side as the field strength is increased. The only difference in helium and hydrogen is that the said line shows a discontinuity at its starting point in the case of helium. The photograph showing the helium line 4026 reproduced in Fig. 3, Pl. IV.

The striking similarity in the Stark effect on the corresponding lines of helium and hydrogen seems to suggest some hidden links in the mechanism of emission from the atoms of these two elements.

Summary.

1. Including the results previously published in Part I and Part II, the Stark effect on the following 26 helium lines were examined in all.

6678, 5876, 5048, 5016, 4922, 4713, 4686, 4518, 4472, 4438, 4388, 4169, 4144, 4121, 4046, 4026, **4009**, 3965, **3889**, **3868**, **3830**, 3820, 3614, **3448**, **3188**, **2945**.

For the seven lines printed in gothic types in the above table the effect has not been observed by other investigators.

2. The lines 4438, 4121 and 3965, which have hitherto been said to be merely shifted by an electric field, were found to be resolved into a number of components, all being shifted in the same direction.

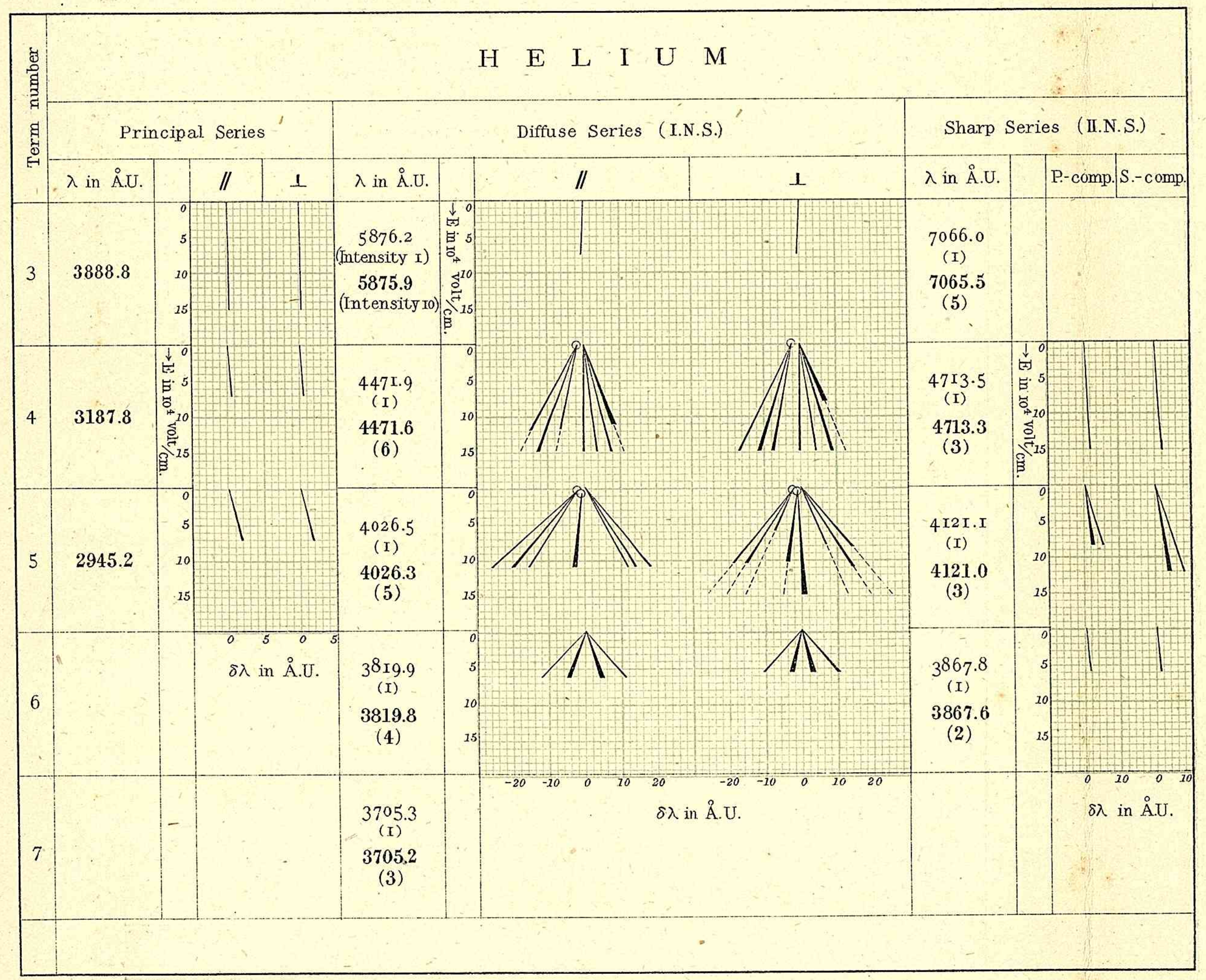
3. A striking similarity was noted in the Stark effect on 4388, 4026, and on the hydrogen line H_γ, in the following points:—

