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Influence of collisions on beam-emission of spectral lines

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Introduction

The emission of spectral lines produced by interaction of a neutral beam with plasma particles is one of the essential diagnostics for the plasma core. On the one hand the measurements provide the information on the pitch angle of magnetic field due to Motional stark effect [1] and on the other hand they complement the charge-exchange recombination studies on impurity ions [2, 3]. The analysis of beam-emission spectra H_α(n=3→n=2) and H_β (n=4→n=2) performed at the tokamak JET and TEXTOR [3, 4] demonstrates systematic deviations between the beam-emission data and beam-stopping cross section. As a result the neutral beam density obtained by the two techniques differs more than 30% especially in low density plasmas at plasma edge ($N_e<10^{13}$ cm^{-3}). The aim of this paper is the detailed study of the influence of collisions among *l*-states on the intensity of the hydrogen beam emission.

Collisional-radiative model

The collisional-radiative model presented here is chosen for the conditions of fusion plasma: the Stark field is strong enough to mix the *l*- levels of atomic hydrogen but much less than the energy difference between the different *n* states. For magnetic field of 2 T and a radial beam with energy of 100keV/amu this conditions holds up to $n_{\max} \approx 10$. For higher *n* states the Stark effect mixes the different *n* states as well. Taking this fact into account one has the following equation for the total beam emission between the states $n_1 < n_{max}$ and $n_2 < n_{max}$:

$$I(n_1 - n_2) = \sum_{k_1 m_1} \sum_{k_2 m_2} I(n_1 k_1 m_1 - n_2 k_2 m_2) = \sum_{l_1} \sum_{l_2} I(n_1 l_1 - n_2 l_2), \quad \textbf{(1)}$$

where (n, k, m) is the set of parabolic numbers describing the correspond upper and lower levels in the hydrogen beam. In general, equation (1) represents the conservation of energy, where we ignore the energy of electrical field as $\Delta E_{n_1 - n_2} >> \Delta E_{n_1 k_1 m_1 - n_1 k_2 m_2}$. In the case of the total beam-emission we are not interested in the magnetic pattern structure and so the model can be generated still in the *nl* coupling scheme. The detailed description of the Motional stark effect requires of course the (n, k, m) identification of excited states.

The equation for population of any excited *nl* level N_i in the neutral beam can be written as

$$\frac{dN_i}{dt} = \sum_{j \neq i} W_{ji} N_j - N_i \sum_{j \neq i} W_{ij} - N_i S_i$$
$$W_{ji} = N_e \kappa^e_{ji} + \sum_l N_l \kappa^{Z_l}_{ji} + A_{ji}$$
$$S_i = N_e \kappa^e_i + \sum_l N_l \kappa^{Z_l}_i ,$$

where $\kappa^e{}_{ji}$ is the (de)excitation rate coefficient from the level *j* to the level *i* due to collisions with electrons; $\kappa^{Z_l}_{ji}$ is the (de)excitation rate coefficient from the level *j* to the level *i* due to collision with the ion Z_l; κ^e_i is the ionization rate coefficient from the level *i* by electron collisions and $\kappa^{Z_l}_i$ is the sum over the ionization and the charge-exchange rate coefficient from the level *i* by ion collisions. Finally, A_{ji} is the radiative transition probability from the state *j* to the state *i*. The *nl* model was extended up to *n*=5 states, for higher *n* numbers the n-model [5] was continued up to *n*=50.

The cross sections for excitation and ionization by electrons are based on the FAC code calculations [6]. The major difficulty represents, however, the data for heavy particle collisions. The excitation cross sections for beam particle in *nl* scheme by collisions with impurity ions are still not fully represented in the literature. In this work we generalized the eikonal (Glauber) approximation for the collisions among all *nl* excited states of the neutral beam [7]. It is probably the major difference between the present and existing neutral beam models. As an example we demonstrate in the Fig. 1 the excitation cross section for 2s-4p and 2p-4d transitions.

