Determination of level populations and radiative properties of optically thin and thick carbon plasmas

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1. Introduction.

In several research fields of current interest such as astrophysics or inertial fusion confinement the knowledge of the interactions between the photons and the plasma particles, i.e. plasma radiative properties, result essential. Thus, for example, the understanding of these plasmas requires properties such as emissivities and opacities both for hydro-simulations and diagnostics.

Carbon is one of the most interesting elements under investigation, since it is likely to be a major plasma-facing wall component in ITER, and it plays a major role in inertial fusion scenarios. Also, some laser experiments have focused on the spectrally resolved emission from hydrocarbon systems. Therefore, radiative properties from carbon plasmas must be known and, as a consequence, the theoretical study of these plasmas is a subject of current interest and many efforts are headed. In particular, recent NLTE workshops have focused on comparisons of modelling calculations for specific cases that allow testing the models since there are very few experimental measurements for carbon plasmas. For these reasons it is interesting to characterize them in a wide range of plasma conditions.

In a previous work we carried out an exhaustive study of optically thin carbon plasmas under steady state condition in a wide range of electron densities and temperatures given by (1-200) eV and (10^{12}-10^{22}) cm^{-3} respectively [1], where CE, NLTE or LTE regimes are achieved.

In this work we analyse the reabsorption radiation effects for homogeneous carbon plasmas in planar geometry by means of the escape factor formalism. We focus our attention on the average ionization and ionic populations as well as the multifrequential and mean opacity. All the calculations presented in this work were performed by using ABAKO code

[1] which integrates the RAPCAL code [2] in order to calculate optical properties for a wide range of temperatures and electron number densities.

2. Description of the ABAKO/RAPCAL Code

ABAKO is composed of three modules: atomic data, level populations and optical properties. The first one can work using two complementary levels description of the atomic data depending on the atomic number or the ionization degree of the element under consideration. For low-Z or highly ionized medium and high-Z plasmas it uses a detailed level description provided by the FAC code in which the bound states of the atomic systems are calculated with convenient specification of jj-coupling schemes and including configuration mixing. On the other hand, for lowly ionized intermediate and high-Z plasmas this detailed calculation becomes impracticable and a detailed relativistic configuration accounting approach is chosen. In particular, ABAKO works using a set of analytical potentials developed by us which can model both isolated ions [3] and ions immersed into plasmas [4] including plasma effects and single and core excited configurations [5]. Even for situations wherein more celerity is desired, the code can perform the atomic calculations using a relativistic screened hydrogenic model [6].

The second module is devoted to determinate the ionic state distributions and level populations by solving a colisional-radiative steady state (CRSS) model. The processes included in the CRSS model are the following: collisional excitation and de-excitation; spontaneous decay; collisional ionization and three body recombination; radiative recombination; autoionization and electronic capture, being the majority of the rate coefficients evaluated by analytical formulas that can be found in the literature. In order to solve the set of rate equations, we employed the technique of sparse matrix to storage the non-zero elements. This implies substantial savings in computing time and memory requirements and it also allows us to include a large amount of ionic configurations in our calculations. The populations can be computed with a reasonable accuracy for plasmas of any element in a wide range of conditions both for optically thin and thick plasmas, and in the last case, the radiation transport is modelled through the escape factor formalism [7]. The escape factor θ denotes the mean probability that a photon emitted anywhere in the source travels directly to the surface of the source in any direction and escapes. Escape factors are frequently used in plasma spectroscopy as an approximate way to account for the effects of reabsorption, which can be very important, especially for resonance line transitions. Escape factors, θ, enter the calculations in two ways. Firstly, they enter the atomic physics calculations of excited-state populations; as a result there is a reduction in the Einstein spontaneous emission coefficient, $A_{u \to l}$, which is written as $\theta A_{u \to l}$. Secondly, they appear in the determination of the total emergent line intensity. This modification circumvents the need to perform a simultaneous resolution of radiation transport and kinetics equations. In this work we have assumed a uniform distribution of emitting atoms and isotropic emission and a slab geometry.

Finally, in the third module, the spectrally resolved and mean emissivities and opacities are determined making use of the populations and the atomic data given in the previous modules. Bound-bound opacity and emissivity are calculated by using Voigt profile for all the lines and assuming complete redistribution of the photons. In this Voigt profile, there are included natural, Doppler and Stark widths, using a simplified semiempirical method for obtaining the last one. The bound-free cross section can be calculated from quantum mechanically procedure (distorted wave approach) or from Kramer´s formula. Finally, the free-free spectrum has been obtained employing the Kramer's formula for the cross section (corrected by the gaunt factor).

