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Similarity of gas discharges at low pressure in the gaps between two plane-parallel electrodes

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The experiments show that the breakdown voltage of the gap between plane-parallel electrodes can be expressed with $U_b = f(p{\cdot}d, d/r)$ where p, d, r are gas pressure, gap length and electrode radius, respectively. It was proved that $U_b = f(p{\cdot}d, d/r)$ fulfils two necessary conditions for the similar discharges, which implies that $U_b = f(p{\cdot}d, d/r)$ is an expression of the similarity theorem in non-uniform electric field. There exist similar glow discharges in argon only when the scaled-down factor k for the two gaps is limited, which was explained that the forbidden processes such as the stepwise ionization and the inelastic collision of second kind violate the similarity of discharge as k increases. The Paschen's curves for the gaps with a same d but different r intersect as p rises, which was explained based on the mean free path length of the electrons inversely proportional to p and the electron impact ionization coefficient exponentially increasing with the electric field.

If two gaps are similar in geometry with all linear dimensions in proportion, they are called geometrically similar gaps. If the discharges in these gaps have same voltage-current characteristics, they are said to be similar. For the similar discharges, the physical parameters of the plasma in one gap are proportional to those in the other gap. Similarity of gas discharge enables us to use the known properties of the discharge in one gap to extrapolate the features of the discharges in the other geometrically similar gap for which the experimental studies may not be feasible or even possible.

Paschen's law, $U_b = f(p{\cdot}d)$, described the gas breakdown in uniform electric field. Townsend indicated that Paschen's law is just a special case of a more general similarity theorem which can be applied equally to the discharges in non-uniform fields if the discharges are dominated by the electron collision. In this paper, the results from the investigation of the discharge similarity in low-pressure gas between plane-parallel electrodes were presented.

It was found by experiments that the breakdown voltage of the gap depends not only on the product of gas pressure p and gap length d but also on the aspect ratio of the gas gap d/r where r is the electrode radius, *i.e.*, $U_b = f(p{\cdot}d, d/r)$. It was mathematically proved that $U_b = f(p{\cdot}d, d/r)$ fulfils two necessary conditions for the similar discharges in the non-uniform electric field, which implies that $U_b = f(p{\cdot}d, d/r)$ is an expression of the similarity theorem in the breakdown of a gap between two plane-parallel electrodes and confirms the Townsend's prediction that the general similarity theorem can be applied equally to the breakdowns in non-uniform fields.

It was also found by experiments that there exist similar glow discharges in argon only when the scaled-down factor k for two geometrically similar gaps is limited. By theoretical analysis, it was explained that the forbidden processes such as the stepwise ionization and the inelastic collision of second kind violate the similarity of discharge as k increases, which was verified by the numerical simulations of the discharges with or without these two forbidden processes taken into account.

The intersection of Paschen's curves for the gaps with a same gap length but different electrode radius was observed. While the breakdown voltage increases with the increase of the nonuniformity in the electric field of the gap at lower pressures, it decreases at higher pressures. The reason for the intersection of Paschen's curves was given based on the mean free path length of the electrons inversely proportional to the gas pressure and the electron impact ionization coefficient exponentially increasing with the electric field. The intersection of the Paschen's curves was qualitatively reproduced by numerical simulation.

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