Luminosity produced by Electric Discharges in Tubes containing Gases at slightly reduced Pressures

By

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When an electric discharge takes place in a tube containing a gas at a reduced pressure, the positive column shows striation. If the pressure of the gas be increased the striae get closer and closer, and then a thin and apparently unstriated glow appears along the axial portion of the tube. On further increase of the pressure this glow is then branched into a number of finer ones, and the discharge assumes a noisy character. When the glows were analysed by a rotating mirror, the striation of the positive column appeared to remain almost stationary, but the thin unstriated one occurring at a pressure of a few centimeters got curved, showing that a luminosity has apparently started at the anode and then proceeded toward the cathode. The nature of this luminosity was studied and the result obtained so far is described below.

A tube provided with aluminium wire electrodes was prepared from glass tubing having a diameter about 1·5 cm. This was connected to a pump and a manometer, and excited by a Blitzen transformer of $\frac{1}{4}$ K.W., a glow oscilloscope and a milliammeter being inserted in the circuit. A visual study of the process of the discharge was made by means of a rotating mirror and its successive stages were photographed with a falling plate camera. In some cases, vibrations of a tuning fork were recorded simultaneously on the photographic plates to determine the velocity of the latter. The arrangement of the discharge tube and the optical system is shown in the accompanying figure.

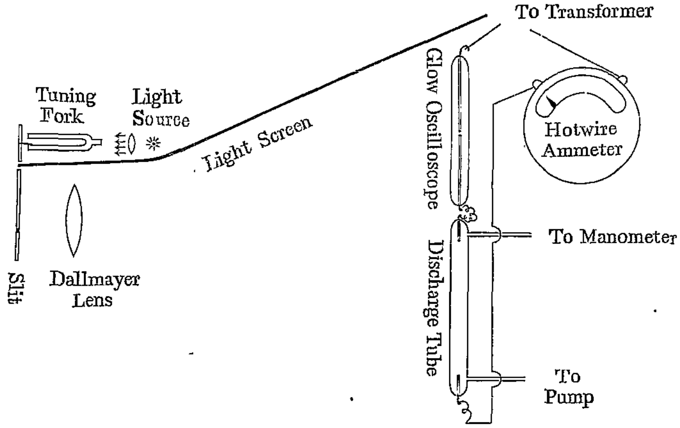


Fig. 1.

In a tube containing the air, the positive column was uniform at the pressure of 1·5 mm., the distance between the electrodes being about 5 cm. A photograph taken with the falling plate camera shows that the column really consists of uniformly illuminated bands, and consequently we may consider the light as almost simultaneously emitted from every point of the positive column. But when the pressure was increased to 2·0 mm. a slight horizontal concentration of the light was observed on the plate at the initial stage of the discharge. This got brighter and began to curve as the pressure was further increased, and then detached

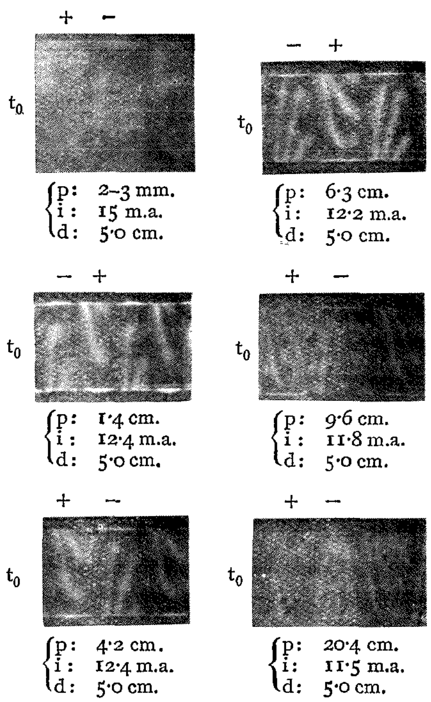


Fig. 2.

from the remainder, when the pressure was raised to 1 cm. This will be seen from the photographs shown in Fig. 2. In all these and the following figures, the sides marked by t_0 represent the lower edges of the falling plates; " + " and " – " anode and cathode of the tube respectively, "p" denoting the pressure in the tube, "i" the current and "d" the electrode distance. Thus the luminosity seems to start at the anode and proceed toward the cathode at the beginning of the discharge, the apparent velocity being about 70 m/sec. at its start. Further increasing the pressure, and keeping the current constant, the second luminous band appeared at the pressure of 1·4 cm., and the third one at a still higher pressure. The number of these luminous bands and their thickness increased with the pressure, and when the current was raised, keeping the pressure constant, their number also increased and they approached more to the cathode, but did not reach it.

