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Development of collisional-radiative model of xenon ions for electric propulsion devices

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Ⅰ. Introduction

In the recent years, the development of commercial space activities and space science missions are prosperous, which promotes the development of a variety of new electric propulsion (EP) devices. It is of great significance to master knowledge of the plasma characteristics and the dominant kinetic processes in different regions of a thruster, for modelling of the thruster and analyzing the mechanism of various physical phenomena. Besides, it can also be of assistance for the optimization of thruster design.

Collisional-radiative (CR) model reveals the kinetic processes of plasma. It is capable of support the optical emission spectroscopy, which is a kind of non-invasive diagnostic method that has bright prospect [1]. Since xenon is a commonly used propellant in EP systems, CR models for xenon has been widely studied. However, due to the limitations of fundamental physical data, e.g. inadequacy of cross sections, the CR modelling of xenon ions are not studied in detail. In this presentation, a CR model of xenon ions for EP devices is presented. The model is verified on several EP devices, by comparing the population distribution of excited species predicted by the model with the result measured by experiments [2]. An analyze of dominant kinetic processes in these devices is presented as well.

II. Cross section and coefficients

Experimental and theoretical studies on electron collision and radiative transition processes of atomic xenon states could be found in literatures. However, detailed studies on transitions of ionic states are very limited, and inadequacies of fundamental data of these processes limits modelling ionic states. In this work, a comprehensive study on the electron collision process and radiative transition of ionic xenon states is presented based on the fully relativistic Dirac *B*-spline *R*-Matrix (DBSR) method [3]. The targets and the collision systems are described by the Dirac-Coulomb Hamiltonian. Cross sections for electron collision processes and Einstein coefficients for radiative transitions are generated to support a comprehensive modelling of xenon EP plasma.

III. Collisional-radiative model and kinetic processes

Based on the above cross sections and coefficients, a CR model of xenon ionic $5p^46s$, $5p^46p$ and $5p^45d$ states is built. Level density distribution predicted by the model is compared with those measured in EP devices. For example, figure 1 shows the comparison of $5p^46p$ levels in the discharge channel of a Hall thruster. Take it by and large, the level densities predicted by the model are in agreement with those measured from experiment.

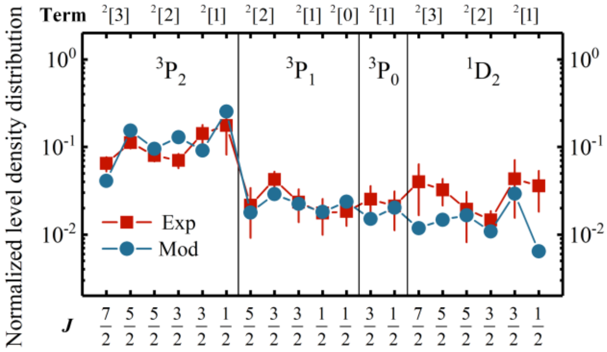

Figure 1 Comparison between level density distribution predicted by the model and measured by experiment.

Analysis for dominant kinetic processes of ionic excited levels is carried out based on the model. And it is found that for ionic $5p^46p$ levels, radiative decay is always the dominant de-population mechanism. Even when electron temperature is high enough to make the electron-impact ionization process an important de-population mechanism for atomic levels, radiative decay could still contribute more than 98% of the loss rate for ionic 6p levels. In those regions where electron temperature is relatively higher (for example, the acceleration region of Hall thruster), the contribution of electron-impact ionization excitation process in population $5p^46p$ level could not be ignored.

IV. Improvement of rate coefficients

The model could make an acceptable prediction of ionic level density distribution for $5p^46p$ levels that have ^3P cores. However, for some high-lying levels, there are perceptible differences between model and experiment. It may be due to the higher bound energy of these levels, which is close to the boundary of the R-Matrix method and lead to a relatively larger deviation. By using the idea of CDAP method [4], rate coefficients of some levels could be modified to improve the performance of the model.

References

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