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Emissivity Calculations Under DCA-UTA Approximation for NLTE Plasmas

J. Q. Pang*, Z. Q. Wu and J. Yan

Institute of Applied Physics and Computational Mathematics, Laboratory of Computational Physics, P. O. Box 8009-57, Beijing 100088, China.

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Abstract. A model is developed to calculate emission spectrum from plasmas in non-local-thermodynamic-equilibrium (NLTE). The populations are obtained with a Collisional Radiative Model and the spectrum is calculated with the Unresolved-Transition-Array (UTA) approximation. The present model is applied to the calculation of emissivity from low-, medium- and high-Z plasmas. The integrated emissivity and the spectra are compared with those calculated by other theoretical models. In general speaking, the present results of the mean charge state and emissivity agree well with some theoretical ones while large differences are found when all the theoretical results are included.

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Key words: Non-local-thermodynamic-equilibrium (NLTE), emissivity, Unresolved-Transition-Array (UTA).

1 Introduction

In plasma diagnostics, optimizing X-ray source design et al, emission spectra for NLTE plasmas may be used. In a hydrodynamic simulation code, the spectrally integrated emissivity provided by the atomic physics model determines the evolution of the electronic and radiation temperatures. The spectrum is itself of interest, as hard X-ray photons can generate target preheating in ICF capsules. As the NLTE condition is universal in laboratory and astrophysical plasma studies, the capability to accurately predict emissivity from NLTE plasmas is of primary interest. Calculation of complete spectra for NLTE plasmas needs detailed atomic structure codes, radiative and collisional processes calculations for numerous ion species, level population models and treating a large number of

*Corresponding author. *Email addresses:* `pang_jinqiao@mail.iapcm.ac.cn` (J. Q. Pang), `wu_zeqing@mail.iapcm.ac.cn` (Z. Q. Wu), `yan_jun@mail.iapcm.ac.cn` (J. Yan)

transitions. Despite these difficulties, we have to tackle these problems because spectral information is an invaluable tool for providing information on the plasma parameters.

In recent years, many codes, such as Fine [1], Hullac [2], Nomad [3], Transpec [4] et al., have been developed to calculate the populations and the spectra from NLTE plasmas. In order to obtain accurate spectra, taking into account all the important configurations as well as high accurate atomic model is required. On the other hand, the unendurable computational time compel us to employ various approximations in atomic or population models. That is why the results from different codes do not agree well. Very recently, a 'virtual workshop' is performed to compare NLTE emissivities produced by widely differing type of atomic physics codes [5]. The workshop shows that even with similar ionizations, the dispersion in emissivity can be enormous. The differences can be orders of magnitude if an otherwise closed shell has been opened. As regards the integrated emissivity, the results of the workshop show roughly a factor from 2-50 scatter which indicates that we should not be surprised at discrepancies between experimental and theoretical emissivities in the design of multi-keV X-ray sources.

Because of the important application of the emission spectra from NLTE plasmas, tests of theoretical model are essential. Accordingly, it is important to provide a method in which the NLTE calculations can be benchmarked against the well-characterized experimental data. In an attempt to reach this goal, some recent experiments in laser-irradiated argon gas bag [6], in laser-produced plasmas on gold targets [7], in inertial confinement fusion (ICF) hohlraums [8], in a simulated coronal plasma environment produced in electron beam ion trap (EBIT) [9] and in laser-heated xenon gas jet plasmas [10] have been performed. Comparisons show that some of the theoretical models have reasonable ionizations compared with the experimental values, but the discrepancies are substantial in some cases. As for the emissivity, some theoretical models can usually reproduce part of the experimental spectra while the remains are in very poor agreements. Although good agreements between experimental spectra and theoretical simulations are not reached, the comparisons give information on what accuracy of theoretical calculations can be reasonably expected. The discrepancies demonstrate that there is still much room to improve the NLTE calculations and more well-determined experiments are needed to check the theoretical models.

In this paper, we develop a model and a corresponding code to calculate the NLTE emission spectra. The code includes selecting configurations, producing all the required atomic parameters, establishing and solving the rate equations to get the populations and using the UTA approximation to obtain the spectra. In the present model, the populations are obtained by a detailed configuration accounting (DCA) collisional radiative model (CRM) [11]. In the population calculations, the steady-state approximation is used. The detailed description of the present CRM is given in our previous publication [11]. In the following section, the theory of the present model will be given. In the third section, the model will be applied to plasmas and the results will be compared with other theoretical ones.