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Influence of Multiple Ionization on Charge State Distributions

D. W. Savin* [1] **and M. Hahn***

* Astrophysics Laboratory, Columbia University, New York, NY 10027, USA

Synopsis We describe the influence of electron-impact multiple ionization (EIMI) on the ionization balance of collisionally ionized plasmas. Previous ionization balance calculations have largely neglected EIMI. Here, EIMI cross-section data are incorporated into calculations of both equilibrium and non-equilibrium charge-state distributions (CSDs). For equilibrium CSDs, we find that EIMI has only a small effect. However, for non-equilibrium plasmas the influence of EIMI can be important. In particular, we find that for plasmas in which the temperature oscillates there are significant differences in the CSD when including versus neglecting EIMI. These results have implications for modeling and spectroscopy of impulsively heated plasmas, such as nanoflare heating of the solar corona.

The spectrum emitted by a plasma depends on the CSD of the gas. For collisionally ionized plasmas, the CSD is determined by the corresponding rates for electron-impact ionization and recombination. In astrophysics, such plasmas are formed in stars, supernova remnants, galaxies, and galaxy clusters. Current CSD calculations generally do not account for EIMI, a process in which multiple electrons are ejected by a single electron-ion collision. We have estimated the EIMI cross sections for all charge states of iron using a combination of the available experimental data and semi-empirical formulae. We then modeled the CSD and observed the influence of EIMI compared to only including single ionization (cf., Figure 1).

One case of interest for astrophysics is nanoflare heating, which is a leading theory to explain the heating of the solar corona. In order to determine whether this theory can indeed explain coronal heating, spectroscopic measurements are being compared to modeled nanoflare spectra. Such models have attempted to predict the spectra of impulsively heated plasmas in which the CSD is time dependent. These nonequilbirium ionization calculations have so far ignored EIMI, but our findings suggest that EIMI can have a significant effect on the CSD of a nanoflare-heated plasma, changing the ion abundances by up to about 50%. A detailed discussion of this work has been published in [1].

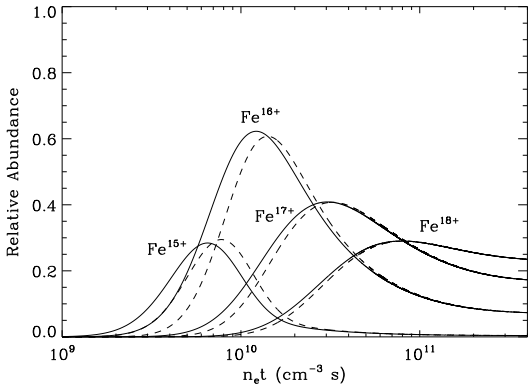

Figure 1. Ion abundances of Fe^{15+} to Fe^{18+} vs. scale $n_e t$, where n_e is electron density and t is time, following a sudden jump in temperature from 10^5 K to 10^7 K. The solid curves indicate the results with EIMI and the dashed curves are the calculations including only single ionization. It is clear that EIMI causes the charge states to evolve faster than if it is ignored.

References

[1] Hahn & Savin 2015, *Astrophys. J.* **800** 68

[1] E-mail: savin@astro.columbia.edu