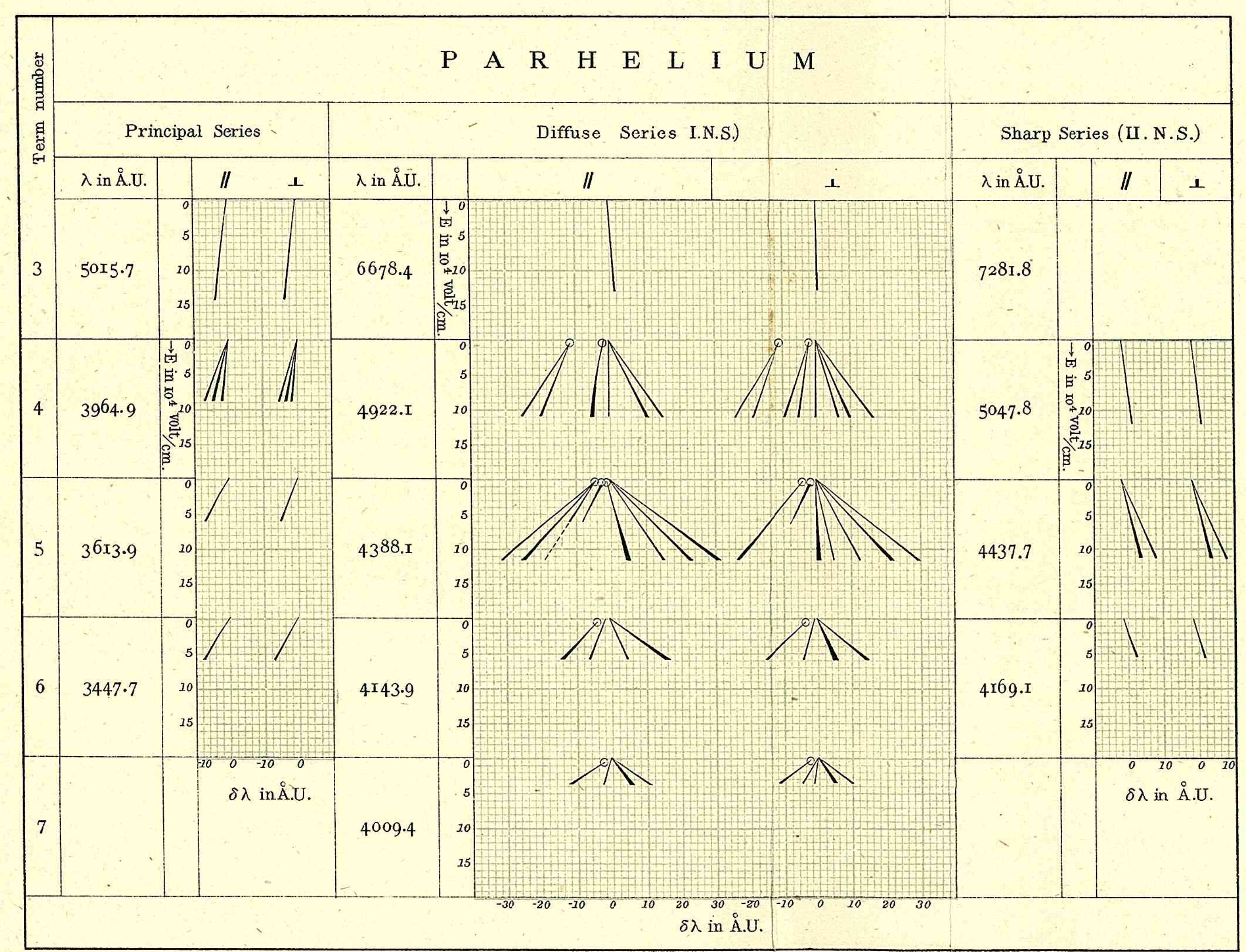
a) The central line in the *s* component is the strongest of all the components.