The following table shows how the number of the bands and their lengths vary with the currents when the pressure was kept constant at 4·2 cm., the distance of the electrodes being 11·5 cm.

Currents	Number of Bands	Lengths of Bands 1st	2nd	3rd	4th	5th
4·0 m.a.	2	7·7 cm.	1·9			
5·2	3	10·2	3·8	0·6		
6·0	4	10·9	7·0	3·8	0·9	
8·0	5	11·2	9·6	6·4	3·5	0·9

The distribution of light in one of these luminous bands was not uniform; its convex side was generally brighter, and the light gradually faded away toward the concave side of the band. On the whole, the cathode side of the band was brighter, and lined by a thin but bright layer. Besides this, it was a cathode that is the brightest part of the band.

The formation of these luminous bands is not only not restricted to the air, but also in coal gas such bands appeared in a remarkable way. Photographs shown in Fig. 3 represent successive stages of the discharge in the coal gas when pressure was varied from 2·0 mm. to 82.0 mm. In a tube containing hydrogen only one such band was observed at a pressure of about 7 cm., and no more, while in oxygen no such luminous band could be detected.

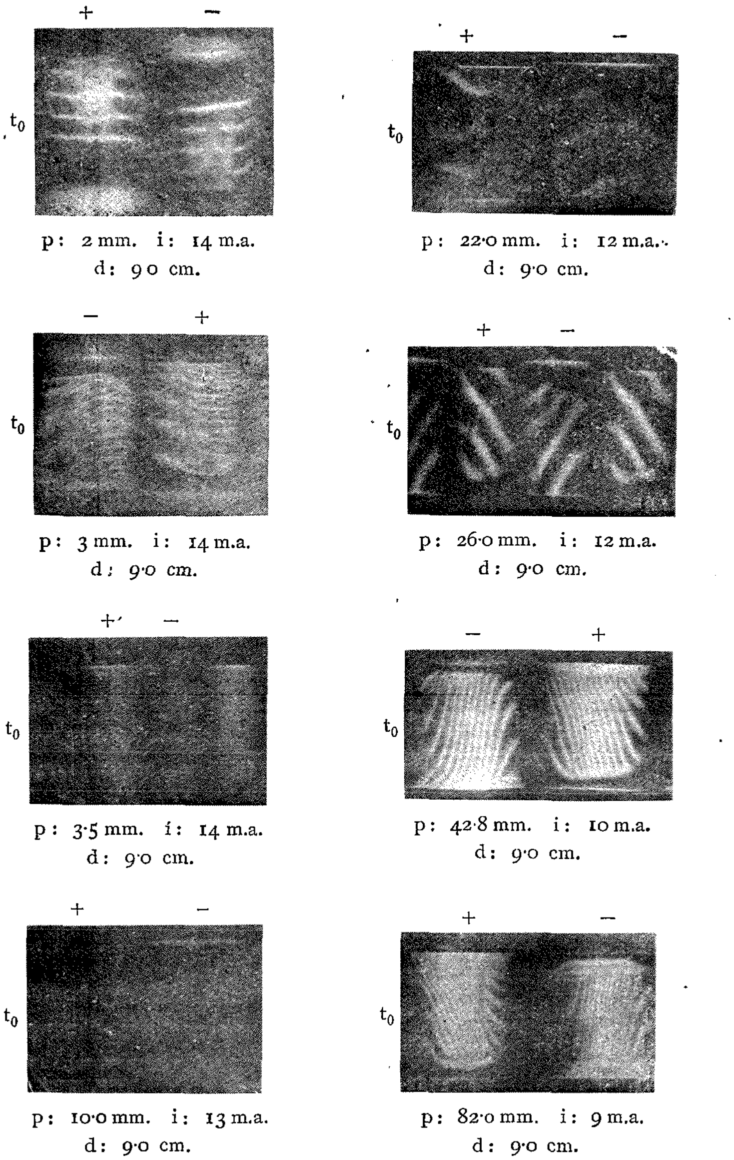


Fig. 3.