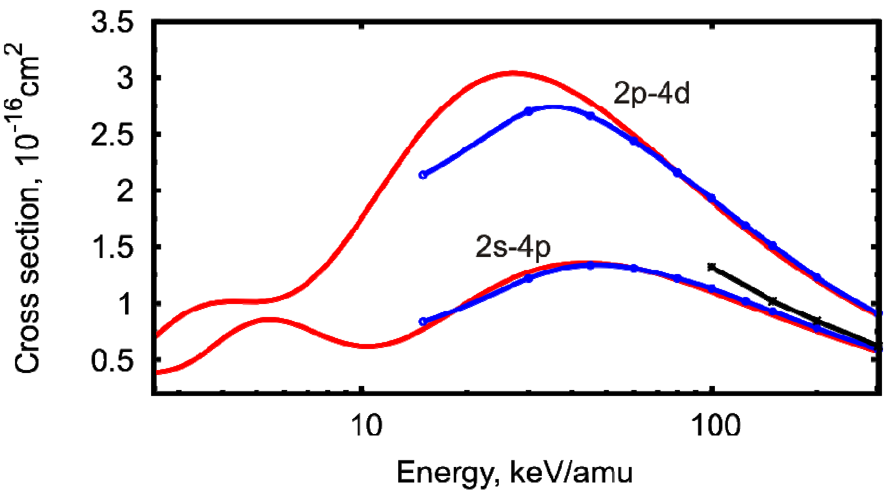

Fig. 1 Excitation cross sections for H^+ impact with H: red curve – present calculation, blue curve – the singled-centered method [8], black curve - fisrt Born approximation [8].

The cross sections calculated in the Glauber and coupled-state approximations [8] show quite satisfactory agreement in the energy range above 40keV/amu. In contrast, the Born approximation demonstrate significant overestimation of 15 % already at the energy of 100 keV/amu. The new *l*-summed cross-sections agree well with *n*-resolved data [9]. The cross sections for other transitions were also compared, if possible, with other atomic data [10].

Results

The result of the calculation for the H_α and H_β lines is demonstrated in the Fig. 2. The difference in emission rates between *n* and *nl* model is explained as following. In the case of a *n* model the population of *nl* subleves is assumed to be proportional to the statistical weights $(2l+1)/n^2$. In the low density limit it is not true: the radiative rate exceeds considerably the collisional channel. In the high density limit both models should converge to the same value. The drop of the emission rate in the high density range is explained by ionization from the excited states of the beam. As seen, the difference between the *nl*- and *n*-model in the low density range is quite considerable. So, for H_α line, the difference in the total emission rates reaches up to 50%. For H_β emission the maximum deviation is less and equals to 30%.