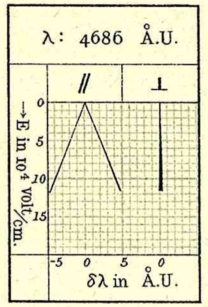
b) The said line is shifted toward the red as the field strength is increased.

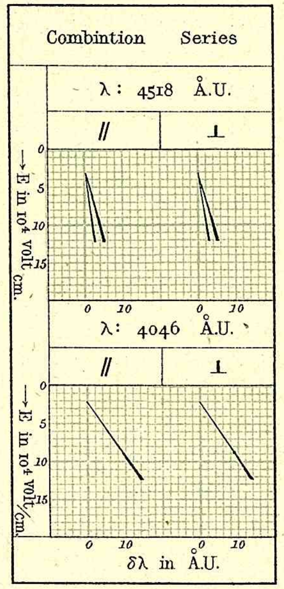
4. Advantages of using an echelon grating for examining the Stark effect is discussed. The behaviour of the faint line accompanying 5876 and 4472 as analysed by an echelon grating is described.

In conclusion, the writers wish to express their thanks to Prof. Mizuno for the interest he has taken in their work.

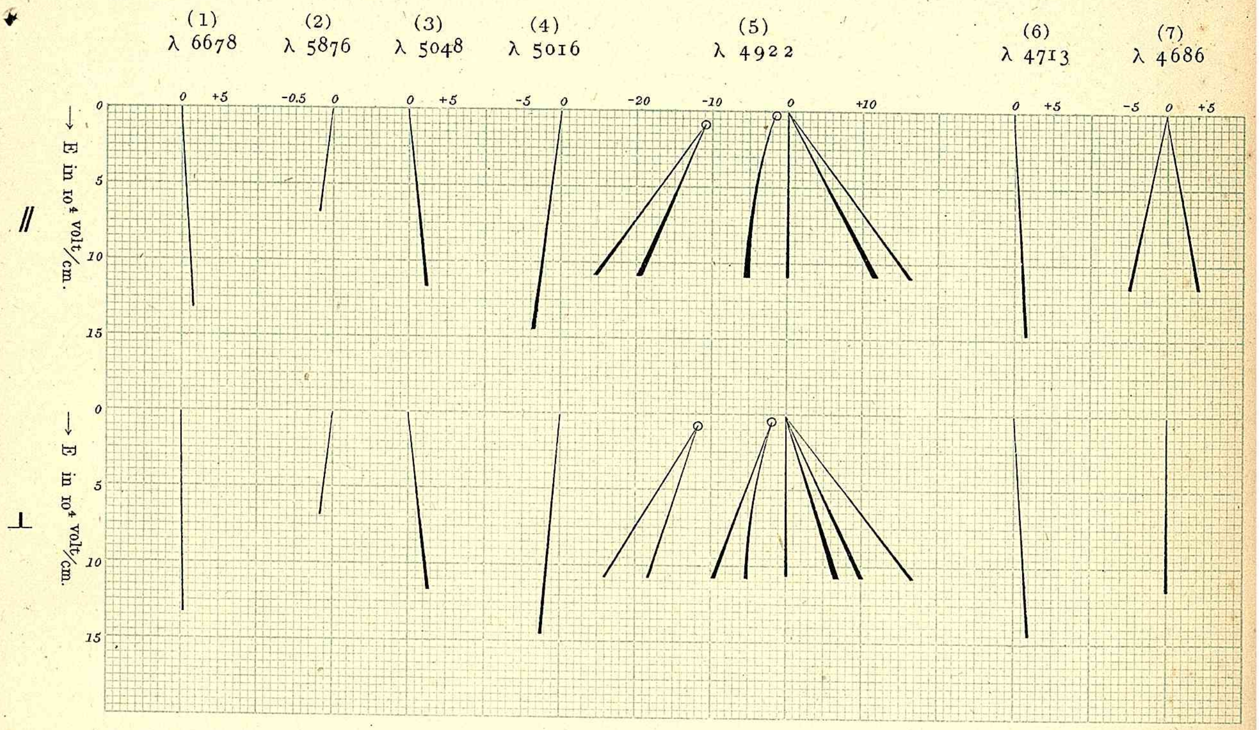

HELIUM
Term number
Principal Series
Diffuse Series (I.N.S.)
Sharp Series (II.N.S.)
