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Calculation of ionization and runaway electrons characteristics in helium with iron vapor

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On the basis of the Monte Carlo method and the many particles dynamics, the ionization and drift characteristics of electrons in a constant field drifting in helium with a certain amount of iron vapor are calculated. The main attention is paid to the study of the influence of iron vapor concentration on the characteristics of escaping electrons. The formulation of the problem involves the death of electrons on the wall and the balance between the birth of ionization and leaving the escape mode (whiz). The obtained results indicate a sharp change in the ionization characteristics when an easily ionizable additive in the form of iron vapor is added to helium. Starting with a fraction of a percent of the concentration of iron atoms in helium, due to the strong ionization of iron atoms, there is a strong change in the electron distribution function, which leads to a significant increase in the frequency of ionization and a non-monotonic dependence of the number of escaping electrons on the concentration of iron vapors.

Key words: gas discharge, electron runaway, ionization, collision simulation, helium, iron vapor.
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1. Introduction

In a strong electric field, electrons can, under certain conditions, gain more energy than they lose in collisions with atoms, ions, and electrons. This phenomenon was first considered by Wilson in 1925 [1]. Such electrons, called escaping electrons, play an important role in the physics of fully ionized plasma [2, 3], the physics of atmospheric electricity [4-6], and thermonuclear fusion [7].

Fast electrons with energy significantly exceeding the threshold excitation and ionization energies are usually also represented in low-temperature plasma of gas discharges [8, 9]. Sometimes they have a decisive influence on the characteristics of the discharge. In particular, it is escaping electrons that influence the mechanism of formation of lightning discharges not only in the earth's atmosphere, but also on other planets [10].In low-temperature plasma, escaping electrons are also used to form active laser media, in particular, copper vapor lasers, to generate powerful subnanosecond electron beams in dense gases[11].

Iron vapors in the gas can appear due to sputtering of the iron cathode by ions of the working gas in the glow discharge, due to explosive processes at the cathode in pulsed discharges at high overvoltages. Therefore, the analysis of the influence of small impurities of metal atoms on the ionization-drift characteristics of discharges is an urgent task [12, 13].

2. Problem statement

The processes of excitation, ionization and recombination in real conditions often cannot be taken into account in the framework of a spatially homogeneous model when modeling by swarm drift particles (swarm) of electrons in a gas. Nevertheless, the model of a spatially homogeneous, stationary electron flow can even better show the influence of individual factors on the discharge, since it lacks very significant factors of influence of a spatial and temporal nature. It is this task that is set in this paper – the influence of an easily ionizable impurity on the characteristics of electron drift [11].

The following characteristics of the electron system (see [12 – 20]) were calculated by the swarm particle drift (swarm) method in a gas: the drift velocity, the average energy and the characteristic Townsend energy, which is determined by the ratio of the transverse diffusion and mobility coefficients, the ionization coefficient of Townsend, the Stoletov constant, the energy distribution function and the electron runaway coefficient introduced by analogy with Townsend's second ionization coefficient.

The balance of particles in the simulation were maintained as follows:

1) the act of ionization by electron impact for incident electron the atom loses energy equal to the sum of ionization energy and kinetic energy of the knocked out electron, the energy is redistributed equally between them, and a new electron replaces the most energetic electron in the system;

2) when an electron reaches a certain threshold energy: – the electron was considered to be escaping and instead a new one was introduced into the system, randomly selected from the swarm. Such procedure of replenishment of particles instead of the left does not change energy distribution function of electrons.

3. Results of calculations and their discussion

A detailed analysis of the distribution functions shows that they can in no way be described by any one-parameter function with an effective temperature determined by the relation. Several characteristic energy ranges can be distinguished in the calculated in the computational experiment, the distribution of energy distribution function of electrons is determined by the dominance or competition of various processes:

1) the subthermal energy region, the distribution in this range is largely determined by the acts of excitation and ionization, after which the electrons are in the region of low energies;

2) the region of thermal energies, the distribution in this range is determined by the drift in the energy space with the diffusion coefficient determined by the elastic collision cross section;

3) the energy domain, the distribution in this range is determined by the drift in the energy space and the slope of the line in the linear approximation of the excitation cross-section;

4) the energy domain , the distribution in this range is determined by the drift in the energy space and the slope of the line in the linear approximation of the ionization cross-section;

5) the energy region ,the distribution in this range is determined by the effect of escaping electrons.

