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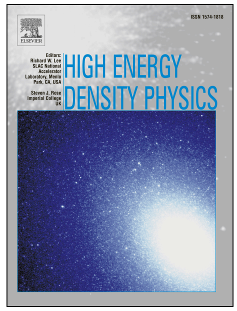

Accounting for highly excited states in detailed opacity calculations

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Accounting for highly excited states in detailed opacity calculations

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Abstract

In multiply-charged ion plasmas, a significant number of electrons may occupy high-energy orbitals. These "Rydberg" electrons, when they act as spectators, are responsible for a number of satellites of X-ray absorption or emission lines, yielding a broadening of the red wing of the resonance lines. The contribution of such satellite lines may be important, because of the high degeneracy of the relevant excited configurations which give these large Boltzmann weights. However, it is in general difficult to take these configurations into account since they are likely to give rise to a large number of lines. We propose to model the perturbation induced by the spectators in a way similar to the Partially-Resolved-Transition-Array approach recently published by C. Iglesias. It consists in a partial detailed-line-accounting calculation in which the effect of the Rydberg spectators is included through a shift and width, expressed in terms of the canonical partition functions, which are key-ingredients of the Super-Transition-Arrays model. The resulting method can *a priori* be used in any detailed-configuration/line-accounting opacity code.

Keywords: hot plasma, atomic physics, highly excited states, satellite lines
PACS: 32.70.Cs, 32.70.-n, 32.80.Ee, 32.80.Zb

1. Introduction

Highly charged ions may have electrons in their high-lying loosely-bound orbitals. These "Rydberg" electrons, when they act as spectators, yield satellite lines that may not be clearly separated from the resonance line: they contribute as a broadening of its red wing. Some satellite lines are sufficiently strong that they can be used for diagnostics purposes. In ICF (Inertial Confinement Fusion) plasmas, electron temperature T and density N_e of the fuel are inferred from the X-ray emission of H-like and / or He-like lines of impurity ions, *e.g.*, Ar ions [1]), which are enhanced and broadened by unresolved satellite lines. Concerning the Hohlraum emission, satellites of 3d-4f transitions of Ni-like gold ions form a quasi-continuum in the 2-4 keV energy range [2]. In another context, a large number of satellite lines due to 4d-4f transitions contribute significantly to the EUV emission of Xe over the range [10-17] nm [3] (see Fig. 1), which is important for lithographic applications.

The contribution of dielectronic satellite transition arrays, with spectator electrons in shell n=5, was studied by Bauche-Arnoult *et al.* for the case of a tantalum plasma [4]. The main mechanism for the formation of doubly-excited states is the dielectronic recombination. However, for high electron densities, those excited states can also be populated by successive collisional and radiative excitations from the inner shells. In general, the study of the corresponding satellite lines requires a non-LTE (local thermodynamic equilibrium) modeling, in which all microscopic processes are accounted for in a master equation in order to determine the population of states. Most of the doubly-excited states involved lie above the ionization potential of the next ion, so that they may broaden some transition arrays by autoionization. Biedermann *et al.* [5] measured the X-ray emission from high-n spectator electrons following radiative stabilization in dielectronically excited Ba^{40+} to Ba^{42+} ions produced by an electron beam ion trap. They observed an enhanced emission due to transitions from $n>3$ to n=3.

In LTE, the contribution of those satellites may be important because of the large Boltzmann statistical weight of the relevant excited configurations (due to high electron temperature and/or high degeneracy). In fact, even if their

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