FEATURES OF THE KINETIC PROCESSES IN A DUSTY PLASMA INDUCED BY A SHOCK WAVE PROPAGATING IN THE ATMOSPHERE

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The upper middle atmosphere contains different kinds of ions, clusters, and nanoparticles. The shock waves forming in the air over the vehicles crossing the upper and middle layers of the atmosphere with a hypersonic velocity perturb the atmosphere and induce the fast nonequilibrium processes in high temperature plasma behind the shock front. In the most cases the processes in such high temperature plasma are far from being equilibrium. The knowledge of the kinetic features of these processes for a given atmosphere composition, construction of the vehicle, and its flight trajectory is necessary to evaluate the energy and particle fluxes to the vehicle surface, for the definition of the effect of thermal protection erosion as well as ion and electron concentrations and number density of charged clusters and particles which cause the blackout effect.

For the past decades a great progress has been achieved in the understanding of different nonequilibrium processes that take place in high-temperature gases behind the shock wave propagating in the atmosphere, including the processes behind the leader shock over a spacecraft or an aircraft moving in the atmosphere [1, 2]. However, besides molecules, atoms, electrons, and ions the plasma in the post-shock flow may involve different clusters and nanoparticles that present in the background atmosphere (Aitken nuclear, micrometeorite dust, ionic clusters, etc.). They also may be formed over the vehicle surface due to ablation or erosion of vehicle thermal protection as well as clustering and aggregation of primary particles. However, up to now in modern studies there is no quantitative information about possible effects of the abundance of clusters and nanoparticles in the plasma behind the shock and plasma surrounding the hypersonic vehicle. The purpose of this paper is to analyse the influence of cluster and nanoparticle abundance in a flow behind the shock on the plasma properties.

In order to investigate the processes in dusty plasma that is generated behind the shock front, the novel kinetic model involving nonequilibrium excitation of vibrational and electronic states of atoms and molecules, dissociation, ionization, chemical transformation due to various plasma-chemical reactions involving excited and neutral species, clustering of monomers and nanoparticles, electron and ion attachment to nanoparticles, charging of cluster and particle aggregates has been developed. The possible role of these processes in dusty plasma forming at different parameters behind the leader shock and the hierarchy of its characteristic times are estimated. The influence of the nonequilibrium excitation of molecular vibrations and electronic states of the reagents behind the shock in the Earth's atmosphere on the electron and ion generation as well as dynamics and features of nanoparticle charging are considered.

The computations have shown that the formation of electronically and vibrationally excited O_2 and N_2 molecules in plasma-chemical reactions behind the shock front considerably influences the ionization processes due to the lowering of the barrier of chemoionisation reactions and results in a faster ion and electron formation. The abundance of a large amount of electrons and ions in the shock layer leads to charging of nanoparticles. If these nanoparticles have a high electroconductivity, they can acquire a significant charge on their surface. Even a rather small particle of 20nm diameter can be charged up to 20-30 negative elementary charges. Lager-size particles may accumulate 60-80 negative elementary charges. The positively charged nanoparticles are also abundant in the plasma. This influences considerably the plasma properties and may lead to aggregation of primary particles. At the region near the stagnation point and in the boundary layer over the vehicle where the gas residence time is larger than 0.5 s the coagulation of charged particles begins to influence significantly the size particle distribution, leads to the formation of larger-size aggregates and changes plasma properties.

References

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[2] Sarma G.S.R. (2000) Physico-chemical modeling in hypersonic flow simulation. Progress in Aerospace Sciences. V.36. p.281-349.