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AN UNCONSTRICTED POSITIVE COLUMN OF A HIGH-VELOCITY FLOW OF GAS

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The creation of a homogeneous unconstricted discharge in large-diameter tubes with high pressures of the gas is of importance for a number of problems in quantum electronics, plasma physics, etc.

It is well known that, with pressures of the gas greater than 10 mm Hg, the positive column of a glow discharge is constricted, i.e., it is forced toward the axis. In [1-9] various mechanisms for explaining this phenomenon are discussed. The general criterion for a strongly compressed current pinch is inhomogeneity of the temperature over the radius of the tube. Article [10] gives the results of an investigation of the constriction of a positive column in a longitudinal flow of gas.

An unconstricted discharge in a flow of gas was obtained in [11] in a supersonic nozzle located between the cathode and the anode. It is assumed that a uniform discharge is achieved as a result of the development of shock waves in the discharge.

In [12] an unconstricted discharge in a tube was set up thanks to a nozzle made of metal, which at the same time served as the cathode. The gas entered the discharge tube through the nozzle. An unconstricted discharge, uniform over the cross section, was observed under the most greatly differing flow conditions of the gas, with both subsonic and supersonic nozzles. From this the conclusion is drawn that turbulence of the flow is of very little importance in the formation of a uniform discharge.

The present article reports the conditions necessary for obtaining a uniform, unconstricted discharge at high pressures of a high-velocity flow of gas (without a nozzle). It is shown that the unconstricted character of the discharge is due to the appearance of a turbulent flow of gas. The experiments were made in a glass water-cooled tube with an inside diameter of 10 and 15 mm and a length of from 10 to 30 cm, with cylindrical electrodes. The gas was introduced radially into the anode section.

In a tube with an inside diameter of 10 mm, in a flow of He a velocity of 250 m/sec was achieved by connecting a pump with a capacity of 0.0183 m^3/sec to the cathode section. The value of the gas velocity increased by 5-10% with the ionization of the discharge gap by a current of 30 mA. The temperature of the gas, measured with a thermocouple, increased by 3-5°C on the average. The velocity of the flow was measured with a Pitot tube, introduced into the middle of the discharge tube. A velocity of the gas of 40 m/sec was achieved by connecting-in a pump with a capacity of 0.0033 m^3/sec.

The positive column was investigated with discharge currents of 0.01-0.075 A. Electrical breakdown occurred at a gas pressure of 10^{-1} mm Hg. With a direct current, the pressure in the tube increased. Up to p = 3 mm Hg, the luminescing region of the positive column fills the whole volume of the tube (a diffusion discharge). A further increase in the pressure of the gas leads to a constriction, as a result of which the

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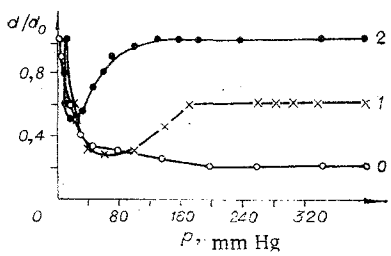

Fig. 1

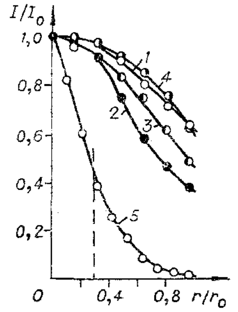

Fig. 2

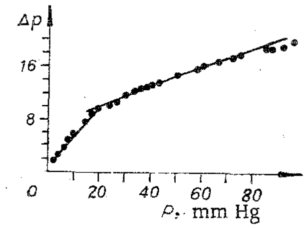

Fig. 3

diameter of the visible boundary of the positive column decreases. The start of the constriction is fixed by a jumpwise lowering of the value of the voltage drop at the electrodes (by approximately two times).

Figure 1 shows the dependences of the diameter of the positive column on the pressure of He. The diameter was determined from the luminescence of the visible boundary of the positive column.