λ in Å.U.
//
⊥
P.-comp.
S.-comp.
→E in 10⁴ volt/cm.
3
3888.8
5876.2
(Intensity 1)
5875.9
(Intensity 10)
7066.0
(1)
7065.5
(5)
4
3187.8
4471.9
(1)
4471.6
(6)
4713.5
(1)
4713.3
(3)
5
2945.2
4026.5
(1)
4026.3
(5)
4121.1
(1)
4121.0
(3)
6
3819.9
(1)
3819.8
(4)
3867.8
(1)
3867.6
(2)
7
3705.3
(1)
3705.2
(3)
δλ in Å.U.

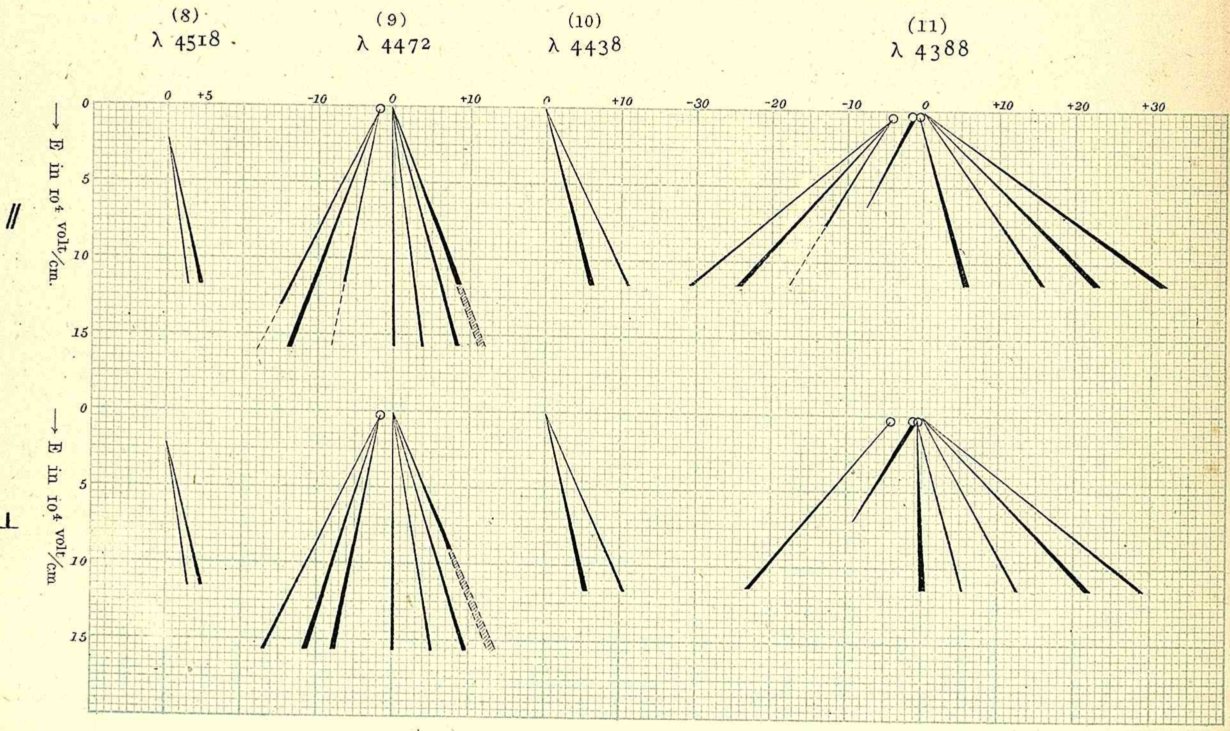

PARHELIUM
Term number
Principal Series
Diffuse Series I.N.S.
Sharp Series (II. N.S.)
λ in Å.U.
//
⊥
→E in 10⁴ volt/cm.
3
5015.7
6678.4
7281.8
4
3964.9
4922.1
5047.8
5
3613.9
4388.1
4437.7
6
3447.7
4143.9
4169.1
7
4009.4
δλ in Å.U.


