The Effect of an Electric Field on the Spectrum Lines of Calcium and Magnesium.

By

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§ 1.

For elementary gases, such as hydrogen and helium, the effect of an electric field on their spectrum lines has been frequently studied; and fairly concordant results have been obtained by different investigators.

On the other hand, similar researches with respect to the metallic spectra are rather few in number, and the results show many discrepancies, according to different authors.

In 1914, Stark and Kirschbaum[1] examined the transverse electric effect on the lines of *Li*, *Hg*, *Al*, *C*, *Ca*, *Mg*, *Na* and *Tl* using canal rays as the source of light. Later, a similar research was carried out by Lüssem[2] for *Li*; and also by Wendt and Wetzel,[3] for *Al* and *Hg*.

Adopting the method due to Lo Surdo,[4] Howell[5] observed both the transverse and longitudinal effect on certain lines of calcium and lithium. In Howell's experiment, no electric effect was observed for the lines of *Fe*, *Ni*, *Mg*, *Al*, *Zn* and *Sr*.

Quite recently, Anderson[6] examined the electric effect on the lines of several different metals by modifying the method of Lo Surdo. But the results are not yet fully published, except for chromium.

In the present experiment, the discharge tube used as the source of light was of Lo Surdo's type. The experimental arrangements were quite the same as reported in our former communication relating

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1 Stark and Kirschbaum, Ann. d. Phys., **43**, 1017 (1914).
2 Lüssem, Ann. d. Phys., **49**, 865 (1916).
3 Wendt and Wetzel, Ann. d. Phys., **50**, 419 (1917).
4 Lo Surdo, Rendiconti d. Lincei, **22**, 664 (1913).
5 Howell, Astrophys. J., **44**, 381 (1916).
6 Anderson, Astrophys. J., **46**, 104 (1917); Phys. Rev., **9**, 575 (1917).

to the electric effect on helium lines. The metallic rod of calcium and magnesium was used directly as the cathode, the residual gas in the tube being air in most cases. In order to attain a very strong electric fields, thick-walled capillary tubes having the inner diameter of 1 or 2 mm., and the outer diameter of 5 or 6 mm. were found most suited for the purpose.

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.

The dispersion of the three spectrographs employed in the present experiment was as follows:—

4 prism spectrograph...... 23.9 Å per mm. at H_γ,
3 „ „ ...... 40 Å per mm. at H_δ,
Quartz spectrograph ...... 16 Å per mm. at λ3000 Å,
9 Å per mm. at λ2500 Å.

The region examined in the present experiment ranges between λ 5100 and 2200 Å.

In Pl. III and IV, several photographs obtained by the writers are reproduced, notations // and ⊥ being employed to represent parallel and perpendicular component respectively.

§ 2.

Calcium Lines.

Of calcium lines, Stark and Kirschbaum observed only very small displacements on the following 10 lines in a field of 44000 volt/cm. 4226 (g), 3969 (H), 3934 (K), 3737, 3706, 3179, 3159, 3645, 3631, 3624.

Here it is to be mentioned that the above authors remark that their measurements are far more inaccurate in the case of metallic spectra than in the case of helium and hydrogen lines. In fact, of the 10 lines mentioned above, the displacements were measured only for the parallel components of the four lines λ 3737, 3706, 3179, 3159. For the remaining 6 lines, we have only qualitative data as regards the sign and amount of displacement. Stark and Kirschbaum also noted that the calcium lines λ 4456, 4455, 4436, 4435 and 4426 were unaffected by the electric field.

Howell's experiments on calcium lines relate only to H and K lines. In the transverse electric effect on these two lines, one positive and one negative component was observed both for the parallel and perpendicular component.

The results obtained by the present experiment are by no means satisfactory. For most of the calcium and magnesium lines, only qualitative observations are recorded with respect to the sign of displacement in an electric field.

In order to give a glance at results, we give here a table of the affected lines of calcium grouped according to their series relations.

TABLE I.

Calcium Lines.

	I.N.S.	SL_2	Narrow triplet	Non-series line
$m=5$	*3644.5 (−)	5041.9 (+)	4586.1 (+)	*4685.4 (−)
	*3630.9 (−)	4527.2 (+)	4581.7 (+)	
	3624.2 (−)		4578.8 (+)	
		SL_3	*4098.8 (+)	
			* 95.3 (+)	
		4878.3 (+)	* 92.9 (+)	
		*4355.4 (+)		

In the above table, the lines marked by asterisks were those whose amounts of displacement have been measured. The displacements of the remaining lines were only qualitatively observed. The signs (+) and (−) refer to the side toward which the line is displaced in an electric field. SL_1, SL_2 and SL_3 are the single line series observed by Saunders[1].

