# FURTHER STUDIES ON THE STRIATED ELECTRIC DISCHARGE FIGURE[1-7]

By

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*With 2 Plates*

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## Introduction

This peculiar pattern of electric discharge figure, considering its generation, belongs in a wide sense to the so-called "electric figure." It is rather lately that the "electric figure" has become one of the most interesting themes for study, though its origin was indeed a few centuries ago. According to the reports already published by a number of investigators, the methods of causing the electric figure to appear are miscellaneous, such as by photo-chemical action, by strewing fine dielectric powder before or after the discharge, by straining the dielectric due to the mechanical action of the discharge, and so on.[8] All of these methods however are indirect, and the auxilliaries for producing the figure themselves more or less disturb the discharge because the features of the figures thus revealed differ somewhat from each other as different auxilliaries are used. But in our striated discharge, luminous striae simultaneously appear along the discharge paths (or we may well say that the luminosity itself is a part of the electric discharge). Therefore, we can see, in the present, clean discharge figures with our naked eyes or take photographs by a camera set quite independently to the discharging apparatus.

The following descriptions are in continuations of the previouly published papers. There remain, however, some untouched problems concerning this peculiar electric phenomenon. One of the most interesting must be the investigation of the colour of the luminous striae by means of a spectrograph, for this method is quite easy for such a stable discharge as the present one but impossible for ordinary electric figures.

## I. On the Propagation Velocity of the Striae

When one of the electrodes in the discharge vessel is a needle point or a circular disc, the discharge figure along the dielectric surface is composed of radial striae around that electrode in spite of various shapes of the dielectric.[2]

The propagation velocity of the striae of the figure can be measured by a method similar to that used by others.[9][10]

Let two needle points stand upright on a dielectric plate and every electric impulse reach them simultaneously, then two discharge figures quite similar to each other appear around the needle points. The boundary of these figures is very fine composed of a straight line which bisects at right angles the line connecting two centres of the figures. (Pl. I, Fig. 1). Further if a conducting wire of some length, a small coil or a small spark gap be inserted into the wire leading to one of the two needles, the time of occurrence of the "discharge" phenomenon at that needle point will in every instance somewhat lag behind the other, and consequently, the boundary line will be displaced from its initial position. Next, connecting a conducting wire of variable length (two halves of it being streched parallel to each other for making it inductionless), we shall be able to return the boundary to the initial position. Thus we can measure the propagation velocity of the striae and the time lag due to a wire, coil or spark gap. The mean velocity of propagation of the striae in the usual conditions has been at the rate of $10^7$ centimeters per second.

Pl. I, Fig. 2 is a reproduction of the figure showing a displacement of the boundary line caused by connecting a 48 meters wire inductionlessly to one of the two electrodes. Fig. 3 shows that the boundary line comes back to the initial position (as given in Fig. 1) by connecting the 48 meters wire to one and a certain small coil to the other needle.

The process above described can be performed very easily and even in a few minutes by observing the boundary line of the double figure through a telescope fixed or sliding but set quite independently to the discharge system. This method of compensation for measuring small time intervals is superior to that using an ordinary electric figure on a photographic plate(9) (10) in time taken for measurement, in ease of procedure and in logic.

## II. Effect of Different Gases on the Striated Figure

We have made some experiments on the striated discharge using various gases in place of air in the discharge vessel. Such gases were used as hydrogen, nitrogen, oxygen, carbon dioxide, coal gas and chlorine. Though the gases used at present were prepared commercially and the observations were only preliminary, we have obtained some important peculiarities concerning the striated discharge. We note here that a high tension alternating electromotive force from the transformer(2) was applied throughout the experiments.

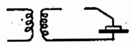
With hydrogen, oxygen or nitrogen, we could generate a similar striated discharge figure to that with air. The colour of the luminous striae of the figure is different with different gases. This fact shows that the luminosity of the striated discharge is due to the gas but not to the metal of the electrodes in the discharge vessel. The luminosity of the striae of the figure was much more intense with nitrogen than with other gases, and this is the reason for the fact that the colour of the figure when air is used is apparently the same as when nitrogen is used. A few photographic reproductions of the striated figures gotten with various gases are shown in Pl. II.

The number (or spacing) of striae of the discharge figure when nitrogen or oxygen is used is almost the same as when air is used, provided that the same dielectric plate be used, while there is a tendency, though insignificantly small in comparison to the probable error of the experiment, of increasing that number in the figure when hydrogen is used. (Table I).

