Collisional-radiative modeling for plasma population kinetics and spectroscopy

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The modern diagnostics of terrestrial and astrophysical plasmas are based on variety of techniques. Particularly important is the spectroscopic plasma diagnostics that is based on measurements and analyses of line and continuum spectra in emission and absorption, line intensity evolution, spectral line shapes and shifts and so on. These physical quantities may be very sensitive to crucial plasma parameters such as particle densities and temperatures, distributions of electromagnetic fields, deviations from equilibrium (Maxwellian) energy distributions of collisional partners, opacities, anisotropy of collisions, to name a few. To this end, a trustworthy calculation of the radiation generated from plasmas becomes a crucial task for reliable spectroscopic diagnostics of diverse plasmas.

Such calculations involve different levels of complexity depending upon plasma conditions. For dense plasmas in equilibrium, the simple Local Thermodynamic Equilibrium (LTE) model may be well applicable. For the optically thin LTE case, it only requires level energies, their statistical weights, and the radiative transition probabilities to generate complete spectra. For dilute plasmas in equilibrium, the Coronal Equilibrium (CE) may provide reasonable results; however, it needs large amounts of collisional data. The most general approach for simulation of plasma emission is based on the collisional-radiative (CR) model that attempts at account of all major physical processes affecting populations of atomic states (levels). These processes typically include collisions with electrons (e.g., excitation, deexcitation, ionization; 3-body, radiative and dielectronic recombination), radiative processes (spontaneous emission, photoabsorption for opaque plasmas), and non-radiative processes (autoionization). For some plasmas, other effects such as charge exchange with fast neutrals or other collisions with heavy particles may need to be added. CR models typically require extensive sets of basic atomic data (e.g., cross sections or rate coefficients for collisions) to be calculated with the state-of-the-art atomic structure and collision codes.

In this talk we will present an overview of the modern methods and techniques for CR modeling (see, e.g., Ref. [1]). Special attention will be given to the atomic data production and quality required by modern CR codes. Over the recent years, a number of sophisticated atomic structure and collision codes were developed that allow CR modelers to quickly and reliably generate large sets of quality data. Those may include energy levels, radiative and autoionization transition probabilities, electron-impact cross sections and rate coefficients, heavy-particle cross sections, and so on. The generated atomic data can then be benchmarked against the available online databases of evaluated and recommended data (e.g., the NIST Atomic Spectra Database [2]).

The examples of CR simulations in this presentation will include several cases emphasizing the flexibility and universality of the CR approach. We will present the analysis of x-ray/EUV spectra from highly-charged high-Z ions produced in non-Maxwellian plasmas of electron beam ion traps. Then, a CR model for the motional Stark effect diagnostics in magnetic fusion devices will be outlined [3]. Due to the induced electric field, this model is built using parabolic rather then more common spherically-symmetric atomic states which requires a novel approach to calculation of atomic data. Then, the recent results of simulations for the charge exchange recombination spectroscopy in the hot plasma of ITER (see fig. 1 below) will be discussed as well [4].

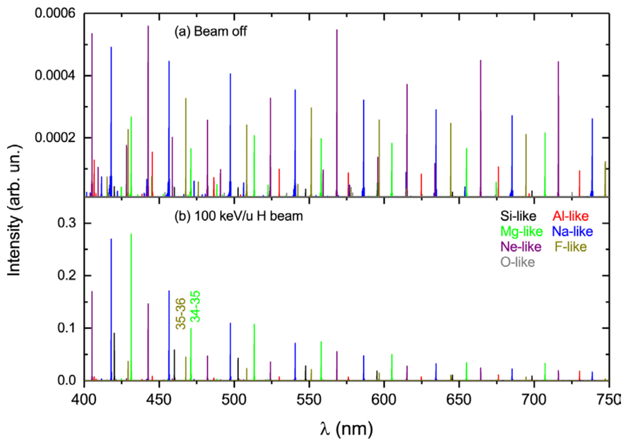

Figure 1. Comparison of the simulated spectra in the visible range with and without neutral beam injection [4].

References

[1] *Modern Methods in Collisional-Radiative Modeling of Plasmas*, ed. by Yu. Ralchenko, Springer, 2016.

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