Collisional-radiative modeling of a thermal Helium beam penetrating the edge plasma of a Tokamak

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A nonlinear time-dependent Collisional-Radiative (CR) model is developed to simulate the progressive excitation and ionization of a thermal Helium beam crossing the edge plasma in a Tokamak. The model can be used to determine the electron density and temperature distributions in the framework of the BES (Beam Emission Spectroscopy) diagnostics. The results show that, for typical conditions, the penetration depth does not exceed 5 cm.

In a Tokamak, the region between the plasma core and the wall is characterized by strong free electron density (~ 10^{20} m^{-4}) and temperature (~ 10^7 K m^{-1}) gradients [1]. Such plasma properties are very difficult to measure accurately. The Thomson scattering is a powerful mean [2] whose results worth to be confirmed by another kind of experimental technique. From this point of view, the Beam Emission Spectroscopy which has been successfully applied on fusion facilities at PISCES and TEXTOR [3] is a good candidate: an injected atomic beam is progressively excited when it crosses the plasma edge. The resulting radiative emission can be analyzed and related to the local free electron properties by means of a Collisional-Radiative (CR) model.

In this work, a model elaborated to simulate the interaction between a typical Tokamak edge plasma and an atomic beam resulting from the pneumatic injection of Helium is developed and some results are presented. The model is mainly based on the following assumptions:

1- the He atoms penetrate the plasma under weak density and low temperature conditions,
2- the properties of the plasma are not significantly modified by the Helium beam,
3- the contribution of heavy particles to the He excitation is negligible,
4- the He^+ ions are totally reflected by the local magnetic field,
5- the free electron density and temperature gradients are uniform,
6- the He emission lines are optically thin and collisions between He atoms are negligible,
7- the He^+ ions are only produced on the 1s $^2S_{1/2}$ ground state.

The Helium energy diagram is taken from the NIST database [4]. 192 excited states are involved in the calculation (see Table 1). The individual balance equation is written considering the electron-induced transitions (excitation and ionization) whose cross sections are derived from convergent close coupling calculations performed by Ralchenko et *al.* [5]. Charge transfer and momentum transfer [6,7] are also included. The resulting set of ordinary differential equations is solved using the DVODE library [8].

Figure 1 displays the results obtained in typical conditions for injection and electron properties. Owing to the values for electron density and temperature at the edge, the excitation and ionization is very efficient near z = 0. Beyond, the decrease of the population densities takes place with a weaker rate until the excited states population densities can be considered as too weak to induce a significant radiative signature. A penetration depth of 5 cm can be estimated in the present conditions. It is worth to notice that this characteristic length is longer than that obtained using a Carbon beam produced by laser ablation [9].

From this point of view, Figure 1 shows also the evolution of the upper states density of transitions at wavelengths 667.82 nm, 706.52 nm and 728.13 nm often used when BES diagnostics is implemented. Knowing the amount of injected Helium atoms, it may be possible to follow directly the distribution of these population densities instead of their ratios and improve the measurements accuracy.

Table 1. Part of the 193 Helium states involved in the present CR model (from NIST).

i	Configuration	Term	Energy (eV)	J
1	$1s^2$	^1S	0.000000	0
2	1s 2s	^3S	19.81961	1
3	1s 2s	^1S	20.61577	0
8	1s 2p	^3S	22.71846	1
9	1s 2p	^1S	22.92031	0
10	1s 2p	$^3P°$	23.00707	2
192	1s 15p	$^1P°$	24.52702	1
193	1s	^2S	24.58729	1/2

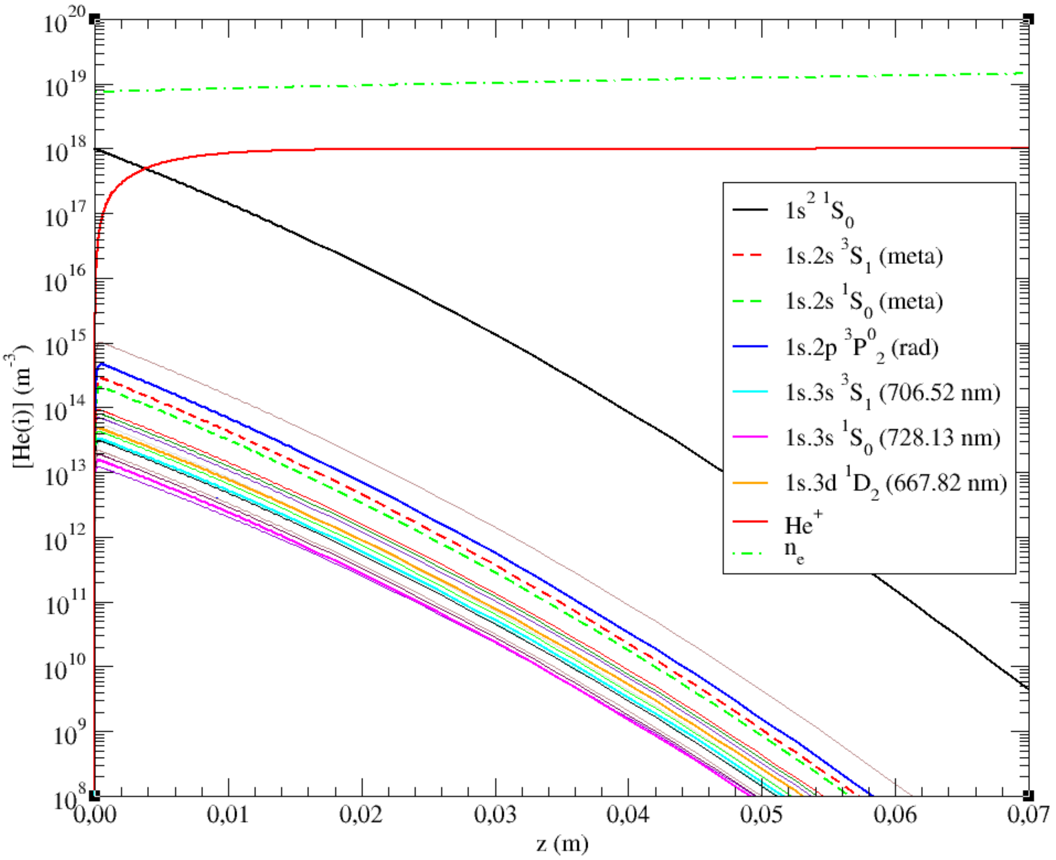

Fig.1. He excited states distribution in a typical edge plasma ($dn_e/dx = 10^{20}$ m^{-4} and $dT_e/dx = 3x10^7$ Km^{-1}).

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