TABLE I.

| Dielectric | Size (cm.) | Gas pressure (cm.) | Width of spark gap (cm.) | Number of striae | |
|---|---|---|---|---|---|
| | | | | I | II |
| Glass (circular) | Dia. 10.0 Thick. 1.5 | 7.1 | | | 20(17) |
| Bakelite ( ,, ) | Dia. 10 0 Thick. 0.33 | 10.6<br>7.6 | | 18(14.5) | <br>35(29) |
| Ebonite ( ,, ) | Dia. 10.0 Thick. 0.315 | 5.6 | | | 24(24) |
| Glass (rectangular) | Sides 16.0 8.0 Thick. 0.17 | 8.1 | 0.20 | | 14(13) |
| Glass ( ,, ) | Sides 16.0 4.0 Thick. 0.17 | 8.1 | 0.15 | | 6( 6 ) |

Gas in the discharge vessel: hydrogen.

Electric connection: 

The numbers in the parentheses correspond to those when air is used.

Using $CO_2$, very poor discharge figures were obtained as shown in Pl. II, Fig. 5.

Using coal gas, no figure has appeared, though a bright discharge has taken place all over the surface of the dielectric (provided that a spark gap exists in the discharge circuit).

Using chlorine, neither striated figure nor brightness on the dielectric surface, but a solitary spark or arc has resulted. The existence of the spark gap in the discharge circuit gives little effect in this case. Moreover, the rectification, when the alternating electromotive force is applied, is negative to the needle electrode (while positive in the case of a striated discharge)[4][7], and its amount is very small, say one tenth of that in the striated discharge.

Thus we see that gas in the discharge vessel must be electropositive and never -negative for obtaining the present striated discharge figure.

Using any one of the indirect methods for observing electric figures (e.g., discharging on a photographic plate) and filling the discharge vessel with chlorine, however, both positive and negative "electric figures" can be obtained by changing the polarity of the applied electromotive force[11].

The peculiarities mentioned above—especially about the discharge using chlorine—will perhaps give a new clue to the mechanism of the electric discharge.

## III. On the Mechanism of the Characteristic Striated Discharge.

It may be practically impossible to determine the whole mechanism of the present striated discharge as that of the usual electric discharge. On the active element which produces the so-called electric figure—especially the positive figure—there exist a few different theories, such as positive ions of gas[8], protons[12], or electrons[13]. Researches on this problem have been made by several authors, but the theory explaining it seems not yet to be determined*. On the other hand, little has been studied[14], so far as the present writer is aware, about the regularity of the striae of the figure and its relation to the discharge in question. We have tried accordingly some hypothetical explanations about the mechanism under which the present striated figure is generated basing our results of investigations already described[2].

Oscillographic researches[7] of the striated discharge reveal to us that several thousands of similar discharge take place in a second. The individual discharges in question are necessarily quite similar to

* The results of applying magnetic field on the electric figure published recently by C. E. MAGNUSSON (A. I. E. E. Oct. 1930, p. 1384) is a powerful supporter of the theory ascribing the cause of the figure to electrons. Further, the same theory is probable for the following reasons: the propagation velocity of the striae of the figure (both positive and negative) is very near to that of electrons in the electric field of the same strength, but the velocity of positive ions or protons under the same conditions is far smaller; the fact that the number of striae of the figure is almost the same in different gases suggests that the active element causing an electric disturbance and causing the characteristic discharge figure to appear must not be ions of the gas despite the fact that the luminosity is due to the gas as a secondary effect of the electric disturbance in question.

each other, and moreover, the striae of the figure due to any one of these discharges always superimpose on those due to the preceding one: this must be the reason for the fact that the striations of the figure stand stationary to our eyes. Accordingly, the individual discharges are independent of each other from the view-point of the course of the discharge. And the striae occur intermittently but on the same paths possibly because of certain traces (amongst which are the residual charges) which remain for some time intervals after the individual discharge.