In the following, detailed accounts are given for the measured lines.

(1) {3645, 3631, 3624} (Pl. I, Figs 3, 4)

In the arc spectrum, the first two lines are each a doublet; and, according to Exner and Haschek[2], we have 3644.90 (intensity 8) 3644.50 (20) and 3631.07 (8) 3630.87 (20). The lines were also studied by Crew and Mccauly[3], who used the calcium arc under re-

1 Saunders, Astrophys. J., **32**, 153 (1910).

2 Exner and Haschek, Tabellen der Bogenspectra, Wien (1904).

3 Crew and Mccauly, Astrophys. J., **39**, 29 (1913).

duced pressure as the source of light. According to them, the line 3644 consists of three lines which are resolved only at low pressure.

The dispersion of our instrument was of course insufficient to resolve these fine lines, and, as shown in Table I, we could measure only the first two lines.

Contrary to our observation, Stark and Kirschbaum record that these lines are slightly displaced toward the red side in electric field. We think it may be possible that the presence of neighbouring lines on the red side may disturb the appearance of the lines under consideration. In order to decide the question, it will be necessary to re-examine the phenomenon with greater dispersion.

(2) 4355 (Pl. I, Fig. 2.)

It is rather curious that this line, which is most distinctly affected by the electric field, has not been noted by former investigators. The mode of its displacement in two different stages of electric field ($E_{max.}=39000$ volt/cm. and $E_{max.}=68000$ volt/cm.) is shown in Pl. III, Figs 11*a* and 11*b*.

In Pl. I, Fig. 2, the curve showing the displacement of the parallel component is turned slightly concave upwards; but, as our measurement is by no means accurate owing to the hazy appearance of the line, the question of proportionality between the field strength and the amount of displacement cannot be definitely settled by the present experiment.

(3) {4099, 4095, 4093} (Pl. I, Figs 5, 6, 7)

In 1905, Fowler[1] observed a new triplet series in the strontium spectrum, in which the lines are situated more closely together than in the Rydberg triplet, and denoted the new series as "narrow triplet." Similar series of lines were subsequently found by Saunders[2] in the calcium spectrum.

In the present experiment, the electric effect on the first member λ 4586, 4582, 4579, corresponding to $n=3$ in Saunder's notations, was

1 Fowler, Astrophys. J., **21**, 181 (1905).
2 Saunders, Astrophys. J., **21**, 195 (1905).

only qualitatively observed, while the next member under discussion appeared fairly well in the neighbourhood of $H\delta$. In the reproduction Pl. III, Fig. 12, the components of $H\delta$ appear only very faintly.

Unfortunately, the initial position of the line λ 4093 is obscured by an impurity line.

As shown in the diagrams, Pl. I, Figs. 5, 6, 7, all the members of this triplet are affected in nearly the same manner. A similar feature was observed for the magnesium triplet 3097, 3093, 3091 also.

It is important to remember that the phenomenon of the Zeeman effect gives great facility for discriminating the series relation in spectrum lines. Quite analogously, we may expect that the effect of an electric field also will furnish us another powerful means for discriminating the series relations. For such a purpose, systematic studies on the electric effect for lines having well known series relations seem to be of much importance.

We may even proceed a step further and remark that for some particular class of lines, for instance, the narrow triplet lines of calcium above described, the electric effect is perhaps more easily observed than the Zeeman effect, since these lines are intensely excited only in a strong electric field.

It may worthy of note that most of the affected lines above described are denoted as " hazy " in the wave-length tables given by Saunders[1] for the arc spectrum of calcium. Thus, in his table the lines 5042 (+), 4878 (+), 4355 (+), 4099 (+), 4095 (+), 4093 (+) are marked hR (hazy toward the red), while the line 4685 (−) is marked hV (hazy toward the violet). The broadening of the narrow triplet lines 4099, 4095, 4093 toward the red side was noted by Crew and Mccauly[2] also in the calcium arc spectrum under reduced pressure.

An exceptional case occurs for the triplet 3645, 3631, 3624, marked hR in Saunder's table, but displaced toward the violet in electric field.

