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Abstract

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FORMATION OF THE PLASMA STRUCTURE DURING THE DEVELOPMENT OF A DISCHARGE

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As is known, the plasma of a discharge in long discharge gaps, usually called the positive column, does not always constitute a homogeneous region. Under many conditions the positive column breaks up into luminous layers separated by darker intervals. In such cases the density of charged particles of either sign, the drift velocities of the particles, the electron temperature, and other electrical and kinetic quantities of the plasma have along the axis of the discharge the same periodic, or almost periodic, variation as the brightness of the gas glow.

We investigated the process by which spatially stable layers are established in pulsed discharges at pressures of 4.5, 3.8, and 2.8 mm Hg in hydrogen. The discharge vessel was a cylindrical glass tube 3 cm in diameter, provided with two plane electrodes separated from one another by 9 cm. As the power source for the discharge tube, a generator of repeated microsecond pulses was used. Control of the pulse shape and measurement of its duration were carried out by means of a synchroscope with a special time calibration built into the generator. The pulse had a sufficiently good rectangular shape. The duration of the leading edge of the pulse was 0.1 μsec; the duration was varied from 1 to 10 μsec; the repetition frequency was 100 pulses per second. The amplitude of the current flowing during the pulsed discharge was maintained everywhere equal to 1 A. Between pulsed discharges there elapsed a considerable time, necessary for the decay of the plasma from the preceding discharge.

By varying the duration τ of the voltage pulse applied to the tube, we could interrupt the process of formation of the layered positive column at various stages. In this way the sequence of phenomena shown for a pressure of 3.8 mm in Fig. 1 was observed. Taking into account that the exposure time in photographing was 1/20 sec, it should be noted that the photographs gave an image of the integral picture for 5 entirely identical discharges. In Fig. 1, *a* the discharge is shown at the stage ($\tau = 4$ μsec) when it fills the tube with the glow of the cathode region, the Faraday dark space, and the homogeneous glow of the positive column. At a pulse duration of about 4.5 μsec, on the cathode side of the positive column one can discern one indistinct stable layer (Fig. 1, *b*). As τ is further increased, new layers arise one after another at equal distances from one another. The distance between corresponding points of neighboring layers (the layer length) d_s is equal to 2.7 mm. Although the moments at which individual layers appear cannot be established with great accuracy, since the outlines of the layers emerge and become distinct gradually, it can nevertheless be said with certainty that their total number grows proportionally to the time elapsed after the appearance of the first layer. The observations gave the following numbers of layers n in the positive column for various pulse durations τ:

τ, μsec	4.5	5	6	7	8	9	10
n	1	2*	3*	4*	4	5	6*

* The last layer on the anode side is indistinct.

We see that the formation of each subsequent layer takes, on average, a time T somewhat greater than 1 μsec. This description applies

and for pressures of 4.5 and 2.8 mm Hg, except that the pulse duration $\tau = \tau_k$, at which the first stable layer begins to be traced at the start of the positive column, and also the layer length d_s, have different values for different pressures, as shown by the following data:

p, mm Hg	2.8	3.8	4.5
d_s, mm	4	2.7	2
τ_k, sec	7	4.5	3

The simplest explanation of the observed phenomena may be based on the assumption that the formation of layers stable in space begins after the cathode region approaches the steady state corresponding to the developing discharge.

At low pressures the development of a self-sustained discharge is caused by a strong increase of electron avalanches in the gas. Oscillographic recording of the development of the discharge under these conditions shows that between the moment of breakdown onset and the moment when the breakdown current reaches a steady value, depending on the pressure and type of gas, the distance between the electrodes, and the magnitude of the overvoltage on the electrodes, there elapses a time of the order of from 1 μsec to several tens of microseconds ([1,2]). It is assumed that during this time, in the near-cathode region, an accumulation of space-charge density occurs, determining the cathode potential drop, and a plasma is formed that serves to transmit current from the cathode region to the anode. Druyvesteyn indicates ([3]) that the transition from a Townsend discharge to a self-sustained high-current discharge is characterized by instabilities and oscillations.

Denoting the statistical delay time by t_1 and the time of passage of the current through the tube by t_2, we have $\tau = t_1 + t_2$. Under the experimental conditions t_1 could amount to tenths of microseconds, and it may be neglected in comparison

Fig. 1. a $-\tau = 4$ μsec; b -4.5 μsec.; c -6 μsec.; d -9 μsec. On the left is the cathode.

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with the magnitude of t_2. It should be assumed that the time τ_k is identical with the time of formation of the cathode region with a definite cathode drop suitable for the usual form of glow discharge. As is seen from the results presented above, this time decreases with increasing pressure. Let us note that an analogous result was obtained earlier for the dependence of the breakdown development time on pressure ([1]). The rate at which the stratification of the positive column occurs may be characterized by the quantity d_s/T, which increases with decreasing pressure, since in this case the layer length d_s increases; at a pressure of 3.8 mm this rate is approximately $2.7 \cdot 10^5$ cm/sec.

Thus, the experiment described showed that, during the development of the discharge in time, regular layers fixed in space arise earlier on the cathode side of the positive column, and the layered state gradually spreads toward the anode at a rate reaching several thousand meters per second. The results obtained do not contradict Thomson' s theory ([4]), according to which the layers in the discharge represent, in a certain sense, a repetition of the cathode region.

It is necessary to note that, beginning with a pulse duration of about 7–8 μsec, together with the stable layers located on the cathode side of the positive column, trembling layers are observed in all the remaining part. In Fig. 1 the trembling layers appeared in the form of indistinct transverse bands. There are no indications that the appearance of such layers is directly connected with the conditions existing near the cathode.

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CITED LITERATURE

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[4] J. J. Thomson, G. P. Thomson, *Conduction of Electricity through Gases*, 2, 1933.

Fig. 1. *a* $-\tau = 4$ μsec; *b* -4.5 μsec.; *c* -6 μsec.; *d* -9 μsec. On the left is the cathode.

Note: Figure translations are in progress. See original paper for figures.