Next, the active time range of the impulse electromotive force (or more precisely, the steep part of the gradient $\frac{dV}{dt}$ in the voltage-time curve as shown in the annexed diagram, where $V$ denotes the voltage and $t$ the time) is very small compared with the time

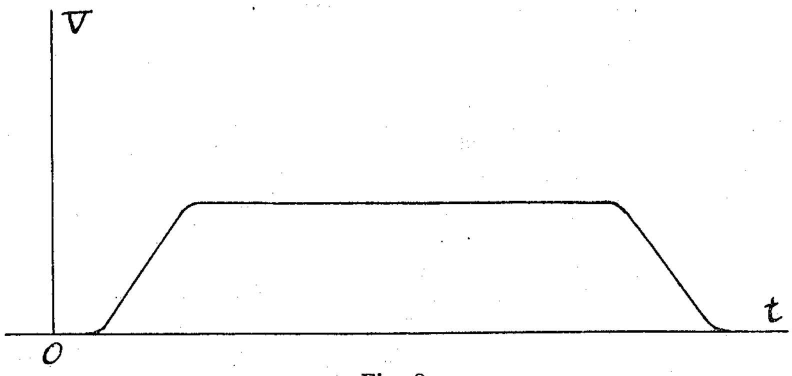



Fig. 8.

interval between two consecutive discharges, and possibly far smaller even compared with the time range required for the discharge in question to travel from the needle (or filament) to the other electrode (brass plate) or vice versa. Then we can apply the principle of a ballistic galvanometer (or a forced vibration of which the active time range of the external force is much shorter compared with the duration of vibration of the system to be forced) to the present striated discharge. We assume accordingly that an electric impulse, or to say more precisely the head or tail of an impulsive electromotive force, plays the rôle of the external force giving a certain electric disturbance to the discharge system (composed of electrodes, dielectric and gas in the discharge vessel), but that the impulse itself vanishes (say, at the needle point electrode) when the electric disturbance is beginning to take place. Except for the initial stage of the discharge, this electric disturbance must be independent, of the form of the applied electromotive force, but dependent chiefly of the characteristics due to the discharge system above mentioned. The luminous striated figure in question is nothing but a direct effect of such an electric disturbance taking place and causing ionizations along the surface of the dielectric. We can imagine that the mode of this electric disturbance is determined chiefly by the electric field distribution, that is the size and substance of the dielectric, considering the fact that the same factors fix the number (or spacing) of striae which are the principal characteristics of the figure. Moreover, the fact that the striae are always uniformly distributed along the discharge path gives us an idea that the electric disturbance itself consists of a certain oscillation of both electric field and current (accompanied by luminosity in the course of its propagation) and is proper to the discharge system used.

On the other hand, the striated figure in question is not an effect due to the mechanical vibration of the dielectric plate, for we can get a striated figure having just the same number of striae and appearance on each of two dielectric plates of the same substance and equal size one of them being single while the other consists of a number of thin sheets.

Again, the width of the spark gas is the principal factor deciding the amount of electric flow in a single discharge, and the gas pressure, the voltage of a single impulsive electromotive force. But the regulation of these variables causes also changes of wave-length of the applied electromotive force (for a non-oscillating impulse, we think of a quantity like a wave-length, say the length of the head or tail in the potential-time diagram of the impulse), and makes a certain resonance-like phenomenon between that impulse and the oscillation proper to the discharge system. Moreover, under such considerations, we can expect a second or higher ordered discharge figure in addition to the proper one. Beside the above mentioned variables, the factors in the discharge circuit such as the electric connection, the resistance, the capacity and the inductance affect more or less the form of the electric impulse (i. e. the potential-time curve), and if the whole time range of the impulse is larger than the time range required for the discharge (or the head of the curve) to travel from the needle to the other electrode we can expect the appearance of such a striated figure as shown in Fig. 4, but if smaller, that in Fig. 7.

A quantitative relation among the number of striae and other factors in the radially striated figure has been already deduced[2] from the experimental results, expresed as

$$N = G \cdot k \cdot \sqrt{C},$$

where N is the number of striae of the figure, G a factor due to the substance of gas which however is actually the same for different gases, k the order of the figure, i.e. 1, 2, 3......, lastly C an apparent capacity corresponding to a supposed condenser having parallel plates and medium the same as the dielectric used in respect to both area of surface and substance. For a figure of parallel striated type, however, we use S the spacing and C′ the apparent capacity corresponding to the unit area of the surface each in place of 1/N and C in the above equation.

$$S = \frac{G'}{k \cdot \sqrt{C'}}.$$

**Summary.**

1. Very short time intervals about $10^{-6}$ sec. to $10^{-9}$ sec. can be measured very simply by a method of compensation using the striated discharge figure.

2. Striated discharges with various gases in the discharge vessel are studied, among which those with chlorine gas are remarkable.

3. An explanation on the mechanism of the striated discharge is proposed in analogy with the principle of a forced oscillation.