(4) Enhanced lines of calcium.

With the dispersion used in the present experiment, no marked effect was presented by the enhanced lines of calcium up to the field of 90000 volt/cm.

1 Saunders, loc. cit.

2 Crew and Mccauly, loc. cit.

For H and K lines, we could only observe that they were considerably broadened in strong field, notably toward the violet side. In the transverse effect of these lines at $E=20000$ volt/cm., Howell observed a separation of about 1 Ångström for both of the p- and s-components. We were unable to observe such a large separation, and it appears that our observation is more in conformity with that of Stark and Kirschbaum.

According to Stark and Kirschbaum, the next member 3737, 3706 as well as lines 3179, 3159 and the strong arc line 4226 (g) are said to be displaced toward the red; but we were unable to observe the phenomena.

In agreement with Stark and Kirschbaum, the following calcium lines were found to be unaffected by electric field:

4318.8, 4307.9, 4302.7, 4299.1, 4289.5, 4283.2

§ 3.

Magnesium lines.

In Table II, we give a list of the affected lines with their series relations:

TABLE. II.

Magnesium Lines.

	I.N.S.	S.	Non-series line
$m=4$	3838.4 (−)?	4703.3 (+)	4571.3 (−)
	32.5 (−)?	*4352.2 (+)	
	29.5 (−)?		
$m=5$	*3097.1 (+)		
	* 93.1 (+)		
	91.2		

(1) 4352 (Pl. II, Fig. 8.)

As shown in Table II the line belongs to the diffuse single line series, together with the line λ 4703. Both of these lines are displaced toward the red side in the electric field. The photographs showing the line λ 4352 at the fields $E_{max.}=58000$ volt/cm. and $E_{max.}=74000$ volt/cm. are reproduced in Pl. IV, Figs. 13 *a*, 13 *b*.

(2) 3097, 3093 (Pl. II, Figs. 9, 10.)

These two lines, together with the line λ 3091, form a triplet in the first subordinate series. In our photograph, the line 3091 was obscured by an impurity line.

In Pl. IV, Fig. 14, a portion of a photograph obtained by a quartz spectrograph is reproduced.

There still remains much doubt about the behavior of the strong triplet 3838, 3833, and 3830 in the electric field. In our study, they showed a tendency of being displaced toward the violet side in a very strong field; while Stark and Kirschbaum state that a component appeared on the red side of each line. Since the dispersion of our instrument was very small (about 30 Å per mm. at these lines), the results obtained in the present experiment cannot be taken as decisive, and we hope to investigate, in the near future, the phenomenon more thoroughly by means of a plane grating.

Just as in the case of the calcium non-series line λ 4686, a magnesium non-series line 4571 was found to be displaced to the violet side in an electric field.

The well known triplet 5183, 5173, 5168 appeared with great intensity at the cathode, but no electric effect was observed for these lines. A similar remark applies to the line 2852, belonging to the first subordinate series.

(3) Enhanced lines of magnesium.

Stark and Kirschbaum observed that the enhanced lines 2803 and 2796 showed a red side component in the electric field. Although a number of enhanced lines appeared in our photographs, we were unable to detect the electric effect on these lines.

It may be noted that the line 4481 always appeared with great intensity, while the line 3105 was very weak. The lines 2936, 2929, 2803, 2798, 2796 and 2791, belonging to the wide doublet series in the classification of Fowler[1], appeared with considerable intensities.

1 Fowler, Phil. Trans., A. **214**, 225 (1914).

In connection with this, it may be remarked that in some of our photographs mercury lines appeared as impurity lines. According to Stark and Kirschbaum, the following 10 mercury lines are all displaced slightly toward the red side in an electric field :—

4359, 4078, 4047, 3663, 3655, 3650, 3132, 3131, 3126, 3022.

In our case, we could find no sign of the said effect on these lines even though the dispersion of our instrument was sufficiently great for detecting it.

§ 4.

As remarked by Howell[1], the spectra of metals used as the cathode in the Lo Surdo tube are in many respects different from the ordinary arc and spark spectra. Further, in these cathode spectra, the relative intensities of various arc and spark lines are greatly influenced by the nature of the residual gas employed. As was remarked by Anderson[2], the metallic spectra are generally brighter in oxygen or air than in hydrogen, and, in fact, most of the affected lines of calcium and magnesium above described were more strongly developed when the residual gas was air.

