Stepwise ionization of gas discharge plasma of inert gases

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General principles are discussed for a gas discharge plasma involving excited atoms where electron-atom collision processes dominate. It is shown that an optimal mode kinetic model of this plasma at not large electric field strengths may be based on the rate constants of quenching of excited atom states by electron impact. The self-consistent character of atom excitation in a gas discharge plasma is of importance and results in the influence of the excitation process on the tail of the energy distribution function of electrons, that in turn influences on the excitation rate.

The ionization rate constants evaluated for an inert gas uniform gas discharge plasma in the regime of a high electron density where the Maxwell distribution function is valid for a corpus of EEDF. In the scheme under consideration, electron-collision and radiative processes are taken into account. Along with the processes involving the ground atom states with the electron shell np^6, 4 states with electron shell $np^5(n+1)s$ and 10 states with the electron shell $np^5(n+1)p$ are taken in consideration. The radiative and electron-atom collision processes are represented in Fig.1. In principle, the scheme under consideration is similar to that used in [1], but we analyze more careful the cross section of used processes. For example, the absorption coefficient for resonant radiation in the indicated paper is in 7 times smaller that followed for accurate data.

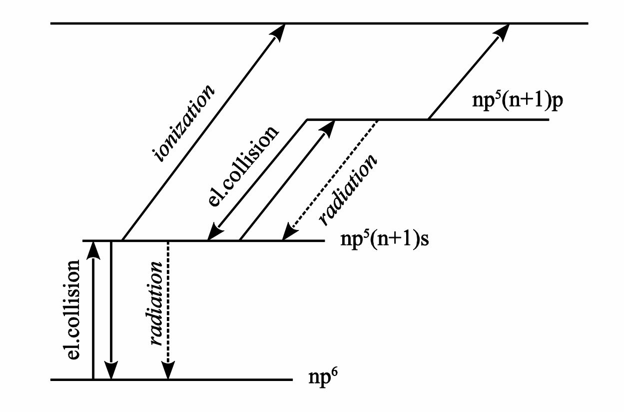

Fig.1 The radiative and electron-atom collision processes

The peculiarity of kinetics of a gas discharge plasma is that the theory does not allows to evaluate the cross sections of electron-atom collisions reliable in an arbitrary range of electron energy, whereas we have scanty information from experiments. Therefore, the data used are based on the similarity laws and theoretical energy dependencies for the cross sections based on experimental results [2]. In particular, it is used that the transitions resonantly coupled states are more effective than those involving other states, we are based on the cross sections of excitation of alkali atoms by electron impact for the cross sections of excitation and quenching of inert gas atoms by electron impact. In addition, states with the same electron shell are joined in blocks in accordance with the block model [3] in the cases when it is possible. The self-consistent character of atom excitation is of principle and means that excitation of atom states leads to a decrease of EEDF near the excitation threshold, that in turn causes a decrease in the excitation rate. Quenching of atom excitation states by electron impact near the threshold gives a specific form of EEDF [4]. From this it follows also that population of highly excited atoms is small compared to low excited states, and therefore highly excited states give small introduction to stepwise ionization. These effects are included in the scheme under consideration.

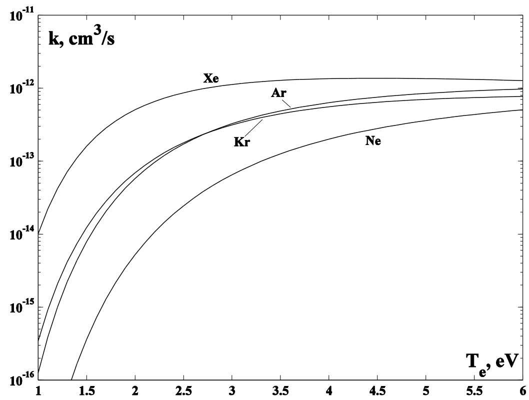

Fig.2 Excitation rate constant by electron impact

Along with the cross sections transitions between states related to different electron shells as a result of electron-atom collisions, mixing of states of the electron shell $np^5(n+1)s$ is of importance, because the population of the metastable and resonant states of this group of atom states is different. Within the framework of the model under consideration, one can represent this process as a result of exchange of an incident and valent electron when they have different directions of spins. Then the final state follows from statistical consideration, and the exchange cross section of electron-atom collisions is taken from the analysis of other processes.

As a result, we evaluate the rates of atom ionization depending on the electron temperature and the number densities of atoms and electrons. These data may be used for an inductively excited plasma [5] or to a plasma of the discharge positive column. In the latter case it is necessary takes into account heat processes and diffusion of electrons and excited atoms. In addition, the scheme used may be a basis of a computer code to analyze a no uniform gas discharge plasma of inert gases and their mixtures for regimes where the processes under consideration are important along with transport of electrons, ions and metastable atoms.

We also note that often-numerical computer modelling is opposed often to analytic methods in the modelling of kinetics of a gas discharge plasma. It is not correct because, on the one hand, a gas discharge plasma is a complex physical object and requires computer methods in any case and, on the other hand, the analysis of rate constants of appropriated processes is necessary for this modelling. Never the less, we can conclude on the basis of our experience that on the contemporary stage of study, namely the careful analysis of the rate constants of processes is required for the reliable plasma modelling.

References

[1] N.A.Dyatko e.a. J.Phys. **41D**, 055204(2008)
[2] B.M.Smirnov. *Theory of Gas Discharge Plasma.* (Berlin, Springer, 2015)
[3] L.M.Biberman, V.S.Vorob'ev, I.T.Iakubov. Kinetics of Nonequilibrium *Low-Temperature Plasma*.(New York, Consultant Bureau, 1987)
[4] J.Bretagne, M.Capitelli, C.Gorse, V.Puech. Europhys. Lett. 3, 1179(1987)
[5] J.B.Boffard e.a. J.Phys. **45D**, 045201(2012)