Charge exchange between $W^{64+}$ and H for neutral-beam diagnostics in ITER

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Synopsis

Two variations of the Classical Trajectory Monte Carlo (CTMC) method are used to calculate the $nl$-resolved charge exchange (CX) cross sections between H and $W^{64+}$ in a wide range of collision energies from 10 keV/u to 1000 keV/u. The calculated cross sections are then used in an extensive collisional-radiative (CR) model for tungsten ions in order to calculate the CX spectra under typical conditions of neutral-beam diagnostics in ITER tokamak. The calculated CTMC cross sections and the simulated CR spectra will be presented and discussed in detail.

Charge exchange recombination spectroscopy (CXRS, or CHERS) is an important diagnostic technique used to determine various plasma properties. It requires, as its name implies, knowledge of the charge transfer process involved in the collision of the highly charged ions either intrinsic to these plasmas or which have been introduced intentionally. The charge exchange occurs between these highly charged ions and atomic hydrogen or deuterium introduced through high-energy neutral beam injection, either for diagnostic purposes or, most often, to heat the plasma allowing the diagnostic to proceed parasitically. Detection and analysis of the resulting spectrum following CX into high principal quantum numbers $n$ then allows determination of characteristics of the plasma.

In this work we present calculations of CX spectra in collisions between energetic atoms of hydrogen and Ne-like $W^{64+}$. This type of interaction is expected to occur in the core of a 20-keV plasma of ITER where $W^{64+}$ will have the highest abundance due to its closed-shell structure.

A well-established scaling indicates that charge exchange will preferentially populate high atomic shells, with $n \approx 23$. This justifies utilization of the Classical Trajectory Monte Carlo (CTMC) method [1, 2] known to provide good results for large values of $n$. Here we implement two versions of this approach, namely, the “pCTMC” method utilizing a microcanonical distribution of initial orbits and the “rCTMC” method developed to mimic closely the quantum mechanical electronic radial distribution. Both methods were used to calculate $nl$-resolved state-selective CX cross sections in a wide range of impact energies from 10 keV/u to 1000 keV/u and for $n \leq 120$. An example of calculations is given in Fig. 1 where $n$-resolved pCTMC and rCTMC cross sections at 100 keV/u are presented along with the $1/n^3$ asymptotics.

The calculated sets of CX cross sections were used as an input to an extensive collisional-radiative (CR) model for calculation of photon emission in an ITER plasma of 20 keV and electron density of $n_e = 10^{14}$ cm$^{-3}$. Since the CXRS spectra originate from the Na-like $W^{63+}$, the model includes only Na- and Ne-like ions of W, however, the total number of atomic states below and above the ionization limit exceeds 6000. The CR code NOMAD [3] was used to calculate the ionization balance, level populations, and line intensities with account of CX and other processes. The simulated CX spectra between 1 Å and 10,000 Å will be presented and discussed for various sets of input CX cross sections and collision energies.

References