In the course of measuring the photographs, we noticed that the following lines of unknown origin appear very often on the plates :—

A. 4367.1
B. 4152.8
C. 4110.7 (slightly displaced toward the violet side in electric field)
D. 4100.3 (do)

These lines appeared in all cases using *Al*, *Ca*, *Mg*, and *Ta** as the cathode, the residual gas being air or hydrogen. They were especially strong near the cathode, and some of them were evidently displaced by the electric field in the direction above indicated. As our photographs show many impurity lines, beside the bands of *N* and *CO*, we cannot be sure of anything as regards their origin. So

1 Howell, loc. cit.

2 Anderson, loc. cit.

* It may worthy of note that, in the case of tantalum cathode, the disintegration is considerably smaller than that of aluminium.

far, our search for the likely corresponding lines in the wave-length tables of the cathode metals has all been in vain. In Howell's paper, it is stated that three new lines were found in the case of *Mg* cathode. These lines are nearly coincident with *B*, *C* and *D* in the above table, but we think it very unlikely that the lines found in the present case are due to *Mg*. Some of these lines are marked in the reproductions shown in Pl. III and IV.

Summary.

1. Employing Lo Surdo's method, the effect of an electric field on the following *Ca* and *Mg* lines has been investigated :—

Ca : 5042, 4878, 4685*, 4586, 4582, 4579, 4527, 4355*, 4099*, 4095*, 4093*, 3645*, 3631*, 3624.

Mg : 4703, 4571, 4352*, 3097*, 3093*.

On the lines marked by asterisks, quantitative measurements have been carried out. The maximum electric field employed was about 90000 volt/cm.

2. All the above lines were displaced either toward the red or toward the violet in the electric field.

3. In general, the lines belonging to the same series were affected in nearly the same way, and further, each line constituting a triplet was affected in a similar manner. The latter statement is well exemplified in the case of the calcium lines 4099, 4095, 4093 belonging to the "narrow triplet" series.

4. An exceptional case seems to be the magnesium triplet λ 3838, 3833, 3830; but, as the lines are only very slightly affected, further experiments, using a larger dispersion, are needed for ascertaining the phenomenon.

In conclusion, we wish to express our sincere thanks to Prof. T. Mizuno for the interest he has taken in the work.

