§16. Rate Equations near LTE

More, R. (LLNL, USA)
Kato, T.

Atomic processes assume special importance in the fusion reactor edge plasma. The edge temperature is lower than the plasma core by a large factor and the electron density is much higher. The edge plasma contains impurity ions, especially carbon, oxygen and structural metals which enter from walls or divertor. For these three reasons - low temperature, high density, and high atomic number - the edge plasma is the active region for atomic processes such as ionization, recombination, line emission, dielectronic capture and charge transfer as well as impurity transport.

Recent research has identified circumstances under which H_α line emission in a divertor plasma can be optically thick.(1) High optical depth increases excited state populations toward their LTE values. However, edge plasmas are essentially non-LTE and must be treated by kinetic equations which include many atomic processes. The chief tool is an atomic model with many levels and atomic data for transitions linking these levels, the Collisional-Radiative (CR) model.

We have been exploring the theory of non-LTE plasmas under conditions of large optical depth. The purpose of this investigation is to strengthen our fundamental understanding of general features of atomic rate equations. In certain cases, properties which are intuitively evident can be demonstrated by mathematical proofs which give insight into the structure and behavior of the atomic model.

An example is the stable evolution of atomic populations. It is intuitively clear that if an atom or ion is injected into a plasma environment whose electron temperature and radiation spectrum are held constant, any arbitrary initial atomic populations will stably relax to the ionization-equilibrium steady-state. This intuitive statement translates mathematically into the requirement that the eigenvalues of the transition rate matrix must be zero or negative. The formal proof of this stability property connects mathematical properties of the rate equations to atomic dynamics.

A second general property is the statement that when a plasma is near LTE, all populations and spectra become independent of collisional rates, and depend only on energy levels and degeneracies (the spectra also depend on line intensities determined by oscillator-strengths). The mathematical proof of this property uses a near-LTE linear-response matrix whose properties we have recently investigated.(2)

The general study of CR models from the matrix-theory viewpoint is likely to be useful for providing guidance for the construction of models which represent a group of excited states by a single superlevel. The calculation of effective rates linking the superlevel to normal excited states, consistent with detailed balance, is the challenge.

(1) H. A. Scott, A. S. Wan, D. E. Post, M. E. Rensink and T. D. Rognlien, J. Nuc. Materials 266-269, 1247 (1999).

(2) R. More and T. Kato, Physical Rev. Letters **81**, 814, 1998.