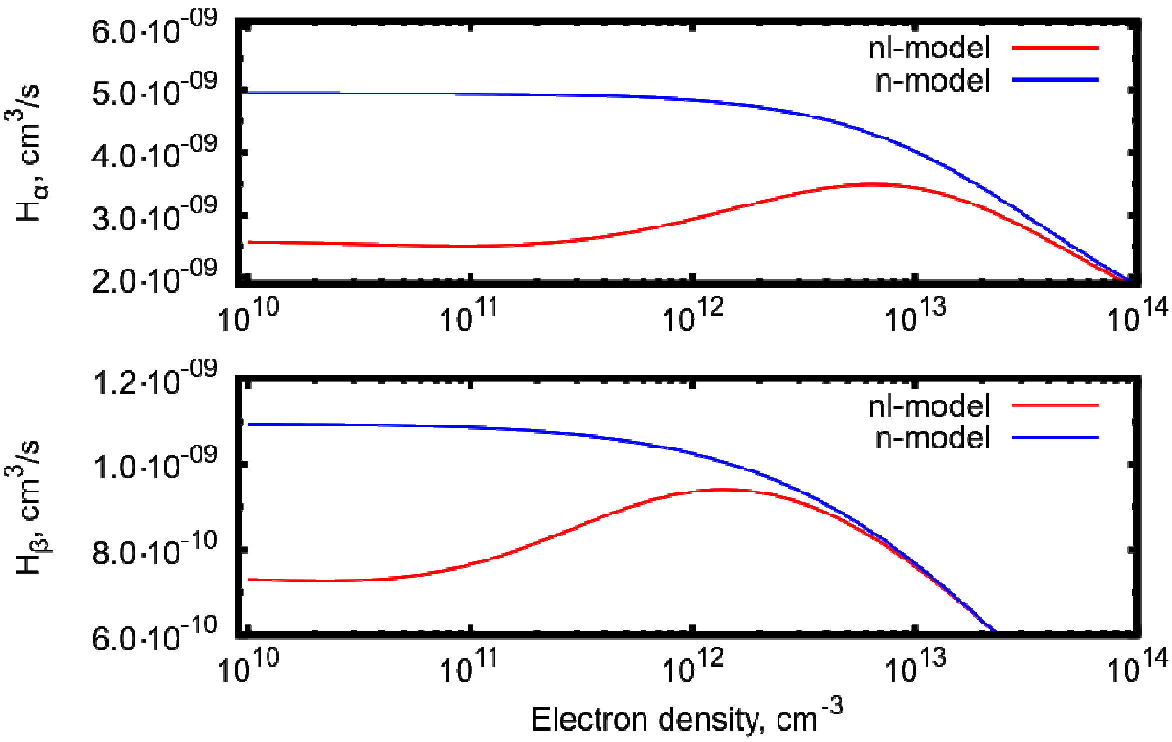

Fig.2 Emission rate for H_α and H_β spectral lines. The energy of the beam E_b was taken 100keV/amu, the plasma temperature was taken to be 3 keV and $Z_{eff}=1$.

It is worth to note that the critical densities where both models converge to the same limit are quite different in the case of H_α and H_β lines. In Fig. 4 we demonstrate the ratio between the emission rates calculated using *n* and *nl* model as a function of beam energy and plasma contamination.

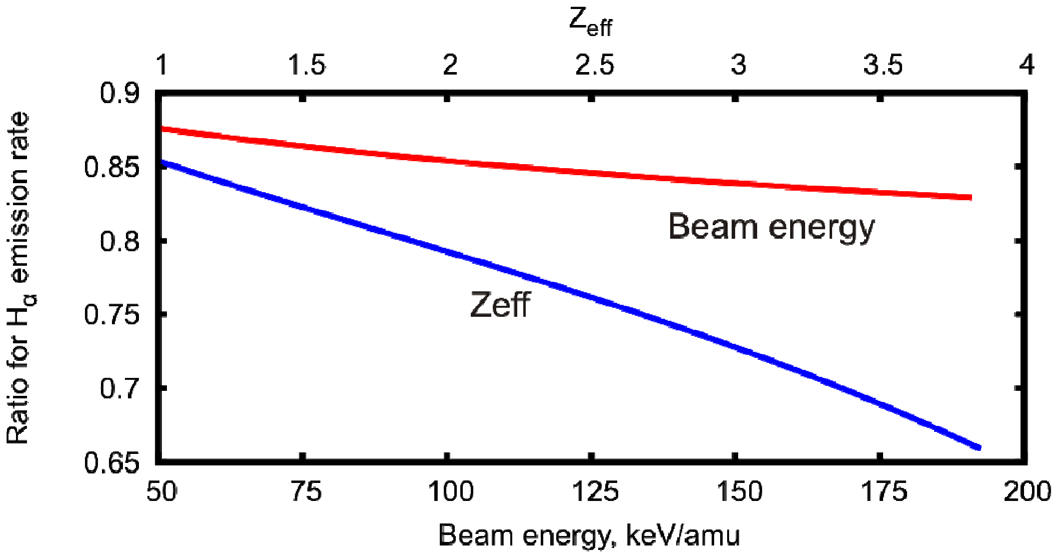

Fig. 4 Ratio of emission rate calculated using nl and n model. Plasma parameters for the blue curve: electron density 10^{13} cm^{-3}, plasma temperature 3 keV, beam energy 100keV/amu. Plasma parameters for the red curve: electron density 10^{13} cm^{-3}, plasma temperature 3 keV, Zeff = 1.

As shown in the Fig. 4 the ratio between the emission rates is a rather weak function of the beam energy. The variation does not exceed 10 % on the energy range between 50-150 keV. The plasma contamination has a much stronger influence on the deviation between the results of *n* and *nl* model. Here, for the condition of fusion plasma, the variation is more than 15%.

Conclusions

The *nl* collisional-radiative model demonstrates a reduction of the neutral beam emission data relative to the *n*- model at low plasma density. It can partly explain the deviations between the experimental observation and results from the beam attenuation codes. More detailed investigation and first of all a comparison with experimental data from TEXTOR is foreseen in the near future.

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