Now, it appears from the photographs given above that the luminosity was set up in the neighborhood of the anode, and thence proceeded toward the cathode. A question then naturally arises: how does it so proceed? At first sight, this seems to resemble the steamer observed by Schuster and Hemsalech[1] in a spark discharge. According to Milner[2] it is the cathode from which the steamer emanates, but he also remarked that there is, however, in all cases a tendency to a discharge from the anode, and that with soft metals this becomes very pronounced, being very strong, as in the case of the cathode steamer. In our case, it is, however, the anode from which the luminosity apparently started, and no luminosity starting from the cathode could be detected. Thus these luminosities seem not to be related to the so-called steamer of Schuster and Hemsalech.

Next, the supposed velocities with which the luminosity proceeded from the anode were roughly measured from their inclinations, the velo-

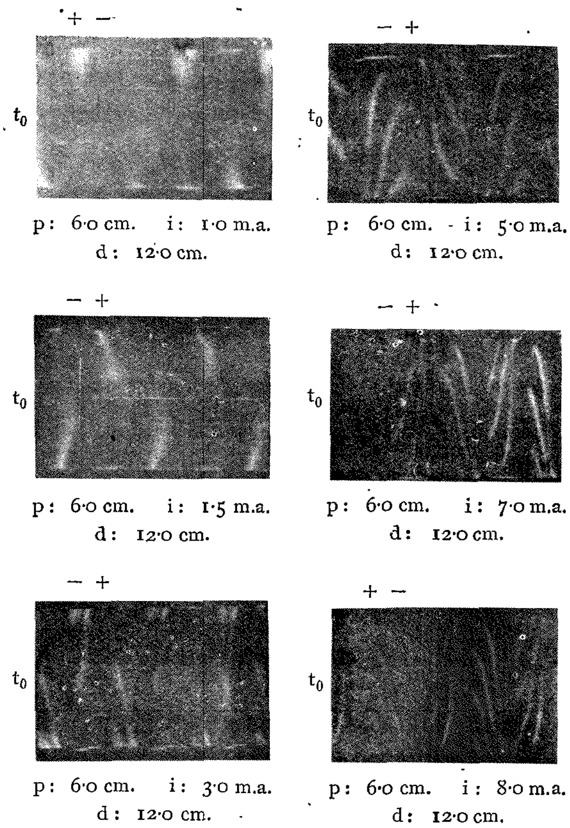


Fig. 4, a.

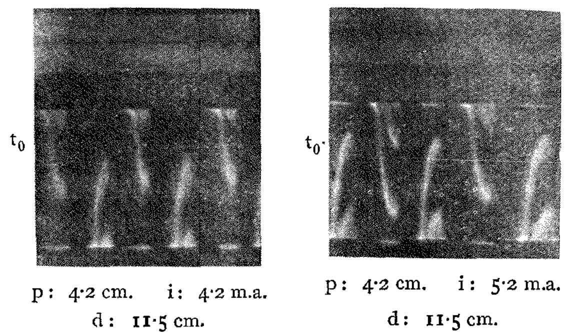
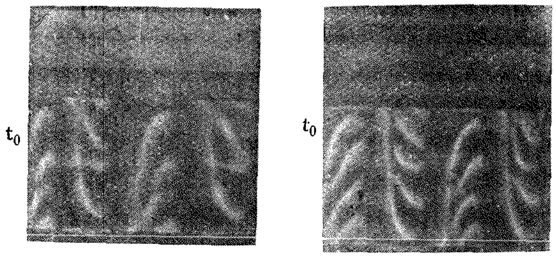


Fig. 4, b.

