Influence of complete different sets of collision rates on helium emission: Sophia code simulations and comparisons with experiments

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Abstract

We have investigated the influence of three different sets of collisional cross-sections on the population of helium atomic levels with the Sophia code [1]: the Convergent Close Coupling method [2] (quantum shells n=1 to 4), the 'ab initio' LSJ-split method provided by FAC [3] (quantum shells n=1 to 5) and the K-matrix method [4] (quantum shells n=1 to 5). We have compared collision rates to the singlet and triplet levels and identified optical emission lines that are suitable for the comparison with the different theories of cross section calculations. Finally we investigate the effects of a second electron population which can be defined as supra-thermal electrons. Numerical results are compared with spectra realized in a helium discharge capillary and line ratio measurements carried out with the MISTRAL device, a linear magnetized plasma column.

I Introduction

Helium is one of the most important species for plasma fusion magnetic confinement devices. In ITER recombining α-particles produced from fusion reactions lead to the formation of He^{1+} and He^{0+} and the corresponding line emission. The analysis of the He radiation emission provides therefore the possibility for a wide and unique characterization of the plasma. Of particular interest are line emissions, which enable to characterize the plasma under extreme conditions: high density, opacity, particle transport, supra-thermal electrons and charge exchange coupling with the neutral hydrogen background. For these purposes, a complex atomic physics code “Sophia” [1] has been developed.

II theoretical results

The Sophia code determines the helium atomic population including all atomic processes for detailed studies. A bi-maxwellian distribution for electrons can be included in the Sophia code in order to describe the effects of supra-thermal electrons on the line emission.

Simulations have been focused on a low electron density 10^9 cm^{-3} in order to avoid collisional coupling effects between excited levels for the investiation of the different cross sections. We have compared in particular the optical line emission for the transitions 1s3d 1D – 1s2p 1P, 1s3d 3D -1s2p 3P and 1s2 1S – 1s3s 3S which allow a direct link to the cross sections from the ground to the upper level from which the optical transition originates.

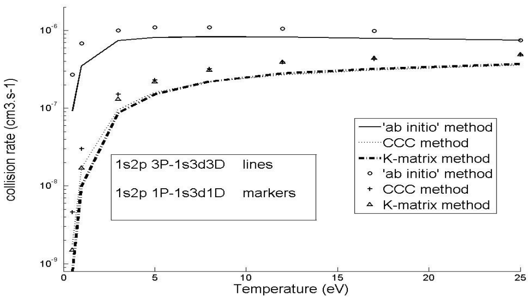

fig.1

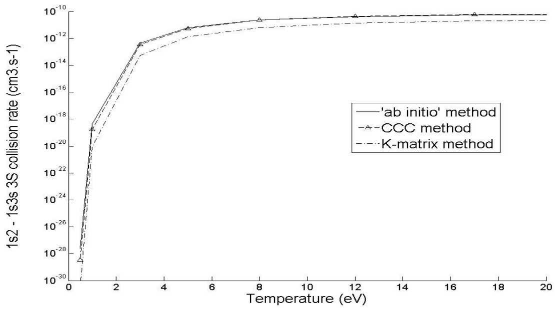

fig.2

The rates from the 'ab initio' LSJ-split method is typically 4 times higher (for Te>5 eV) than the CCC and the K-matrix calculations. Strong differences appear for low electron temperature. The CCC and the K-matrix calculations are in good agreements for Te>12 eV.

Collision rate from the ground state 1s2 1S – 1s3s 3S show good agreements for the CCC and the 'ab-initio' calculations. The rates from the K-matrix method is typically 3-4 times lower than the other one. For the collision rates (1s3d $_1$D – 1s2p $_1$P) and (1s3d $_3$D – 1s2p $_3$P) the same behavior is observed.

In Mistral device, hot electrons are created to ionize the puffing gas, creating then a bi-population of electron. In order to characterize these phenomena calculations with a bi-maxwellian distribution for electrons have been carried out with the SOPHIA code. Interesting studies can be achieved concerning the influence of hot electrons in atomic populations or in rates calculations. We have compared collision rates with and without 'hot electrons' for the transitions 1s2 1S – 1s3s 3S and 1s3d $_3$D – 1s2p $_3$P . Simulations employing the CCC method are carried out for ne=10^9 cm^{-3} with 7% of hot electrons where Te$_{hot}$=15 eV with the CCC method calculation.