A detailed analysis of the distribution functions shows that they can in no way be described by any one-parameter function with an effective temperature determined by the relation $1.5T_{eff} = <\varepsilon>$. Several characteristic energy ranges can be distinguished in the calculated in the computational experiment, the distribution of energy distribution function of electrons is determined by the dominance or competition of various processes:

1) the subthermal energy region $\varepsilon < T_{eff}$, the distribution in this range is largely determined by the acts of excitation and ionization, after which the electrons are in the region of low energies;

2) the region of thermal energies $\varepsilon < E_1, I$, the distribution in this range is determined by the drift in the energy space with the diffusion coefficient determined by the elastic collision cross section;

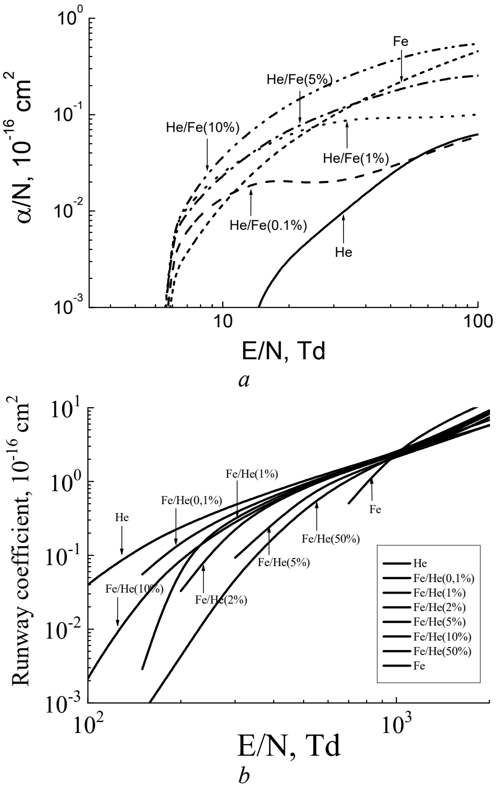
3) the energy domain $E_1 < \varepsilon < I$, the distribution in this range is determined by the drift in the energy space and the slope of the line in the linear approximation of the excitation cross-section;

4) the energy domain $I < \varepsilon < I + 3T_{eff}$, the distribution in this range is determined by the drift in the energy space and the slope of the line in the linear approximation of the ionization cross-section;

5) the energy region $\varepsilon >> I + 3T_{eff}$, the distribution in this range is determined by the effect of escaping electrons.

This division of characteristic regions of electron energy is very conditional, its main purpose is to indicate the importance of multifactoricity in the formation of electron energy distribution in different regions of the energy spectrum [9, 12, 15], which does not allow to apply the concept of temperature to the electronic component of the gas discharge.

The aim of this work is to present new computational data on the characteristics of electron drift in the He-Fe mixture. The results of the calculations allow us to estimate the influence of the percentage composition in the helium – iron mixture on the characteristics of electron drift in a constant, uniform electric field in the range from 1 to 1000 Td, typical for discharges in a gas.



a

b

Figure 1 – a) the dependence of the reduced ionization coefficient on the concentration of Fe in He; b) the dependence of the reduced electron runaway coefficient on E / N at various concentrations of Fe.

Of interest is the question of the maximum energy efficiency of maintaining the gas discharge. The calculations show that at E/N=10 Td the largest share of energy spent on ionization by electron at 1% concentrations of iron atom, and when E/N=20 Td high proportion of the cost of ionization is achieved at 2 % concentration *Fe*.

4. Conclusions

Based on the Monte Carlo simulation method and the dynamics of many particles, the ionization and drift characteristics of electrons in a constant field drifting in helium with a certain amount of iron vapor were calculated. The main attention is paid to the study of the effect of the concentration of iron vapor on the characteristics of runaway electrons.

The statement of the problem includes the death of electrons on the wall and the balance between birth during ionization and escape into runaway mode. The results obtained indicate a sharp change in the characteristics of ionization and runaway electrons when iron vapor is added to helium. Starting from a fraction of a percent, due to the strong ionization of iron atoms, a sharp change in the electron distribution function occurs, which leads to a significant increase in the ionization frequency and the nonmonotonic dependence of the number of runaway electrons on the concentration of iron vapor.

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