[1] Phil. Trans., **193** A, 189 (1900).

[2] Phil. Trans., **209**, 71 (1909).

city of falling plates being determined by means of tuning fork recorded on the photographic plates as shown in Fig. 4, b. In a certain case, the initial velocities of the first five luminosities were found to be 75·0, 66·3, 55·3, 40·9, and 37·5 m/sec. respectively, the pressure being about 20 cm. These values appear to be too small for velocities of positive atomions acquired by passing through the anode fall, and also it is hardly conceivable that luminous particles should have travelled from the anode to such great distances in the air at a pressure of 20 cm.



p: 4·2 cm. i: 6·8 m.a. d: 11·5 cm. p: 4·2 cm. i: 8·0 m.a. d: 11·5 cm.

Fig. 4, b.

The maximum distance travelled by the first luminosity increased with the pressure when the current was kept constant. This is clear from the preceding figures. This maximum distance also increased with the current in the tube when the pressure was kept constant as shown in Fig. 4. The accompanying curves also represent these two relations.

The first of these facts is inconsistent with the idea that the luminosity is due primarily to the anode. The phenomenon can be explained by assuming that the luminosity is caused by ionization due to electrons coming from the

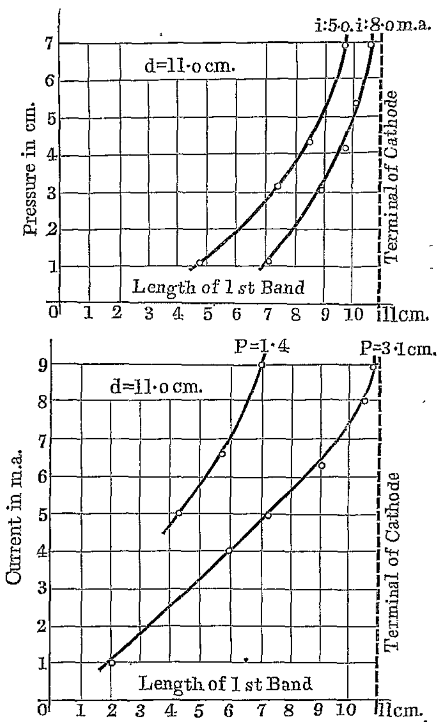


Fig. 5.

cathode. Beside this, all the facts mentioned before, namely, that the luminous bands got broader as the pressure was increased, that cathode ends were thicker than the remainder, and that the cathode side of the band was brighter and lined by a thin but bright layer, are all in harmony with the above mode of explanation.

This is confirmed by the plates obtained when the tube was excited by an induction coil. Reproductions of such photographs were shown in Fig. 6. It will be noticed that the discharge consisted of a series of partial ones, and that the first discharge made its whole path uniformly luminous, while the following ones gave alternately bright and dark spots. Thus the discharge, when analysed by a rotating mirror, presents an appearance exactly as if the luminosity proceeded toward the cathode. But the real nature of the phenomenon is that a luminous place changed its position at successive instants.

The difference of the figures shown by the luminous bands produced by transformer and coil discharges as shown in Figs. 7 and 8 depends upon the form and the magnitude of the current in the tube. This will be seen from the record of an oscilloscope as shown in the left hand side of the photographs. In a transformer discharge,

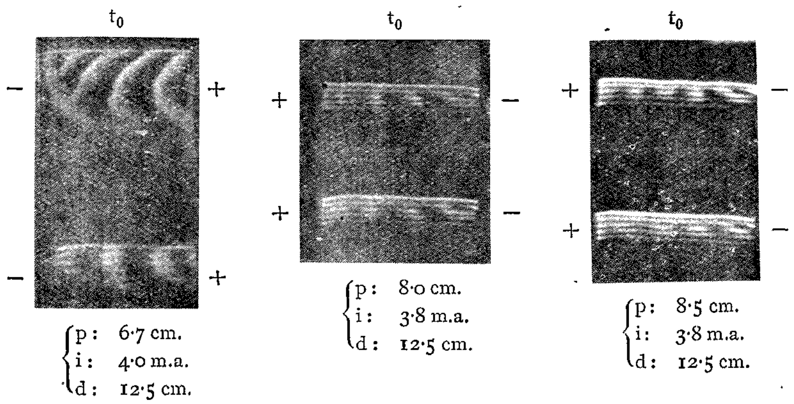


Fig. 6.

the current is initially zero, and the corresponding luminosity appears in the neighborhood of the anode, while in the case of the coil discharge the current is maximum at its start, giving the first luminosity at a place very near the cathode.