λ: 4686 Å.U.
//
⊥
→E in 10⁴ volt/cm.
δλ in Å.U.


Combintion Series
λ: 4518 Å.U.
//
⊥
→E in 10⁴ volt/cm.
λ: 4046 Å.U.
δλ in Å.U.

Pl. II.


(1) λ 6678
(2) λ 5876
(3) λ 5048
(4) λ 5016
(5) λ 4922
(6) λ 4713
(7) λ 4686
// → E in 10⁴ volt/cm.
⊥ → E in 10⁴ volt/cm.


(8) λ 4518
(9) λ 4472
(10) λ 4438
(11) λ 4388
// → E in 10⁴ volt/cm.
⊥ → E in 10⁴ volt/cm.

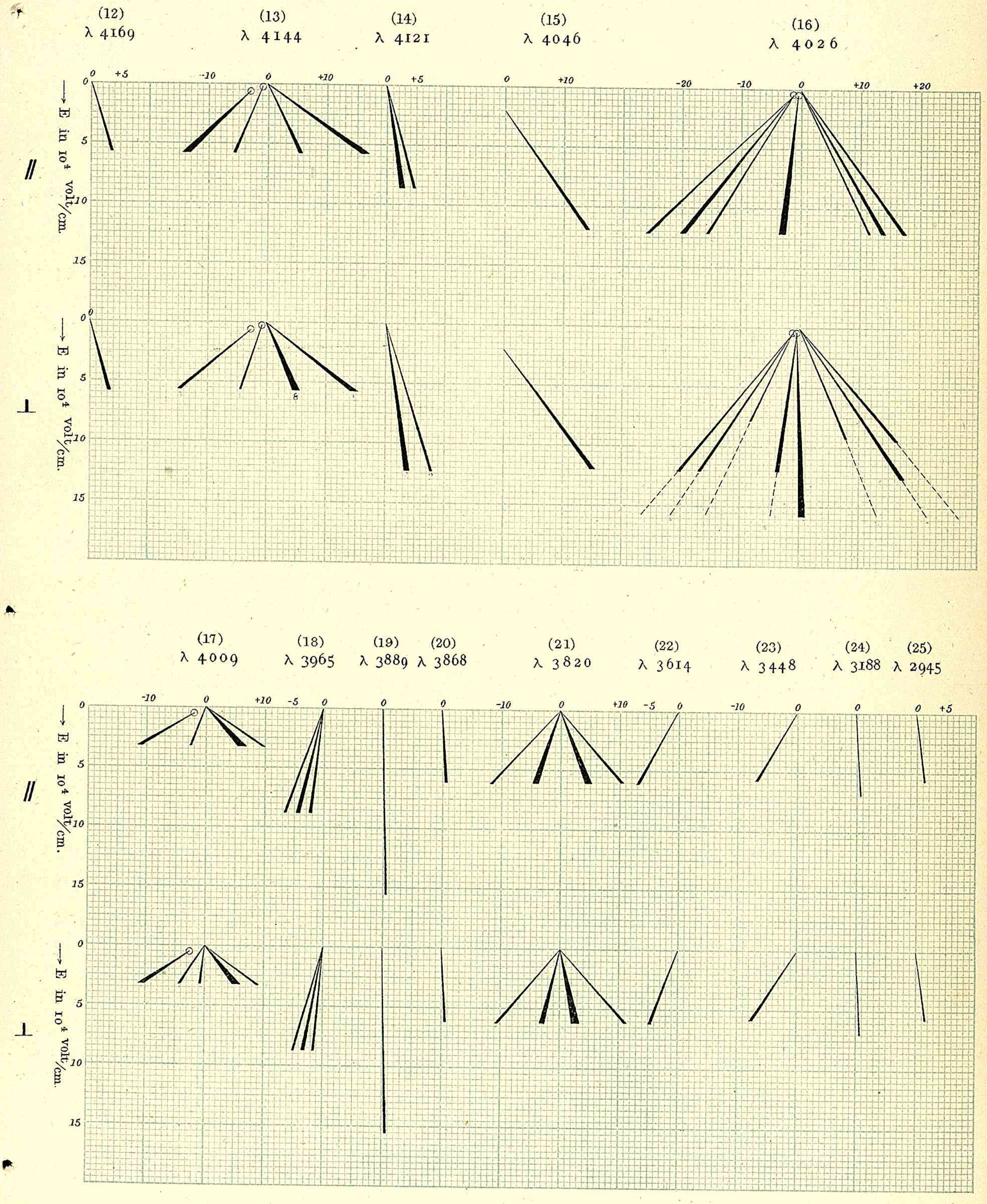
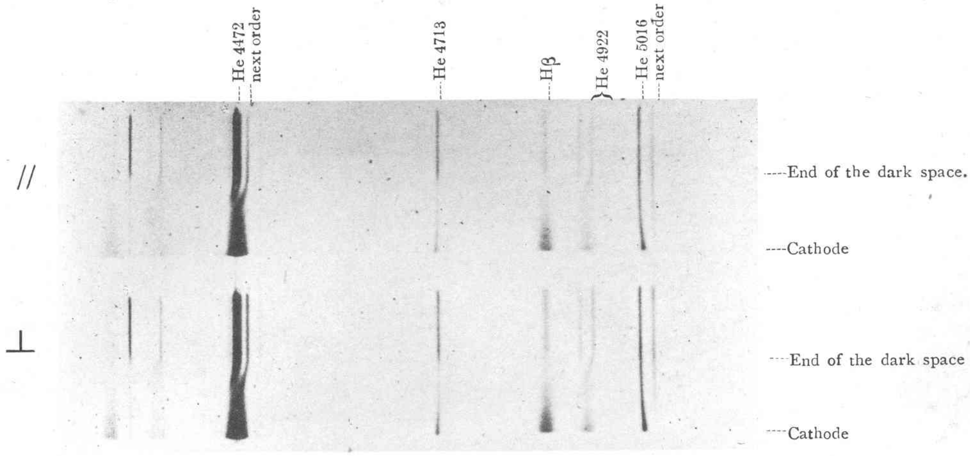