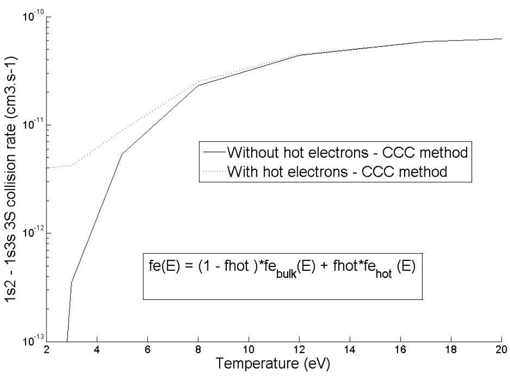

fig.3

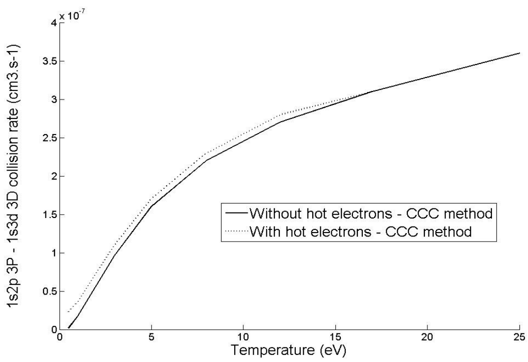

fig.4

The threshold energy of the cross section for excitation by collisions with electrons is equal to the difference of energy ΔE between the upper and lower level of the transition. As can be seen on figure 4, a few percents of hot electrons do not change the rate coefficients results between excited states because bulk electrons are already very effective. For the transition 1s2 1S – 1s3s 3S, ΔE is much larger (22.7 eV) and for Te_{bulk} lower than 4 eV, hot electrons (15 eV) strongly contribute to the populating of the upper level. For Te_{bulk}=15eV, hot electrons play a minor role. We can therefore conclude that the effect of hot electrons must be taken into account for the calculations of electron collision rates when Te_{bulk} is low.

II Experiments

In the Mistral device [5], the plasma is produced by primary energetic electrons (energy of several tenth of eV) coming from the 32 tungsten filaments located in the source chamber. In the capillary discharge [6], a plasma channel (300 mA) is started by a high voltage of 30 kV for a few μs. The discharge is maintained by the use of a set of capacitors loaded by a voltage of 1-5 kV. In the Mistral device the lines observed correspond to transition 1snl – 1sn'l' with n=8 to 3 and n'=2,3 whereas in the discharge experiment only transition with n=4,3 and n'=2,3 are apparent. The different range of temperature can explain these spectra : In Mistral device, the temperature range is 2-10 eV and high levels are populated (ne and Te are estimated by a Langmuir probe). In the discharge, the electron temperature is estimated around 0.7 eV by the best fit of the data. Line ratios are calculated with the Sophia code.

III Comparisons with simulations

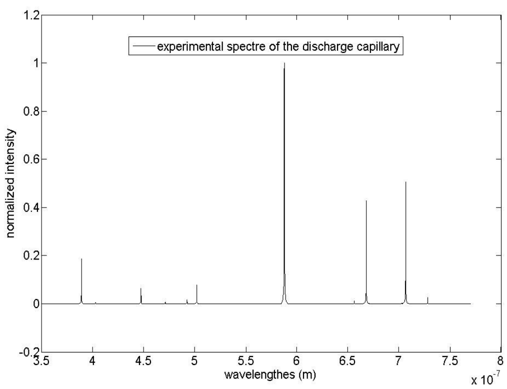

Fig.5

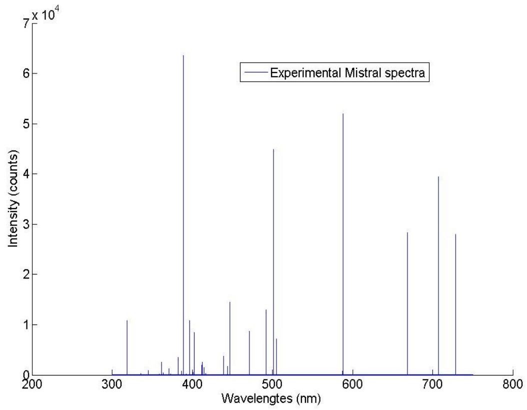

Fig.6

We have compared three line ratios of neutral helium lines of the discharge capillary with numerical results for ne = 10^{13}cm^{-3} and Te=0.7eV: we obtain the best agreements with the CCC method.

	Experiments	CCC-method	K-matrix method	'ab-initio' method
I_{706}/I_{587}	0.5	0.45	0.12	0.2
I_{388}/I_{587}	0.18	0.16	0.12	0.1
I_{667}/I_{587}	0.4	0.28	0.08	0.08

λ (1s3d 1D – 1s2p 1P) = 667.8 nm, λ (1s3d 3D – 1s2p 3P) = 587.7 nm,
λ (1s2p 3P – 1s3s 3S) = 706 nm, λ (1s2s 3S – 1s3p 3P) = 388 nm

In order to conclude for the best set of cross sections, Te and ne need to be varied in an independent manner for each set separately: for example, a data fit employing the K-matrix cross sections might be better for another set of (Te2, ne2) and for the CCC cross sections employing the set (Te1, ne1).

IV conclusions

The comparisons of the three complete sets of collision rates show interesting different features for the line emission of neutral helium. The implementation of the complete set in the SOPHIA code allowed to identify optical transitions which are sensitive to cross sections from the ground state. This will not only allow to conclude for the general selection of the best set of cross sections but also to conclude for details of single direct and exchange cross sections. The analysis of the data has identified interesting features in the emission spectrum to analyze near threshold cross section features for the triplet levels 1s3l 3L. We also have started to identify the influence of supra-thermal electrons on the optical line emission spectrum.

Acknowledgements

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