Thus the process of formation of the luminous patches at a relatively high pressure seems to be similar to that of striation in the

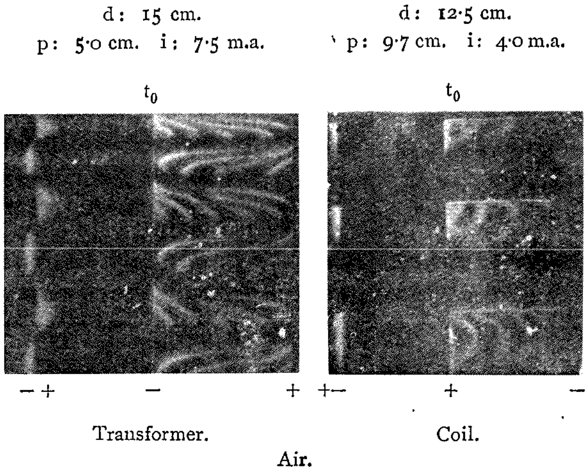


Fig. 7.

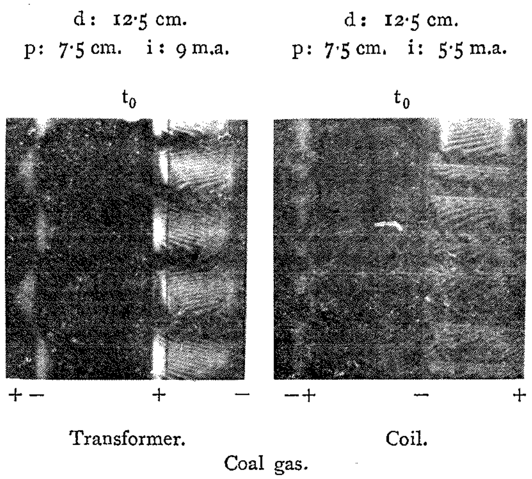


Fig. 8.

positive column. The only difference to be considered is that in the case of the positive column the distance between the striae is smaller than the mean free path of the gas molecules in the discharge tube, while in the case o the luminous patches their distance is generally greater than the free path.

To sum up, the formation of the luminous bands may now be conveniently explained in the following way. As the potential difference acting on the terminals of the discharge tube is increased, positive ions bombarding the cathode will produce a number of electrons which, driven by an intense electric field in the neighborhood of the cathode, will acquire sufficient kinetic energy to make the gas luminous. By this process they lose their velocities, and consequently their path becomes dark. But they soon regain sufficient energy after having travelled through certain distances, and then they make the gas luminous again. This process will go on repeatedly giving alternately dark and bright spots. Thus for a single partial discharge the distance between bright and dark spots should be nearly equal, and it should increase as the potential difference between the terminals is lowered. This will be seen to be the case in our preceding photographs.

Summary

1. Electric discharges through tubes containing the air, hydrogen or coal gas at pressures of a few centimeters were examined with a falling plate camera, and the apparently unstriated discharges consisting of a number of luminous bands were studied.
2. An explanation of formation of these luminous bands was given.

It is here desirable to add the following. The present invetigation was started at the beginning of October, 1919 and finished at the end of April, 1920. While this paper was going through the press, Drs. Aston and Kikuchi's papers dealing with the similar subject appeared in the *Nature* [vol. 105, 633 (1920)] and also in the *Proceedings of the Royal Society of London* [A. vol. 98, 50 (1920)].

In conclusion, the writer wishes to express his hearty thanks to Prof. M. Kimura for his valuable suggestions he has given throughout the work.