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Investigation on Collision of Si^{2+} with H from Intermediate to High Projectile Energies

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Abstract. Total and state-selective charge transfer, ionization and stripping cross sections due to the collision of Si^{2+} ion with atomic hydrogen are investigated using the classical-trajectory Monte-Carlo (CTMC) method in the collision energy from 1 keV/amu to 10 MeV/amu. Total electron capture rate coefficient is obtained in the temperature range from 10^5 K^o to 10^8 K^o. Comparison with the data available shows that our CTMC results are reliable. The behaviors for these cross sections varying with the projectile energy are analyzed. A classical physical picture is presented to explain the reason behind the behaviors.

Key words: CTMC method; charge transfer; ionization; stripping.

1 Introduction

Charge transfer, collisional ionization and stripping, as important processes of heavy particle collisions occur in astrophysics and laboratory plasma physics universally. Charge transfer is the dominant collision channel for ions with energies below about 0.1 MeV/amu, above which ionization is the most important channel. Charge transfer provides a recombination mechanism for multiply charged ions in X-ray ionized astronomical environments where there may be sparse electron and atomic hydrogen abundances (see, for example, Lepp and McCray [17]). In the divertor region of a tokamak fusion device, charge exchange

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of impurity ions with neutral atom and molecules plays an important role in the ionization balance and the production of radiative energy loss leading to cooling (Krasheninnikov et al. [15,16], Janev et al. [12]) and in the core of plasmas, charge exchange spectra produced by neutral beam injections is also an important method to diagnose the populations of stripping impurities. Recently, it is found these ion-atom/molecule charge transfer processes are of particular significance to EUV and X-ray emission from comets and from planetary atmospheres. Soft X-ray emissions have been observed from many comets, including comet Hale-Bopp (Owens et al. [23]) and comet Hyakutake (Lisse et al. [18], Mumma et al. [21]). It has been suggested that these X-ray emissions are due to charge transfer of heavy solar wind ions (such as $\mathrm{O^{q+}}$, $\mathrm{C^{q+}}$, $\mathrm{Ne^{q+}}$ and $\mathrm{Si^{q+}}$, here $q=1-Z$ and Z is nuclear charge) with cometary neutral species such as H, O, $\mathrm{H_2}$, $\mathrm{H_2O}$, OH and CO(Cravens [5], Haberli et al. [11]). Indeed, recent analysis of X-ray and EUV spectra of comet Hyakutake (Krasnopolsky and Mumma [14]) is said to have confirmed that such charge transfer processes are responsible for the observed X-ray emissions. In a similar way, X-ray emissions from the Jovian aurora are thought to be driven by charge transfer in collisions of multiply charged oxygen and sulfur ions with atmospheric neutrals such as H, He, and $\mathrm{H_2}$ (Cravens et al. [6], Liu and Schultz [19]). Usually besides slow solar wind components, there exist fast solar wind components with the energies from 300 keV/amu to 3MeV/amu (Liu and Schultz [19]). The collision ionization of such fast charged ions with cometary neutral species or Jovian atmospheric neutrals is the most important way of their energy loss and becomes much more important than charge transfer. In the research of inertial confinement fusion (ICF), recent experiment shows the charge transfer may be important to explain some unusual high-intensity spectrum of silicon in the high-density and high-temperature plasmas (Elton et al. [8], Rosmej et al. [25]). In order to model and understand the behavior under these environments, it is necessary to obtain total and state-selective capture cross sections. Meanwhile, the ionization and stripping processes are the important competitive processes of electron capture. It is very necessary to include the ionization and stripping processes in the calculations because their cross sections are also needed in the simulations (Cravens et al. [6], Liu and Schultz [19]).

So far the collision processes of some charged ions such as $\mathrm{O^{q+}}$, $\mathrm{C^{q+}}$, $\mathrm{N^{q+}}$ with atomic hydrogen have been studied sufficiently in the analysis of X-ray and EUV spectra. However, there exist seldom data in the collisions of $\mathrm{Si^{q+}}$ ($q=1-14$) with atomic hydrogen. In the previous paper, we investigated the collision processes of $\mathrm{Si^{3+}}$ with atomic hydrogen from 10^{-2} eV/amu to 10^6 eV/amu (Wang et al. [29]). In the present paper, we study the collision processes of $\mathrm{Si^{2+}}$ with H, namely, the charge transfer

$$\mathrm{Si^{2+}}(3s^2)+\mathrm{H}(1s)\rightarrow \mathrm{Si^{+}}(3s^2nl)(n\geq 3)+\mathrm{H^+}, \tag{1.1}$$

the collision ionization

$$\mathrm{Si^{2+}}(3s^2)+\mathrm{H}(1s)\rightarrow \mathrm{Si^{2+}}(3s^2)+\mathrm{H^+}+\mathrm{e^-}, \tag{1.2}$$

and the stripping process

$$\mathrm{Si^{2+}}(3s^2)+\mathrm{H}(1s)\rightarrow \mathrm{Si^{3+}}(3s)+\mathrm{H}+\mathrm{e^-}, \tag{1.3}$$