(12) λ 4169
(13) λ 4144
(14) λ 4121
(15) λ 4046
(16) λ 4026
→ E in 10⁴ volt/cm.
//
⊥
(17) λ 4009
(18) λ 3965
(19) λ 3889
(20) λ 3868
(21) λ 3820
(22) λ 3614
(23) λ 3448
(24) λ 3188
(25) λ 2945

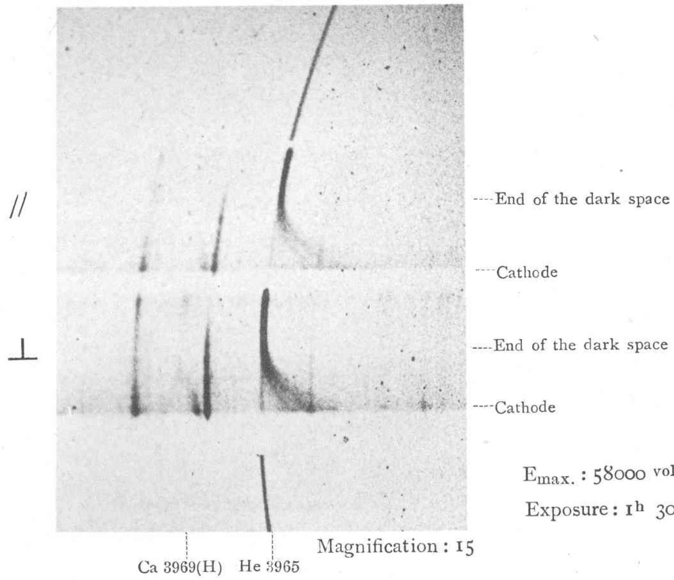
Fig. 1. The Stark Effect examined by an echelon grating