Fig. 1. λ: 4685.4 Fig. 2. λ: 4355.4 Fig. 3. λ: 3644.5 Fig. 4. λ: 3630.9

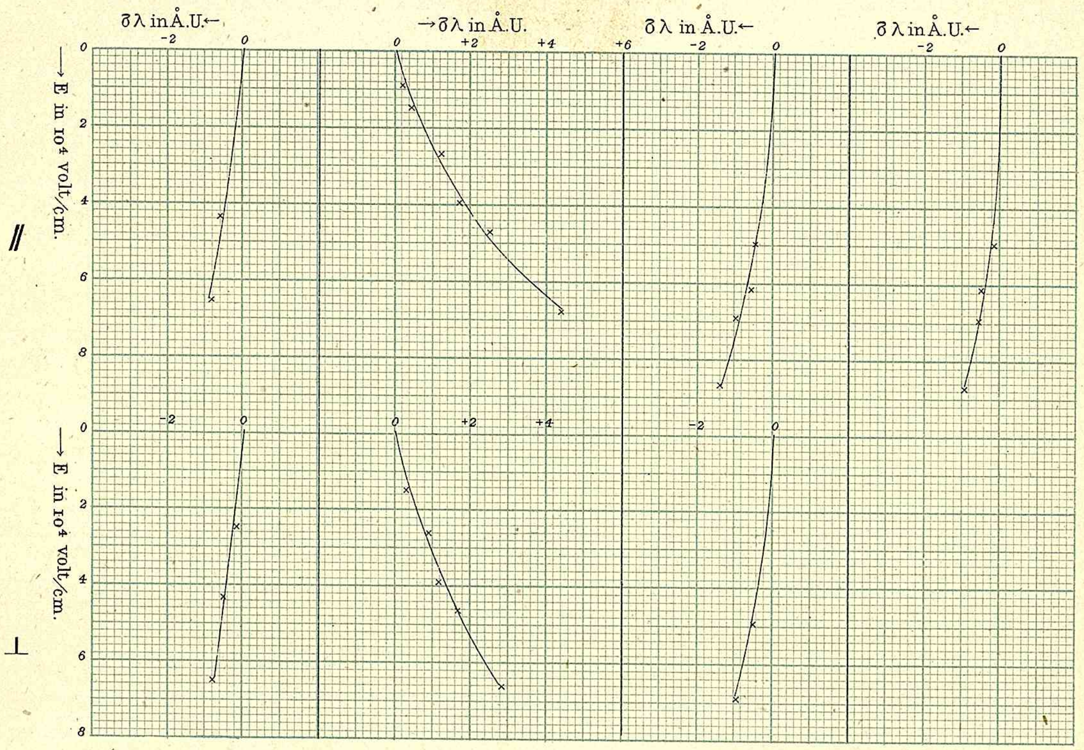
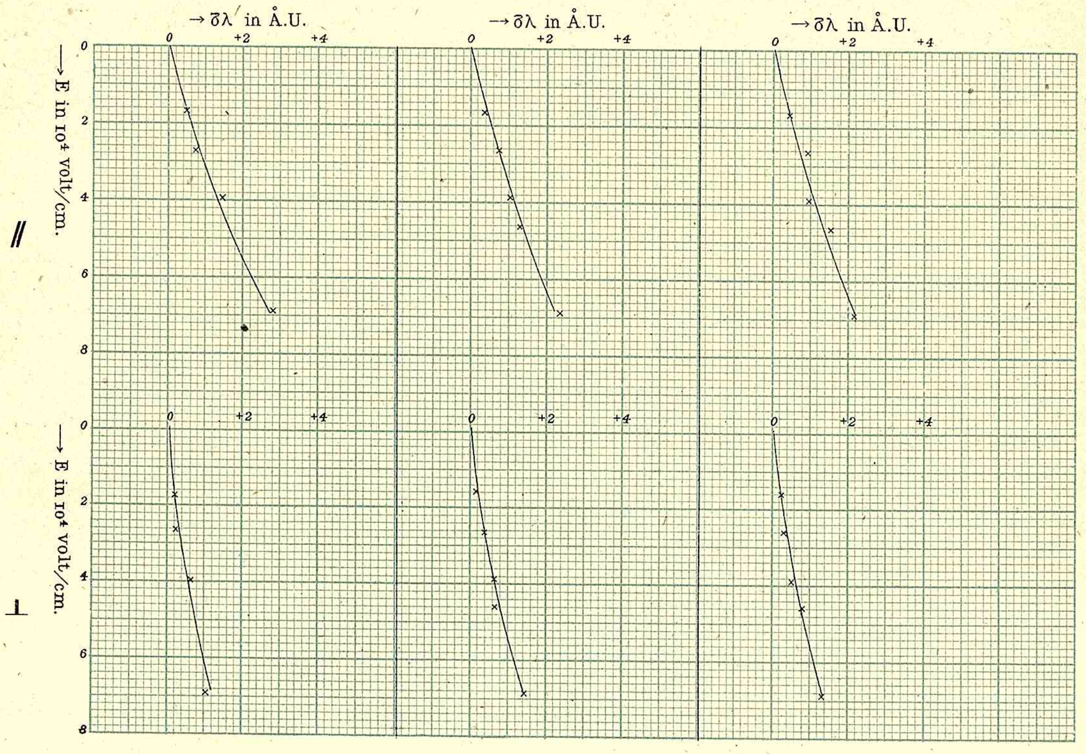


Fig. 5. λ: 4098.8 Fig. 6. λ: 4095.3 Fig. 7. λ: 4092.9



Magnesium.