3. Results.

In figure 1 we have plotted the average ionization and ion population for a carbon plasma at fixed conditions of electron density and temperature. From the figure we can observe that the average ionization increases with the plasma thickness showing an asymptotic behaviour given by the situation corresponding to infinite thickness which is close to the results obtained assuming LTE conditions. Therefore, the increase of the plasma thickness implies that the plasma tends to results more similar to LTE ones. This fact is also illustrated in figure 2 where the spectrally resolved and mean opacity for this situation is shown.

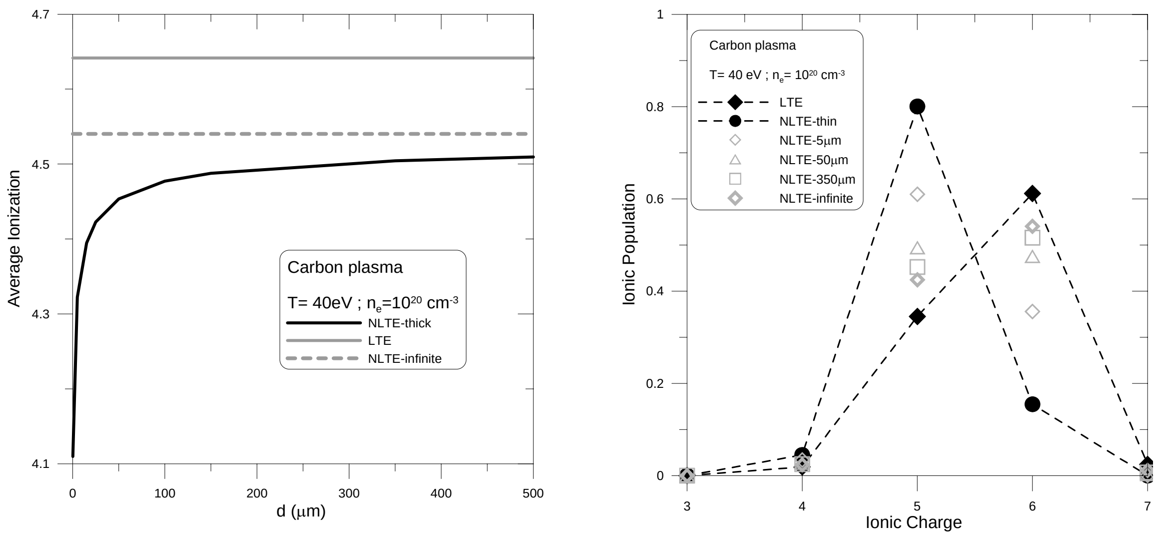

Figure 1. Average ionization and ion population for a carbon plasma

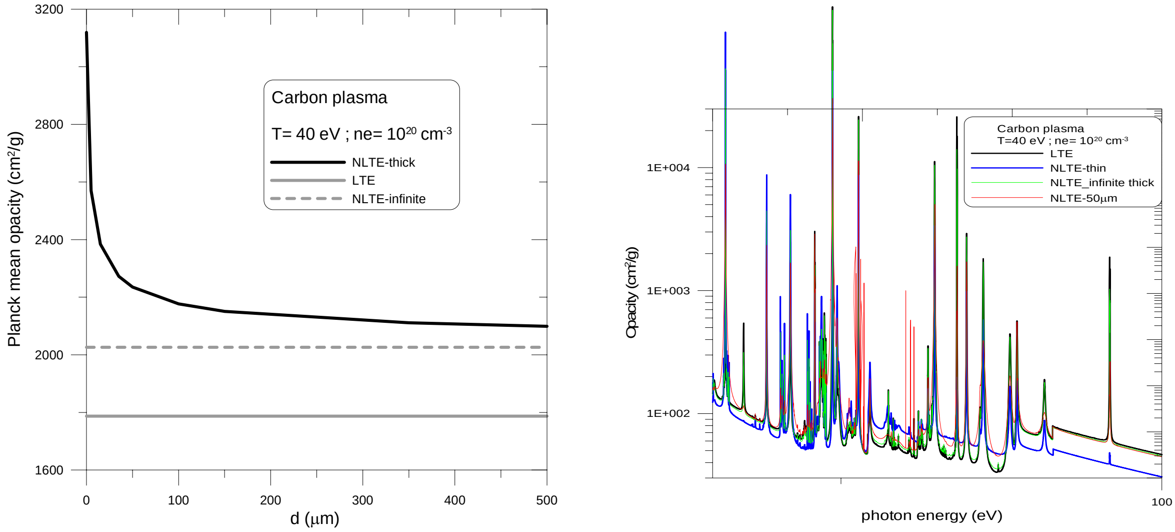

Figure 2. Planck mean and spectrally resolved opacities for a carbon plasma.

Acknowledgments

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