Topic number 11

Collisional-radiative modelling for multi-temperature plasma composition calculation

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This paper concerns the calculation of multi-T argon plasma composition with a collisional-radiative model. This model takes into account a great number of electronic levels of Ar and Ar^+ and it is based upon an extended database of reaction rate coefficients (excitation/de-excitation, ionisation/recombination, spontaneous emission and radiative recombination). A particular attention is paid to problematic reactions with electrons in one side and only heavy species on the other: $Ar+Ar \rightarrow Ar+Ar^{+}+e$. The detailed balance relations obtained for ionisation/recombination processes demonstrate the non-uniqueness of the multi-temperatures law of mass action. Plasma compositions exhibit abrupt densities variations associated to the transition between the domination of heavy particle reactions (low temperature) and the predominance of electron collisions (high T).

1. Introduction

Most of theoretical studies concerning thermal plasmas are achieved with the local thermodynamic equilibrium (LTE) assumption. However, it is clear that this assumption is not realised in some regions of the plasma (electrode sheaths, vicinity of walls and cold fringes) and for transient or low power arcs. Thus, electrons have a kinetic temperature T_e higher than that of the heavy species T_h ($\theta = T_e/T_h$).

There are 3 methods for the calculation of the plasma composition: The minimization of a thermodynamic function, the law of mass action or a CR model. They obviously all lead to the same results in the case of thermodynamic equilibrium but they strongly differ in non-equilibrium conditions, depending on the initial calculation assumptions. The more accurate technique to obtain the multi-T plasma composition is the CR model. Indeed, this approach allows avoiding the simplifying assumptions associated to the internal excitation modes (electronic, vibrational and rotational).

2. CR Model

The energy diagram of argon used in this study is taken from [1]: 379 electronic levels for Ar and the first 7 states for Ar^+. Thus, all possible transitions between levels until 32.2 eV above the ground state of Ar are taken into account (coherent with the temperature range considered i.e. T_e and T_h lower than 15000K). The CR model is thus formed of 387 nonlinear coupled ordinary differential equations. The DVODE library [2] dedicated to stiff problems is used to solve the system of equations. Direct reaction rate coefficients for inelastic collisions are calculated with the Drawin formalism [3-4]. Reverse rate coefficients are obtained from accurate detailed balance relations. Concerning radiative processes, radiative recombination rate coefficients are taken from [5] and Einstein coefficients from [1].

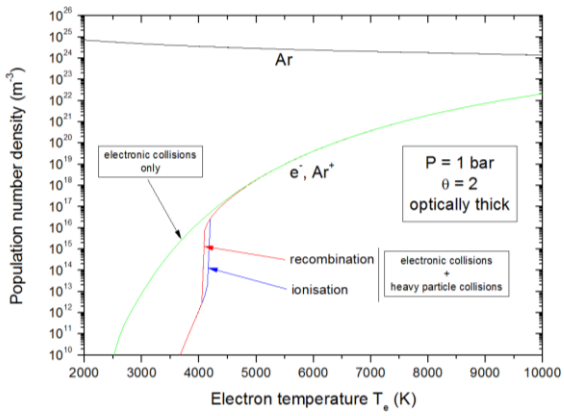

Figure 1. Argon plasma composition: influence of electron and heavy particle collisions

The argon plasma composition (optically thick case, $\theta = T_e/T_h = 2$) is given in figure 1. This result illustrates the influence of electrons and heavy particle collisions on the plasma composition.

3. References

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