Fig. 8. λ: 4352.2 Fig. 9. λ: 3097.1 Fig. 10. λ: 3093.1

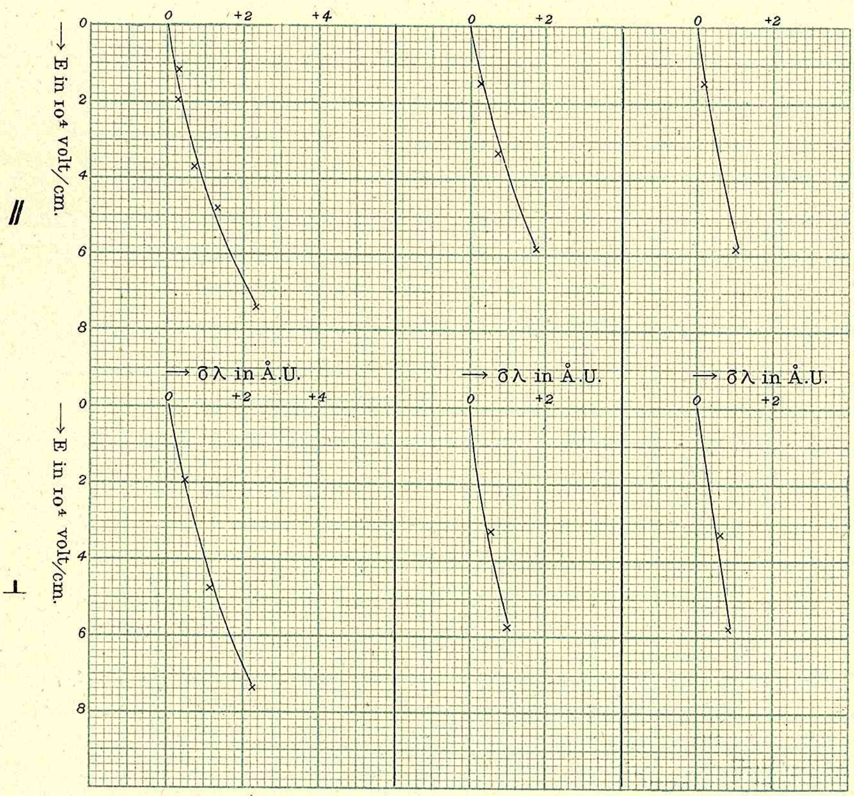
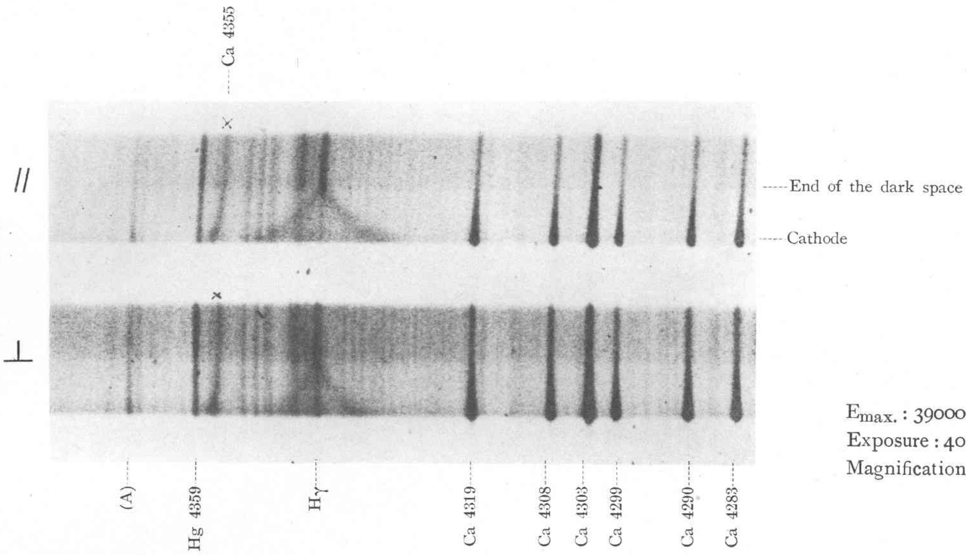
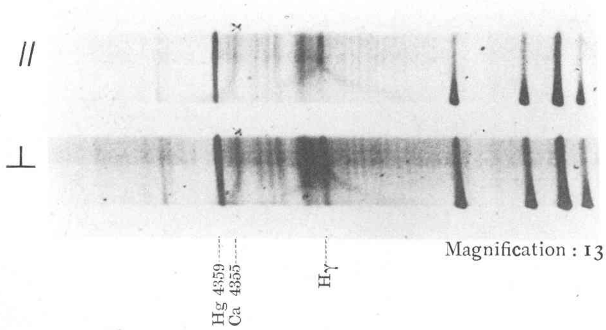