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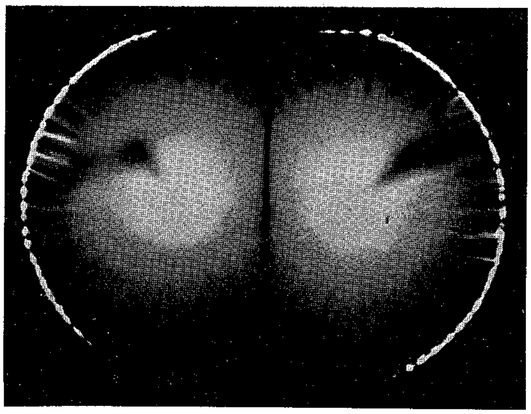
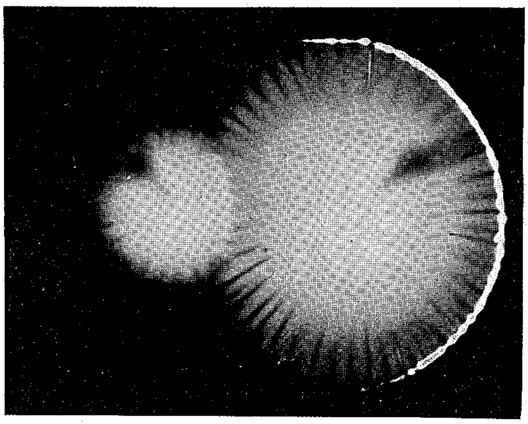
Fig. 1.



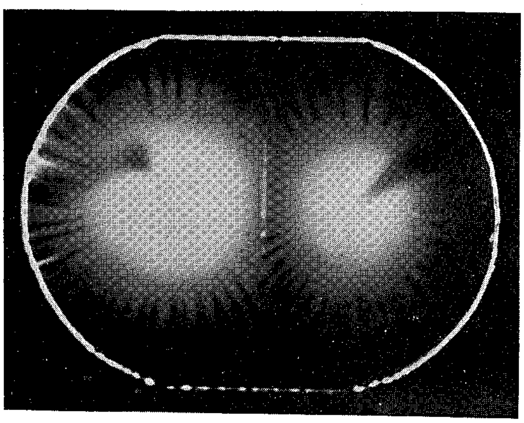
$\times \frac{1}{3}$

Fig. 2.



$\times \frac{1}{3}$

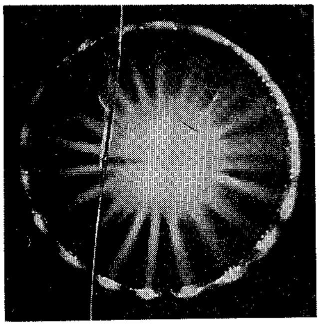
Fig. 3.



$\times \frac{1}{3}$

*T. Itoh : Further Studies on the Striated Electric Discharge Figure.*

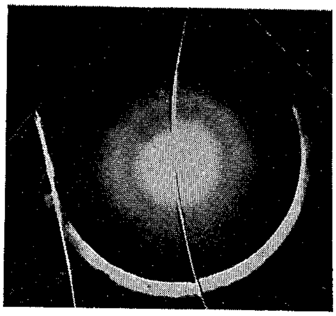
Hydrogen



$\times \frac{1}{3}$

Fig. 4.

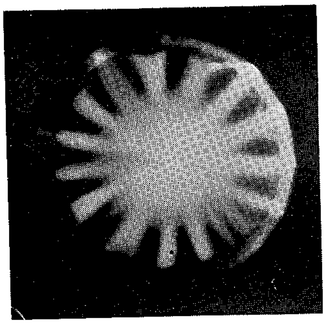
Carbon dioxide



$\times \frac{1}{3}$

Fig. 5.

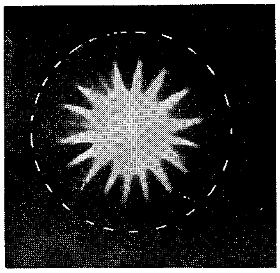
Nitrogen



$\times \frac{1}{3}$

Fig. 6.

Nitrogen



$\times \frac{1}{4}$

Fig. 7.

The dielectric used is a circular glass plate 10 cm. in diameter and 1.5 cm. in thickness.

The electric circuit applied has a series spark gap for Figs. 4, 5 and 6, but a parallel one for Fig. 7.

*T. Itoh : Further Studies on the Striated Electric Discharge Figure.*