After a sharp decrease in the diameter of the current pinch in a flow of He with a velocity of 250 m/sec (curve 2), a further increase in the pressure of the gas leads to an increase in the diameter of the positive column and, with p = 80 mm Hg, the luminescing region of the discharge again fills the whole volume of the tube.

The diameter of the positive column in He with a velocity of 40 m/sec (curve 1) after constriction does not exceed 6 mm with an increase in the pressure of the gas up to 700 mm Hg.

For purposes of comparison, Fig. 1 gives curve 0, describing the dependence of the diameter of the positive column in a discharge without a flow of gas (v = 0). A strongly constricted state arises with pressures of 50-100 mm Hg. An increase of the pressure up to 700 mm Hg does not lead to any appreciable change in the diameter of the pinch.

Double electrical probes were used to make probe measurements (Fig. 2) of a diffusion discharge in a flow of He with p = 3 mm Hg (1) (v = 250 m/sec), constricted in a flow of He with p = 22 mm Hg (2), with p = 58 mm Hg (3), unconstricted with p = 78 mm Hg (4), and constricted in the absence of a flow of gas (v = 0) with p = 50 mm Hg (5).

The distribution of the probe saturation current over the radius in a diffusion-type positive column corresponds to the Schottky theory [13]. In a constricted discharge with p = 22 mm Hg, the distribution is steeper. In the case of an unconstricted discharge (curve 4), the distribution of the probe current over the radius becomes close to parabolic.

Curve 5 in Fig. 2 is in good agreement with the well-known bell-shaped distribution of the charges over the radius of a positive column in a constricted discharge in the absence of a flow [13]. On curve 5 of Fig. 2, the dashed line is a plot of the diameter of the visible diameter of the pinch. The intersection of the straight line with curve 5 is confirmed by analogous data in [13]. Consequently, the probe measurements of a positive column shown in Fig. 2 with different pressures of the gas in the discharge are in qualitative agreement with the results given in Fig. 1 and confirm the possibility of creating an unconstricted discharge at high pressures by a high-velocity flow of gas.

Figure 3 shows the dependence of the difference in the pressures Δp at the inlet and outlet of a tube with a length of 200 mm and a diameter of 10 mm (the pressure difference was measured with a U-shaped manometer) on the static pressure in the middle of the tube with v = 250 m/sec. The static pressure was measured at the inlet and outlet of the tube with U-shaped mercury manometers. The curve undergoes a point of inflection at 20 mm Hg, which coincides with the minimum on curve 2, Fig. 1. The point of inflection indicates that, at this pressure, there is a change in the character of the flow of the gas. Up to 20 mm Hg, there is fully established laminar flow of the gas. With a pressure greater than 20 mm Hg, the flow loses its stability. Immediately after the loss of stability, a new turbulent character of the flow of the gas is established.

Under the action of turbulent pulsations, at determined pressures there can arise in the flow both vibrations of the positive column as a whole and local oscillations of the ionization density in an unconstricted column. The investigation of these vibrations is of importance for a number of practical applications of a discharge in a high-velocity flow of gas.

In [12], where the gas was fed into the discharge region through a nozzle, there were chaotic combustion conditions of the discharge; under these circumstances, there were irregular vibrations of the positive column. With pressures from 25 to 45 mm Hg, chaotic combustion conditions could be observed; under these circumstances, the needle of the M265M microammeter, used to measure the probe current, performed small fluctuations around a mean value. However, with larger pressures of the gas, where the discharge was unconstricted, the vibrations became inappreciable. The question of investigating the fluctuations of the ionization density in a discharge in a high-velocity flow of gas must be considered separately.

Dependences analogous to those presented on Fig. 1 were also obtained for CO_2, argon, and air, and lead to the conclusion that the diameter of a constricted positive column in a high-velocity flow increases with an increase in the pressure of the gas, and the luminescing region of the discharge fills the whole volume of the tube, thanks to the turbulent flow of the gas.

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