Fig. 11a. Ca λ : 4355



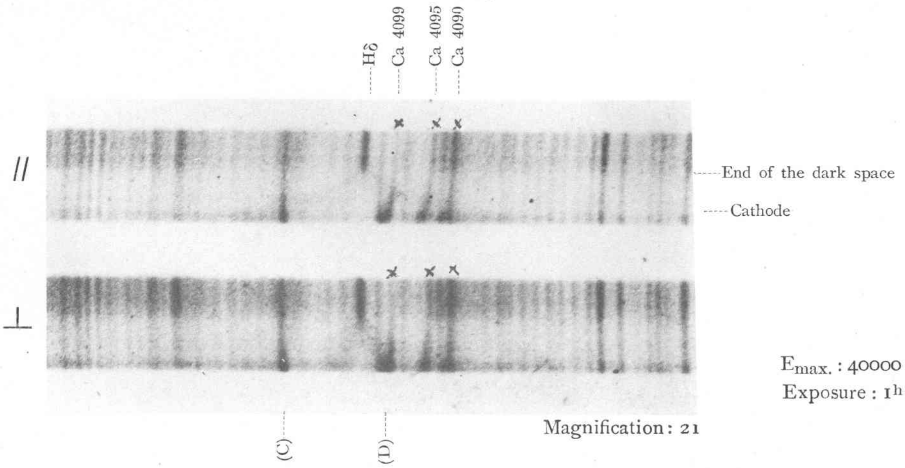
$E_{max.}$: 39000 volt/cm.
Exposure : 40^m
Magnification : 21

Fig. 11b. Ca. λ : 4355



$E_{max.}$: 68000 volt/cm.
Exposure : 30^m
Magnification : 13

Fig. 12. Ca $\begin{pmatrix}\lambda : 4099\\ \lambda : 4095\\ \lambda : 4093\end{pmatrix}$



$E_{max.}$: 40000 volt/cm.
Exposure : 1^h 20^m
Magnification : 21

Fig. 13a. Mg λ : 4352

Mg 4352

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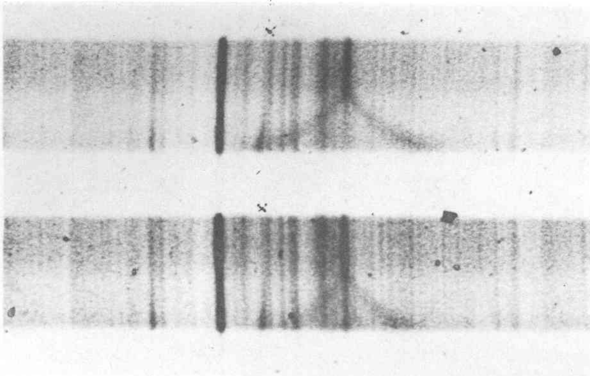

End of the dark space

Cathode

(A) Hg 4359 Hg

Magnification : 21

$E_{max.}$: 58000 volt/cm.
Exposure : 40^{m}

Fig. 13b. Mg λ : 4352

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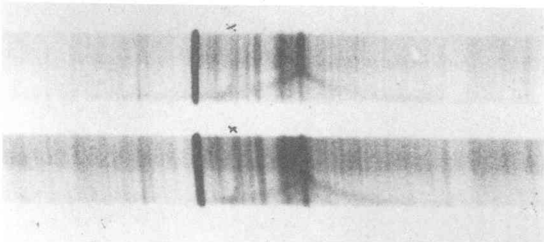
⊥



Hg 4359 Mg 4352 Hγ

Magnification : 13

$E_{max.}$: 74000 volt/cm.
Exposure : 40^{m}

Fig. 14 Mg {λ : 3097, λ : 3093}

Mg 3093 Mg 3097 Hg 3126 Hg 3132

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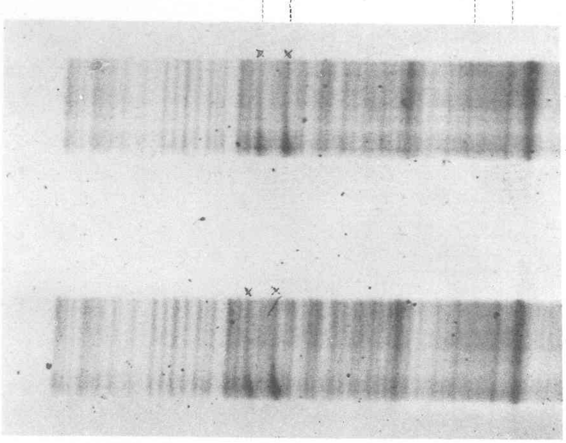

End of the dark space

Cathode

Magnification : 15

$E_{max.}$: 58000 volt/cm.
Exposure : 40^{m}
Quartz spectrograph