Magnification : 12

$E_{max.}$: 31000 volt/cm.
Exposure : 10^{m}

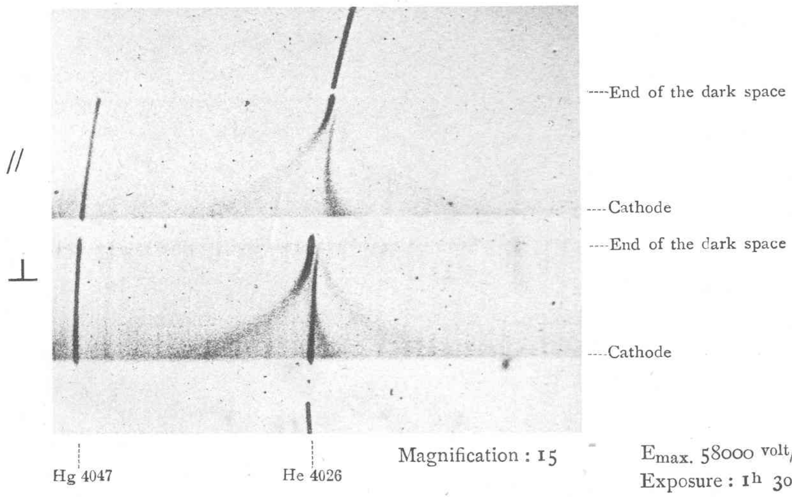
Fig. 2. Fine resolution of He λ 3965



Magnification : 15

$E_{max.}$: 58000 volt/cm.
Exposure : 1^{h} 30^{m}

Fig. 3. He λ 4026



Magnification : 15

$E_{max.}$ 58000 volt/cm.
Exposure : 1^{h} 30^{m}

Fig. 4 (The isolated component of He 4922)

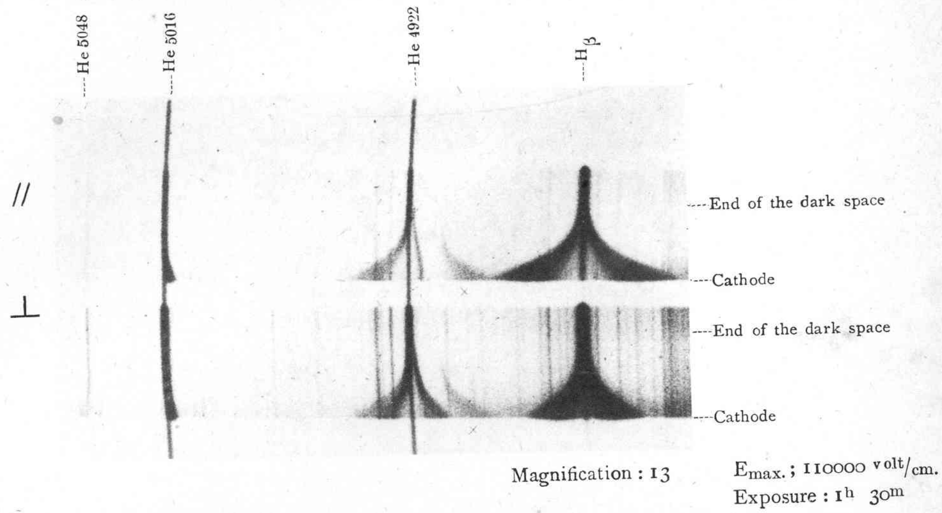


Fig. 5 (The combination line 4518)

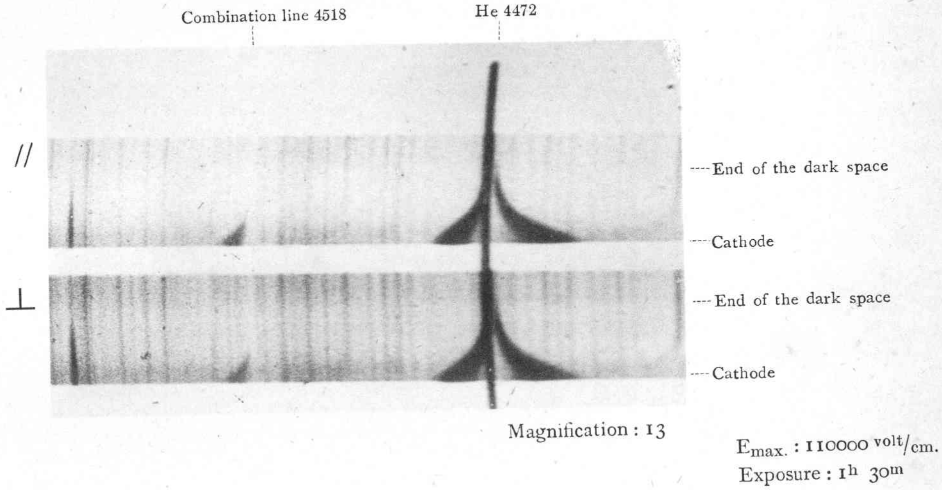


Fig. 6 (The combination line 4046)